Environmental Assessment of the Alaskan Continental Shelf

Volume 13. Geology

Principal Investigators' Reports
for the Year Ending March 1976

U. S. DEPARTMENT OF COMMERCE
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Annual Reports from Principal Investigators

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Environmental Assessment of the Alaskan Continental Shelf

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Fourth quarter and annual reports for the reporting period ending March 1976, from Principal Investigators participating in a multi-year program of environmental assessment related to petroleum development on the Alaskan Continental Shelf. The program is directed by the National Oceanic and Atmospheric Administration under the sponsorship of the Bureau of Land Management.

ENVIRONMENTAL RESEARCH LABORATORIES / Boulder, Colorado / 1976

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QUARTERLY REPORT

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FAULTING AND SLOPE INSTABILITY IN THE SAINT GEORGE BASIN AREA, SOUTHERN BERING SEA

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April 15, 1976

I. Task Objectives

The task objectives are to outline and document problems related to sea-floor instability in the St. George Basin area of the southern Bering Sea. This area includes the St. George Basin, the Bering and Pribilof submarine canyons, and the surrounding continental shelf and slope regions. Major environmental problems are related to slope instability and active faulting. Steep slopes along the shelf break and around the sides and ends of the canyons, headward eroding canyons, and thick accumulations of young thixotropic sediments promote slope instability. Fault scarps cut the sea floor in the St. George Basin area and frequent earthquakes jar the region, particularly in the southern part.

II. Field or Laboratory Activities

A month of ship time on the S.P. LEE was planned during late September and October of 1975. The cruise was designed to collect about 2,000 miles of single channel seismic data and some sediment. Unfortunately, the main rudder broke on the ship during the early part of September and the cruise had to be delayed until 1976. About 400 miles of multichannel data were collected by Marlow in the Saint George Basin area, but the single channel data were not of high quality and are of very little help. Apparently, interference with the multichannel computer decreased sensitivity of the single channel gear. We are planning a six week cruise during August and September of 1976 and hope to bring back about 2,000 miles of single channel seismic lines and some sediment.

III. Results and Interpretations

Preliminary analyses of high resolution seismic records that have been collected by other investigators, even though most records are of very poor quality, show many faults in the Saint George Basin and a great deal of slope instability along the shelf edge. These potential environmental problems make the upcoming survey both necessary and worthwhile.

IV. Estimate of Funds Expended

Equipment for research ship

Fiscal 1975 - $16,000
Fiscal 1976 - $10,000

Annual Report

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Yukon Delta Coastal Processes Study

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I. SUMMARY

A. Objectives:

The overall objective of this project is to provide data on geologic processes active within the Yukon-Kuskokwim delta in order to aid in the evaluation of the potential impact of scheduled oil and gas exploration and possible production. In particular, attention has been focused on the following:

1) Study the processes along the Yukon-Kuskokwim delta shoreline (e.g., tides, waves, sea-ice, river input) in order to develop a coastal classification including morphology, coastal stability, and dominant direction of longshore transport of sediments.
2) Study the hydrology and sediment input of the Yukon and Kuskokwim Rivers as they largely determine the sediment budget of the northern Bering Sea.
3) Determine the type and extent of Quaternary faulting and volcanism in the region.
4) Reconstruct the late Quaternary chronology of the delta complex in order to determine:
   a) frequency of major shifts in the course of the Yukon River.
   b) effects of river diversion on coastal stability.
   c) relative age of faulting and volcanism.
   d) frequency of major coastal storms as recorded in chenier-like sequences along the coast.

B. Conclusions:

1) The Yukon-Kuskokwim delta region is characterized by Quaternary tectonism. Northwest-trending faults and structurally-controlled volcanic vents are mainly restricted to the onshore extension of the Nunivak Arch, previously

recognized only in the offshore. Tectonic subsidence appears to be largely restricted to the region around Bethel and the Kuskokwim River (i.e., the Bethel Basin). Although most of the volcanic activity has been relatively mild, the presence of volcanic maars suggests the occurrence of phreatic explosions as magmas came in contact with ground water or permafrost.

2) The coastline is highly variable with respect to its morphology, processes, and overall coastal stability. Of particular importance in determining the relative coastal stability is the proximity of the Yukon River sediment input, local protection by barrier islands and early-forming shorefast ice, laterally migrating tidal inlets, and local tectonic patterns. In spite of its heterogeneity, however, the dominant direction of longshore drift is toward the north, coincident with the oceanic and wind-generated currents.

3) The Yukon delta consists of a series of sublobes, many of which have undergone constructional and destructional phases which have significantly affected both coastal stability and morphology.

4) Whereas the absolute rate of change along the shoreline has been relatively slow, rapid changes have occurred along the major rivers, particularly during breakup. Relatively rapid erosion can also occur along the edges of many of the large lakes, particularly during late summer/early fall storms.

5) Most of the sediment in the Bering Sea is introduced from the mouths of the Yukon and Kuskokwim rivers, yet significant amounts are also transported through an interconnected series of lakes and abandoned river courses, thereby complicating the overall pattern of sediment dispersion.

6) Much of the delta plain is underlain by active and relict permafrost, the distribution of which appears to be a complex function of the age of the deposits, their physical properties, and the microclimate.

7) The location of the shear zone marking the edge of the shorefast ice to the west of the Yukon delta is remarkably constant, and can be approximated by the 5 meter bathymetric contour. The shear zone to the north of the delta is more highly variable. In addition, areas of the shorefast ice adjacent to the mouths of the distributaries are generally weaker than the surrounding ice, often breaking and forming leads several times during the winter. This suggests that some lateral movement may occur within the shorefast zone during the winter.

8) The distribution of sea ice off the mouth of the Kuskokwim River differs significantly from that off the Yukon. Its distribution is controlled largely by the tidally-dominated bathymetry and offshore barrier islands.

C. Implications:

Much of the delta is underlain by the on-land extension of the Nunivak Arch; this would seem to exclude most of the region for serious consideration for exploration. Nevertheless, the Quaternary faults and volcanoes which characterize the zone constitute serious geologic constraints on the selection of transportation corridors. The discontinuous permafrost and the complex hydrology of the delta further complicate the location of such corridors, as well as making it difficult to predict the effects of oil spills.

The selection of shoreline sites (e.g., docking and pipeline terminals) must take into account the present coastal stability, including the possibility of erosion associated with major storm surges, even in an area of long-term progradation. In addition, the effects of shorefast ice for over half of the year must be considered.

The siting of offshore facilities (e.g., drilling platforms, underwater pipelines) must take into account the extent and variability of shorefast ice, the possibility (as yet unproven) of offshore permafrost, and the possible effects of altering offshore bathymetry in changing coastal stability. In addition, the effects of possible oil spills must take into account not only the dominant northward drift of water and sediments, but also the local and seasonal variability of current patterns.

II. Introduction:

The purpose of this project is to initiate a study of the recent history of the Yukon-Kuskokwim delta complex, including the processes which characterize the region, in order to gain insights as to the possible environmental impacts of oil and gas exploration and production from the nearby Norton Basin. The specific objectives of the study include the following:

1) Study the processes along the Yukon-Kuskokwim delta shoreline (e.g., tides, waves, sea-ice, river input) in order to develop a coastal classification including morphology, coastal stability, and dominant direction of longshore transport of sediments.

2) Study the hydrology and sediment input of the Yukon and Kuskokwim rivers as they largely determine the sediment budget of the northern Bering Sea.

3) Determine the type and extent of Quaternary faulting and volcanism in the region.

4) Reconstruct the late Quaternary chronology of the delta complex in order to determine:

   a) frequency of major shifts in the course of the Yukon River.

   b) effects of river diversion on coastal stability.

   c) relative age of faulting and volcanism.

   d) frequency of major coastal storms as recorded in chenier-like sequences along the coast.

This project was designed to provide as much information as possible to the problems of petroleum development in the region. A better understanding of the tectonic framework of the delta region should aid in the exploration of oil and gas. Those same tectonic features, to the extent to which they are active today, also provide serious constraints to the selection of transportation corridors, as does the existence of discontinuous permafrost and the actively shifting river courses.

A better understanding of coastal processes will aid in the siting of shoreline installations (e.g., docking and transfer facilities), as well as in evaluating the possible impacts of such facilities on coastal stability. The siting of offshore facilities (e.g., drilling rigs, underwater pipelines) must take into account frequency and magnitude of a variety of nearshore processes, including those associated with sea-ice. An understanding of these processes, including their seasonal variability, will also aid in predicting the paths of possible oil spills. An inventory of coastal materials will also serve as baseline data should spills come onshore.

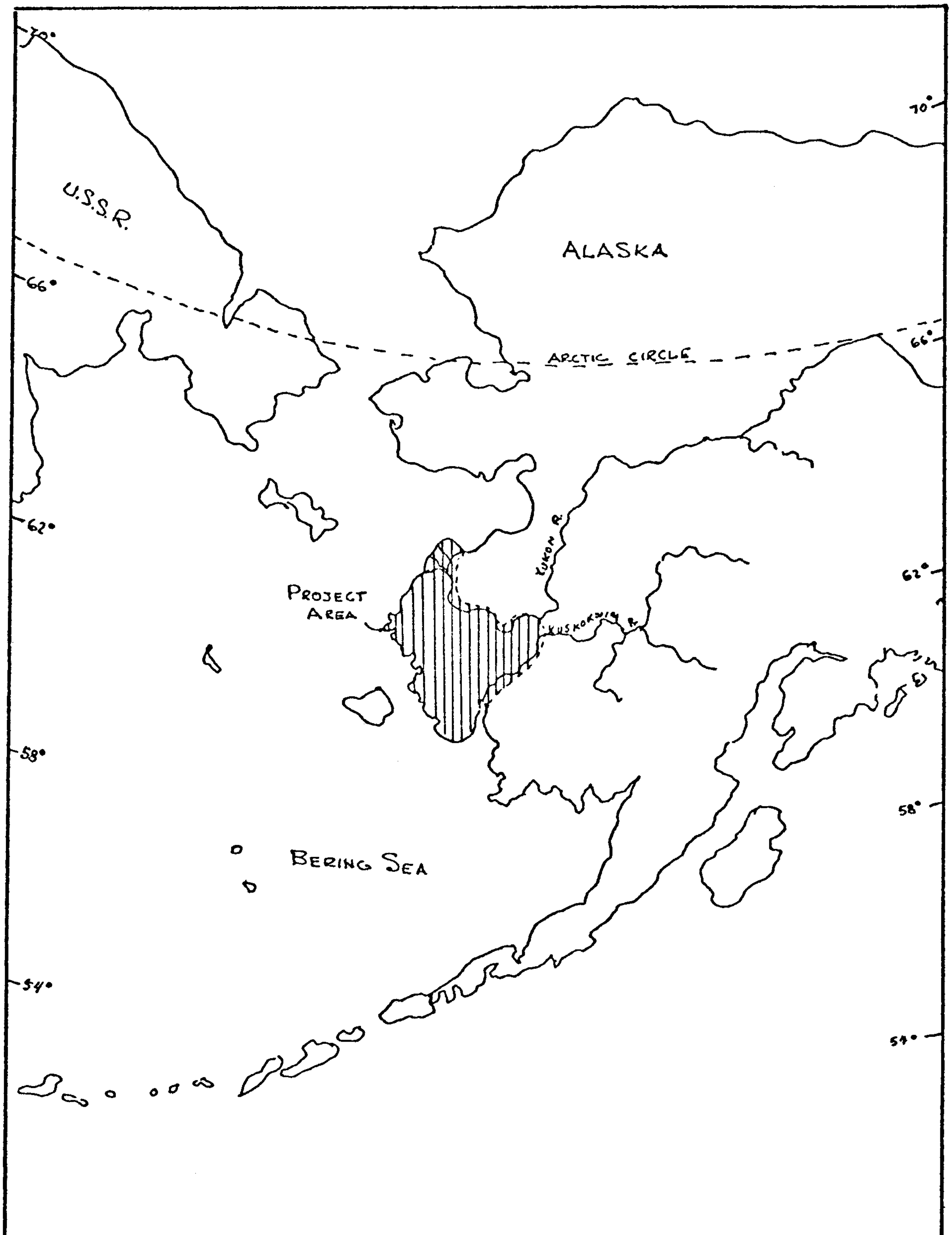


Figure 1. Location of Project Area

III. Current state of knowledge.

During the early Cenozoic, the ancestral Yukon River emptied into the Pacific in the vicinity of Cook Inlet. Late Miocene uplift of the Alaska Range resulted in the diversion of the drainage system into the Bering Sea, where it has remained to the present (Nelson et al., 1974). Gradual submergence during the late Miocene and Pliocene was followed during the Pleistocene by repeated glacioeustatic fluctuations of sea-level. Glacial intervals were characterized by emergence of the shallow Bering Sea. During this time the major rivers, including the Yukon and the Kuskokwim, emptied near the heads of major submarine canyons at the shelf edge (e.g., Scholl, Buffington et al., 1970; Hopkins, 1972). River valleys cut into the exposed continental shelf were filled during the most recent rise in sea-level with estuarine and marine sediments (e.g., Moore, 1964; Creager & McManus, 1967; Knebel and Creager, 1973). This was apparently accompanied by a general northward shift of the Yukon River to the north (Knebel & Creager, 1973; Shepard and Wanless, 1971). Information from one offshore core taken in the Norton Sound suggests that the Yukon may have reached its present position approximately 6,000 years ago (Nelson, C. Hans, in preparation).

The Yukon River is the 17th largest river in the world (Lisitzin, 1972), and provides over 90% of the sediment introduced into the Bering Sea. Its freshwater discharge (approx 180 km^3/yr) is sufficient to noticeably dilute the salinity of the Alaska current. Yet, for all of this, its Holocene history and the geologic processes which characterize the region remain little known. Geologic mapping in the delta region (e.g., Hoare, 1961; Hoare and Coonrad, 1959a, 1959b; Hoare and Condon, 1966, 1968, 1971a, 1971b) has been largely concerned with defining the pre-Quaternary history of the region. Much work has been done on studying the Cenozoic sedimentary and tectonic history of the Bering Sea (see summary by Nelson et al., 1974), including studies of the Holocene sediments of the Yukon River at its mouth (Matthews, 1973) and on the Bering Sea shelf (McManus, 1974), yet this study is the first to deal in detail with the processes and events by which the present-day Yukon-Kuskokwim delta was formed.

IV. Study Area.

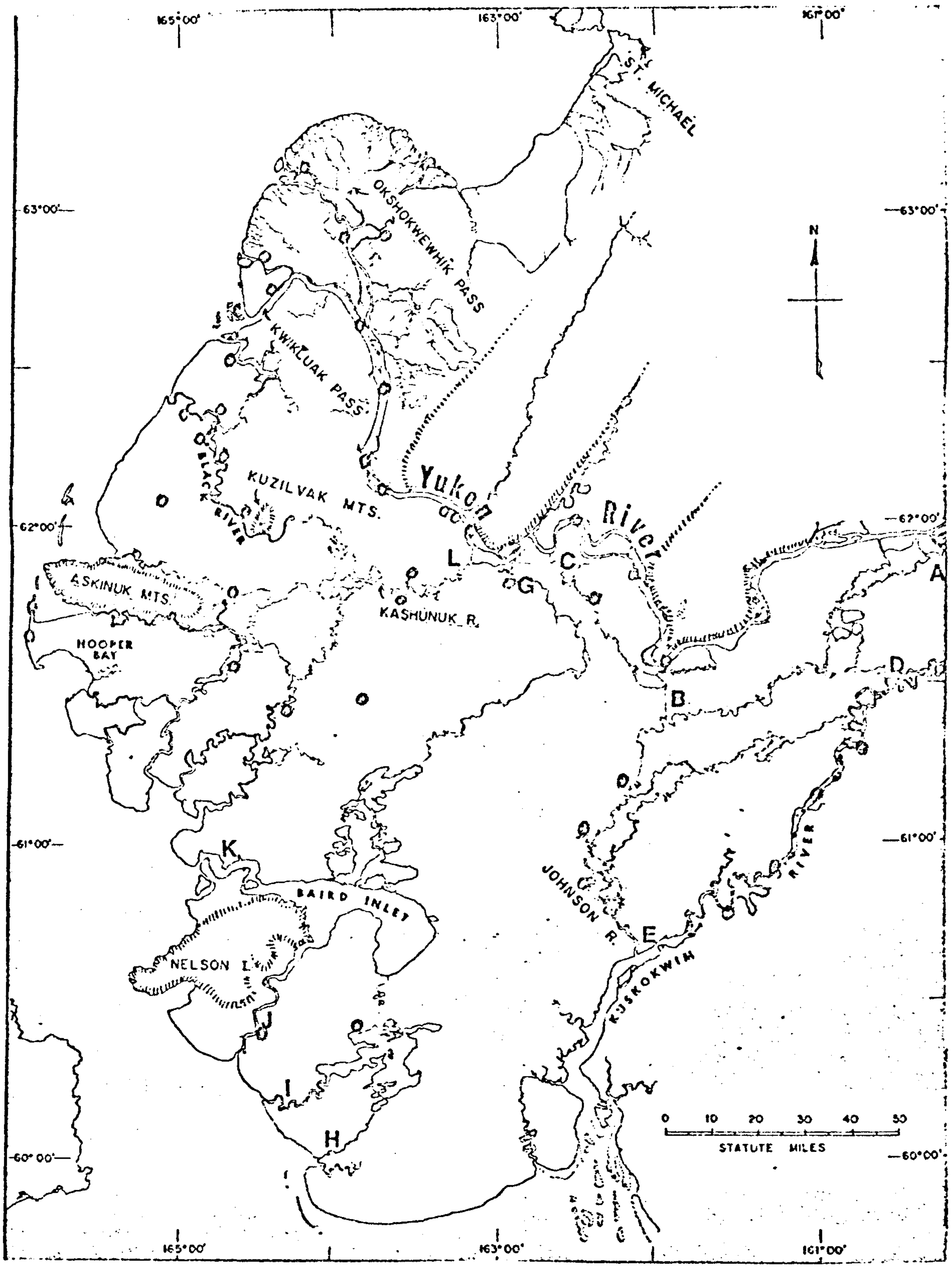
The combined Yukon-Kuskokwim delta region covers over 31,000 mi^2 (Figure 2). It is an area of unique natural resources. It has a large native population living in large extent on a subsistence economy. It contains the spawning grounds for much of the salmon in the region, as well as providing more than 90% of the sediment and nutrients to the northern Bering Sea. It is, in addition, one of the most significant breeding grounds for migratory birds (including the Great White Swan) in North America .

The delta region is largely a flat, featureless plain consisting of wet and dry tundra, interrupted by innumerable lakes, many of which are oriented. Many of these lakes have coalesced laterally to form very large bodies of water (e.g., Baird Inlet) connected to the sea by a series of ancient river channels. The flatness of the delta complex is interrupted by numerous small Quaternary shield volcanoes (generally less than 400 feet high), and the major uplifted massifs of the Askinuk Mts. (2340 feet of relative relief), the Kuzilvak Mts. (2190 feet of relative relief), and the Quaternary volcanic complex which forms Nelson Island (1485 feet relative relief).

V. Sources, methods and rationale of data collection.

A variety of maps, photos, and imagery are available for the Yukon delta

Figure 2.



MAP SHOWING SAMPLE LOCALITIES (∘ = sample location) region. Much of the area has been mapped, albeit with an emphasis on pre-Quaternary geology, at a scale of 1:250, 000 by Hoare and associates at the U. S. Geological Survey. Topographic maps are available for most of the region at a scale of 1:62, 500, as are the 1950-1954 aerial photographs from which the topographic maps were made. Bathymetric maps are also available for parts of the Yukon delta shoreline, as well as for the lower courses of the Kuskokwim and Yukon rivers. These maps date back to the 1890's, thereby allowing some estimate as to rates of erosion and sedimentation. The regional native corporation (Calista), had the entire delta region photographed in 1973, and these photos will be purchased on next year's budget. In addition, small-scale Landsat imagery is available covering much of the interval between 1973 and the present.

Hydrologic data on discharge are available in published form for the Kuskokwim River at Crooked Creek (1951-1965) and for the Yukon River at Kaltag (1957-1965). More recent data are presently unpublished, but available from the Water Resources Division of the U. S. Geological Survey. A new gaging station was established on the Yukon River at Pilots Station in 1974, and will provide information on suspended and bedload sediment as well as discharge.

Additional unpublished geologic information on the delta region, including seismic records, might be obtained from the Calista Corporation.

Much of my work has consisted of photo-geologic mapping on the 1950-1954 vertical aerial photographs. Some of that mapping was field checked during a brief visit to the field in late August, when samples were collected for textural analysis and radiocarbon dating. Many of the samples were selected to date the time of abondonment of major river courses, thereby providing a minimum age for each of the sub-delta sublobes identified by topographic map and aerial photo interpretation. The Landsat imagery has been used not only to provide a synoptic overview of the delta region, and in particular to aid in the delineation of "chenier" ridge sequences, but also to provide sequential coverage of the formation, maximum extent, and breakup of sea-ice adjacent to the Yukon and Kuskokwim deltas.

Overlays are being prepared to show the distribution of the shorelines in the 1890's, the 1950's, and the present in order to approximate the direction and rates of change and hence to provide insight into coastal stability. The dominant direction of long-shore sediment transport was approximated using geomorphic criteria (e.g., prograding spits, oblique offshore bars), wave patterns, and sediment plumes as determined from field reconnaissance, aerial photographs, and Landsat imagery. In most cases the short-term criteria (e.g., wave patterns) was consistent with the direction as determined from long-term geomorphic criteria.

VI. Results.

The results of this project to date can best be summarized in a series of illustrations, to be described in detail under section VII. These illustrations include:

1) A preliminary tectonic map (Figure 4)
2) Selected portions of the geologic map of the delta region (Figure 5)
3) A preliminary zonation of the coastline including the dominant direction of long-shore drift (Figure 8)
4) Maps delineating the extent and variability of shorefast ice adjacent to the mouths of the Yukon and Kuskokwim rivers (Figures 9, 10)

VII. Discussion

A. Tectonic Framework:

Most of the major structural elements in the northern Bering Sea region apparently developed during the late Cretaceous and early Cenozoic (Hoare, 1961; Hopkins and Scholl, 1970), yet the location of the major zones of uplift and basins, as well as many of the transcurrent faults continue to be active to the present (Hoare, 1961; Grim and McManus, 1970). Of particular interest is the pattern of faulting and volcanism over much of the delta plain. The

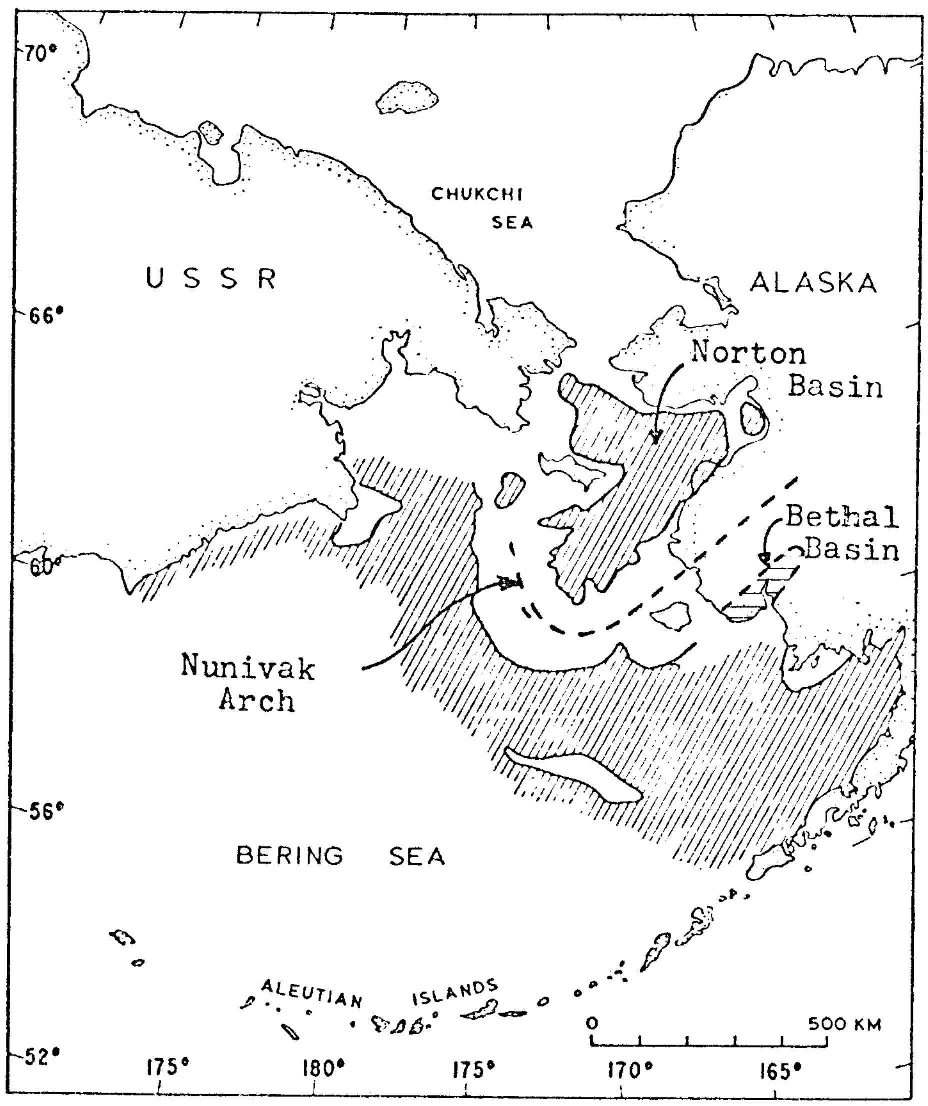


Figure 3. Major Cenozoic basins and areas of uplift, modified after Hoare, 1961; Nelson and others, 1974.

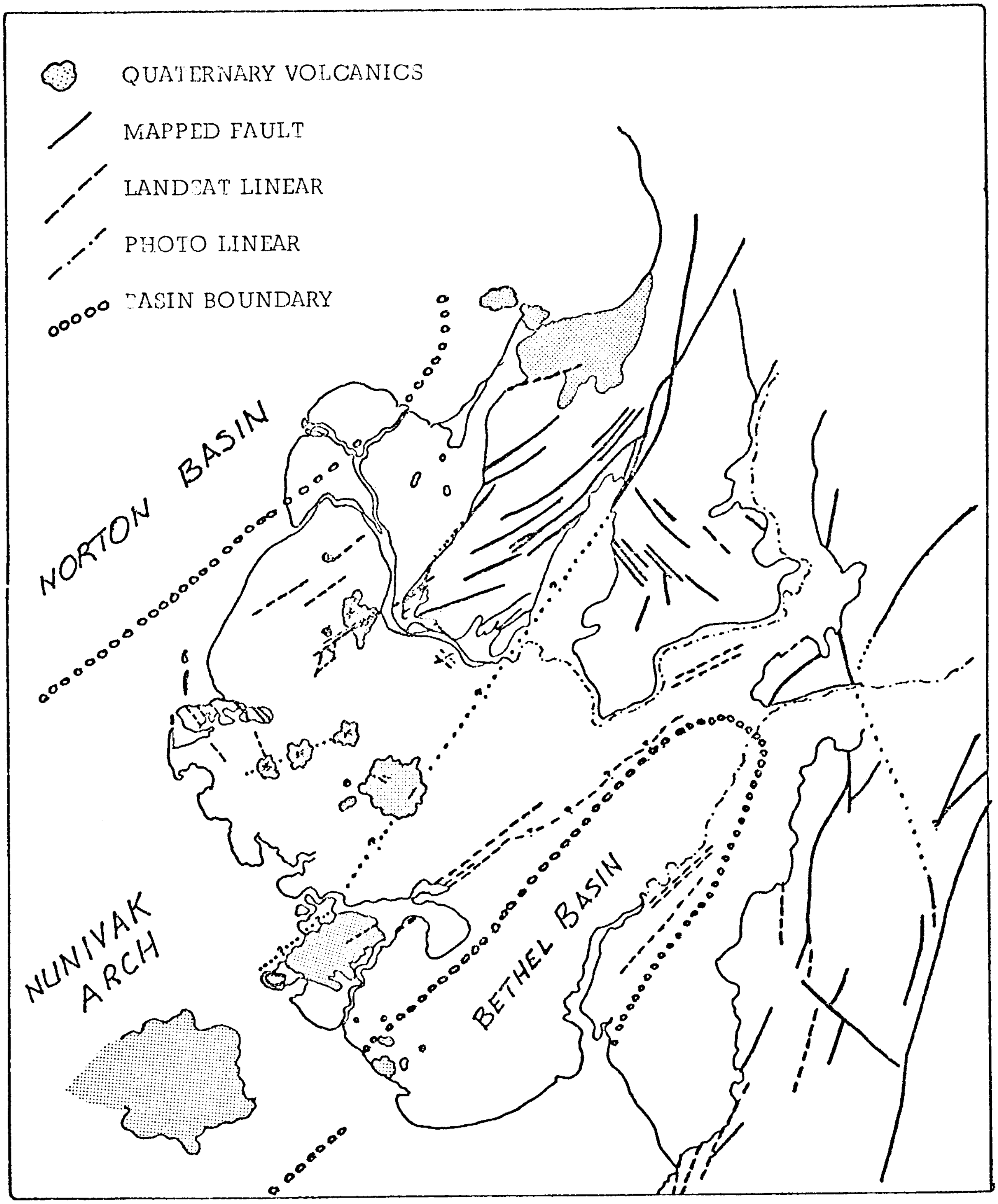


Figure 4. Tectonic map of the Yukon-Kuskokwim delta region (modified after Hoare, 1961; Beikman, 1974).

general trend and distribution of these features suggest that they reflect the onland extension of the Nunivak Arch (Figure 3) previously recognized only in the offshore (Scholl and Hopkins, 1969). Most of the newly recognized faults, photo-linears, and measured joint sets within the Quaternary deposits parallel previously mapped faults. Several of these faults, (e.g., those parallel to the northwest face of the Kuzilvak Mts.) appear to be a continuation of previously mapped faults exposed in the Andresky Mts. The Kuzilvak Mts. are of particular interest because they appear to be a fault-bound lozenge uplifted in response to transcurrent movement along the fault zone. The Quaternary offsets along this zone were mistakenly identified as a looped bar by Hoare and Condon (1966).

The linear alignment of many of the volcanic vents, often on the extension of mapped faults or major photo-linears, suggests that the vents are structurally controlled. Whereas most of the volcanism was apparently mild, forming low shield volcanoes, the presence of several maars suggests that at least some of the volcanism was highly explosive, probably due to contact with ground water or permafrost.

The age of the faulting remains uncertain, although the scarp near the base of the Kuzilvak Mts. is remarkably well preserved. The exact dating must await more extensive radiocarbon dating of the various sublobes of the delta. The age of the volcanism is even less certain. Some of the volcanic vents appear to be highly modified, whereas others are relatively "fresh". Radiocarbon dates, perhaps coupled with the recognition of discrete ash layers, may aid in determining their age.

B. Delta Processes:

The Yukon-Kuskokwim delta consists of a complex sequence of depositional units of various origins and ages. These include:

1) extensive stabilized eolian deposits to the south of the Yukon River,
2) abandoned meander belt sequences, marking the past courses of the Yukon River,
3) abandoned delta plain deposits, including large areas of patterned ground and polycyclic thaw lakes, many of which are oriented,
4) modern deltaic units, including active and abandoned distributaries, channel and distributary mouth bars, and prograding mud flats.

In spite of this complexity, the modern delta of the Yukon can be subdivided into a series of sublobes. A comparison of these modern sublobes with older, abandoned portions of the delta reveal the delta has undergone a series of constructional and destructional phases of development, similar in some ways to that which has occurred along the Mississippi River (Frazier, 1967).

The constructional phase consists of the development and elongation of distributary mouth bars along the active distributaries, coupled with progradation of mudflats along the interdistributary portions of the shoreline. Minor shifts in the course of the distributaries result in their filling, but progradation of mudflats will continue as long as the major source of sediment remains nearby.

Abandonment of the sublobe by river avulsion, perhaps initiated by ice jams, faulting, or major floods, mark the inception of the destructional phase of the delta, characterized by erosion of the shoreline. Subsidence does not appear to be a major process at this stage, except that associated with thermokarst processes. This may be in part a function of the presence within a tec-

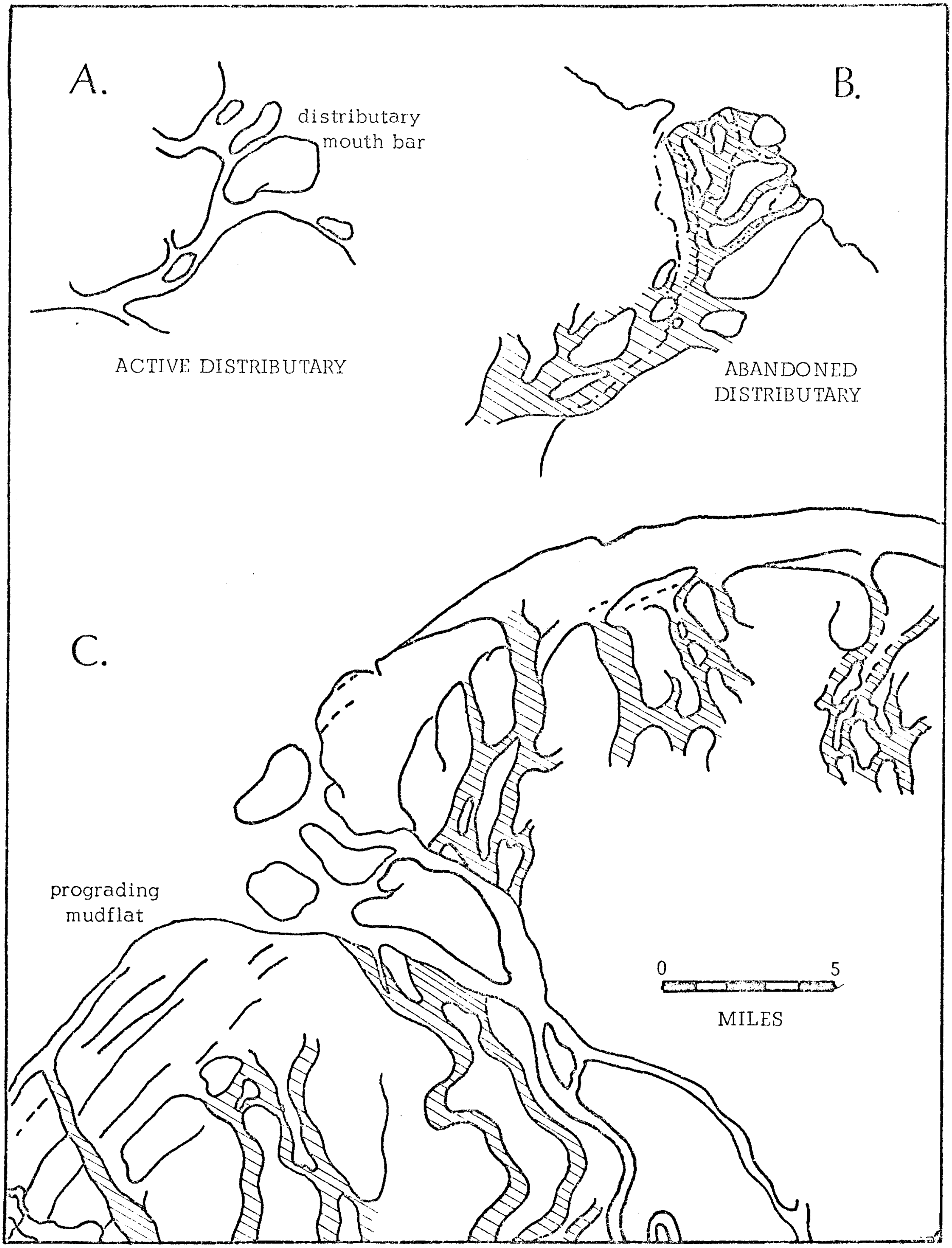


Figure 5. Depositional facies within the modern Yukon delta.

tonic arch, the lack of a thick section of deltaic sediment to allow extensive compaction, and the relatively rapid vertical growth of the wet tundra.

Abandonment of the major course of the Yukon River, for whatever cause, results in extensive alteration of the meander-belt. The riverways are usually not completely abandoned, thus they may continue to meander, albeit with a marked decrease in meander wavelength, and continue to transport some sediment to the coast, especially during periods of major floods.. In general, however, they tend to become segmented by the combined processes of infilling of vegetation and the lateral expansion of standing bodies of water (via thermal erosion) to form large lakes (e.g., Baird Inlet, Dall Lake).

It should be added that the presence or absence of a funnel-shaped mouth cannot be taken directly as evidence for the relative age of various river courses, as was suggested by Shepard and Wanless (1971). One must also take into account the much larger tidal ranges in the southern part of the delta (to 15 feet); thus part of the transition from south to north is the transition from a tide-dominated deltaic shoreline to a wave and river-dominated shoreline. In addition, the Black River is not necessarily the youngest of the older abandoned sub-deltas. The present shoreline along the mouth of the Black River is complicated by the low tidal range, proximity to the main channel of the Yukon, and continued introduction of sediment from the Black River itself.

The implications of these processes should be made clear. The major rivers have repeatedly shifted their courses and in doing so have substantially altered the stability of the natural system. Any construction activity in the vicinity of the Yukon or its distributaries must take into account not only active erosion and deposition along its banks, but also the implications of possible man-induced changes in the river regime.

C. Comparison of the Yukon River and the Kuskokwim River:

The Yukon and Kuskokwim rivers are the main source of sediments into the Bering Sea, yet they are distinctly different in terms of their hydrology, drainage area, sediment load, channel pattern, and delta characteristics.

The Yukon River at Kaltag has a drainage area of 766,600 km^2, a mean annual discharge of 6220 m^3/sec., and is characterized by a meandering stream pattern transporting relatively fine-grained sand. The Kuskokwim River at Crooked Creek has a drainage area of approximately 80,500 km^2, a mean annual discharge of approximately 950 m^3/sec., and it transports coarser grained sediments in channels which tend to be more braided. The difference in grain size is largely a function of source area. Much of the sediment load of the Kuskokwim is derived from the nearby Alaska Range, thereby providing large amounts of coarse sediment which facilitates the formation of braided stream patterns.

The difference between the hydrographs in the two rivers is more difficult to explain. The Yukon River averages approximately 40,000 cfs during the winter months when the ice-covered river is fed mainly by base flow. The major hydrologic event is breakup when, within a matter of a week or less, discharge may be as high as 1,000,000 cfs or more (e.g., Figure 6). Then there is a general decline in the discharge, punctuated with high discharges associated with late summer/early fall storms. In contrast, the hydrograph of the Kuskokwim River at Crooked Creek is more highly variable. In some years (e.g., 1964), breakup is the major event. In other years, (e.g., 1962), late season storms provide runoffs which rival that of breakup. In yet other years (e.g., 1961), breakup simply did not occur, even though it did occur

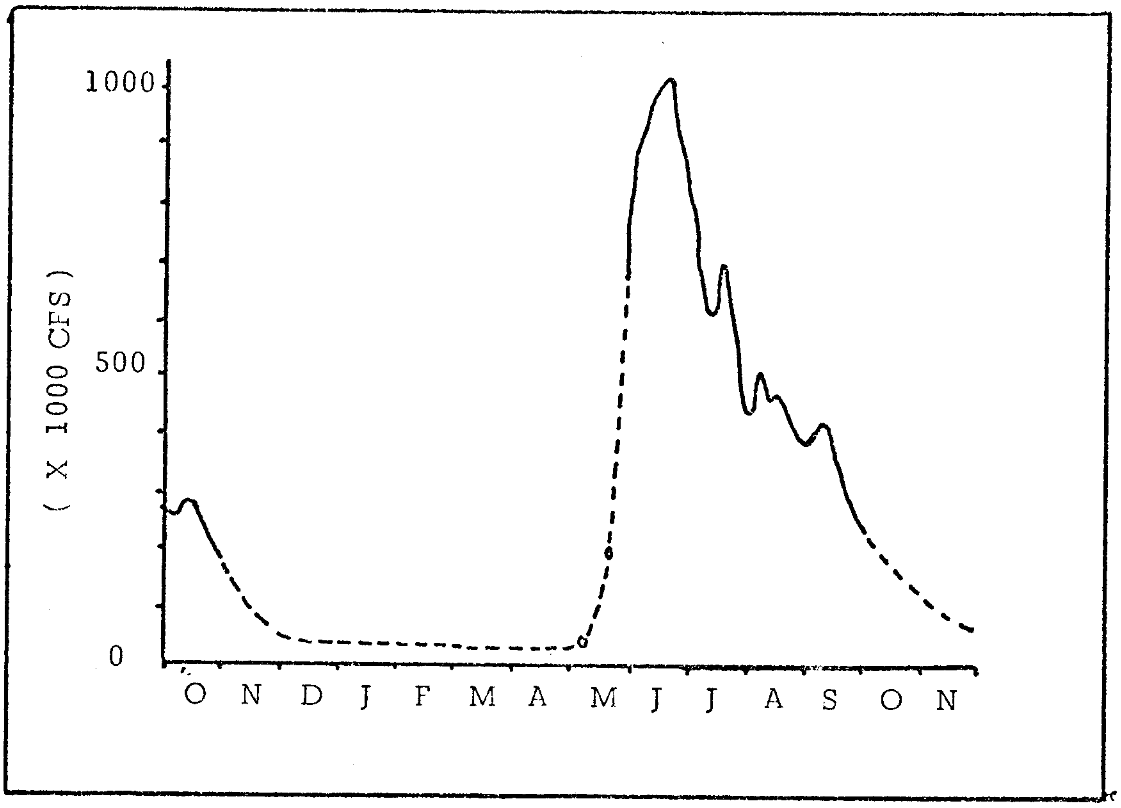


Figure 6. Hydrograph of Yukon River at Kaltag, 1963-1964.

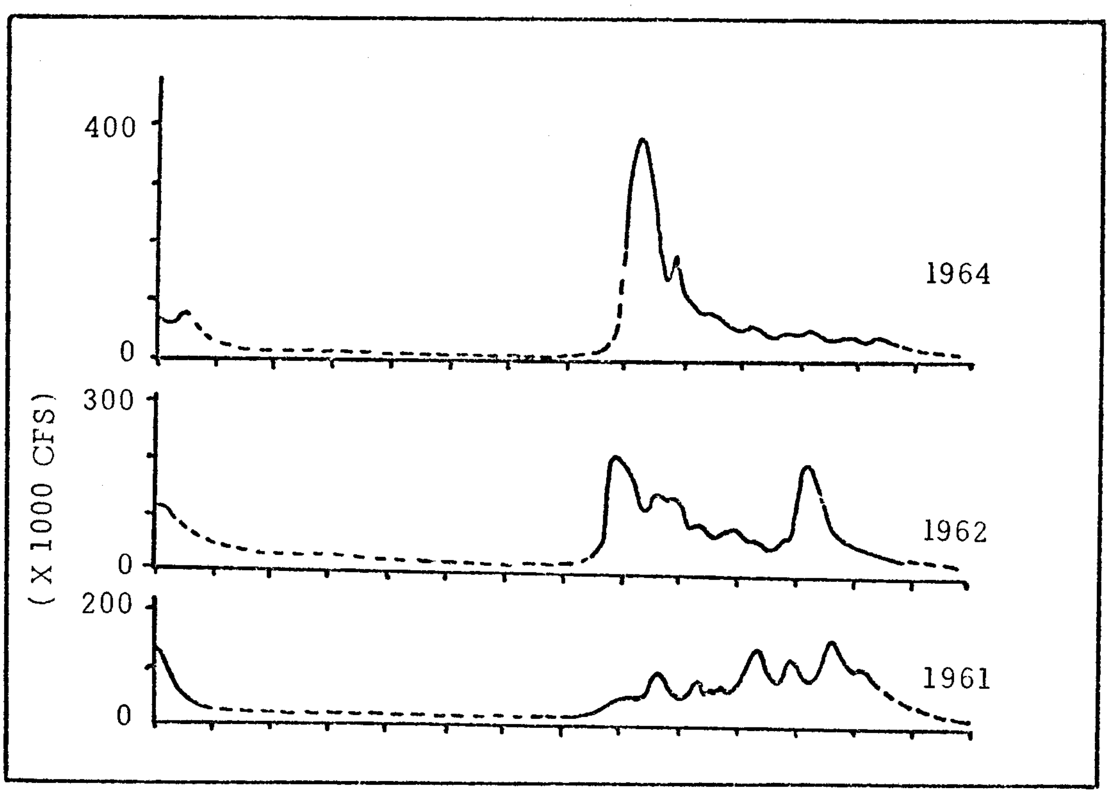


Figure 7. Selected hydrographs of Kuskokwim River at Crooked Creek.

along the Yukon to the north. Under these conditions, the late season storms are the major hydrologic events of the year.

The absence of breakup along the Kuskokwim during some years is puzzling, and should be investigated further. It may simply be related to the fact that much of the drainage area of the Kuskokwim lies to the south of that of the Yukon. It might also be affected by the high tidal currents in the lower end of the Kuskokwim which act to prevent the lower part of the river from completely freezing over (Figure 10). This might act to inhibit the effect of breakup near the mouth of the river also.

D. Coastal processes:

The coastline of the Yukon-Kuskokwim delta region was examined with respect to its morphology, relative coastal stability, and dominant direction of longshore sediment transport. The morphology was determined from examination of aerial photographs and an aerial field reconnaissance (detailed profiling and site investigations will begin next summer). Areas of erosion and sedimentation were determined on the basis of geomorphic criteria (e.g., cliffed shorelines versus prograding mudflats), coupled with the use of historic data. The dominant direction of sediment transport was determined by a variety of criteria, ranging from such short-term evidence as oblique wave incidence and sediment plumes to more long-term geomorphic evidence (e.g., stream deflections, prograding sand spits, and logarithmic spiral bays). The preliminary results are summarized by the coastal zonation scheme shown in Figure 8.

Coastal Stability:

Coastal stability is an especially important parameter as it provides some insights as to the suitability of an area for the establishment of shoreline facilities. The variables which control the patterns of sedimentation and erosion are in many ways more important than the patterns themselves for, as these variables change, either naturally or as the result of man's activities in the region, so too will the coastal stability. The major factors which appear to determine coastal stability in this region include:

1. Proximity of fluvial sediment input: significant changes in the stability of the shoreline can be affected by changes in the location of major rivers or their distributaries.

2. General orientation of the coast: south-facing shorelines tend to be dominantly erosional, whereas the west-facing parts of the shoreline tend to be stable, or areas of deposition.

3. Presence of barrier islands: provide partially sheltered intervals along which deposition is likely to occur.

4. Prograding spits: protect large areas of inland bays, allowing the development of prograding mudflats.

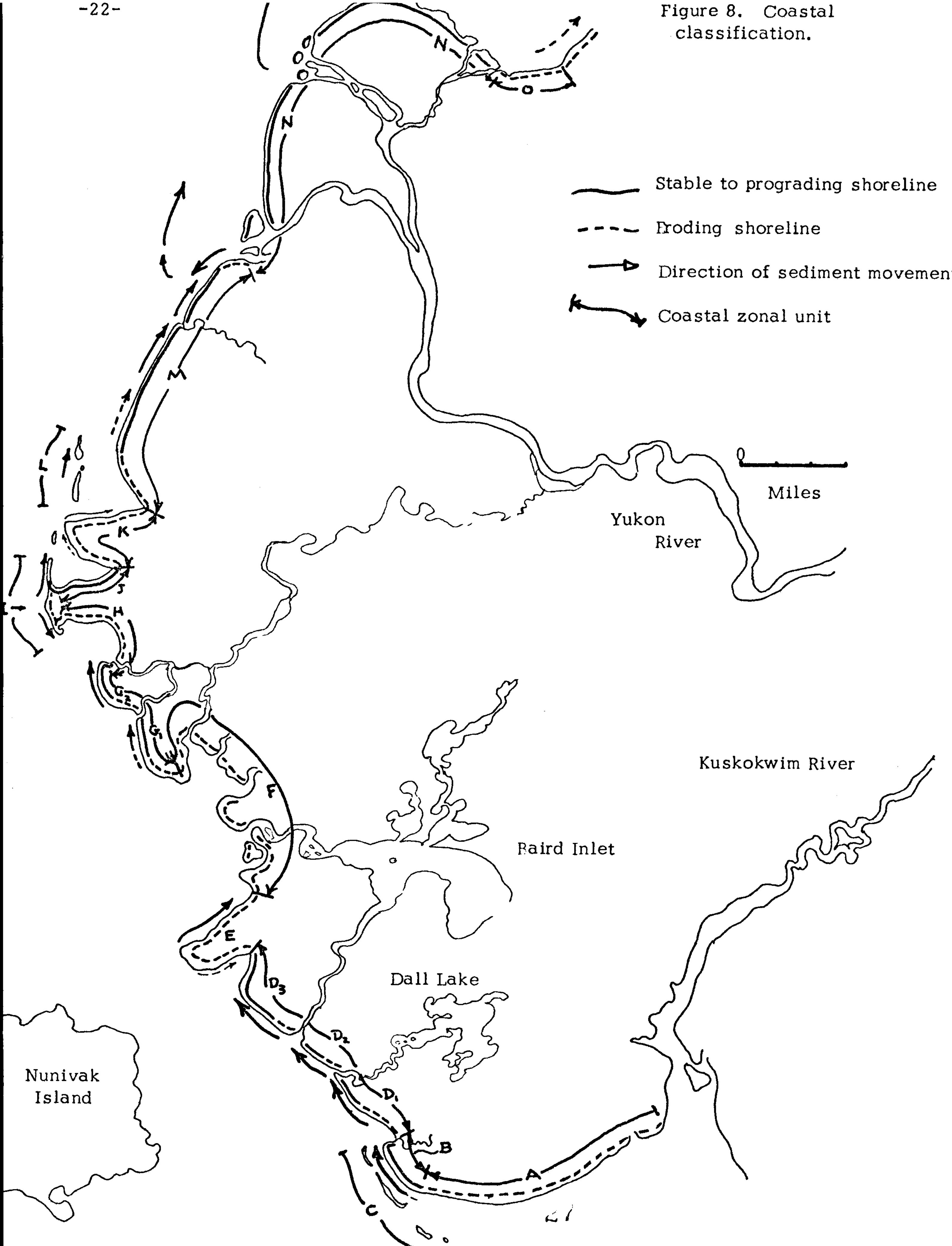
5. Early forming shorefast ice: tends to protect portions of the Yukon delta shoreline from the effects of early Fall storms.

6. Proximity of tidal and sub-tidal channels: lateral erosion of these channels can cause significant local erosion.

7. Tectonics: subsiding regions appear to be characterized by submergence and erosion of the shoreline.

8. Role of storms: major storms can cause significant erosion even in areas of long-term progradation.

Figure 8. Coastal classification.



It should be clear, then, that the classification of coastal stability is meant to indicate long-term trends of erosion and deposition. It does not, and at present cannot, take into account the possible effects of erosion in response to relatively infrequent, major storms. Storm surges in the Norton Sound region have resulted in elevation of the waters up to 4 meters which, when coupled with high winds, can cause significant erosion of the shoreline. One clue as to the effects of such storms is recorded in the chenier-like beach ridges preserved along much of the northern part of the delta region. These represent old shorelines eroded in response to major storms, and dating of these sequences (to begin this summer) should provide a better record of the probable recurrence intervals of such major storms.

Sediment Dispersion Patterns:

The general trend of sediment transport is toward the north, the result of local winds, swells, and major storms from the southwest, coupled with the north-flowing Alaska current. When examined in detail, however, the pattern becomes more complex. It is impossible to determine any dominant direction of sediment transport in much of the southern part of the delta region because of the effects of major tidal currents. Complex wave refraction causes local reversals in the direction of sediment transport (e.g., at Dall Point and along the southern end of some of the barrier islands). River-induced currents off the mouth of the Yukon River have the effect of locally reversing the direction of sediment transport. The configuration of the Yukon delta shoreline and the offshore waves appear to be mutually adjusted to minimize longshore currents. Of particular importance is the fact that virtually nothing is known about the sediment dispersion during the winter months. Matthews (1973) and

Nelson (in preparation) have suggested that much of the sediment deposited off the mouth of the Yukon delta is resuspended by storms and removed from the region by oceanic currents. Without minimizing the role of storms, it is also possible that much of the sediment is removed during the winter months, perhaps resuspended in part by grounded ice.

Role of Sea-ice:

Shorefast ice begins to form along the shores of the Yukon delta in October, but the discharge from the major distributaries causes leads to the sea to remain open until November or December. During the winter months until breakup, the location of the shear zone which marks the seaward edge of the shorefast ice west of the Yukon delta remains remarkably constant (Figure 9), and can be approximated by the 5-10 meter contour. In contrast, the shorefast ice north of the delta is more variable. Large areas of seasonal pack ice become relatively immobile during parts of the winter, and are welded to the preexisting shorefast ice. The healed shear zone can be seen on the Landsat imagery, as can the newly formed shear zone, often 20 miles seaward of the old boundary. This suggests that, whereas the proximity of the Alaska current to the west of the Yukon delta is sufficient to prevent shorefast ice to form beyond the 10 meter contour, the more sheltered portions of Norton Sound will often have seasonal pack ice temporarily attached to the shorefast ice, only to break off, typically at the old "healed" shear zone, later in the season.

There is a relatively strong correlation between the distribution of shorefast ice and the 20 meter bathymetric contour off the Beauford Sea (e.g., Stringer, 1974; Reimnitz and Barnes, 1974), although the explanation for this correlation remains uncertain (Reed and Sater, 1974, p. 300). In the northern

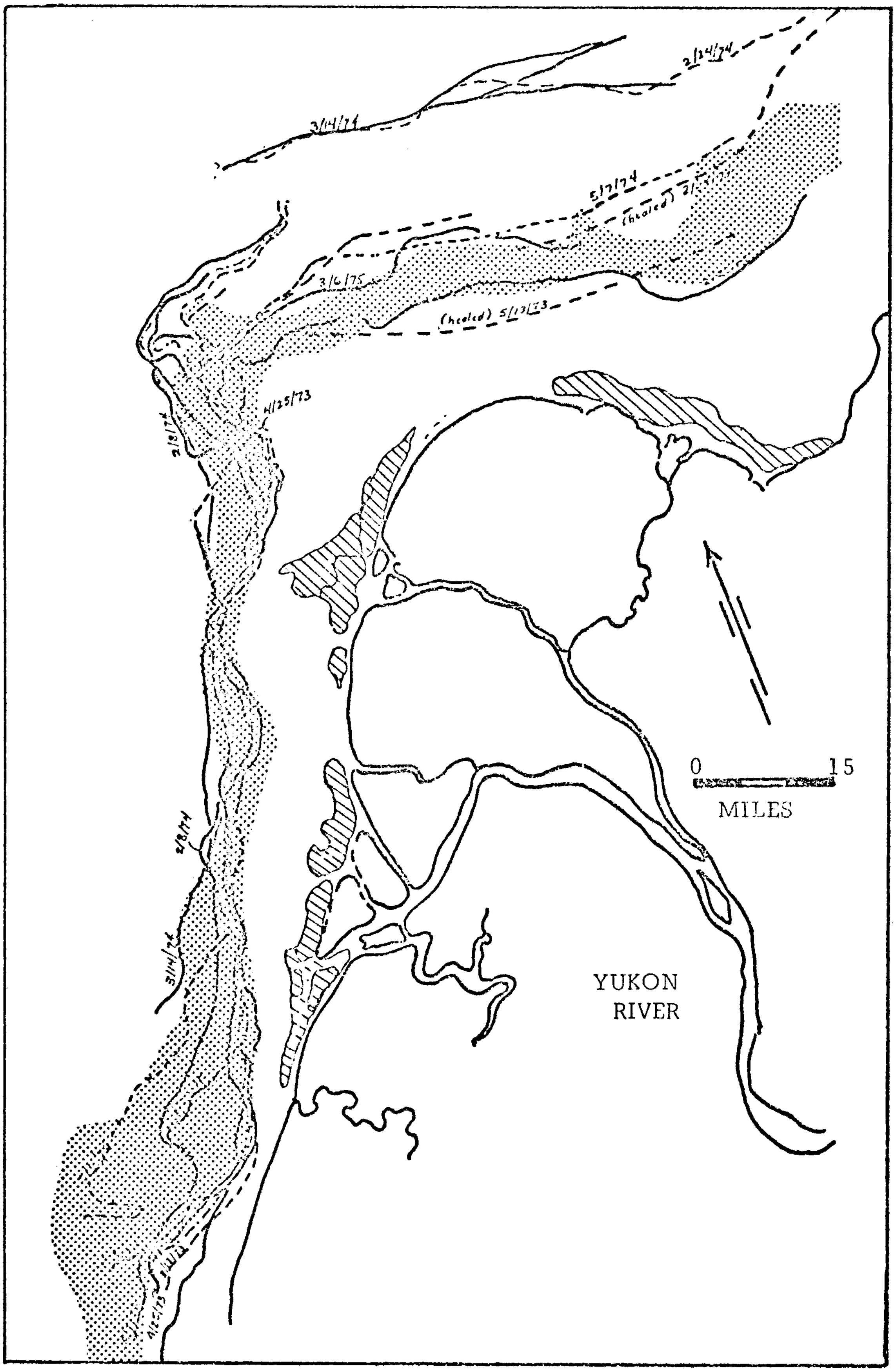


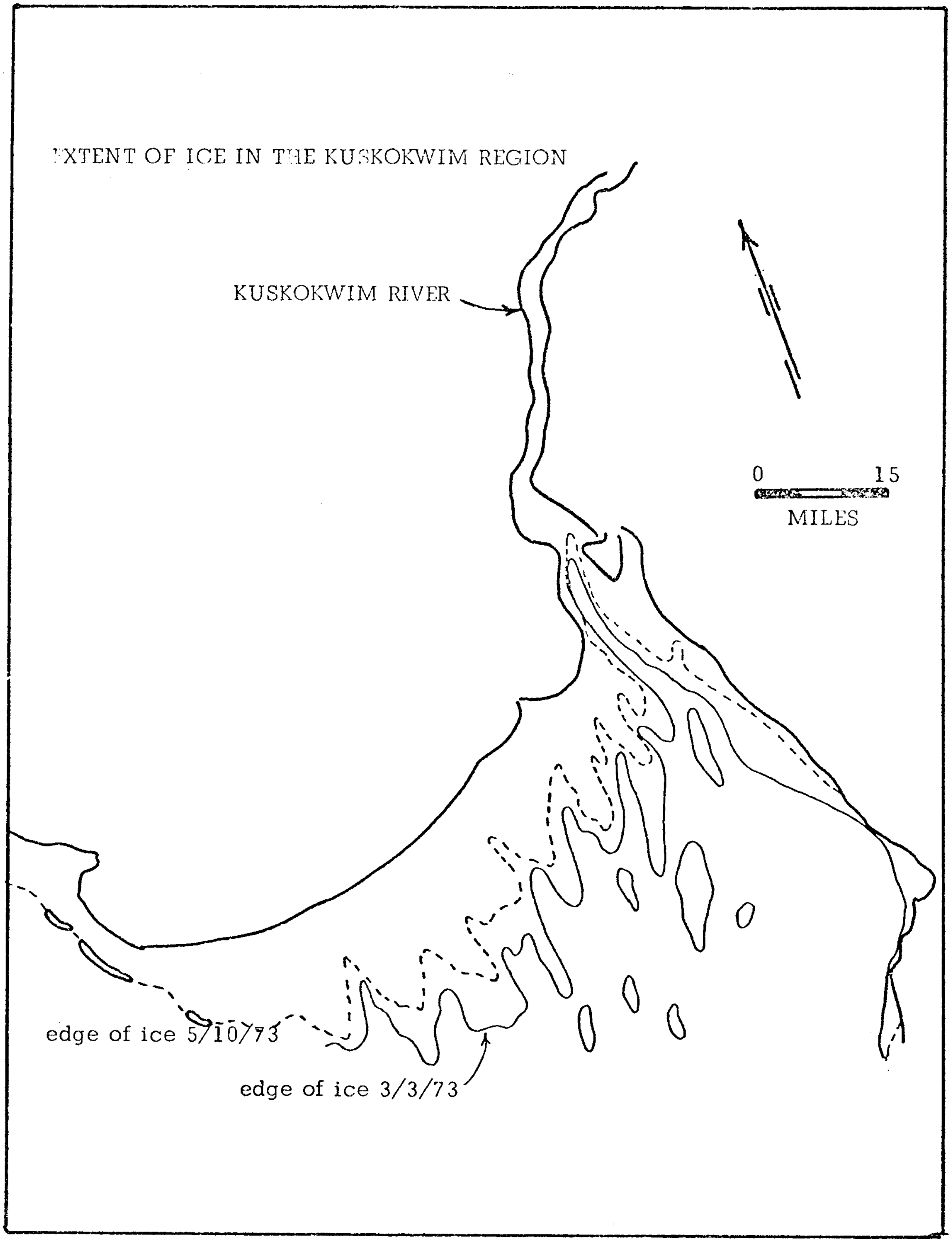
Figure 9. Location of shear zones as determined from Landsat imagery, 3/13/73 to 3/6/75. Hatched areas delineate weak ice. Dotted area delineates the 5 to 10 meter bathymetric interval.

Bering Sea the major circulation patterns, and in particular the Alaska current, appear a major factor in the distribution of the shorefast ice. The correlation with the 5-10 meter depths may be related to the thickness of the ice and to the pressure ridge keels, both of which may be less thick than their counterparts off the Beauford Sea because of the decreased time for formation.

Examination of Landsat imagery for three winter seasons also reveals that there are zones of relatively weak ice within the shorefast ice zone which form near the mouths of the major distributaries of the Yukon (Figure 9). These appear to coincide with major offshore distributary channels, and the currents associated with the winter discharge of the distributaries may be a factor in their formation. Their significance lies in the fact that these areas tend to crack and form open leads several times during the winter, perhaps in response to major shifts in the seasonal pack ice. Whatever the cause, the presence of these ruptures in the shorefast ice suggests that some lateral movement within this zone might be expected during the winter months, thereby significantly affecting offshore facilities (e.g., drilling rigs) which might be sited in this apparently stable zone. Thus, both the extent of the shorefast ice and its stability to movement are major factors to be considered in the siting of offshore facilities. This is all the more important because this is the only area adjacent to the Yukon delta where shorefast ice apparently extends over the Norton Basin, hence may be a prime area for early selections for exploratory drilling.

It should be further noted that the distribution of sea-ice off the mouth of the Kuskokwim is significantly different from that off the Yukon (Figure 10). It is characterized by a general lack of a well-developed shore shear zone, and the strong control of the tidally-influenced bathymetry.

Figure 10


EXTENT OF ICE IN THE KUSKOKWIM REGION
KUSKOKWIM RIVER
0 15
MILES
edge of ice 5/10/73
edge of ice 3/3/73

Breakup along the Yukon delta is a major event during which much of the sediment is transported to the coast , and many of the changes within the delta region occur. The river flows over the ice, depositing much of its sediment, and forming leads to the open sea similar to those described along the Beauford coast (Walker, 1973; Reimnitz and Bruder, 1972). This is such a major event in the seasonal cycle of the delta and adjacent nearshore region that a preliminary monitoring program of breakup is being planned for this May.

Coastal Zonation: (re Figure 8)

Zone A: low, eroding tundra bluffs flanked by extensive tidal flats; entire stretch appears to be tectonically subsiding.

Zone B: prograding tidal flats with oblique offshore bars; dominant direction of sediment transport to the north; progradation due to protection afforded by offshore barrier islands.

Zone C: series of sandy barrier islands, separated by tidal inlets; dominant direction of sediment drift uncertain; relative stability low as it is prone to rapid lateral migration and segmentation during storms.

Zone D: three similar segments of the shoreline, each defined by a large river at its southern boundary, flanked by eroding tidal flats which grade northward to stable or prograding tidal flats; a cliffed shoreline is formed adjacent to a small volcano along a portion of zone C_1.

Zone E: Nelson Island consists of high, steep volcanic cliffs with a few pocket beaches; sediment transport appears to be generally to the east, but evidence is limited.

Zone F: highly indented, estuarine shoreline characterized by low, eroding tundra bluffs, tidal flats, and meandering subtidal channels; channel erosion locally causes accentuated shoreline erosion; circulation patterns complicated by strong tidal currents.

Zone G: consists of two segments, similar to those described in zone D. Zone G_2 is distinguished, however, by a sandy barrier island which formed sometime between 1954 and 1973; northward prograding sandy spits, locally covered with low dunes, mark the northern boundary of this zone.

Zone H: Hooper Bay is characterized by prograding mudflats behind sand spits that flank the entrance to the bay; elsewhere the area is either stable or locally eroding.

Zone I: Dall Point is a cuspate sandy foreland, flanked on either side by eroding cliffs, locally to 70 feet high, cut into Quaternary deltaic deposits; sediment derived from erosion of these cliffs is deposited as prograding spits to the north and south of Dall Point, probably reflecting a zone of wave ray divergence.

Zone J: the south side of Kokechik Bay consists of a series of extensive mudflats which are prograding to the north, coincident with the northward prograding of the spit adjacent to Dall Point.

Zone K: the Askimuk Mts. form high, steep cliffs with only a few pebbly pocket beaches and a single prograding spit; sediment transport is generally to the north and northeast.

Zone L: The Sandwich Islands consist of a pair of offset barrier islands whose orientation suggests a dominant sediment transport to the north; patterns of erosion and sedimentation along these islands is complicated by wave refraction on the intervening ebb-tidal delta; relative stability is low, as they appear to be rapidly migrating and are prone to segmentation during storms.

Zone M: the northern side of Scammon Bay consists of eroding mud flats, but grades laterally into stable to prograding mudflats immediately to the north; the mudflats are prograding because of the high amounts of sediment being delivered from the Black River and the nearby Yukon River; although sediment transport is dominantly to the north, sediment from the Yukon is initially channeled to the south via Acharon channel, subsequently to be transported offshore and to the north by the Alaska current; the northern edge of this zone is presently being eroded by lateral migration of the offshore channel of the Yukon River.

Zone N: the entire shoreline of the Yukon delta is prograding, albeit at varying rates, by the formation and elongation of distributary mouth bars and the deposition of interdistributary mudflats; there is no dominant direction of longshore drift, probably because the configuration of the delta and the offshore waves have mutually adjusted to minimize longshore currents.

Zone O: low, eroding tundra bluffs; sediment transport appears to be toward the east.

VIII. Conclusions

1) The Yukon-Kuskokwim delta region is characterized by Quaternary tectonism. Northwest-trending faults and structurally-controlled volcanic vents are mainly restricted to the onshore extension of the Nunivak Arch, previously recognized only in the offshore. Tectonic subsidence appears to be largely restricted to the region around Bethel and the Kuskokwim River (i. e., the Bethel Basin). Although most of the volcanic activity has been relatively mild, the presence of volcanic maars suggests the occurrence of phreatic explosions as magmas came in contact with ground water or permafrost.

2) The coastline is highly variable with respect to its morphology, processes, and overall coastal stability. Of particular importance in determining the relative coastal stability is the proximity of the Yukon River sediment input, local protection by barrier islands and early-forming shorefast ice, laterally migrating tidal inlets, and local tectonic patterns. In spite of its heterogeneity, however, the dominant direction of longshore drift is toward the north, coincident with the oceanic and wind-generated currents.

3) The Yukon delta consists of a series of sublobes, many of which have undergone constructional and destructional phases which have significantly affected both coastal stability and morphology.

4) Whereas the absolute rate of change along the shoreline has been relatively slow, rapid changes have occurred along the major rivers, particularly during breakup. Relatively rapid erosion can also occur along the edges of many of the large lakes, particularly during late summer/early fall storms.

5) Most of the sediment in the Bering Sea is introduced from the mouths of the Yukon and Kuskokwim rivers, yet significant amounts are also transported through an interconnected series of lakes and abandoned river courses, thereby complicating the overall pattern of sediment dispersion.

6) Much of the delta plain is underlain by active and relict permafrost, the distribution of which appears to be a complex function of the age of the deposits, their physical properties, and the microclimate.

7) The location of the shear zone marking the edge of the shorefast ice to the west of the Yukon delta is remarkably constant, and can be approximated by the 5 meter bathymetric contour. The shear zone to the north of the delta is more highly variable. In addition, areas of the shorefast ice adjacent to the mouths of the distributaries is generally weaker than the surrounding ice, often breaking and forming leads several times during the winter. This suggests that some lateral movement may occur within the shorefast zone during the winter.

8) The distribution of sea ice off the mouth of the Kuskokwim River differs significantly from that off the Yukon. Its distribution is controlled largely by the tidally-dominated bathymetry and offshore barrier islands.

IX. Needs for further study:

1) Obtain more recent imagery of the delta region (e.g., existing 1973 color I.R. photography), in order to provide a relatively up-to-date base for geologic mapping, as well as to provide a datum to measure shoreline and river erosion and sedimentation.

2) Study the processes active on the delta, including river breakup, river-bank erosion and sedimentation, the hydrology of the interconnected lakes and abandoned distributaries, the origin and evolution of the numerous large lakes in the region, and the distribution and stability of permafrost.

3) Make a geologic map of the delta region, emphasizing the delineation of depositional systems, in order to:

a) establish a chronology of delta sublobes to serve as a datum by which the recentness of Quaternary faulting and volcanism can be measured.

b) establish a chronology of storm-induced events recorded in chenier-like sequences along the coast to estimate the recurrence interval of major storms in the region.

c) determine the physical properties of the different units which comprise the delta complex.

4) Develop a system of resource capability united for the entire delta region, using information on the physical properties of depositional units (c.f. Fisher et al., 1972), and the processes active within the delta, in order to optimize the selection of transportation corridors, evaluate the environmental impacts, etc.

5) Study the effects of the 1974 storm surge on the Norton Sound region, as this storm may well serve as a project storm in the future.

6) Study the individual zones along the coastline in more detail, including the establishment of permanent sampling and profiling stations, to be re-occupied repeatedly during the life of the project, and hopefully beyond.

7) Make detailed studies of the nearshore processes along the coastline at selected sites in order to better understand their effect on coastal morphology and sediment transport. This work should be tied in with ongoing work in the offshore portions of the northern Bering Sea.

8) Emphasis in the future should be placed on formation, seasonal variations, and effects of sea-ice as these, in combination with oceanic currents, may be the dominant processes for over half of the year. Particular emphasis should be placed on the effects of breakup, both along the coast and inland.

9) A wave-climate model should be made of the Norton Sound region which, when combined with information on coastal processes, should allow a high degree of predictive capability with respect to the effects of major storms, impacts of offshore construction projects, potential dispersal patterns of oil spills, etc.

X. Summary of 4th quarter operations:

Most of the work this quarter was done at Wesleyan University by William R. Dupre'. This included continued photo-interpretation of available aerial photographs accompanied by a preliminary examination of Landsat imagery to study the distribution and seasonal variations in sea-ice adjacent to the Yukon and Kuskokwim rivers. The hydrologic records of these rivers were also examined to provide insights as to the occurrence and significance of breakup, particularly along the Yukon.

Six samples were submitted to Steve Robinson at the U. S. Geological Survey at Menlo Park for radiocarbon dating, but the results have not become available as yet.

In addition, Dupre' attended the OCSEAP littoral zone interdisciplinary workshop held on the 13th and 14th of January in Seattle, and he will attend a workshop on research needs in the coastal zone of Alaska, also sponsored by NOAA, to be held at the University of South Carolina, on March 28th to 30th.

Annual Report--Research Unit #209

FAULT HISTORY OF THE PRIBILOF ISLAND AND ITS RELEVANCE TO BOTTOM STABILITY IN THE ST. GEORGE BASIN

by

D. M. Hopkins, P.I.

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Annual Report--Research Unit #209

FAULT HISTORY OF THE PRIBILOF ISLAND AND ITS RELEVANCE TO BOTTOM STABILITY IN THE ST. GEORGE BASIN

D. M. Hopkins, P.I.

I. SUMMARY

This study evaluates frequency of faulting and volcanic eruptions on the Pribilof Islands and in nearby waters, examines rates and directions of changes in the island shorelines during the 20th Century, and investigates the nature of the soils and their susceptibility to erosion after disturbance. Volcanos have been active in the Pribilof Island area throughout the last 8 m.y.; activity during the last 300,000 years has been confined to the vicinity of St. Paul Island. Eruptions recur at intervals of about 10,000 years.

Faulting is also an ongoing process. Fault movements recur at rather long but still unknown intervals. The faults extend offshore and are evidently related to continuing movement along a rift, here named the St. Paul rift, which represents an extension of faults bounding the St. George Basin. Although the recurrence interval of movement on individual faults is long, the fault hazard is significant, because faults cross any possible path for a pipeline connecting production areas in the St. George Basin with terminal facilities on the Pribilof Islands.

Certain segments of the shoreline of St. Paul Island have shifted tens of meters between 1897 and 1955. The changes partly reflect movement of sand by longshore drift from areas of erosion to areas of progradation, but removal of sand by wind from the beach to nearby dunes

may be a more significant process. The sandy beaches and sandy soils of St. Paul Island are sensitive to human activity. Perturbations related to construction of logistic bases and pipleine and transhipment facilities are likely to result in extensive changes in the beaches and loss of surface soils by wind deflation.

II. INTRODUCTION

This study was proposed as an investigation of the frequency of faulting and volcanic eruptions on the Pribilof Islands and beneath the shallow waters nearby. A secondary objective was to investigate the rates and directions of changes in different parts of the shoreline during the 20th Century. Considerable data was also collected on the nature of the soils and their susceptibility to erosion. Field work was conducted during June, 1975; lavas were collected for potassium-argon dating, an unsuccessful attempt was made to obtain material for radiocarbon dating, and soil samples were collected. Office work has consisted of laboratory studies, still incomplete, on the rock and soil samples, study of maps and air photos, and compilation and re-interpretation of a geologic map based on earlier studies, largely unpublished.

The Pribilof Islands (St. Paul and St. George) lie near the southern edge of the continental shelf (fig. 1), at the northwestern end of the St. George Basin, and between several other, smaller, outer continental shelf basins. The sedimentary basins of the Bering Sea--especially the St. George Basin--hold considerable promise as oil and gas prospects. When and if leasing takes place, the Pribilof Islands are likely choices for logistic bases. If petroleum is found, a pipeline terminal and trans-shipment facility is likely to be proposed there. Thus, a study of geologic hazards is in order. One must consider not only the hazards to and possible effects of siting industrial and logistic facilities on the islands, but also any possible hazards at the shoreline and in the offshore area to a submerged pipeline approaching the islands.

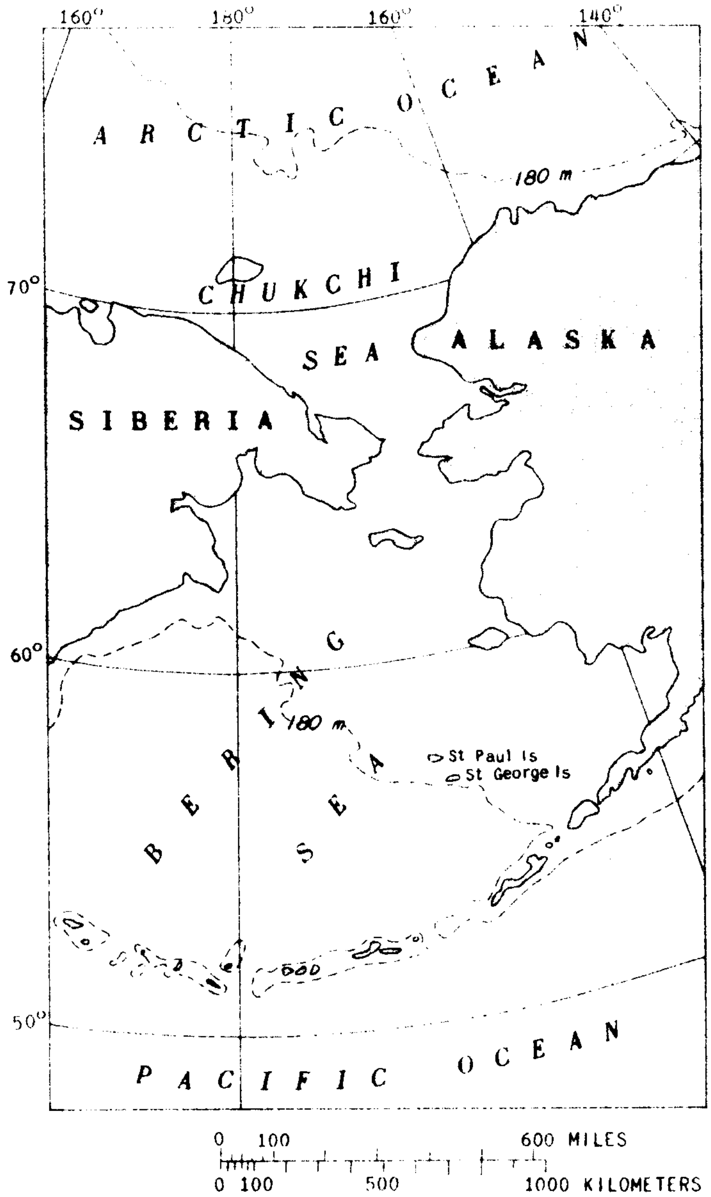


Figure 1. Index map showing location of the Pribilof Islands (St. George and St. Paul). Dashed line is 180-m isobath, representing approximate southern margin of continental shelf of Bering Sea.

III. CURRENT STATE OF KNOWLEDGE

The Pribilof Islands lie on the outer continental shelf of the Bering Sea at the crest of a broad tectonic high surrounded and penetrated by sharply defined northwest-trending sedimentary basins (fig. 2) (Scholl and Hopkins, 1969; Marlow and others, 1976). The volcanic origin of the island group has been recognized for many years (Dawson, 1894), and Barth showed in 1956 that the volcanic rocks are broken by faults. The age of the volcanism remained unknown until paleomagnetic and potassium-argon studies reported by Cox and others (1966) and Hopkins (1967) showed that the lavas comprising St. George Island were mostly erupted between 2.5 and 1.0 million years ago and that those on St. Paul were mostly erupted within the last 300,000 years.

On the basis of studies in 1962, 1965, and 1971, Hopkins completed an unpublished geologic map (scale 1:20,000). He established that the most recent volcanic eruptions took place less than 10,000 years ago, that faults disrupt relatively young lava flows, that faulting can be expected to recur, and that young faults are also present offshore. Better geochronological information was needed, however, in order to evaluate the frequency of faulting and volcanic eruptions and thus to evaluate the future volcanic and fault hazard.

Hopkins established that the Pribilof Islands have been part of the Bering Land Bridge during intervals of low sea level, that both islands are extensively covered by silty soil introduced as wind-blown silt during land-bridge times, and that St. Paul is about 40% covered by wind-blown sand, now stabilised and vegetated (Hopkins, 1970, 1972). The sand was partly blown in from the land bridge when sea level was

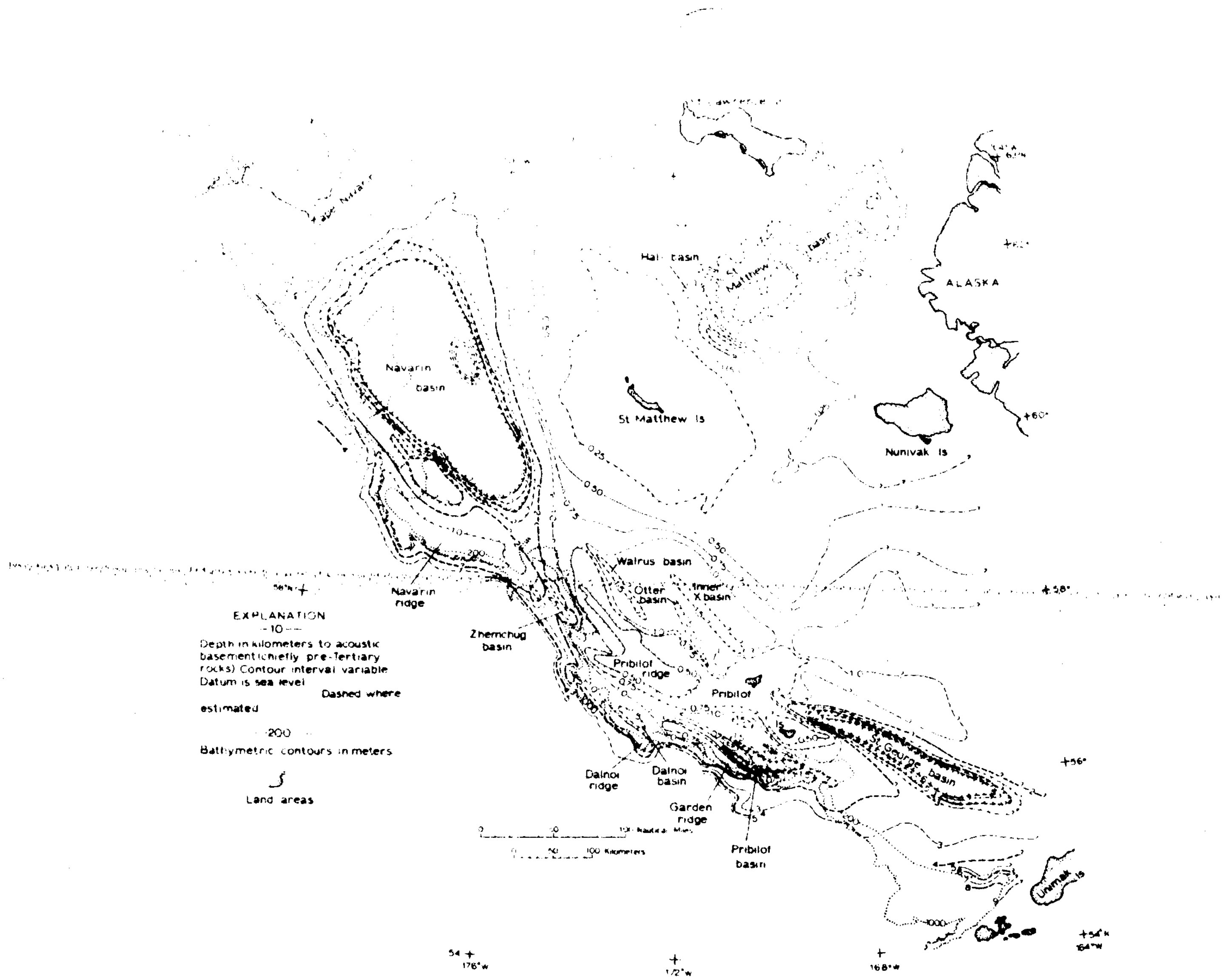


Figure 2. Structure-contour map of acoustic basement on southern continental shelf of Bering Sea (from Marlow and others, 1976).

much lower than at present and partly blown in from extensive sandy beaches when sea level was only slightly lower than now. The silt soils are susceptible to gullying and the sandy soils are vulnerable to wind-deflation wherever the vegetation cover is disturbed.

Hopkins and Einarsson (1966) described evidence of glaciation and mapped the ancient, uplifted shorelines on St. George Island. St. Paul Island has not been glaciated. Vegetation history for the Pribilof Islands during the last 20,000 years has been established by P. A. Colinvaux (1967a, 1967b) on the basis of palynological study of a core from a crater lake on St. Paul Island.

The rate and direction of shoreline changes during recent decades had not been evaluated when this study was first proposed. Hopkins (1973) discusses sea-level history in the Bering Sea region during middle and late Pleistocene time.

IV. STUDY AREA

The study area is the Pribilof Island group and the intervening sea bottom (fig. 3).

V. SOURCES, METHODS, AND RATIONALE OF DATA COLLECTION

The data base for this study consists of published reports; topographic maps (scale 1:20,000) of St. Paul and St. George Islands prepared by the Coast and Geodetic Survey in 1897; rectified nine-lens air photos of St. Paul, Otter, Walrus, and Sea Lion Islands, taken by the Coast and Geodetic Survey in 1955; unpublished PDR records obtained near the Pribilof Islands during the 1965 Navy Electronics Lab-Naval Ordinance Test Center cruise of the R/V DAVIS in 1965; the unpublished

Figure 3. Distribution of faults and their relationship to major sedimentary basins in the Pribilof Island area. Contour interval at sea is 2 fathoms (3.6 m) and on land is 100 feet (30.5 m).

(See end of paper.)

field notes and geologic maps of D. M. Hopkins and his associates; rock and soil samples collected during Hopkins' earlier visits and Hopkins and Silberman's field work in June, 1975; and the potassium-argon age determinations that are now in progress by M. L. Silberman.

For potassium-argon dating, we chose lava flows strategically placed to establish the age of events widely recognizable on the Pribilof Islands, such as episodes of high sea level, episodes of movement of windblown sand and silt, and episodes of ice-wedge formation and intense frost-brecciation of the lavas. The ancient lava flows are intensely faulted and the young ones less so. Thus, the K/Ar chronology will provide information on the frequency of fault movements as well as the frequency of volcanic eruptions.

While on St. Paul Island, we sieved large samples of dune sand representing several different episodes of aeolian action, in the hope that we could concentrate enough detrital organic material to obtain radiocarbon dates. If we had been successful, the resulting dates would have provided information on frequency of faulting, because the dunes show no evidence of disruption by faulting.

We also collected sand and silt samples for granulometric and mineralogical studies in order to establish the origin of the soil, the conditions under which surface soils are replenished, and the susceptibility of different soils to deflation, gullying, and solifluction when not protected by a cover of vegetation.

Shoreline changes on St. Paul Island during the first half of the 20th Century are established on the basis of comparison between the 1897 map and the 1955 air photos. There are no vertical photos available for St. George Island, and no early maps for the three islets near St. Paul, and estimates of shoreline change will have to be based on observations of the character and exposure of the present shores.

This study is essentially a synthesis of the large and growing body of published and unpublished material on the geology and soils of the Pribilof Islands and beneath the intervening waters.

VI. RESULTS

A. GEOCHRONOLOGICAL STUDIES

Potassium-argon dating is still in progress, and age estimates given in later sections of this report are based upon earlier work (Cox and others, 1966; Hopkins, 1967). The basalts have been sectioned and examined for suitability for K/Ar dating. Mineral separates have been prepared for those flows for which mineral-age determinations are possible. Samples intended for whole-rock age determinations have been pulverized. Potassium analyses are underway in Geological Survey laboratories. Argon extraction and mass-spectrometer analyses will be completed in May or early June in a university laboratory specialized for K/Ar analyses of very young rocks.

The radiocarbon-dating program was unsuccessful, and estimates for the ages of the aeolian sands are based upon geological considerations and upon the position of sand layers in the pollen core from St. Paul Island (Colinvaux, 1967a, 1967b). Success in obtaining new radiocarbon dates depended upon our ability to screen out 10-gram samples of detrital plant tissue from large samples of wind-blown sand. Previous results had indicated that at least 100 kg of sand would be required to obtain an adequate sample of organic material.

There are no surface streams on St. Paul Island, and so we were obliged to use ocean water; we undertook to do our screening in protected coves at low tide and at times when the surf was quiet. It proved to be almost impossible to avoid some contamination of samples by kelp and other floating material in the sea. But a more serious problem was the fact that the coastal exposures from which we were obliged to quarry the sand were permeated with modern roots. Every sieve concentrate proved to contain such overwhelming quantities of modern roots that we could not reliably separate out the older detrital plant material that would date the dunes.

B. THE FAULT PATTERN

Faults that break the surface onshore and those detected offshore are shown on figure 3.

There is a general correlation between the density of the fault pattern, the amount of fault separation, and the age of the lava flow affected. Faults that deform lava flows 1.0 to 1.5 m.y. old on St. George Island have separations as great as 60 m. Faults that deform a lava flow less than 100,000 and more than 15,000 years on St. Paul form surface scarps as high as 18 m. There is no clear evidence that faults have yet broken stabilized sand dunes believed to be about 10,000 to 12,000 years old on St. Paul, nor do the two cinder cones and the one lava flow of Holocene age (less than 10,000 years old) show clear evidence of faulting. Although data is not yet adequate to quantify rates of faulting, displacements on individual faults seem to be slow--on the order of one meter per 10,000 years. However, fault movements are no doubt episodic, and the recurrence interval of episodes of movement remains unknown.

Fault scarps 4 to 8 m high break the sea bottom near St. George Island. These scarps probably lie along continuations of faults recognized on the island. Some scarps recognized near St. Paul Island may also represent continuations of faults recognized on land.

A northwest-trending rift-like graben between St. Paul Island and Otter Island may be a segment of a more significant and extensive fault than any of those found ashore. The St. Paul Rift consists of a central graben about 15 m deep adjoined on either side by up-arched material that stands a few meters above the general level of the sea bottom (fig. 4). The trend of the feature is defined by two crossings of our PDR records and by the orientation of a northwest-trending depression in the sea floor (fig. 3). The St. Paul Rift is aligned with the southwest boundary fault of the St. George Basin and it may trend into the northwest trending Otter Basin (fig. 3). The topographic form shown on our PDR crossings, the possible great extent, and the association with volcanism and east-west oriented tensional faults on the Pribilof Islands suggests that the St. Paul Rift is part of a large, right-lateral fault, still active, and that it has a long history of past movement.

C. VOLCANIC ACTIVITY

The Pribilof Islands are centers of persistent basaltic volcanism. The vents are evidently localized along tensional fractures related to

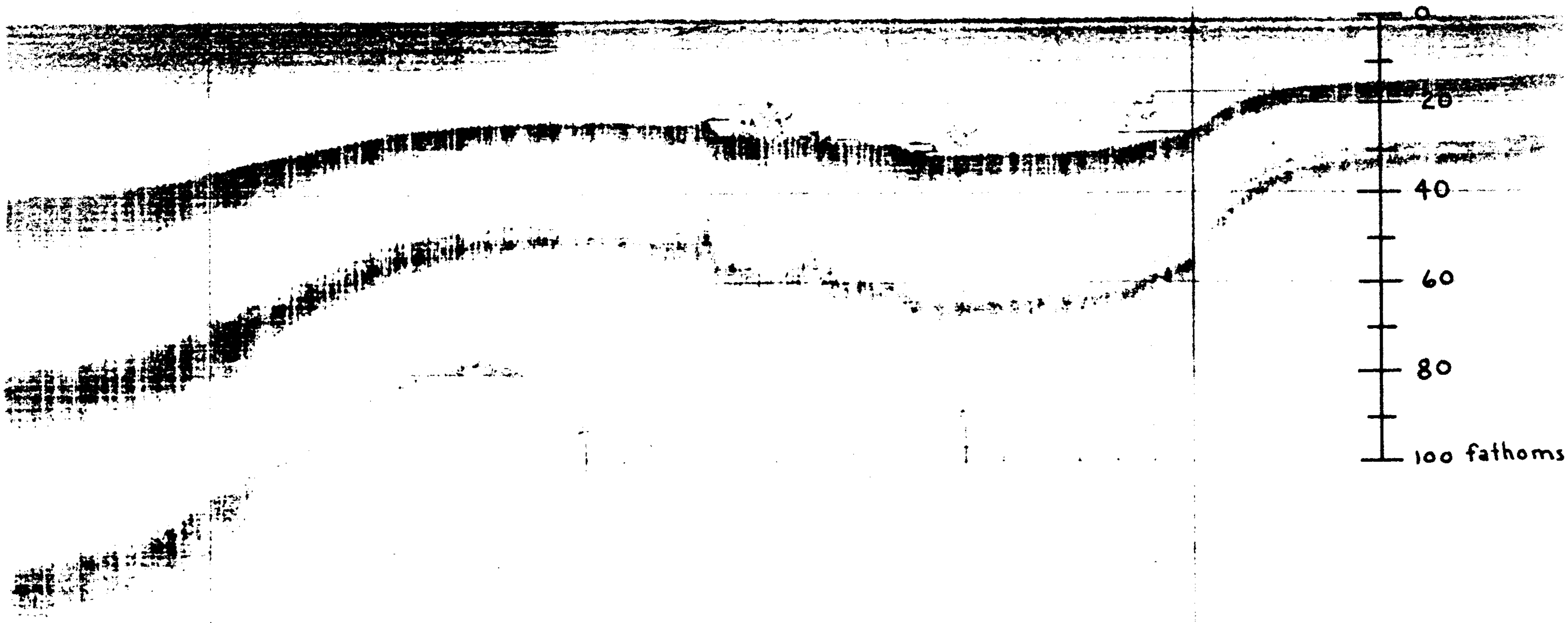


Figure 4. Fathometer record across the St. Paul Rift near Otter Island, (location shown on figure 3). Heavy horizontal lines are spaced at intervals of 20 fathoms (3.6 m).

the St. Paul Rift. Volcanogenic sediments of middle Miocene age are exposed locally on St. Paul Island, indicating that volcanism began in the Pribilof area more than 8 m.y. ago. The focus of volcanic activity has shifted from time to time. The St. George volcanic center (fig. 6) was initiated about 2.5 m.y. ago and eruptive activity ceased there between 1.0 and 1.5 m.y. ago. There have been two eruptions on Otter Island within the last 700,000 years. The present cycle of activity on St. Paul Island (fig. 5) began about 300,000 years ago and continues to the present time. Volcanic activity at Walrus Island, Sea Lion Island, and the numerous submerged shoals in the Pribilof area is still undated but probably fills the interval between the end of activity on St. George Island and the resumption of volcanism on St. Paul Island.

An estimate of the frequency of volcanic eruptions can be calculated for St. Paul Island. Thirty-six eruptive vents have formed during a period of less than 320,000 years; 11 of these erupted during the last 120,000 years; and two erupted during the last 10,000 years. These figures seem to indicate that eruptions are spaced fairly evenly and have a recurrence interval of about 10,000 years.

D. SHORELINE CHANGES ON ST. PAUL ISLAND

Areas of shoreline erosion and progradation are shown on figure 7.

The cliffed coast and the boulder beaches are relatively stable, and little change can be detected between 1897 and 1955. The beach in front of the cliffs of Tolstoi Point has prograded a few meters, evidently because of rock falls, and we have seen fresh rock falls below the Einahnuhto Bluffs.

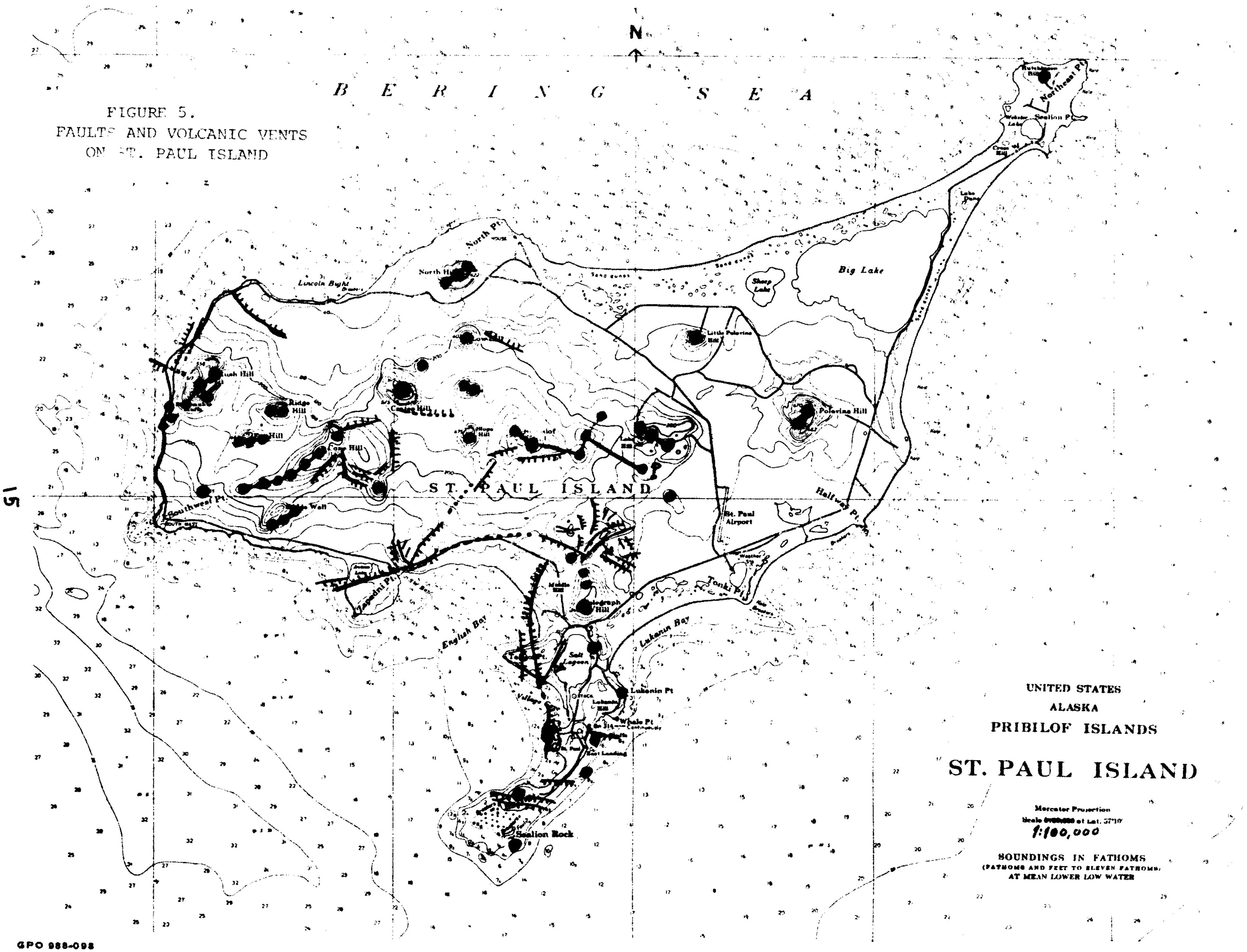
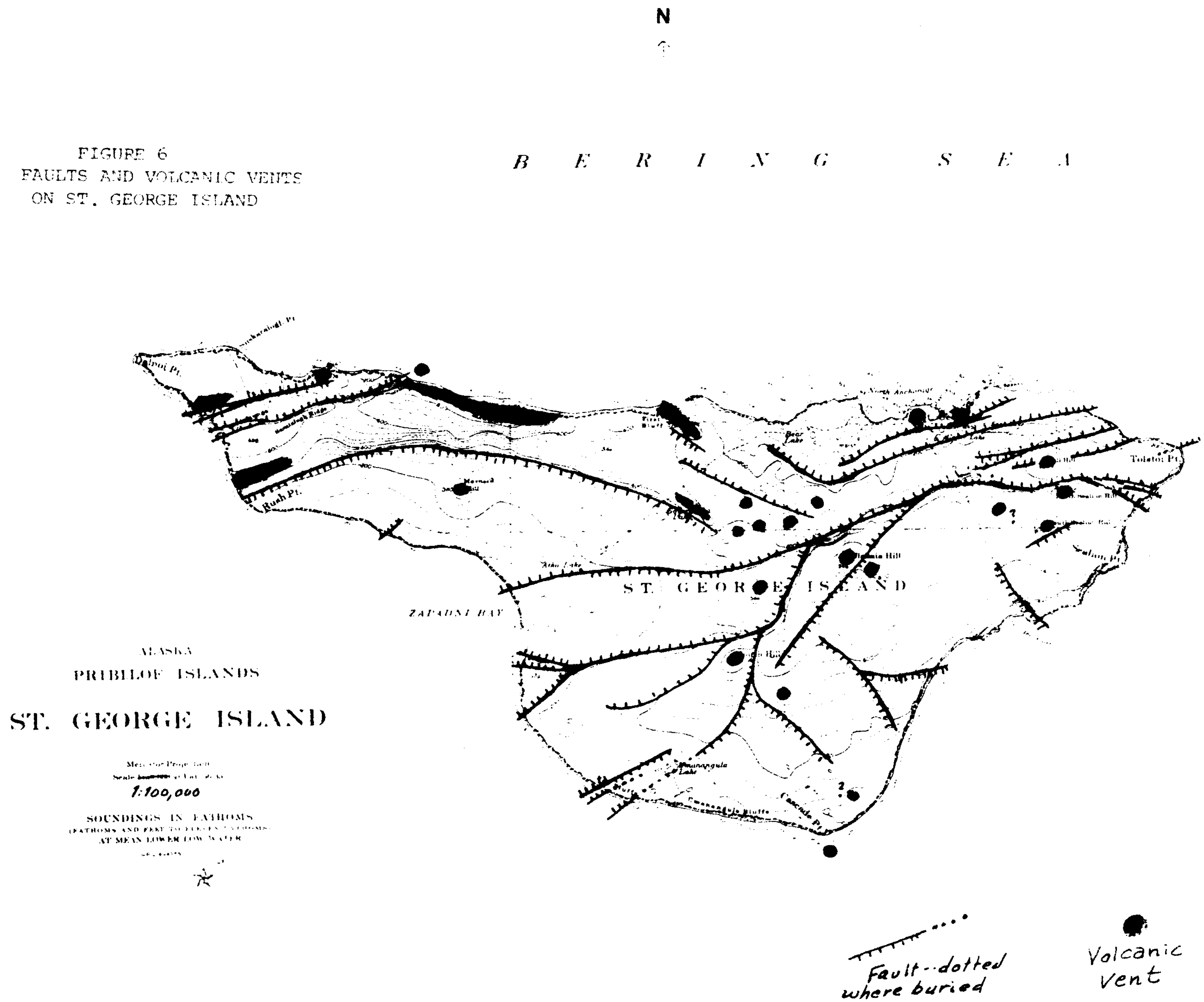


FIGURE 5.
FAULTS AND VOLCANIC VENTS
ON ST. PAUL ISLAND

FIGURE 6
FAULTS AND VOLCANIC VENTS
ON ST. GEORGE ISLAND



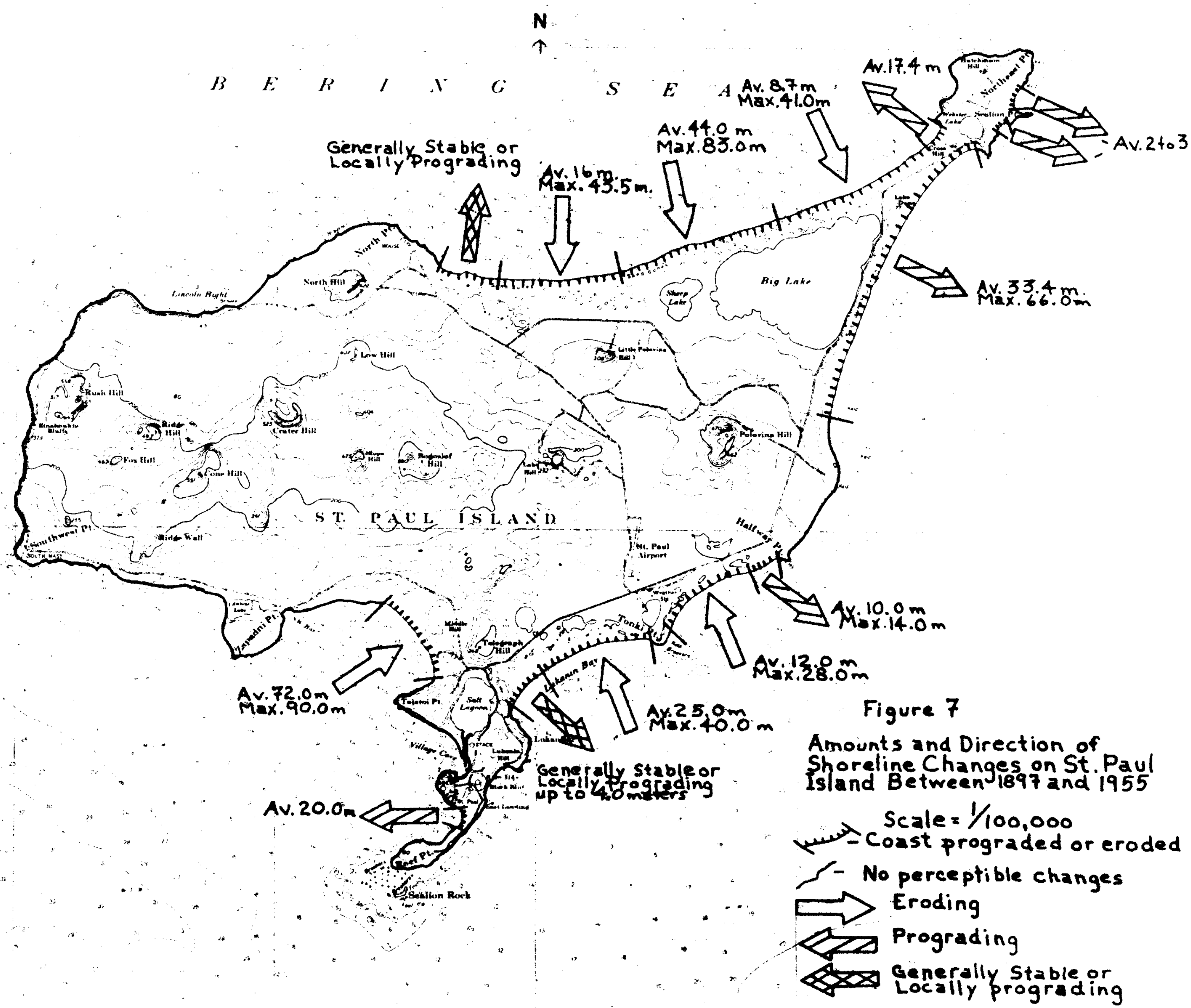


Figure 7

Amounts and Direction of Shoreline Changes on St. Paul Island Between 1897 and 1955

Most of the sandy beaches are retreating at rates of several tens of meters per century. English Bay beach, north of Tolstoi Rookery is the scene of spectacular retreat at a rate of more than one meter per year. Most of the retreat probably results from removal of sand by wind to form the active coastal dunes. However, a small part of the sand is evidently moving toward the beach leading from Little Polovina Rookery to Northeast Point, for this beach is prograding at an average rate of about 0.3 m/year.

E. SOILS AND VULNERABILITY TO EROSION

Soil analyses are completed but the data are not yet compiled in map form.

VII. DISCUSSION

Proximity makes the Pribilof Islands obvious candidates for logistic bases for future petroleum exploration and potential sites for storage and transhipment facilities for any future petroleum production in the St. George Basin. Proximity also makes the islands a useful place to study the tectonic processes responsible for the origin of the basin.

Our studies show that the faulting and volcanism on the Pribilof Islands are consequences of the same deep-seated tectonic processes that are responsible for the growth of the St. George Basin and Otter Basins. Faulting and volcanism are ongoing processes on the Pribilof Islnds, and they indicate that the deep-seated processes involved in the origin of the St. George and Otter Basins also continue.

Volcanic activity is now confined to the vicinity of St. Paul Island, and volcanic eruptions recur there only at intervals on the order of 10,000 years. The chances of a volcanic eruption on or near St. Paul Island are small, and the volcanic hazard on St. George Island and anywhere in the submerged area away from St. Paul are practically nil.

Faulting in the Pribilof Island area and also in the St. George Basin is an ongoing process. However, the long recurrence interval between volcanic eruptions, the small net displacement on faults cutting young lavas, the lack of clear evidence of faults cutting sand dunes and the youngest volcanic features, and the low level of seismicity recorded by a seismometer on St. Paul Island (John Davies and Klaus Jacobs, Lamont-Doherty Geological Observatory, oral commun., 1976) indicate that the recurrence interval between episodes of fault displacement must be rather large. The odds are very small that displacement will take place within a given decade on any given fault. Nevertheless, the odds that movement will take place on some fault, onshore or offshore, are far from negligible. It is important to recognize that any pipeline connecting a producing area in the St. George Basin and a terminal and transhipment facility on the Pribilof Islands would have to cross an active fault.

The sandy beaches on St. Paul Island are undergoing dynamic and rather rapid changes; the cliffed shorelines are more stable but are susceptible to rock falls. Docks and breakwaters will perturb the drift of sediment along the beaches and cause more drastic and rapid changes in the shoreline.

Rapid shoreline retreat could threaten the integrity of pipelines that come ashore to terminal areas and could endanger the terminal facilities themselves. Alterations in the sediment drift regime could also result in progradation in front of present-day seal and bird rookery areas with possible adverse effects upon the suitability of these areas for continuing use by the rich sea mammal and bird fauna of the Pribilof Islands.

Although compilation of a soils map is not yet completed, our studies show that about 30% of St. Paul Island is covered by stabilized and vegetated dune sand, in which a thin hard-pan soil has developed Ungraded roads across the stabilized dune areas have been considerably lowered by wind-deflation of the sand, indicating that the dune areas are vulnerable to rapid wind erosion, if they are disturbed by human activity. The area of sandy soils includes most of the low, flat, well-drained areas that would be the most obvious industrial sites. However, development of industrial sites in the sand areas may result in considerable local erosion and redeposition and could have considerable impact upon the vegetation elsewhere on St. Paul Island.

VIII. CONCLUSIONS

Volcanism and faulting are ongoing processes in the Pribilof Island area. Volcanism is now restricted to the vicinity of St. Paul Island, and eruptions recur at intervals of about 10,000 years. The volcanic hazard is small on and near St. Paul Island and negligible elsewhere. The recurrence interval of episodes of active faulting is also long, but the fault hazard is not negligible and must be considered carefully in siting pipelines between future production areas in the St. George Island and storage and terminal facilities on the Pribilof Islands.

Sand drift is active along the coast of St. Paul Island, and the position of sandy beaches there changed significantly between 1897 and 1955. The sandy soils of lowlying parts of St. Paul Island are vulnerable to deflation by wind if the vegetation cover is destroyed.

IX. NEEDS FOR FURTHER STUDY

New large-scale 1:20,000 air photographs are needed for St. George Island in order to evaluate shoreline changes since the 1897 map was prepared. The photos are also essential for the preparation of an accurate soils map of St. George Island and will be helpful in adding further details to the fault map.

New large-scale 1:20,000 air photographs are also needed for St. Paul Island in order to establish whether the shoreline changes recorded between 1897 and 1955 have continued with the same intensity during the past 20 years.

The seismic observatory at St. Paul Island has been operated for only a rather short period and should be continued in order to establish a longer time base for evaluation of seismicity in the region of the Pribilof Islands and the St. George and Otter Basins.

The trend, extent, and amount of displacement of faults offshore should be established by means of a series of high-resolution and side-scan sonar crossings. Special attention should be focussed upon the St. Paul Rift. Lines should be placed so as to confirm the postulated continuity with boundary faults of the St. George Basin and to establish its relationship with the Otter Basin to the northwest. Study of cores from the center of the rift may help to establish rates of subsidence and frequency of episodes of faulting. Colinvaux's palynological study of a core from Lake Hill Lake on St. Paul Island provides a data base that would permit interpretation of age relationships in a core through young sediments in the offshore area.

The numerous isolated shoals in the vicinity of the Pribilof Islands are probably mostly ancient, eroded, volcanic centers, but some may be exposures of basement rocks. Rock specimens should be dredged from each shoal and appropriate paleontological or radiometric methods used to establish their age.

X. SUMMARY OF FOURTH QUARTER OPERATIONS

1. No cruises or field trips.
2. Scientific party:

   D. M. Hopkins, Principal Investigator

   M. L. Silberman, Geochronologist and Geochemist

   Roger Hartz, Physical Science Technician
3. Activity this quarter consisted of preparation of basalt specimens for K/Ar dating; granulometric analyses of sand samples; and compilation of map data.
4. No new sample localities
5. 25 samples processed for K/Ar dating

   50 samples processed for granulometry.

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ANNUAL REPORT

Contract #
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Reporting Period: 1 July 1975 -
31 March 1976
Number of Pages: 20

TITLE: Earthquake Activity and Ground Shaking in and along the Eastern Gulf of Alaska

PRINCIPAL INVESTIGATORS: John C. Lahr and Robert A. Page
Office of Earthquake Studies
U.S. Geological Survey
Menlo Park, California 94025

12 April 1976

CONTENTS

ILLUSTRATIONS

I. Summary of objectives, conclusions and implications with respect to OCS oil and gas development.

The objective of this research is to evaluate the hazards associated with earthquake activity in the eastern Gulf of Alaska and adjacent onshore areas that pose a threat to the safety of petroleum development.

Work completed at this time indicates that the seismic hazard is extreme in the eastern Gulf of Alaska. First, there is reason to believe a magnitude 7 or 8 earthquake may occur in the eastern Gulf during the next few decades. Such an earthquake would be accompanied by substantial vertical displacement of the sea floor and high ground accelerations throughout much of the eastern Gulf of Alaska, possibly from Cross Sound to Kayak Island, and would likely trigger tsunamis and submarine slumping, either of which would be hazardous to offshore and coastal structures. Second, seismic activity has been correlated with known geologic features. Historic earthquake activity indicates that Pamplona Ridge is tectonically active and has been the site of earthquakes in the magnitude 6 class. Also current earthquake activity in the vicinity of Icy Bay provides evidence for active deformation in that region. These events are on strike with thrust faults bounding the southeastern margin of an offshore anticline and the southern edge of Chaix Hills.

Continued seismic monitoring will no doubt reveal other areas of activity and delineate other active geologic structures. While the locally recorded earthquake data obtained since September 1974 provide evidence of active faulting in the Icy Bay region, the absence of earthquakes elsewhere in the eastern Gulf of Alaska does not guarantee, in itself, the absence of faults capable of generating potentially damaging earthquakes. For some mapped surface faults, however, sufficient geologic and geophysical information may be available or attainable to conclude that a fault is inactive because of the lack of fault movement over a suitably long interval of time.

II. Introduction.

A. General nature and scope of study.

The purpose of this research is to investigate potential earthquake hazards in the eastern Gulf of Alaska and adjacent onshore areas. This will be accomplished by assessing the historic seismic record as well as by collecting new and more detailed information on both the distribution of current seismicity and the nature of strong ground motion resulting from large earthquakes.

B. Specific objectives.

The major aim of this research is to develop an understanding of what geologic structures in the eastern Gulf of Alaska have generated or are capable of generating damaging earthquakes.

A second aim of the proposed research is to obtain recordings of strong ground motion close to the zone of energy release in a major earthquake. Currently no such records have ever been obtained within 40 km of a magnitude 7 earthquake or within more than 100 km of a magnitude 8 earthquake. Without such information, there is currently a disturbing uncertainty in regard to the nature of the ground shaking that causes significant damage in major earthquakes.

C. Relevance to problem of petroleum development.

It is crucial that the potential seismic hazards in the eastern Gulf of Alaska be carefully analyzed and that the results be incorporated into the plans for future petroleum development. This information should be considered in the selection of tracts for lease sales, in choosing the localities for landbased operations, and in setting minimum design specifications for both coastal and offshore structures.

III. Current state of knowledge.

The eastern Gulf of Alaska and the adjacent onshore areas are undergoing compressional deformation caused by north-northwestward migration of the Pacific plate with respect to the North American plate (Figure 1). Direct evidence for this convergent motion comes from studies of large earthquakes along portions of the Pacific-North American plate boundary adjacent to the eastern Gulf of Alaska.

The 1958 earthquake on the Fairweather fault in southeast Alaska was accompanied by right lateral slip of as much as 6.5 m (Tocher, 1960). The 1964 Alaska earthquake resulted from dip slip motion of about 12 m (Hastie and Savage, 1970) on a fault plane dipping northwestward beneath the continent from the Aleutian Trench and extending from eastern Prince William Sound to southern Kodiak Island. In the intervening region between these earthquakes, from approximately Yakutat Bay to Kayak Island, the manner in which this convergent motion is accommodated is not known. There are some indications that a broad region is involved, extending from the continental shelf inland to the Totschunda and Denali faults. Slip on these faults has been right lateral during Quaternary time as would be expected if the southern margin of Alaska were partially coupled to the Pacific plate (Richter and Matson, 1971). The eastern Gulf of Alaska is bounded by the young Chugach and St. Elias mountain ranges (Figure 2).

The historic record of instrumentally located earthquakes in the vicinity of the eastern Gulf is probably complete only for events larger than magnitude 7-3/4 since 1899, earthquakes larger than 6 since the early 1930's and larger than 5 since 1964. The events contained in the N.O.A.A. Earthquake Data File for 1899 through February, 1975 are plotted in Figure 3. Each number corresponds to the decade in which the event occurred. The coordinates of epicenters prior to about 1960 were often rounded to the nearest tenth of a degree. To avoid plotting epicenters on top of one another, the second and subsequent epicenters to be plotted at a given point have been randomly scattered by up to 4 km. The apparent increase in seismicity in the 1960's and 1970's is due in part to aftershocks of the 1964 Prince William Sound earthquake and in part to establishment of seismograph networks in southern Alaska in 1967 by N.O.A.A. (Palmer Observatory) and the Geophysical Institute of the University of Alaska. The seismograph stations closest to the region of study are located on Middleton and Kodiak Islands and near Palmer. Prior to 1967 the closest permanent stations were at Sitka and College.

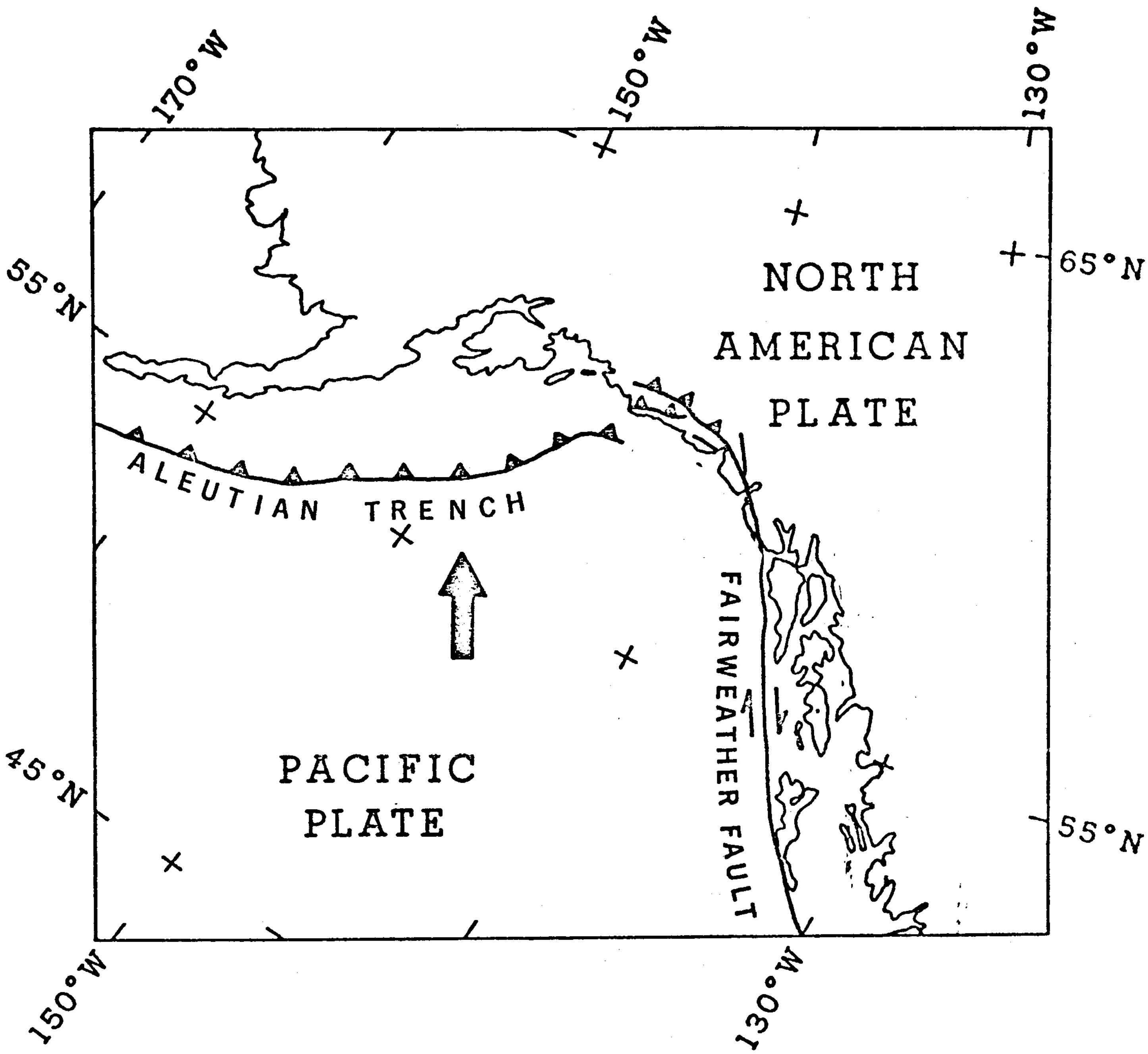


Figure 1. Plate tectonic relationships in the northeast Pacific. Large arrow indicates motion of the Pacific plate relative to a stationary North American plate. Small arrows indicate sense of horizontal slip on faults; barbs are on upper edge of thrust fault.

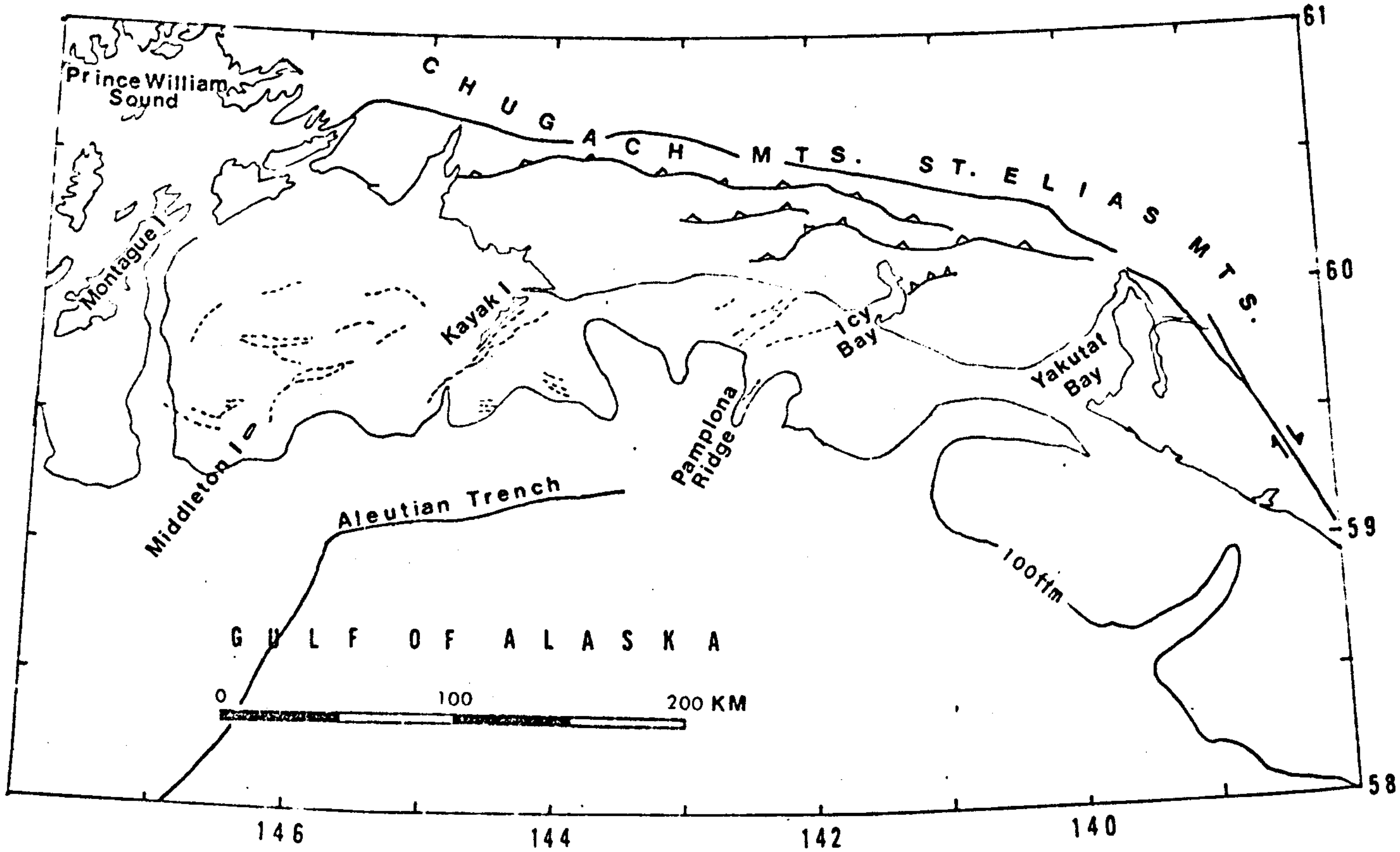
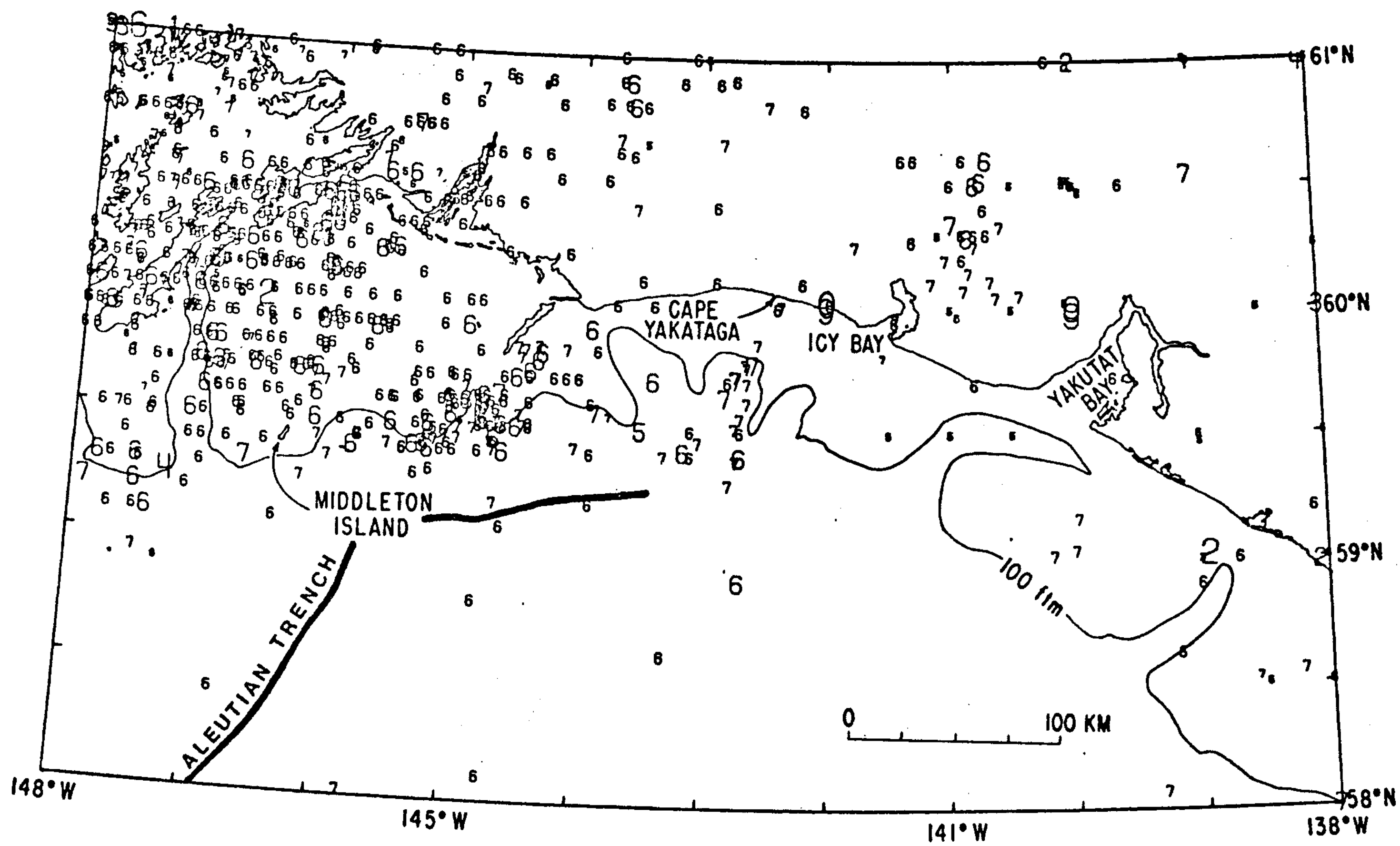


Figure 2. Map of eastern Gulf of Alaska region showing offshore faults and selected onshore faults



GULF OF ALASKA SEISMICITY (1899 - 1975)

SIZE CORRESPONDS TO MAGNITUDE
MAGNITUDE: 0 - 3 - 5 - 7 - 8.5
SIZE: 5 5 5 5

Figure 3. Map of earthquake epicenters in the eastern Gulf of Alaska region, 1899, 1975. Numbers indicate decade in which earthquake occurred, for example, 9 indicates 1890-1899 and 0 indicates 1900-1909. Size of number indicates magnitude of earthquake according to legend.

The largest historic earthquakes in the vicinity of the eastern Gulf of Alaska were three magnitude 8 earthquakes in the Yakutat area in 1899 and 1900 (Tarr and Martin, 1912; Richter, 1958) and the magnitude 8 Prince William Sound earthquake of 1964. Shorelines were uplifted as much as 14 meters in the Yakutat Bay area and about 1 meter at Cape Yakataga during the 1899-1900 earthquakes (Tarr and Martin, 1912). Coastal uplift during the 1964 earthquake ranged from 10 meters at Montague Island to less than 3 meters at Kayak Island (Plafker, 1969). The region between the 1899-1900 and 1964 earthquakes lies on the Pacific-North American plate boundary and has been identified as a likely location for a magnitude 7 or 8 shock in the next few decades (Kelleher, 1970; Sykes, 1971; Page, 1975).

The Chugach and St. Elias Mountains are bounded on the south and southwest by the Gulf of Alaska Tertiary province. Many north-dipping thrust faults have been mapped in this Tertiary province (Plafker, 1967) but it is not known which are currently active. A few of these faults are indicated on Figure 2.

Available information on the offshore structure has been summarized by Bruns and Plafker (1975) and Molnia et. al. (1976). The location of near-surface offshore faults, interpreted largely from minisparker records, are shown in Figure 2. None of these faults was found to offset Holocene sediments at the sea floor with great certainty, so their current state of activity will probably best be determined by earthquake investigations.

IV. Study area.

This project is concerned with seismic hazards within and adjacent to the eastern Gulf of Alaska continental shelf area. This is the southern coastal and adjacent continental shelf region of Alaska between Montague Island and Yakutat Bay (Figure 2).

V. Data collected.

The short-period seismograph stations installed along the eastern Gulf of Alaska under the Outer Continental Shelf Energy Program as well as the other stations operated by the USGS in southern Alaska are shown in Figure 4. Single-component stations record the vertical component of the ground motion, while three-component stations have instruments to measure north-south and east-west motion as well. Data from these instruments are used to determine the parameters of earthquakes as small as magnitude 1. The parameters of interest are epicenter, depth, magnitude, and focal mechanism. These data are required to further our understanding of the regional tectonics and to identify active faults.

A network of strong motion instruments is also operated by the Seismic Engineering Branch (Figure 5). These devices are designed to trigger during large earthquakes and give high-quality records of large ground motions which are necessary for engineering design purposes.

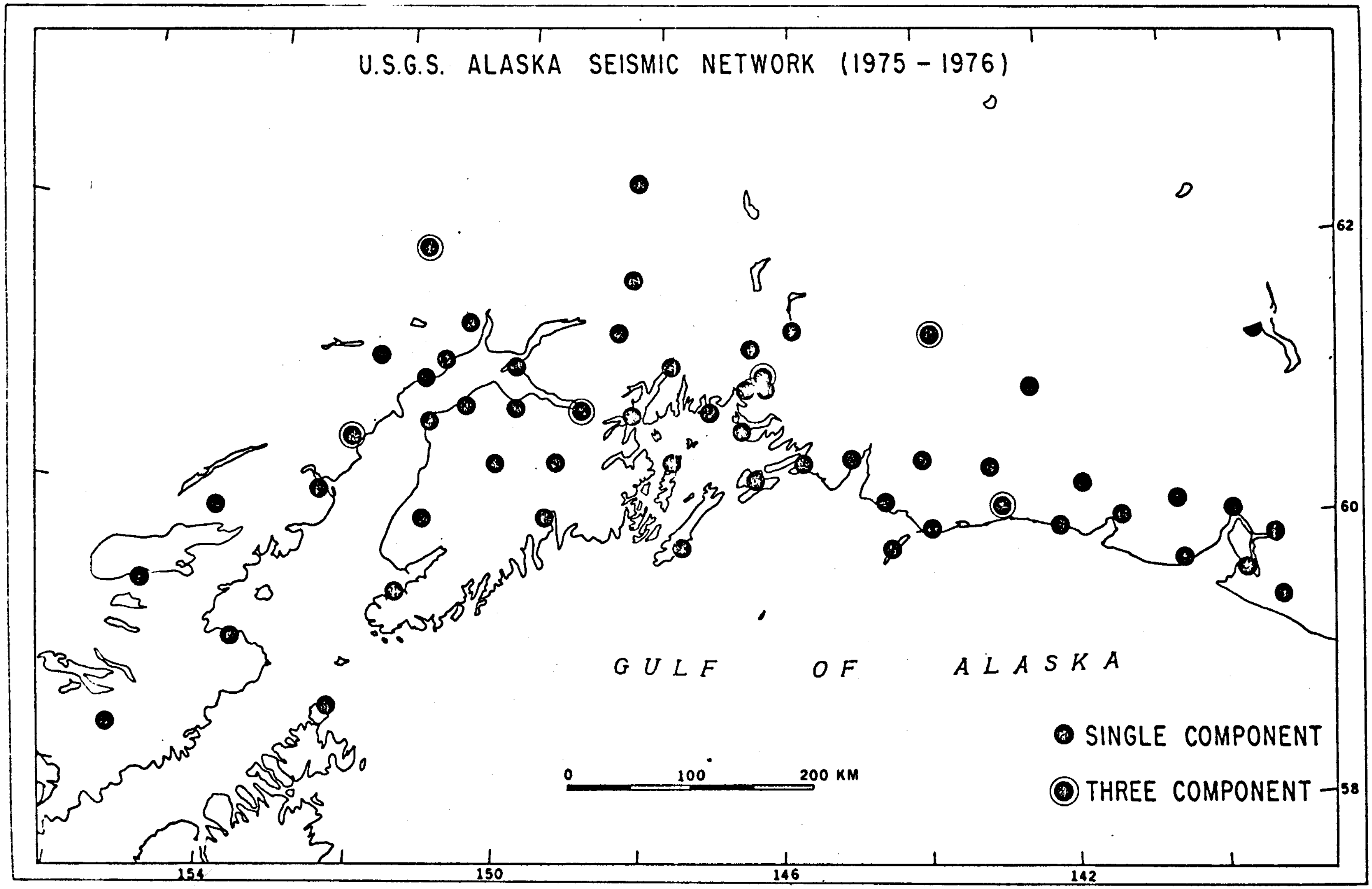


Figure 4. Map of seismograph stations operated by the USGS in south-central Alaska, 1975-1976.

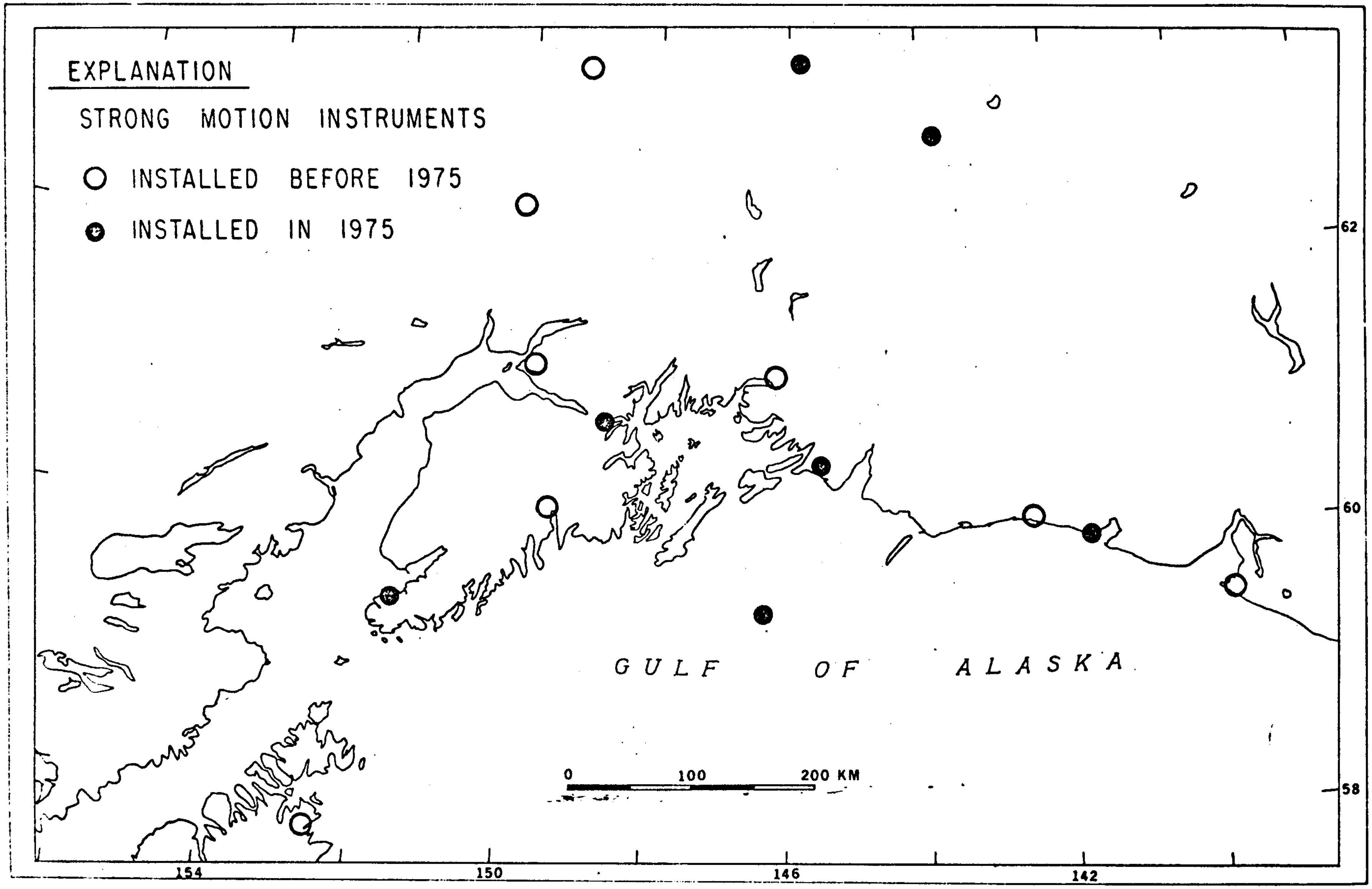


Figure 5. Map of strong-motion instruments operated by the USGS in south-central Alaska, 1975-1976.

VI. Results.

Preliminary earthquake epicenters in the eastern Gulf of Alaska are plotted in Figures 6 through 9. The events shown are the most reliably located earthquakes. For each shock, nine or more P- and S-phase arrival-time readings were used, of which at least one was an S-phase. Also, the root-mean-square residual (difference between observed and theoretical arrival times) was required to be less than or equal to 0.7 seconds.

These data indicate that for the 14 months studied to date, few offshore earthquakes have occurred east of about Kayak Island, with two notable exceptions. One is the cluster of events 50 km south of Yakutat Bay. Relocation of this group of events by the master event technique indicates a very small (less than 5 km diameter) source region for most of these events. This region was not covered by detailed sparker reconnaissance so the presence of faults near the surface of the sea floor is not known. The second exception is the seismic activity near the mouth of Icy Bay. These events are on strike with a fault mapped from sparker work and also with a northwest-dipping thrust fault mapped by Plafker (1967) east of Icy Bay.

There is scattered but substantial activity through the Chugach and St. Elias Mountains which is not clearly associated with any mapped faults. In the continental shelf area west of Kayak Island there is diffuse seismic activity off the southern coast of Montague Island and between Hinchinbrook Island and the shelf edge. This pattern is expected in an area which is being underthrust by the Pacific plate.

Reliable depth estimates are difficult to obtain for events in the eastern Gulf of Alaska region, particularly for events outside the network. As a general rule, to obtain an accurate depth there should be at least one station for which the epicentral distance is less than the focal depth. Thus, a 50-km station spacing provides reliable estimates of depths 50 km or greater. There is no evidence to date that any earthquakes are occurring below the crust, and the better-determined hypocenters have depths ranging from about 5 to 25 km. This aspect of the earthquake locations will be addressed in more detail in future detailed area-by-area studies of the seismicity.

The rate of offshore activity has not always been as low as it currently is, as illustrated in Figure 3. In particular there have been many events in a north-northwest trending zone paralleling Pamplona Ridge on the west. A sequence of events occurred there in April, 1970 and have been relocated using the master event technique with teleseismic data. These relocations are shown in Figure 10. The relative accuracy in the epicenters is probably better than 5 km, however, the absolute accuracy may be no better than 10 or 15 km. Pamplona Ridge is bounded by a fault on the east. Within the uncertainty in the absolute locations, these events may have occurred on this fault especially if it dips to the west below the ridge.

VII. Discussion and Conclusions.

The earthquake hazard in the eastern Gulf of Alaska is extreme. This region lies along the tectonically active margin of the Pacific Ocean, and large earthquakes, possibly as large as those that occurred in 1899-1900 and

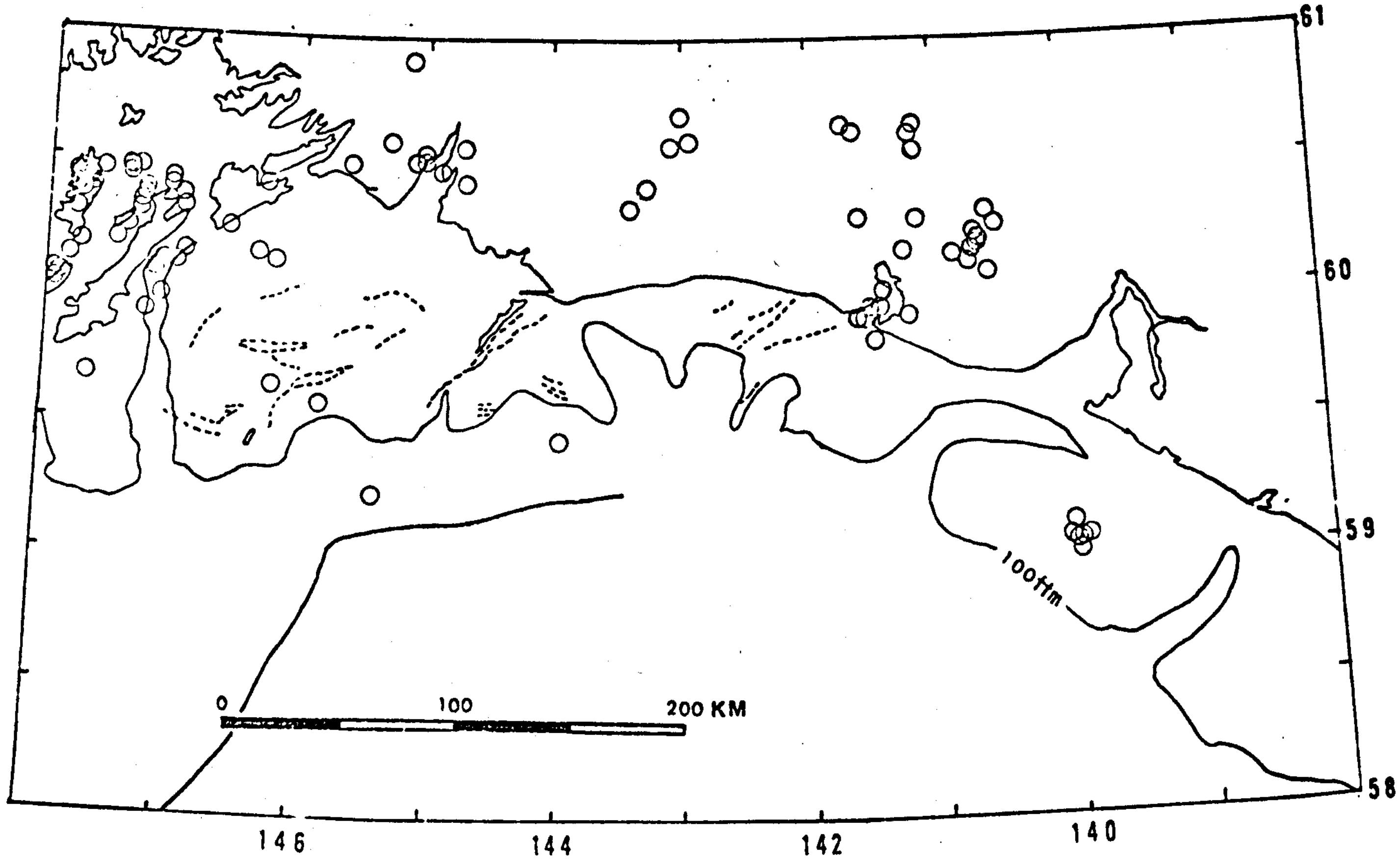


Figure 6. Map of more reliable earthquake epicenters from data from the USGS regional seismograph network, September 1974 - May 1975. All of the events north of 60.5°N and west of 146° W have been excluded.

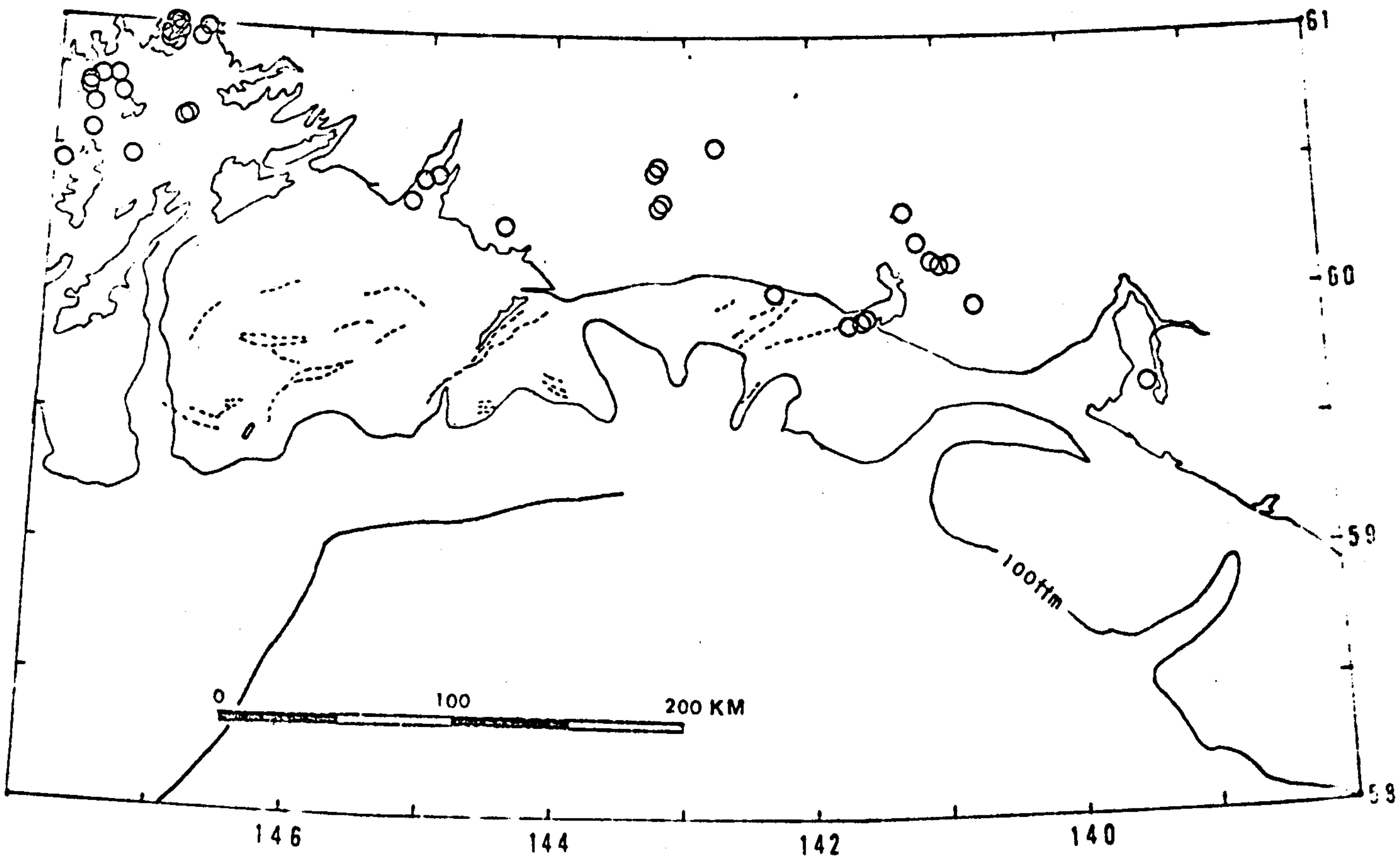


Figure 7. Map of more reliable earthquake epicenters from data from the USGS regional seismograph network, July - September 1975.

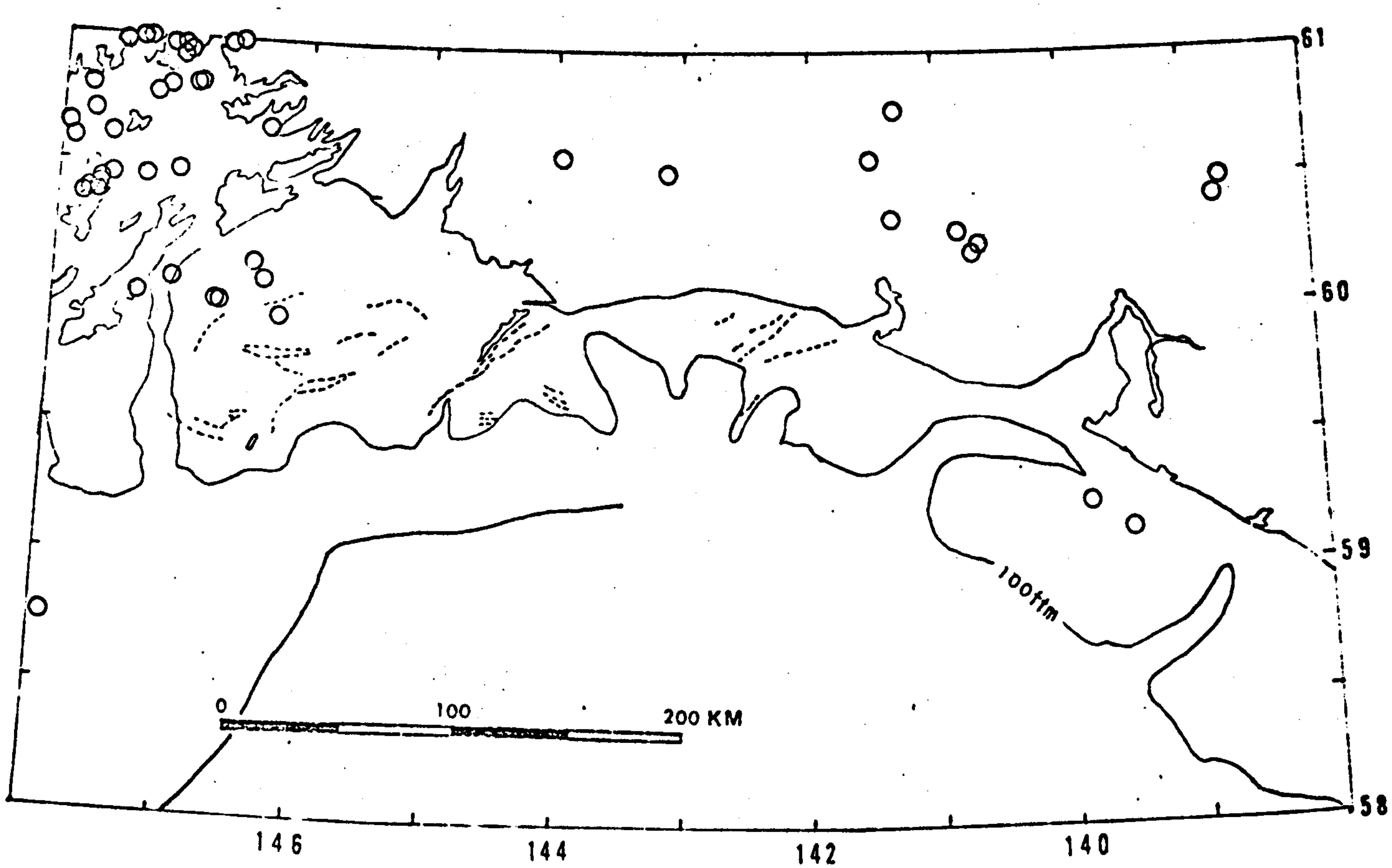


Figure 8. Map of more reliable earthquake epicenters from data from the USGS regional seismograph network, October - December 1975.

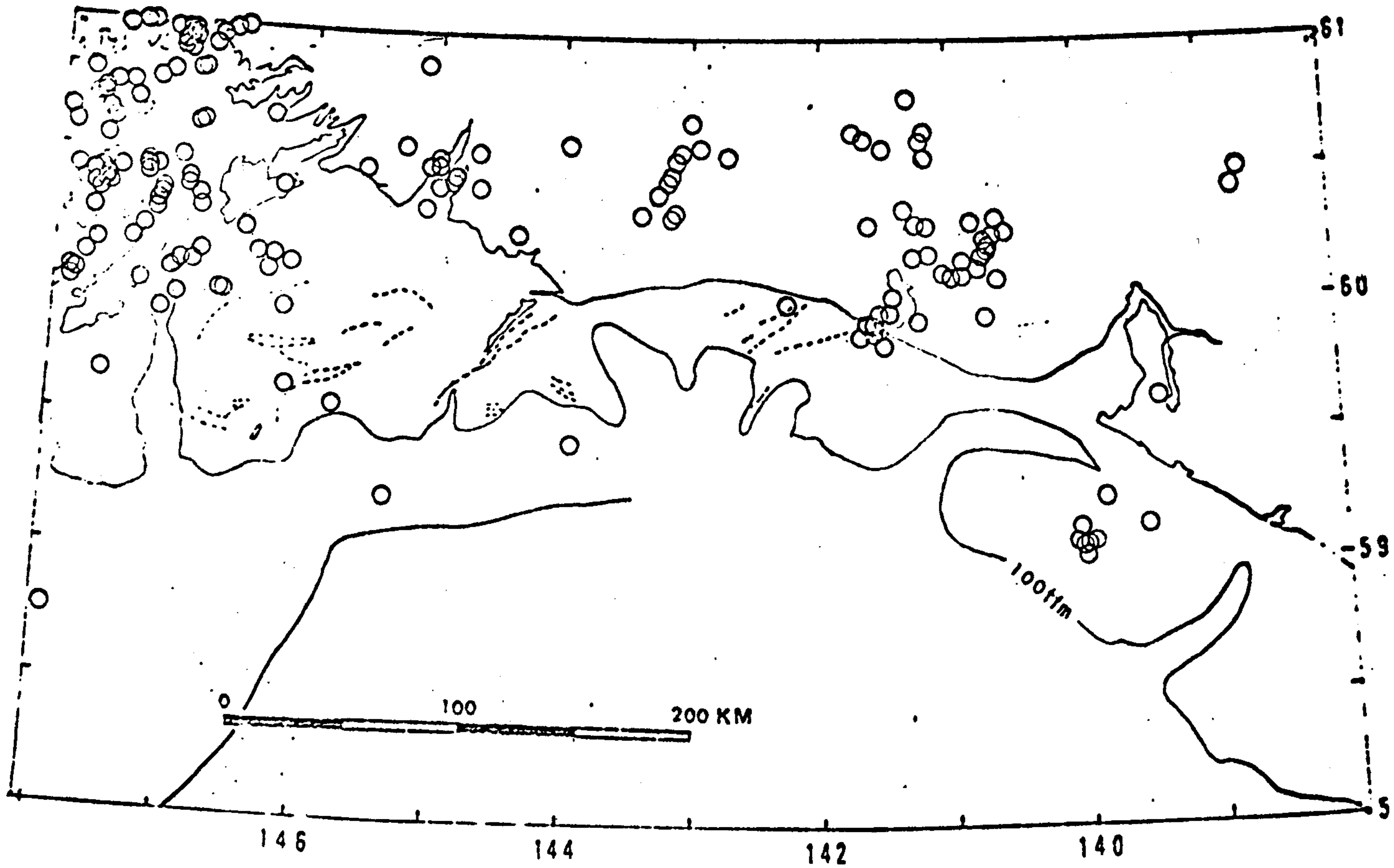


Figure 9. Map of more reliable earthquake epicenters from data from the USGS regional seismograph network, September 1974 - December 1975, except June 1975.

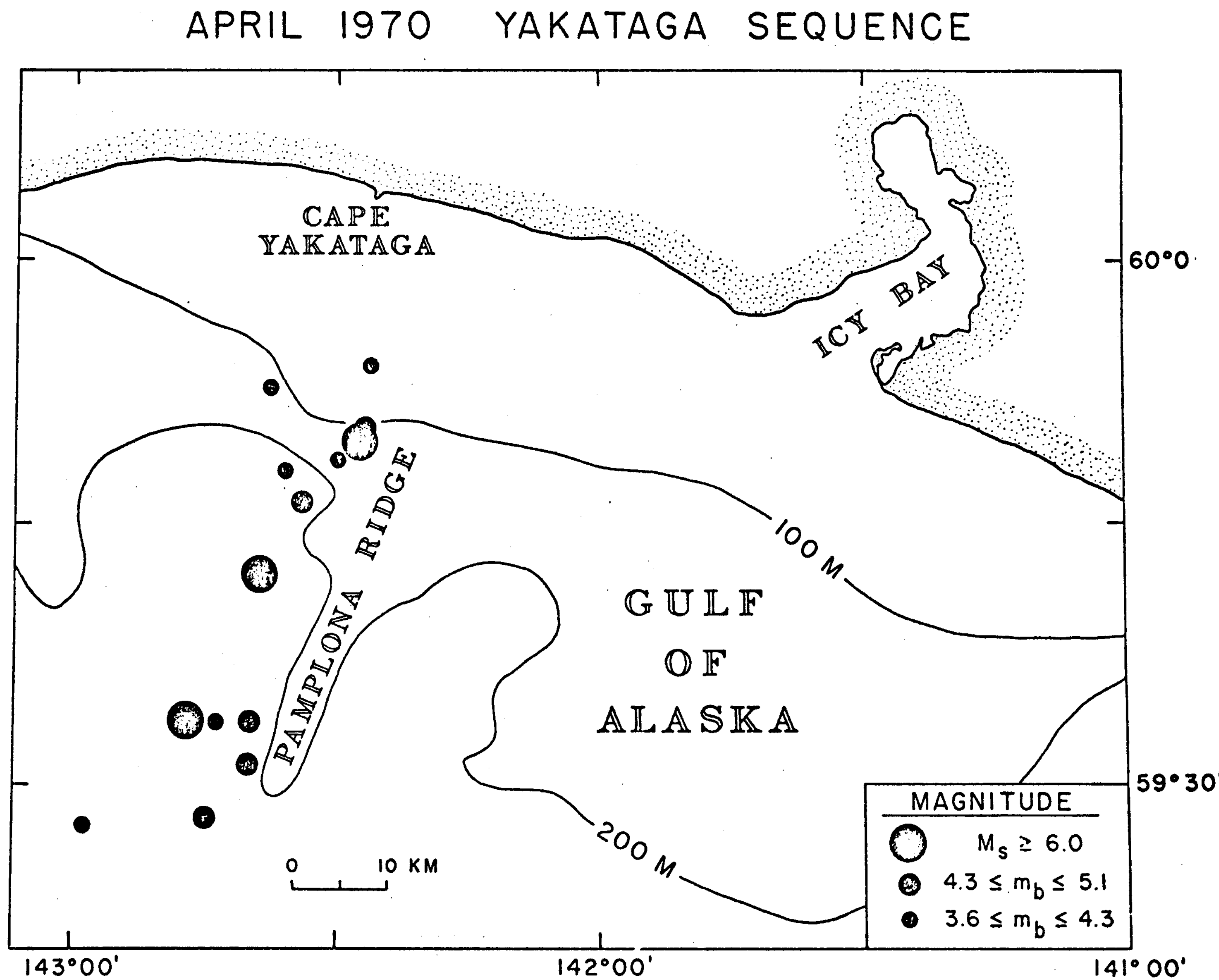


Figure 10. Map of relocated teleseismic epicenters for the Yakataga earthquake sequence of April 1970.

1964, are expected to occur in the future. In particular, the occurrence of a magnitude 7 or 8 earthquake in the eastern Gulf of Alaska is thought to be a likely probability within the next few decades.

The eastern Gulf of Alaska is tectonically complex and many faults have been mapped (Figure 2). Experience from other areas of complex compressional deformation, such as the Transverse Ranges tectonic province of California, indicates that deformation is not concentrated on a single major fault, but rather is spread over a broad zone.

Seismicity studies can identify faults that are seismically active during the time of the investigation, however, they do not disclose potentially dangerous faults that are quiet during the time of study. For these reasons, the seismic data for 1974 and 1975 presented in this report cannot be safely used to conclude that a particular fault or region is seismically inactive and not capable of generating a potentially damaging earthquake, but the data can be used to identify faults or regions that clearly generate earthquakes.

One active region identified in this study is the Icy Bay area. The recently elevated Chaix Hills, east of Icy Bay, are bounded on the south by a thrust fault (Bruns and Plafker, 1975). Southwest of Icy Bay, there is an anticlinal structure which is bounded by a fault on its south side (Bruns and Plafker, 1975). This fault strikes toward Icy Bay and is shown in Figure 2. The earthquakes near the mouth of Icy Bay (Figure 9) suggest that the on-shore and offshore faults may be connected and that the onshore and offshore faults may be capable of generating earthquakes. A second region of known seismic potential is Pamplona Ridge which experienced three magnitude 6 shocks in 1970.

Most of the mapped offshore faults in the eastern Gulf of Alaska shelf area (Bruns and Plafker, 1975; Molnia et al., 1976) have been seismically quiet since earthquake monitoring of the offshore area began in September 1974. Such quiescence may be a temporary feature. To conclude whether or not a particular fault is capable of generating a potentially damaging earthquake, it is prudent to consider also geologic and geophysical evidence that might clearly demonstrate the presence or absence of fault movement over a suitably long interval of time. Because of the presence of many offshore and onshore mapped faults of unknown seismic capability in an active seismic zone, care should be exercised in site selection and engineering design for costly and critical structures built on the shelf in the eastern Gulf of Alaska or along the coast.

Surface faulting is an obvious hazard to structures built directly on a fault that slips in an earthquake, however, a more serious hazard because of its pervasiveness is ground shaking. Not only can shaking damage a structure directly by vibration, but also shaking may cause ground failure in the foundation materials beneath a structure or may trigger a submarine slide and turbidity flow that could endanger structures downslope. A further hazard is regional tectonic uplift or subsidence, which is to be expected in a region of compressional tectonics such as the eastern Gulf of Alaska. In the marine environment, this hazard may be severe because of the potential for tsunami generation and the permanent change in water depth beneath marine installations or in coastal navigation channels.

VIII. Needs for further study.

To improve the reliability of epicenters and to reduce the detection threshold for earthquakes near Icy Bay, three additional stations are planned for installation around Icy Bay in the 1976 field season. In addition, it is recommended that an ocean-bottom seismic monitoring capability be established to improve the locations of events occurring offshore and also to allow detailed observations of very small events near offshore faults suspected to be active.

Some other lines of investigation which would lead to a better understanding of the tectonics of this region are repeated gravity measurements, tilt observations, and geologic investigations of deformed marine terraces. The primary purpose of annually repeated gravity measurements would be detection of current vertical displacement of the coastal region. With tilt and gravity data it might also prove to be possible to predict the largest earthquakes, a result which would have tremendous beneficial implications for the economic development of this region. The USGS is planning in 1976 to repair a tiltmeter on Middleton Island operated by the USGS and to deploy additional meters on Kayak Island and at Yakataga and Yakutat. The holes for these installations were dug in 1975, however, the satellite radio transmitter units were not delivered in time to be installed before winter came. If possible, numerous gravity stations will be monumented and occupied between Yakutat and Cordova. This will be done enroute to seismic stations which need to be serviced. Finally, it is recommended that detailed investigations of the deformed marine terraces along the eastern Gulf of Alaska be undertaken by the USGS in the 1977 field season to obtain information about the prehistoric rate of tectonic deformation and, by extrapolation, seismicity.

Four additional strong motion instruments that were purchased in 1975 will be installed in 1976. The sites currently planned are Cape St. Elias, Chignik, Pelican, and Cape Hinchinbrook. These sites will optimize the chance of obtaining close-in records for magnitude 7 or larger shocks in the eastern Gulf of Alaska.

IX. Field and Laboratory activities.

A. Field trip schedule (land vehicles, fixed-wing or rotary-wing aircraft used for the installation, maintenance and repair of seismic stations as appropriate).

1. October - December, 1975
   - a) Second week of October - completion of 1975 regular field season maintenance and repair by Menlo Park-based personnel.
   - b) First week of November - termination of maintenance by Anchorage-based personnel.
2. January - March, 1976
   - a) 19 January - 2 February - maintenance trip to commerical communication sites to repair or replace defective telemetry receivers.
   - b) 18 March - 1 April - maintenance trip to accessible seismic stations and overflight of inaccessible stations to ascertain winter snow and ice conditions at these sites.

3. April - June, 1976
   a) 10 May - 2 June - installation of 3 new stations in the vicinity of Icy Bay and maintenance and repair of accessible stations along coast of Gulf of Alaska between Yakutat Bay and Montague Island.
   b) Remainder of June, continuing into July - maintenance and repair of stations in remainder of network.
4. July - September, 1976
   a) 30 July - 10 August - completion of routine maintenance and repair of stations along the Gulf of Alaska.
   b) Remainder of August - correction of problems that may have developed in seismic station network since routine maintenance trips.

B. Field party (all members of the party are involved with the installation and/or maintenance and repair of the network seismograph stations and telemetry system).

John Lahr, Geophysicist, Project Chief
Michael Blackford, Geophysicist
Clearthur Lee, Electronics Technician
(Eric Fuglestad, Geological Field Assistant)

C. Method

1. January - March, 1976

Field conditions during the winter quarter do not permit trips to seismic stations except in a few limited cases. During January, Clearthur Lee visited communication facilities at Yakutat, Boswell Bay, and Tolsona and made repairs to the telemetry systems which resulted in the recovery of data from several seismic stations. In addition, he emplaced a temporary seismometer in the Seldovia seismograph station replacing a unit which had been malfunctioning.

2. April - June, 1976

The project will have use of a helicopter from May 20 to June 2. During this time three new stations in the seismically-active Icy Bay region will be installed. Data from these stations will be telemetered to Cape Yakataga to be added to a commercial communication circuit. To accommodate the additional stations on the circuit it will be necessary to reduce SSP to a one-component station.

RCA Alascom will be phasing out the present communication system that exists along the Gulf coast and will be replacing it with a satellite communications system. This has resulted in the need to rearrange some of the receive points for remote seismic stations, particularly at Yakutat and Cordova. This work, as discussed in Section D, will be accomplished during this quarter.

3. July - September, 1976

In anticipation of problems due to weather and residual snow cover at higher altitude stations, the use of a helicopter for a second period during this quarter - July 31 to August 9 - has been planned. Any stations which were not serviced during the previous quarter or which have developed problems since they were visited will be serviced at this time.

Also during this quarter modifications to the recording facility in Palmer will be completed. Four additional visible monitoring channels will be added and a new time encoding unit will be added to the tape recording system.

For the remainder of the quarter and for the next quarter as well, the condition of the stations will be watched closely and, if feasible, station outages will be corrected promptly. The snow cover from September to December usually is light enough to permit access to many of the stations, however, increasingly severe weather conditions and the decreasing availability of appropriate aircraft can reduce the number of accessible stations. It is anticipated that a person stationed in Anchorage may be able to maintain stations at this time.

D. Seismograph network.

Figure 11 illustrates the proposed configuration of the seismograph station network for the next fiscal year. Twelve stations will be closed; seven are in the western portion of the network and five are in the eastern portion. Three new stations will be installed near Icy Bay. At Yakutat the receivers will be moved from the Ocean Cape White Alice Communications station, which is being deactivated, to the Federal Aviation Administration facility adjacent to the RCA Alascom satellite communications earth station.

E. Data analyzed.

Data analysis has not progressed as quickly as was hoped in large part due to a smaller staff over the past year than was anticipated. The data analysis is being streamlined and computerized as much as possible and these changes should speed up the work in future months. The personnel responsible for this processing are Julia Thomas, Lorel Kay, and Sue Conens.

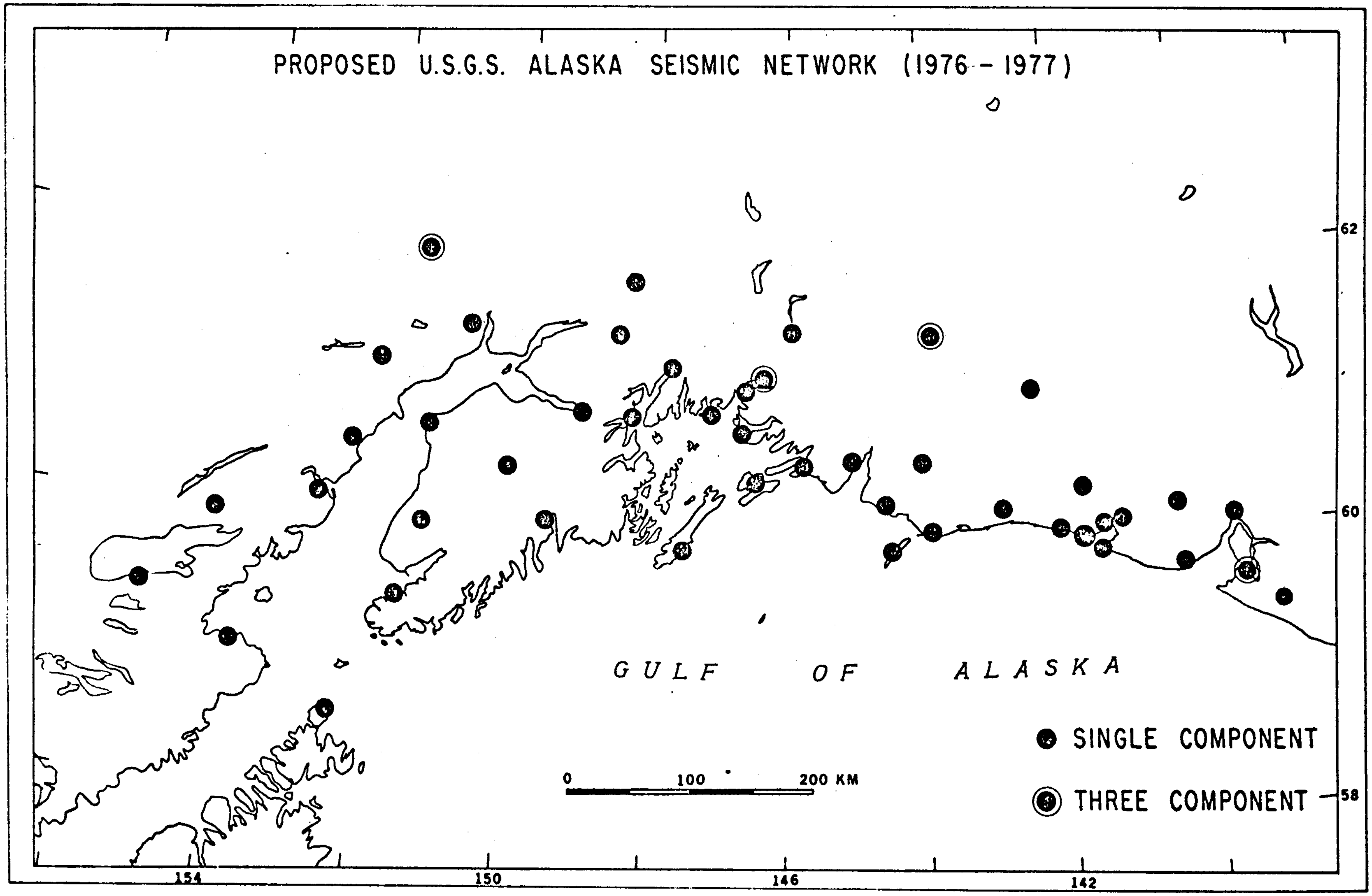


Figure 11. Map of proposed seismograph stations to be operated by the USGS in south-central Alaska, 1976-1977.

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EROSION AND DEPOSITION OF SHELF SEDIMENT: EASTERN GULF OF ALASKA

Principal Investigators: Bruce F. Molnia
Paul R. Carlson

U. S. Geological Survey
Menlo Park, California 94025

Annual Report FY 76
Research Unit #212
April 1, 1976

I. NATURE OF STUDY

A. Study Area

The region examined in this study lies in the Gulf of Alaska, between the southern tip of Montague Island and the eastern entrance of Yakutat Bay. Data have also been collected from areas between Yakutat and Cape Spencer, but these have not yet been analyzed. Future reports will include this information.

The goal of this project is to determine the type and characteristics of bottom sediments in the study area (Task B-10).

B. Purpose

The continental shelf of the eastern Gulf of Alaska is in a dynamic environment. Rivers and streams carry vast quantities of glacial silt and clay to this shelf, which is affected by strong longshore currents, frequent high energy storm waves, and occasional seismic sea waves (tsunamis). If this area is to be considered safe for petroleum production, the sediments found here must be carefully studied and all characteristics thoroughly understood.

C. Foremost Objective

The erosion and deposition - the movements - of sediments are the characteristics of primary interest in this study. Such questions as where does sediment originate? how is it transported? how and where is it finally deposited? will be examined through the use of maps showing sediment distribution, areas of erosion and deposition, bed forms, and other parameters.

D. Significance

The movement of sediment is a vital consideration in any decision as to where to place artificial structures, such as those used by the petroleum industry, to ensure maximum safety.

II. CURRENT STATUS OF INFORMATION

Prior to FY 75, there was virtually no information about the erosion, deposition or distribution of sediment in the NEGOA area. Our work during FY 75 produced much data on these and other topics. Rather than list all of the significant results, I am attaching a recently-released report (Report on the Environmental Geology, OCS area, Eastern Gulf of Alaska, USGS Open-File Report 76-206, by Molnia, Carlson and Bruns) which summarizes our past work.

III. DATA COLLECTION

Three types of data were collected.

(1) Seismic reflection profiles from various high resolution systems provide a three-dimensional view of sediment types, thicknesses, and distribution.

(2) Sediment samples collected by coring, dredging, and grab sampling give grain sizes, mineralogy, and textural patterns.

(3) Interpretation of vertical aerial photographs collected since the 1940's allows us to see alterations in shore line morphology, areas of erosion and deposition, and changes in glaciers and ice. Information on sediment plumes and on dispersal of sediment may be obtained from ETRS (Land Sat) photographs.

The first two types of data were collected by the R/V THOMAS G. THOMPSON, NOAA SHIP SURVEYOR, NOAA SHIP TOWNSEND, CROMWELL and MV CECIL GREENE.

The aerial photographs were purchased from NOAA and the U. S. Geological Survey. Funds for these were not included in the project budget.

IV. RESULTS

Results of work to date have been submitted for publication in the form of two symposium papers, three abstracts of talks to be presented at professional meetings and a number of USGS Open File Reports.

The papers are to be published by the Arctic Institute of North America in _Symposium on Science, Resources and Technology in the Gulf of Alaska_. The authors and titles are:

Carlson, Paul R., in press, Submarine faults and slides that disrupt surficial sedimentary units, northern Gulf of Alaska: 27 p.

Molnia, Bruce F., in press, Surface sedimentary units of the northern Gulf of Alaska continental shelf: 15 p.

The papers to be presented at meetings this spring are:

Molnia, B. F., Carlson, P. R., and Bruns, T. R., 1976, Geologic hazards in the northern Gulf of Alaska: GSA-Cordilleran Section, Pullman, Wash., April 5-7, 1976, Abstract with Programs, Geol. Soc. Am., v. 8, no. 3, p. 396-397.

Carlson, P. R., Molnia, B. F., and Reimnitz, E., in press, Dispersal, distribution and thickness of Holocene sediment on continental shelf, northern Gulf of Alaska: Am. Assoc. Petroleum

Geologists, Pacific Section, San Francisco, April 20-23, 1976.

Carlson, P. R., Molnia, B. F., and Bruns, T. R., in press, Preliminary study of sea floor instability in the offshore Gulf of Alaska Tertiary province: Am. Assoc. Petroleum Geologists, National Meeting, New Orleans, La., May 22-26, 1976.

Only four months have elapsed since our last year-end report. Little new information has been acquired during this period. However, analyses of samples and profiles from the SURVEYOR and from the CROMWELL have continued. These data have confirmed, in the area mapped west of Yakutat, the accuracy of the sediment distribution map, the Holocene isopach map, and the nearsurface slump map made for the FY 75 year-end report.

More than four months have been spent obtaining and locating the proper aerial photographs. Preliminary interpretations indicate that many areas are undergoing significant changes. We hope to have a detailed evaluation of these photographs at the end of the next quarter.

Studies of clay mineralogy were made on over 50 samples (see following table). The clays are mostly chlorite (approx. 50%), with illite (approx. 40%), kaolinite (approx. 10%), and montmorillonite (1 - 3%).

Size analyses of more than 200 samples taken by the CROMWELL show the sediments to be clayey silt with varying amounts of sand and gravel. There are 400 samples available, all of which will be analyzed.

Clay Mineralogy of Sediment Samples

Over 50 sediment samples collected during the June 1975 cruise of FRS CCROMWELL were processed and analyzed to determine their clay mineralogy. Individual minerals were identified by X-raying Mg-saturated <2μ clay separates with a Norelco diffractometer. The quantity of each clay mineral was estimated using the peak-area technique described by Hein, Scholl and Gutmacher (in press).

Chlorite is the predominant clay mineral, averaging 52.6%, illite 37.8%, Kaolinite 9.2% and montmorillonite 0.6%. No other clays were detected. Quartz, feldspar and amphibole were present in the clay size fraction. The percentages of clay minerals found in selected samples are shown in the following table.

Percentages of Clay Minerals Present

Sample	Montmorillonite	Illite	Kaolinite	Chlorite
#63	3	35	9	53
#6	3	36	9	52
#148	0-1	39	9	52
#131	0-1	37	9	54
#296	0	30	10	60
#243	0	35	10	55
#350	0	33	10	57
#225	0	33	10	57
#88	1	40	9	49
#70	0	56	7	37
#325	0	45	8	47

#227	0	35	10	55
#87	0-1	54	7	39
#81	0-1	37	9	54
#259	0	31	10	59
#299	0	35	10	55
#239	0	34	10	56
#54	0	39	9	52
#111	0-1	34	10	56
Range, all samples	0-3	30-56	7-10	37-60
Average, all samples	0.6	37.8	9.2	52.6

V. SUMMARY OF FOURTH QUARTER ACTIVITIES

A. Ship or lab. activities

1. Ship schedule, April 5-16, University of Alaska'a R/V ACONA June 1-15 (tentative) USGS - chartered R/V SEA SOUNDER.

2. Scientific party:

Bruce Molnia, project chief

Paul Carlson	Dave Aldridge
Paul Fuller	Jeff Yarus
Steve Kittelson	Glen Schumacher
Jack Hampson	Steve Wallace
Darlene Condra	

3. Methods

Sediment sampling with box, piston, vibra and gravity cores.

Samples will be analyzed for physical parameters and sedimentary structures. Analysis of 400 sediment samples collected previously continues.

4. Tracklines - not yet established.

5. No new data have been collected in the fourth quarter.

Since the last report we have done size analyses of over 150 samples and run clay mineral analyses of 30 others. Over 2000 km of SURVEYOR seismic lines have been examined in an effort to determine sediment type, thickness and water depth.

VI. DISCUSSION AND CONCLUSIONS

A. Types of sedimentary deposits

Four major sedimentary units, which are characterized by their seismic signatures, occur on the sea floor of the continental shelf in the study area. They are: (1) Holocene sediment, sands to silty clays, (2) Holocene end moraines, gravelly, sandy muds, (3) Quaternary glacial marine sediments, primarily pebbly muds, and (4) Tertiary and Pleistocene lithified deposits, dense, well-cemented sandstones to poorly consolidated pebbly mudstones.

The ages assigned to these units are based on their relative stratigraphic positions. The term "Holocene" is applied to sediment accumulating today and to end moraines formed during historic time. The most widespread of these two Holocene units is largely clayey silt and appears on seismic profiles as relatively horizontal, parallel reflectors, except where disrupted locally by slides and slumps (Carlson and others, 1975). The second Holocene unit appears as a jumbled mass of irregular reflectors representing recent end moraines off the Malaspina and Bering Glaciers.

Holocene sediment is underlain locally by a glacial marine unit of pebbly mud which is characterized on the seismic profiles by very irregular, contorted reflectors. This unit is assigned a Quaternary age because of its stratigraphic position between Holocene sediment and Tertiary to Pleistocene rocks. Elsewhere this glacial marine unit is absent and the Holocene deposits overlie folded, faulted and truncated strata of probable Tertiary or Pleistocene age. This age assignment is based on similarities in lithology and structure of these rocks to onshore lithified strata which have been dated as Tertiary and Pleistocene (Plafker, 1967).

B. Distribution of Sedimentary Units

Holocene sediment blankets the near shore area between Hinchinbrook Island and the south end of Kayak Island. These deposits are thickest southeast of the main channel of the Copper River, where fine sands and clayey silts of the Copper River prodelta are 350 m thick. Thick sequences of sediment also are present: (1) seaward of Icy Bay near Malaspina Glacier (260 m), (2) south of the Bering Glacier (200 m), (3) between Hinchinbrook and Montague Island (250 m), and (4) at the southwest end of Kayak Trough (155 m). In addition, Holocene sediment composes the surface fill in the Hinchinbrook Sea Valley and covers parts of the area between Tarr Bank and Middleton Island. Holocene sediment also blankets the near shore area east of Kayak Island except where Holocene morainal deposits are present at Icy Bay and the Bering

Glacier, and where Tertiary and Pleistocene bedrock crops out southwest of Cape Yakataga between Cape Suckling and Icy Bay. Holocene sediment also occurs in a series of isolated pods toward the outer edge of the continental shelf.

Holocene end moraines are found at the mouth of Icy Bay and south of the Bering Glacier. Morainal sediment also was collected south of the Malaspina Glacier and at the mouth of Yakutat Bay. However, until these deposits are better defined by seismic profiling they cannot be identified positively as end moraines.

Quaternary glacial marine sediment is found in a narrow arc along the north and west side of Tarr Bank and in a broad arc along the outer shelf and upper slope between Kayak Island and Yakutat Bay. Samples of glacial marine sediment generally are composed of pebbly or sandy mud.

Tertiary or Pleistocene stratified sedimentary rocks, commonly folded, faulted and truncated, crop out on the sea floor south of Montague Island and at several localities southeast and southwest of Cape Yakataga. Dart coring was attempted in many areas of submarine outcrop during the CROMWELL cruise. Few samples were recovered, although the presence of bedrock commonly was indicated by dented core barrels.

Bedrock also crops out at Seal Rocks and Wessel's Reef between Cape Hinchinbrook and Middleton Island; these exposures were examined in June 1975. Seal Rocks consists of well indurated sandstone and argillite indistinguishable from rocks assigned to Orca Formation on Montague and Hinchinbrook Islands (Winkler, 1973). Wessels Reef is composed of friable sandstone and granule conglomerate, similar lithologically to rocks of the Katalla-Poul Creek Formation on Kayak Island (Plafker, 1974; Winkler, pers. commun., 1975).

Sampling on Tarr Bank revealed that large areas are covered by a thin veneer (approximately one metre thick) of recent sediment. This veneer is not detectable on seismic profiles because of the transparency of the sediments and the limited resolution (<2m) of seismic systems, and is not shown on the sediment distribution map.

C. Sources of Holocene Sediment

The main sources of Holocene sediment are the Copper River, which supplies 107 x 10^6 metric tons of detritus annually (Reimnitz 1966), and the Bering and Malaspina Glaciers. High resolution seismic profiles from areas seaward of these features show thick sections of Holocene sediment (200-350 m). The sediment supplied by the two large piedmont glaciers is primarily suspended matter. The resultant plumes are easily visible more than 30 km from shore on satellite imagery (Reimnitz and Carlson, 1974). A secondary but significant source is the Copper River plateau and delta; fine sediment is carried by strong north winds which in fall and winter are funneled through the Copper River Gorge with sufficient force to carry dark clouds of silt over 50 km into the northern Gulf of Alaska (Carlson and others, in press).

The sediment, whether supplied by river, glacial runoff, or wind, is exposed to near shore currents which, with the exception of local eddies, move in a counterclockwise direction, as does the offshore Alaska Current (Reimnitz and Carlson, 1974). The counterclockwise movement transports the suspended sediment west. Much Copper River sediment is carried into Prince William Sound through passes east and west of Hinchinbrook Island. Sediments which are part of the Bering Glacier runoff plume are transported around Kayak Island; satellite imagery shows complex gyres of turbid water on both sides of the island (Reimnitz and Carlson, 1974). Some suspended sediment probably settles out over Kayak Trough. However, high resolution seismic profiles indicate that very little suspended matter either from the Copper River or from sources east of Kayak Island accumulates on Tarr Bank or on the Middleton Island platform. The lack of sediment cover on these topographic highs may result from the scouring action of rapid and strong bottom currents and from the frequent storm waves that are particularly large and forceful during the winter season of intense low pressure activity in the Gulf of Alaska.

Rapid accumulation of the glacially derived sands, silts, and clay results in high pore-water pressures and underconsolidation of the sediment, making submarine slides or slumps likely even on slopes of less than one degree. Two areas, both more than 1700 km^2, of thick Holocene sediment show evidence of submarine mass movement: (1) south of Icy Bay and of the Malaspina Glacier, and (2) seaward of the Copper River. Several other areas have been mapped as potentially unstable because of relatively thick accumulations of Holocene sediment on slopes greater than one degree.

Slumping is also common at the shelf edge and on the continental slope. Near the shelf edge south of Kayak Island, the surficial sedimentary units (probable Tertiary age) are cut by a swarm of discontinuous step-scarps. Two scarps have relief of 2-5 m and may delineate slump blocks at the edge of the shelf. These features represent a very serious hazard to any sea floor construction.

VII. FURTHER STUDY

We feel that mapping of sediment in the near shore zone is our most critical need. Such mapping requires the use of a boat with a very shallow draft; this field item is not yet available to us. Also needed are more analyses of aerial photographs, more sediment samples, long sediment cores, and a method for dating samples.

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FAULTING AND INSTABILITY OF SHELF SEDIMENTS: EASTERN GULF OF ALASKA

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Annual Report 1975-76
Research Unit #216

April 1, 1976

I. Summary

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 reach the sea floor cut strata that may be equivalent to the upper Yakataga Formation (Pliocene-Pleistocene). Along several faults the sea floor was offset from 5 to 20 m. A few faults appear to cut Holocene sediments, but none of these showed offset at the sea floor.

Submarine slides or slumps have been found in two places in the OCS region: (1) seaward of the Malaspina Glacier and Icy Bay, an area of 1,770 km^2, that has 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, that has a slope of about one-half degree. Seismic profiles across these areas show disrupted reflectors and irregular topography commonly associated with submarine slides or slumps. Other 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.

II. Introduction

The tectonically active eastern Gulf of Alaska requires close geologic examination of the sea floor of the continental shelf before petroleum activities commence. Major earthquakes will occur that may damage installations on the shelf or along the coast. Hazards include ground shaking, fault displacement, tectonic warping, and ground failure. Numerous onshore faults (several of which have been active in the past century) have been mapped to the shoreline of the Gulf of Alaska. Some of these faults probably continue across the shelf. These offshore faults must be mapped and a determination made regarding magnitude and age of offset. A second and related hazard is ground failure such as submarine slumps or slides. The thick sequences of unconsolidated sediment that are being deposited off rivers (e.g. Copper River) and streams draining this glaciated region are susceptible to failure caused by earthquakes or by agitation related to storm waves, seismic sea waves (tsunamis), and the nebulous internal waves. Ground failure can also result if these water-saturated sediments are overloaded by continuing deposition or by improperly designed and overloaded man-made structures. In order to make sound management decisions, the distribution, thickness, and type of these unconsolidated sediments must be known and understood.

III. Current state of knowledge

Faults and submarine slides or slumps of Quaternary age, potential environmental hazards on the outer continental shelf of the northeastern Gulf of Alaska, have been mapped in reconnaissance fashion (Carlson and others, 1975, U.S.G.S. Open-File 75-504). Additional preliminary maps of (1) distribution of sea floor sedimentary units (Molnia and Carlson, 1975, Open-File 75-505), (2) sea floor morphology (Molnia and Carlson, 1975, Open-File 75-506), (3) Holocene sediment thickness (Carlson and Molnia, 1975, Open-File 75-507), and (4) structure (Bruns and Plafker, 1975, Open-File 75-508), have been prepared from the data obtained on the Sept.-Oct. 1974 cruise of the R/V T. G. THOMPSON (von Huene and others, 1975, Open-File 75-664).

Data collected on the SURVEYOR, CROMWELL, GREENE, and DISCOVERER are in various stages of analysis. These data will enable us to refine our preliminary maps.

IV-V. Study area and methods of data collection

The area of study is the continental margin of the eastern Gulf of Alaska extending from Cross Sound on the southeast to Prince William Sound on the north. The first reconnaissance geophysical survey covered OCS lease area 39 from Yakutat Bay to Montague Island (fig. 1). Additional high-resolution seismic data have been collected as far southeast of Yakutat as Cross Sound (fig. 2). About 440 surface sediment samples have been collected in the OCS lease area (fig. 3).

Seismic reflection data have been and will be obtained with standard geophysical equipment (e.g. 3.5 KHz transducer, minisparker, uniboom, and airguns). Sea floor samples will be collected with corers (piston, box, vibratory, gravity, and dart), dredges (chain-bag and pipe) and grab samplers (Shipek and Van Veen). These data will be analyzed using standard geological and geophysical techniques.

VI. Results

Results of work to date have been submitted for publication as two symposium papers and three abstracts of talks to be presented at professional meetings.

The papers are to be published by the Arctic Institute of North America in Symposium on Science, Resources and Technology in the Gulf of Alaska. The authors and titles are:

Carlson, Paul R., in press, Submarine faults and slides that disrupt surficial sedimentary units, northern Gulf of Alaska: 27 p.

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VII-VIII. Discussion-Conclusions

The northeastern Gulf of Alaska is a region of active seismicity and tectonism, intense storms, and rapid sediment accumulation. Therefore, instability of the sea floor is potentially a serious hazard to development on the outer continental shelf (OCS).

Analyses of high-resolution seismic data and seafloor sediment samples indicate that Holocene sediment covers much of the continental shelf in the northern Gulf of Alaska in thicknesses varying from less than 5 m to more than 300 m (fig. 4). The wedge of Holocene fine sand to silty clay of the Copper River prodelta, the thickest of all the modern sediments measured, is about 350 m thick just southeast of the main channel of the Copper River. Other thick sequences of sediment are seaward of Icy Bay near Malaspina Glacier (260 m), south of the Bering Glacier (200 m), between Hinchinbrook and Montague

Island (250 m), and at the southwest end of Kayak Trough (155 m).

Seaward of the Copper River prodelta and Malaspina Glacier are areas that contain disrupted bedding and irregular topography commonly associated with submarine slides or slumps (fig. 5). Each area consists of more than 1700 km^2 of thick (>150 m) Holocene sediment on slopes of about 1/2°. Additional areas of hummocky topography that suggest submarine sliding are found at the edge of the shelf and upper slope.

Other parts of the OCS that have thick accumulations of under-consolidated sediments (clayey silt and interbedded mud and sand; peak vane shear strengths 0.01-0.09 kg/cm^2) and slopes steeper than 1° are potentially hazardous (fig. 5); they are susceptible to ground failure when large earthquakes provide rapid ground acceleration or tsunami or storm waves disrupt the seafloor.

Evidence of faulting at or near the sea floor has been found on Tarr Bank, around Middleton and Kayak Islands, near structural highs south of Cape Yakataga, and adjacent to Pamplona Ridge. Most of the faults that approach or reach the sea floor cut strata that may be equivalent to the upper Yakataga Formation (Pliocene-Pleistocene). Along several faults the sea floor is offset 5 to 20 m (fig. 6). Where sense of motion could be determined, the north or northwest side was upthrown. A few faults appear to cut Holocene sediments (fig. 7), but none of these show offset at the sea floor.

IX. Needs for further study

Our reconnaissance studies have shown the position of faults and slumps where crossed by seismic lines. However, some uncertainty exists when connecting faults or other sea floor features between lines of 5 km spacing. Therefore, more detailed profiling is necessary to delineate the faults and slumps more completely. Carefully selected sea floor samples are needed to date the age of the faults. Sea floor observations with TV camera and bottom camera can provide information about the character of the fault and slump scarps.

We also need additional seismic lines, samples, and sea floor photographs in the nearshore zone to provide more complete coverage of the continental shelf and to permit connection of faults cutting the sea floor with those faults already mapped on land.

Long piston cores and well-positioned box cores must be obtained to provide samples for geotechnical measurements such as shear strength, bulk density, moisture content, and Atterberg limits. These measurements are necessary for a proper understanding of the stability of sediments, information needed for proper siting of sea floor structures.

X. Summary of 4th quarter operations

A. Ship or Laboratory Activites

1. Ship schedule

a. April 8-18, R/V ACONA, NOAA chartered from University of Alaska.

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a. April 8-18, R/V ACONA, NOAA chartered from University of Alaska.

b. June 1-15, R/V SEASOUNDER, U.S.G.S. chartered.

2. Project staff

Paul Carlson, P.I.

Bruce Molnia, P.I.

Paul Fuller

Jack Hampson

Steve Kittleson

Darlene Condra

Dave Aldridge

Jeff Yarus

3. Methods

a. Analyzed geophysical records for:

Faults, slumps and slides, stratigraphy, thickness and areal distribution of stratigraphic units, sea floor morphology.

b. Analyzed sediment samples for:

Particle size, sand grain morphology, clay mineralogy, Foraminifera.

4. Sample localities and ship tracklines. See sections IV-V, figs. 1, 2, and 3.

5.

	Data collected	Data analyzed
a. Since inception of study		
Bottom samples	435	150
Kilometres of tracklines	15,000	10,000
b. 4th quarter	Collected	Analyzed
Bottom samples	0	100
Kilometres of tracklines	0	2,000

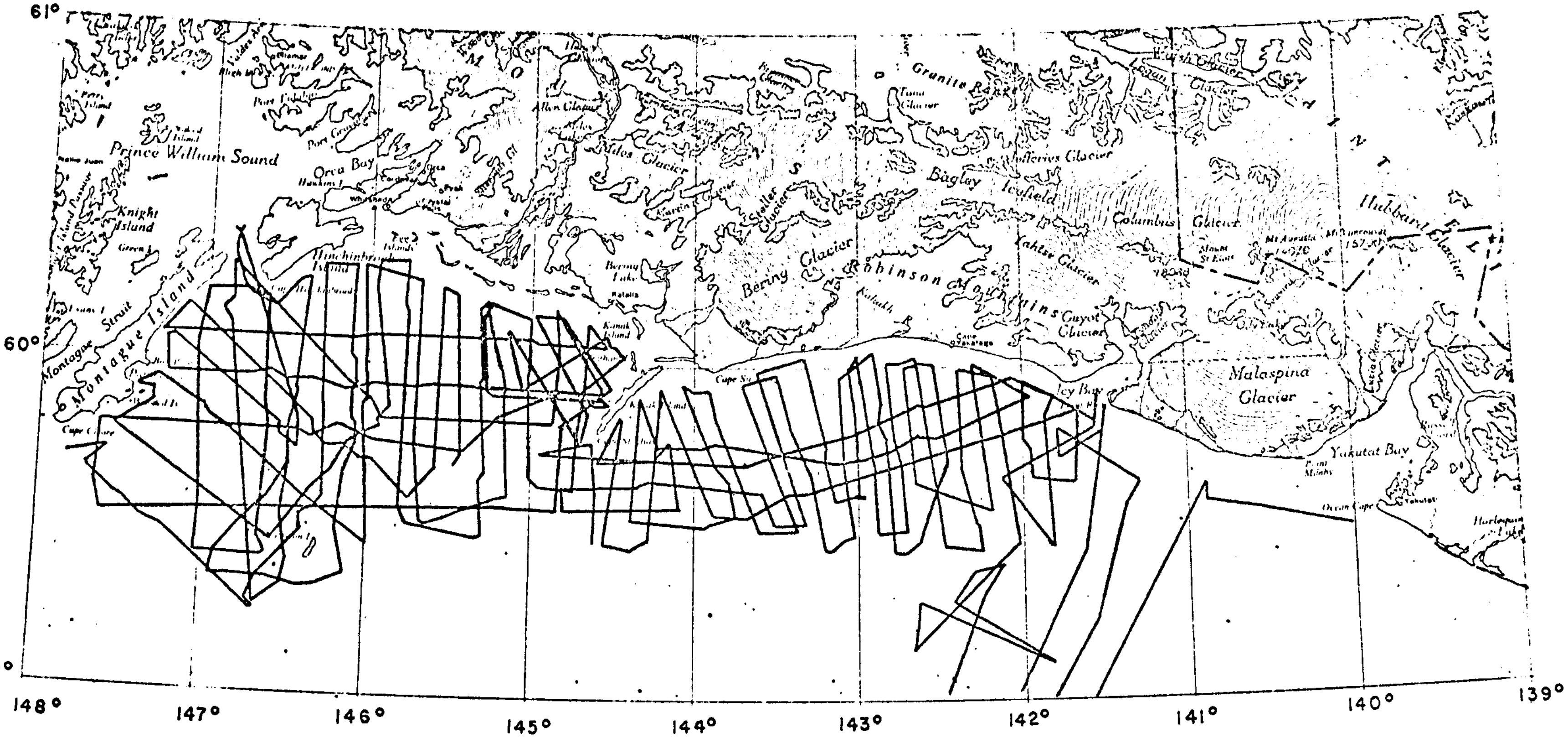

Figure 1. Tracklines of R/V THOMPSON CRUISE (September-October, 1974).

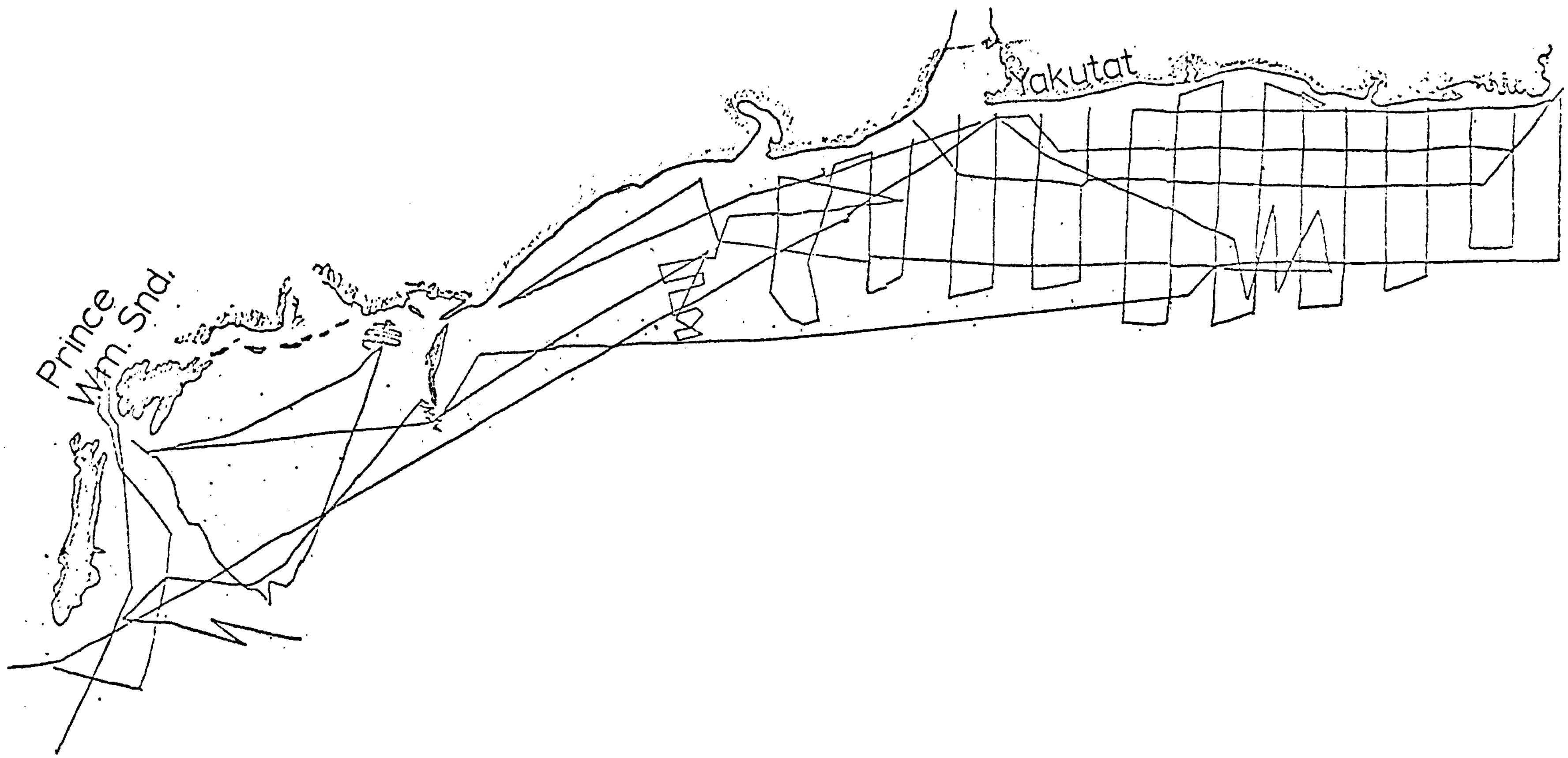

Figure 2. Tracklines of SURVEYOR cruise (April-May 1975).

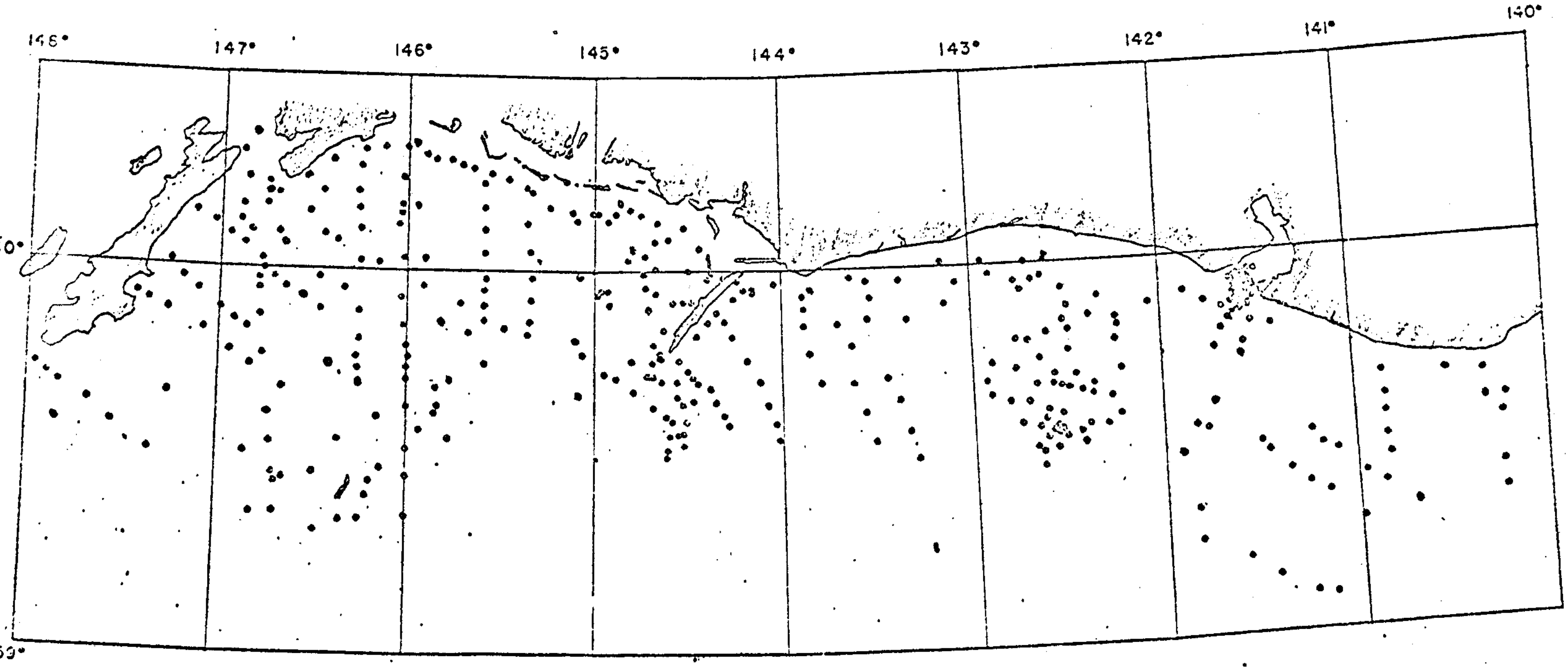

Figure 3. Location of sea floor samples; FRS CROMWELL (May-June, 1975) and DISCOVERER (October, 1975).

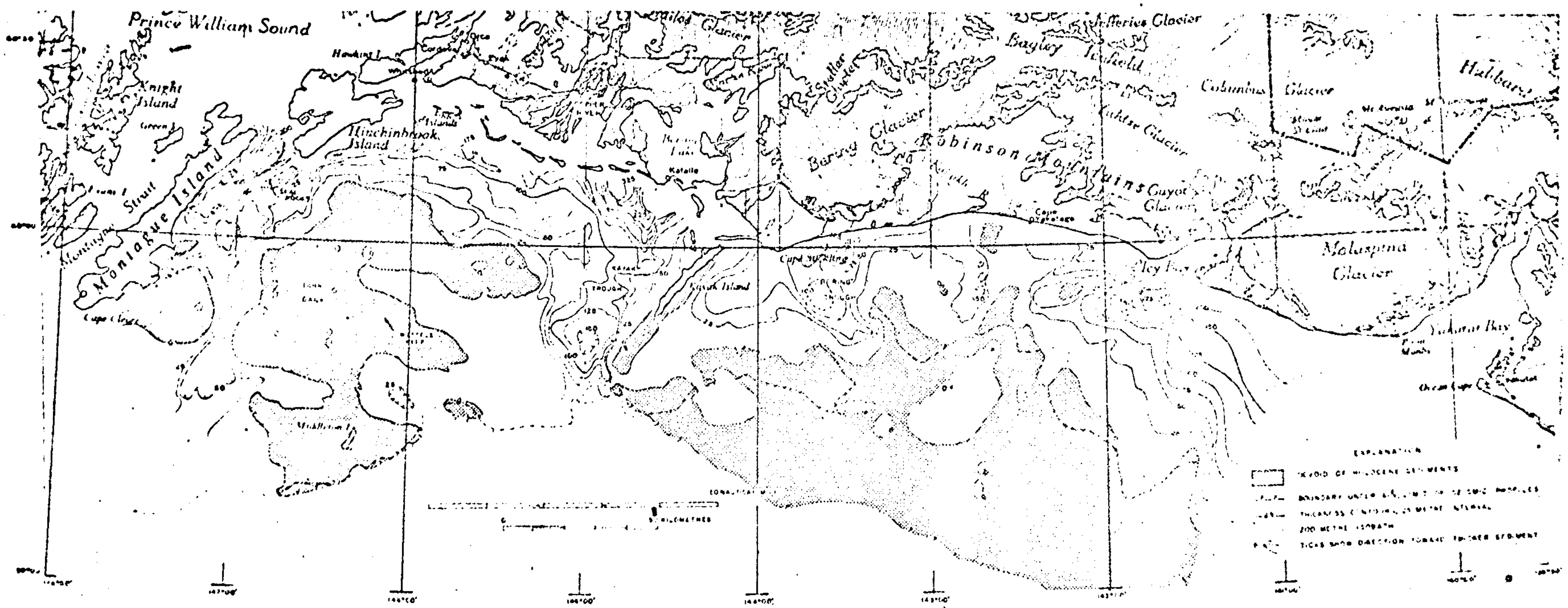

Figure 4. Preliminary isopach map of Holocene sediments, northern Gulf of Alaska.

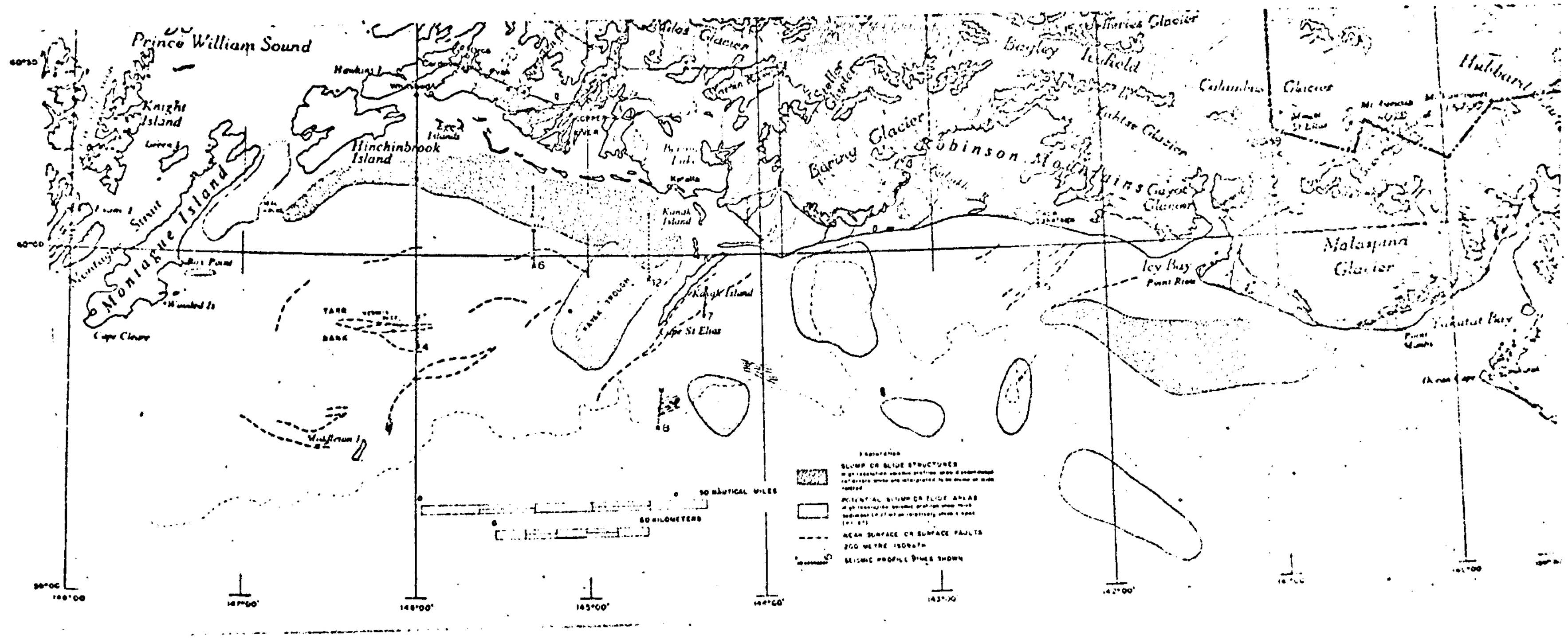

Figure 5. Preliminary map of submarine slides and nearsurface faults, northern Gulf of Alaska.

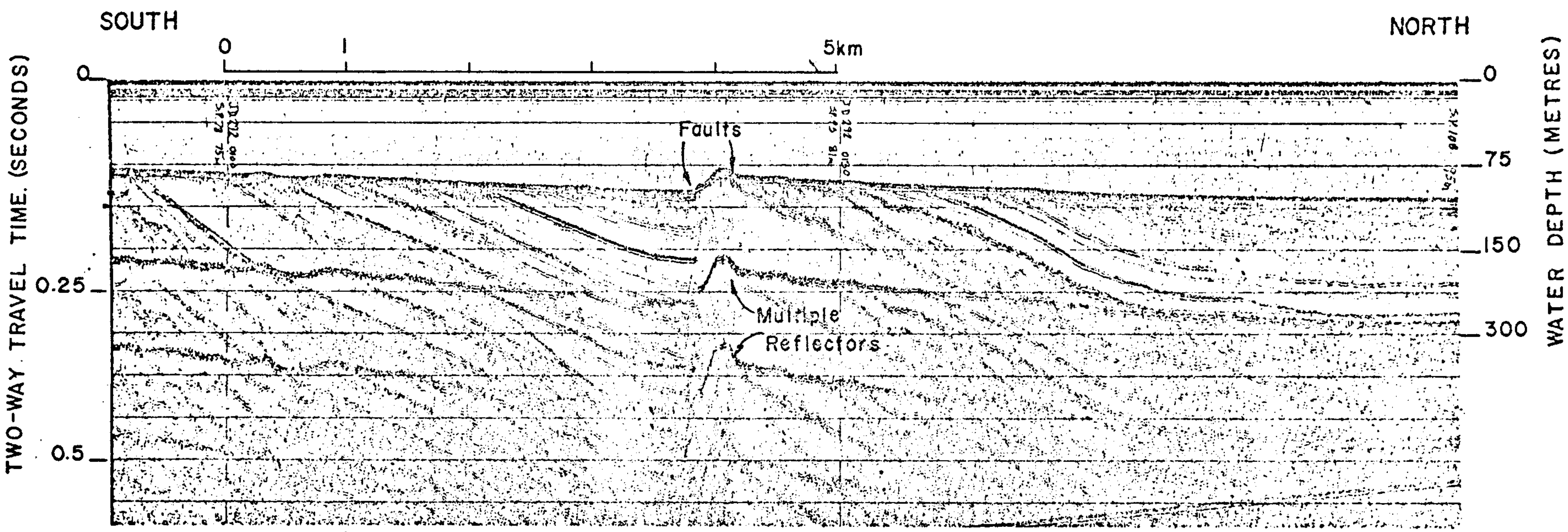

Figure 6. Minisparker profile on Tarr Bank showing older faulted and folded strata (Tertiary-Pleistocene) cropping out at the seafloor (V.E. ∿ 10X).

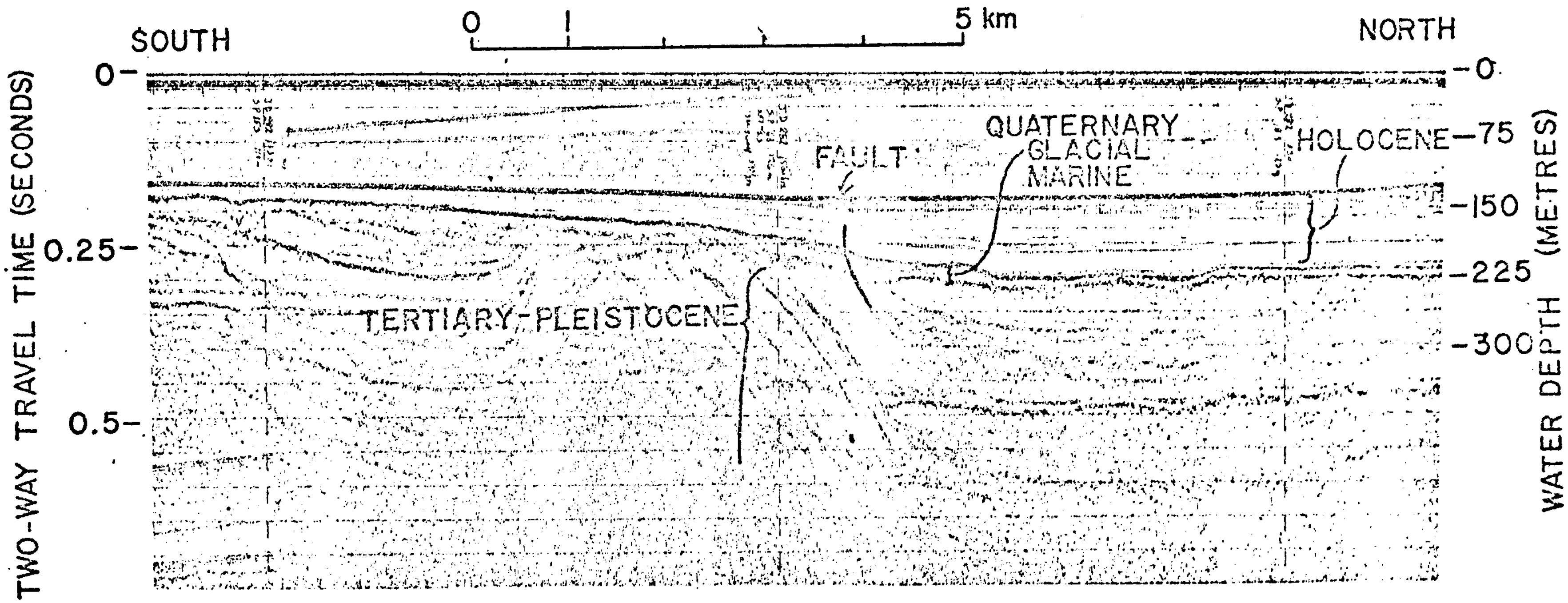

Figure 7 Minisparker profile south of the Copper River showing fault cutting lower part of Holocene sedimentary sequence. The fault also cuts through the underlying glacial marine unit and into the steeply dipping Tertiary sedimentary strata. (V.E. ∿ 10X).

ANNUAL REPORT

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SEISMIC AND VOLCANIC RISK STUDIES - WESTERN GULF OF ALASKA

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I. SUMMARY

It is the purpose of the study to assess seismic and volcanic risk in the western Gulf of Alaska, primarily from seismic data. Eight new seismic stations were installed in the study area to provide a higher resolution than previously existed. Data analysis of existing seismic data and the new seismic network is in progress. Several major eruptions occurred on Augustine Island during the report period and seismic data from before and during the eruption are being analyzed.

II. INTRODUCTION

A. General Nature and Scope of Study

It is the purpose of the study to provide seismological input information relevant to the assessment of the seismic and volcanic risks in the study area. Existing data and data collected from monitoring systems installed as part of the program will be used to provide a basis for such an assessment.

B. Specific Objectives

The real solution to the seismic risk problem would consist of being able to predict where and when an earthquake will occur, and what motion will be induced onto a structure at a given location in association with that earthquake. Since such a state of the art remains elusive, the problem of seismic risk assessment remains necessarily largely empirical and semi-quantitative. A common procedure is to provide a seismic risk map which reflects (1) the general seismicity of the area, (2) the geological-tectonic setting and (3) the details of local soil and subsoil conditions. The specific objectives of this study are associated with (1) and (2). Using historic and currently-recorded data, we will interpret the earthquake data in the light of our present understanding of the large-scale tectonic processes associated with the seismicity of the area, and we hope to also investigate possible systematic patterns in the space-time domain in the light of the seismic risk problem. On a smaller scale, we shall attempt to delineate onshore (and in certain areas, offshore) fault zones. In order to do so, it seems necessary to lower the minimum magnitude earthquake detection level to about 2.5-3 on the Richter scale. Thus, part of the program is the addition of 12 stations to the existing regional seismic network. The seismic studies would be complemented from other data sources such as aerial photography, geological maps and offshore seismic profiling.

Volcanic eruptions and major earthquakes are frequently accompanied by large sea waves (tsunamis). Though the generation, behavior, and damage potential of a tsunami depends on a large number of factors, we shall investigate whether available data and present understanding permits a risk zoning with respect to tsunami damage.

Part of this study would be the development of a volcanic risk map for Cook Inlet and the adjacent area, based on the analysis of recent and historic eruptions of two volcanoes (Augustine Volcano and Mt. Redoubt). Analysis of microearthquake data accumulated over the recent eruptions and other geophysical data will result in the recommendation of a geophysical monitoring system which will allow to distinguish times of volcanic quiescence and preeruptive conditions.

C. Relevance to Problems of Petroleum Development

Consequences of seismic and volcanic activity such as severe ground displacements, tsunami run-ups will put severe strains on offshore and onshore structures, erected in connection with petroleum development. Ash falls, volcanic heat and pressure waves, mudflows and fast moving glowing clouds near active volcanoes will endanger equipment and crews. The investigation of this study will provide pertinent input parameters toward deciding where to put these structures and what design criteria to use.

III. CURRENT STATE OF KNOWLEDGE

It is well known that the area of investigation is one of extremely high seismic and volcanic activity. One of the largest earthquakes ever recorded (1964 Alaska Earthquake) and one of the greatest volcanic explosions (1912, Mt. Katmai) occurred there. It is also well understood that this high activity is primarily a consequence of the convergence of the North American and the Pacific crustal plates resulting in an underthrusting of the latter beneath the former along the Aleutian trench. The underthrusting is not a continuous process, but proceeds in a "jerky" fashion, a jerk (i.e., an earthquake) occurring when the strain accumulated due to convergence exceeds the strength of the material. The area where the accumulated strain is released during the earthquake is defined by its aftershock zone. Studies of historic earthquakes and their aftershock zones indicate certain areas termed "seismic gaps" where substantial strain release has not taken place for a relatively long time and are thus especially prone for large earthquakes. One such gap seems to exist between the western margin of the 1964 Prince William Sound Earthquake aftershock zone (coinciding roughly with the west coast of Kodiak Island) and the Shumagin Islands, thus lying partly within the area of investigation. The apparently much higher level of present-day seismicity in the aftershock zone compared to that in the gap seems to indicate a mechanical decoupling of the two areas that would allow for a completely different state of stress. But there exists also the possibility of a bias since no seismic station coverage existed in the gap until recently.

Andesitic volcanism (which can produce rather violent explosions) is typical for regions of plate convergence. The Cook Inlet volcanoes line up above the 100-110 km depth contour of the underthrusting plate which thus controls the positioning of the volcanic arc.

Eleven volcanoes have been active in the study area since 1760. Five more probably erupted in post-glacial time. Most of these volcanoes are located on the Alaskan mainland at relatively safe distances from the offshore areas. Without a doubt the greatest volcanic hazard to offshore oil development is Augustine Volcano, a small island volcano in the lower Cook Inlet. The recent eruptions of January 22, 23, 24 and February 6 and 12, 1976, resulted in explosions reaching the stratosphere, the extrusion of a new lava plug dome and extensive glowing cloud deposits which created new land on the northeastern side of the island.

IV. STUDY AREA

The area of investigation is the arcuate region on and off the Alaska Peninsula between the southern margin of Cook Inlet to the northeast (along 65°N) and the Semidi Islands to the southwest (along 157°W). This area includes the lower Cook Inlet, the Shelikof Strait, and the offshore area between the western margin of Kodiak Island and the Semidi Islands. Non marine areas included are the chain of volcanoes on the

Alaska Peninsula between Redoubt Volcano and Aniakchak Volcano, and Kodiak Island.

V. SOURCES, METHODS AND RATIONALE OF DATA COLLECTION

Data sources in this study are both existing data files and data collected from the regional short period seismic network. Hypocenter files of NOAA, USGS and the University of Alaska, and WWSS film chips will be used. Existing files will be tested with new hypocenter location routines, incorporating more detailed crustal models. Data from the regional network are recorded continuously at a central recording site providing an accurate, common time base to all signals. Signals from the individual stations are transmitted via VHF telemeter links and telephone lines to the recording site. Recording is done on film from which pertinent data for hypocenter and magnitude determinations are read.

VI. RESULTS

During the first three quarterly terms of the program, much of our time was devoted to the field operations. Eight new seismic stations were installed under the study program (an additional three new stations were installed as part of the regional network covering the study area but were funded by other ongoing programs). Of these eight new stations, seven are located on Kodiak Island, one in Kamishak Bay, and one on the Alaska Peninsula. Two stations were relocated, and twelve existing stations were serviced. Presently the whole system comprises 23 seismic stations (not counting a new three-station array on Augustine Island installed after the January-February eruptions) (see Figure 1, Table I) and four telemeter sites without seismic transducers. Performance of the system has varied thus far. The Kodiak system failed early January shortly after recording was initiated. A flight over the stations revealed that all stations, except for two were working properly. At two stations the VHF antennas were completely buried in the snow neither transmitting nor receiving signals. Unfortunately, both stations were the last relay stations of the two "daisy-chains" of telemeter shots making up the Kodiak system. The system should start working again after some period of melting. The two stations will be relocated to lower elevations, but this will require an additional telemeter relay station. Part of the Kamishak and Augustine networks failed in mid-winter, partly due to electronic equipment failure and partly as a consequence of the Augustine eruptions in late January. The Alaska Peninsula system performed well, but two stations at Chowiet Island and Chirikof Islands failed for reasons presently unknown. Data from the system have been readied for computer processing, but hypocenter location has fallen behind schedule because of the conversion of the University's computer system during January and February. This has also delayed reprocessing of existing data.

The January and February Augustine eruptions were signalled by increased micro-earthquake activity since mid-October, 1975. The main explosions of January 23, 1976, were preceded by intense earthquake activity. Harmonic tremor was recorded during the extrusion of a new lava plug dome on February 12, 1976. The public was informed and kept up to date on the developments at Augustine through news releases throughout January, February and March, 1976. The extrusion of the new plug dome was accurately predicted. Sample newspaper clippings are included (Appendix I).

A vast amount of seismic data associated with the recent eruptions at Augustine is presently being analyzed.

VII. DISCUSSION

Some modifications of the new seismic network will have to be made in order to make the system perform more reliably. Information products are presently being readied and will come forward shortly.

VIII. CONCLUSIONS

No conclusions have been reached as analysis of data has just begun.

IX. NEEDS FOR FURTHER STUDY

No statement can be made to that respect until more analysis has been performed.

X. SUMMARY OF FOURTH QUARTER OPERATION

A major field operation during the fourth quarter was conducted in connection with the Augustine eruptions. Supplementary funding was granted to install a new tri-partite seismic array on the island and to monitor the eruptions.

One flight with commercial, small plane was conducted over Kodiak Island to determine the status of the seismic network there.

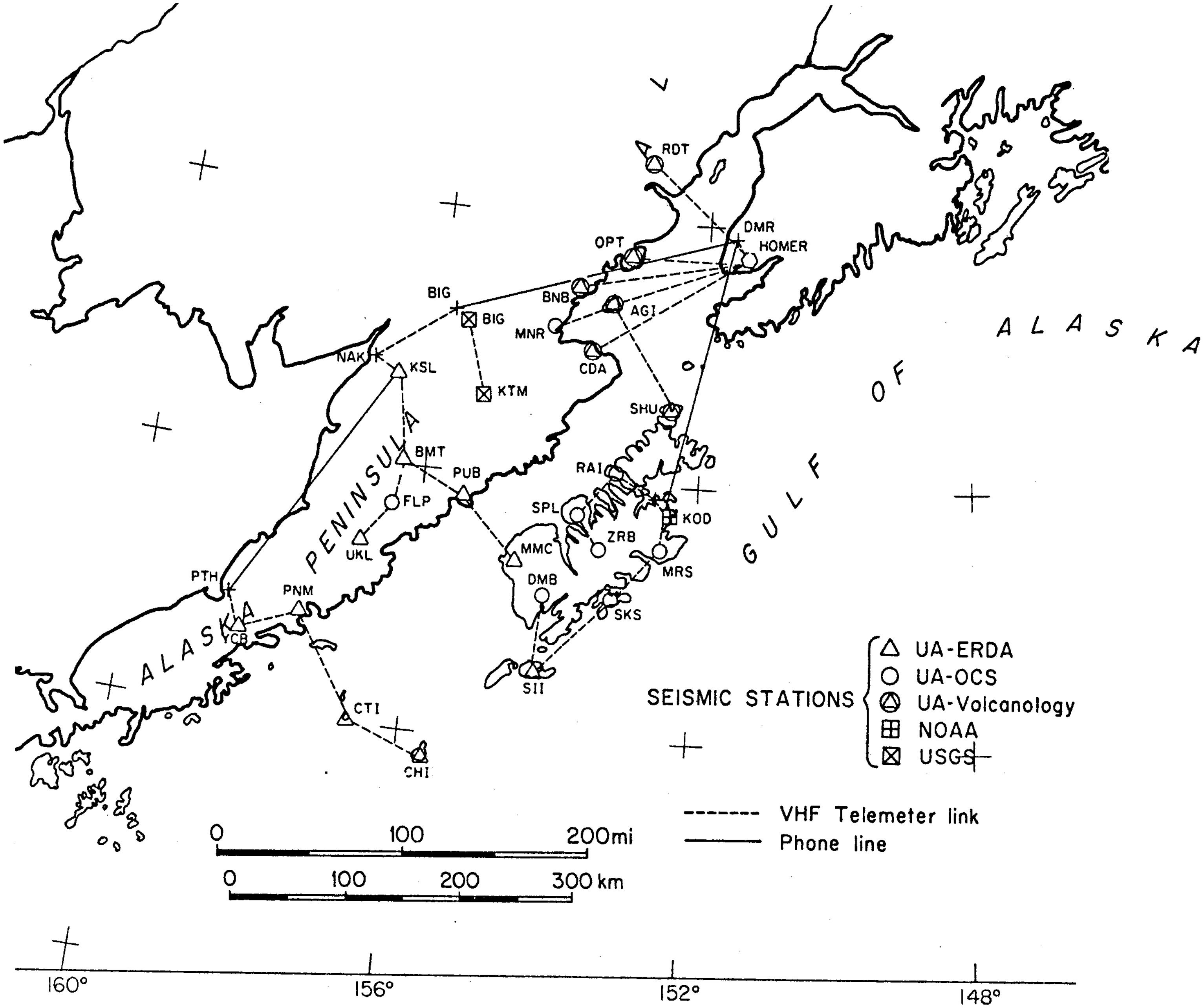


Figure 1. Western Gulf of Alaska seismic network, recorded in Homer.

TABLE I

University of Alaska

Southern Seismic Network

Kodiak Island and Alaska Peninsula

Station List

Station Name	Code	Latitude (N)	Longitude (W)	Elevation (M)	Components
Augustine Is. Mound	AUM	59 22.26	153 21.17	106	SPZ
Augustine Is. West	AUW	Operable, but accurate coordinates not yet available			SPZ
Augustine Is. 3	AU3	59 20.05	153 25.62	259	SPZ
Blue Mountain	BMT	58 02.8	156 20.2	548	SPZ
Bruin Bay	BRB	59 25.20	153 56.78	500	SPZ
Cape Douglas	CDA	58 57.32	153 31.77	386	SPZ
Chirikof Island	CHI	55 48.5	155 38.6	250	SPZ
Chowiet Island	CTI	56 02.0	156 42.7	160	SPZ
Deadman Bay*	DMB	57 05.23	153 57.63	300	SPZ
Featherly Pass*	FLP	57 42.7	156 15.9	485	SPZ
King Salmon	KSL	58 42.2	156 39.7	25	SPZ
Sitkalidak Is.*	SKS	57 09.25	152 57.80	480	SPZ
Sitkinak Is.	SII	56 34.15	154 10.43	440	SPZ
Marin Range*	MRS	57 32.38	152 24.03	560	SPZ
McNeil River*	MCN	59 06.06	154 11.99	273	SPZ
Middle Cape	MMC	57 00.0	154 38.1	340	SPZ
Oil Point	OPT	59 39.16	153 13.78	625	SPZ
Pinnacle Mountain	PNM	56 48.3	157 35.0	442	SPZ
Puale Bay	PUB	57 46.4	155 31.0	280	SPZ
Raspberry Is.*	RAI	58 03.63	153 09.55	520	SPZ
Redoubt Volcano	RED	60 25.14	152 46.32	1067	SPZ
Shuyak	SHU	58 37.68	152 20.93	34	SPZ
Spiridon Lake*	SPL	57 45.55	153 46.28	600	SPZ
Ugashik Lake	UKL	57 24.1	156 51.3	410	SPZ
Yellow Creek Bluff	YCB	56 38.9	158 40.9	320	SPZ
Zachar Bay*	ZRB	57 32.58	153 34.68	770	SPZ

*Seismic stations insatlled under the OCS program.

March 3, 76 Anchorage Times

Augustine Forms New Dome

Scientists say recent activity at Mt. St. Augustine, the volcanic island some 175 miles southwest of Anchorage in Cook Inlet, has formed a new dome, some 350 feet lower than the old one.

Dr. Juergen Kienle of the University of Alaska's Geophysical Institute at Fairbanks, said Tuesday the new dome apparently was formed during the harmonic tremors reported Feb. 11 and 12. Kienle said at that time such tremors usually are associated with magma, or lave, flow.

"That could be the end of the cycle," Kienle said Tuesday. "It's gone through an explosive and a magmatic phase. Now it entirely depends on how much gas is left in the shallow magma chamber. It could go through the whole thing again— or it could just quit."

Kienle said the eruptions created a new crater, some 1,250 feet below the volcano's 4,304-foot summit. That peak, he said, was relatively new and was formed during the 1964 eruptions.

The new dome, extruded during the harmonic tremors, rose only 850 feet from the bottom of the new crater, Kienle said, although remnants of the old rim maintain the volcano's height at about 4,000 feet.

Kienle said he and two other scientists from the Fairbanks Institute, Dr. Robert Forbes and Doug Lalla, a Ph.D. candidate, returned Tuesday from their fourth visit to the site since activity began earlier this year.

He said during earlier exploration, they measured temperatures of the flowing ash clouds, which moved some three miles from the summit to the edge of the island. He described ash cloud deposits as "gas clouds so heavily laden with ash it is too heavy to really rise."

He said although air temperatures were near zero, temperatures at probed depths of seven and one-half feet were as high as 604 degrees Centigrade, or 1,112 degrees Fahrenheit.

Kienle said he estimated the peak temperature of the flows at about 650 degrees Centigrade.

He said gases and water were collected at the site and are being analyzed at the university. He said the staff is mainly interested in the relative quantities of seawater, rainwater and magmantic, or juvenile water. He said juvenile water is water from the earth's interior. Kienle said proportions of the three types of water will be determined by isotopic studies.

Kienle said during their recent visits the men installed a new three-station array of seismic stations.

"We put the new units on the farthest edge of the island," he said. The scientists' seven original units were destroyed during the activity in January. "Hopefully, with our new array out of the path of the explosions, we'll be able to predict activity a little better."

Kienle said this year's activity was "definitely not" milder than the 1964 eruptions.

Feb 13, 76 Anch. Daily News

Daily News photo by Rob Stapleton

Volcano signals a new lava flow

Mt. Augustine has signaled that it's about ready to ooze some lava.

Seismic signals being received from the volcano changed dramatically Wednesday, reports Dr. Juergen Kienle of the Geophysical Institute at the University of Alaska, Fairbanks.

"WE'RE NOW SEEING a harmonic tremor, that in other volcanoes is associated with magma movement," said Kienle. "I think it's near the surface, and is likely to ooze out slowly, though there will probably be some explosions associated with it."

Since the volcano's second eruption Friday, it has been steadily pouring out moderate quantities of ash, with an occasional small plume. The last infrasonic signal was received Sunday. A light ash fall was reported in Homer at 7 p.m. Wednesday, but otherwise the ash appears to be traveling little.

A PLANE HAS FLOWN to Mt. Augustine almost daily this week to monitor the volcano's behavior, and Kienle is returning for an inspection trip today.

Mt. Augustine's volcano broke 11 years of quiet with a series of explosions Jan. 23 that sent ash thousands of feet in the air.

Kienle is sure the volcano will go on with its rumblings and belchings for a couple of months, but he doesn't expect any more 40,000 foot clouds like the one that coated Anchorage with volcanic dust. "But you can't really predict," he hedges.

The one seismograph Kienle was able to reestablish on the island itself is again out of commission, he reported Thursday. "It'll be hard to keep it going," he said.

The other five were completely buried in flows of hot ash and mud from the initial eruption.

GECPHYSICAL INSTITUTE • UNIVERSITY OF ALASKA

College, Alaska 99701 U.S.A.

RU #253

March 31, 1976

Dr. Gunter Weller
Alaska Project Office
OCS Energy Program
University of Alaska
Fairbanks, Alaska

Dear Dr. Weller:

We are enclosing 10 copies of our Annual Report for the OCS project "Offshore permafrost-drilling, boundary conditions, properties, processes and models". This report also contains the 4th quarter progress report.

Sincerely

Tom Osterkamp

Tom Osterkamp
Assoc. Prof. of Physics & Geophysics

Will Harrison

Will Harrison
Assoc. Prof. of Physics

TO/cr

cc: A. Lachenbouch
J. Robinson
J. Rogers
D. Rosenberg
B. Sackinger
P. Sellman

ANNUAL REPORT

OFFSHORE PERMAFROST-DRILLING, BOUNDARY CONDITIONS, PROPERTIES, PROCESSES AND MODELS

T. E. Osterkamp and W. D. Harrison

Geophysical Institute
University of Alaska
Fairbanks, Alaska 99701

April 1, 1976

Prepared for

U. S. Department of Commerce
National Oceanic and Atmospheric Administration
Environmental Research Laboratories
Boulder, Colorado 80302

Research Unit Numbers: 253, 255, 256
Contract Number: 03-5-022-55

I. SUMMARY

A. Objectives

(1) To carry out a near shore drilling program in spring 1975, with an emphasis on conditions near the shore - completed.

(2) To determine the properties of sea bottom sediments in shallow water areas (< 5m) which are particularly important to off-shore permafrost; specifically, temperature, salt content and sediment characteristics. These provide essential thermal and chemical boundary conditions for models.

(3) To carry out preliminary laboratory and theoretical work necessary for an understanding of the permafrost regime, with an emphasis on tne coupling of chemical to thermal processes.

B. Conclusions

(1) The sea bed at Prudhoe Bay is thawed even though mean annual temperatures are about -1°C. The thickness of this thawed layer increases with distance from the beach and is at least 46m thick 3,370m offshore, along the line of our drilled holes (Figure 1).

(2) A sharp interface was found between this thawed layer and the underlying ice-bonded subsea permafrost at all positions within 481m from land.

(3) The subsea soils are sandy gravel with some silt overlain by a thin layer of silty sand. This layer of silty sand increases in thickness from a few meters nearshore to about 14m at 3,370m offshore.

(4) The mean annual temperature at the sea bed increases from -3.5°C at 203m offshore where ice freezes to the sea bed to roughly -1.2°C at 481m offshore to -0.7°C at 3,370m offshore.

(5) Where ice freezes to the sea bed the mean annual temperature is several degrees Celsius colder (see (4) above) and the thickness of the thawed layer is only a few meters. A few hundred meters farther offshore (481m from the beach) where the ice does not freeze to the sea bed, the thickness of the thawed layer increases rapidly to about 19m.

(6) At a site on land the permeability of the permafrost is zero.

(7) A laboratory experiment indicates that the hydraulic conductivity of the thawed sea bed sediments is about 4×10^{-7} $m\ s^{-1}$.

(8) Salt concentrations where ice freezes to the sea bed range up to 3-4 times that of normal sea water. Where there was 10-20 cm of water under the ice cover, the salt concentration was about 2 times that of normal sea water. Normal sea water was found under the ice cover 3,370m offshore where there was about 1m of water under the ice cover.

(9) A few small ice lenses were found in a hole 195m from shore. No massive ice was found in any of the offshore holes.

(10) A coupled heat conduction-salt diffusion model for subsea permafrost was developed and solved. The results imply that salt diffusion cannot account for the thickness of the thawed layer; some other salt transport process must be rate-controlling. We conclude that salt transport is predominantly by advection, but heat transport is predominantly by conduction.

C. Implications for Oil and Gas Development

(1) Massive ice that exists in the top 25m of soil on land is

probably absent offshore near Prudhoe Bay at water depths greater than 2m. This conclusion may not hold where shoreline history and/or soil conditions are substantially different from those at our drilling site.

(2) The presence of the thawed layer offshore indicates that it may be possible to use standard construction techniques for foundations in this layer. The sandy gravel is an excellent foundation material and since the material is already thawed there will not be any settlement due to ice melting. A somewhat different situation will prevail if the foundation penetrates into the ice-bonded subsea permafrost.

(3) The presence of a sharp, moving interface between the thawed layer and the ice-bonded subsea permafrost may create problems for structural features that transect this interface (e.g., pipelines, tunnels).

(4) The presence of the thawed layer and other physical considerations imply that it may be impossible to freeze structures like ice islands, gravel islands, gravel causeways, etc., into the sea bottom where the water depths exceed a few meters. This would substantially reduce the shearing forces that these structures could withstand.

The above statements must be regarded as somewhat tentative since the data we obtained have not been fully analyzed. In addition, much more work will be necessary for us to develop a full understanding of the transport processes in the subsea permafrost.

II., III., IV., V., VI.

A. Introduction

A subsea permafrost drilling program was carried out during late April and May 1975 at a site near the northwest side of Prudhoe Bay, Alaska. Two-meter thick fast ice was used as a drilling platform to drill into the seabed. The drilling was contracted to the Alaska Department of Highways, Road Materials Laboratory, which is located on the University of Alaska campus. The drilling crew consisted of a geologist, driller and helper who had extensive experience in drilling and sampling permafrost. The principal investigators were also present. The site location was a line extending from the North Prudhoe Bay State #1 well seaward toward Reindeer Island. All holes were drilled within 3.4 km of shore and the location of the line of drilled holes is shown in Figure 1. The new Atlantic Richfield Company causeway is $\approx$ 0.5 km to the west of our drilling line.

This report describes the drilling and sampling procedures used. The techniques and results of the soil analysis, temperature measurements, salt concentration measurements, permeability measurements, and penetration tests are also given. Field drilling logs are included in Appendix I. A more complete analysis of the data will be presented separately in a Geophysical Institute report to be issued next quarter.

B. Drilling and Sampling Procedures

The drill rig was a Mobile B-61 rotary drill mounted on an RN-110 Nodwell tracked vehicle. Logistics support was provided with an RN-75 Nodwell tracked vehicle and two snowmobiles with sleds. Drilling methods included rotary wash boring and the use of hollow stem and standard augers. Rotary wash boring using NX casing, BW rod and sea water mixed with the drilling mud as a drilling fluid was the most satisfactory method for the deeper holes. The mud was used in an effort to reduce the sample contamination by infiltration with drilling fluid. A hollow stem auger with a 7.5 cm I.D. was suitable for shallow holes (< 23m), except those in the frozen silty soil on land. It was observed that fine sand tended to cause the pilot bit to stick in the auger, and that available power limited the depth. A standard auger with an outside diameter of 15 cm was used for two holes in the permafrost on land drilled to 12.2m. Drilling with this auger was very fast and no problems were encountered using it.

Soil samples were obtained with Shelby tubes and by drive sampling. The Shelby tubes, 6 cm I.D. and 76 cm long, could only be used in the fine-grained sea bed sediments. These tubes were pushed into the sediments below the bottom of the casing and removed with the sample. The casing was then driven to the next sampling position, cleaned out and another tube pushed into the sediments below the casing. In one hole, Shelby tube samples were obtained to a depth of 5.4m below the seabed in silty sand sediments. All other soil samples were obtained with a 5 cm I.D. split-tube drive sampler. Generally, the drive sampler was driven ahead of the casing and the sampler containing the sample removed from the hole. The casing was then driven to the next depth, the hole cleaned out and the next sample taken. One effort to rotate this sampler, fitted with a cutting shoe, into frozen subsea permafrost caused failure of the sampler which remained in hole 195 and forced us to abandon this hole. The drive sampler was also used to sample ahead of the bit in the hollow stem auger.

Shelby tube samples were sealed in the tubes by driving tight-fitting rubber corks into both ends of the sample tubes. The Shelby tubes were then shipped in the thawed state by truck to our laboratory at Fairbanks. Drive samples were removed from the sampler immediately and when evidence of mud existed on the sample, it was carefully scraped clean of the drilling mud and then placed in a glass jar. No attempt was made to control the sample temperature. The jars were returned to Fairbanks by a Highway Department truck. A few samples of the frozen permafrost were placed in plastic tubing and shipped by air to Fairbanks in an insulated box cooled with containers of ice-alcohol mixture. These samples were stored in a freezer at the Geophysical Institute, University of Alaska.

A summary of drilling and sampling methods and additional information is given in Table I. The holes are located along a line bearing N32.5°E from North Prudhoe Bay State #1 well. The hole number is the distance from the beach in meters; negative values apply to holes on land and positive values to holes offshore. A field designation number was assigned to the holes according to the order in which they were drilled. All hole depths and sample depths were measured from the ice surface. The drilling time was the amount of time spent drilling and does not include down time. It was estimated from the field notes and logs.

Holes were located by standard surveying methods from a benchmark, a spike driven into a large beam, located about 3.79m N47.5°E from the axis of the borehole known as North Prudhoe Bay State #1 well. The well coordinates are 70°22'36"N, 148°31'28"W. The distance to each hole from

TABLE I: SUMMARY OF DRILLING AND SAMPLING INFORMATION

HOLE NUMBER	FIELD DESIGNATION	DRILLING METHOD	SAMPLING METHOD	HOLE DEPTH (m)	DRILLING TIME (hrs)	ICE THICKNESS (m)	NOTES
-226	5	Standard Auger	Drive	12.2	5	-	
-225	1	Hollow stem Auger	Drive	2.9	3	-	
- 69	14	Standard Auger	-	12.2	3	-	
0	2	Hollow stem Auger	Drive	3.5	2	-	
190	4	Rotary wash boring	Drive	55.8	20	1.1	Ice frozen to bottom
195	3	Hollow stem Auger	Drive	9.9	6	1.1	Ice frozen to bottom
196	9	Penetration test	-	3.4	0.5	1.1	Ice frozen to bottom
203	3A	Hollow stem Auger	Drive	22.4	10	1.1	Ice frozen to bottom
334	10	Penetration test	-	3.0	1	1.6	Ice frozen to bottom
403	11	Penetration test	-	4.7	1	1.6	Ice frozen to bottom

TABLE I (Cont'd)

HOLE NUMBER	FIELD DESIGNATION	DRILLING METHOD	SAMPLING METHOD	HOLE DEPTH (m)	DRILLING TIME (hrs)	ICE THICKNESS (m)	NOTES
481	13	Rotary wash boring	Shelby tube and drive	28.4	18	1.8	<0.1m water under ice
486	12	Penetration test	-	21.4	1.5	1.8	<0.1m water under ice
493	8	Penetration test	-	16.8	1	1.8	<0.1m water under ice
964	7	Penetration test	-	16.8	1	1.8	0.2m water under ice
3,370	6	Rotary wash boring	Drive	45.7	30	2.0	0.8m water under ice

the benchmark was measured with a Hewlett-Packard 3800A Distance Ranger. The angle between each hole and the edge of the sheet piling comprising the NE corner of the Atlantic Richfield causeway was measured with a Wild T-2 theodolite. The positions of most holes are known to within 0.1m. In this report, distance is measured relative to the beach and given to the nearest meter.

All of the offshore holes were destroyed in the course of breakup. The last data were obtained June 14, 1975.

C. Penetration Tests

A series of penetration tests was performed in an attempt to locate the bonded permafrost table. While these tests were not the usual standard penetration tests, they were relatively fast and simple to perform. Additionally, the data provides an indication of the subsea soil properties in an area where very little soil data exists. The tests were performed by driving BW drill rod (54 mm diameter), which did not have a driving point, into the sea bottom with a 155 kg hammer dropped 0.75m. The blow count data are given in Appendix I. Note that zero depth was taken at the sea ice surface. The position of the bonded permafrost table was taken as the depth where the blow count increased substantially. It was also based on discussions with the driller and geologist at the time the tests were performed. The blow count profiles are shown in Figures 2-7.

A sharp unbonded-bonded permafrost boundary was found in hole 481 at a depth of 21m from the ice surface; the boundary was identified in the course of drilling and by a sharp break in the temperature gradient.

The position of the boundary is consistent with the blow count data from hole 486. No bonded permafrost was encountered in hole 3,370 to the depth of 46m (from the ice surface) that was reached. However, it may be possible to deduce the depth to ice-bonded permafrost by the following argument. If the salt concentration in the pore liquid is constant with depth, and the same as that of sea water, the ice-bonded permafrost should be found at a depth at which the temperature is the freezing point of sea-water, -1.84°C. Extrapolation of our data indicate that this depth is about 49m from the ice surface (46m from the sea bed). Whether the salinity is constant with depth is not known. This is probably not inconsistent with the salinity profiles of Section F, given the uncertainties.

Depth to the ice-bonded subsea permafrost table is summarized in Figure 8.

D. Soil Analysis

The soil analysis was done by the Road Materials Laboratory, Alaska Department of Highways, on the University of Alaska campus. The following test procedures were used: Gradation - AASHTO T-11 and T-27, Hydrometer - AASHTO T-88, Atterburg Limits - AASHTO T-89 and T-90, Specific gravity - Alaska T-2, Density - AASHTO T-233, Consolidation AASHTO T-216, and Triaxial compression - AASHTO T-234. Moisture content was obtained by oven-drying at 105°C. The results are based on the dry weight of the soil. Results of the soil analysis are included in Appendix II.

Generally, the sea bed was sandy gravel overlain by a thin layer of silty sand which increased in thickness seaward from a few meters near shore to about 14m at hole 3,370.

Identification of the mineral constituents of some of the soil samples was done by the State of Alaska, Department of Natural Resources, Division of Mines and Geology, located on the University of Alaska campus. The mineral constituents were identified by x-ray diffraction analysis and these results are given in Appendix III. Quartz was the major mineral present in all samples with calcite, feldspar, dolomite and chlorite occurring in minor (< 10%) or trace quantities.

E. Saturated Hydraulic Conductivity

The saturated hydraulic conductivity of a Shelby tube sample from hole 3,370 was measured by the Road Materials Laboratory. The sample was obtained from the 6.7m depth by pushing a Shelby tube into the bottom of the cased hole. Rubber stoppers were used to seal the sample in the tube and it was then transported in a thawed state to the laboratory. The tests were performed with the Shelby tube placed in a cold box with a temperature varying between -2 and 0°C. Sea water was passed through the sample in the Shelby tube mounted in a vertical position under a constant head and Darcy's law was used to calculate the saturated hydraulic conductivity. The value for the first run was 1.75×10^{-7} m s^{-1}, and for the second run 6.91×10^{-7} m s^{-1}, which gives an average value of 4×10^{-7} m s^{-1}.

Hole 69 was a 0.17m diameter hole drilled on land to a depth of 12.2m for the purpose of measuring the in situ permeability of the ice-bonded permafrost to a non-freezing fluid. The fluid level remained constant in this hole for at least 9 days after an initial transient change in level which we believe was due to seepage of the fluid into the cuttings at the bottom of the hole. It was concluded that the permeability of the bonded permafrost was essentially zero.

F. Salt Concentration Profiles

The salt concentration of the pore water was studied by three methods. The first type of measurement, which was performed on most of the samples, was the determination of the electrical conductivity of the supernatant water that all but a few samples contained. The second measurement was the determination of the Cl content of the samples with insufficient supernatant water for conductivity measurement, and of several other selected samples. In the third measurement the major ions in three soil samples were analyzed. The first measurements were performed at the Geophysical Institute, the second by the Road Materials Laboratory, Alaska Department of Highways, and the third by the Division of Mines and Geology, Alaska Department of Natural Resources.

The electrical conductivity of the supernatant water was measured by drawing off 3 ml of water into a small-volume conductivity cell and then measuring the conductivity at room temperature and a frequency of 1000 Hz. All conductivity values were normalized to 25°C using a correction factor of 2% $°C^{-1}$. Precision of these measurements is about 5%. The conductivity profiles are shown in Figures 9-14. In a few cases the conductivity of water samples obtained from under the ice or from the drilling mud were measured and these values are noted on the figures.

The chloride contents of the soil samples were measured using a titration method designed for determining chloride content of concrete. A variation from the usual technique was that the soil grains were left intact and not powdered as in the concrete test. These chloride contents are given with the soil analysis in Appendix II, and the values listed are based on percent of the weight of the dry soil sample.

Major ions in these samples were determined by quantitative atomic absorption except for Cl which was determined by titration. The results are given in Appendix V.

All of the above measurements made on the thawed soil samples obtained by drive sampling are questionable because of the possibility of sample contamination and the possibility of an evaporative loss of water from some of the sample jars. After shipment by truck over the gravel road from Prudhoe Bay it was found that most of the soil sample jars had slightly loose lids which may have led to a small evaporative loss of water from some of them. A more serious problem involves the possibility of sample contamination during the soil sampling procedures. All of the thawed drive samples were taken when the holes were filled with sea water brine or with drilling mud made from sea water brine. Since a split-tube drive sampler was used it was possible for the brine or mud to enter the sampling tube and contaminate the sample. It was possible to alleviate this problem somewhat by using cylindrical sample liners, and by carefully scraping the drilling mud from the soil sample when the sampler was opened. However, the possibility of some contamination still exists. The soil samples taken in Shelby tubes are probably not seriously contaminated nor affected by evaporative loss.

In the following paragraphs a description of conditions in the individual holes is given in order that possible contamination effects may be better assessed.

Holes 225 and 226 were drilled on land without the use of drilling mud. The soil samples were taken in the frozen state and kept frozen during transport to the laboratory. Those samples used to determine the electrical conductivity were allowed to melt in closed containers overnight and the conductivity of the supernatant water was measured the following day.

Hole 0 was drilled on the beach without the use of a drilling mud and the hole remained dry throughout the course of sampling and drilling. The soil samples were taken in the frozen state, placed in sample jars and allowed to thaw during transportation to the laboratory where the conductivity of the supernatant water was measured. Chlorinity was measured on two samples and the values obtained agree with the results of the conductivity measurement.

Hole 190 was a cased hole drilled in frozen soils using a drilling mud made from sea water taken from beneath the ice over 500m offshore. These samples were frozen initially and the mud was easy to remove. The samples thawed during transportation by truck to the laboratory. Water extracted from the drilling mud had a conductivity of 8.9 $(ohm\text{-}m)^{-1}$. The conductivity of all pore water samples in this hole were less than this value.

Holes 195 and 203 were open holes drilled in frozen soils with a hollow stem auger. These holes filled with a brine of very high conductivity [14.0-16.8 $(ohm\text{-}m)^{-1}$] and the drive samples were taken in this concentrated brine environment. No mud was used in drilling and the samples were frozen but in some cases were disaggregated by the sampling process. The samples were allowed to thaw during shipping by truck to the laboratory.

Hole 481 was a cased hole drilled in thawed soil but which penetrated the frozen permafrost table. The drilling mud was made with sea water from under the ice cover. Brine from under the nearby ice cover had a conductivity of 9.2 $(\text{ohm-m})^{-1}$. Samples obtained in this hole were placed in jars and allowed to warm during transport by truck to the laboratory. The value of the pore water conductivity at the bonded permafrost table was calculated from the measured temperature there.

Hole 3,370 was a cased hole drilled in thawed soils using a drilling mud made with sea water from under the ice cover. The soil samples were placed in jars and allowed to warm during transport by truck to the laboratory. Sea water from under the ice had a conductivity of 5.1 $(\text{ohm-m})^{-1}$ which was less than the conductivity of the pore water of any of the samples. Thus, the sea water in the brine could only have diluted the pore water of the soil samples. This situation is the reverse of that in the other holes where the conductivity of the brine in the drilling mud or hole was always greater than that of the pore water in the soil samples.

G. Borehole Temperatures

All borehole temperatures were measured with thermistor sensors. The readout device was a portable, battery-powered Wheatstone bridge (Leeds and Northrup #4289) modified to limit the self-heating in the thermistors to a few thousandths °C. Sensitivity of this bridge is a few thousandths °C or better and the manufacturer's stated limits of error of the resistance measurements amounts to $\pm$ 0.01°C. The bridge was checked in the field by measuring a precision resistor with a low temperature coefficient of resistance. Values of this resistance measured in the laboratory averaged 6000.5 ohms while field measurements averaged 6004.6 ohms or about 4 ohms high for ambient temperatures ranging from +5°C to -15°C. This increased resistance in the field is primarily due to the temperature coefficient of the bridge.

A 50m cable containing 11 thermistors (Fenwal GB32 JM19) was installed in hole 190. Details of the calibration and construction of this cable are given in Rogers et al. (1975). The installation procedure consisted of putting the cable into the cased, mud-filled hole and supporting it at the top while the casing was pulled around it. The cable was then supported above the ice with the cable head about 1.6m out of the ice. All measurements were made with the cable in this position.

The temperatures in holes 225, 203, 481, 493 and 3,370 were obtained by logging pipes installed in the holes with a thermistor on the end of a cable. These Schedule 40 steel pipes of 0.019m I.D. were installed in the holes after drilling. The casing was pulled around the pipes and the holes were allowed to cave. The pipes were filled with fluid and logged periodically until the fast ice became impractical to walk on about the middle of June. A plastic pipe of 0.019m I.D. was used in hole 225. This hole was not cased but was backfilled with snow and cuttings from the drilling after the pipe was placed in the hole. The pipe in hole 493 was forced into the hole made by the drill rod during the penetration test.

Rubber jacketed, 2 conductor, #24 AWG, shielded cables (Belden 8413) with a thermistor (YSI #44005) on the end were used to log the pipes. Initially the thermistors were mounted inside stainless steel tubes. However, the time constants of these units were too long and they were modified by removing the stainless steel sheaths, remounting the thermistors on the ends of the cables and encapsulating them in epoxy.

The initial calibration of the thermistors in their stainless steel tubes was done by comparison with a Hewlett-Packard 2801A quartz crystal thermometer in a constant temperature bath. These calibrations were checked periodically by measuring the resistance of the thermistors in an ice bath prepared with deionized water and ground up ice made from deionized water. Calibration temperatures were a nominal -20°C, -10°C, 0°C and +10°C. The measured thermistor resistances at -10°C, 0°C and +10°C were used to determine the constants A, B, C in

$$\frac{1}{T} = A + B \log R + C (\log R)^3 \qquad (1)$$

where T is the temperature in °K and R is the thermistor resistance in ohms. Equation (1) was then used to obtain temperatures for corresponding measured resistances.

The properties of the thermistors, the mounts and the borehole itself were such that 30 minutes or more were sometimes required for the thermistors to reach equilibrium at a given depth in the pipes; the time also depended upon the temperature differences between readings. As a result, the total logging time for a single pipe was several hours. However, we found by trial and error that a graph of thermistor resistance vs time^{-1} was linear and could be extrapolated to infinite time after 5-15 minutes. (This is the time dependence expected for an axial line source pulse at time zero.) To be consistent in reduction of the data, the measured resistances at each depth were graphed as a function of time^{-1} and the resulting straight lines extrapolated to obtain resistance at infinite time. This procedure removes the thermal disturbance associated with temperature logging. The disturbance due to the drilling process is a separate problem.

The accuracy of these temperature measurements is estimated to be about ± 0.01°C at most depths with a sensitivity of a few thousandths °C. Corrections were not made for the decrease in resistance of the thermistor cable due to cold ambient temperatures in the field nor for the temperature coefficient of the bridge since these effects partially compensate each other.

The borehole temperatures are given in Appendix VI and the data taken on May 28 for holes 226, 203, 481 and 3,370 are shown in Figure 15. By May 28 the disturbance associated with drilling had died out to the point that most of the temperatures seemed to be within about 0.05°C of their undisturbed values. For one hole (203) the calculation of undisturbed temperatures is given in Appendix VI.

H. References

Rogers, J. C., Harrison, W. D., Shapiro, L. H., Osterkamp, T. E., Gedney, L. D., and VanWormer, J. D., 1975, Nearshore permafrost studies in the vicinity of Point Barrow, Alaska. Report UAG R-237, Geophysical Institute, University of Alaska, Fairbanks, Alaska.

I. List of Figures

Figure 8. Depth to the ice-bonded subsea permafrost table as determined by the penetration tests and drilling during May, 1975.

Figures 9-14. Electrical conductivity profiles of the soils on land and offshore. These values were obtained by measuring the electrical conductance of supernatant water in the thawed soil samples.

Figure 15. Temperature profiles obtained on May 28, 1975 at various distances from shore.

VII. DISCUSSION

We are presently analyzing the data in this report. A discussion will be available for the next quarterly report.

VIII. CONCLUSIONS

See Section I above.

IX. NEEDS FOR FURTHER STUDY

See Section X below.

X. SUMMARY OF 4th QUARTER OPERATIONS

Much of the work accomplished in the 4th quarter is covered in the preceding parts of this report. A brief summary of field work, theoretical work, and interpretation, together with some recommendations, is given here.

A. Field Work

A visit was made to Prudhoe Bay on March 3 and 4 to log temperatures in five shallow, hand-driven pipe wells, and in one shallow onshore hole. These holes are located on the same line as shown in Figure 1.

B. Theoretical Work

Temperature data in hole 203 was analyzed with a two-dimensional time-dependent theory to estimate the rate of shore-line retreat. The analysis is not yet complete, but the rate seems to be in the vicinity of 1-1/2 m a^{-1}. This number is of great utility in determining the subsea permafrost regime.

Considerable effort is being spent to understand the mechanisms of heat and mass transport in the thawed subsea layer. It is these mechanisms, together with the shoreline history and thermal and chemical boundary conditions (which we are studying) which determine the subsea permafrost regime. This work is far from complete, but theory and the data we have analyzed so far suggest the following preliminary interpretation: Salt transport at Prudhoe Bay is advective and fairly rapid, but heat transport is still diffusive. The identification of these processes and their relative roles is an important step in the early stages of subsea permafrost study.

C. Preliminary Interpretation of Results

Prediction is really premature, but perhaps warranted since it may be of use to the imminent USGS-CRREL-Lewellen drilling program. We emphasize that the predictions are tentative.

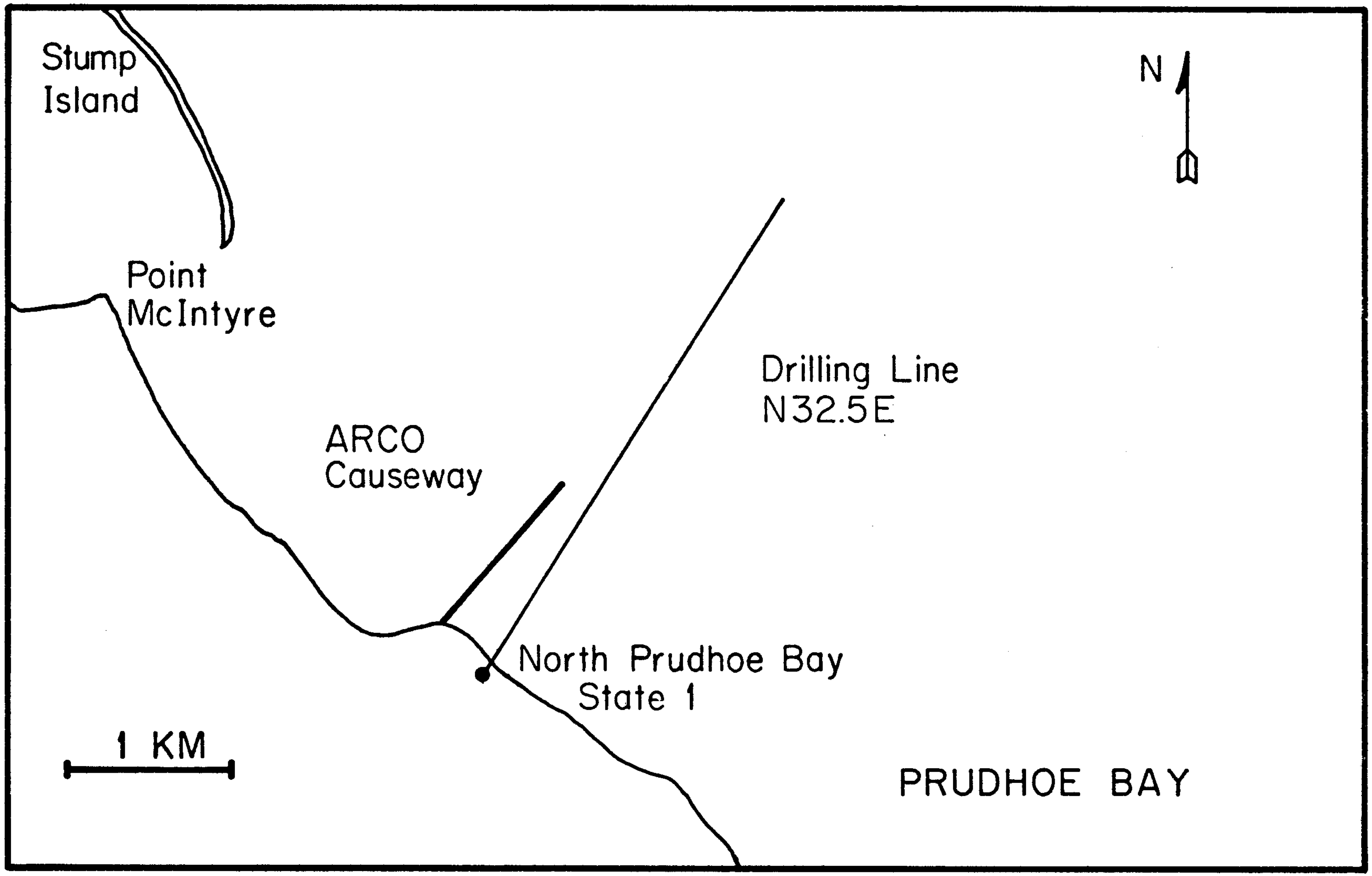
Five thousand years ago the shoreline was 5 or 10 km from its present position, given what appears to be its rate of retreat over the last century or more. If our interpretation of the heat and mass transport mechanism is correct, and the sea-bed temperature has been approximately constant, the subsea layer there should be thawed to a depth of the order of 75m, or what is more relevant, a depth not exceeding the drilling capability of the upcoming experiment. The thawed depth at our hole 3,370 would of the order of 50m; we possibly just missed reaching the bonded-unbonded subsea permafrost table there. The situation will be complicated by the lateral transport of salt, which we have not yet analyzed but feel may be important, the presence of old taliks, or by presence of salt prior to ocean transgression. The frozen permafrost under the thawed layer may still be hundreds of meters thick out to 5 or 10 km.

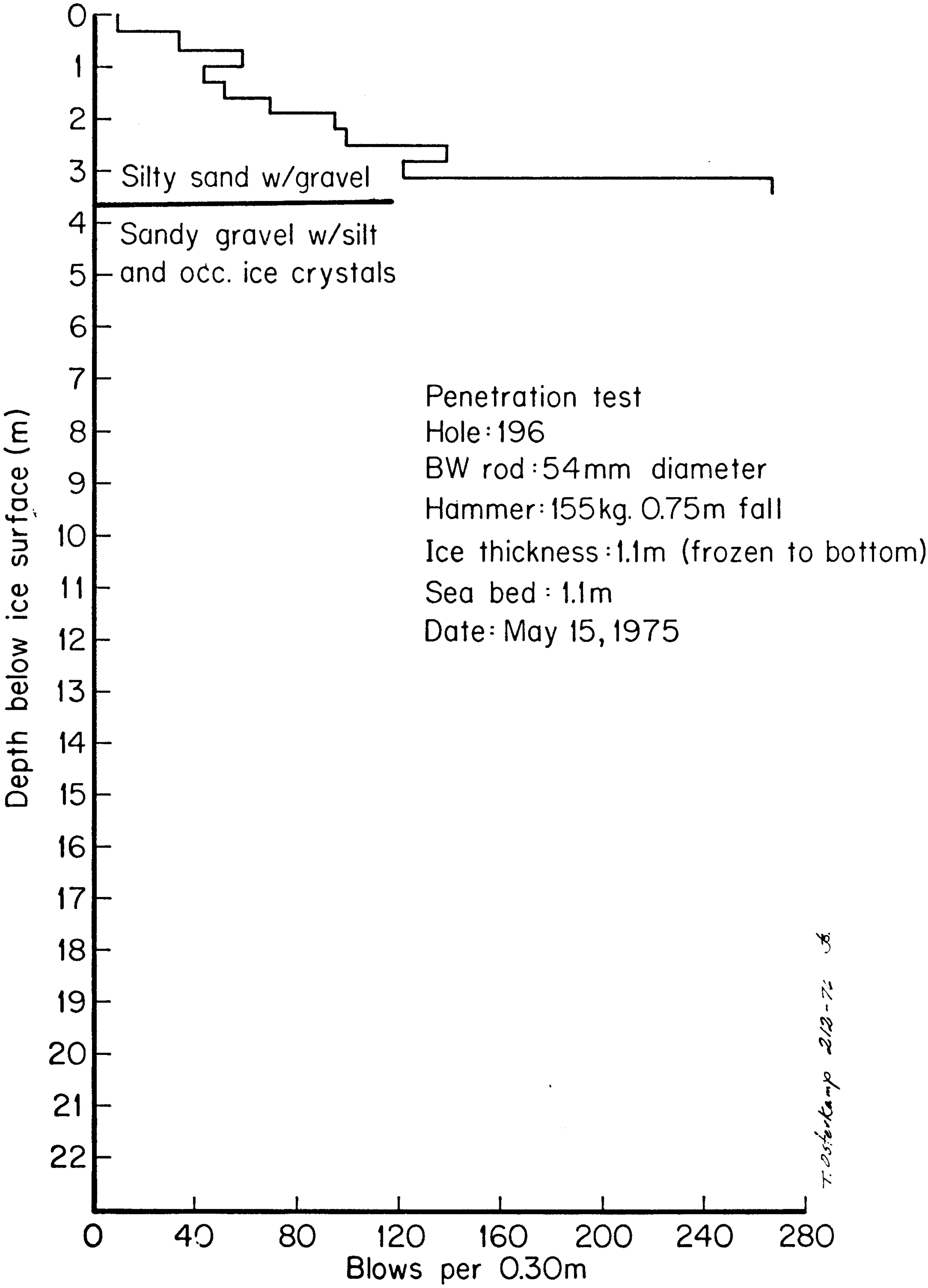
D. Recommendations

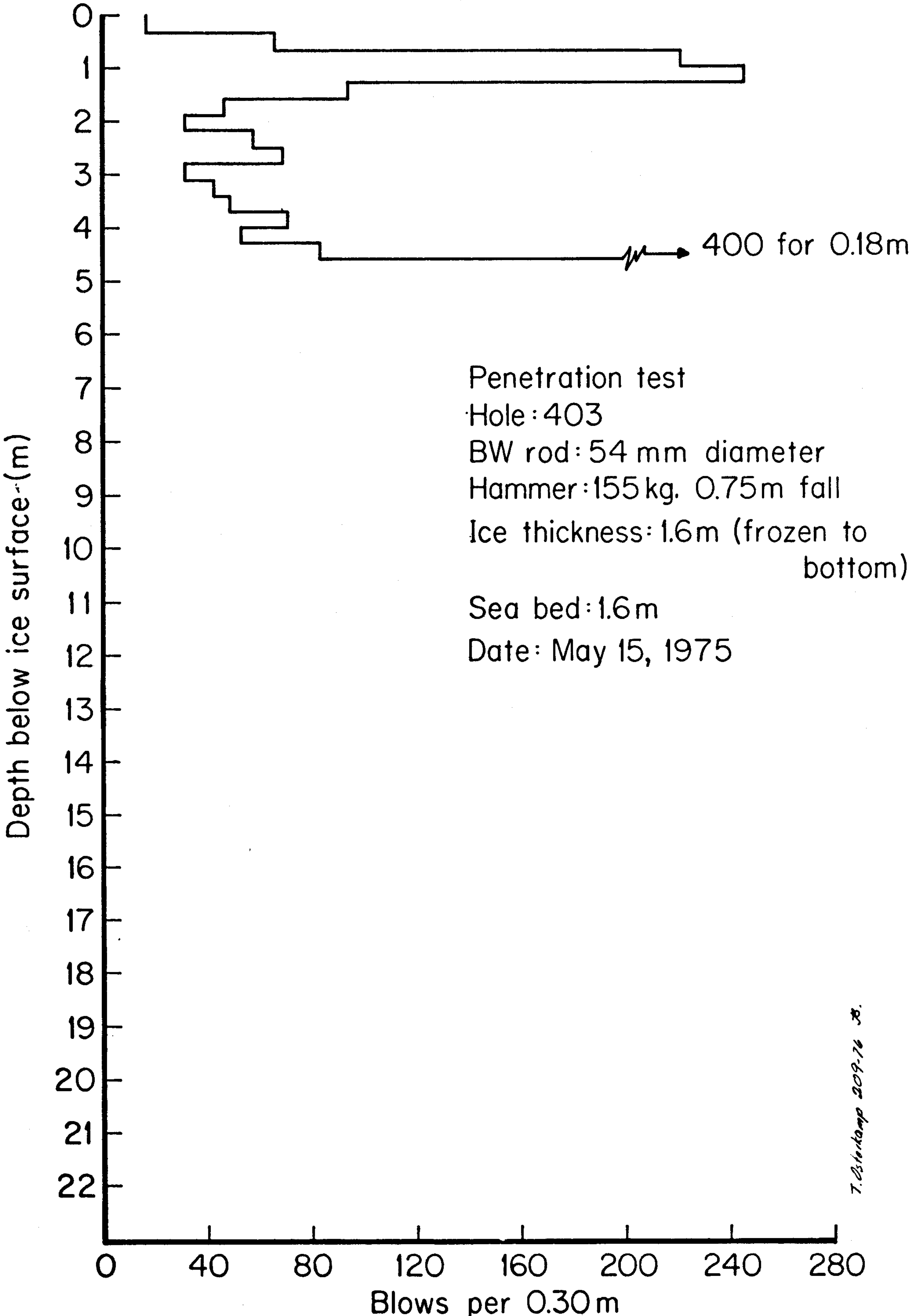
We have little to recommend to the USGS-CRREL-Lewellen experimenters that is not implied in the above, or that we have not discussed with them. We are hopeful that a sharp thawed-frozen boundary will be searched for at their drilling sites, and that the temperature there and the gradients above and below will be determined. Since the permafrost may still be quite thick, at least within 5 or 10 km of shore, it might be preferable to obtain the above kind of data at a number of holes rather than expend too much effort trying to penetrate it. We feel that this data can probably be interpreted in terms of a shoreline history and the heat and mass transport mechanisms operating. A hole slightly inshore from our hole 3,370 seems desirable given what we know about the permafrost out to there; as far as we know, this is planned.

A hole on land to a depth of 75m would provide the necessary background information needed for interpreting thawing from the seabed downward after an ocean transgression takes place. Water content and salt concentration profiles should be measured.

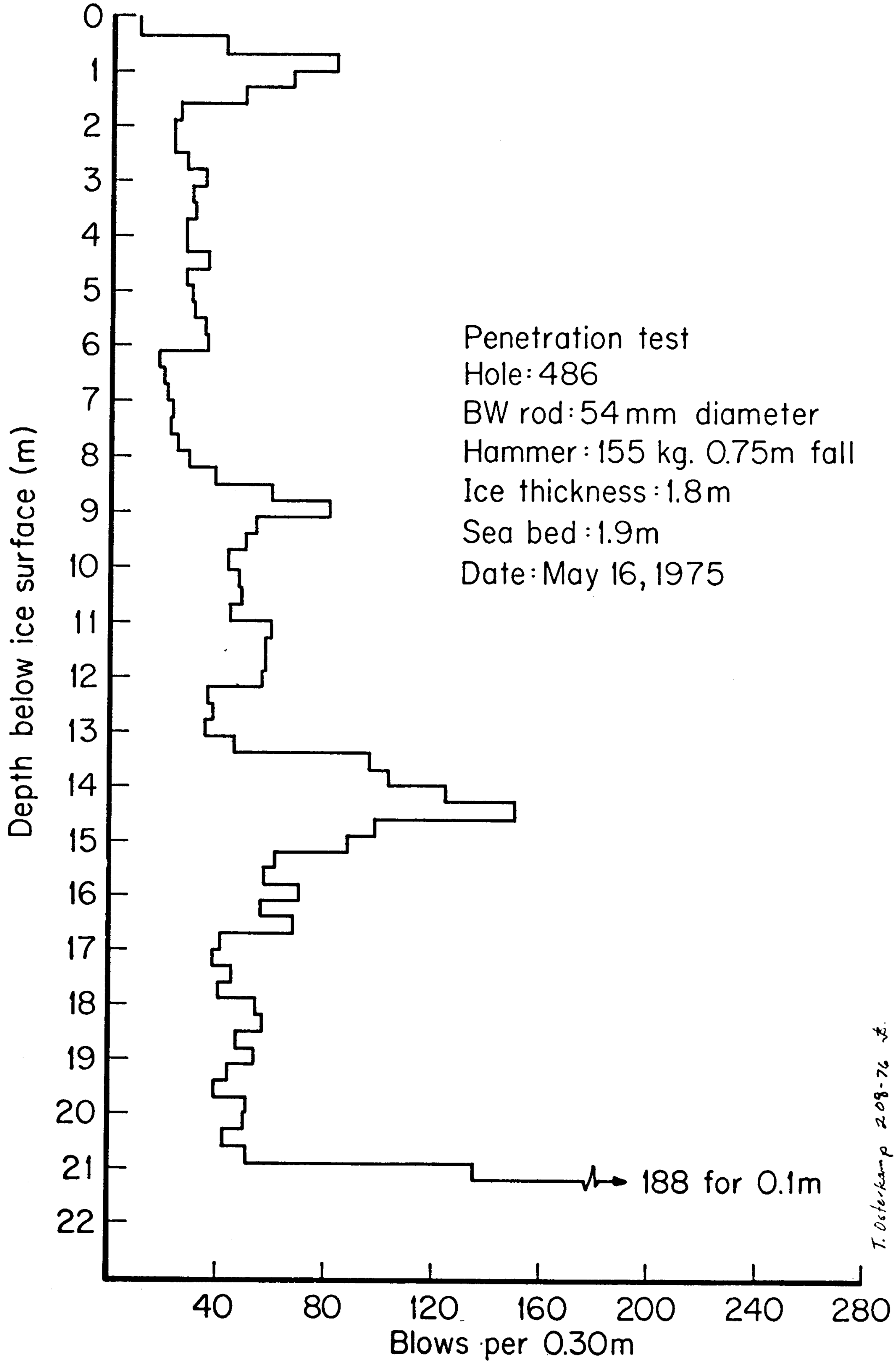
A meeting of CRREL-USGS-Lewellen and University of Alaska investigators in Fairbanks prior to this season's drilling would be profitable.

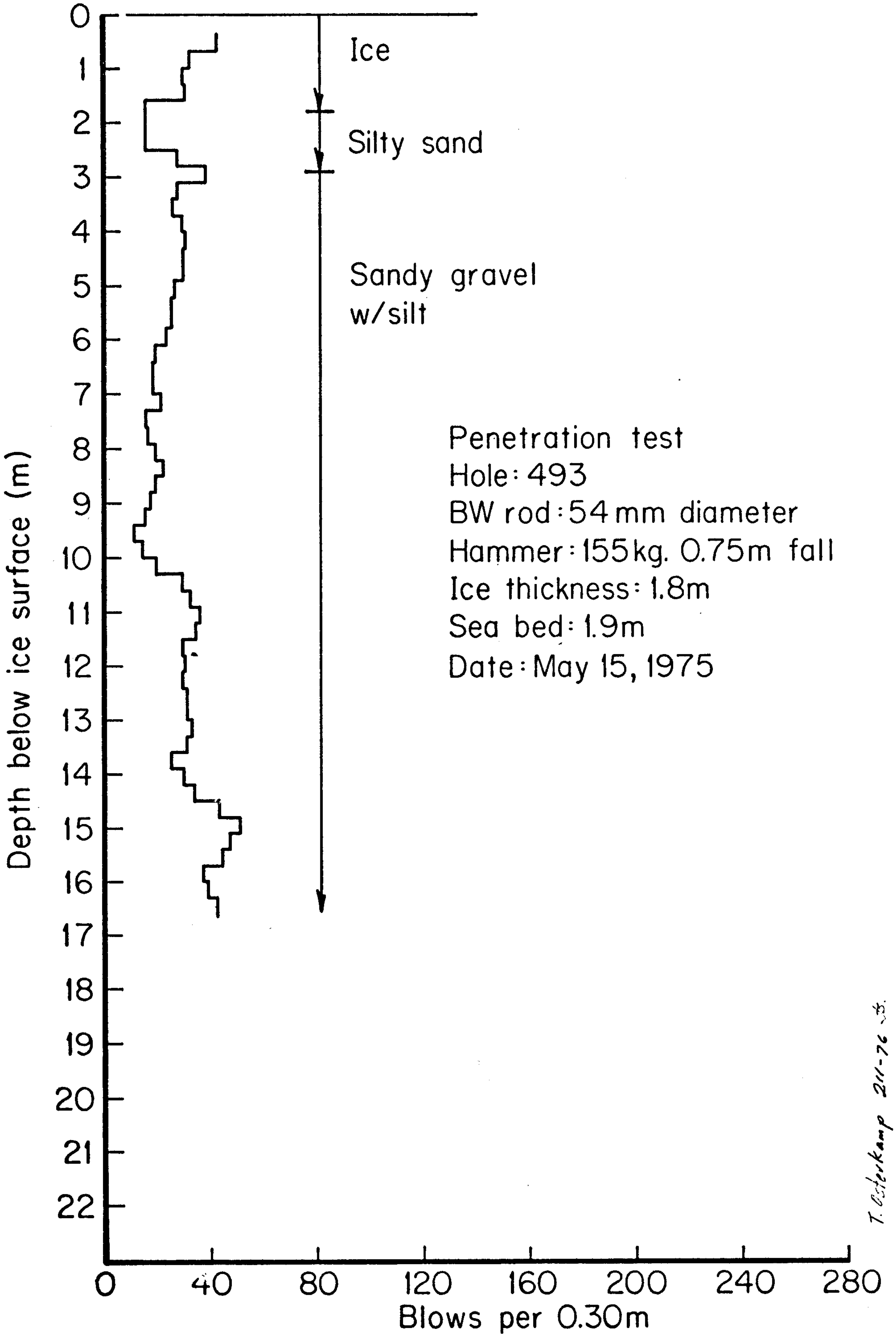

Stump Island
Point McIntyre
N
Drilling Line N32.5E
ARCO Causeway
North Prudhoe Bay State 1
1 KM
PRUDHOE BAY

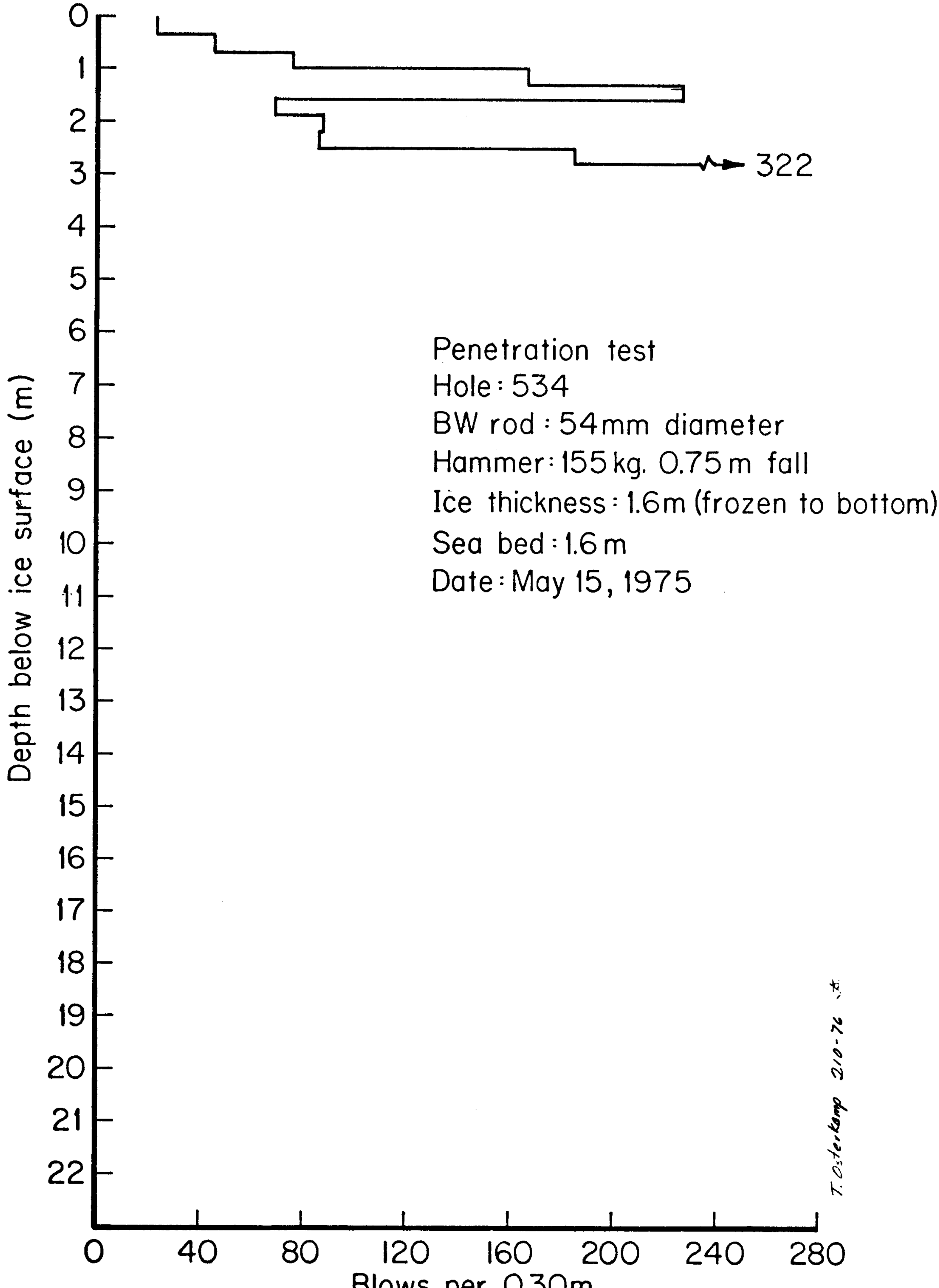

Silty sand w/gravel
Sandy gravel w/silt
and occ. ice crystals
Penetration test
Hole: 196
BW rod: 54mm diameter
Hammer: 155kg. 0.75m fall
Ice thickness: 1.1m (frozen to bottom)
Sea bed: 1.1m
Date: May 15, 1975
Depth below ice surface (m)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
0
40
80
120
160
200
240
280
Blows per 0.30m
T. Osterkamp 2/2-76



400 for 0.18m
Penetration test
Hole : 403
BW rod : 54 mm diameter
Hammer : 155 kg. 0.75m fall
Ice thickness : 1.6m (frozen to bottom)
Sea bed : 1.6m
Date : May 15, 1975
Depth below ice surface - (m)
Blows per 0.30m


Penetration test
Hole: 486
BW rod: 54 mm diameter
Hammer: 155 kg. 0.75m fall
Ice thickness: 1.8m
Sea bed: 1.9m
Date: May 16, 1975
Depth below ice surface (m)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
188 for 0.1m
40
80
120
160
200
240
280
Blows per 0.30m
T. Osterkamp 208-76


Ice
Silty sand
Sandy gravel w/silt
Penetration test
Hole: 493
BW rod: 54 mm diameter
Hammer: 155 kg. 0.75 m fall
Ice thickness: 1.8 m
Sea bed: 1.9 m
Date: May 15, 1975
Depth below ice surface (m)
Blows per 0.30m
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
0
40
80
120
160
200
240
280


Depth below ice surface (m)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
322
Penetration test
Hole: 534
BW rod: 54mm diameter
Hammer: 155 kg. 0.75 m fall
Ice thickness: 1.6m (frozen to bottom)
Sea bed: 1.6 m
Date: May 15, 1975
0
40
80
120
160
200
240
280
Blows per 0.30m

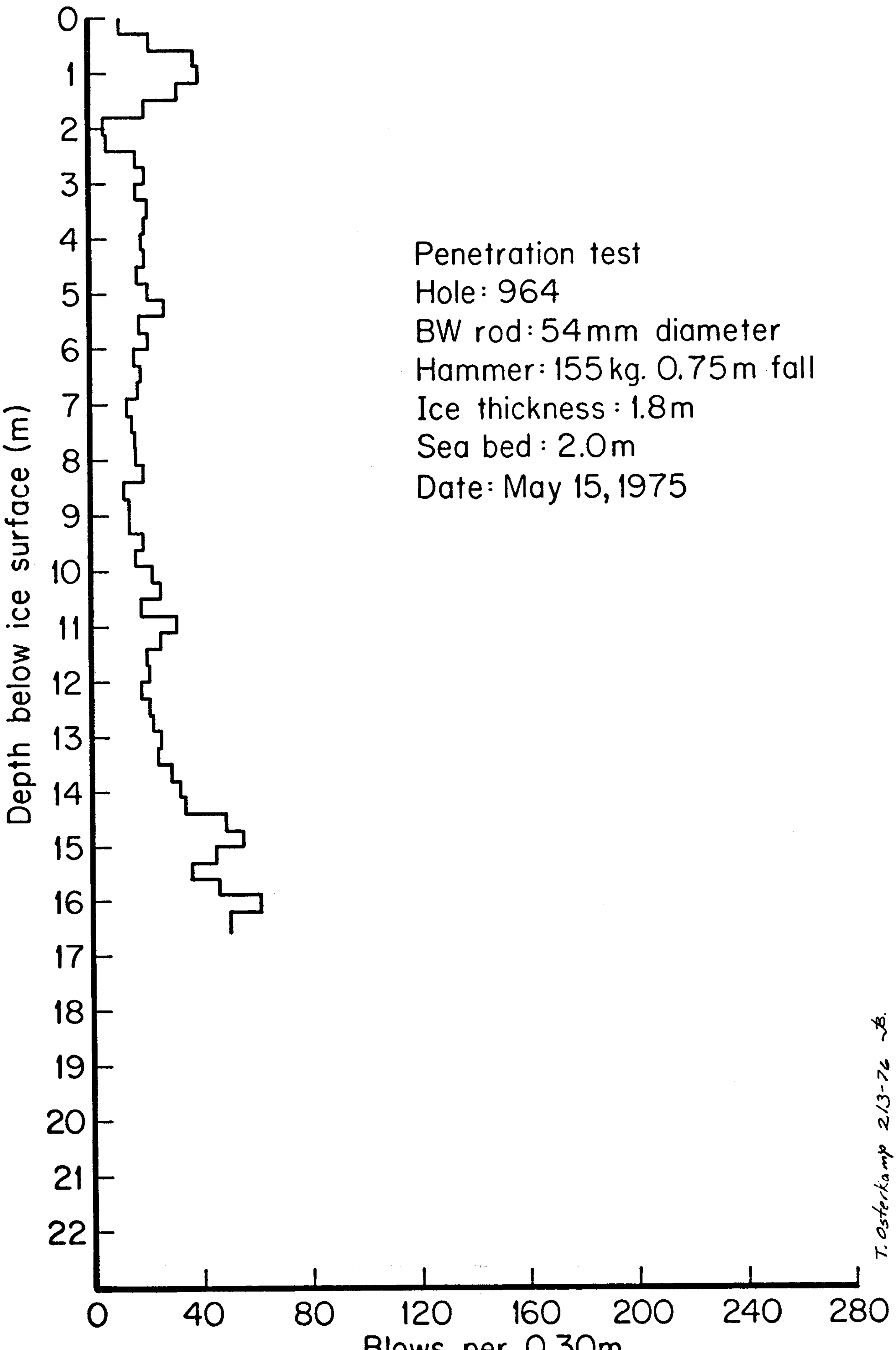
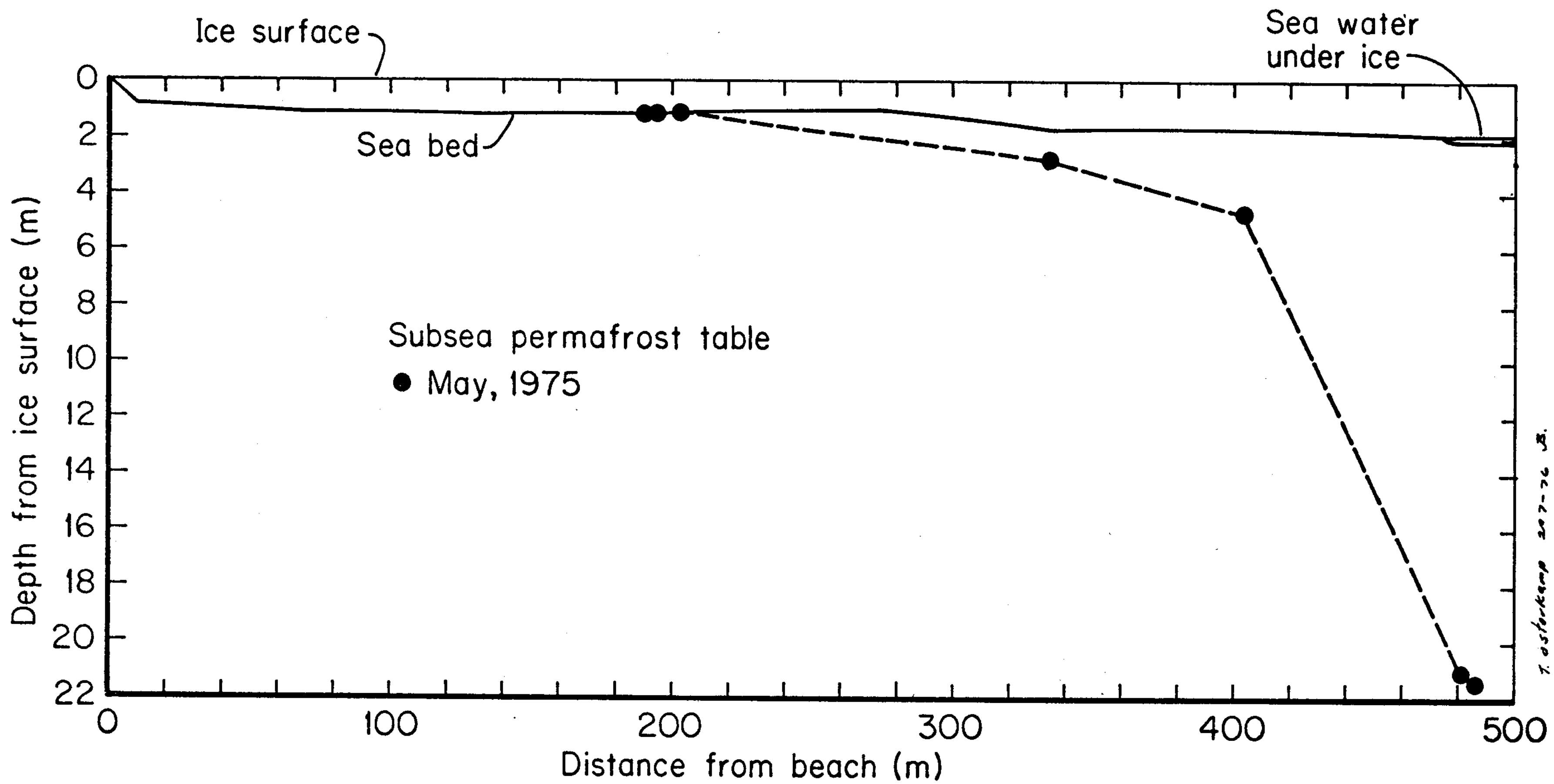
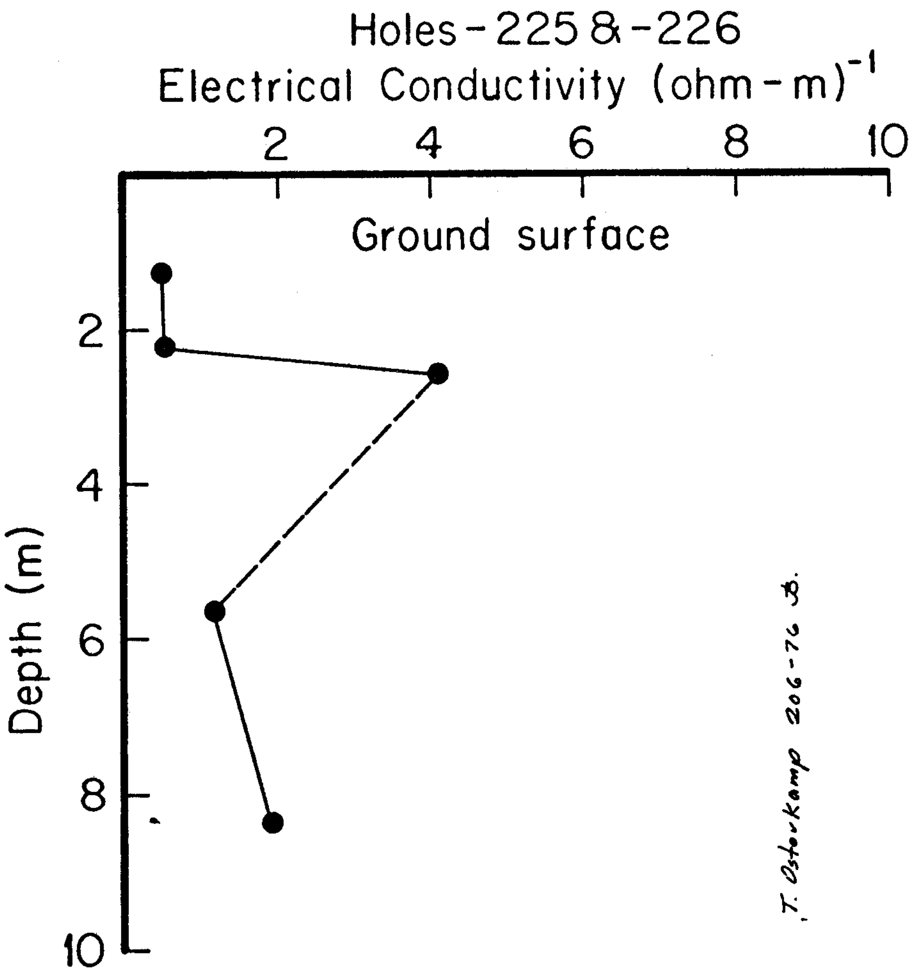

Penetration test
Hole: 964
BW rod: 54mm diameter
Hammer: 155kg. 0.75m fall
Ice thickness: 1.8m
Sea bed: 2.0m
Date: May 15, 1975
Depth below ice surface (m)
Blows per 0.30m
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
0
40
80
120
160
200
240
280
T. Osterkamp 2/3-76

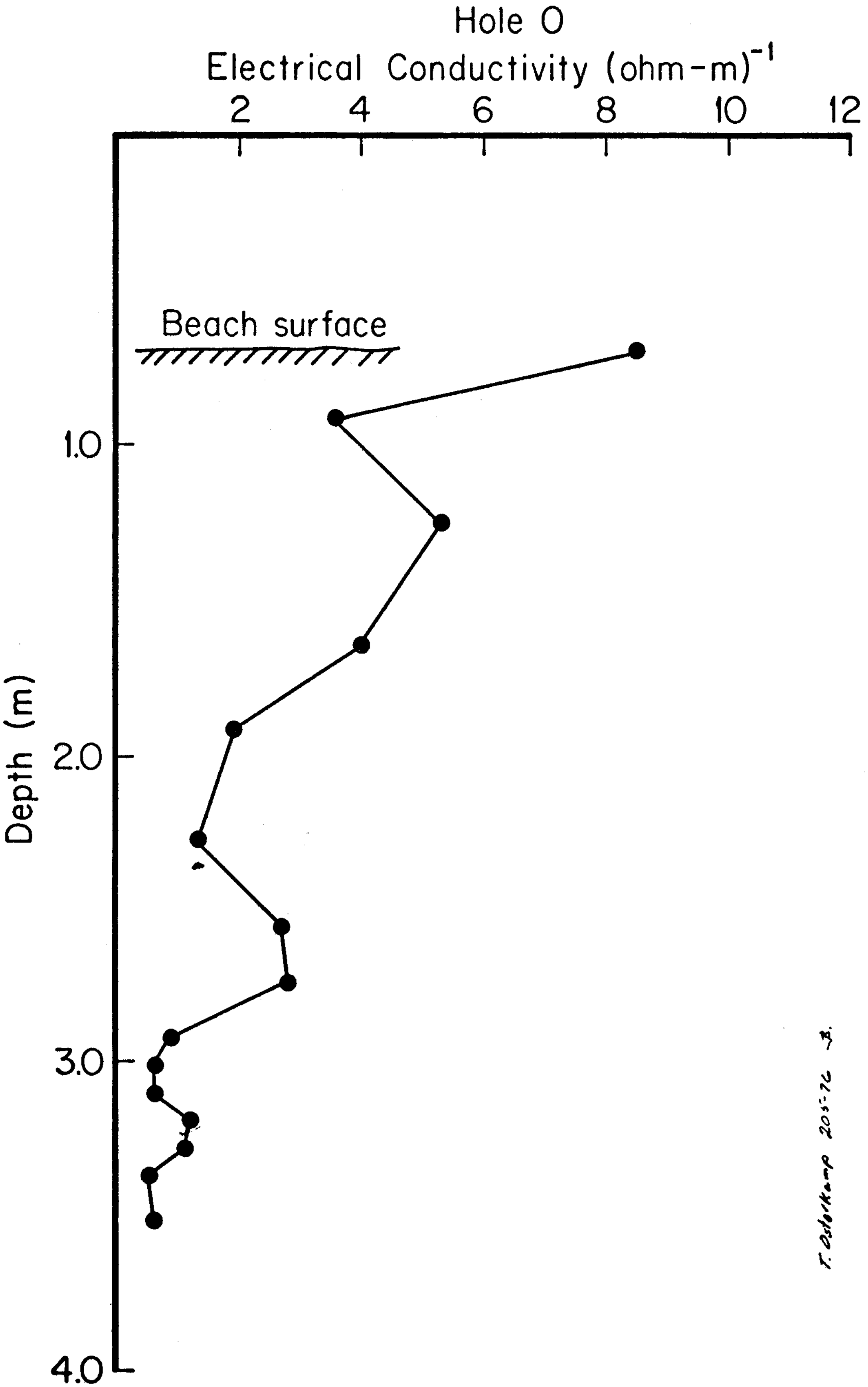
Fig 7



Reduce 1. Fig 8



Holes-225 & -226
Electrical Conductivity (ohm-m)$^{-1}$
2
4
6
8
10
Ground surface
Depth (m)
2
4
6
8
10
T. Osterkamp 206-76 B.


Hole O
Electrical Conductivity (ohm-m)$^{-1}$
2
4
6
8
10
12
Beach surface
1.0
2.0
3.0
4.0
Depth (m)
T. Osterkamp 205-76

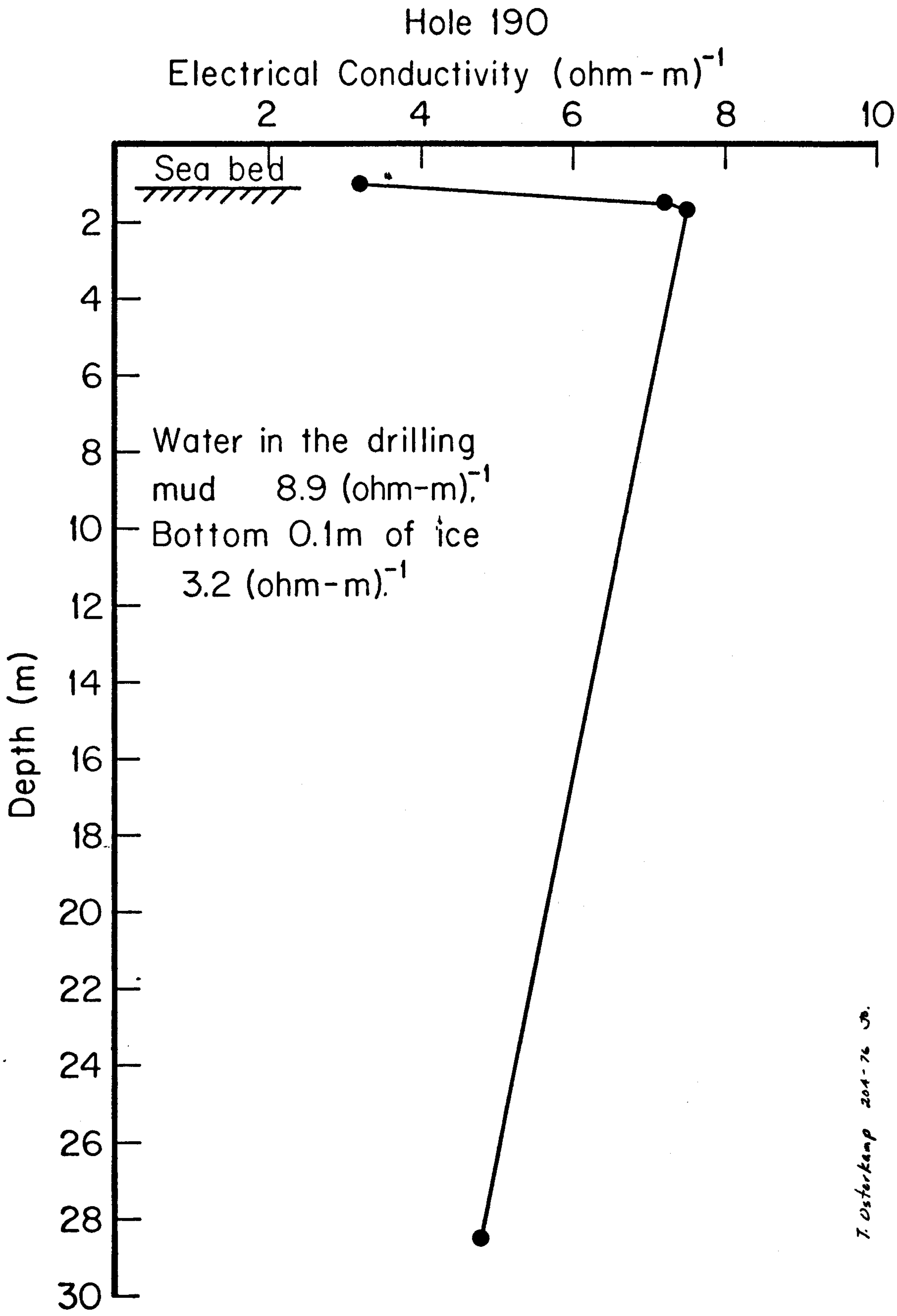

Hole 190
Electrical Conductivity (ohm-m)$^{-1}$
2
4
6
8
10
Sea bed
Depth (m)
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
Water in the drilling mud 8.9 (ohm-m)$^{-1}$
Bottom 0.1m of ice 3.2 (ohm-m)$^{-1}$
T. Osterkamp 204-76

Fig 11

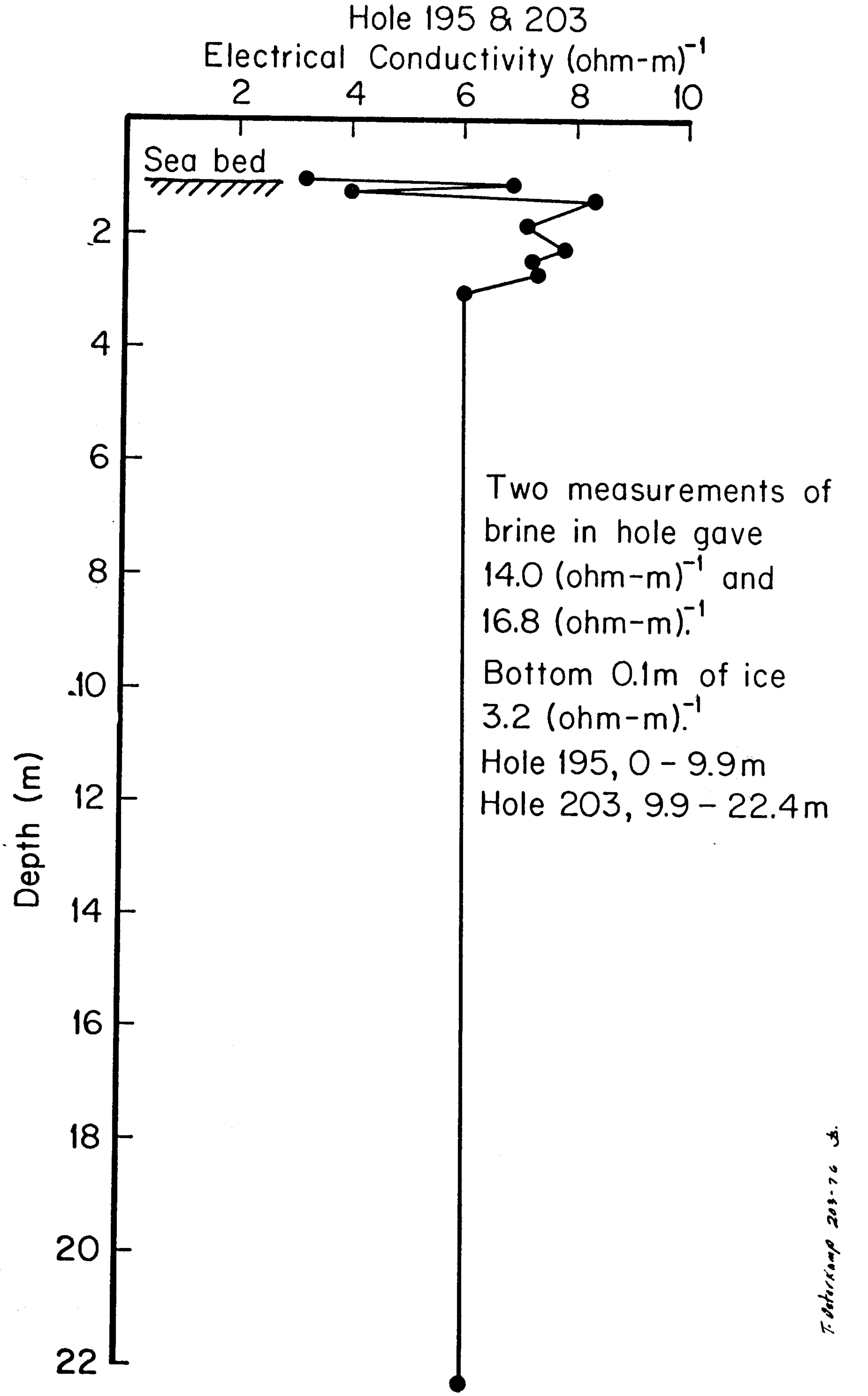
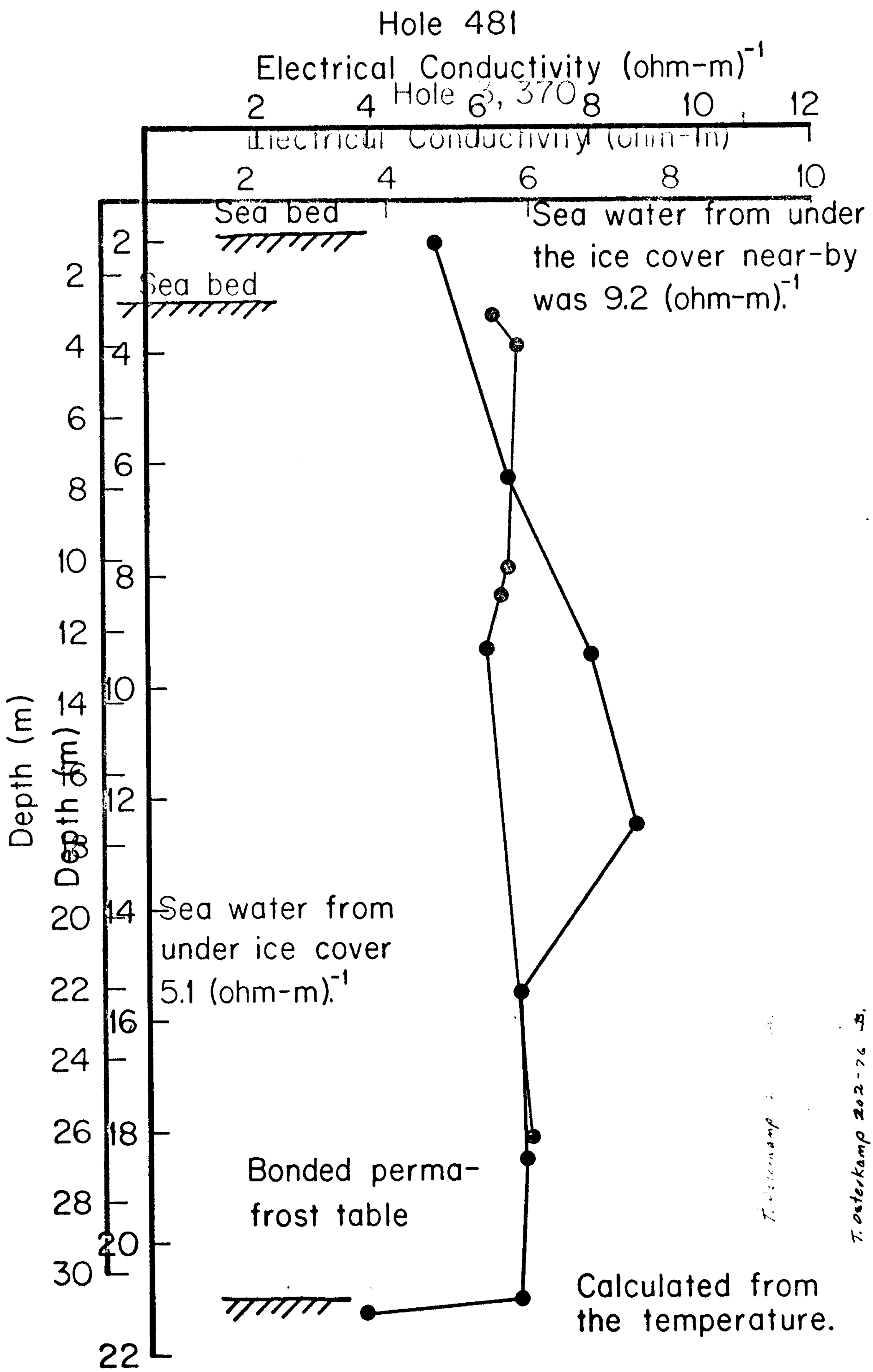
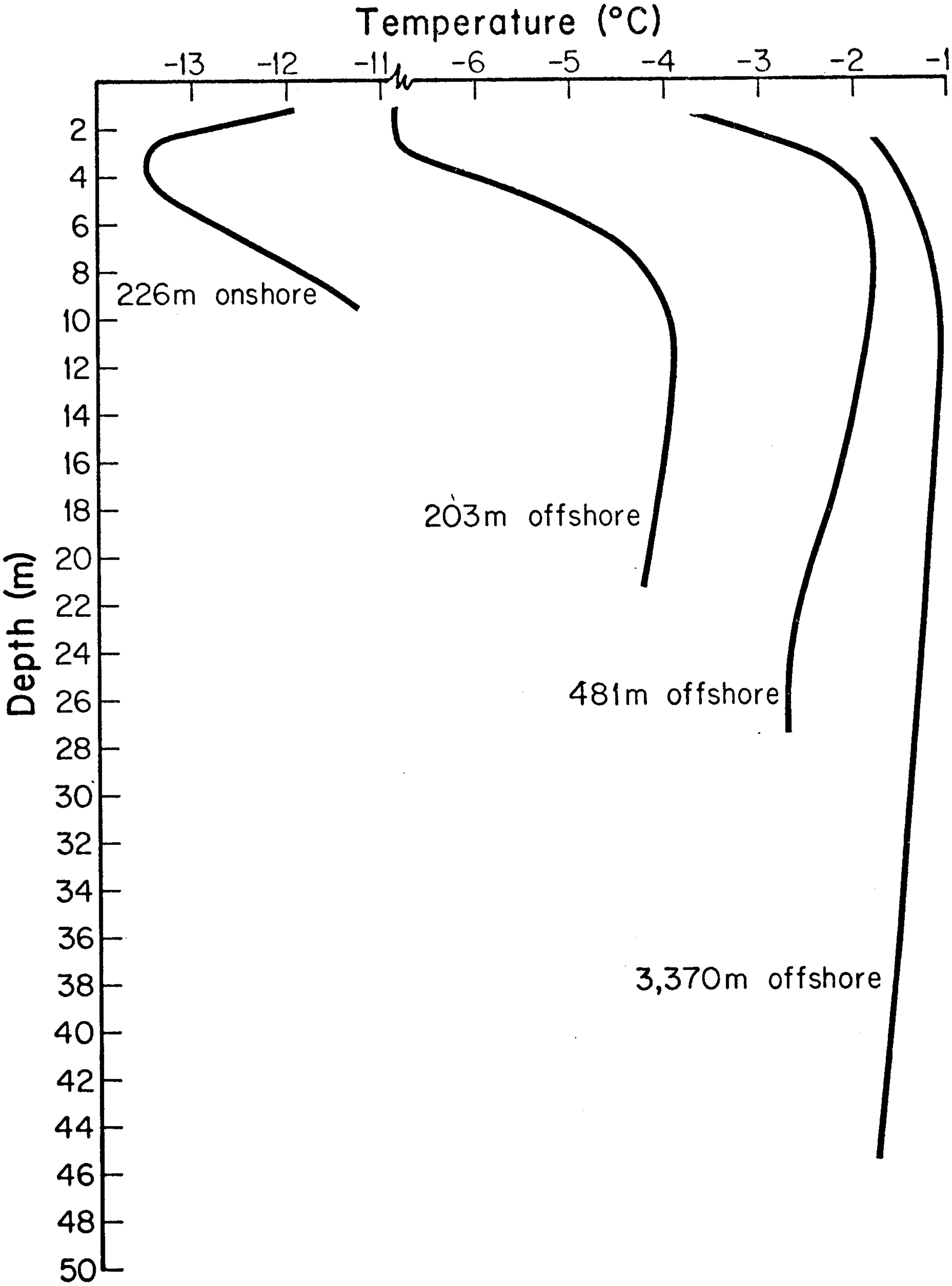

Hole 195 & 203
Electrical Conductivity (ohm-m)$^{-1}$
2
4
6
8
10
Sea bed
Depth (m)
2
4
6
8
10
12
14
16
18
20
22
Two measurements of brine in hole gave 14.0 (ohm-m)$^{-1}$ and 16.8 (ohm-m)$^{-1}$.
Bottom 0.1m of ice 3.2 (ohm-m)$^{-1}$.
Hole 195, 0 - 9.9m
Hole 203, 9.9 - 22.4m

Fig 12



Hole 481
Electrical Conductivity (ohm-m)^-1
2 4 6 8 10 12
Hole 3, 370
Electrical Conductivity (ohm-m)
2 4 6 8 10
Sea bed
Sea water from under the ice cover near-by was 9.2 (ohm-m)^-1
Sea bed
Depth (m)
Depth (m)
2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
2 4 6 8 10 12 14 16 18 20 22
Sea water from under ice cover 5.1 (ohm-m)^-1
Bonded perma-frost table
Calculated from the temperature.
T. Osterkamp 202-76

TEMPERATURE PROFILES (MAY 28, 1975)



APPENDIX I

FIELD DRILLING LOGS

These drilling logs were prepared by Mr. M. Grahek of the Alaska Department of Highways, Road Materials Laboratory, in the field at the time of drilling. The soils were classified according to a visual classification system based on the Unified Soil Classification System as used by the Alaska Department of Highways. The graphical borehole logs were prepared from these drilling logs. Corresponding hole numbers, as used in the report, for the field-designated hole numbers can be obtained from Table I in the report.

Project Name: CORE | STATE OF ALASKA DEPARTMENT OF HIGHWAYS | Hole No: 1 | Sheet 1 of 1

Project No: | Bridge No: | Engineering Geology Section, Box F, College, Alaska | Total Depth: | Hole Dia: 3 1/4

Date Begin: 30 Apr 75 | End: | **LOG OF TEST BORING** | Hole Log By: Grahek

Weather: +20 O.C. Lt. snow | Type of Structure:

Hole Station: Rt. Ft. Lt. Ft. of ¢

Collar Elevation: Reference:

Field Party: Collar, Walden, Manthey, Overcamp, Harmon | Rig: 05431

Notes: Near No. Prudhoe Bay State No. 1

Ground Water Data

Depth in ft.		
Time		
Date		

Drilling Method	Depth in Feet	Casing Size: Blows/Ft. Depth	Sample Method	Sample No	Blow Count	Subsurface Material	Drilling Notes
Hollow Stem Auger →	0		2" (140)	1000	20	1" moss, 1" sand	
					68	Organic silt	Auger to 18"
	1				125	w/sand	
					13	V. ice rich silt, TR. F. sand	
	2		2" (340)	1001.5	17		
					17		
	3				25		
					158		sample @ 1.5'
	4				200+	200/2"	sampler full
							Auger to 4.5'
	5		2" (340)	1004.5	10		
					17		
	6				25		
					34		
	7				84		sample
				10073	100+	100/3"	sampler full
	8				27		drove sampler down
					53	occ. more sand	same hole
	9				52		End hole @ 9.5' 30 Apr 75
					84		due to ext. slow progress w/H.S.
					100	100/3"	
	10						
	11						
	12						
	13						
	14						
	15						
	16						
	17						
	18						
	19						
	20						

Note: Unless otherwise noted all samples are taken w/1.4" ID Standard Penetration Sampler driven w/140 lb hammer w/30" drop.

STATE OF ALASKA
DEPARTMENT OF HIGHWAYS
Engineering Geology Section
Box F, College, Alaska
LOG OF TEST BORING

Project Name: CORE
Project No:
Bridge No:
Date Begin: 30 Apr 75 End: 30 Apr 75
Weather: +20° O.C. Lt. Snow

Hole No: 2 Sheet 1 of 1
Total Depth: 11.5 Hole Dia.: 3 1/4
Hole Log By: Grahek
Type of Structure:

Hole Station: Rt. Ft. Lt. Ft. of ℄
Collar Elevation: Reference:
Field Party: Grahek, Walker, Martha, Estercamp, Hersey Rig: 05431

Notes: ON Beach

Ground Water Data

Depth in ft.		
Time		
Date		

Drilling Method	Depth in Feet	Casing Size: Blows/Ft. Depth	Method	Sample No	Blow Count	Subsurface Material	Drilling Notes
Hollow Stem Auger	0		2" (342)	2000	1	ICE	±2' snow on surface
					5		
	1				9		
					25		Sample
	2				32		
					34	Org. silt w/ ice, sand; 2.3-2.8	in jar discard rest
	3			2003	38	Silty sand; 3.0-3.4	Auger to 3'
					34		
	4				34	gravelly; 4.1-4.5	"
					60		
	5				68		Sample
					100+	100/3"; 5.4-5.8	"
	6			2006	18	6.3-6.7	" Auger to 6'
					48	TR gravel	Sample
	7				53		
					58	7.5-7.9	"
	8				86		
					95	95/3"; 8.4-8.8	" Auger to 9'
	9			2009	59	sample divided into 9 parts numbered 2009 (1-9)	Sample
					27		
	10				29		
					57		
	11				225		
	12					T.D. = 11.5'	
	13						
	14						
	15						
	16						
	17						
	18						
	19						
	20						

Note: Unless otherwise noted all samples are taken w/ 1.4" ID Standard Penetration Sampler driven w/ 140 lb hammer w/ 30" drop.

Project Name: CORE
Project No:
Bridge No:
Date Begin: 1 MAY 75
End: 2 MAY 75
Weather: +10° O.C. Lt. SNOW

STATE OF ALASKA
DEPARTMENT OF HIGHWAYS
Engineering Geology Section
Box F, College, Alaska
LOG OF TEST BORING

Hole No: 3-3A
Sheet 1 of 4
Total Depth: 73.5
Hole Dia: 3 1/4
Hole Log By: Gahek
Type of Structure:

Hole Station: Rt. Ft. Lt. Ft. of ℄
Collar Elevation: Reference:
Field Party: Gahek, Walder, Manthey, Osterkamp, Harrison Rig: 05431

Notes: 3-0 3A 325.0

Ground Water Data		
Depth in ft.		
Time		
Date		

Drilling Method	Depth in Feet	Casing Size	Blows/Ft., Depth	Method	Sample No	Blow Count	Loc. Sampled	Recovery	Frozen	Soil Graph	Subsurface Material	Drilling Notes
Hollow Stem Auger	0										±6" SNOW ON SURFACE — ICE	AUGER to 30"
	1											
	2											
	3			2" (SPT)	3002.5	8, 8						SAMPLE
	4					26, 56					3.8 - 4.6 IN JARS (1-2); Silty sand	SAMPLE IN SAME HOLE
	5				3004.5	26, 23					4.6 - 5.0 "; ORG. Silty F. Sand	
	6					33, 35					5.4 - 5.8 "; 6.1 - 6.6 "; Silty Sand w/Gravel	AUGER to 6.5'
	7				3006.5	24, 27					7.4 - 7.8 "	
	8					22, 19					8.1 - 8.5 "	
	9				3008.5	15, 14					TR. ORG. wet; 9.0 - 9.4	SAMPLE IN SAME HOLE
	10					33, 38					10.1 - 10.5	AUGER to 17½'
	11											
	12											
	13										Sandy Gravel w/Silt	
	14											
	15											
	16											
	17											
	18				3017.5	80, 295						SAMPLE; AUGER to 20'
	19											
	20										177	

Note: Unless otherwise noted all samples are taken W/1.4" ID Standard Penetration Sampler driven W/140 lb hammer W/30" drop.

Project Name: CORE | STATE OF ALASKA DEPARTMENT OF HIGHWAYS Engineering Geology Section Box F, College, Alaska | Hole No: 3-3A | Sheet 2 of 4

LOG OF TEST BORING

Project No: | Bridge No: | Total Depth: 73.5 | Hole Dia.:

Date Begin: | End: | Hole Log By: Grahek

Weather: | Type of Structure:

Hole Station: Rt. Ft. Lt. Ft. of ¢

Collar Elevation: Reference:

Field Party: Rig:

Notes:

Ground Water Data		
Depth in ft.		
Time		
Date		

Drilling Method	Depth in Feet	Casing Size: Blows/Ft., Depth	Method	Sample No	Blow Count	Loc. Sampled	Recovery	Frozen	Soil Graph	SUBSURFACE MATERIAL	DRILLING NOTES
Hollow Stem Auger (20–40)	20									Sandy gravel w/silt	Auger to 32½'
	22									occ. sm x-tals ice	
	32–33		2" rotate	3032.5		X				No Sample	Rotated sampler w/carbide teeth broke off sampler move over ±23' (hole 3A) Auger to 40'
	40										

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Note: Unless otherwise noted all samples are taken W/1.4" ID Standard Penetration Sampler driven W/ 140 lb hammer W/30" drop.

STATE OF ALASKA
DEPARTMENT OF HIGHWAYS
Engineering Geology Section
Box F, College, Alaska
LOG OF TEST BORING

Project Name: CORE
Project No:
Bridge No:
Date Begin:
End:
Weather:
Hole Station: Rt. Ft. Lt. Ft. of ℄
Collar Elevation: Reference:
Field Party: Rig:

Hole No: 5-3A
Sheet 3 of 4
Total Depth: 73.5
Hole Dia:
Hole Log By: Gralok
Type of Structure:

Notes:

Ground Water Data

Depth in ft.	39'
Time	0900
Date	2 May 75

Drilling Method	Depth in Feet	Casing Size	Blows/Ft., Depth	Method	Sample No	Blow Count	Loc. Sampled	Recovery	Frozen	Soil Graph	SUBSURFACE MATERIAL	DRILLING NOTES
Hollow Stem Auger	40										SAND, gravel w/silt	Auger to 52½
	41											
	42											
	43											
	44											
	45											
	46											
	47											
	48											
	49											
	50											
	51											
	52											2 May 75 Auger to 60'
	53											
	54											
	55											
	56											
	57											
	58											
	59											
	60											

Note: Unless otherwise noted all samples are taken W/1.4" ID Standard Penetration Sampler driven W/140 lb hammer W/30" drop.

STATE OF ALASKA
DEPARTMENT OF HIGHWAYS
Engineering Geology Section
Box F, College, Alaska
LOG OF TEST BORING

Project Name: CORE
Project No:
Bridge No:
Date Begin:
End:
Weather: +18 O.C. Lt. Snow, BR

Hole No: 3A
Sheet 4 of 4
Total Depth: 73.5
Hole Dia:
Hole Log By: Grahek
Type of Structure:

Hole Station: Rt. Ft. Lt. Ft. of ¢
Collar Elevation: Reference:
Field Party: Rig:

Notes:

Ground Water Data

Depth in ft.		
Time		
Date		

Drilling Method	Depth in Feet	Casing Size: Blows/Ft., Depth	Method	Sample No	Blow Count	Loc. Sampled	Recovery	Frozen	Soil Graph	SUBSURFACE MATERIAL	DRILLING NOTES
Hollow Stem Auger (60–72)	60									Sandy gravel w/silt	
	61										Auger to 72½
	62										
	63										
	64									becoming more sandy	
	65										
	66										
	67									Appears to be sand w/occ. gravel	
	68										
	69										
	70										Sample @ 72.5 (14", 15, 11-10) drove thru fill
	71										
	72		2" (342)	3A072.5	18	X				sandy gravel	pilot bit stuck in auger - pull auger
	73				2.0						
	74									T.D. = 73.5'	
	75										
	76										
	77										
	78										
	79										
	80										

Note: Unless otherwise noted all samples are taken W/1.4" ID Standard Penetration Sampler driven W/140 lb hammer W/30" drop.

Project Name: CORE
Project No:
Bridge No:
Date Begin: 3 May 75 End: 5 May 75
Weather: +14 Lt Snow, Lt Br.

STATE OF ALASKA
DEPARTMENT OF HIGHWAYS
Engineering Geology Section
Box F, College, Alaska
LOG OF TEST BORING

Hole No: 4 Sheet 1 of 9
Total Depth: 183 Hole Dia: 3"
Hole Log By: Gralek
Type of Structure:

Hole Station: Rt. Ft. Lt. Ft. of ¢
Collar Elevation: Reference:
Field Party: [illegible] Rig: [illegible]

Notes:
4 3 3A
±25' ±25'

Ground Water Data		
Depth in ft.		
Time		
Date		

Drilling Method: Rotary tri cone / HS Auger

Depth in Feet	Method	Sample No	Blow Count	Subsurface Material	Drilling Notes
0–1					Auger to 2½'
1–2				ICE	NX to 4.3'
2–3					drill to 5'
4				silty sand	sample drill to 8'
5–6	2"(SPT)	4005	[illegible] / [illegible]	sandy gravel 5-5.5 5.5-6 in JAR	
8–9		4008	25 / 25	silty sand tr. gravel 8.5-9 "	sample drill ahead to 13
12–13				sand gravel w/silt	
13–14		4013	175 / 128	13.6 in JAR lenses sandy silt & silty sand	sample drill ahead to 28
15–16					NX to 25'

Note: Unless otherwise noted all samples are taken W/ 1.4" ID Standard Penetration Sampler driven W/ 140 lb hammer W/ 30" drop.

Project Name: CORE

Project No:

Bridge No:

Date Begin:

End:

STATE OF ALASKA
DEPARTMENT OF HIGHWAYS
Engineering Geology Section
Box F, College, Alaska

LOG OF TEST BORING

Hole No: 4 | Sheet 2 of 7

Total Depth: 183 | Hole Dia.:

Hole Log By: Grahek

Type of Structure:

Weather:

Hole Station: Rt. Ft. Lt. Ft. of ¢

Collar Elevation: Reference:

Field Party: Rig:

Notes:

Ground Water Data

Depth in ft.		
Time		
Date		

Drilling Method	Depth in Feet	Casing Size / Blows/Ft., Depth	Method	Sample No	Blow Count	Loc. Sampled	Recovery	Frozen	Soil Graph	SUBSURFACE MATERIAL	DRILLING NOTES
Rotary Tri Cone ↓	20	↓								Sandy gravel w/silt ↓	drill ahead to 53'
	21										
	22										
	23										
	24										
	25									occ. thin lenses silty sand, sandy silt	NX to 50'
	26										
	27										
	28										
	29										
	30										
	31										
	32										
	33										
	34										
	35										
	36										
	37										
	38										
	39										
	40										

Note: Unless otherwise noted all samples are taken W/1.4" ID Standard Penetration Sampler driven W/ 140 lb hammer W/30" drop.

STATE OF ALASKA
DEPARTMENT OF HIGHWAYS
Engineering Geology Section
Box F, College, Alaska
LOG OF TEST BORING

Project Name: CORE
Project No:
Bridge No:
Date Begin:
End:
Weather:
Hole No: 4
Sheet 3 of 7
Total Depth: 183
Hole Dia:
Hole Log By: Galek
Type of Structure:
Hole Station: Rt. Ft. Lt. Ft. of ℄
Collar Elevation: Reference:
Field Party: Rig:
Notes:

Ground Water Data		
Depth in ft.		
Time		
Date		

Columns: Drilling Method | Depth in Feet | Casing Size: NX | Blows/Ft. Depth | Sample Data: Method, Sample No, Blow Count, Loc. Sampled, Recovery | Frozen | Soil Graph | SUBSURFACE MATERIAL | DRILLING NOTES

Drilling Method: Rotary Tri-Cone (40–60 ft)

Depth in Feet: 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57, 58, 59, 60

SUBSURFACE MATERIAL:
- 40: Sand, gravel w/ silt
- 42: occ. lenses sand, silt, silty sand

DRILLING NOTES:
- 50: drill ahead to 73'
- 51: NX to 65'

183

Note: Unless otherwise noted all samples are taken w/ 1.4" ID Standard Penetration Sampler driven w/ 140 lb hammer w/ 30" drop.

STATE OF ALASKA
DEPARTMENT OF HIGHWAYS
Engineering Geology Section
Box F, College, Alaska
LOG OF TEST BORING

Project Name: CORE
Project No: | Bridge No:
Date Begin: | End:
Weather:
Hole Station: | Rt. | Ft. Lt. | Ft. of ¢
Collar Elevation: | Reference:
Field Party: | Rig:

Hole No: 4 | Sheet 4 of 9
Total Depth: 183 | Hole Dia:
Hole Log By: GRAKEK
Type of Structure:

Notes:

Ground Water Data		
Depth in ft.		
Time		
Date		

Drilling Method	Depth in Feet	Casing Size: NX	Blows/Ft. Depth	Method	Sample No	Blow Count	Loc. Sampled	Recovery	Frozen	Soil Graph	SUBSURFACE MATERIAL	DRILLING NOTES
Rotary / Tri-Cone	60	↓									SAND gravel w/silt ↓	
	61											
	62											
	63											
	64										OCC. LENSES SAND, silt, siltysand	drill ahead to 87'
	65											
	66											NX to 80'
	67											
	68											
	69											
	70											
	71											
	72											
	73											
	74											
	75											
	76											
	77											
	78											
	79											
↓	80	↓									↓	

Note: Unless otherwise noted all samples are taken W/ 1.4" ID Standard Penetration Sampler driven W/ 140 lb hammer W/ 30" drop.

STATE OF ALASKA
DEPARTMENT OF HIGHWAYS
Engineering Geology Section
Box F, College, Alaska
LOG OF TEST BORING

Project Name: CORE
Project No:
Bridge No:
Date Begin:
End:
Weather:
Hole No: 4
Sheet 5 of 9
Total Depth: 183.
Hole Dia:
Hole Log By: Gerlek
Type of Structure:
Hole Station: Rt. Ft. Lt. Ft. of ℄
Collar Elevation: Reference:
Field Party: Rig:

Ground Water Data		
Depth in ft.		
Time		
Date		

Notes:

Casing Size: NX

Drilling Method	Depth in Feet	Sample Method	Sample No	Blow Count	Subsurface Material	Drilling Notes
Rotary Tri-Cone (80–100)	80				Sandy gravel w/silt	
	81					drill ahead to 92'
	82				occ. lenses sandy silt, silty sand	
	83					
	84					
	85					
	86					
	87					NX to 90'
	88					4 May 75 +24° 15-20mph o.c.
	89					drill out & ahead to 93'
	90					
	91					
	92					
	93	SP(?)	D93	22/6, 23/5		SAMPLE
	94					drill ahead to 113'
	95					NX to 110'
	96					
	97					
	98					
	99					
	100					

185

Note: Unless otherwise noted all samples are taken W/1.4" ID Standard Penetration Sampler driven W/140 lb hammer W/30" drop.

STATE OF ALASKA
DEPARTMENT OF HIGHWAYS
Engineering Geology Section
Box F, College, Alaska
LOG OF TEST BORING

Project Name: CORE
Project No: | Bridge No:
Date Begin: | End:
Weather:
Hole Station: Rt. Ft. Lt. Ft. of ¢
Collar Elevation: Reference:
Field Party: Rig:

Hole No: 4 | Sheet 6 of 9
Total Depth: 183 | Hole Dia.:
Hole Log By: Gealek
Type of Structure:
Notes:

Ground Water Data		
Depth in ft.		
Time		
Date		

Drilling Method: Rotary Tri-cone (100–120)
Casing Size: NX
Columns: Drilling Method | Depth in Feet | Casing Size | Blows/Ft. Depth | Sample Data: Method | Sample No | Blow Count | Loc. Sampled | Recovery | Frozen | Soil Graph

Depth in Feet	SUBSURFACE MATERIAL	DRILLING NOTES
100	SANDY GRAVEL w/ ...	
101		
102	Occ. lenses sandy silt, silty sand	
103		
104		
105		
106		
107		
108		
109		drill ahead to 133'
110		
111		NX to 128'
112		
113		
114		
115		
116		
117		
118		
119		
120		

186

Note: Unless otherwise noted all samples are taken w/ 1.4" ID Standard Penetration Sampler driven w/ 140 lb hammer w/ 30" drop.

STATE OF ALASKA
DEPARTMENT OF HIGHWAYS
Engineering Geology Section
Box F, College, Alaska
LOG OF TEST BORING

Project Name: CORE
Project No:
Bridge No:
Date Begin:
End:
Weather:
Hole No: 4
Sheet 2 of 9
Total Depth: 183
Hole Dia.:
Hole Log By: GRALEK
Type of Structure:
Hole Station: Rt. Ft. Lt. Ft. of ℄
Collar Elevation: Reference:
Field Party: Rig:
Notes:

Ground Water Data		
Depth in ft.		
Time		
Date		

Drilling Method: ROTARY TRI-CONE (120–140)
Casing Size: NX

Depth in Feet	Subsurface Material	Drilling Notes
120	SANDY GRAVEL W/SILT	
121		
122	OCC. LAYERS SAND, SILT, SILTY SAND	
123		
124		
125		
126		
127		
128		drill ahead to 158'
129		
130		NX to 150'
131		
132		
133		
134		
135		
136		
137		
138		
139		
140		

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Note: Unless otherwise noted all samples are taken W/1.4" ID Standard Penetration Sampler driven W/140 lb hammer W/30" drop.

Project Name: CORE
Project No:
Bridge No:
Date Begin:
End:

STATE OF ALASKA
DEPARTMENT OF HIGHWAYS
Engineering Geology Section
Box F, College, Alaska
LOG OF TEST BORING

Hole No: 4 | Sheet 8 of 9
Total Depth: 183 | Hole Dia.:
Hole Log By: Gralek
Type of Structure:

Weather:
Hole Station: Rt. Ft. Lt. Ft. of ¢
Collar Elevation: Reference:
Field Party: Rig:

Notes:

Ground Water Data		
Depth in ft.		
Time		
Date		

Drilling Method	Depth in Feet	Casing Size: NX	Blows/Ft. Depth	Method	Sample No	Blow Count	Loc. Sampled	Recovery	Frozen	Soil Graph	SUBSURFACE MATERIAL	DRILLING NOTES
Rotary Tri-Cone	140										Sandy gravel w/silt	
	141											
	142										occ. lenses sandy silt, silty sand	
	143											
	144											
	145											
	146											
	147											
	148											
	149											
	150											5 May 75 #6 hrs cleaning drill ahead to 170'
	151											
	152											
	153											
	154											
	155											
	156											
	157											
	158											
	159											
	160											

Note: Unless otherwise noted all samples are taken W/1.4" ID Standard Penetration Sampler driven W/140 lb hammer W/30" drop.

Project Name: CORF		STATE OF ALASKA DEPARTMENT OF HIGHWAYS Engineering Geology Section Box F, College, Alaska **LOG OF TEST BORING**	Hole No: 4	Sheet 9 of 9
Project No:	Bridge No:		Total Depth: 183	Hole Dia:
Date Begin:	End:		Hole Log By: GEALEK	
Weather:			Type of Structure:	

Hole Station: Rt. Ft. Lt. Ft. of ℄

Collar Elevation: Reference:

Field Party: Rig:

Notes:

Ground Water Data

Depth in ft.		
Time		
Date		

Columns: Drilling Method | Depth in Feet | Casing Size: / Blows/Ft. Depth | Sample Data: Method, Sample No, Blow Count, Loc. Sampled, Recovery | Frozen | Soil Graph | SUBSURFACE MATERIAL | DRILLING NOTES

Drilling Method	Depth in Feet	Subsurface Material	Drilling Notes
Rotary – Tri-Cone (160–180)	160	Sandy gravel w/silt	
	161		
	162	OCC. LAYERS Sand, silt & silty sand	
	163		
	164		
	165		
	166		
	167		
	168		
	169		Tried to install thermistor
	170		cable – hole caved to ±160
	171		pulled cable – mix to 155'
	172		drill out & ahead to 183'
	173		put in cable – hole caved @ ±162' again
	174		
	175		
	176		
	177		
	178		
	179		
	180	Sand to 183'	T.D.=183'

189

Note: Unless otherwise noted all samples are taken W/1.4" ID Standard Penetration Sampler driven W/ 140 lb hammer W/30" drop.

STATE OF ALASKA
DEPARTMENT OF HIGHWAYS
Engineering Geology Section
Box F, College, Alaska

LOG OF TEST BORING

Project Name: CORE
Project No:
Bridge No:
Date Begin: 6 MAY 75
End: 7 MAY 75
Weather: +30 FOG

Hole No: 5
Sheet 1 of 2
Total Depth: 20'
Hole Dia.: 6"
Hole Log By: GRAHEK
Type of Structure:

Hole Station: Rt. Ft. Lt. Ft. of ℄
Collar Elevation: Reference:
Field Party: GRAHEK, WALDEN, MARTHA, HARRISON
Rig: 05431

Notes: ±5' from Boring 1

Ground Water Data

Depth in ft.		
Time		
Date		

Drilling Method: 6" Cont. Flt. Solid Auger

Depth in Feet	Method	Sample No	Blow Count	Subsurface Material	Drilling Notes
0				1" MOSS; 1" SAND; ORG. SILT w/SAND	
1					SAMPLES to 9.5' IN BORING 1
2				V. ICE Rich Silt TR. F. SAND	
9				LESS ICE	AUGER to 9.5'
10			87, 90, 200/3"	ICE F. SAND	SAMPLE; AUGER to 11'
11			132, 200		SAMPLE; AUGER to 12½'
12–14			150, 63, 130, 200/4"	V. LITTLE SEG. ICE	SAMPLE; AUGER to 15½'
15–16			140, 200/3"	TR. F. GRAVEL	AUGER to 17½
17					
18–19				SILTY SAND	SAMPLE METHOD [illegible]
20					AUGER to 21½

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Note: Unless otherwise noted all samples are taken W/1.4" ID Standard Penetration Sampler driven W/140 lb hammer W/30" drop.

STATE OF ALASKA
DEPARTMENT OF HIGHWAYS
Engineering Geology Section
Box F, College, Alaska
LOG OF TEST BORING

Project Name: CORE
Project No: | Bridge No:
Date Begin: 6 MAY 75 | End:
Weather: +30 FOG

Hole No: 5 | Sheet 2 of 2
Total Depth: 40' | Hole Dia.:
Hole Log By: Grahek
Type of Structure:

Hole Station: Rt. Ft. Lt. Ft. of ℄
Collar Elevation: Reference:
Field Party: Rig:

Notes:

Ground Water Data		
Depth in ft.		
Time		
Date		

Drilling Method	Depth in Feet	Casing Size: Blows/Ft., Depth	Sample Method	Sample No	Blow Count	Loc. Sampled	Recovery	Frozen	Soil Graph	SUBSURFACE MATERIAL	DRILLING NOTES
6" Cont'Flt. Solid Auger (20–40)	20										
	21									Silty SAND TR. F. GRAVEL	SAmple
	22		2" (OD)	50/3.5	350	X					7 MAY 75
	23									becoming more gravelly	Auger to 24½
	24										Sample
	25		↓	50/4.5	250	X				SANDy GRAVEL	18" Fill-in - clean thaw
										w/silt TR. org	
	26										Auger to 27½'
	27										Sample
	28		↓	50/2.5	350	X				sample in jar	40" Fill-in - dense thaw
	29										Auger to 40'
	30–39										
	40									T.D. = 40'	

Note: Unless otherwise noted all samples are taken W/1.4" ID Standard Penetration Sampler driven W/140 lb hammer W/30" drop.

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LOG OF TEST BORING

Project Name: CORE
Project No:
Bridge No:
Date Begin: 7 Mar 75
End: 19 Mar 75
Weather: Fog
Hole No: 6
Sheet 1 of 8
Total Depth: 150
Hole Dia.: 3"
Hole Log By:
Type of Structure:
Hole Station: Rt. Ft. Lt. Ft. of ℄
Collar Elevation: Reference:
Field Party: Rig:

Notes: ±2 mi. out from end of dock

Ground Water Data

Depth in ft.	2.0
Time	
Date	

Drilling Method: Rotary Tri-Cone 7 6" Cast ...

Depth in Feet	Sample No	Subsurface Material	Drilling Notes
0–6		ICE	2: auger through ICE
6–9.5		WATER	9: Push Shelby into bottom
9.5		Silty SAND black w/ org.	
11			NX to 12' (push)
12			drill to 12'; pushed Shelby
14			NX to 14.5
15		becoming coarser	drill to 14.5; push Shelby
16			NX to 17"
17			drill to 17'; push Shelby
19			NX to 19.5'
19.5		... Gravel	drill out to 19.5; push Shelby

192

Note: Unless otherwise noted all samples are taken W/1.4" ID Standard Penetration Sampler driven W/ 140 lb hammer W/30" drop.

Project Name: CORE

Project No: Bridge No:

Date Begin: End:

Weather:

Hole Station: Rt. Ft. Lt. Ft. of ℄

Collar Elevation: Reference:

Field Party: Rig:

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LOG OF TEST BORING

Hole No: 6 Sheet 2 of 8

Total Depth: Hole Dia.:

Hole Log By: Grahek

Type of Structure:

Notes:

Ground Water Data

Depth in ft.		
Time		
Date		

Drilling Method: Rotary, Tri-Cone

Casing Size: NX

Depth in Feet	Blows/Ft. Depth	Sample No	Blow Count	Subsurface Material	Drilling Notes
20		6-20/5		Silty SAND (Black) Tr. F. Gravel	NX to 22'
21				Tr. Org.	drill out to 22'
22				—	Push Shelby
23		6-5022		—	NX to 24½'
24				—	drill out to 24½
25		6-5024.5		Occ. Ang. gravel	Push Shelby
26				—	NX to 27 / drill to 27'
27		6-5027		—	Push Shelby
28				—	NX to 29½'
29				—	drill to 29½'
30	2' (30')	6-5029.5	3 / 5 / 7	Sample washed	Sample - 7" Fill in
31	30			—	NX to 32½'
32	17			—	Sample - 12" Fill in / NX went down 4" w/sampler
33		6-5032.5	10 / 9 / 8	Most of sample washed	NX to 35'
34	22			—	drill out to 35'
35		6-5035	5	—	Sample
36				—	5' Fill in - v. soft - [illegible]
37				—	NX to 40
38	27			—	drill out to 40'
39	37			—	
40				—	

Note: Unless otherwise noted all samples are taken W/1.4" ID Standard Penetration Sampler driven W/140 lb hammer W/30" drop.

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LOG OF TEST BORING

Project Name: CORE
Project No:
Bridge No:
Date Begin:
End:
Weather:
Hole Station: Rt. Ft. Lt. Ft. of ¢
Collar Elevation: Reference:
Field Party: Rig:

Hole No: 6 Sheet 3 of 8
Total Depth: Hole Dia.:
Hole Log By: GRAHEK
Type of Structure

Notes:

Ground Water Data

Depth in ft.		
Time		
Date		

Drilling Method	Depth in Feet	Casing Size: NX Blows/Ft. Depth	Sample Method	Sample No	Blow Count	Loc. Sampled	Recovery	Frozen	Soil Graph	SUBSURFACE MATERIAL	DRILLING NOTES
Rotary Tri-cone	40		2"	6040	6	X				Silty sand w/ tr. gravel occ. tr. org. — No recovery	Sample 12" Fill-in - drove then
	41				6	X					
					5	X					NX to 45'
	42	50									drill to 45'
	43	58									
	44	65									
	45			6045	8	X				Samples in 2 jars	Sample 1" Fill in
	46				7	X					
					6	X					NX to 55'
	47	75									drill out to 55'
	48	59									
	49	58									
	50	49									
	51	38									
	52	37									
	53	39									
	54	53								Sandy gravel w/ silt	
	55			6055	10	X					Sample - 2" Fill in
	56				10	X					
					10	X					NX to 65'
	57	98									drill out to 65'
	58	98									
	59	96									
	60										

Note: Unless otherwise noted all samples are taken W/1.4" ID Standard Penetration Sampler driven W/ 140 lb hammer W/30" drop.

Project Name: CORE	Project No:
Bridge No:	Date Begin:
End:	Weather:

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LOG OF TEST BORING

Hole No: 6 | Sheet 4 of 8
Total Depth: | Hole Dia.:
Hole Log By: Gazhek
Type of Structure:

Hole Station: Rt. Ft. Lt. Ft. of ¢
Collar Elevation: Reference:
Field Party: Rig:

Notes:

Ground Water Data		
Depth in ft.		
Time		
Date		

Drilling Method: Rotary / Tri-Cone

Depth in Feet	Casing Size: Blows/Ft., Depth	Method	Sample No	Blow Count	Loc. Sampled	Recovery	Frozen	Subsurface Material	Drilling Notes
60	83							Sandy gravel 10/5, 1+	
61	105								
62	95								
63	70								
64	75								SAMPLE Placed temp. probe in hole caved 5'- left there
65		(3W)	6055	9	X				+2" ROCKS STUCK IN JAR IN shoe 9 May 75 +28°Lt.82 O.C.
66				8	X				NX to 75'
67	60			6					drill out to 75'
68	68								
69	60								
70	57								
71	59								
72	47								
73	47								
74	50								
75									Inserted temp probe to 76.5'
76		Temp			X				
77	72								NX to 85'
78	75								drill out to 85'
79	92								
80									

Note: Unless otherwise noted all samples are taken W/1.4" ID Standard Penetration Sampler driven W/140 lb hammer W/30" drop.

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LOG OF TEST BORING

Project Name: CORE
Project No:
Bridge No:
Date Begin:
End:
Weather:
Hole No: 6
Sheet 5 of 8
Total Depth:
Hole Dia.:
Hole Log By: Seahek
Type of Structure:
Hole Station: Rt. Ft. Lt. Ft. of ¢
Collar Elevation: Reference:
Field Party: Rig:
Notes:

Ground Water Data		
Depth in ft.		
Time		
Date		

Drilling Method: Rotary / TRI-CONE (80–100)

Casing Size: NX

Depth in Feet	Blows/Ft. Depth	Method	Sample No	Blow Count	Soil Graph	Subsurface Material	Drilling Notes
80	158				o./.	SANDY GRAVEL w/silt	
81	265						
82	265						
83	260						
84	196						
85		2"(342)	6085	19 / 17 / 17		2 JARS	SAmple
86							NX to 90'
87	165						drill out & Ahead to 93'
88	140						
89	133						
90							Losing mud below NX
91							NX to 100'
92							
93	125						drill out to 100'
94	135						
95	118						Lose water @ bottom of NX
96	138						
97	146						
98	176						
99	193						
100							

Note: Unless otherwise noted all samples are taken w/1.4" ID Standard Penetration Sampler driven w/140 lb hammer w/30" drop.

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LOG OF TEST BORING

Project Name: CORE
Project No: Bridge No:
Date Begin: End:
Weather:
Hole No: 6 Sheet 6 of 8
Total Depth: Hole Dia.:
Hole Log By: GEAKEK
Type of Structure:
Hole Station: Rt. Ft. Lt. Ft. of ℄
Collar Elevation: Reference:
Field Party: Rig:
Notes:

Ground Water Data

Depth in ft.		
Time		
Date		

Drilling Method: ROTARY TRI-CONE (100–120)
Casing Size: NX

Depth in Feet	Blows/Ft., Depth	Soil Graph	Subsurface Material	Drilling Notes
100	120		SANDY GRAVEL w/SILT	NX to 105'
101	148			drill out to 105'
102	115			
103	119			
104	212			
105	120			10' Fill-in after pulling bit; NX to 110'
106	130			
107	157			
108	158			drill out to 110'
109	188			10 MAY 75 +25 clr.
110	135			NX to 115
111	218			drill out & ahead to 125
112	270			Losing water below NX
113	325			
114	342			NX to 130'
115				
116				
117				
118				
119				
120				

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Note: Unless otherwise noted all samples are taken w/ 1.4" ID Standard Penetration Sampler driven w/ 140 lb hammer w/ 30" drop.

Project Name: CORE | **Project No:** | **Bridge No:** | **Date Begin:** | **End:** | **Weather:**

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LOG OF TEST BORING

Hole No: 6 | **Sheet** 7 **of** 8
Total Depth: | **Hole Dia.:**
Hole Log By: Gerthek.
Type of Structure:

Hole Station: . Rt. Ft. Lt. Ft. of ℄
Collar Elevation: **Reference:**
Field Party: **Rig:**

Notes:

Ground Water Data		
Depth in ft.		
Time		
Date		

Drilling Method: Rotary - Tri-cone (120–140)

Casing Size: NX

Depth in Feet	Blows/Ft. Depth	Method	Sample No	Blow Count	Loc. Sampled	Recovery	Frozen	Soil Graph	Subsurface Material	Drilling Notes
120	↓							o / .	sandy gravel w/silt	drill out to 130'
121	156									
122	174									
123	178									
124	[illegible]									
125	136									
126	143									
127	2?5									
128	[illegible]									
129	[illegible]									drill ahead to 133'
130	↓									NX to 135'
131										drill out & ahead to 143'
132	↓									
133	380									Lose water below NX
134	525									
135										
136										NX to 145
137										
138										
139	↓								↓	
140										

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Note: Unless otherwise noted all samples are taken W/1.4" ID Standard Penetration Sampler driven W/140 lb hammer W/30" drop.

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LOG OF TEST BORING

Project Name: CORE
Project No: Bridge No:
Date Begin: End:
Weather:
Hole Station: Rt. Ft. Lt. Ft. of ℄
Collar Elevation: Reference:
Field Party: Rig:

Hole No: 6 Sheet 8 of 8
Total Depth: Hole Dia:
Hole Log By: GRAHEK
Type of Structure:
Notes:

Ground Water Data		
Depth in ft.		
Time		
Date		

Drilling Method	Depth in Feet	Casing Size: NX / Blows/Ft., Depth	Sample Data: Method	Sample No	Blow Count	Loc. Sampled	Recovery	Frozen	Soil Graph	SUBSURFACE MATERIAL	DRILLING NOTES
Rotary Tricone (140–150)	140								o.o	SANDy GRAVEL w/ Silt	
	141										
	142										drill out & Ahead to 148'
	143	↓									Lose WATER below NX
	144	319									
	145	301									NX to 147½'
	146										drill out & Ahead to 150'
	147										NX to 150'
	148										14 MAY 75 +25 clr 20-25 mph
	149										drill out to 150'
	150									T.D. = 150'	installed pipe to ±147'
	151										
	152										After pulling NX, DISTANCE top of ice to Mudline = 8.5'
	153										
	154										
	155										
	156										
	157										
	158										
	159										
	160										

Note: Unless otherwise noted all samples are taken W/ 1.4" ID Standard Penetration Sampler driven W/ 140 lb hammer W/ 30" drop.

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LOG OF TEST BORING

Project Name: CORE
Project No:
Bridge No:
Date Begin: 15 Mar 75
End: 15 Mar 75
Weather: +20 Clr Lt. Br.

Hole No: P7
Sheet 1 of 1
Total Depth: 55'
Hole Dia.: 2 7/8
Hole Log By: Chalek
Type of Structure:

Hole Station: Rt. Ft. Lt. Ft. of ℄
Collar Elevation: Reference:
Field Party: [illegible] Rig: CS 431

Notes: @ "E"

Ground Water Data		
Depth in ft.		
Time		
Date		

Drilling Method: BW Rod driven w/ 340# hammer 30" drop

Columns: Drilling Method | Depth in Feet | Casing Size: | Blows/Ft. Depth | Sample Data: Method | Sample No | Blow Count | Loc. Sampled | Recovery | Frozen | Soil Graph | Subsurface Material | Drilling Notes

Subsurface Material						Drilling Notes
0/1	11	20/21	16	40/41	18	
2	22	22	18	42	21	
3	38	23	17	43	22	
4	40	24	13	44	25	
5	32	25	15	45	24	
6	20	26	16	46	29	
7	5	27	16	47	32	
8	6	28	19	48	36	
9	17	29	12	49	49	
10	20	30	14	50	55	
11	17	31	14	51	45	
12	21	32	19	52	36	
13	20	33	16	53	46	
14	19	34	22	54	61	
15	20	35	25	55	50	
16	17	36	18	56		T.D. = 55'
17	21	37	31	57		
18	27	38	25	58		
19	18	39	20	59		
20	21	40	21	60		200

Note: Unless otherwise noted all samples are taken w/ 1.4" ID Standard Penetration Sampler driven w/ 140 lb hammer w/ 30" drop.

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LOG OF TEST BORING

Project Name: CCRE
Project No: Bridge No:
Date Begin: 15 Mar 75   End: 15 Mar 75
Weather: +25° Clr Lt. Br.

Hole No: P8   Sheet 1 of 1
Total Depth: 55   Hole Dia: 2 3
Hole Log By: Grerick
Type of Structure:

Hole Station: Rt.   Ft. Lt.   Ft. of ℄
Collar Elevation: Reference:
Field Party: [illegible]   Rig: [illegible]

Notes: 300-400 yds So. of 'E'

Drilling Method: Blu Rod/Drive w/312# Hammer 30" Drop

Ground Water Data		
Depth in ft.		
Time		
Date		

Columns: Drilling Method | Depth in Feet | Casing Size: Blows/Ft. Depth | Sample Data: Method, Sample No, Blow Count, Loc. Sampled, Recovery, Frozen | Soil Graph | SUBSURFACE MATERIAL | DRILLING NOTES

						Drilling Notes
0-1	—	20-21	19	40-41	29	
2	42	22	18	42	31	
3	36	23	18	43	31	
4	29	24	21	44	33	
5	30	25	15	45	31	
6	15	26	16	46	25	
7	15	27	19	47	30	
8	15	28	22	48	34	
9	27	29	19	49	43	
10	38	30	17	50	51	
11	27	31	15	51	47	
12	25	32	11	52	44	
13	29	33	14	53	37	
14	30	34	19	54	39	
15	29	35	29	55	42	
16	29	36	32	56		T.D. = 55'
17	26	37	36	57		Installed 3/4 pipe to ±41'
18	25	38	34	58		
19	25	39	29	59		
20	23	40	30	60		

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Note: Unless otherwise noted all samples are taken W/1.4" ID Standard Penetration Sampler driven W/140 lb hammer W/30" drop.

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LOG OF TEST BORING

Project Name: CORE
Project No: Bridge No:
Date Begin: 15 May 75 End: 15 May 75
Weather: +22 Clr. Lt. Br.

Hole No: P9 Sheet 1 of 1
Total Depth: 11 Hole Dia: 2 7/8
Hole Log By: Graber
Type of Structure:

Hole Station: Rt. Ft. Lt. Ft. of ℄
Collar Elevation: Reference:
Field Party: [illegible] Rig: 05431

Notes: NEAR 3, 3A, 4

Ground Water Data		
Depth in ft.		
Time		
Date		

Drilling Method: BW Drill Ed driven w/342# hammer, 30" drop

Columns: Drilling Method | Depth in Feet | Casing Size: Blows/Ft. Depth | Sample Data: Method | Sample No | Blow Count | Loc. Sampled | Recovery | Frozen | Soil Graph | SUBSURFACE MATERIAL | DRILLING NOTES

SUBSURFACE MATERIAL			DRILLING NOTES
0 1	8	20 21	—
2	32	22	—
3	57	23	—
4	42	24	—
5	50	25	—
6	68	26	—
7	93	27	—
8	98	28	—
9	*137	29	—
10	*120	30	—
11	*266	31	— T.D. = 11'
12		32	—
13		33	—
14		34	—
15		35	—
16		36	—
17		37	—
18		38	—
19		39	* Marty
20		40	—

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Note: Unless otherwise noted all samples are taken w/1.4" ID Standard Penetration Sampler driven w/140 lb hammer w/30" drop.

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LOG OF TEST BORING

Project Name: CORE
Project No: | Bridge No:
Date Begin: 15 MAY 75 | End: 15 MAY 75
Weather: +27° Clr. Lt. Br.

Hole No: P10 | Sheet 1 of 1
Total Depth: 10' | Hole Dia: 2½
Hole Log By: Gerhek
Type of Structure:

Hole Station: Rt. Ft. Lt. Ft. of ℄
Collar Elevation: Reference:
Field Party: Gerhek, Wilder, [illegible] Rig: 25431

Notes: Between P8 & P9

Ground Water Data: Depth in ft. / Time / Date

Drilling Method: BW Drill rod driven w/340# hammer, 30" drop

Columns: Drilling Method | Depth in Feet | Casing Size: Blows/Ft., Depth | Sample Data: Method, Sample No, Blow Count, Loc. Sampled, Recovery, Frozen | Soil Graph

SUBSURFACE MATERIAL | DRILLING NOTES

0 1	22	20 21	40 41	—
2	44	22	42	—
3	75	23	43	—
4	165	24	44	—
5	225	25	45	—
6	68	26	46	—
7	86	27	47	—
8	85	28	48	—
9	183	29	49	—
10	322	30	50	—
11		31	51	—
12		32	52	—
13		33	53	—
14		34	54	—
15		35	55	—
16		36	56	—
17		37	57	—
18		38	58	—
19		39	59	—
20		40	60	—

T.D. = 10'

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Note: Unless otherwise noted all samples are taken w/1.4" ID Standard Penetration Sampler driven w/140 lb hammer w/30" drop.

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LOG OF TEST BORING

Project Name: CORE
Project No: | Bridge No:
Date Begin: 15 May 75 | End: 15 May 75
Weather: +28° CLR Lt. BR.

Hole No: P11 | Sheet 1 of 1
Total Depth: 15'7" | Hole Dia: 2 1/8
Hole Log By: Gealek
Type of Structure:

Hole Station: Rt. Ft. Lt. Ft. of ℄
Collar Elevation: Reference:
Field Party: Gealek, Walden, Martin, Harrison, Overcash | Rig: [illegible]

Notes: Between P8 & P10

Ground Water Data		
Depth in ft.		
Time		
Date		

Columns: Drilling Method | Depth in Feet | Casing Size: Blows/Ft., Depth | Sample Data: Method, Sample No, Blow Count, Loc. Sampled, Recovery | Frozen | Soil Graph | SUBSURFACE MATERIAL | DRILLING NOTES

Drilling Method (written vertically): BW Rod driven w/ 342# hammer, 30" drop

SUBSURFACE MATERIAL:

0 / 1	16	20 / 21		40 / 41	
2	65	22		42	
3	220	23		43	
4	244	24		44	
5	93	25		45	
6	46	26		46	
7	31	27		47	
8	57	28		48	
9	68	29		49	
10	31	30		50	
11	42	31		51	
12	48	32		52	
13	70	33		53	
14	52	34		54	
15	82	35		55	
16	400/7"	36		56	T.D. = 15'7"
17		37		57	
18		38		58	
19		39		59	
20		40		60	

Note: Unless otherwise noted all samples are taken w/ 1.4" ID Standard Penetration Sampler driven w/ 140 lb hammer w/ 30" drop.

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LOG OF TEST BORING

Project Name: CORE
Project No:
Bridge No:
Date Begin: 5 [illegible] 75
End: 16 MA 75
Weather: [illegible]

Hole No: P12
Sheet 1 of 1
Total Depth: 70'4"
Hole Dia.: 2 [illegible]
Hole Log By: [illegible]
Type of Structure:

Hole Station: Rt. Ft. Lt. Ft. of ℄
Collar Elevation: Reference:
Field Party: [illegible] Rig: 05431

Notes: Just So. of P8

Ground Water Data

Depth in ft.		
Time		
Date		

Column headings: Drilling Method | Depth in Feet | Casing Size: Blows/Ft. / Depth | Sample Data: Method, Sample No, Blow Count, Loc. Sampled, Recovery | Frozen | Soil Graph | SUBSURFACE MATERIAL | DRILLING NOTES

Drilling Method: EW Rod driven w/ 342 # hammer, 30" drop

SUBSURFACE MATERIAL:

0 / 1	9	20 / 21	17	40 / 41	36	60 / 61	57	
2	41	22	19	42	38	62	47	
3	82	23	20	43	35	63	54	
4	66	24	22	44	46	64	44	
5	48	25	21	45	96	65	39	
6	24	26	24	46	105	66	51	
7	22	27	28	47	124	67	50	
8	22	28	38	48	150	68	42	
9	27	29	59	49	98	69	51	
10	34	30	80	50	88	70	135	
11	29	31	53	51	61	71	188/4"	T.D.=70'4"
12	30	32	49	52	57	72		
13	27	33	43	53	70	73		21.4m
14	27	34	47	54	56	74		
15	35	35	48	55	68	75		
16	27	36	44	56	41	76		
17	29	37	59	57	38	77		
18	30	38	57	58	45	78		
19	34	39	57	59	40	79		
20	35	40	56	60	54	80		205

Note: Unless otherwise noted all samples are taken w/ 1.4" ID Standard Penetration Sampler driven w/ 140 lb hammer w/ 30 drop.

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Box F, College, Alaska
LOG OF TEST BORING

Project Name: CORE
Project No:
Bridge No:
Date Begin: 17 MAY 75 End: 17 MAY 75
Weather: +22 O.C. LT. BZ.
Hole No: 13 Sheet 1 of 5
Total Depth: 93
Hole Dia.: 3"
Hole Log By: Gaalek
Type of Structure:
Hole Station: Rt. Ft. Lt. Ft. of ℄
Collar Elevation: Reference:
Field Party: Gaalek, Waldon, Manthe, ... Rig: 05431

Notes: ±20' So. P12

Ground Water Data

Depth in ft.	13"
Time	0900
Date	17 MAY 75

Drilling Method	Depth in Feet	Casing Size: NX / Blows/Ft. Depth	Method	Sample No	Blow Count	Loc. Sampled	Recovery	Frozen	Soil Graph	SUBSURFACE MATERIAL	DRILLING NOTES
Rotary thru CONE 6" C.F.S. 1 ft Auger	0–5								*	ICE	Auger to 68"
	5									Some WATER seeping in @ CONTACT	
	6–7		2½" Shelby	13S5.5–8	Push					Silty SAND	Push Shelby
	7–8										NX to 8'
	8–9			13S08	Push						drill out to 8' push shelby
	10									sand, gravel w/silt — not frozen below 10'	NX to 10½' ; drill out to 10½' ; NX not clean - NX fell to 11.5 drill out to 11.8
	12–14			13S11.8	Push						NX to 14'
	14–16			13S14	Push					no Recovery	drill out to 14 push shelby ; 17 MAY 75 +23 Lt. Snow
	17										NX to 20'
	17–18	15									drill out to 20'
	18–19	26									
	19–20	29									

Project Name: CORE

Project No: | Bridge No:

Date Begin: | End:

Weather:

STATE OF ALASKA
DEPARTMENT OF HIGHWAYS
Engineering Geology Section
Box F, College, Alaska
LOG OF TEST BORING

Hole No: 13 | Sheet 2 of 5

Total Depth: | Hole Dia:

Hole Log By: GRANEK

Type of Structure:

Hole Station: Rt. Ft. Lt. Ft. of ℄

Collar Elevation: Reference:

Field Party: Rig:

Notes:

Ground Water Data		
Depth in ft.		
Time		
Date		

Drilling Method	Depth in Feet	Casing Size: 1½ Blows/Ft. Depth	Sample Method	Sample No	Blow Count	Loc. Sampled	Recovery	Frozen	Soil Graph	SUBSURFACE MATERIAL	DRILLING NOTES
Rotary/Tri-Cone	20		2" (3942)	13020	5	X				Sandy gravel w/silt 22.5 in lar	NX to 30'
					4	X					
	21				3						
	22	10									drill out to 30'
	23	22									
	24	37									
	25	34									
	26	52									
	27	52									
	28	56									
	29	54									Sample
	30			13030	9	X				31 in lar	
					9	X					
	31				9						
	32	54									NX to 40'
	33	49									
	34	56									drill out to 40'
	35	57									
	36	55									
	37	51									
	38	57									
	39	54									
	40										

Note: Unless otherwise noted all samples are taken W/1.4" ID Standard Penetration Sampler driven W/140 lb hammer W/30" drop.

STATE OF ALASKA
DEPARTMENT OF HIGHWAYS
Engineering Geology Section
Box F, College, Alaska

LOG OF TEST BORING

Project Name: CORE
Project No: Bridge No:
Date Begin: End:
Weather:
Hole Station: Rt. Ft. Lt. Ft. of ℄
Collar Elevation: Reference:
Field Party: Rig:

Hole No: 13 Sheet 3 of 5
Total Depth: Hole Dia.:
Hole Log By: Grahek
Type of Structure:

Notes:

Ground Water Data

Depth in ft.		
Time		
Date		

Drilling Method	Depth in Feet	Casing Size: NX / Blows/Ft., Depth	Sample Data: Method	Sample No	Blow Count	Loc. Sampled	Recovery	Frozen	Soil Graph	SUBSURFACE MATERIAL	DRILLING NOTES
Rotary TRI-CONE	40		2" (SS)	13040	9, 8, 6					SAND, GRAVEL (GRAVELLY SAND) WET 41' in JAR	
	41										NX to 50'
	42	68									
	43	70									drill out to 50'
	44	120									
	45	100									
	46	90									
	47	90									
	48	72									
	49	92									sample
	50			13050	10, 11, 10					51' in JAR	
	51										NX to 60
	52	90									
	53	106									
	54	107									DRill out to 60'
	55	72									
	56	68									
	57	75									
	58	80									
	59	123									208
	60										

Note: Unless otherwise noted all samples are taken w/1.4" ID Standard Penetration Sampler driven w/140 lb hammer w/30" drop.

STATE OF ALASKA
DEPARTMENT OF HIGHWAYS
Engineering Geology Section
Box F, College, Alaska
LOG OF TEST BORING

Project Name: CORE
Project No: Bridge No:
Date Begin: End:
Weather:
Hole Station: Rt. Ft. Lt. Ft. of ℄
Collar Elevation: Reference:
Field Party: Rig:

Hole No: 13 Sheet 4 of 5
Total Depth: Hole Dia.:
Hole Log By: GRZEK
Type of Structure:
Notes:

Ground Water Data

Depth in ft.		
Time		
Date		

Drilling Method: ROTARY TRI-CONE (60–80)

Depth in Feet	Casing Size NX / Blows/Ft. Depth	Method	Sample No	Blow Count	Loc. Sampled	Recovery	Frozen	Soil Graph	Subsurface Material	Drilling Notes
60			13068	7 / 10 / 11					SANDY GRAVEL W/SILT — 60' IN JAR	SAMPLE
61										
62	72									NX to 69'5"
63	77									
64	72									drill out to 69.4'
65	75									
66	114									
67	125									
68	148								FROZEN	
69	200 / 5"		13069	133 / 77 / 88					69.9 IN JAR	SAMPLE
70										drill ahead to 80'. LOSE ±75% WATER BELOW NX PROB. NO SEAL IN FROST
71										
72										NX to 80'
73										
74										
75										drill out to 80'
76										
77										
78										
79										
80										

209

Note: Unless otherwise noted all samples are taken W/1.4" ID Standard Penetration Sampler driven W/140 lb hammer W/30" drop.

STATE OF ALASKA
DEPARTMENT OF HIGHWAYS
Engineering Geology Section
Box F, College, Alaska
LOG OF TEST BORING

Project Name: CORE
Project No:
Bridge No:
Date Begin:
End:
Weather:
Hole No: 13
Sheet 5 of 5
Total Depth: 93
Hole Dia.:
Hole Log By: GRALEK
Type of Structure:
Hole Station: Rt. Ft. Lt. Ft. of ℄
Collar Elevation: Reference:
Field Party: Rig:
Notes:

Ground Water Data	
Depth in ft.	5.5
Time	0445
Date	12 MA 75

Drilling Method	Depth in Feet	Casing Size	Blows/Ft., Depth	Method	Sample No	Blow Count	Loc. Sampled	Recovery	Frozen	Soil Graph	SUBSURFACE MATERIAL	DRILLING NOTES
Rotary Tri-Cone (80–93)	80			2" (SPT)	13080	53					Sandy gravel w/silt	Sample 12 MA 75 +22° PC LT BR.
	81					107						
	82					280						drill ahead to 93'
	83											
	84											
	85											
	86											
	87											
	88											
	89											
	90											
	91											
	92											
	93										T.D. = 93'	
	94											INSTALL 3/4" pipe to 89.9 w/±57" STICK UP
	95											Also Tell 15' NX in hole w/1" STICK UP
	96											
	97											
	98											
	99											
	100											

Note: Unless otherwise noted all samples are taken w/1.4" ID Standard Penetration Sampler driven w/140 lb hammer w/30" drop.

Project Name: CORE

Project No: | Bridge No:

Date Begin: [illegible] | End: [illegible]

Weather: [illegible]

STATE OF ALASKA
DEPARTMENT OF HIGHWAYS

Engineering Geology Section
Box F, College, Alaska

LOG OF TEST BORING

Hole No: 14 | Sheet 1 of 2

Total Depth: 40' | Hole Dia: 5"

Hole Log By: Grahek

Type of Structure:

Hole Station: Rt. Ft. Lt. Ft. of ¢

Collar Elevation: Reference:

Field Party: [illegible] Rig: 25A31

Notes:

Ground Water Data		
Depth in ft.		
Time		
Date		

Depth in Feet	Subsurface Material	Drilling Notes
0	1" sod	
1	silt w/sand	auger to 40'
2		
3	V. ICE rich	
4		
5		
6		
7		
8		
9		
10		
11		
12	silty sand	
13		
14		
15		
16	sandy gravel w/silt	
17		
18		
19		
20		

Column headings: Drilling Method | Depth in Feet | Casing Size: Blows/Ft. Depth | Sample Data: Method, Sample No, Blow Count, Loc. Sampled, Recovery | Frozen | Soil Graph | Subsurface Material | Drilling Notes

[illegible]

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Note: Unless otherwise noted all samples are taken w/1.4" ID Standard Penetration Sampler driven w/140 lb hammer w/30" drop.

Project Name: CORE
Project No:
Bridge No:
Date Begin:
End:
Weather:
Hole Station: Rt. Ft. Lt. Ft. of ℄
Collar Elevation: Reference:
Field Party: Rig:

STATE OF ALASKA DEPARTMENT OF HIGHWAYS

Engineering Geology Section
Box F, College, Alaska

LOG OF TEST BORING

Hole No: 12 Sheet 2 of 2
Total Depth: Hole Dia.:
Hole Log By: [illegible]
Type of Structure:

Notes:

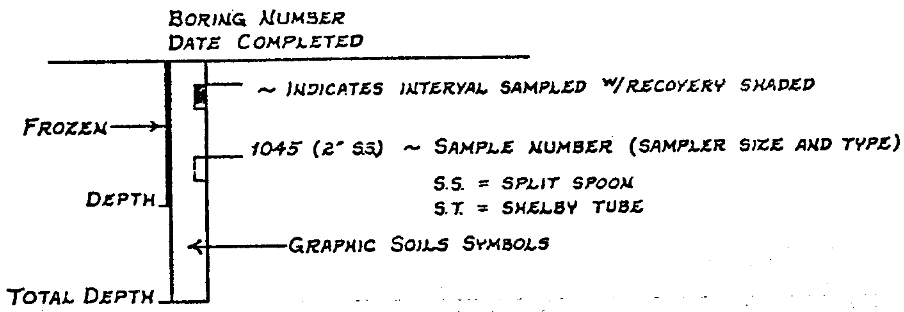
Ground Water Data		
Depth in ft.		
Time		
Date		

Drilling Method	Depth in Feet	Casing Size	Blows/Ft., Depth	Method	Sample No	Blow Count	Loc. Sampled	Recovery	Frozen	Soil Graph	SUBSURFACE MATERIAL	DRILLING NOTES	
6" Csg. ft. & [illegible]	20										Sandy gravel w/ Silt		0
	21												1
	22												2
	23												3
	24												4
	25												5
	26												6
	27												7
	28												8
	29												9
	30												0
	31												1
	32												2
	33												3
	34												4
	35												5
	36												6
	37												7
	38												8
	39												9
	40												0

Note: Unless otherwise noted all samples are taken W/1.4" ID Standard Penetration Sampler driven W/140 lb hammer W/30" drop.

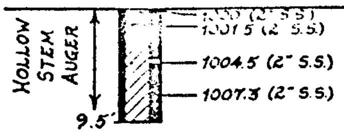
PRUDHOE BAY

KEY



PRUDHOE BAY

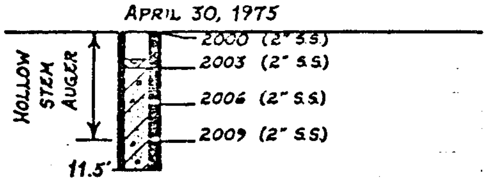
BORING 1
APRIL 30, 1975



0.0'-1.3'	MOSS OVER ORGANIC SILT AND SAND
1.3'-9.5'	VERY ICE RICH SILT, TRACE SAND

PRUDHOE BAY

BORING 2
APRIL 30, 1975



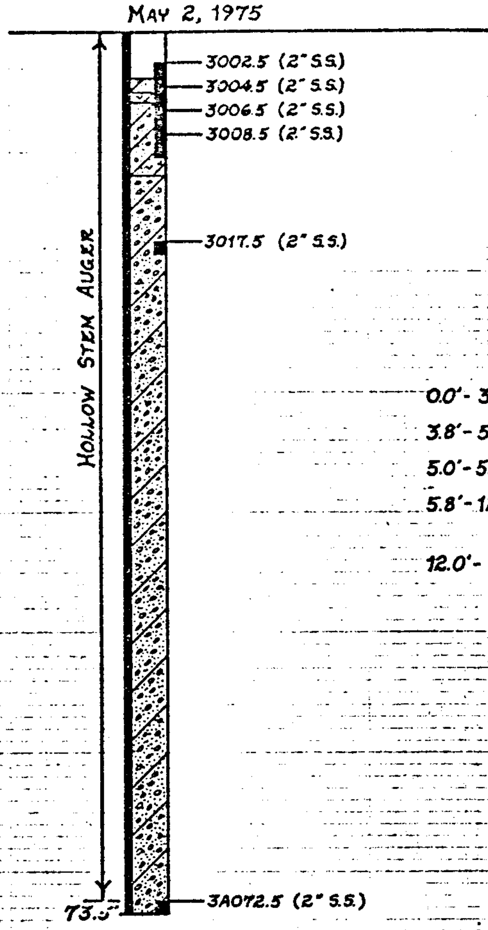
0.0'-2.3'	ICE
2.3'-3.0'	ORGANIC SILT W/SAND AND ICE
3.0'-11.5'	SILTY SAND, TRACE GRAVEL

BY .... DATE .... CHKD. BY .... DATE .... SUBJECT .... SHEET NO. .... OF .... JOB NO. ....

BY ... DATE ...
CHKD. BY ... DATE ...
SUBJECT ...
SHEET NO. ... OF ...
JOB NO. ...

PRUDHOE BAY

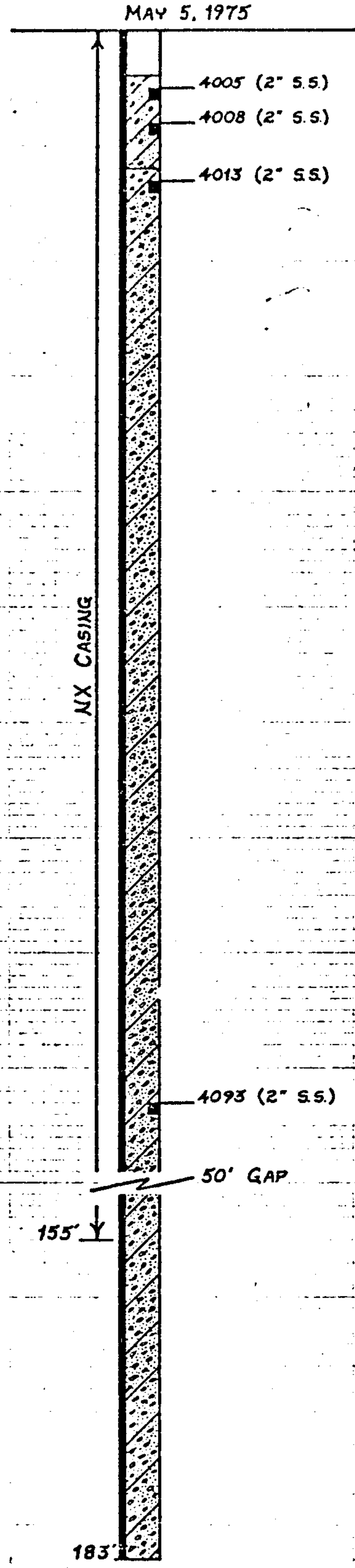
BORING 3 & 3A
MAY 2, 1975



0.0'-3.8'	ICE
3.8'-5.0'	SILTY SAND
5.0'-5.8'	ORGANIC SILTY SAND
5.8'-12.0'	SILTY SAND W/GRAVEL; TRACE ORGANIC
12.0'-73.5'	SANDY GRAVEL W/SILT AND OCC. ICE CRYSTALS

PRUDHOE BAY

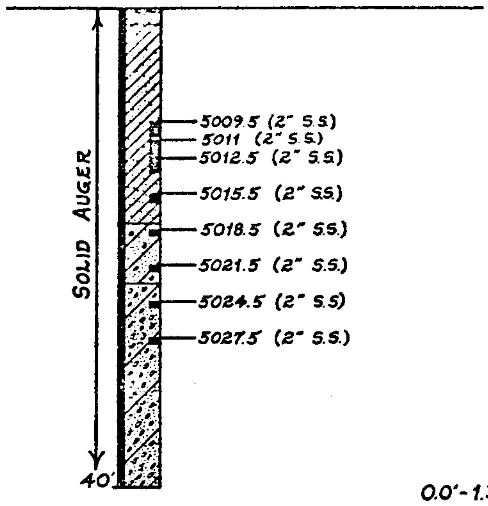
BORING 4
MAY 5, 1975



0.0'-3.8'	ICE
3.8'-12.0'	SILTY SAND W/GRAVEL
12.0'-183.0'	SANDY GRAVEL W/SILT; OCC. LAYERS SANDY SILT AND SILTY SAND

PRUDHOE BAY

BORING 5
MAY 7, 1975



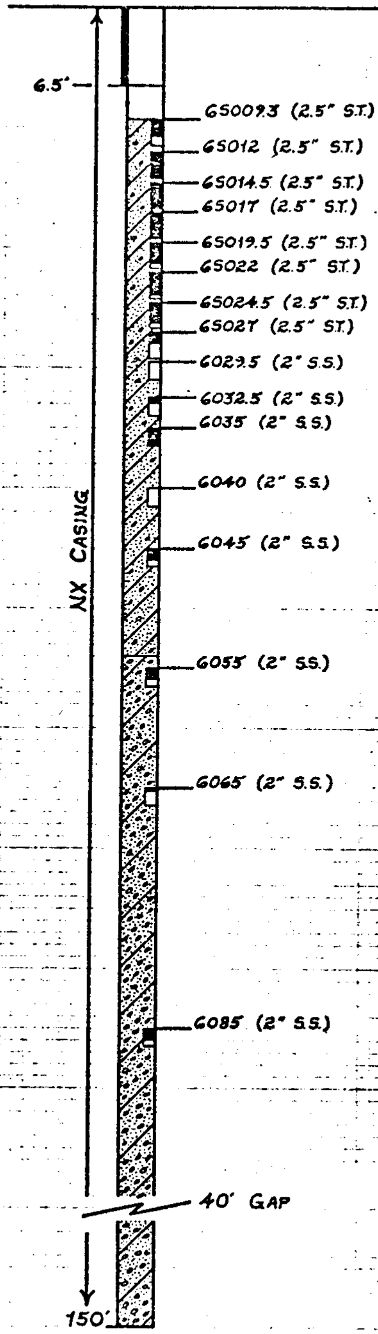
0.0'-1.3'	MOSS OVER ORGANIC SILT AND SAND
1.3'-18.0'	VERY ICE RICH SILT W/SAND; DECREASING ICE W/DEPTH
18.0'-40.0'	SANDY GRAVEL W/SILT; TRACE ORGANICS

BY ... DATE ... CHKD BY ... DATE ... SUBJECT ... SHEET NO. ... OF ... JOB NO. ...

BY .... DATE .... SUBJECT .... SHEET NO. .... OF ....
CHKD. BY .... DATE .... JOB NO. ....

PRUDHOE BAY

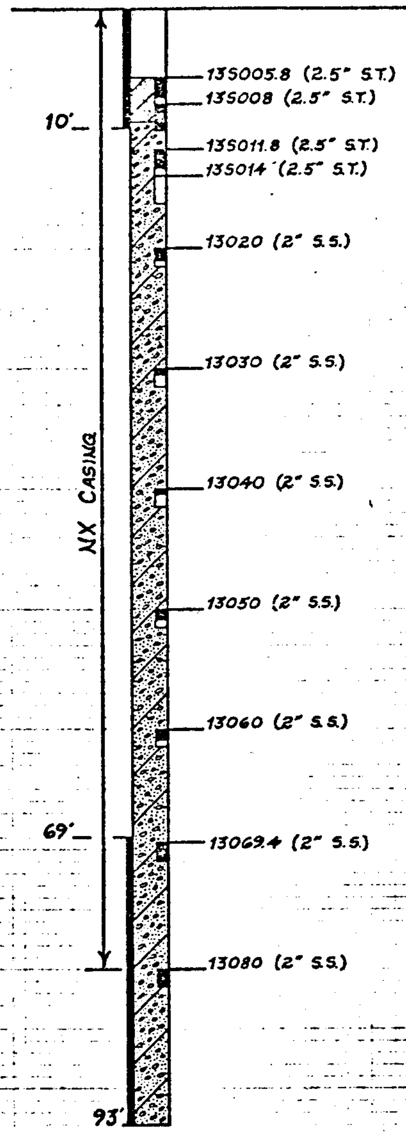
BORING G
MAY 14, 1975



0.0'-6.5'	ICE
6.5'-9.3'	WATER
9.3'-54.0'	SILTY SAND, TRACE GRAVEL; TRACE ORGANICS
54.0'-150.0'	SANDY GRAVEL W/SILT

PRUDHOE BAY

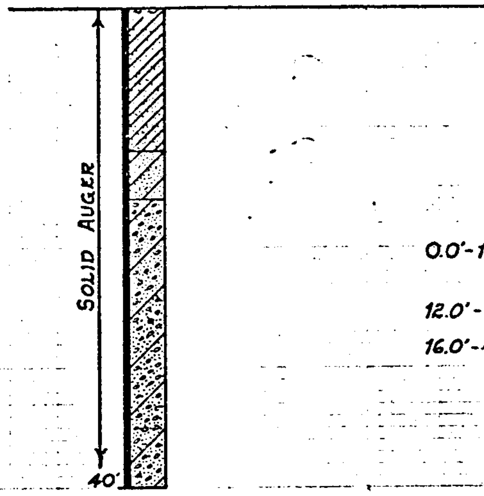
BORING 13
MAY 18, 1975



0.0' - 5.8'	ICE
5.8' - 9.5'	SILTY SAND
9.5' - 93.0'	SANDY GRAVEL W/ SILT

PRUDHOE BAY

BORING 14
MAY 18, 1975



0.0'-12.0' VERY ICE RICH SILT W/ SAND; THIN LAYER MOSS AT TOP

12.0'-16.0' SILTY SAND

16.0'-40.0' SANDY GRAVEL W/ SILT

BY ... DATE ... CHKD. BY ... DATE ... SUBJECT ... SHEET NO. ... OF ... JOB NO. ...

APPENDIX II

SOIL ANALYSIS

This soil analysis was prepared by the Road Materials Laboratory, Alaska Department of Highways, under the supervision of Mr. D. Esch according to standard AASHTO test procedures as listed in Section IV of this report. The boring and sample numbers can be converted to the hole numbers in the text by using Table I.

ALASKA DEPARTMENT OF HIGHWAYS
ENGINEERING GEOLOGY SECTION
SUMMARY OF TEST DATA — FOUNDATION SOILS

Project No. R13002 **Project Name** Geophysical Institute U of A **sheet** 1 **of** 1 **sheets**

Boring & Sample No.	Depth ft.	Laboratory Number	Grading Analysis — % Passing: Gravel			Sand		Silt		Clay	Atterberg Limits		Nat. Dry Density P.C.F.	Nat. Moist. %	Spec. Gravity	F.S.V. (Corps of Eng.)	AASHO Group Classif.	% Organic	% Chlorides as CL-ion	Triax (staged)	PERM
			1"	3/8"	#4	#10	#40	#200	.02	.002	Liquid Limit	Plastic Index									
135	5.8	75F-549				100	99	15	10.3	5.7	NV	NP	109.8	21.6	2.67			6.2	.36		
135	8	550					100	13	10.5	6.2	NV	NP	99.5	23.0	2.67			9.1	0.51		
65	9.3	551					100	34	7.8	3.5	NV	NP	100.0	23.0	2.68			16.1	.54	XX	
65	12	552					100	80	40.3	9.0	26	NP	96.0	27.8	2.63			15.8	.52	XX	
65	17	553	100	99	98	97	95	9	5.5	3.6	NV	NP	106.4	21.1	2.64			6.1	.37		
65	22	554	100	93	78	67	58	17	8.7	4.9	14	NP		9.2	2.68			9.2			XX
65	27	555	100	85	72	66	51	7	5.4	3.1	NV	NP	118.1	11.5	2.65			4.5	.25		

Remarks:

ALASKA DEPARTMENT OF HIGHWAYS

ENGINEERING GEOLOGY SECTION

SUMMARY OF TEST DATA — FOUNDATION SOILS

Project No. R13002 Project Name Geophysical Institute U of A sheet 1 of 3 sheets

Boring & Sample No.	Depth ft.	Laboratory Number	Grading Analysis — % Passing: Gravel 1"	Gravel 3/8"	Gravel #4	Sand #10	Sand #40	Silt #200	Silt .02	Clay .005	Atterberg Limits: Liquid Limit	Plastic Index	Nat. Dry Density P.C.F.	Nat. Moist. %	Spec. Gravity	F.S.V. (Corps of Eng.)	AASHO Group Classif.	% Organic	% Chloride	
4	5(5)	75F-867		100	92	84	59	10						20.0				5.5		
4	5(5.5	868	100	99	93	86	70	26						17.5				7.6		
4	8	869				100	93	16						18.5				7.6	0.501	
4	13	870	100	93	84	74	54	13						12.0				5.9	0.185	
4	93	871	100	56	41	32	22	9						9.1				2.1		
5	18.5	872	100	99	98	93	76	17						16.7				4.5		
5	27.5	873	100	84	54	41	29	10						11.9				3.3		
6	32.5	874	100	77	63	52	40	12						9.1				5.3		
6	35	875		100	99	94	90	14						15.5				6.6		
6	40	876	100	84	72	62	59	10						17.8				2.2	0.30	
6	55	877	*92	74	55	40	26	7						8.3				2.4	0.16	
6	65	878	*34	26	19	13	8	3						3.4						
6	85.5	879	100	79	51	31	19	5						8.9				2.0	0.25	
6	86	880	100	87	71	49	27	8						9.5				1.9	0.27	
13	20	881	100	82	66	56	45	6						13.2				3.5	0.39	

Remarks: * 100% pass 1½"

All samples are nonplastic

ALASKA DEPARTMENT OF HIGHWAYS
ENGINEERING GEOLOGY SECTION
SUMMARY OF TEST DATA — FOUNDATION SOILS

Project No. R13002 Project Name Geophysical Institute U of A sheet 2 of 3 sheets

Boring & Sample No.	Depth ft.	Laboratory Number	Grading Analysis — % Passing: Gravel 1"	Gravel 3/8"	Gravel #4	Sand #10	Sand #40	Silt #200	Silt .02	Clay .002	Atterberg Limits: Liquid Limit	Plastic Index	Nat. Dry Density P.C.F.	Nat. Moist %	Spec. Gravity	F.S.V. (Corps of Eng.)	AASHO Group Classif.	% Organic	% Chloride	
13	30	75F-882	100	68	52	35	22	6						10.2				2.4		
13	40	883	*88	73	64	56	37	5						16.3				3.9		
2	2.3	884		100	97	92	87	31						23.9				11.7	0.724	
2	4.1	885			100	99	94	24						18.1				9.7		
2	6.3	886	100	99	96	90	82	23						45.8				8.6		
2	8.4	887		100	99	97	92	27						22.5				10.1		
2	9(2)	888			100	99	94	26	16.9	9.4				13.9				8.0	0.108	
2	9(9)	889		100	97	95	89	56						166.5				18.5		
3	2.5(1)	890				100	98	11						26.0				9.5		
3	4.5(4.6)	891	100	99	96	93	83	16						29.1				8.0		
3	4.5(5.4)	892		100	98	96	85	25						30.4				9.1	.809	
3	4.5(6.1)	893		100	97	94	85	15						23.0				13.4		
3	6.5(7.4)	894		100	96	93	87	23						21.1				9.4		
3	6.5(8.1)	895			100	99	92	23						17.3				8.4		
3	8.5(9.0)	896				100	97	49						22.7				7.5		

Remarks: * 100% Pass 1½"
All samples are nonplastic

ALASKA DEPARTMENT OF HIGHWAYS
ENGINEERING GEOLOGY SECTION
SUMMARY OF TEST DATA — FOUNDATION SOILS

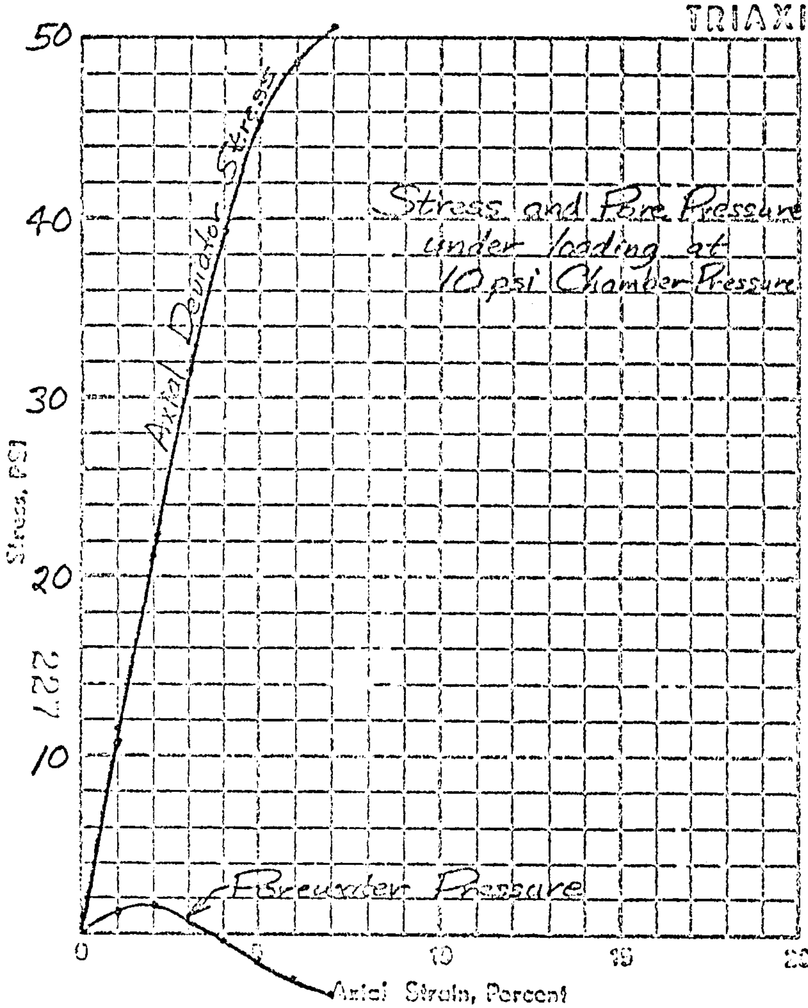
Project No. R13002 Project Name Geophysical Institute U of A sheet 3 of 3 sheets

Boring & Sample No.	Depth ft.	Laboratory Number	Grading Analysis — % Passing: Gravel 1"	Gravel 3/8"	Gravel #4	Sand #10	Sand #40	Silt #200	Silt .02	Clay .005	Atterberg Limits: Liquid Limit	Atterberg Limits: Plastic Index	Nat. Dry Density P.C.F.	Nat. Moist. %	Spec. Gravity	F.S.V. (Corps of Eng.)	AASHO Group Classif.	% Organic	% Chloride
3	8.5(10.1)	75F-897				100	99	11						23.9				7.3	
3	17.5	898	100	75	53	38	29	8						8.8				4.0	0.084
3A	72.5	899	100	89	75	56	38	12						13.0				2.1	
13	50	900	*95	75	56	39	23	7						7.7				3.5	
13	69.9	901	100	65	46	29	15	6						9.7				2.1	0.21
13	60	902	*90	77	63	46	25	2						14.2				3.6	
13	80	903	*97	81	53	34	27	6						8.9				3.6	0.24

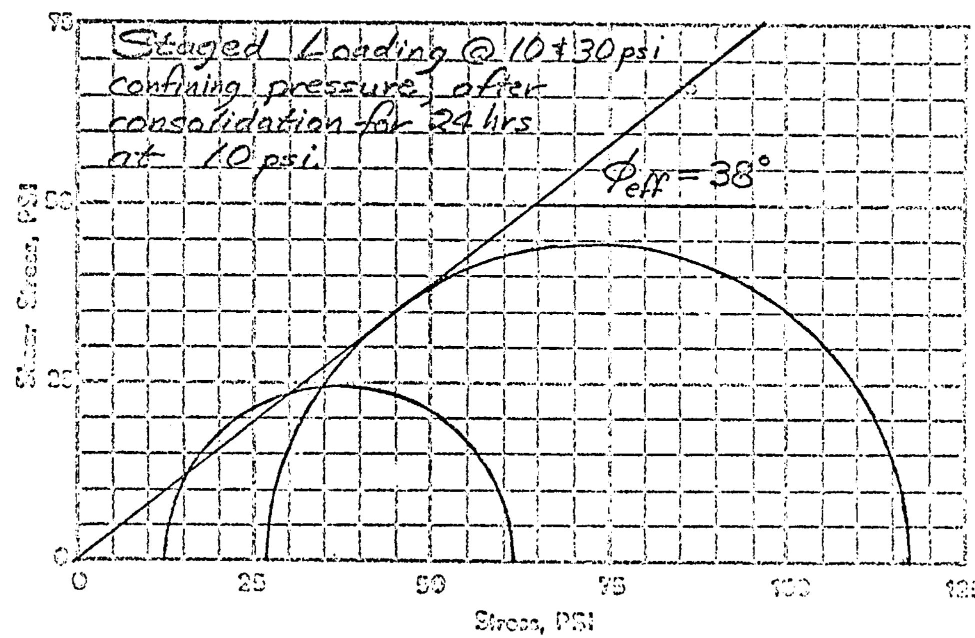
Remarks: *100% Pass 1½"

All samples are nonplastic

TRIAXIAL COMPRESSION TEST



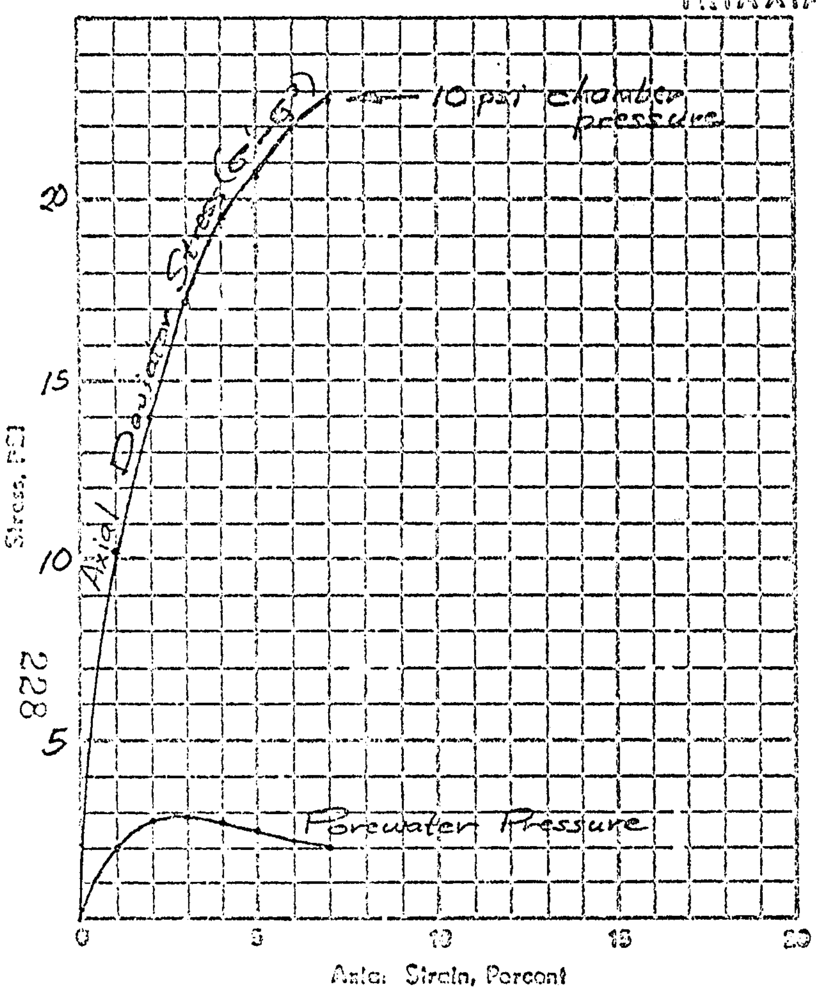
SPECIMEN NO.	INITIAL MOISTURE CONTENT(%)	INITIAL DRY DENSITY (PCF)	CONFINING PRESSURE (PSI)	DEVIATOR STRESS AT FAILURE (PSI)	SOIL TYPE
75F-551	23.0	100.0	10	48.7	Organic, Silty Sand
	"	"	30	90.1	



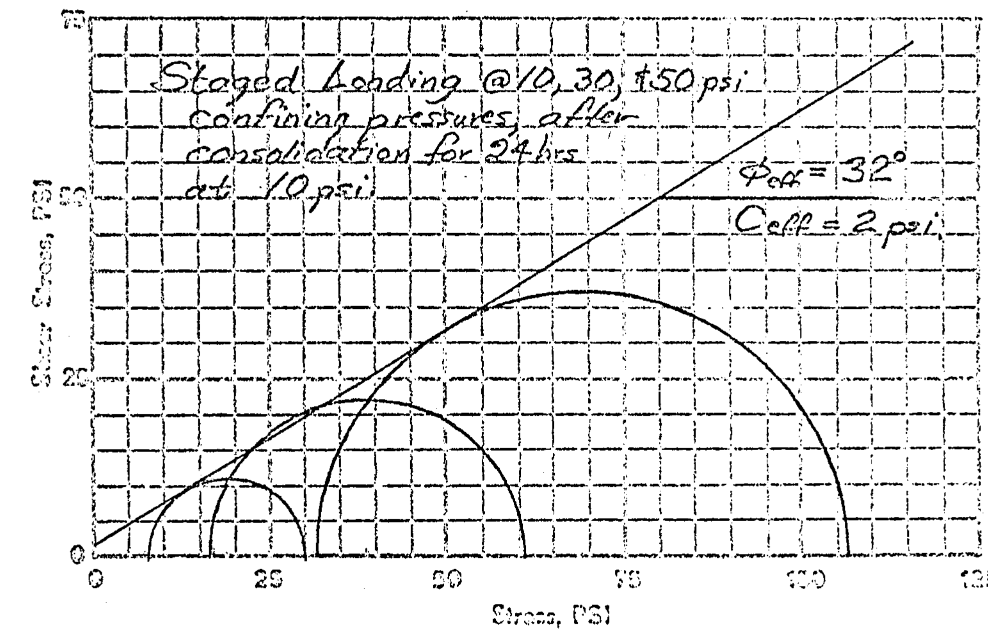
Remarks: Effective Stress Plots
Consolidated - Undrained Triaxial Shear
with Pore Pressure Measurements
Strain Rate ≈ 2% per hour

State of Alaska
DEPARTMENT OF HIGHWAYS
ROAD MATERIALS LAB
PROJECT TITLE: Offshore Permafrost
PROJECT NO: Study @ Prudhoe

TRIAXIAL COMPRESSION TEST



SPECIMEN NO.	INITIAL MOISTURE CONTENT(%)	INITIAL DRY DENSITY (PCF)	CONFINING PRESSURE (PSI)	DEVIATOR STRESS AT FAILURE (PSI)	SOIL TYPE
75F-552	27.8	96.0	10	22.3	Sandy,
	"	"	30	44.1	Organic
	"	"	50	76.3	Silt



Remarks: Effective Stress Plots
Consolidated - Undrained Triaxial Shear
with Pore Pressure Measurements.
Strain rate ≈ 2.5% per hour

State of Alaska
DEPARTMENT OF HIGHWAYS
ROAD MATERIALS LAB
PROJECT TITLE: Offshore Permafrost
PROJECT NO.: Study @ Prudhoe

APPENDIX III

MINERAL ANALYSIS

This mineral analysis was prepared by Ms. N. C. Veach of the Division of Mines and Geology, Alaska Department of Natural Resources. X-ray diffraction analysis was used to identify the mineral constituents of the soil samples. The marked sample numbers give the field-designated hole number and the depth in feet from the ice surface at which the sample was taken. For example, 4093 means field-designated hole 4 with the sample taken at the 93-foot depth. The field-designated hole numbers can be converted tothe hold numbers used in the text using Table I.

Thomas Osterkamp
Geophysical Institute

Received 11-6-75
Report 11-25-75

Sample No.	Marked	Meshes Number	Weight (gram)	Weight (per cent)	Major	Minor + Trace
To-1	3AO	+2.5	27.5	29.70	quartz	calcite
	72.5	-2.5, +4	24.9	26.89	quartz	calcite
		-4, +9	36.3	39.20	quartz	calcite
		-9, +40	2.1	2.27	quartz	feldspar
		-40	1.8	1.94	quartz	feldspar, calcite
To-2	4013	+2.5	36.5	20.81	quartz	calcite
		-2.5, +4	17.7	10.09	quartz	
		-4, +8	20.5	11.69	quartz	
		-8, +9	28.1	16.02	quartz	
		-9, +20	8.4	4.79	quartz	
		-20, +40	4.7	2.68	quartz	feldspar
		-40, +60	26.2	14.94	quartz	
		-60, +100	18.4	10.49	quartz, calcite	feldspar
		-100	14.9	8.49	calcite, quartz	dolomite, feldspar
To-3	4093	+2.5	166.8	55.54	quartz	
		-2.5, +4	55.9	18.61	quartz	
		-4, +10	52.3	17.42	quartz	feldspar
		-10	25.3	8.43	quartz	feldspar
To-4	5027.5	+2.5	93.4	39.64	quartz	calcite
		-2.5, +4	88.5	37.56	quartz	calcite
		-4, +10	51.2	21.73	quartz	calcite, feldspar
		-10, +20	0.3	0.13	quartz	calcite, feldspar
		-20, +40	0.3	0.13	quartz	calcite
		-40, +100	1.2	0.51	quartz	calcite, feldspar
		-100	0.7	0.30	quartz	calcite, feldspar
To-5	6040	+2.5	30.0	46.30	quartz	calcite
		-2.5, +4	16.7	25.77	quartz	
		-4, +10	15.0	23.15	quartz	
		-10, +100	2.5	3.86	quartz	feldspar
		-100	0.6	0.92	quartz	calcite, feldspar
To-6	6085	+2.5	94.6	28.15	quartz	
		-2.5, +4	74.4	22.14	quartz	feldspar
		-4, +10	128.0	38.08	quartz	
		-10, +20	15.4	4.58	quartz	
		-20, +40	9.8	2.92	quartz	
		-40, +100	11.0	3.27	quartz	
		-100	2.9	0.86	quartz	feldspar, chlorite
To-7	13020	+2.5	148.8	42.61	quartz	feldspar
		-2.5, +4	75.5	21.62	quartz	calcite
		-4, +10	64.5	18.47	quartz	calcite
		-10, +20	3.2	0.92	quartz	
		-20, +40	3.3	0.95	quartz	
		-40, +100	48.8	13.97	quartz	
		-100	5.1	1.46	quartz, calcite	feldspar, dolomite chlorite

Sample No.	Marked	Meshes Number	Weight (gram)	Weight (per cent)	Major	Minor + Trace
To-8	13050	+2.5	202.2	44.85	quartz	calcite, feldspar, chlorite
		-2.5, +4	93.0	20.63	quartz	calcite
		-4, +10	120.1	26.64	quartz	calcite, feldspar
		-10, +20	11.2	2.48	quartz	
		-20, +40	14.7	3.26	quartz	
		-40, +100	8.5	1.89	quartz	calcite
		-100	1.1	0.24	quartz	calcite, feldspar
To-9	13080	+2.5	187.3	48.54	quartz	
		-2.5, +4	40.5	10.49	quartz	
		-4, +10	93.1	24.13	quartz	
		-10, +20	11.0	2.85	quartz	
		-20, +40	10.9	2.82	quartz	
		-40, +100	35.3	9.15	quartz	
		-100	7.8	2.02	quartz	feldspar, chlorite, dolomite

Major; more than 10%
Minor + Trace; less than 10%
Determined by X-ray diffraction analysis

Namok C. Veach

Namok C. Veach
Analyst & work done

APPENDIX IV

ELECTRICAL CONDUCTIVITY OF THE SOIL WATER

The electrical conductivity of the soil water in the soil samples is given below. The first column of values (σ_1) were determined by measuring the electrical conductivity of the supernatant water in the soil samples. The second column of values (σ_2) were obtained by converting the chloride contents (Appendix II) to values of electrical conductivity by assuming that the ionic ratios of the soil water solution were the same as for normal sea water. The estimated error for this procedure is probably less than 20%. All electrical conductivity values are normalized to 25°C.

Sample Number	Depth (m)	σ_1 (ohm m)$^{-1}$	σ_2 (ohm m)$^{-1}$
Hole - 226			
5018.5	5.64	1.2	
5027.5	8.38	1.9	
Hole - 225			
100-1.30	1.3	0.44	
1007.3	2.2	0.50	
1008.5	2.6	4.1	
Hole 0			
2002.3	0.70	8.5	7.8
2003	0.91	3.6	
2004.1	1.25	5.3	
2005.4	1.65	4.0	
2006.3	1.92	1.9	
2007.5	2.28	1.3	
2008.4	2.56	2.7	
2009(1)	2.74	2.8	
2009(2)	2.83		2.4
2009(3)	2.92	0.87	
2009(4)	3.01	0.64	
2009(5)	3.10	0.62	
2009(6)	3.19	1.2	
2009(7)	3.28	1.1	
2009(8)	3.37	0.53	
2009(9)	3.51	0.59	
Hole 190			
4005.0	1.52	7.2	
4005.5	1.68	7.5	
4008	2.44		7.1
40013	3.96		4.2
4093	28.5	4.8	
Brine in drilling mud		8.9	
Hole 195			
3002.5(1)	1.16	6.9	
3002.5(2)	1.28	4.0	
3004.5	1.40	8.3	
3006.1	1.86	7.1	
3006.5(7.4)	2.26	7.8	
3006.5(8.1)	2.47	7.2	
3008.5(9.0)	2.74	7.3	
3008.5(10.1)	3.08	6.0	
3017.5	5.52		3.3
Brine in hole		14.0	
Brine in hole		16.8	
Hole 203			
3A072.5	22.3	6.2	

Sample Number	Depth (m)	σ_1 (ohm m)$^{-1}$	σ_2 (ohm m)$^{-1}$
Hole 481			
13S005.8	2.1	5.2	4.7
13S008	2.44		5.9
13S017.5	5.34		3.0
13020	6.25	6.5	7.8
13030	9.45	8.0	
13040	12.5	8.8	
13050	15.5	6.7	
13060	18.5	6.8	
13069.9	21.3	3.9	5.9
13080	24.7		7.1
Brine from under nearby ice cover		9.2	
Hole 3,370			
6S09.3	3.14	5.5	
6S012	4.0	5.8	
6S017	5.48		5.0
6S027	8.23		6.0
6032.5	10.2	5.7	
6035	11.0	5.6	
6040	12.5	5.4	4.7
6055	16.8		5.2
6085.5	26.1		7.4
6086	26.2	6.0	7.4

APPENDIX V

CHEMICAL ANALYSIS OF SOIL WATER

The major ions in three soil water samples were determined by Mr. H. Potworowski of the Division of Mines and Geology, Alaska Department of Natural Resources. Atomic absorption was used for all ions except Cl which was determined by titration.

DM-11
Rev. 10/67

Report No.

STATE OF ALASKA
Department of Natural Resources
DIVISION OF MINES AND GEOLOGY
Box C, College, Alaska 99701

Date of Report February 20, 1976

LABORATORY ANALYSIS REPORT

For Tom Osterkamp

Address Geophysical Institute, U. of A.

Number of Samples

Date Sample Received

Work Done: (for Analyst see below)
A. X-ray flourescence quant. ☐ semi-quant. ☐
B. X-ray diffraction ☐
C. Spectrographic quant. ☐ semi-quant. ☐
D. Spectroscopic ☐
E. Atomic absorption quant. ☒ semi-quant. ☐
F. Fire assay ☐
G. Microscopic examination ☐
H. Other (Specify) ☐
I. Ultraviolet light ☐

LABORATORY NUMBER	SAMPLE MARKED	ANALYSIS OR IDENTIFICATION

Core Sample Analysis

	K g/kg	Na g/kg	Mg g/kg	Ca g/kg	Cl^- g/kg	$So_4^=$ g/kg
Core 4093 (93,5)	0.339	6.228	0.857	1.152	20.269	2.41
Core 6040 (41)	0.250	3.752	0.306	0.517	12.49	2.30
Core 13 569.9 (69.9)	0.199	4.920	0.341	0.676	16.27	2.36

ANALYST & WORK DONE

ANALYST & WORK DONE

ANALYST & WORK DONE

APPROVED: [signature]
LABORATORY SUPERVISOR

NOTE: Samples discarded after 60 days and pulps after 6 months unless instructed otherwise.

APPENDIX VI

BOREHOLE TEMPERATURES

The depths in the first column were measured from the ice surface. Resistances were obtained by graphing resistance vs. $time^{-1}$ for each depth and then extrapolating resistance linearly to infinite time. The temperatures were then calculated from these extrapolated resistances using Equation 1. Hole numbers can be related to the field-designated hole numbers using Table I. No corrections have been made for the decrease in cable resistance due to colder ambient temperatures nor for the temperature coefficient of the Wheatstone bridge.

Hole - 226: May 29, 1975 - First Reading 01:55 ADT

DEPTH (m)	RESISTANCE (ohms)	TEMPERATURE (°C)	NOTES
1.40	18,571	-12.119	
3.40	20,016	-13.465	
5.40	19,547	-13.041	
7.40	18,563	-12.111	
9.40	17,750	-11.301	

Hole - 190: May 7, 1975 - First Reading 09:00 ADT

DEPTH (m)	RESISTANCE (ohms)	TEMPERATURE (°C)	NOTES
3.7	7,676.3	-6.4874	
8.7	6,829.0	-3.9524	
13.7	6,774.1	-3.7785	
18.7	6,839.5	-3.9855	
23.7	6,881.5	-4.1176	
28.7	6,986.5	-4.4448	
33.7	7,082.5	-4.7402	
38.7	7,062.1	-4.6777	
43.7	7,126.2	-4.8735	
48.7	7,238.9	-5.2138	

Hole - 190: May 9, 1975 - First Reading 13:27 ADT

DEPTH (m)	RESISTANCE (ohms)	TEMPERATURE (°C)	NOTES
3.7	7,794.5	-6.8187	
8.7	6,811.4	-3.8967	
13.7	6,787.0	-3.8194	
18.7	6,867.0	-4.0721	
23.7	6,908.1	-4.2009	
28.7	6,993.5	-4.4665	
33.7	7,100.2	-4.7943	
38.7	7,103.0	-4.8028	
43.7	7,176.6	-4.0263	
48.7	7,254.0	-5.2590	

Hole - 190: May 15, 1975 - First Reading 10:09 ADT

DEPTH (m)	RESISTANCE (ohms)	TEMPERATURE (°C)	NOTES
3.7	7,876.6	-7.0457	
8.7	6,822.6	-3.9322	
13.7	6,810.8	-3.8949	
18.7	6,888.9	-4.1408	
23.7	6,931.7	-4.2746	
28.7	7,014.6	-4.5317	
33.7	7,111.6	-4.8290	
38.7	7,135.5	-4.0918	
43.7	7,196.5	-5.0863	
48.7	7,266.6	-5.2966	

Hole - 190: May 28, 1975 - First Reading 23:00 ADT

DEPTH (m)	RESISTANCE (ohms)	TEMPERATURE (°C)	NOTES
3.7	7,884.5	-7.0674	
8.7	6,917.0	-4.2287	
13.7	6.826.4	-3.9442	
18.7	6,896.9	-4.1659	
23.7	6,941.4	-4.3048	
28.7	7,022.2	-4.5551	
33.7	7,129.5	-4.8835	
38.7	7,147.5	-4.9382	
43.7	7,200.0	-5.0969	
48.7	7,268.6	-5.3026	

Hole - 190: June 12, 1975 - First Reading 18:35 ADT

DEPTH (m)	RESISTANCE (ohms)	TEMPERATURE (°C)	NOTES
3.7	7,826.0	-6.9061	
8.7	6,986.4	-4.4445	
13.7	6,834.0	-3.9682	
18.7	6,898.6	-4.1712	
23.7	6,943.3	-4.3107	
28.7	7.023.7	-4.5597	
33.7	7,144.5	-4.9291	
38.7	7,152.2	-4.9524	
43.7	7,302.2	-5.1065	
48.7	7,271.3	-5.3107	

Hole 190 - Equilibrium Temperature

DEPTH (m)	RESISTANCE (ohms)	TEMPERATURE (°C)	NOTES
3.7		-6.917	
8.7		-4.456	
13.7		-3.990	
18.7		-4.182	
23.7		-4.325	
28.7		-4.573	
33.7			
38.7		-4.973	
43.7		-5.118	
48.7		-5.316	

Hole 203:- May 17, 1975 - First Reading 09:10 ADT

Hole 203: May 17, 1975 - First Reading 09:10 ADT

DEPTH (m)	RESISTANCE (ohms)	TEMPERATURE (°C)	NOTES
1.63	14,463	-7.542	
2.63	14,391	-7.450	
4.63	12,911	-5.420	
7.63	12,031	-4.085	
11.63	11,901	-3.879	
15.63	11,973	-3.994	
20.63	12,097	-4.189	

Hole 203: May 29, 1975 - First Reading 00:07 ADT

DEPTH (m)	RESISTANCE (ohms)	TEMPERATURE (°C)	NOTES
0.63	13,864	-6.755	
2.63	13,881	-6.778	
4.63	12,999	-5.548	
6.63	12,329	-4.549	
8.63	12,001	-4.038	
10.63	11,908	-3.890	
12.63	11,917	-3.905	
14.63	11,947	-3.952	
16.63	11,990	-4.021	
18.63	12,038	-4.096	
20.63	12,086	-4.172	

Hole 481: May 20, 1975 - First Reading 15:25 ADT

DEPTH (m)	RESISTANCE (ohms)	TEMPERATURE (°C)	NOTES
0.55	12,384	-4.633	
2.55	11,216	-2.748	
4.55	10,677	-1.803	
6.55	10,616	-1.693	
8.55	10,612	-1.685	
10.55	10,643	-1.742	
12.55	10,694	-1.834	
14.55	10,759	-1.950	
16.55	10,831	-2.079	
18.55	10,925	-2.245	
20.55	11,036	-2.439	
22.55	11,155	-2.644	
24.55	11,200	-2.721	
27.55	11,225	-2.764	

Hole - 481: May 21, 1975 - First Reading 07:58 ADT

DEPTH (m)	RESISTANCE (ohms)	TEMPERATURE (°C)	NOTES
0.55	12,446	-4.728	
2.55	11,251	-2.808	
3.55	10,816	-2.052	
4.55	10,702	-1.848	
5.55	10,659	-1.771	
7.55	10,622	-1.704	
17.55	10,885	-2.174	
18.55	10,940	-2.271	
19.55	10,993	-2.364	
20.05	11,013	-2.399	
20.55	11,044	-2.452	
21.55	11,132	-2.605	
26.55	11,176	-2.680	
27.55	11,204	-2.728	

Hole - 481: May 28, 1975 - First Reading 19:33 ADT

DEPTH (m)	RESISTANCE (ohms)	TEMPERATURE (°C)	NOTES
0.55	12,179	-4.317	
2.55	11,196	-2.714	
4.55	10,730	-1.898	
6.55	10,660	-1.772	
8.55	10,648	-1.751	
10.55	10,674	-1.798	
12.55	10,723	-1.886	
14.55	10,784	-1.995	
16.55	10,849	-2.110	
18.55	10,948	-2.285	
19.55	10,991	-2.360	
20.55	11,040	-2.445	
21.55	11,084	-2.522	
22.55	11,125	-2.592	
23.55	11,118	-2.580	
24.55	11,136	-2.611	
25.55	11,168	-2.666	
26.55	11,165	-2.661	
27.55	11,190	-2.704	

Hole - 481: June 13, 1975 - First Reading 15:17 ADT

DEPTH (m)	RESISTANCE (ohms)	TEMPERATURE (°C)	NOTES
0.55	11,242	-2.791	
2.55	11,227	-2.765	
4.55	10,799	-2.022	
6.55	10,697	-1.840	
8.55	10,678	-1.806	
10.55	10,695	-1.836	
12.55	10,749	-1.933	
14.55	10,810	-2.041	
16.55	10,875	-2.156	
18.55	10,971	-2.325	
19.55	11,003	-2.380	
20.55	11,056	-2.472	
21.55	11,067	-2.491	
22.55	11,105	-2.557	
23.55	11,115	-2.574	
24.55	11,132	-2.603	
25.55	11,158	-2.648	
26.55	11,176	-2.678	
27.55	11,196	-2.713	

Hole - 493: May 17, 1975 - First Reading 15:40 ADT

DEPTH (m)	RESISTANCE (ohms)	TEMPERATURE (°C)	NOTES
1.61	12,068	-4.144	
3.61	10,713	-1.868	
5.61	10,670	-1.790	
7.61	10,629	-1.716	
9.61	10,651	-1.756	
11.61	10,677	-1.803	
12.51	10,707	-1.857	

Hole - 3,370: May 16, 1975 - First Reading 13:00 ADT

DEPTH (m)	RESISTANCE (ohms)	TEMPERATURE (°C)	NOTES
0.48	11,144	-2.625	
3.48	10,559	-1.589	
4.48	10,455	-1.398	
6.48	10,339	-1.183	
8.48	10,284	-1.079	
13.48	10,271	-1.055	
18.48	10,321	-1.149	
23.48	10,377	-1.253	
28.48	10,406	-1.307	
33.48	10,491	-1.464	
38.48	10,563	-1.596	
44.98	10,634	-1.725	

Hole - 3,370: May 18, 1975 - First Reading 13:58 ADT

DEPTH (m)	RESISTANCE (ohms)	TEMPERATURE (°C)	NOTES
0.48	11,541	-3.294	
3.48	10,566	-1.602	
9.48	10,277	-1.066	
13.48	10,277	-1.066	
18.48	10,322	-1.151	
23.48	10,378	-1.255	
28.48	10,412	-1.318	
33.48	10,492	-1.466	
38.48	10,563	-1.596	
44.98	10,633	-1.724	

Hole - 3,370: May 20, 1975 - First Reading 11:38 ADT

DEPTH (m)	RESISTANCE (ohms)	TEMPERATURE (°C)	NOTES
0.48	11,853	-3.802	
2.48	10,623	-1.705	
4.48	10,453	-1.394	
6.48	10,340	-1.184	
8.48	10,286	-1.083	
10.48	10,264	-1.042	
12.48	10,262	-1.038	
14.48	10,284	-1.079	
16.48	10,299	-1.108	
18.48	10,313	-1.134	
20.48	10,334	-1.173	
22.48	10,357	-1.216	
24.48	10,379	-1.257	
26.48	10,392	-1.281	
28.48	10,408	-1.311	
30.48	10,444	-1.378	
32.48	10,471	-1.428	
34.48	10,496	-1.474	
36.48	10,526	-1.529	
38.48	10,553	-1.578	
40.48	10,561	-1.593	
42.48	10.581	-1.629	
44.98	10,629	-1.716	

Hole - 3,370: May 28, 1975 - First Reading 14:15 ADT

DEPTH (m)	RESISTANCE (ohms)	TEMPERATURE (°C)	NOTES
0.48	11,959	-3.971	
1.48	11,325	-2.933	
2.48	10,633	-1.724	
3.48	10,561	-1.593	
4.48	10,469	-1.424	
6.48	10,352	-1.207	
8.48	10,303	-1.115	
10.48	10,280	-1.072	
12.48	10,275	-1.063	
14.48	10,288	-1.087	
16.48	10,305	-1.119	
18.48	10,321	-1.149	
20.48	10,342	-1.188	
22.48	10,364	-1.229	
24.48	10,385	-1.268	
26.48	10,403	-1.302	
28.48	10,422	-1.337	
30.48	10,448	-1.385	
32.48	10,474	-1.433	
34.48	10,498	-1.477	
36.48	10,528	-1.532	
38.48	10,559	-1.589	
40.48	10,574	-1.616	
42.48	10,596	-1.656	
44.98	10,632	-1.722	

Hole - 3,370: June 14, 1975 - First Reading 00:01 ADT

DEPTH (m)	RESISTANCE (ohms)	TEMPERATURE (°C)	NOTES
0.48	10,194	-0.912	
2.48	9,994.2	-0.530	
4.48	10,508	-1.497	
6.48	10,405	-1.308	
8.48	10,336	-1.179	
10.48	10,314	-1.138	
12.48	10,307	-1.125	
14.48	10,314	-1.138	
16.48	10,333	-1.174	
18.48	10,350	-1.205	
20.48	10,370	-1.243	
22.48	10,389	-1.278	
24.48	10,409	-1.315	
26.48	10,434	-1.361	

Annual Report

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BEAUFORT SEACOAST PERMAFROST STUDIES

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I. SUMMARY

Preliminary results of a coastal offshore permafrost study are reported. The results include seismic refraction data which was gathered to probe the ocean bottom along the Alaskan Beaufort Seacoast.

The objectives of the study are the gathering of offshore permafrost distribution information including depth to the top of the ice bonded permafrost. Results of work performed at Prudhoe Bay and Pt. Barrow Alaska during the 1975 summer field season are reported. A high velocity refractor, characteristic of sub-bottom permafrost, was located in Prudhoe Bay near the shore and followed a distance of 1.4 km offshore. The surface of the layer, which dips downward in the offshore direction, ranges in depth from 12 to 20 meters to about 27 to 35 meters. The first depth estimates correspond to a distance of approximately 400 m from shore while the latter correspond to a distance of 1.4 km from shore. The average slope of the permafrost surface is about 0.8°, a figure that is in agreement with the results of drilling into the bottom material by Harrison and Osterkamp of the University of Alaska. However, local variations in the surface slope appear to be large, perhaps as much as 10 degrees. Refraction lines in Elson Lagoon near Pt. Barrow did not indicate the presence of ice bonded permafrost within the depth capability of the equipment used (about 30 meters).

II. INTRODUCTION

The known oil reserves along the Beaufort Seacoast coupled with a national need to develop these resources have focused increased attention on the distribution and character of permafrost in that area. Of particular concern to this project is the comparatively unknown areas offshore and along the barrier islands. Recently priorities have been established for attacking the problem area and a high priority was established for mapping the distribution of offshore permafrost.

A study of coastal offshore permafrost which utilizes seismic refraction techniques to probe the ocean bottom along the Alaskan Beaufort Seacoast was initiated in April of 1975. It will provide information relevant to task D-8 in NOAA's proposal to BLM.

The most important parameter to be determined in this study is the distribution of offshore permafrost. Also, the depth to the top of the bonded permafrost beneath the ocean floor. Using the equipment purchased in this program, data are being gathered which are of immediate the practical value in determining the distribution and nature of offshore permafrost existing today. An objective is compilation of the above parameters for use by other principal investigators, as well as appropriate agencies and industries.

The distribution study focuses primarily on the Prudhoe Bay area with secondary emphasis at Pt. Barrow. The truncation of permafrost beneath the ocean is of interest, particularly the shape of the frozen-nonfrozen boundary. Thus, the second major objective is the determination of the shape of this boundary near Barrow and Prudhoe Bay. These results will provide valuable information for refinement and testing of thermal models.

The third major objective is to provide information to support drilling programs including those of the University of Alaska, CRREL, and the USGS. Drilling provides good information on bottom conditions only near the drill hole. It is possible, using the seismic technique, to extend such information to areas remote from the drill site, by correlating seismic refraction data at the drill site and at the remote locations. Moreover, the seismic data can be used to suggest areas for drilling investigations. Thus the seismic refraction data obtained in September of 1975 will be valuable information for the spring 1976 drilling planned by the USGS and CRREL. It also extends the information gained by the University of Alaska drilling in May of 1975.

III. CURRENT STATE OF KNOWLEDGE

Permafrost, which commonly occurs in high latitudes and altitudes on the earth, also exists beneath the sea floor along the Arctic Coast. At this time, relatively little is known about offshore permafrost properties including its distribution and the dynamics of its formation and destruction. Several of the problem areas needing investigation have recently been discussed in "Priorities for Basic Research on Permafrost" and also in a position paper for the National Science Foundation titled: "Problems and Priorities in Offshore Permafrost".

The existence of offshore permafrost has long been suspected as the result of ocean transgression upon land permafrost in northern latitudes. Such relict permafrost can take thousands of years to dissipate. Black (1954) and Lachenbruch (1957, 1968) discuss the possibilities of relict permafrost as well as stable permafrost in equilibrium as the result of mean annual ocean bottom temperatures below 0°C. More recently permafrost has been reported beneath the Canadian Beaufort Sea (Hunter, 1975, MacLauley, 1976) and beneath the waters of Prudhoe Bay, Alaska (Harrison and Osterkamp, 1975). Some of the physical processes involved in the degradation of relict permafrost are beginning to be understood and it is clear that in addition to temperature the porosity of the sediments and the salinity of the interstitial liquids are important (personal conversation with W. M.Harrison). The results reported herein are in agreement with the drilling results obtained during the spring of 1975 by Harrison and Osterkamp. From their records and the refraction records presented in the following sections it is clear that offshore permafrost which is ice bonded exists in Prudhoe Bay. The distribution of this permafrost and the depth to its upper surface are currently known along a linear transect. Areal distribution and depth information remain to be determined.

IV. STUDY AREA

Two principal areas investigated during the 1975 summer season are shown in Figures 1 and 2. The first is the western end of the Beaufort Seacoast while the second area is closer to the eastern end of the Beaufort Seacoast. Due to particularly bad ice conditions southeast of Barrow, the field work was delayed approximately three weeks and some curtailment of the measurement program was necessary.

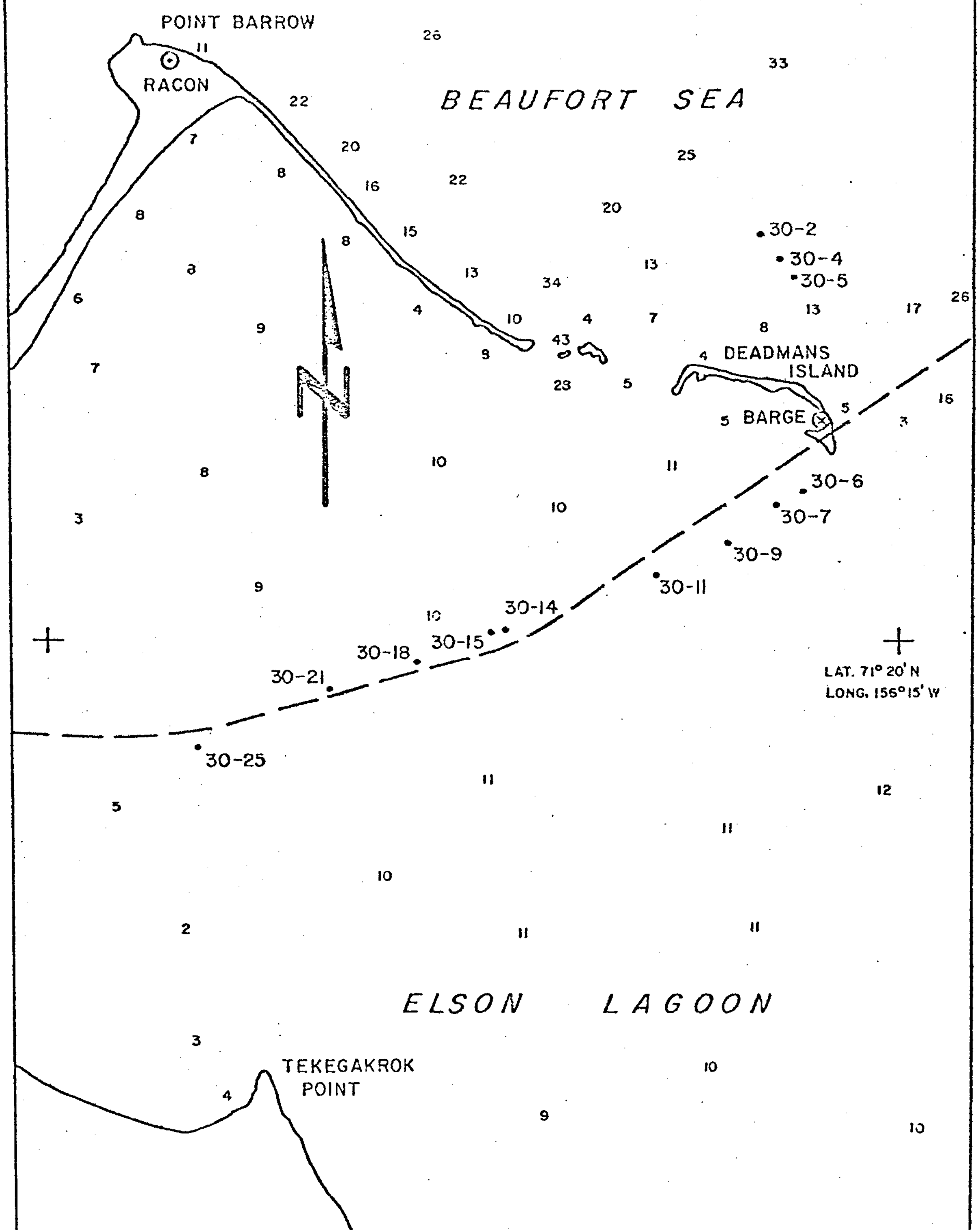

Figure 1. Refraction line near Point Barrow as identified by numbers 30-25, 30-21, etc.

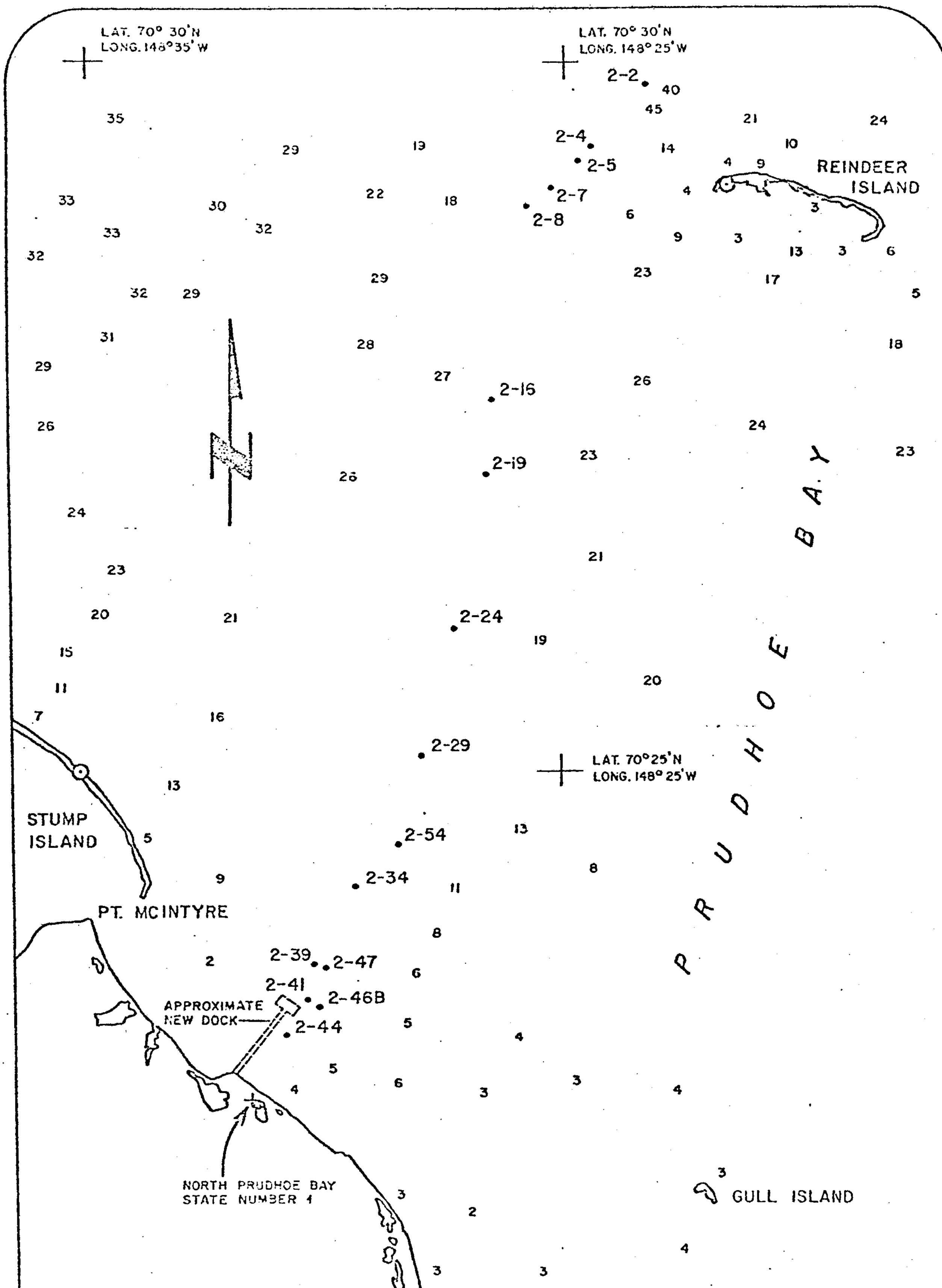

Figure 2. Refraction line in Prudhoe Bay as identified by numbers 202, 2-4, etc.

V. SOURCES AND METHODS

Shallow seismic refraction techniques have been documented by Hunter (1974) and their application to the detection of sub-sea permafrost has also been described (Hunter and Hobson, 1974). The seismic refraction data consist of 24 channels recorded in analog form by a chart recorder. These data are gathered at several points along the ship transects later scaled and reduced to time distance plots as shown in the appendix. Finally, the inverse slopes of the time distance plots are used to determine seismic velocities in the sub-bottom material and the velocities are then used to determine whether the bottom materials are frozen. Permafrost velocities in the Barrow area along Pt. Barrow are typically between 2500 m/s and 3000 m/s while similar materials in the nonfrozen state typically have velocities ranging from 1600 m/s to 2000 m/s (Rogers, et al, 1975). Significant velocity contrasts such as these, which are typical of coarse sandy materials, allow easy classification of materials into the frozen or unfrozen state.

Initial plans included several refraction lines near Barrow and at Prudhoe Bay. However, the very late ice season curtailed the refraction measurements and only one line was run at each location.

VI. RESULTS AND DISCUSSION

Figure 1 shows the location of some of the refraction shots near Pt. Barrow. Each shot is identified by a sequential number from 30-2 through 30-25. Corresponding numbers are given to the appropriate time distance plots in the appendix. Similarly, shot points identified in Figure 2 by numbers from 2-2 through 2-52 correspond to data taken in Prudhoe Bay and presented in the appendix in the form of time distance plots.

In general, the Barrow area data indicated velocities of 2000 m/s or less. Thus it is concluded that no ice bonded permafrost was observed on the transect through Elson Lagoon. It is concluded, based upon the results from the Prudhoe Bay area discussed later, that if continuous ice bonded permafrost is located beneath the transect shown in Figure 1 its depth is probably in excess of thirty meters. This is an interesting result in view of the sub-bottom temperatures reported by Lewellen. His drilling traverse line, shown approximately by the dashed line in Figure 1, produced temperatures of -1.8 to -1.1°C in the mid-point of the refraction line. It is probable that these temperatures do not indicate a continuous ice bonded permafrost layer because of the presence of pore water salinity approaching that of sea water. The velocities observed at Prudhoe Bay ranged from about 1500 m/s, a figure typical of water, to as high as 4000 m/s which is associated with ice bonded permafrost in a dipping layer. Figure 3, a sketch of the shot location near the New ARCO Dock, shows the profiles which indicated ice bonded permafrost. Those profiles included numbers: 2-41, 2-42, 2-44 and 2-45. These profiles indicated the presence of a high velocity refractor ranging in depth from about 12 meters to about 27 meters.

A vertical section through the shot location given in Figure 3 is shown in Figure 4. Note that although the hydrophone cable length was about 480 meters, the average length of cable that received the refracted seismic

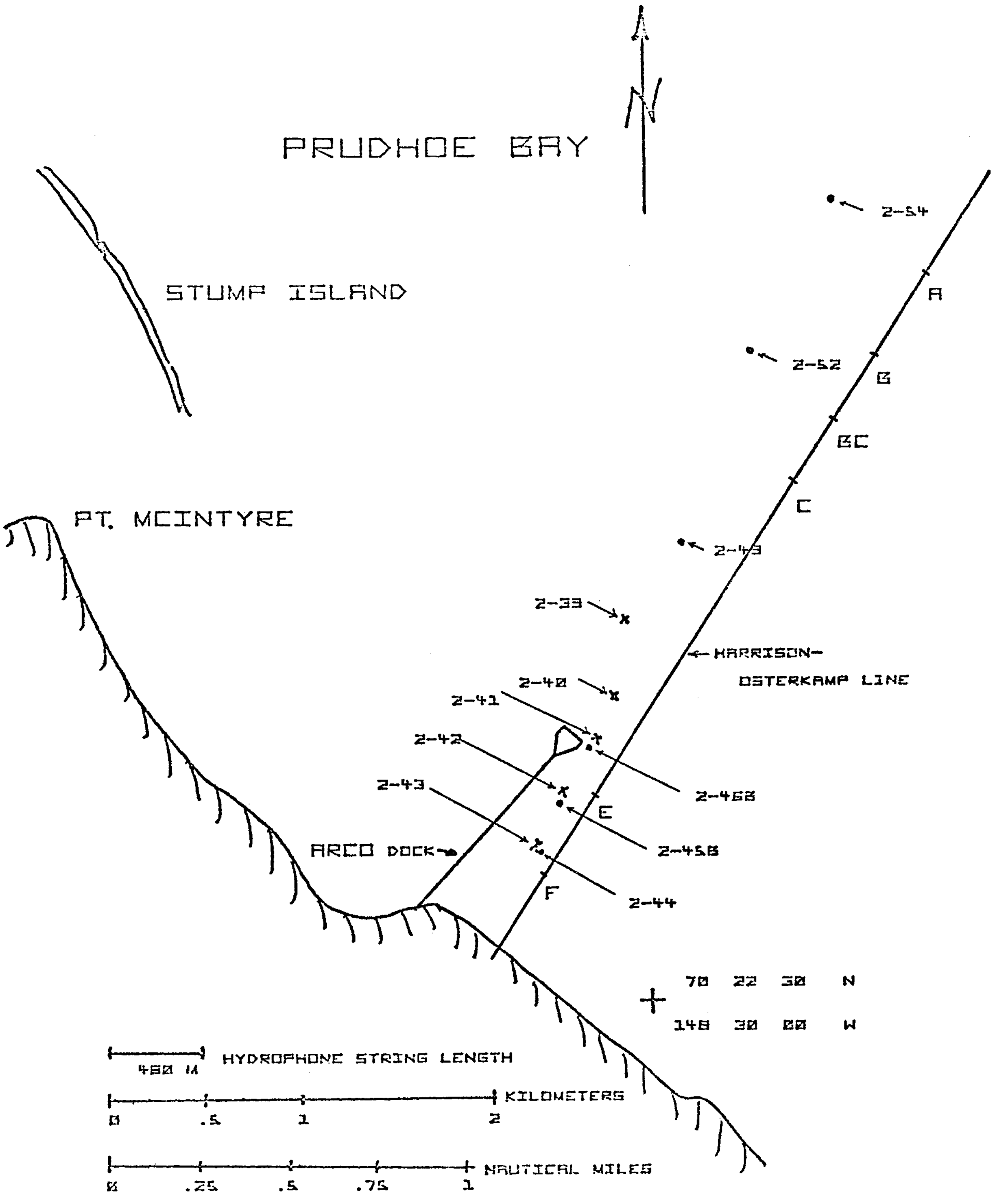

Figure 3. Plan of seismic refraction lines in Prudhoe Bay near New ARCO Dock. X's indicate shots taken while boat moved away from shore and •'s represent shots taken while boat moved toward shore.

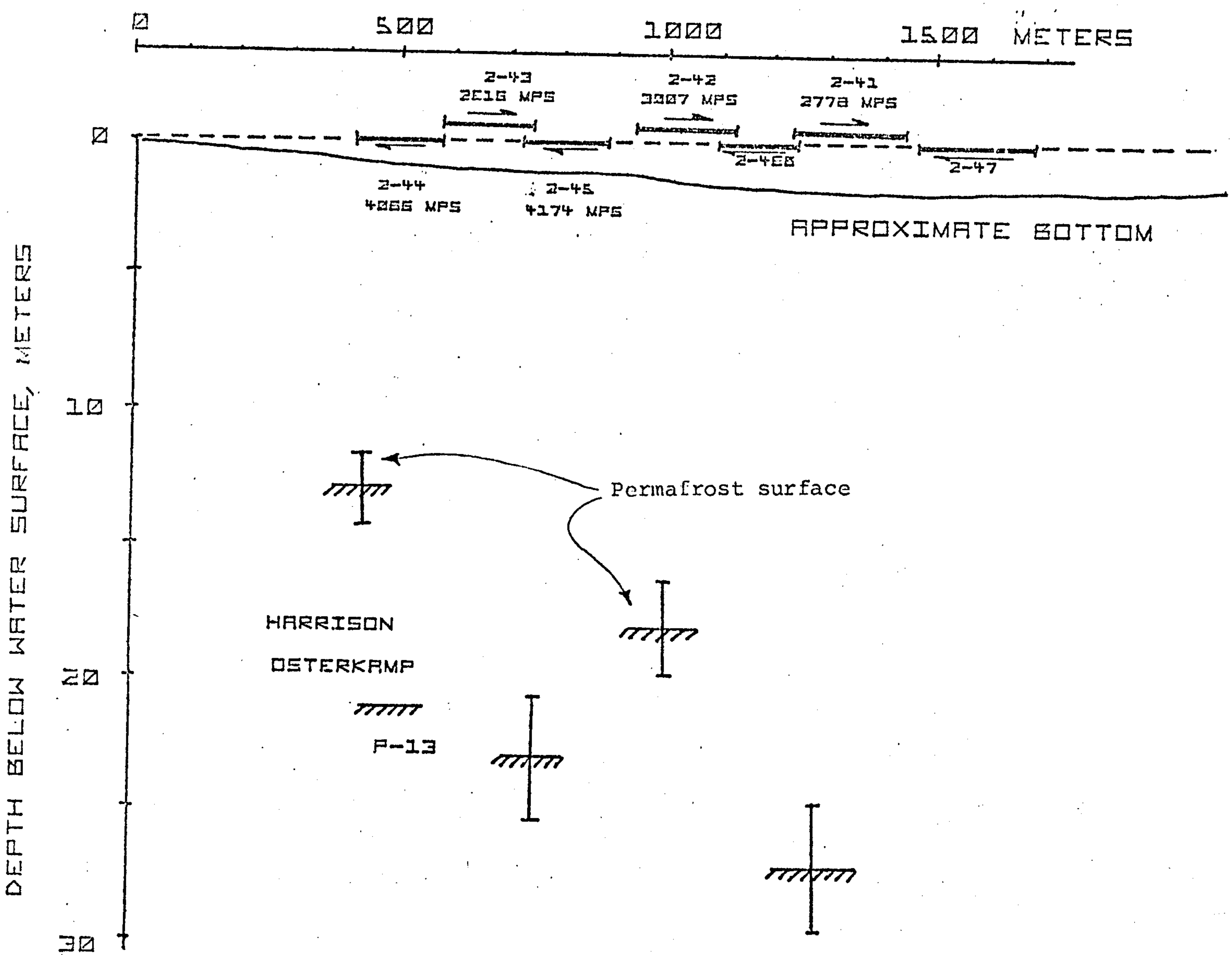

Figure 4. Vertical section through Prudhoe Bay track shown in Figure 3. Depths to permafrost surface are shown with error bars.

energy from the air gun source was typically 170 meters. This length is shown by the series of heavy lines that are drawn along the top of Figure 4. Each line is identified by a number and is labeled with the highest refractor velocity observed for that shot point. The arrow associated with each shot point indicates the direction the seismic energy traveled from the air gun to the hydrophones. Those shots where seismic energy traveled toward the shore had velocities about 4000 m/s while those with the reverse direction had velocities from about 2600 m/s to 3000 m/s. These results are consistent with an interpretation of the permafrost surface dipping downward away from the shore.

Two of the refraction lines, 2-46b and 2-47, did not give evidence of a high velocity refractor. It is likely that the permafrost layer beneath shot 2-47 was about 30 meters or greater in depth and thus that it was beyond the depth resolution of the equipment used. However, it is not clear why line 2-46b failed to display a high velocity refractor since refraction lines on either side of it did indicate such a refractor. The absolute refraction velocity of the seismic energy in the high velocity refractor is not known. However, if we assume it to be constant and 3000 m/s we can calculate the slope of the permafrost beneath the various refraction lines which indicated a frozen layer. We also can estimate the depth to the layer. Using the calculations of Hunter and Hobson we find that the estimate of depth we obtain may be in error by as much as 10% provided that the slope of the refractor is less than about 12°. Thus, the estimated depths shown in Figure 4 are shown with error bars of ± 10%. Also shown on the figure is point P-13 of Harrison and Osterkamp. Their point which is between line 2-44 and 2-43 is nearer in depth to the depth estimate of line 2-43. Using an estimate of 2000 m/s as representative of the non-frozen bottom materials, a figure representative of the refraction lines run in Prudhoe Bay, the slope of the refractor has been calculated for several of the lines and displayed in the table below. The local slope appears to be quite variable but is in general always dipping downward toward the ocean with the exception of line 2-42 which is essentially flat.

Line #	Highest Velocity Observed	Apparent Slope
2-44	4086 m/s	12°
2-43	2616 m/s	8°
2-45	4174 m/s	13.1°
2-42	3007 m/s	0.1°
2-41	2778 m/s	4.2°

If a line is drawn through the estimated depths shown in Figure 4 an average slope for the refractor appears to be about 0.8°, a figure considerably smaller than the local slopes indicated beneath the individual refraction lines.

The vessel transect shown in Figure 2 failed to indicate permafrost beneath the ocean other than for the first one and one-half kilometers from the shore near the New ARCO Dock. It is concluded from the data obtained along the remainder of the transect that if permafrost exists along this part of the transect its depth is greater than 30 meters.

VII. CONCLUSIONS

Although only a limited amount of time was available during the first field season several useful conclusions can be drawn from the data. The Elson Lagoon data indicate the absence of ice bonded permafrost beneath the lagoon to depths of about 30 meters. This conclusion is supported by the findings of Roger, et al. Permafrost has been located beneath Prudhoe Bay near the shore and it is found within 12 to 30 meters of the water surface. These findings are supported by the work of Harrison and Osterkamp. At other locations covered by the vessel in Prudhoe Bay any continuous ice bonded permafrost must be below 30 meters depth.

The surface of the permafrost appears to slope downward away from the shore at an average slope of 0.8° but the slope is apparently quite irregular ranging to values as high as about 12° in some locations.

VIII. NEEDS FOR FURTHER STUDY

Several items remain to be investigated. First, with a larger seismic source and increased system sensitivity it is desirable to follow the permafrost surface to greater depths and farther from the shore in Prudhoe Bay and the surrounding area. Also, the permafrost surface should be examined using more closely spaced refraction shots and reversed profiles to determine the nature and size of surface irregularities. This will necessitate several lines run both parallel and perpendicular to the shore line. Finally, the area around the islands should be examined closely with the refraction equipment in order to determine sub-bottom conditions associated with the offshore islands.

IX. FOURTH QUARTER ACTIVITIES

The fourth quarter work entailed further reduction of the data gathered during the 1975 field season. Data interpretation and report writing were also accomplished.

X. REFERENCES FOR ANNUAL REPORT

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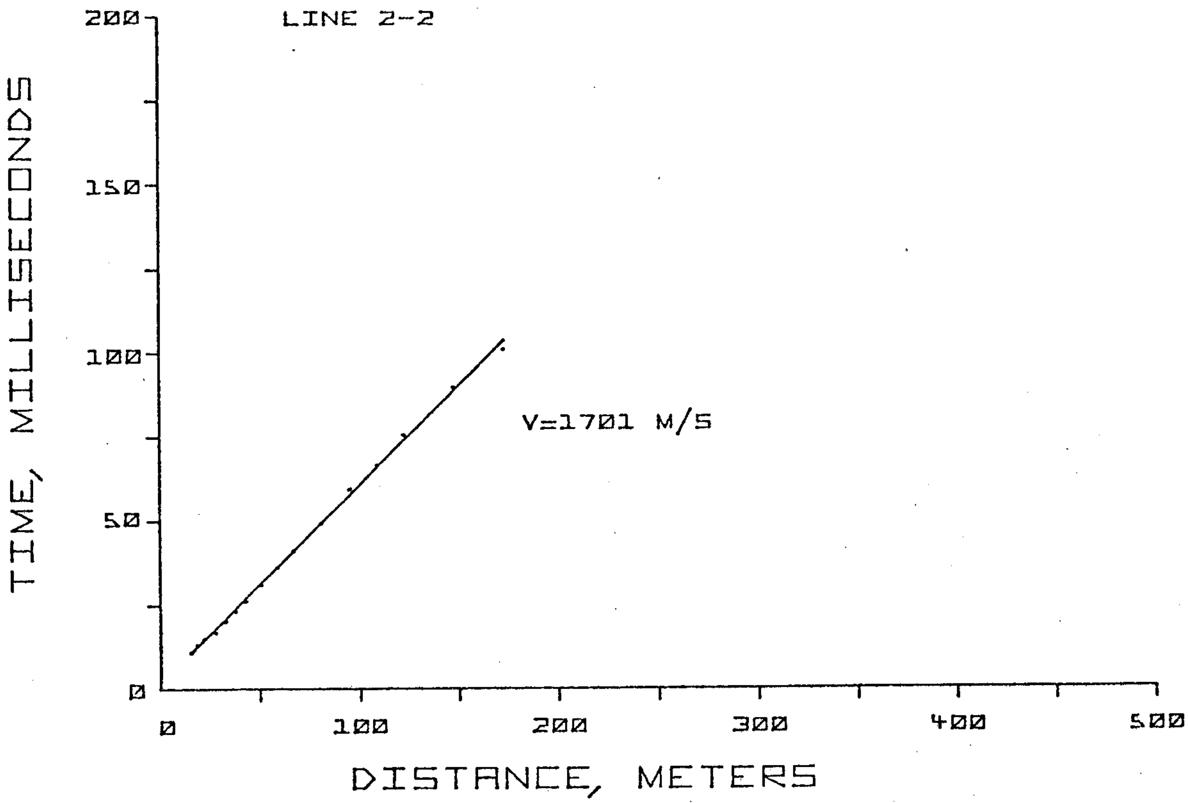
APPENDIX

Seismic Refraction Lines:

Lines 30-x	are Barrow area data, see figure in text
Lines 2-x	are Prudhoe Bay data, see figure 2 in text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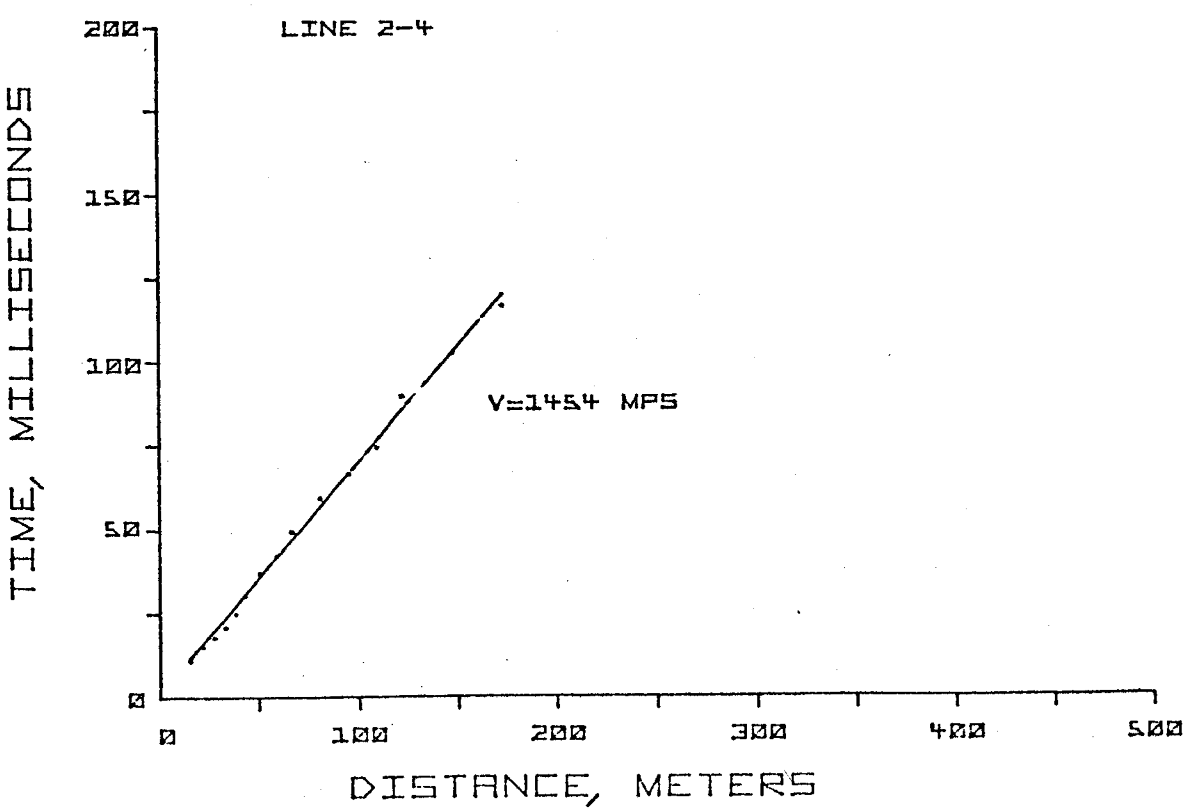
300
400
500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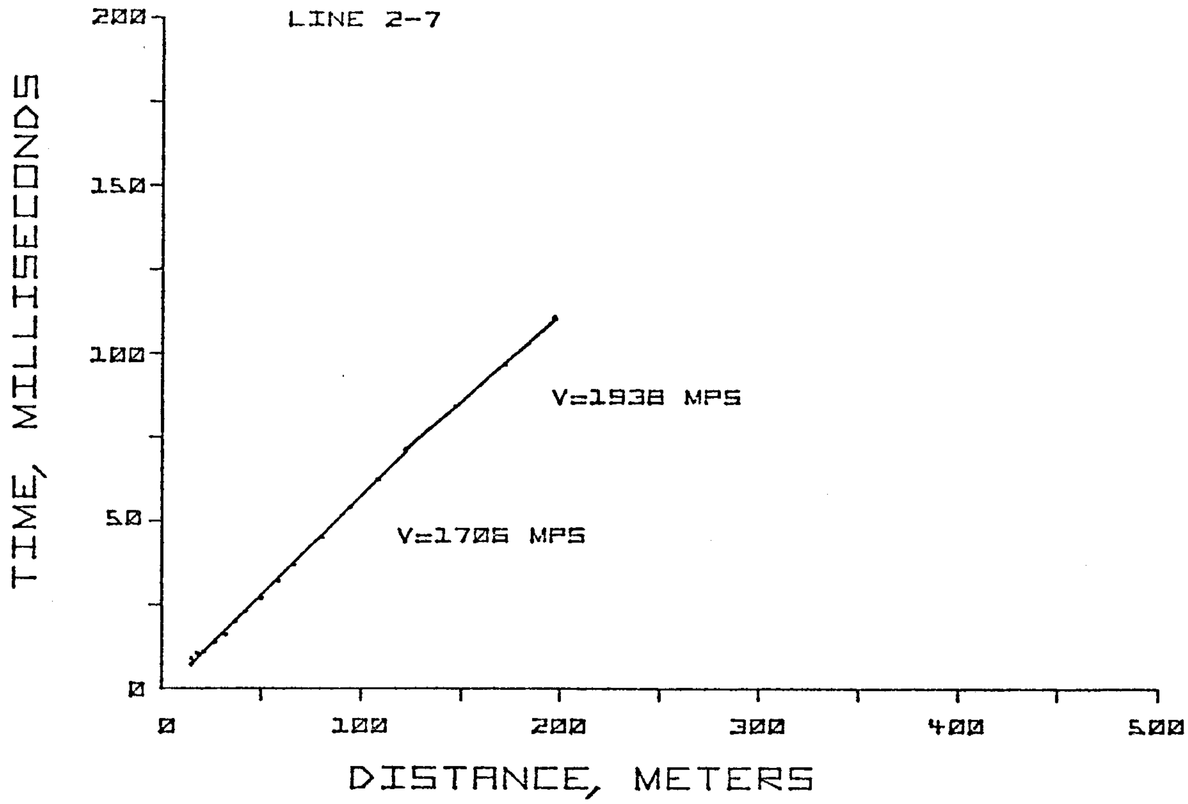

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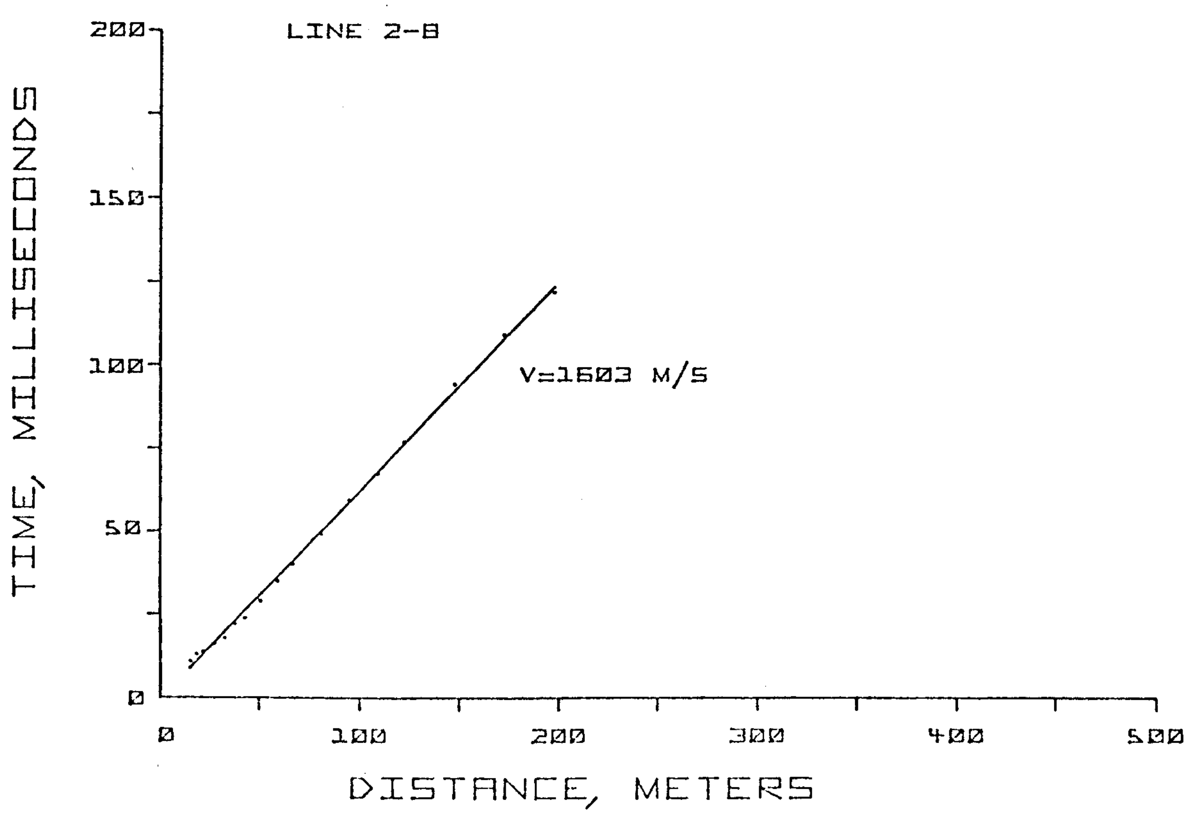
V=1706 MPS
TIME, MILLISECONDS
DISTANCE, METERS



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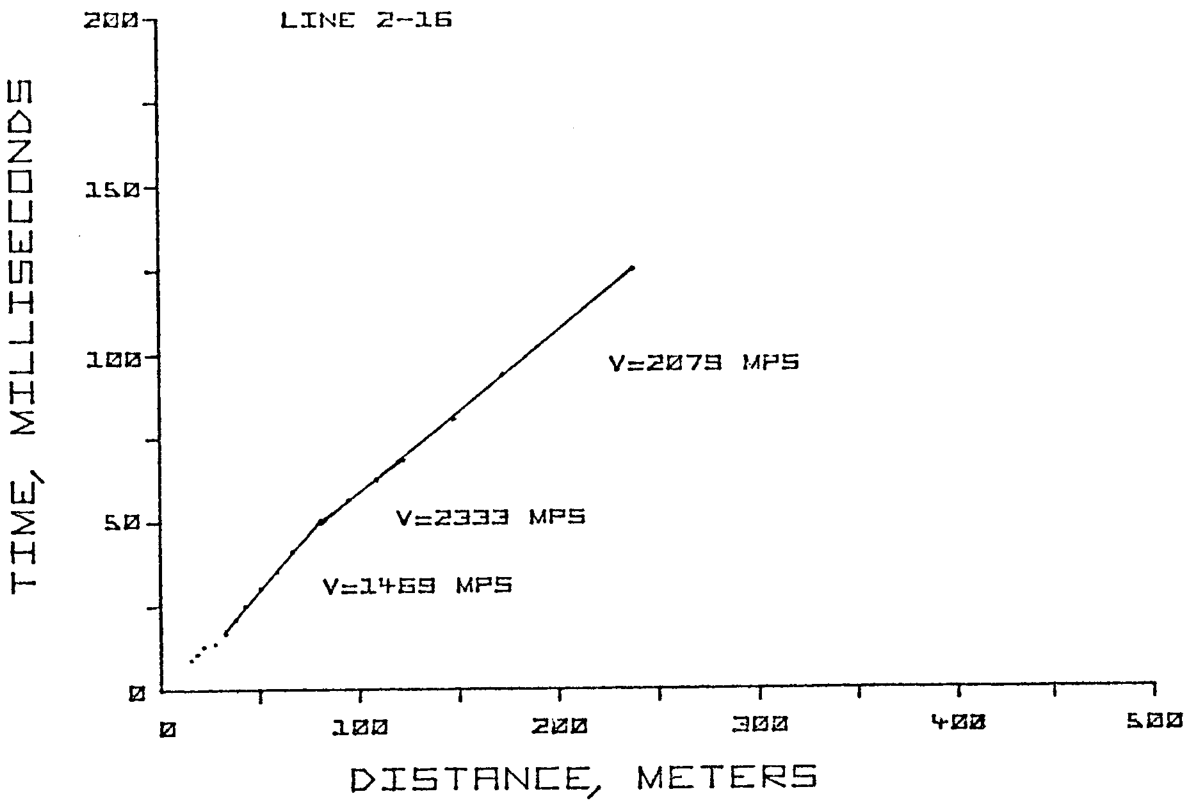
TIME, MILLISECONDS
DISTANCE, METERS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DISTANCE, METERS
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V=2333 MPS
V=1469 MPS
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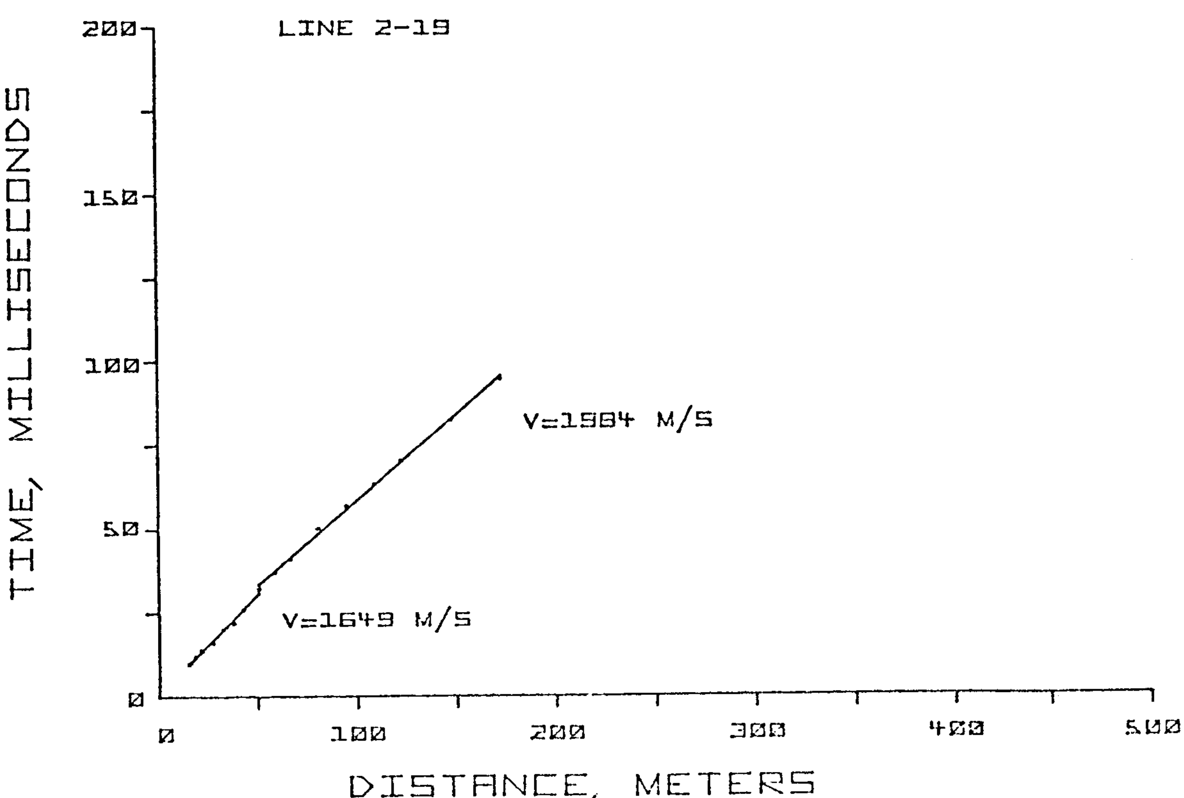
100
200
300
400
500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DISTANCE, METERS
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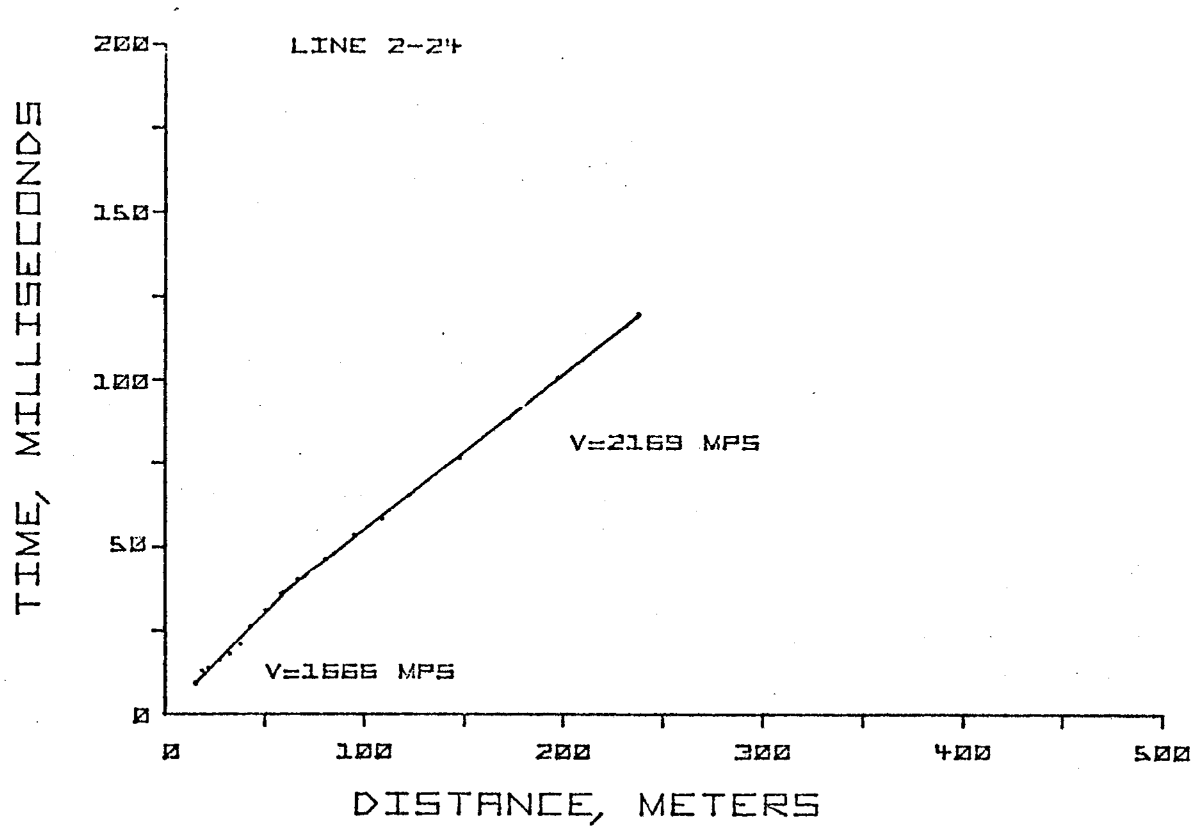
100
200
300
400
500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DISTANCE, METERS
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V=1666 MPS
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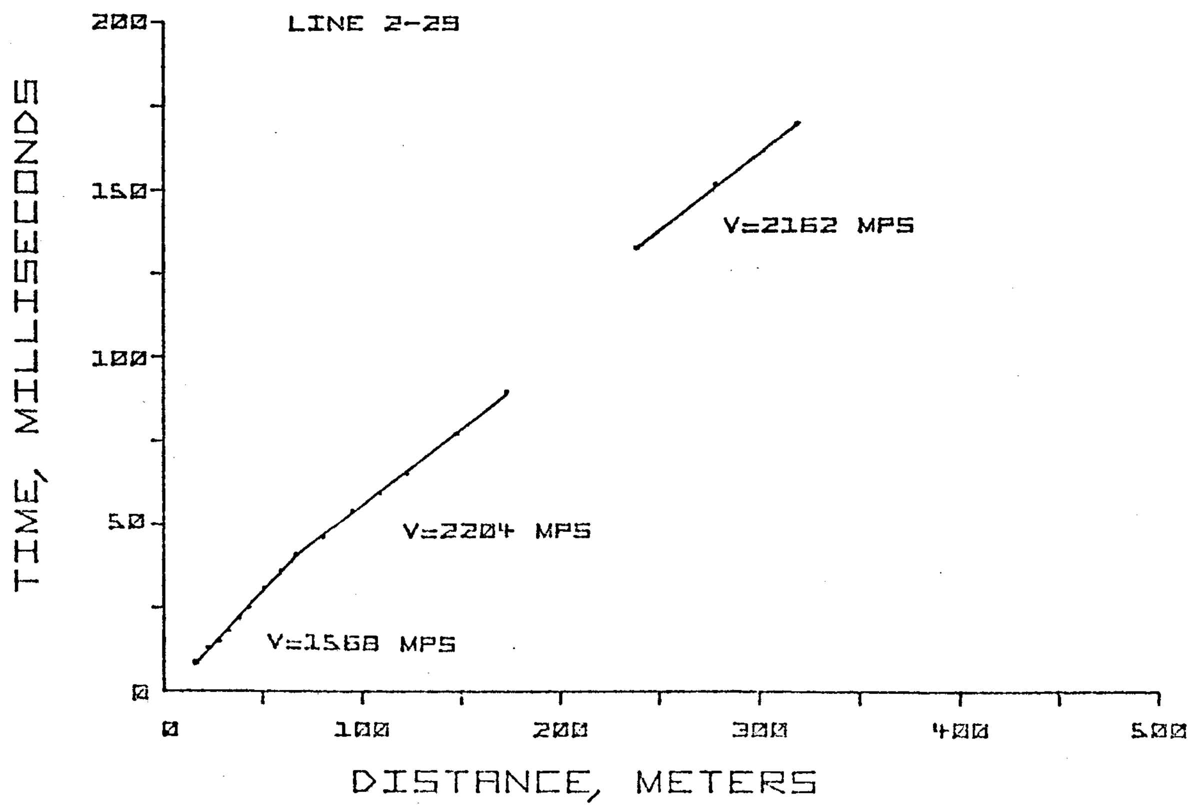
100
200
300
400
500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DISTANCE, METERS
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V=2204 MPS
V=1568 MPS
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50
100
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200
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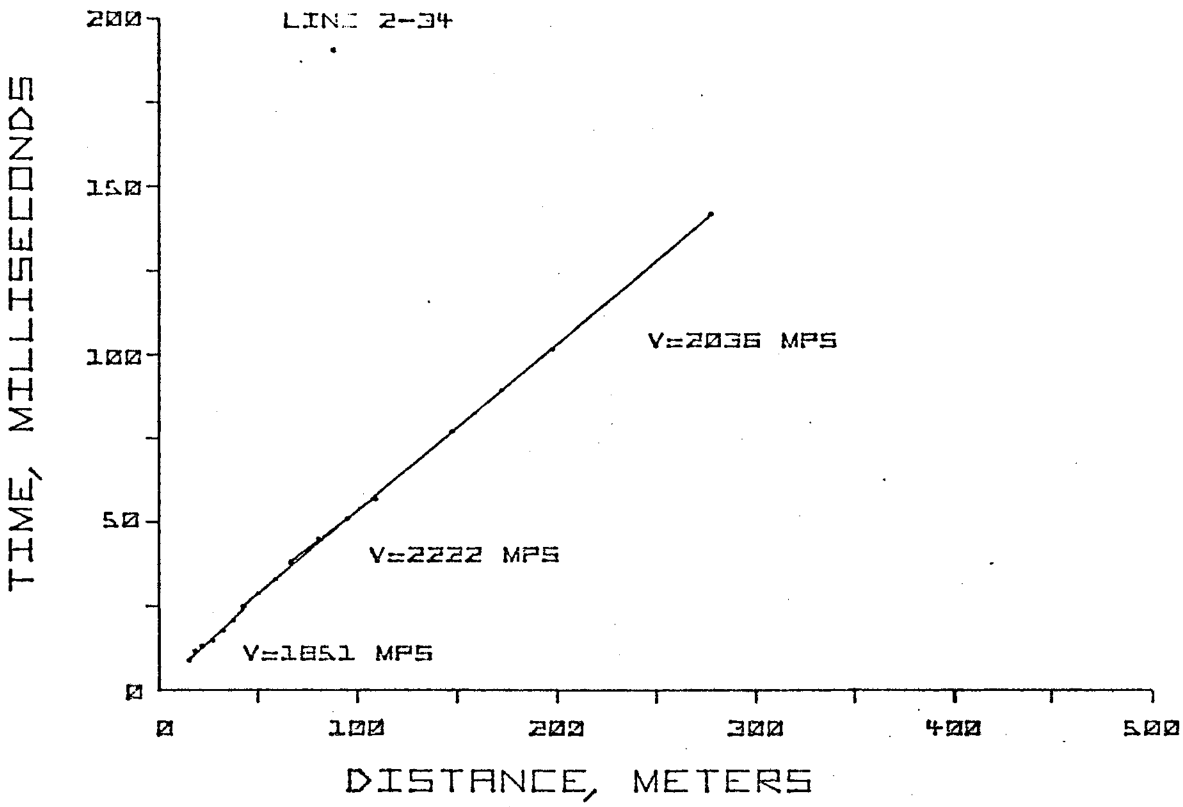
100
200
300
400
500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DISTANCE, METERS
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V=2222 MPS
V=1851 MPS
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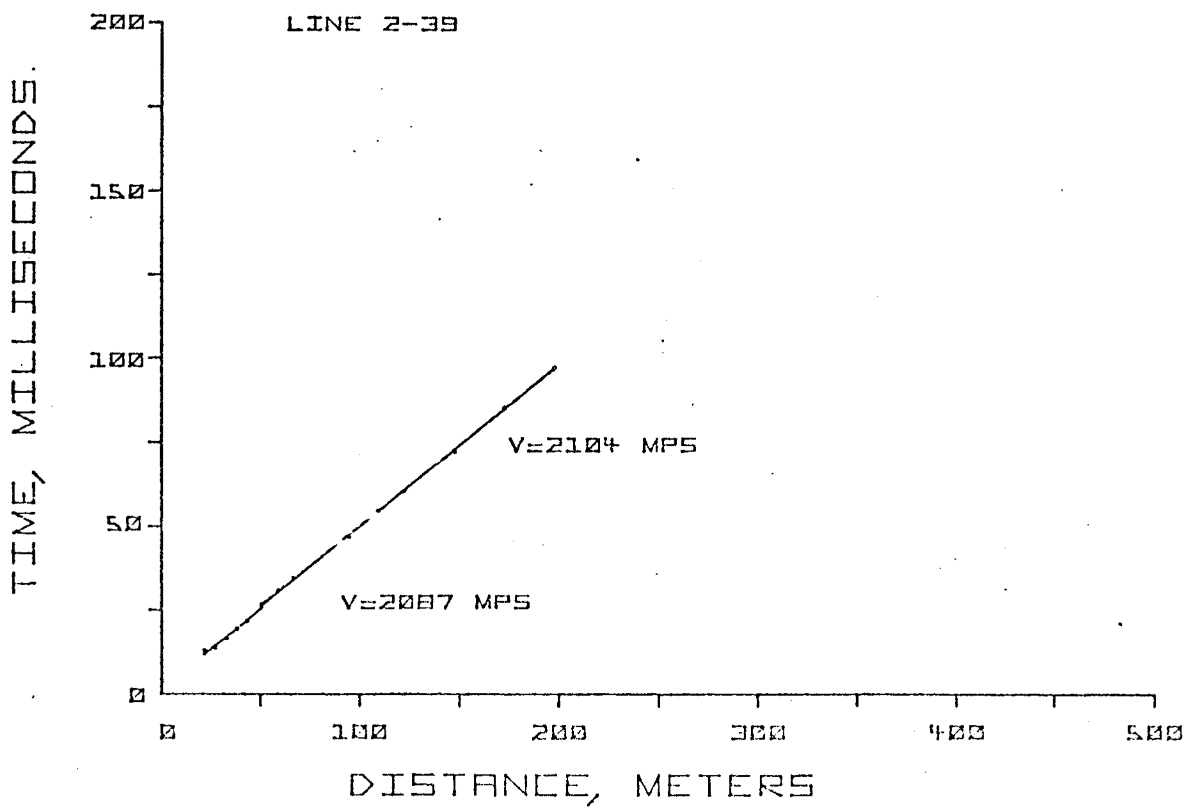
0
100
200
300
400
500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DISTANCE, METERS
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V=2087 MPS
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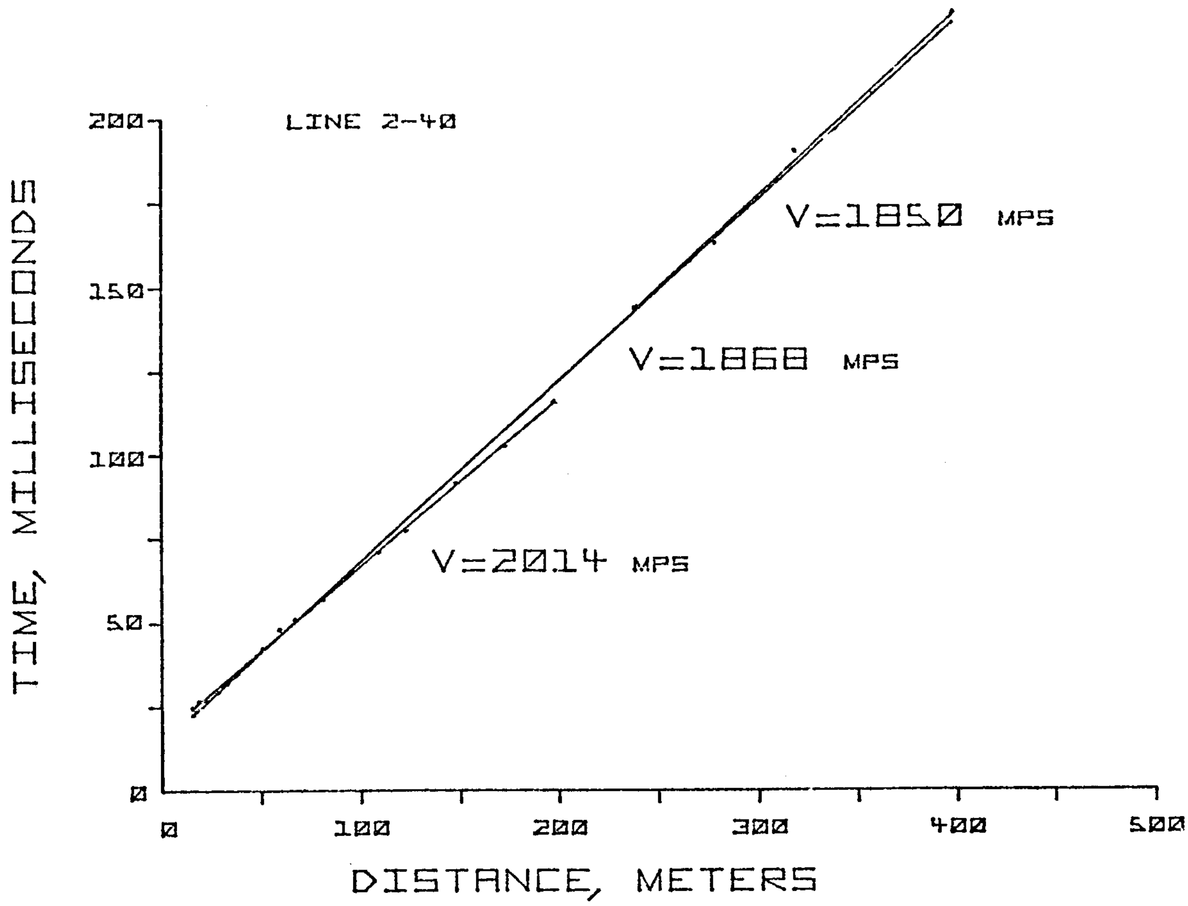
100
150
200
0
100
200
300
400
500



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V=1868 MPS
V=2014 MPS
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DISTANCE, METERS
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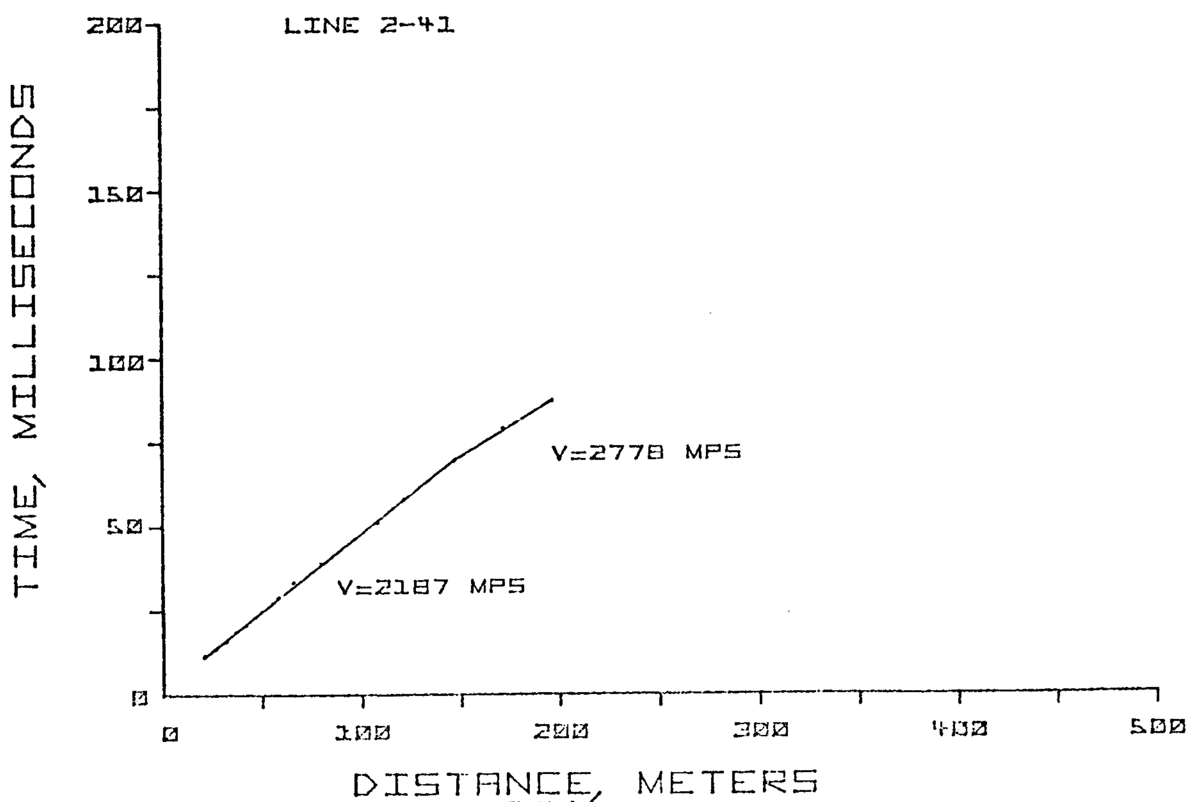

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DISTANCE, METERS
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200
300
400
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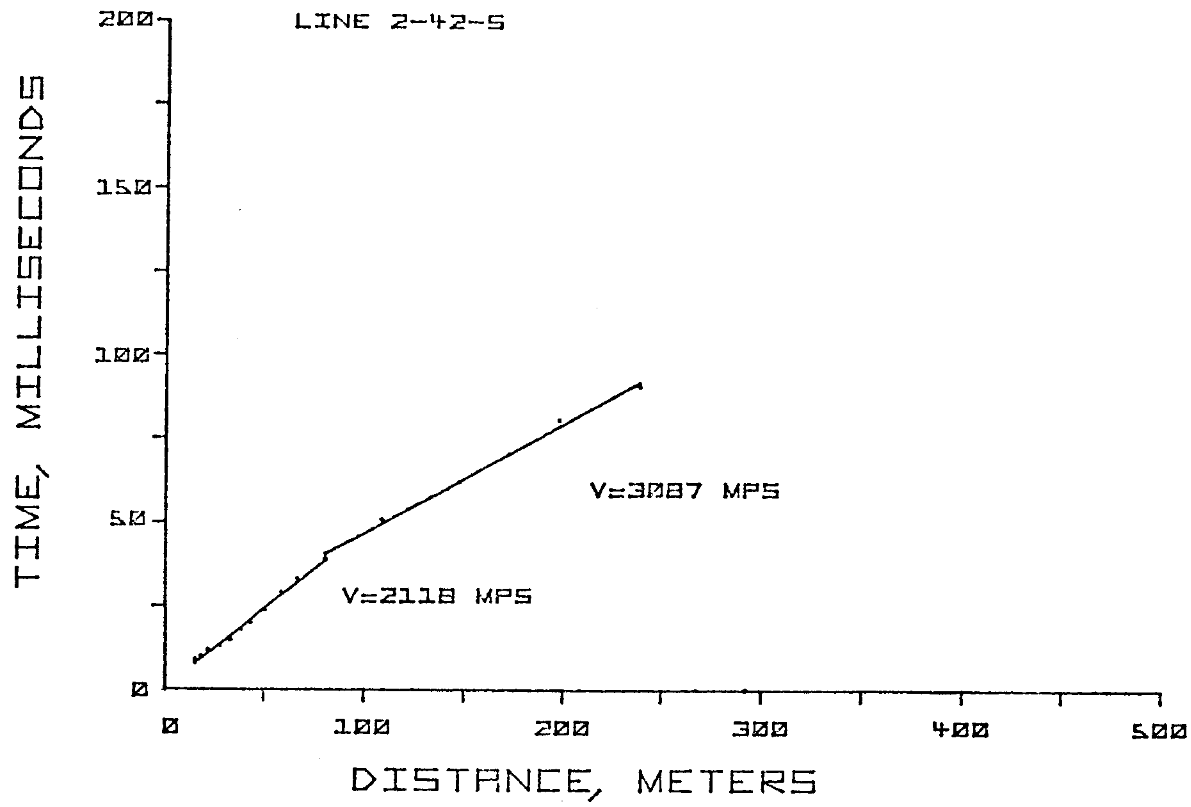
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DISTANCE, METERS
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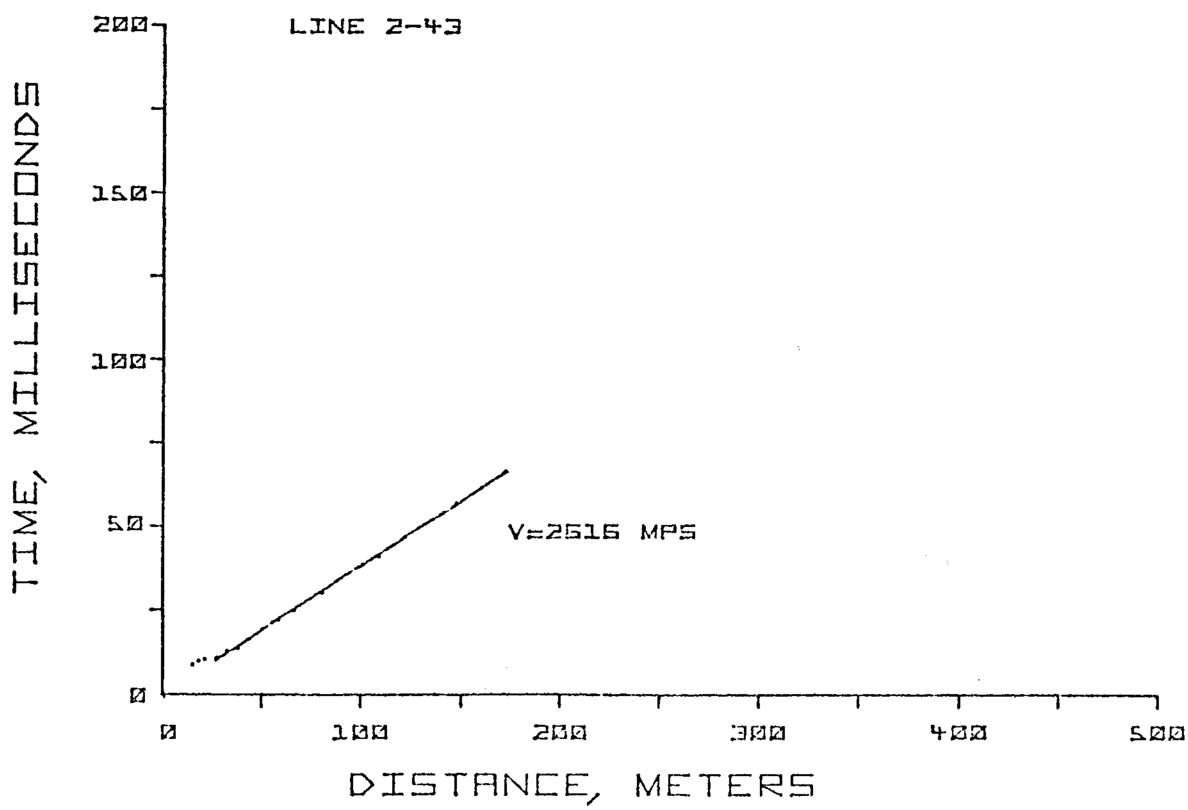
V=2118 MPS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DISTANCE, METERS
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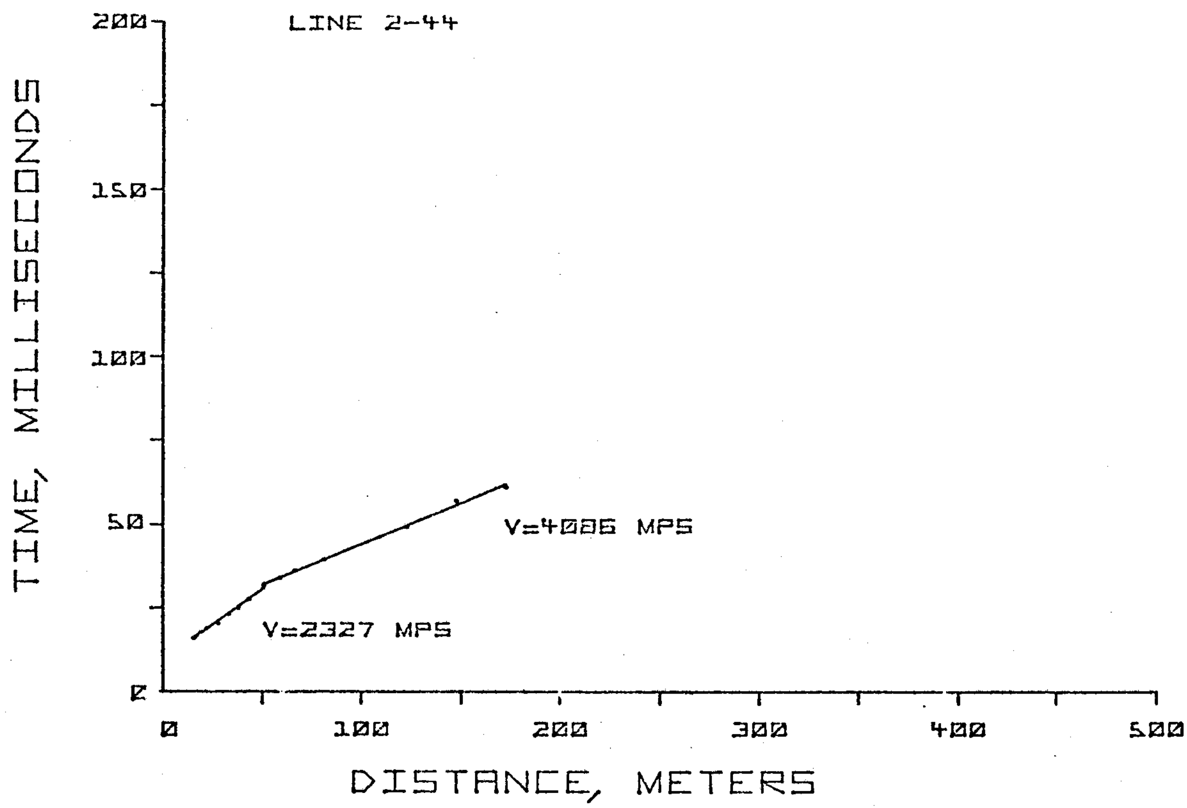
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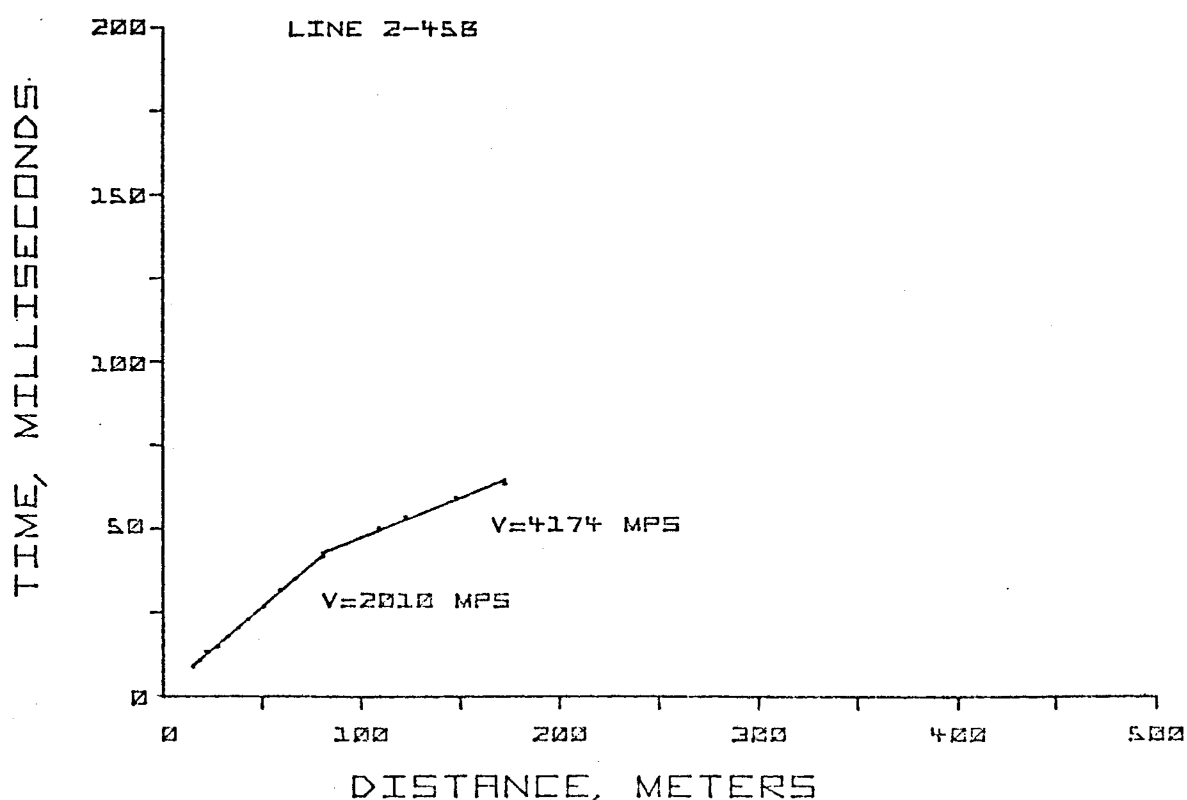
400
500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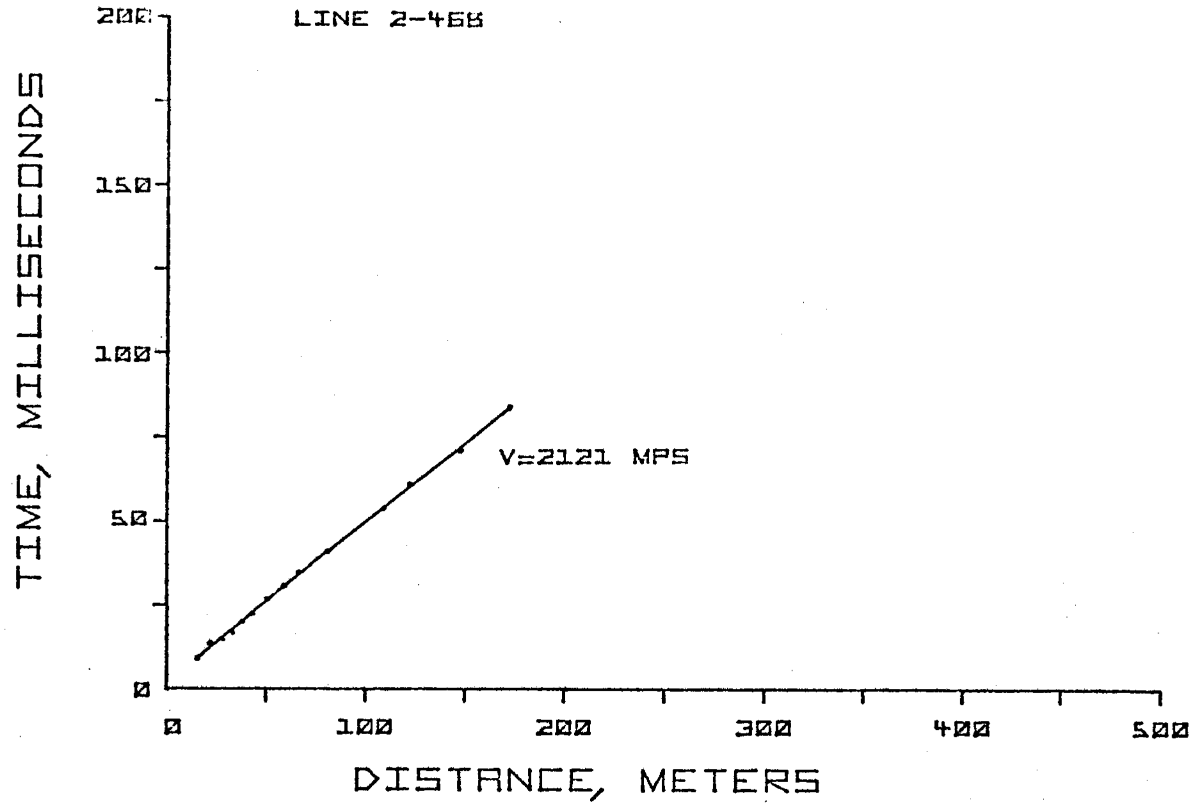

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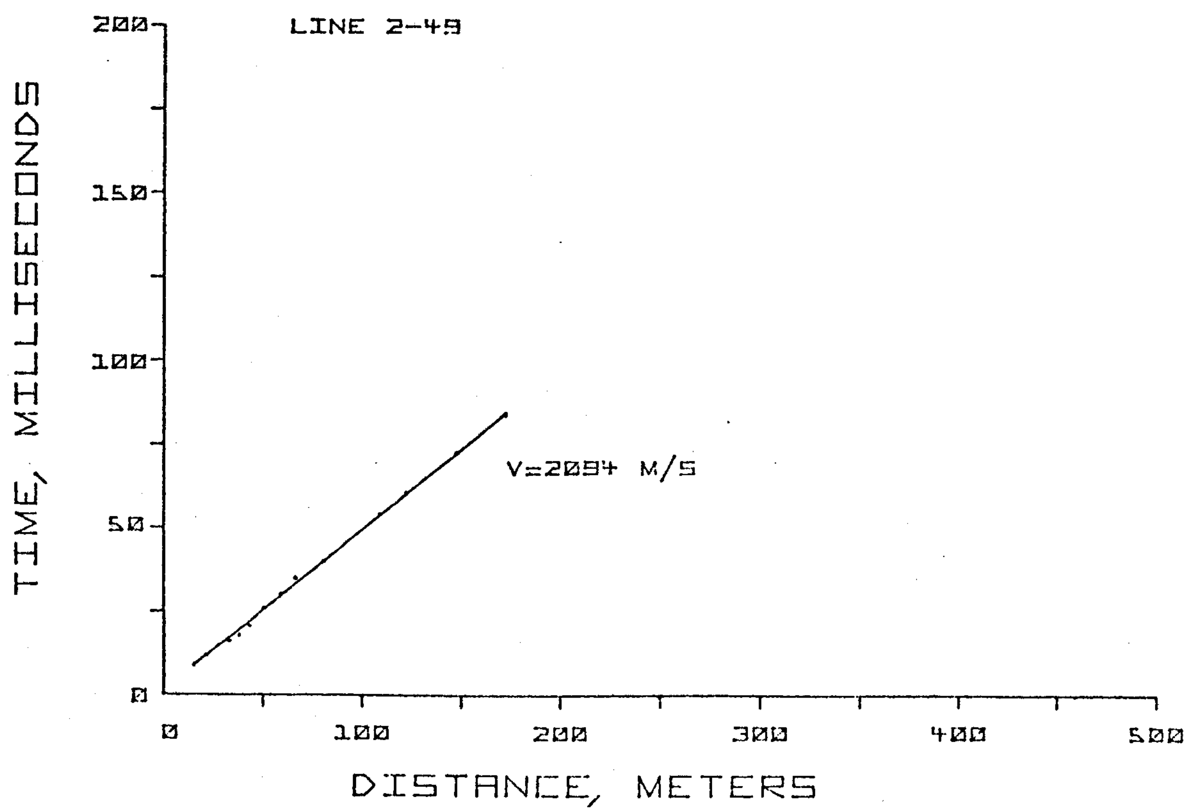

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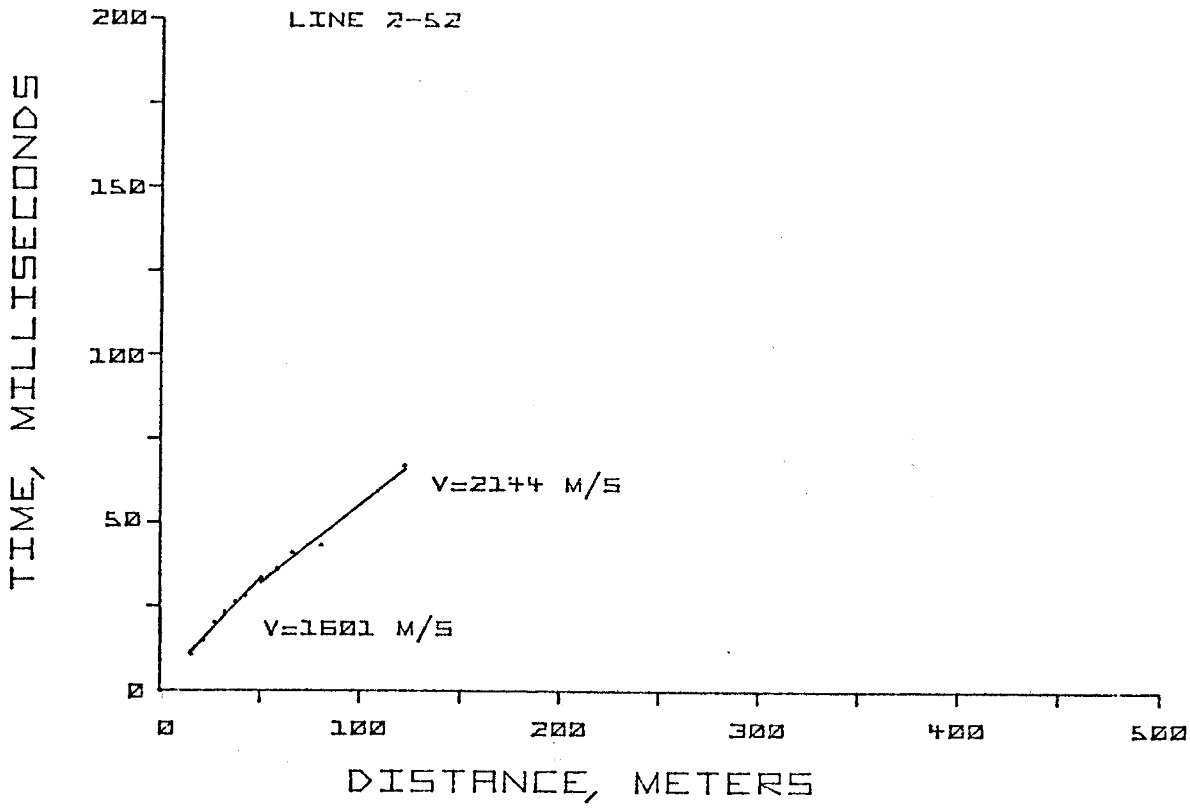
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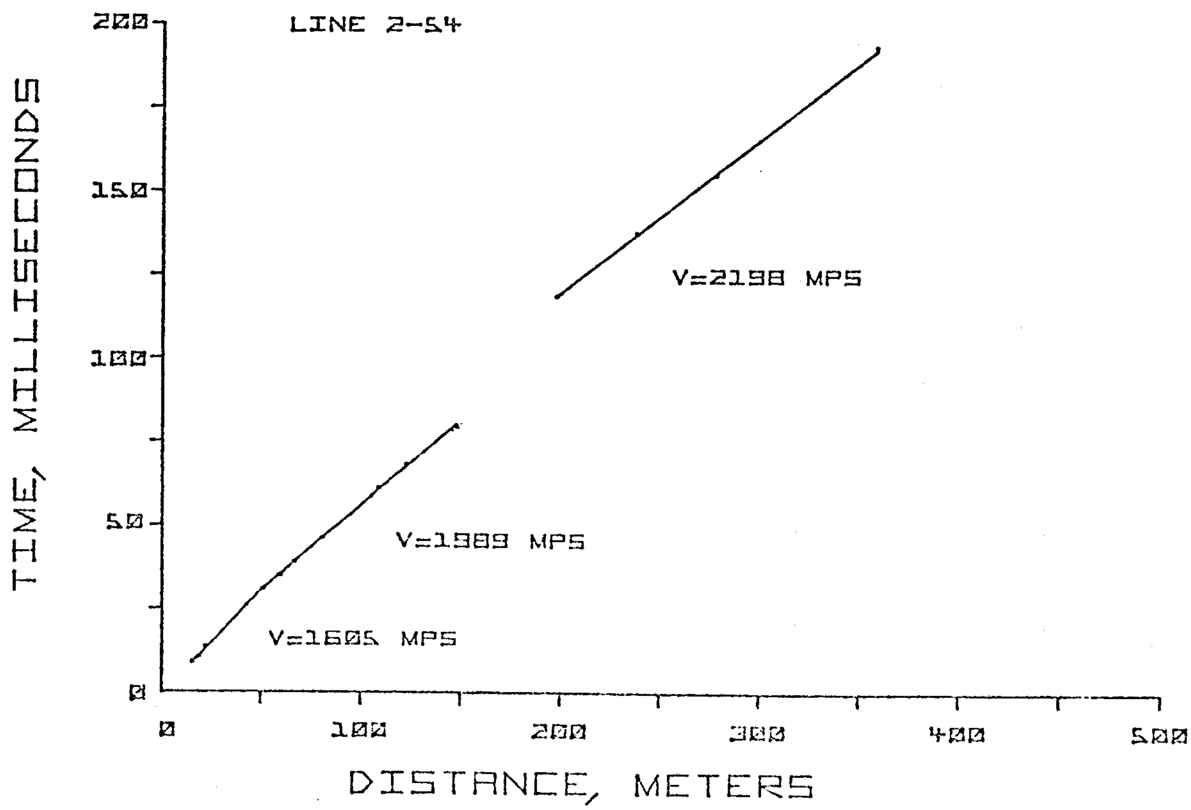
DISTANCE, METERS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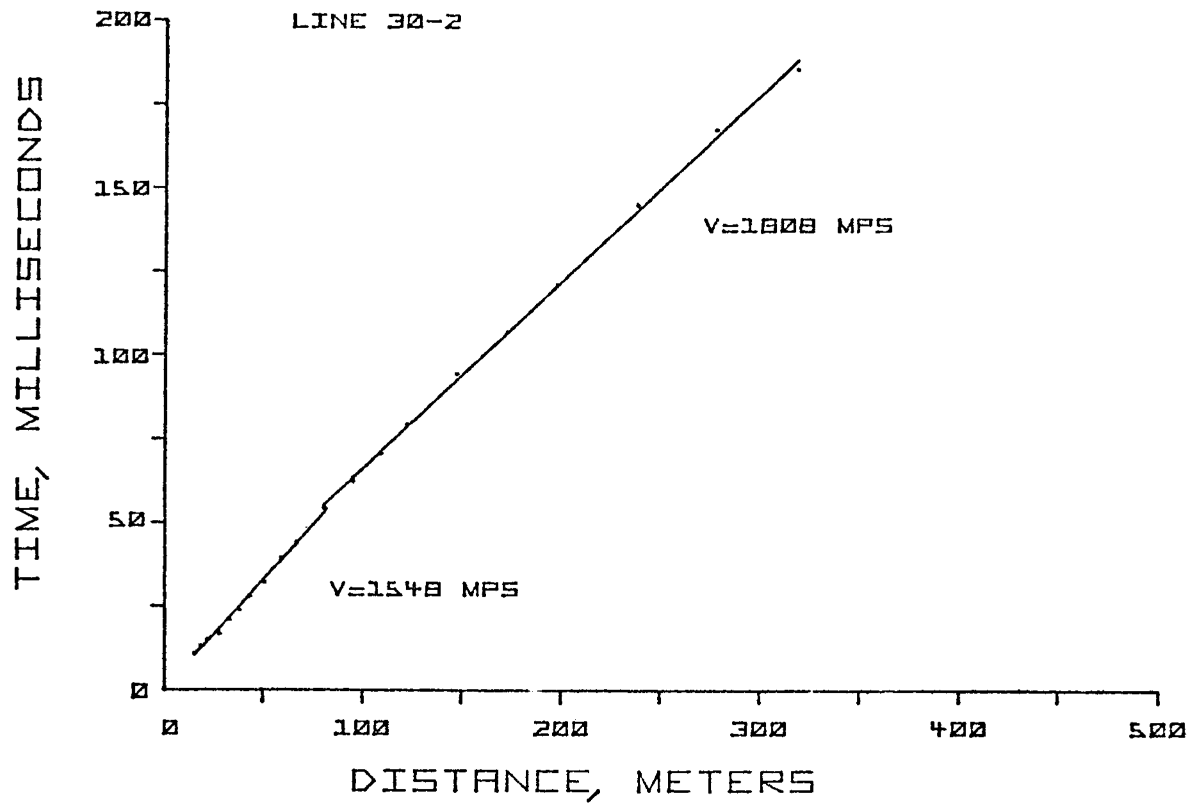
DISTANCE, METERS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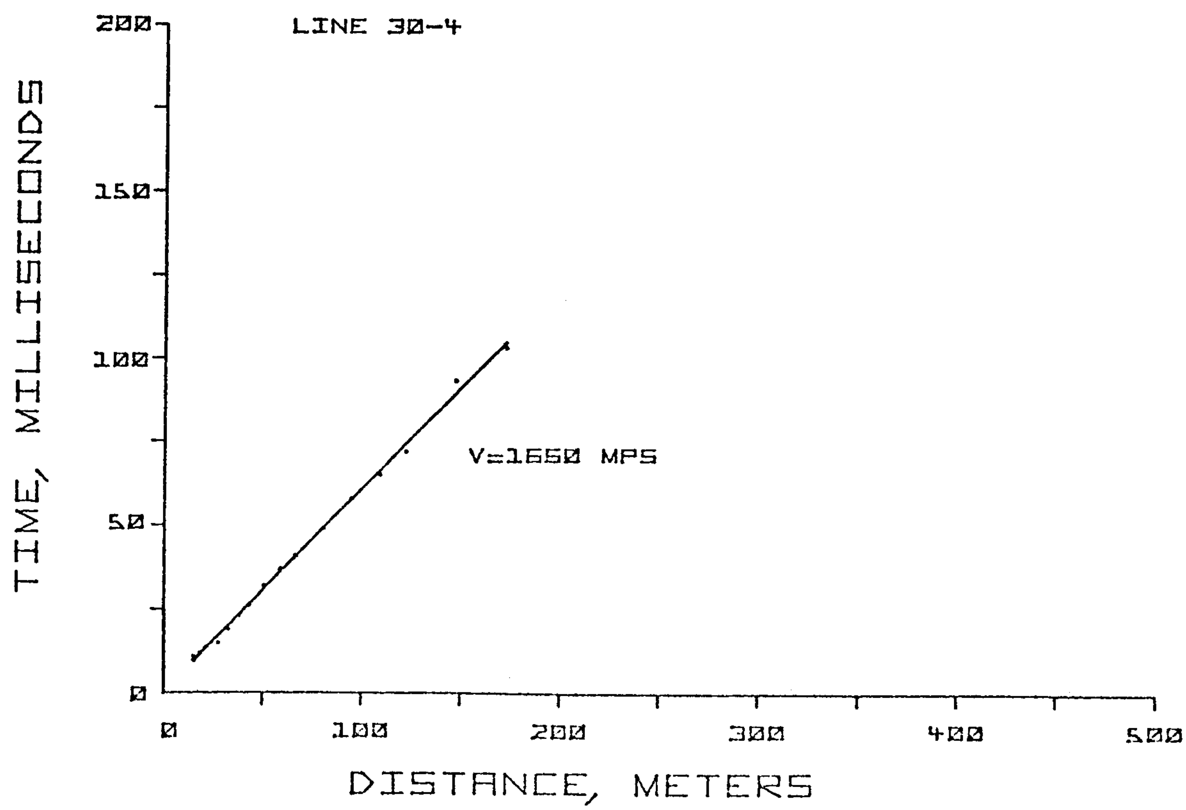
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DISTANCE, METERS
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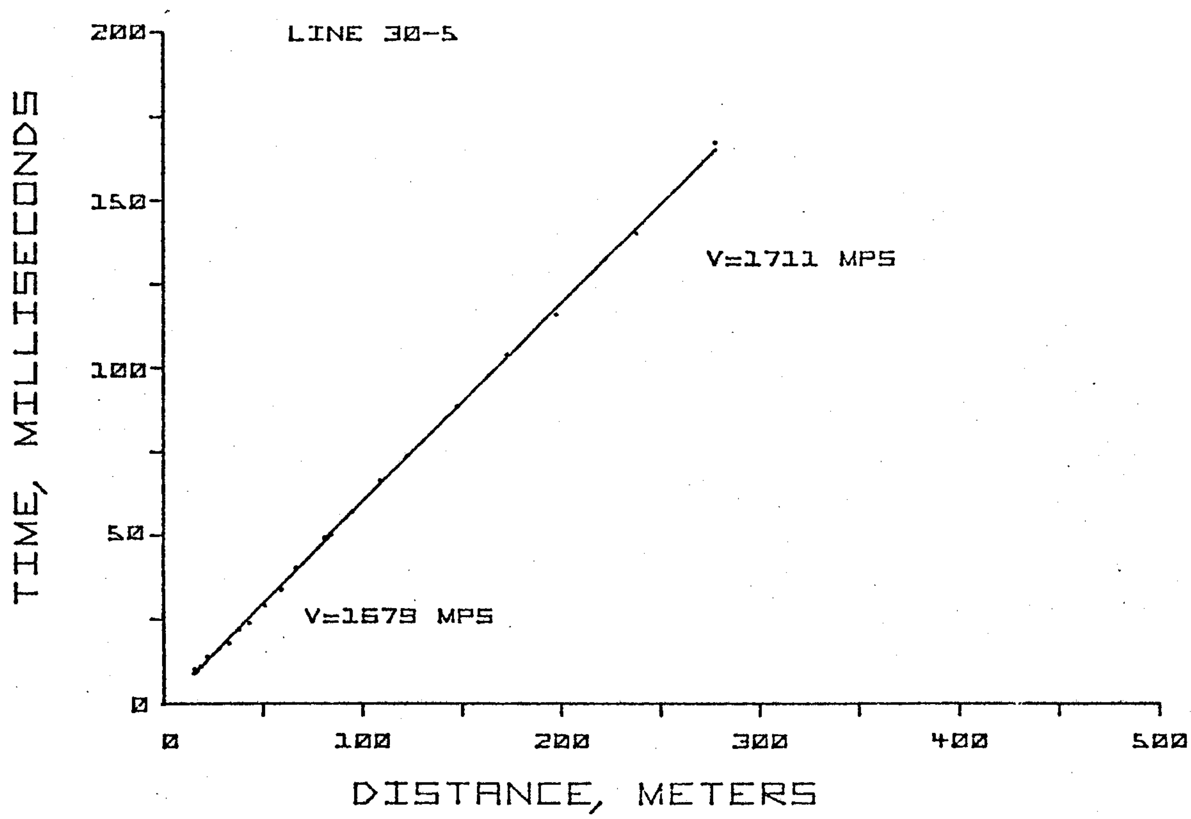
50
100
150
200
0
100
200
300
400
500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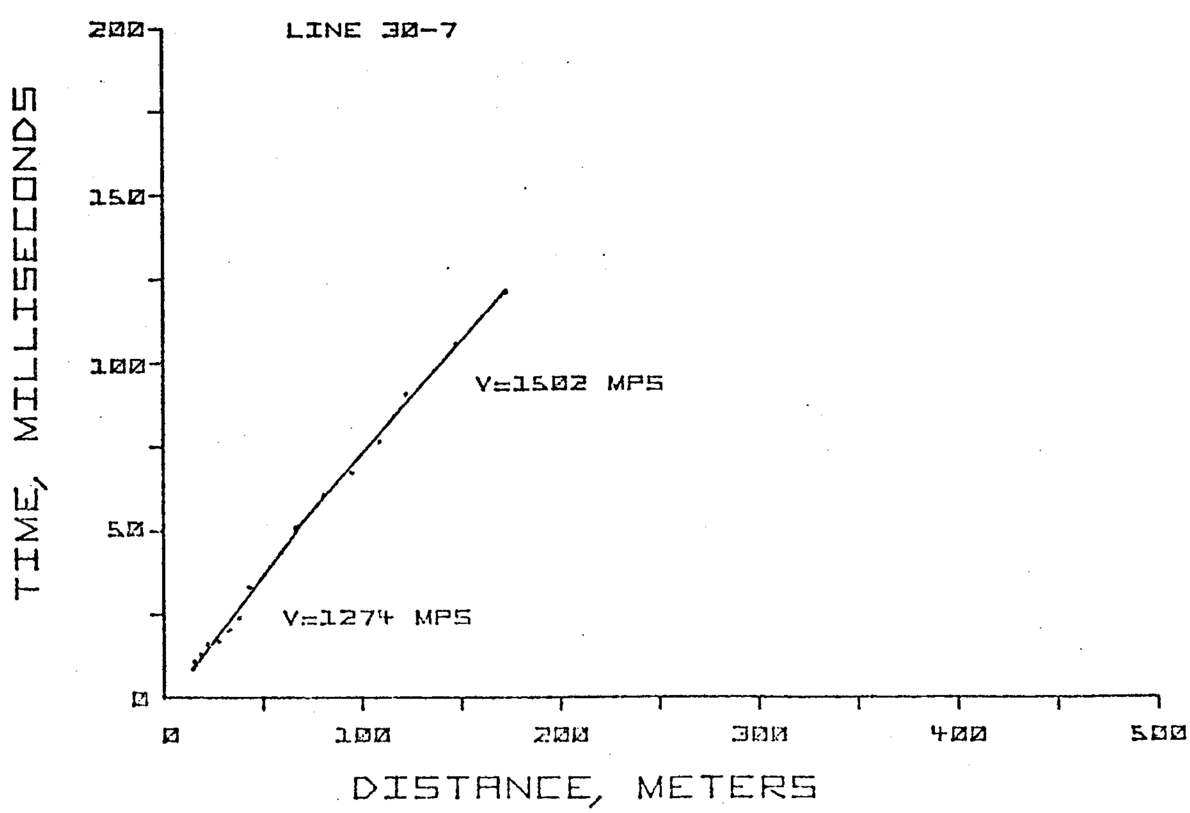
V=1711 MPS
V=1679 MPS
TIME, MILLISECONDS
DISTANCE, METERS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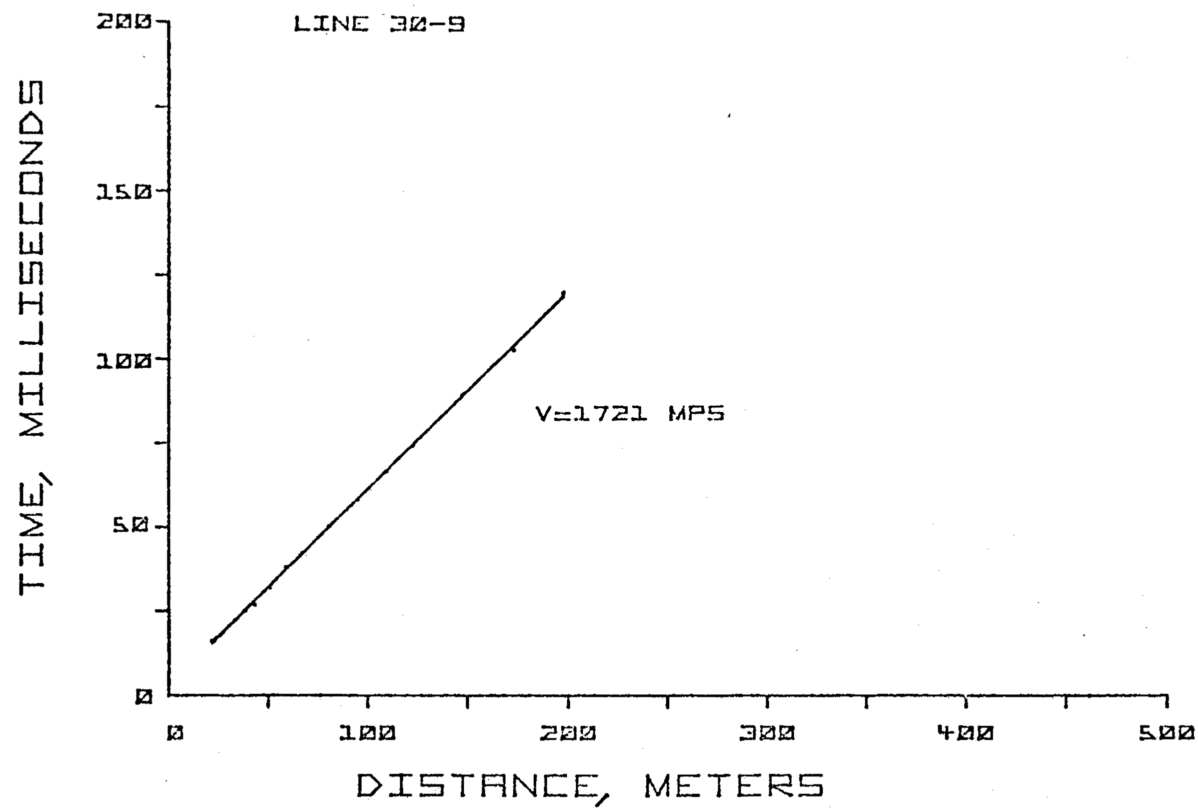
V=1502 MPS
V=1274 MPS
TIME, MILLISECONDS
DISTANCE, METERS


LINE 30-9
V=1721 MPS
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DISTANCE, METERS
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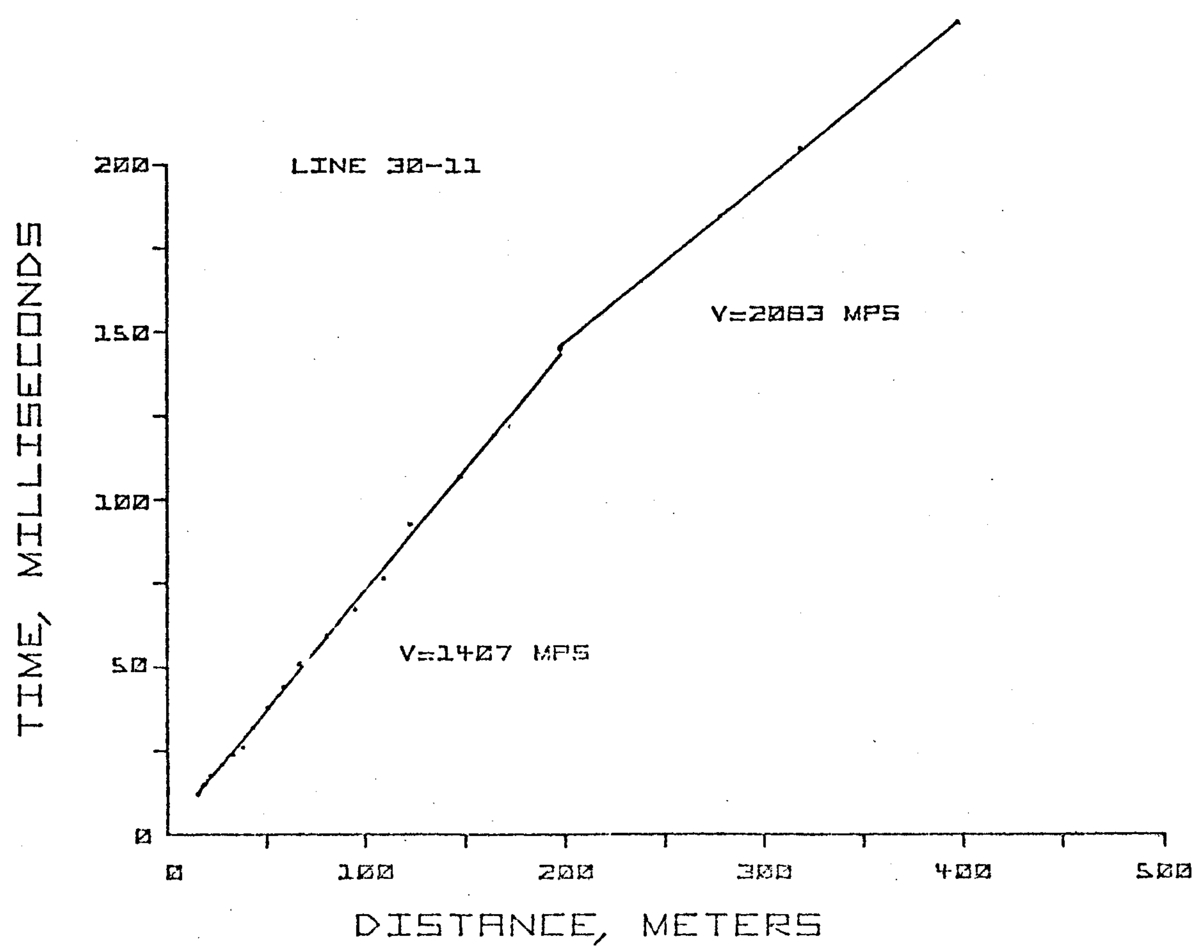
50
100
150
200
0
100
200
300
400
500


LINE 30-11
V=2083 MPS
V=1407 MPS
TIME, MILLISECONDS
DISTANCE, METERS
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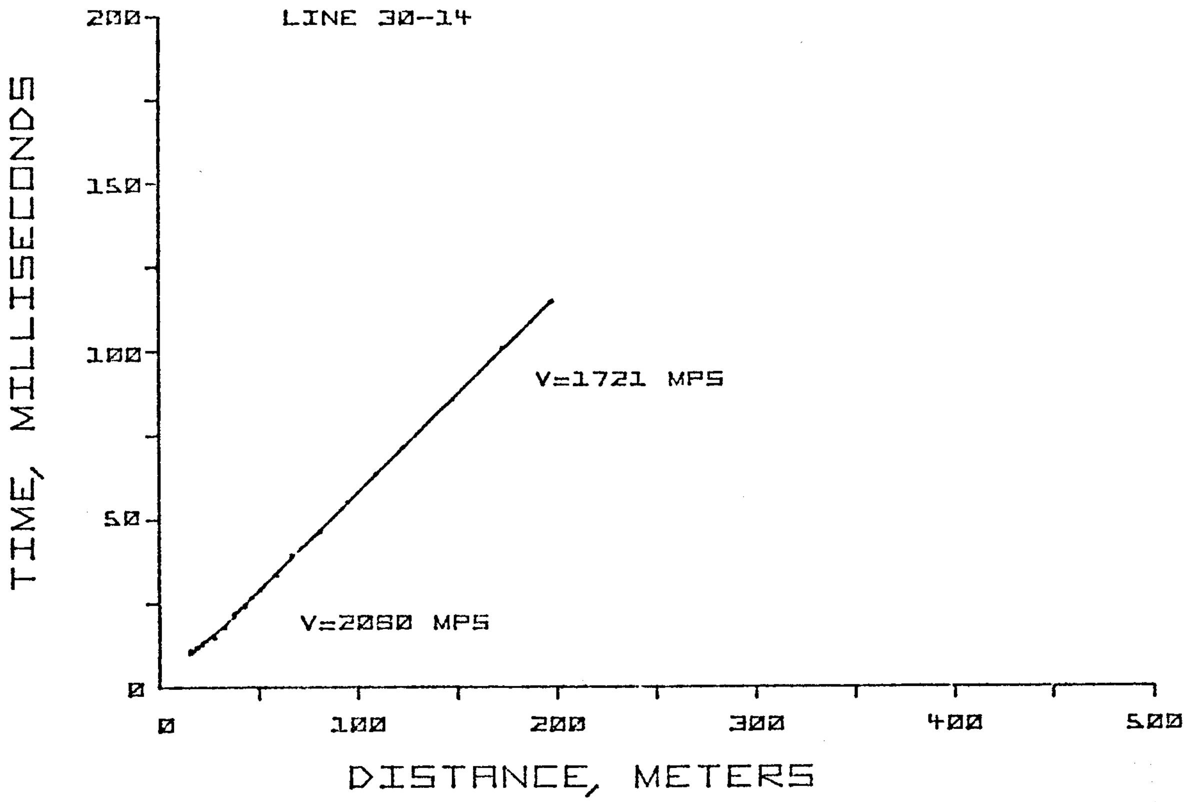
50
100
150
200
0
100
200
300
400
500


LINE 30-14
TIME, MILLISECONDS
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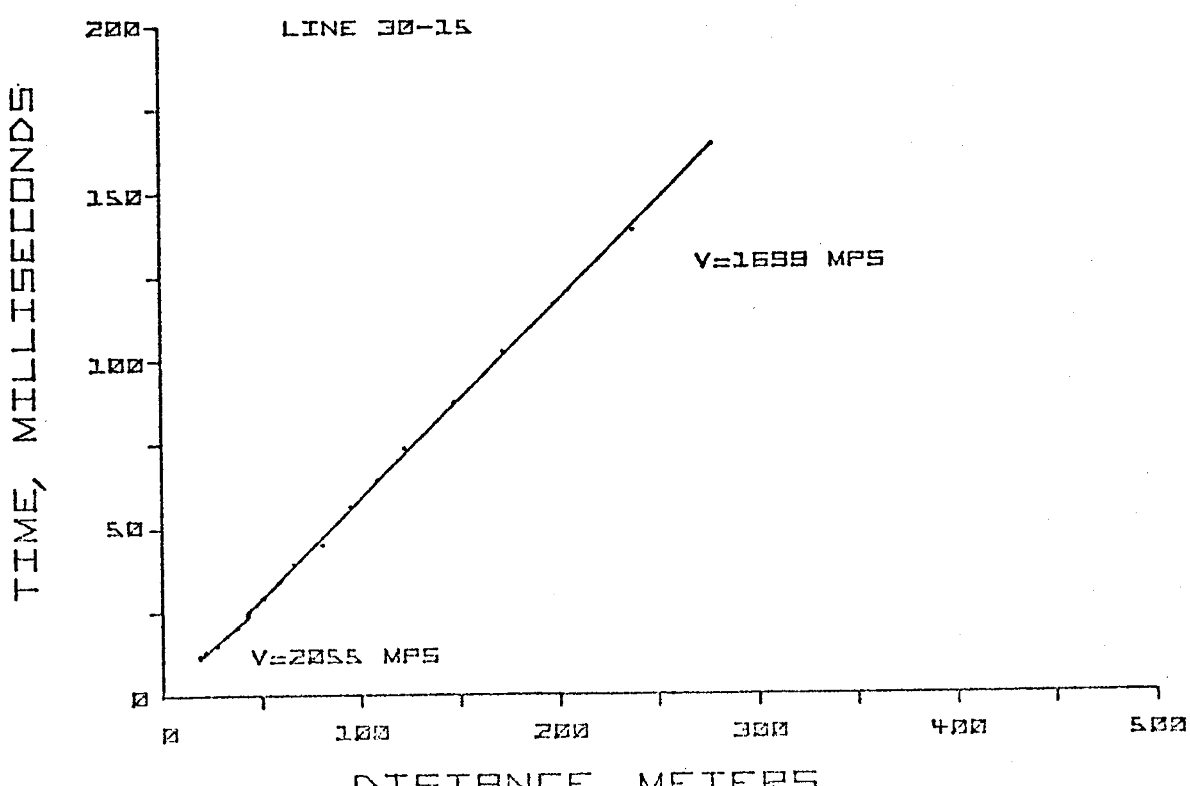
150
100
50
0
V=1721 MPS
V=2080 MPS
0
100
200
300
400
500
DISTANCE, METERS


LINE 30-15
TIME, MILLISECONDS
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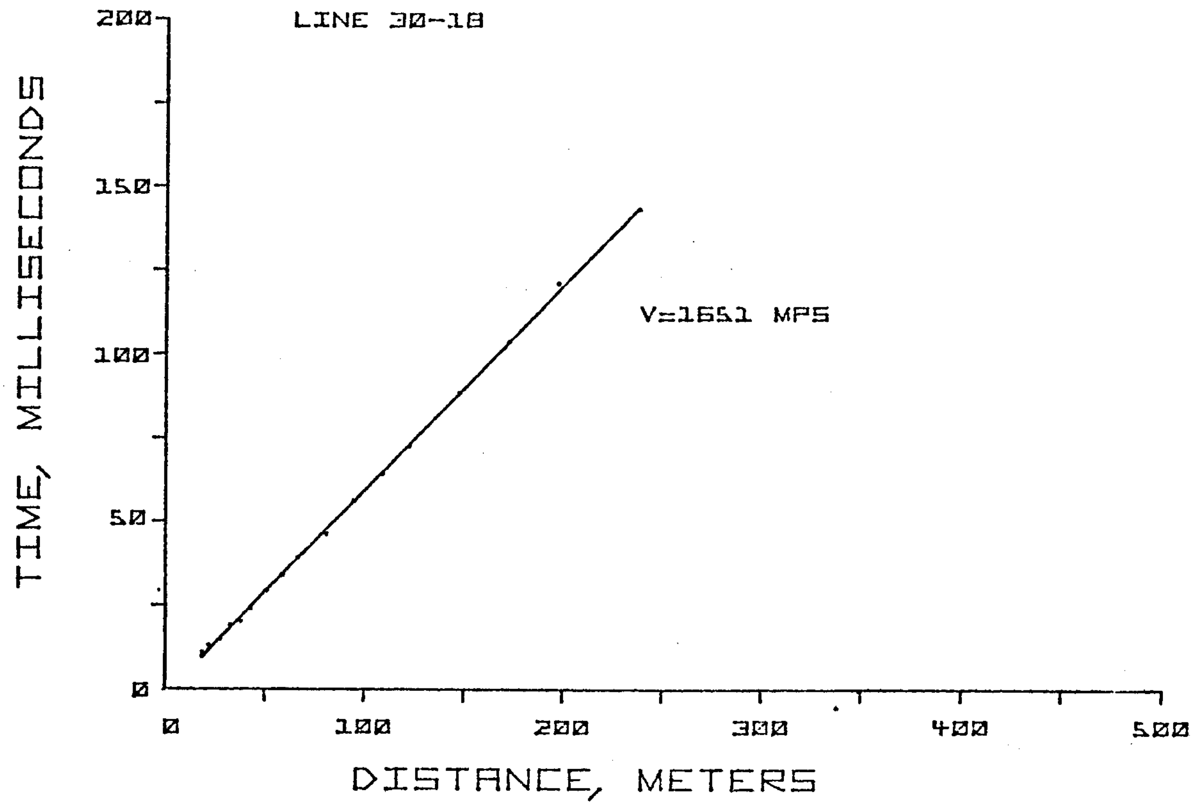
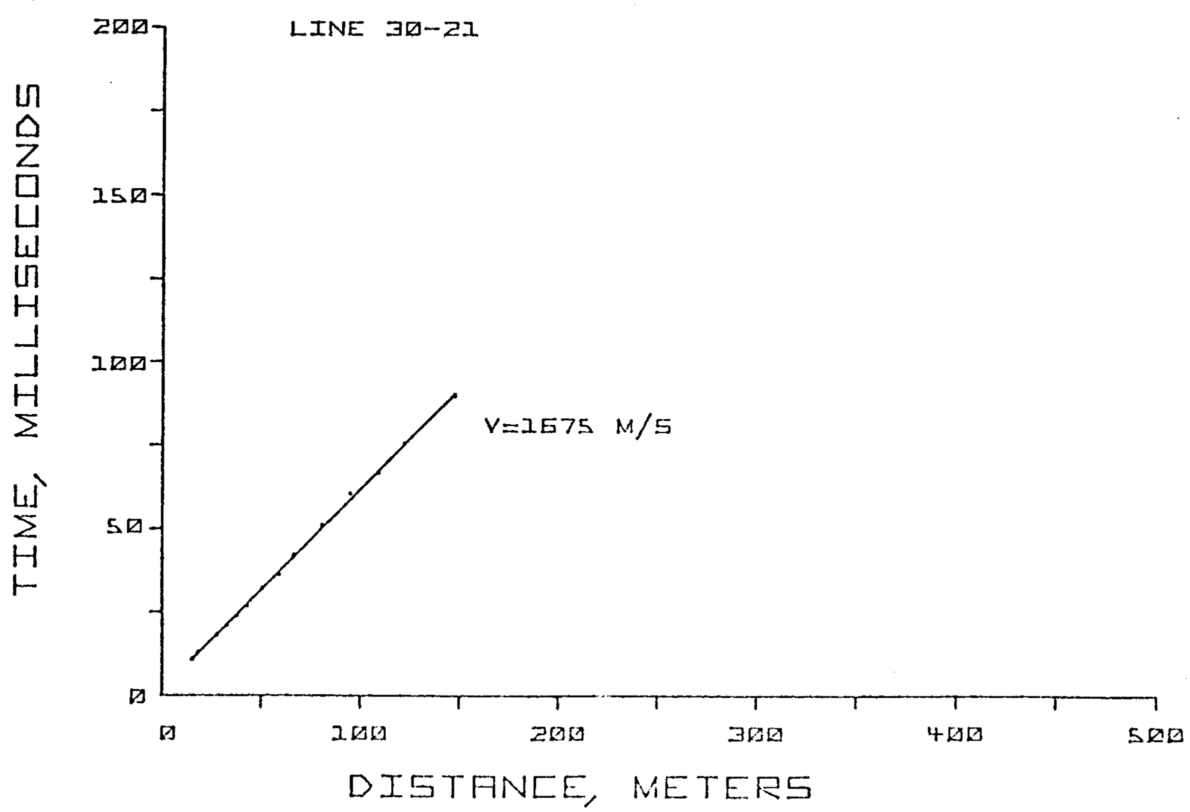
150
100
50
0
V=1699 MPS
V=2055 MPS
0
100
200
300
400
500
DISTANCE, METERS


LINE 30-18
V=1651 MPS
TIME, MILLISECONDS
DISTANCE, METERS
0
50
100
150
200
0
100
200
300
400
500


LINE 30-21
V=1675 M/S
TIME, MILLISECONDS
DISTANCE, METERS
0
50
100
150
200
0
100
200
300
400
500

ANNUAL REPORT

Contract # 03-5-022-56
Research Unit # 290/291/292
Reporting Period 4/1/75-3/31/76
Number of Pages 16

BENTHOS-SEDIMENTARY SUBSTRATE INTERACTIONS

Dr. Charles M. Hoskin
Institute of Marine Science

UNIVERSITY OF ALASKA

March 31, 1976

I. Summary of Objectives

The overall goal of this work is to relate grainsize characteristics of bottom sediment to the distribution and abundance of benthos living in and on the sedimentary substrate. Laboratory analyses are far too imcomplete to warrant conclusions, but of 66 samples available, all but 2 have significant amounts of mud (particles smaller than 0.0625 mm). Because mud has a large surface area, the potential exists for sorption reactions with substances like metal-rich brine and petroleum hydrocarbons released to the water column as a result of exploitation of oil and gas from the continental shelf. Those organisms that obtain their food by filter-feeding will be among the first to be affected by sorbed substances. Mud removed from water by filter-feeding mollusks is ejected as pseudofeces. These agglomerates are large enough to accumulate in the bottom sediments. Thus, one effect of filter-feeding is to extract suspended mud from the water column, increase the particle size through biologically formed aggregates, which causes mud accumulation in the bottom sediment. The next group of organisms which could be affected by sorbed substances would be those which obtain their food by eating sediment. One implication for oil and gas exploitation is that a route exists for substances released, possibly as co-produced fluids, to impinge on the benthos via sorbing reactions with suspended mud.

II. Introduction

A. General nature and scope of study

Particle size analyses of bottom sediment forms the bulk of the laboratory work. Correlation of these data with results from George Mueller's analysis of species composition and abundance of the benthos will follow, and will be an important end-product of this work.

B. Specific objectives

1. Particle size analysis over the range 32.0 to 0.00098 mm of the 66 samples available from the southeastern Bering Sea.
2. Correlation of grainsize data with species composition and abundance of benthos.

C. Relevance to problems of petroleum development

Because there are interactions between living benthos and their sedimentary substrate, perturbations in the physical or chemical nature of the substrate may cause perturbations in the distribution, species composition, and/or abundance of the benthos. Because the benthos, and man, are important parts of the food web in the Bering Sea, baseline data are needed to evaluate changes in the sedimentary substrate that could occur through exploitation of oil and gas resources.

III. Current state of knowledge

To the best of my knowledge, there are no data available relating sediment grainsize and benthos in the southeastern Bering Sea. There are general maps for sediment grainsize (Bezrukov 1964; Lisitsyn 1966; Sharma, et al., 1972) but because of the patchy nature of sediment and benthos distributions, these general maps have little applicability to the objectives of this work.

The following paragraphs are presented to indicate some of the interactions known between sediments and benthos for places other than the Bering Sea. Two excellent general reviews are Rhoads (1974) and Gray (1974). Rhoads (1963) found that a population of 22 *Yoldia* (a clam) per m^2 moved 5-6 liters of sediment/year in Buzzards Bay, and in Long Island Sound that an average of 377 ml sediment was moved/clam/year. Prokopovich (1969) found in California that *Corbicula fluminea* (a clam) caused the deposition of 5.4 g sediment/clam/year from water with an average suspended sediment load of 30 mg/1. Lund (1957a, 1957b) reported that *Crassostrea virginica* (an oyster) deposited 0.82 g (dry wt.) sediment/oyster/day which represented 5-23 percent of the available suspended sediment load. By volume, 1.67 cc was pseudofeces, and 0.74 cc was feces for a total volume of 2.41 cc sediment/oyster/day. Haven and Morales-Alamo (1966) found that 95 percent of the sediment particles deposited by oysters were smaller than 3μm.

Ginsburg (1957) showed from aquarium experiments that oligochaetes (worms) homogenized 100 mm-thick layered sediments in 30 days. Gordon (1966) studied *Pectinaria gouldii* (a worm) in Barnstable Harbor and found that a population density of 10 worms/m^2 moved sediment at the rate of 600 g/worm/year. Half the organic matter in the sediment moved was removed by the worms. Nichols (1974) found that *Pectinaria californiensis* (a worm) moved sediment to a depth of 5 cm in Puget Sound, each worm moving 1-20 mg sediment/hour. Sheldon and Warren (1966) reported that *Pandalus montaguii* (pink shrimp) contained 0.3-3.8 mg sediment/animal in its alimentary tract. MacGinitie (1934) found that *Callianassa californiensis* (mud shrimp) reworked sediment to a depth of 75 cm in 8 months. Each shrimp moved 20-50 cc sediment/day. Hartnoll (1973) found that the crab *Dotilla fenestrata* produced about 25 pellets/minute from sand in Africa. Warme (1967) found in Mugu Lagoon, California, that per unit time, organisms move 10-100X more sediment than all other non-living transport agents. Crozier (1918) reported that a population of 675 *Stichopus* (sea cucumber) ate 13.5 kg sediment/day.

From these data, there is little doubt about the interactions of benthos and sedimentary substrates.

IV. Study area

Samples for this study came from the southeastern Bering Sea, bounded by 54-61° N. Lat.; 158-174° W. Long. (Fig. 1).

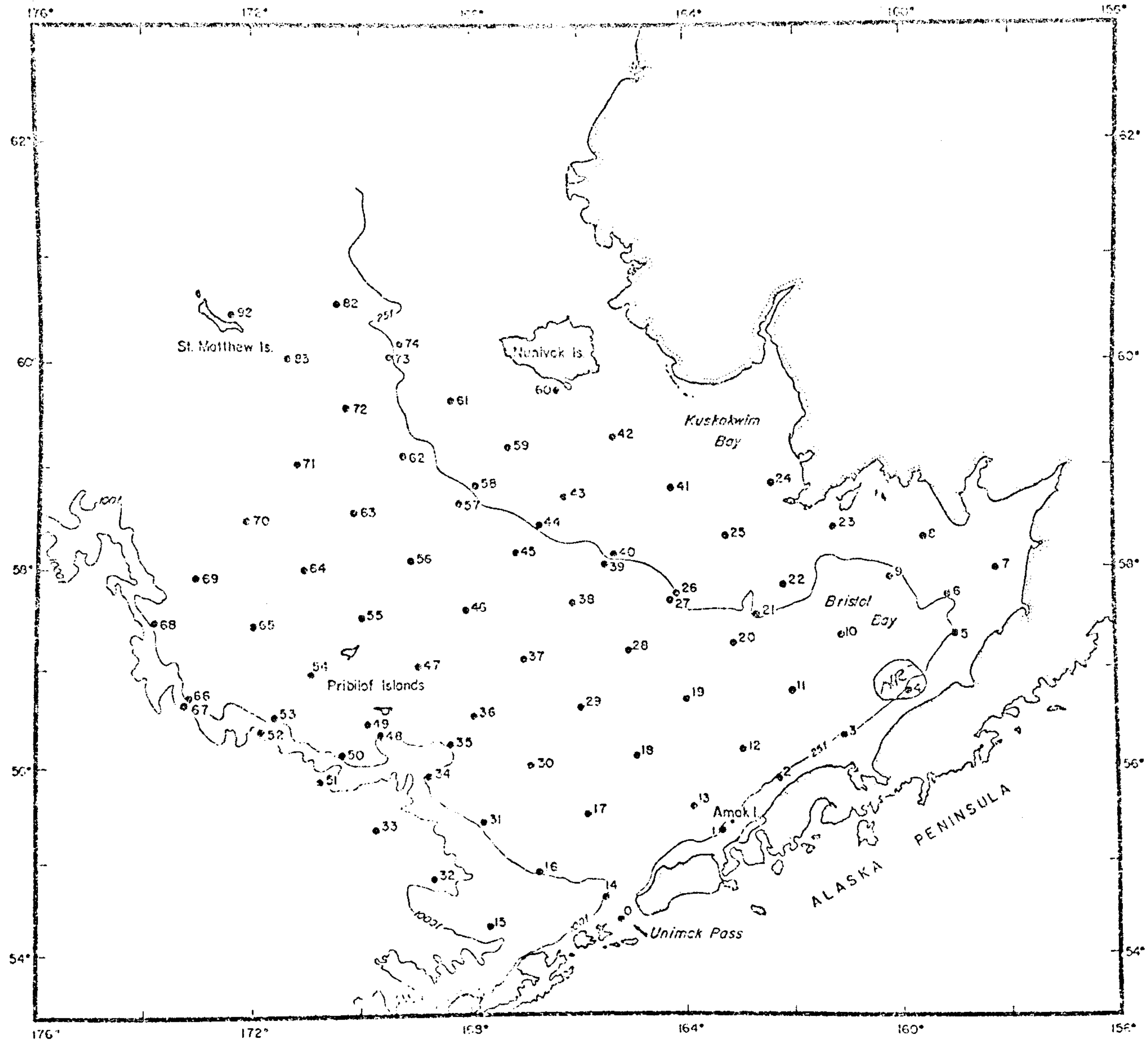


Figure 1. Index map of the southeastern Bering Sea, showing location of Van Veeb grab stations.

V. Sources, methods, rationale of data collection

All samples were aliquots taken from the van Veen grab program designed by Dr. Howard Feder and his colleagues. Samples obtained in this way give positive assurance that sediment grainsize data will be pertinent to species composition and abundance of the benthos as both sets of data came simultaneously from the same site. Methods of analysis and data reduction are described in a separate section and therefore will not be repeated here.

VI. Results

The status of the 66 samples available is shown in Table 1; 45 samples have been through peroxide digestion, 61 through wet sieving, 33 have been dry sieved, 6 have been pipetted, and as of this writing (12 March 1976), 6 samples have completed grainsize analyses. Data for these completed analyses are given in Table 2.

VII. Discussion

None.

VIII. Conclusions

As so few completed analyses are available at this time, it is meaningless to discuss results and to draw conclusions.

TABLE 1

Status of Laboratory Analyses

Sample Number	Split of Raw Sample	Digestion	Wet Sieving	Dry Sieving	Pipettings	Completed Data Reduction
1	x		x			
3	x		x	x		
4	no recovery					
5	x		x			
6	x		x	x		
7	x		x	x		
8	x		x			
9	x		x	x		
10	x		x	x		
11	x	x	x	x		
13	x	x	x	x		
14	x	x	x			
16	x	x	x	x	x	x
17	x	x	x	x		
19	x	x	x			
20	x	x	x	x		
21	x	x	x			
22	x	x	x	x		
23	x		x			
24	x		x	x		
25	x	x	x	x		
26	x	x	x	x		
27	x	x	x			
28	x	x	x			
29	x	x	x			
31	x	x	x	x	x	x
32	x	x	x	x	x	x
33	x	x	x	x		
34	x	x	x			
35	x					
36	x	x	x			
37	x	x	x	x	x	x
38	x	x	x			
39	x	x	x			
40	x	x	x			
41	x	x	x			
42	x					
43	x					
44	x	x	x	x		
45	x	x	x	x		
46	x	x	x			
47	x					
48	x					
49	x	x	x	x		
50	x		x	x		
54	x	x	x			
55	x		x	x		

292

Sample Number	Split of Raw Sample	Digestion	Wet Sieving	Dry Sieving	Pipettings	Completed Data Reduction
56	x	x	x	x		
57	x	x	x	x		
58	x		x			
59	x	x	x	x		
60	x	x	x	x		
61	x	x	x			
62	x	x	x	x		
63	x	x	x			
64	x	x	x			
65	x	x	x			
66	x	x	x	x		
68	x	x	x	x		
69	x	x	x			
70	x	x	x	x		
71	x		x	x	x	x
72	x		x			
73	x	x	x			
82	x	x	x			
83	x		x	x	x	x
92	x	x	x			
TOTAL	66	45	61	33	6	6

TABLE 2

Results of Grain-Size Analysis
(data in grams)

Retained on Screen mm	MB16	MB31	MB32	MB37	MB71	MB83
32.0						
22.6						
16.0						
11.2						
8.0						
5.6						
4.0						
2.8						
2.00	0.08	0.24	0.02	0.00	0.08	0.01
1.68	0.00	0.0256	0.00	0.00	0.0322	0.00
1.41	0.0600	0.0256	0.00	0.00	0.0095	0.0217
1.19	0.0287	0.0331	0.0047	0.00	0.0235	0.0285
1.00	0.0353	0.0531	0.0235	0.0446	0.0863	0.00
0.84	0.0405	0.0468	0.0161	0.0627	0.0248	0.0281
0.71	0.0523	0.1055	0.0162	0.0648	0.0219	0.0325
0.59	0.0591	0.1153	0.0228	0.0652	0.0208	0.0253
0.50	0.1319	0.2665	0.0381	0.1426	0.0380	0.0422
0.42	0.1831	0.3677	0.0440	0.2238	0.0468	0.0418
0.35	0.4248	0.6688	0.146	0.4614	0.0943	0.0619
0.30	0.7632	2.6638	0.404	1.2395	0.1634	0.1113
0.25	1.4515	3.0492	1.038	2.9488	0.5351	0.3693
0.21	2.7029	5.8138	2.60	6.004	2.1231	0.9089
0.177	4.4482	9.5886	4.92	11.349	5.0109	2.2346
0.149	1.1106	25.5591	13.05	28.6619	15.7540	6.6547
0.125	12.5937	39.6929	16.01	28.8226	17.9179	9.9983
0.105	12.3093	33.1093	15.56	22.0447	16.4372	12.7862
0.088	13.7359	35.7291	16.32	22.3748	15.4440	22.3682
0.074	22.8903	41.8903	33.75	44.0725	24.9953	52.0570
0.0625	2.0697	2.9594	8.39	5.5569	4.8010	10.7409
0.044	35.801	18.346	55.302	39.546	28.032	49.66
0.031	24.105	5.71	12.868	7.875	14.745	18.031
0.022	15.384	4.537	4.985	2.481	9.548	9.226
0.0156	10.27	3.383	2.554	5.451	8.466	6.725
0.0113	5.51	2.17	2.006	2.18	7.149	3.425
0.0078	3.49	1.799	1.459	2.538	5.08	4.309
0.0055	3.22	1.056	0.912	1.691	2.305	2.668
0.0039	2.75	1.154	1.135	2.143	3.198	2.27
0.0020	4.12	2.19	1.155	2.331	3.457	2.858
0.00098	4.52	1.76	2.168	2.594	3.763	1.808
<0.00098	10.551	5.847	3.891	7.217	8.513	8.637

IX. Needs for further study

As distinct from grainsize parameters, sedimentary substrates can also be characterized by their chemical nature, which derives from the mineral composition of the substrate particles. Within certain constraints (clay minerals are usually clay size, for example), mineral composition and grainsize are independent variables. In the Bering Sea, substrate minerals come from detrital silicate particles of quartz, feldspars, clay minerals, and volcanic ejecta, and from biogenically percipitated skeletons of opal and carbonate minerals. Analogous to the benthos-grainsize responses, substrate mineralogy controls, and in turn is controlled by, the abundance and distribution of the benthos.

The search for significant correspondence between the benthos and mineral composition of the substrate will be done in successive years. Mineral studies will be integrated with trace metal and nutrient cycling studies. It is expected, for example, that coincidence of populations of certain clams with abundant clay minerals will result in a copper-enriched substrate as clams extract copper from sea water. Another example, coincidence of abundant volcanic ash and biogenic opal will identify sites of greater-than-usual recycling of silica from sediment porewater to the overlying water column.

X. Summary of Fourth Quarter operations

A. Ship Activities

None

B. Laboratory Activities

Size analysis of sediments is now in progress with approximately 30 percent of the task completed. Ms. Connie Espe, a temporary technician, and Ms. G. H. Kris Tommos, a graduate student working towards the MS in geological oceanography, are both working on size analysis; Espe is doing pipetting and Tommos is doing dry sieving. The requested description of the sample analysis procedure has been written and submitted to Mr. Ray Hadley. Data is starting to come from George Mueller's group for species composition and abundance of the benthos, and increasing amounts of time will be spent in the next two quarters correlating grainsize data with benthos data. A request has been made to the University of Washington for a computer program to perform automated data reduction.

C. Results

Please see section in Annual Report above.

D. Problems Encountered

During the course of dry sieving, it was discovered that particle aggregates were much more abundant than originally expected. It was necessary to borrow a low-power stereo-microscope to examine each size fraction as it came from the sieves to be sure aggregates were not present. For those samples in which aggregates survived the first digestion, a recycling through the digestion step was made. The borrowed microscope had to be returned at the loaners' request, and a request to purchase a microscope for this project has been submitted. Unused travel funds would be converted to equipment purchase, if the request is approved.

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OCS COORDINATION OFFICE

University of Alaska

ENVIRONMENTAL DATA SUBMISSION SCHEDULE

DATE: March 31, 1976

CONTRACT NUMBER: 03-5-022-56 T/O NUMBER: 3 R.U. NUMBER: 291

PRINCIPAL INVESTIGATOR: Dr. C. M. Hoskin

Submission dates are estimated only and will be updated, if necessary, each quarter. Data batches refer to date as identified in the data management plan.

Cruise/Field Operation	Collection Dates		Estimated Submission Dates[1]		
	From	To	Batch 1		
Discoverer Leg I #808	5/15/75	5/30/75	6/30/76		
Discoverer Leg II #808	6/2/75	6/19/75	6/30/76		
Miller Freeman	8/16/75	10/20/75	6/30/76		

Note: [1] Estimated submission dates are contingent upon final approval of data management plan submitted in draft form Oct. 9, 1975 and University of Alaska approved form Nov. 10, 1975, to NOAA. Also, receipt and approval of data format is necessary.

OCS COORDINATION OFFICE

University of Alaska

ESTIMATE OF FUNDS EXPENDED

DATE: March 31, 1976

CONTRACT NUMBER: 03-5-022-56

TASK ORDER NUMBER: 3

PRINCIPAL INVESTIGATOR: Dr. Charles M. Hoskin

Period April 1, 1975 - March 31, 1976* (12 mos)

	Total Budget	Expended	Remaining
Salaries & Wages	23,296.00	9,940.96	13,355.04
Staff Benefits	3,955.00	1,689.95	2,265.05
Equipment	550.00	198.00	352.00
Travel	1,500.00	273.74	1,226.26
Other	3,000.00	1,618.85	1,381.15
Total Direct	32,301.00	13,721.50	18,579.50
Indirect	13,325.00	5,686.23	7,638.77
Task Order Total	45,626.00	19,407.73	26,218.27

* Preliminary cost data, not yet fully processed.

Following is part 2 of the quarterly report R.U.# 290/291/292 for the period ending December 31, 1975. This was received after the printing of the Quarterly Reports, July - September 1975, therefore is included here.

RECEIVED
JAN 19 1976

OCS COORDINATION OFFICE

University of Alaska NEGOA

Quarterly Report for Quarter Ending December 31, 1975

Project Title: Benthos-Sedimentary Substrate Interactions

Contract Number: 03-5-022-56

Task Order Number: 3

Principal Investigator: Dr. Charles M. Hoskin

I. Task Objectives

Acquisition of equipment and supplies has been completed. Considerable effort has been put into hiring a part-time technician and Ms. Connie Espe is expected to begin work on this project 10 January. Ms. G. H. Kris Tommos is also expected to join this project as a graduate student. Ms. Espe and Tommos will assist in grain size analysis. Coordination of data management format was worked out with Dr. Joe Creager (University of Washington) and Mr. Ray Hadley (University of Alaska) concerning grain size boundaries to be used in sample analysis. Work was started on preparing a step-by-step account of sample acquisition-storage-analysis as requested by Mr. Hadley. This is to be submitted with the next Quarterly Report. Planning for bench space was completed. This is about to enter the construction phase. Two requests were prepared and submitted for OASIS Computer Literature Searches in support of Principal Investigator's Projects for the Alaska OCSEP. One of these searches has been received and is being analyzed.

II. Field Activities

A cruise under the direction of Dr. Howard Feder has provided about 40 new samples of sediment from the Bering Sea floor, bringing the total number of samples available to approximately 100.

III. Results

Laboratory analysis has not yet begun.

IV. Problems Encountered

Laboratory bench and assistants for laboratory analysis are not yet available.

OCS COORDINATION OFFICE

University of Alaska

ENVIRONMENTAL DATA SUBMISSION SCHEDULE

DATE: December 31, 1975

CONTRACT NUMBER: 03-5-022-56 T/O NUMBER: 3 R.U. NUMBER: 291

PRINCIPAL INVESTIGATOR: Dr. C. M. Hoskin

Submission dates are estimated only and will be updated, if necessary, each quarter. Data batches refer to data as identified in the data management plan.

Cruise/Field Operation	Collection Dates		Estimated Submission Dates[1]			
	From	To	Batch 1			
Discoverer Leg I #808	5/15/75	5/30/75	3/31/76			
Discoverer Leg II #808	6/2/75	6/19/75	6/30/76			
Miller Freeman	8/16/75	10/20/75	6/30/76			

Note: (1) Estimated submission dates are contingent upon final approval of data management plan submitted in draft form Oct. 9, 1975 and University of Alaska approved form Nov. 20, 1975, to NOAA.

OCS COORDINATION OFFICE

University of Alaska

ESTIMATE OF FUNDS EXPENDED

DATE: December 31, 1975

CONTRACT NUMBER: 03-5-022-56

TASK ORDER NUMBER: 3

PRINCIPAL INVESTIGATOR: Dr. Charles M. Hoskin

Period April 1 - December 31, 1975* (9 mos)

	Total Budget	Expended	Remaining
Salaries & Wages	23,296.00	4,667.36	18,628.60
Staff Benefits	3,955.00	793.45	3,161.55
Equipment	550.00	175.00	375.00
Travel	1,500.00	323.74	1,176.26
Other	3,000.00	1,127.69	1,872.31
Total Direct	32,301.00	7,087.24	25,213.76
Indirect	13,325.00	2,669.73	10,655.27
Task Order Total	45,626.00	9,756.97	35,869.03

* Preliminary cost data, not yet fully processed.

ANNUAL REPORT

FAULTING AND INSTABILITY OF SHELF SEDIMENTS

WESTERN GULF OF ALASKA

OCSEAP Research Unit #327

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SUMMARY

An environmental geologic survey is being conducted on the western Gulf of Alaska outer continental shelf. The objectives are to determine the distribution and displacement histories of surface and near-surface faults, to identify areas of slope instability, and to characterize the unconsolidated Quaternary sediments with respect to thickness, physical properties, and dispersal patterns.

Surface faulting has been identified in a zone along and offshore of the southeast coast of Kodiak Island, extending northeast to Montague Island. Scattered surface faults also exist on Albatross Bank, near the edge of the continental shelf. Movement along the surface faults could affect OCS resource activities near them.

No major zones of slumping have been discovered so far, although some might exist on the sloping sides of major sea valleys where quantities of fine-grained sediment are accumulating. The major sea valleys appear to be likely dispersal routes for contaminated sediments, and some local storage of these sediments also is possible in the valleys.

INTRODUCTION

Several environmental geologic conditions can impact, or be impacted by, OCS resource development of the western Gulf of Alaska. Primary among these are fault movement and the associated seismic activity, instability of sediments on the shelf and upper continental slope, and storage and dispersal of contaminants absorbed onto sedimentary particles. The amount of data on which to base an environmental assessment of the western Gulf of Alaska OCS presently is very limited.

The objectives of this project are to determine the distribution and displacement histories of surface and near-surface faults, to identify areas of slope instability, and to characterize the unconsolidated Quaternary sediments with respect to thickness, physical properties, and dispersal patterns. Attention is being directed mainly to the proposed area of federal OCS oil and natural gas lease sale no. 46 (Fig. 1). The results of this study can be used to identify areas where geologic conditions adverse to resource development exist and to determine the regional dispersal patterns and storage sites of contaminants introduced into marine sediments.

CURRENT STATE OF KNOWLEDGE

The geologic data on which to base an environmental geologic assessment of the western Gulf of Alaska are presently limited to a few published reports (e.g., see Arctic Environmental Information and Data Center, 1974) and some unpublished U. S. Geological Survey records. These data were acquired prior to any program for OCS resource development and were directed to other types of geologic studies. No systematic environmental geologic study has been conducted.

The western Gulf of Alaska continental shelf has been shaped by recent tectonic and glacial processes. The area is one of intense high-magnitude seismic activity (Table 1, Fig. 2) and is currently undergoing surface tectonic deformation, as shown by the effects of the 1964 Alaska earthquake (Plafker, 1969; Malloy and Merrill, 1972). A zone of Cenozoic faulting has been identified along and offshore of the southeast coast of Kodiak Island (Moore, 1967; von Huene, 1972). Surface rupturing along faults during the 1964 earthquake was documented along and off the southwest end of Montague Island (Malloy and Merrill, 1972; Plafker, 1969).

Sparse data suggest that the majority of unconsolidated sediments on the western Gulf of Alaska continental shelf are of terrigenous origin, having been transported by glacial and glacially associated processes during Pleistocene low stands of sea level. Other components include volcanic debris and biogenic material (Hays and Ninkovich, 1970; Gershanovich, 1970; Gershanovich, Kotenev and Novihov, 1964). Sediment thicknesses typically are a few tens of metres over bedrock (AEIDC, 1974), and grain sizes normally are sandy, with local areas of pebbles and mud. No published data on instability, geotechnical properties, dispersal, or depositional rates are available for these sediments.

STUDY AREA

Federal lease-sale area 46 covers about 25,000 sq. mi. of the continental shelf between Chirikof and Montague Islands (Fig. 1). This project is concerned with regional environmental geology, and although it is focused on lease-sale area 46, it is not strictly limited to it. Seismic profiling lines and sediment coring stations extend beyond the lease area where necessary to obtain environmental data that complete the regional picture. For example, surface faults that extend adjacent to the lease area should be traced out to their full extent.

SOURCES, METHODS, AND RATIONALE OF DATA COLLECTION

Because no sediment samples and essentially no high-resolution seismic data were collected during the 1975 field season, our preliminary study this year made use of published and unpublished reports, U. S. Coast and Geodetic Survey Boat Sheets, U. S. Geological Survey sparker records, and personal communications with scientists who have worked in the area. An extensive program of high-resolution seismic profiling and sediment sampling is planned for summer of 1976.

RESULTS

During June-August 1975, the M/V Cecil H. Green, a seismic vessel contracted from Geophysical Service Inc., acquired approximately 5500 line kilometres of geophysical data in the Gulf of Alaska between approximately Unimak Pass and Cross Sound. This activity was directed by Terry R. Bruns. Data acquired over the 5500 km include 24 or 48-fold multichannel seismic reflection data, gravity, magnetics and bathymetric data. In addition, high resolution data were acquired over approximately 2350 km of these track lines.

Of the multichannel, gravity, magnetic, and bathymetric data, approximately 1700 line km are on the Kodiak shelf roughly between Middleton Island and the Trinity Islands (southwest of Kodiak Island),

and 450 line km on the Shumagin Shelf between the Trinity Islands and Sanak Island, for a total of approximately 2150 line km on the Kodiak-Shumagin Shelf. Approximately 350 line km of additional gravity, magnetic, and bathymetric data were run in this area for a total of approximatly 2500 line km of these data.

Unfortunately, high resolution data were acquired on only about 150 km of this total due to (1) the high resolution equipment not being obtained and placed aboard ship by GSI until almost three weeks into the program and (2) severe mechanical and electrical problems with the high resolution equipment at both the beginning and end of the cruise when most of the Kodiak-Shumagin shelf data were gathered.

Because so little new information was obtained in the 1975 field season, we searched other available data for environmental information. U. S. Coast and Geodetic Survey Boat Sheets, published and unpublished reports, and U. S. Geological Survey sparker profiles were used to construct generalized physiography and sediment-distribution maps (Figs. 3 and 4) and to locate general areas of environmental-geologic concern. The results of these investigations are being used in the planning of efficient ship using during our 1976 field season. A discussion of these results follows in the next section.

The week of February 4-11, 1976, was spent visiting persons in Alaska who are concerned with the geology of the western Gulf of Alaska. Among those visited were Robert McMullen, Bruce Turner, John Whitney, and Frank Chmelik of the U. S. Geological Survey, Conservation Division; Dan Patton, Jerry Imm, and Robert Cook of the Bureau of Land Management;

G. D. Sharma, Richard Neve, and Donald W. Hood of the University of Alaska'a Institute of Marine Science; Eugene Buck and William Wilson of the Arctic Environmental Information and Data Center (AEIDC); and Thomas Miller of the U. S. Geological Survey, Geologic Division. Discussions with these persons added greatly to our knowledge of the marine geology of the western Gulf of Alaska, gave us insight into the leasing procedures for OCS lands, and opened avenues of possible scientific collaboration. The cooperation and courtesy we received in Alaska will be reflected by a more efficient and productive field season in 1976 than we would have had otherwise.

DISCUSSION

Physiography and bathymetry

The western Gulf of Alaska was subjected to glacial processes in Pleistocene time, which left a profound imprint because glaciers are strong agents of erosion and deposition. This imprint was superimposed on the continually evolving features resulting from tectonic processes. Glaciation is obvious from the fiord-indented coastline and the bathymetry of the shelf. Glacial periods were separated by interglacial periods (von Huene and others, 1973, 1976) during which times the environment was subjected to non-glacial processes. Since all of these processes played part in shaping the sea floor, a great deal can be inferred about the surficial geology from an analysis of physiography.

The physiography of the continental shelf on various charts of the western Gulf of Alaska is marked by relatively flat areas that are cut by transverse valleys. Gershanovich (1964) and Gershanovich, Kotenev, and Kovihov (1970) subdivided the shelf into three morphologic units: (1) the nearshore, (2) plateau-like surfaces, and (3) sea valleys.

The nearshore fringes the coastline, ranging from 5 to 8 km in width are reaching depths of 30-50 m. Fiords, associated deep inlets, and their seaward extensions are characteristic of the nearshore.

Plateaus cover the major part of the shelf. They have gradients of 1-5 minutes and are in water depths of 80-120 m. Local banks and shoals protrude from the sea floor, some having small steep scarps and minor reefs. The shoals, as well as the shelf banks and scarps, represent tectonic uplifts.

Sea valleys cut the plateau areas and are of two general types. First is Shelikof Strait, which trends more or less parallel to the shelf edge with a broad, flat floor and with banks sloping 1 to 3 degrees. Second are the smaller valleys extending offshore from bays and inlets in a direction transverse to the shelf. They have broad, flat floors and slopes of about 2 to 3 degrees. In longitudinal profile they commonly show deepening in their outer course followed by shoaling, which is typical of glacially formed channels.

Figure 3 summarizes the sea floor morphology of the lease-sale area and surrounding regions, outlining the major physiographic features. To relate the text more conveniently to this figure, a number of names have been informally introduced for the major banks and troughs.

A major trough - Hinchinbrook Sea Valley - is located off Prince William Sound, just east of Montague Island. Von Huene and Shor

(1969) indicated that it is flanked by banks on both sides that are at least 100 m high. Molnia and Carlson (1975) have found that one of the sides, which is formed by Tarr Bank, is composed of Tertiary and Pleistocene stratified deposits. There is no indication of an end moraine within Hinchinbrook Sea Valley.

Between Resurrection Bay and Montague Strait, several fiords converge. Bathymetric data suggest that the glaciers, following the fiords during low stands of sea level, converged into two major glaciers. The one occupying Bainbridge Trough moved in a southeasterly direction around the end of Montague Island. The other one, occupying Resurrection Trough, extended in a more southerly direction. Both troughs have a rise in the lower part of their course inferred to be end moraines.

The topographic high between Bainbridge and Resurrection troughs may be composed mostly of morainal material, or it may be an erosional remnant of a former bedrock plateau with morainal cover. The complex bathymetry of this area indicates tectonism as well as glaciation.

Resurrection Trough terminates along the northern bank of Amatuli Trough and the terminal deposits of glaciers in the former are thought to form the northern bank of the latter (von Huene, 1966). The southern bank of Amatuli Trough is formed by the northern end of Portlock Bank. Since Portlock Bank is an uplifted deformed and eroded area (von Huene, and others, 1972), the southern flank of Amatuli Trough is therefore a tectonic feature.

Off the Kenai Peninsula, the troughs are probably filled with fine sediment, much like the trough extending seaward from Nuka Bay (von Huene, 1966). These sediments are mainly fine-grained terrigenous muds from streams and glacial melt water.

Between Kenai Peninsula and the Kodiak group of islands are two straits named Kennedy Entrance and Stevenson Entrance, which are separated by the Barren Islands. The southeasterly continuation of both straits presently is uncertain, but Portlock Bank divides them. Due to the counterclockwise motion of the Alaskan Gyre and the superimposed tidal forces, major flood currents may follow Amatuli Trough into Kennedy Entrance, while ebb flows follow Shelikof Strait and Stevenson Entrance and Stevenson Trough. Since the bottom sediment in Stevenson Trough is coarser than that in Amatuli Trough, it is assumed that a stronger current flows through Stevenson Trough.

The source of a former glacier in Stevenson Trough was most likely Cook Inlet; however, there is no clearly defined connection across Barren Deep between Stevenson Trough and the Stevenson or Kennedy entrances.

Immediately southwest of Portlock Bank is Albatross Bank, which is divided into three parts by Chiniak Trough and Kiliuda Trough. It has an intricate detailed bathymetry with small steeply dipping scarps and depressions. The bank is an eroded anticline with several fault scarps on the sea floor (Fig. 5).

Both Chiniak Trough and Kiliuda Trough were originally formed by glaciers during low stands of sea level. Chiniak Trough is relatively straight and uniform with steep sides and axial depressions, but with no end moraine. Kiliuda Trough is wider than Chiniak and seems to have a large area of former glacial convergence directly off Kodiak Island.

A large depression is followed by a rather high end moraine near the edge of the continental shelf, which may lead to a submarine canyon down the continental slope, although the bathymetric evidence is uncertain. There are enough data to reconstruct the area of glacial convergence at the head of Kiliuda Trough. Ugak Bay, which is about midway between the heads of Kiliuda and Chiniak Troughs, has a short relatively steep slope at its mouth that continues in a southerly direction. This suggests that the Ugak Bay glacier joined the Kiliuda Trough glacier along with the glaciers from Kiliuda Bay and Sitkalidak Strait.

Figure 6 shows bathymetric cross sections through two troughs and one over southern Albatross Bank. The vertical exaggeration helps to emphasize detail.

Bathymetry and physiography (Fig. 3) also reveal fault scarps; for instance the major scarp off Ugak Island. A number of cross sections show a steep slope facing seaward (Fig. 7); marked by arrows on this figure. This fault scarp corresponds with a fault defined by seismic records (von Huene, Shor and Malloy, 1972) off Kodiak Island. This scarp diminishes southwestward and is not very strong in line 6, whereas in line 7 it can be debated whether the left or right hand slope represents this fault or a depositional erosional face.

Sitkinak Trough near the southern end of the area is a broad embayment at the edge of the continental shelf. According to von Huene, Shor, and Malloy (1972) and to von Huene (unpublished data) this feature is mainly tectonic and not erosional.

The Kodiak shelf glacial physiography is mainly relict, having been developed in the Pleistocene during times of intense glaciation. This physiography does not reflect the present sedimentary processes well. Pleistocene glaciers eroded channels across tectonically uplifted banks. The tops of the banks probably were eroded by wave action during the times of lowered sea level that accompanied glaciation. During glacial retreat, coarse debris may have been left along the channels and particularly along their banks, and in other physiographically low areas as well. Some of this material probably was affected by ice pressures, melt water, and wave action. During interglacial periods, deposition and erosion also occurred but at a greatly reduced rate and mostly finer grained material was deposited. On Tarr Bank in the central Gulf of Alaska, currents appear presently to be sweeping the fine-grained material away, thereby allowing carbonate-building organisms to collect (Molnia, 1976). In the topographic lows on the other hand, the conditions are favorable for deposition of fine-grained sediments.

Bottom Sediments

The bottom sediments in the western Gulf have received relatively little study. Notations from the C & G S Boat Sheets were used to construct a generalized bottom sediment map (Fig. 4). The notations on the C & G S Boat Sheets were not made by geoscientists but by persons concerned with depth measurements in regard to ship lanes and anchorages. Certain terms, like "rocky", are therefore imprecise for a geologic analysis and not specific enough for an environmental geologic assessment. The only other sources of published information are by Gershanovich

(1970) and Gershanovich, Kotenev and Novihov (1964). Since these authors do not present their basic data, their information is difficult to substantiate and reinterpret in an environmental geologic context.

Unconsolidated sediments typically form a thin veneer on the banks and are less than 50 to 100 metres thick in most of the lower areas. These sediments are largely of terrigenous origin, having been transported by glacial or glacially associated processes during Pleistocene low stands of sea level. Other components include volcanic debris and biogenic materials (Hay and Ninkovich, 1970; Gershanovich, 1970; Gershanovich, 1970; Gershanovich, Kotenev and Nivihov, 1964; G. D. Sharma, pers. comm.).

The majority of the veneer consists of coarse-grained deposits including sandy sediment with pebbles and shell material. Off the Kenai Peninsula, however, the Boat Sheets indicate a relatively large area of mud with local pebbles and shells. Similar muddy sediments also occur beyond the shelf break at water depths over 150-200 m.

Because no major sources of sediment similar to the Copper River exist in the area off Kodiak or the Kenai Peninsula, and because the circulation patterns are different from the eastern Gulf of Alaska, it probably is incorrect to make close analogies of sedimentary environments between the eastern and western Gulf (Molnia and Carlson, 1975; Reimnitz, 1966). The counterclockwise Alaska Current and Alaska Stream may move muds discharged from the numerous fiords along the Kenai Peninsula in a westward direction. Tidal currents probably are weak in the offshore region. But the relatively sparse discharge of coarse sediments beyond the fiords adjacent to the Kodiak Shelf, and the channeling of sediments from Cook Inlet through Shelikof Strait, suggest that very little deposition may presently occur on this shelf. The lack of clastic deposition gives biogenic sediments an opportunity to form.

The above statements are general and tentative. A high resolution seismic survey and sampling program will be conducted by the U.S.G.S. during the summer of 1976, from which a more precise bottom sediment distribution map will be constructed.

Environmental Geologic Considerations

In the absence of a site-specific analysis of environmental geology, some of the types of geologic factors that may be of concern for OCS resource development in lease-sale 46 region are enumerated. Primary factors are sediment dispersal, sediment stability, and seismicity.

Sediment dispersal--As suggested earlier, no major post glacial sediment accumulations are likely to exist on the Kodiak shelf since the major coarse sediment from the Kodiak group of islands or the Kenai Peninsula are presently being trapped in deep fiords. Some fine material probably is carried seaward from fiords and is likely to be transported through the troughs and also be deposited in them. According to G. D. Sharma (pers. comm.), the reason that very little sediment escapes the fiords on Kodiak is due to tidally influenced circulation that also traps finer material within the fiords. Since offshore accumulation rates of fine-grained detritus are unmeasured, the rate of sediment accumulation in possible depositiories of pollutants is unknown. Most pollutants are sorbed to individual fine particles, primarily clay minerals and organic debris, and can reside for long periods of time in sediment. If bottom-living organisms feed on such materials, a magnification of pollutants throughout the food chain could result. However, it seems unlikely that at the present significant quantities of pollutants are being concentrated on the offshore banks which are the major fishing grounds.

Sediment stability--Instability is most likely where thick accumulations of unconsolidated saturated sediment are located. Since it is unlikely that thick sediment accumulations occur on the higher portions of this continental shelf, the only areas for potential sediment failure are the slopes of the glacial troughs, inside fiords, and on the continental slope. In the few seismic records available no slides or slumps have been detected in such areas on the shelf.

However, if a comparison between the shelf off Prince William Sound and the one off Kodiak is valid, the consolidated deposits representing Tertiary and Pleistocene stratified units or glacial debris are generally stable. Hinchinbrook Sea Valley represents a good example (Molnia and Carlson, 1975; Molnia, in press, Carlson, in press). The upper surface of the glacial deposits in the valley and along the banks is very irregular with local steep slopes. There is no indication on the seismic records that slumping has occurred in these strata. The finer-grained overlying sediments, sometimes ponding in former depressions and at other times draping over the old topography, reveal some local slumping, as well as minor deformation resulting from differential compaction.

The stability of these sediments, with regard to slumping and erosion, as well as their lithologic nature, can only be inferred until geotechnical measurements can be made.

Seismicity--The Gulf of Alaska - Aleutian area is one of the most seismically active on earth, accounting for about 7% of the world-wide release of seismic energy annually. Most of this energy release is associated with large earthquakes (greater than magnitude 7). Since 1902, at least 95 potentially destructive earthquakes (m>6) have occurred in the vicinity of the western Gulf of Alaska, (Fig. 2, Table I).

Recurrence intervals of major earthquakes within a given area along the Gulf of Alaska-Aleutian system have been estimated by various geoscientists. A maximum average recurrence interval of about 800 years has been estimated from geologic evidence and the uplift sequence of Middleton Island (Plafker, 1971). On the basis of historic seismic patterns recorded over the past 75 years, Sykes (1971) estimated a minimum interval of 33 years. Since the last major earthquake to affect the western Gulf of Alaska area occurred in March 27, 1964, the minimum recurrence interval will be exceeded by the lifetime of a major oil-producing province.

The western Gulf of Alaska is included in seismic risk zone 3, defined as areas susceptible to earthquakes of magnitude 6.0-8.8 and where major structural damage could occur (Evans, et al., 1972). Damage to marine activities can be produced either directly by ground shaking, fault displacement, and surface warping, or indirectly by ground failure and consolidation of sediments.

Damage from ground shaking is likely to be greatest in areas underlain by thick accumulations of saturated, unconsolidated sediments, rather than in areas underlain by solid bedrock. This is especially true if the frequency of seismic waves is equal to the resonant frequency of the sediment. Furthermore, ground shaking weakens sediments and thereby can trigger other types of instability such as landsliding and ground fissuring.

Plateaus and banks in the offshore lease area apparently are covered with a thin veneer of unconsolidated sediments, less than a few metres thick. Lack of subsurface geotechnical and stratigraphic data precludes identification of specific dangerous areas, but the glacial troughs, fiords, and the continental slope might contain sufficient accumulations of unconsolidated sediment to experience amplified seismic shaking.

The distribution of active surface faulting in the Kodiak shelf region was studied in a reconnaissance fashion in connection with the 1964 Alaska earthquake. Surface rupturing along faults during 1964 was documented along and off the southwest end of Montague Island (Malloy and Merrill, 1972; Plafker, 1969) within a major fault zone that has been active during geologically recent time. A similar zone extends along and off the southeast coast of Kodiak Island (von Huene, Shor, and Malloy, 1972; see Fig. 8) but here it could not be established when the fault scarps were formed.

Closely spaced high-resolution seismic reflection lines are needed to determine the precise distributions and extent of active faults, particularly in the zone of deformation along Kodiak to Montague Island, and also in the remainder of the lease area. Possible active faults have been noted on Albatross Bank (von Huene, 1972). The fact that it is a structural and topographic ridge suggests active uplift of the bank.

Surface deformation in the form of regional warping accompanied the the 1964 earthquake covering an area of about 280,000 sq. km of land and sea floor. Offshore it was documented off Montague and Middleton Island and along Albatross Bank (Malloy and Merrill, 1972, von Huene, Shor and Malloy, 1972). The remainder of the outer continental shelf probably underwent similar deformation, but data to substantiate this are lacking. Maximum observed uplift was 15 m, maximum subsidence was 2.5 m and maximum horizontal displacement was 19.5 m on land. This suggests the possible magnitude of regional deformation that could accompany a large earthquake. Offshore tectonic deformation can produce problems when shallow navigation channels are uplifted and require recharting and perhaps dredging.

Offshore areas that are underlain by thick, unconsolidated sediments are vulnerable to various types of ground failure typically associated with large earthquakes. The types of failure include liquefaction, block sliding along weak subsurface strata, rotational slumps, earth flow and avalanching, ground fissuring, and consolidation subsidence. All of these types of failure occurred in coastal areas, both onshore and nearshore, during the 1964 earthquake.

It is presently uncertain if the offshore shelf sediments in the Gulf, away from unstable coastal deltas, will fail during earthquakes.

Most of the sediments probably are normally consolidated as a result of slow deposition and reworking by currents and are therefore stable. The possibility of earthquake-induced sliding in areas of steep slopes and of localized liquefaction cannot be overlooked, however. Large-scale block slumping has been identified in the areas of high sedimentation rates and sloping sea floor in the nearby eastern Gulf of Alaska in U. S. Geological Survey high-resolution seismic profiles (Carlson and Molnia, 1975; Carlson, Bruns and Molnia, 1975) and it is likely that these slumps are earthquake-induced. No large slumps have been identified in the existing seismic records on the Kodiak Shelf.

CONCLUSIONS

Active surface faulting has been identified on the western Gulf of Alaska OCS, within and near lease-sale area 46, which could affect resource development activities. The major zone of faulting identified along and offshore of the southeast coast of Kodiak Island shows fresh, steep scarps that suggest recent activity. The less extensive zone southwest of Middleton Island, in line with the Kodiak fault zone, has experienced movement as recently as 1964. Scattered surface faults have been identified near the edge of the continental shelf on Albatross bank and tectonic deformation of the bank in 1964 suggests that at least some of the faults are active.

No zones of major slumping have been identified on the western Gulf shelf. The predominating thin, coarse-grained nature of the sediments on the flat plateau areas lessens the likelihood of major slumping there. Major slumping might exist on the sloping sides of the major sea valleys, however, where sufficient quantities of fine-grained sediments might be accumulating. Present records show no such slumping, however. The major sea valleys appear to be the likely dispersal routes for contaminated sediments. Some local storage of contaminated sediments also is possible in the valleys, although much of the sediment probably would be carried over the shelf edge to be deposited on the continental slope or within the Aleutian Trench. Little or no modern sediment seems to be accumulating on the extensive plateau areas, mainly because of the lack of a sediment source.

NEEDS FOR FURTHER STUDY

The conclusions made from the available data concerning the environmental geology of the western Gulf of Alaska OCS are tentative and sketchy, but they point the need for further concentrated study. A program involving detailed high-resolution seismic profiling and extensive core sampling is necessary for providing the base from which to make an adequate regional environmental geologic assessment of the area.

The seismic profiling records can be used to delineate the zones of surface faulting and to determine the lengths of individual faults. The ages and states of activity of the faults might be determined using supplemental methods of side-scan sonar, bottom photography, dart coring, and age dating. Zones of sediment instability and thicknesses of unconsolidated sedimentary units also can be determined from the seismic records.

Analysis of sediment samples will yield information as to the physical and geotechnical properties of surface and shallow subsurface materials. These data are required to characterize the regional sediment types, to identify potentially unstable sedimentary unts, and to determine regional patterns of sediment dispersal.

Significant products of the seismic and coring program, valuable for environmental decision making on OCS leasing, would be detailed maps and analyses of faults, slumps, sediment distribution, and isopachs of Holocene sediment.

SUMMARY OF 4TH QUARTER OPERATIONS

The majority of the previous three months has been spent drawing environmental information from available sources of data as discussed in preceeding sections, and defining our field and laboratory program for the coming season. No shipboard or other field activities were conducted.

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Table 1. Large earthquakes in the western Gulf of Alaska region, 1902 to 1975.

(Includes earthquakes whose epicenters lie between latitude 53° and 63° N and longitude 145° and 165° W. Data courtesy of Robert Page and John Lahr, U.S. Geological Survey).

Date Day	Month	Year	Origin Hr/Min	Time GMT	Latitude (Degrees N)	Longitude (Degrees W)	Depth (Kilometers)	Magnitude
01	01	02	0520		55.00	165.00	25	7.80
02	06	03	1317		57.00	156.00	100	8.30
22	08	07	2224		57.00	161.00	120	6.50
19	09	09	2100		60.00	150.00		7.40
13	05	10	1758		57.00	160.00	100	6.75
22	09	11	0501		60.50	149.00	60	6.90
31	01	12	2011		61.00	147.50	80	7.25
07	06	12	0955		59.00	153.00		6.40
10	06	12	1606		59.00	153.00		7.00
07	11	12	0740		57.50	155.00	90	7.50
05	12	12	1227		57.50	154.00	90	7.00
04	05	23	1626		55.50	156.50		7.10
21	06	28	1627		60.00	146.50		7.00
24	12	31	0340		60.00	152.00	100	6.25
14	09	32	0843		61.00	148.00	50	6.25
30	10	32	2046		55.00	159.75		6.75
04	01	33	0359		61.00	148.00		6.25
04	05	34	0436		61.25	147.50	80	7.20
14	05	34	2212		57.75	152.25	60	6.50
02	06	34	1645		61.25	147.00		6.25
18	06	34	0913		60.50	151.00	80	6.75
28	07	34	2136		55.50	156.75		6.75
02	08	34	0713		61.50	147.50		6.00
10	11	38	2018		55.50	158.00	25	8.50
17	11	38	0354		55.50	158.50		7.20
12	02	40	0917		55.00	161.50		6.75
11	10	40	0753		59.50	152.00		6.00
01	04	41	1040		56.00	153.50		6.50
06	08	41	0615		55.75	163.00	150	6.75
28	09	41	0534		56.50	157.50	100	6.75
05	12	42	1428		59.50	152.00	100	6.50
03	11	43	1432		61.75	151.00		7.30
03	11	45	2209		58.50	151.00	50	6.75
12	01	46	2025		59.25	147.25	50	7.20
26	05	48	0916		56.00	156.00		6.00
27	09	49	1530		59.75	149.00	50	7.10
13	02	51	2212		56.00	156.00		7.00
08	11	51	1345		55.60	160.40		6.60
29	11	52	2346		56.30	153.80		6.90
25	02	53	2116		56.00	156.20		6.75
15	06	53	1747		56.30	153.80		6.50
03	10	54	1118		60.50	151.00	100	6.70
17	06	54	0142		56.00	154.50		6.50

Table 1. (continued)

Day	Date Month	Year	Origin Hr/Min	Time GMT	Latitude (Degrees N)	Longtidue (Degrees W)	Depth (Kilometers)	Magnitude
19	07	55	2352		56.50	153.00		6.00
26	07	55	0404		56.50	153.00		6.00
27	07	55	1819		56.50	153.00		6.25
15	11	55	1006		55.40	155.60		6.50
04	04	57	0013		58.17	155.04	89	6.00
10	04	57	1130		55.96	153.86		7.10
24	01	58	2317		60.00	152.00	60	6.38
19	04	59	1503		58.00	152.50		6.25
26	12	59	1819		59.76	151.38		6.25
13	05	60	1607		55.00	161.50		6.25
01	09	60	1537		56.30	153.70	24	6.13
20	01	61	1709		56.60	152.30	46	6.38
31	01	61	0048		56.00	153.90	26	6.38
10	05	62	0003		62.00	150.10	72	6.00
12	05	63	1205		57.30	154.00	60	6.10
24	06	63	0426		59.50	151.70	52	6.80
06	02	64	1307		55.70	155.80	33	6.75
28	03	64	0336		61.00	147.80	33	8.50
28	03	64	0454		59.80	149.40	25	6.10
28	03	64	0643		58.30	151.30	25	6.10
28	03	64	0710		58.80	149.50	20	6.10
28	03	64	0901		56.50	152.00	20	6.00
28	03	64	1035		57.20	152.40	33	6.10
28	03	64	1220		56.50	154.00	25	6.00
28	03	64	1447		60.40	146.50	10	6.10
28	03	64	1449		60.40	147.10	10	6.10
28	03	64	2029		59.80	148.70	40	6.60
30	03	64	0709		59.90	145.70	15	6.00
03	04	64	2233		61.60	147.60	40	6.20
20	04	64	1155		61.40	147.30	30	6.60
21	04	64	0501		61.50	147.40	40	6.00
06	02	65	0140		53.20	161.90	33	6.40
06	02	65	1650		53.30	161.80	33	6.10
04	09	65	1432		58.20	152.70	10	6.20
22	12	65	1941		58.40	153.10	51	6.50
23	04	68	2029		58.70	150.00	23	6.30
15	11	68	0007		58.32	150.36	26	6.38
17	12	68	1202		60.17	152.84	86	6.50
24	11	69	2251		56.20	153.56	33	6.00
16	01	70	0805		60.31	152.72	91	6.00
11	03	70	2238		57.46	153.91	29	6.50
18	08	70	1752		60.70	145.38	16	6.00
24	03	72	0338		56.14	157.18	69	6.00
06	04	74	0356		55.12	160.44	40	6.00
02	08	75	1018		54.10	161.78	60	6.20

FIGURE CAPTIONS

1. Area of OCS lease sale #46.
2. Epicenters of m>6 earthquakes, 1902-1975, western Gulf of Alaska region.
3. Generalized physiography, western Gulf of Alaska.
4. Generalized sediment distribution, western Gulf of Alaska.
5. Structural profile across Albatross Bank and Albatross Basin.
6. Bathymetric cross sections across two troughs and across southern Albatross Bank.
7. Bathymetric cross sections across steep scarps off southeast coast of Kodiak Island.
8. Generalized zone of faulting, Kodiak Island to Montague Island.

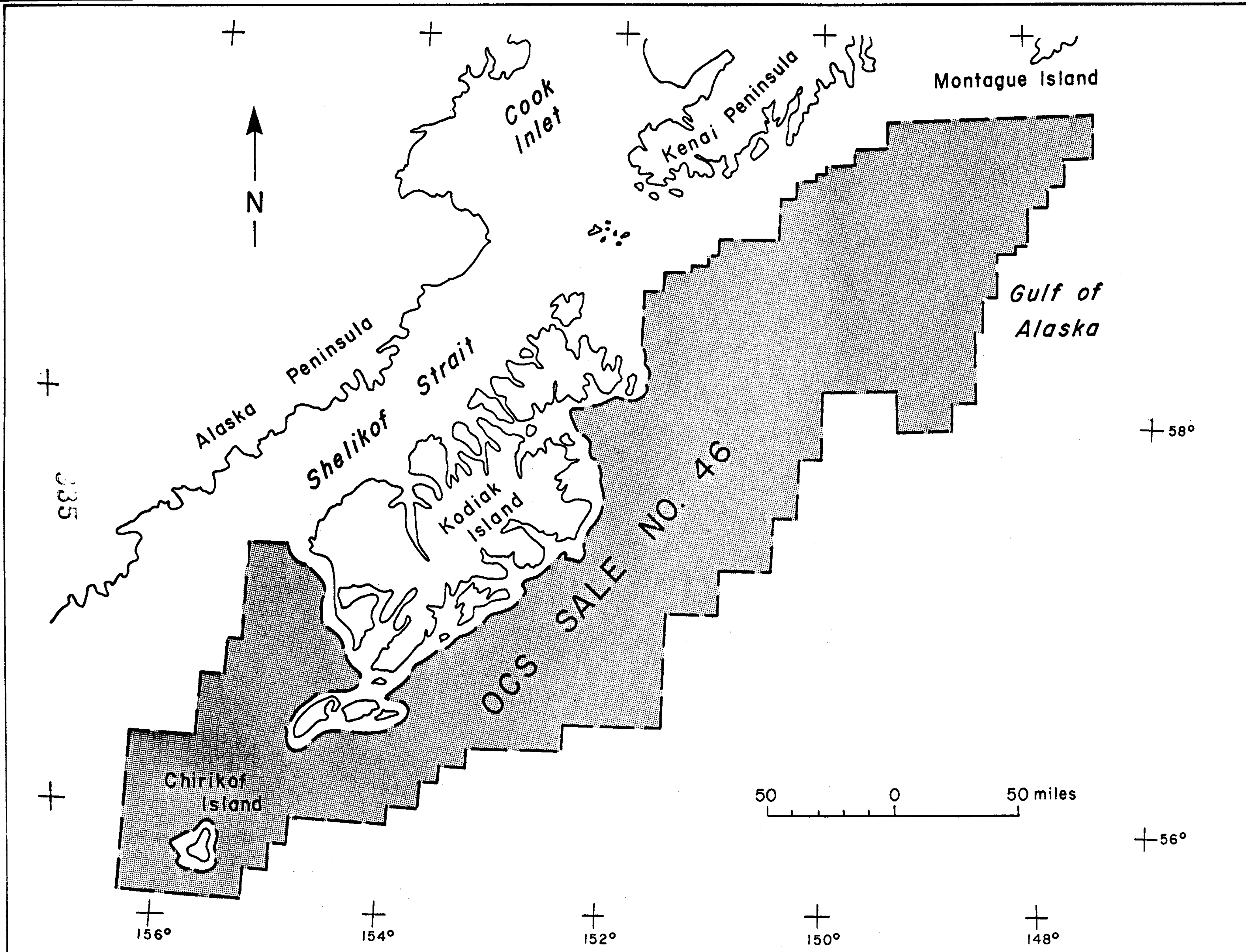

Cook Inlet
Kenai Peninsula
Montague Island
N
Alaska Peninsula
Shelikof Strait
Kodiak Island
Gulf of Alaska
OCS SALE NO. 46
Chirikof Island
50 0 50 miles
58°
56°
156°
154°
152°
150°
148°

Fig. 1

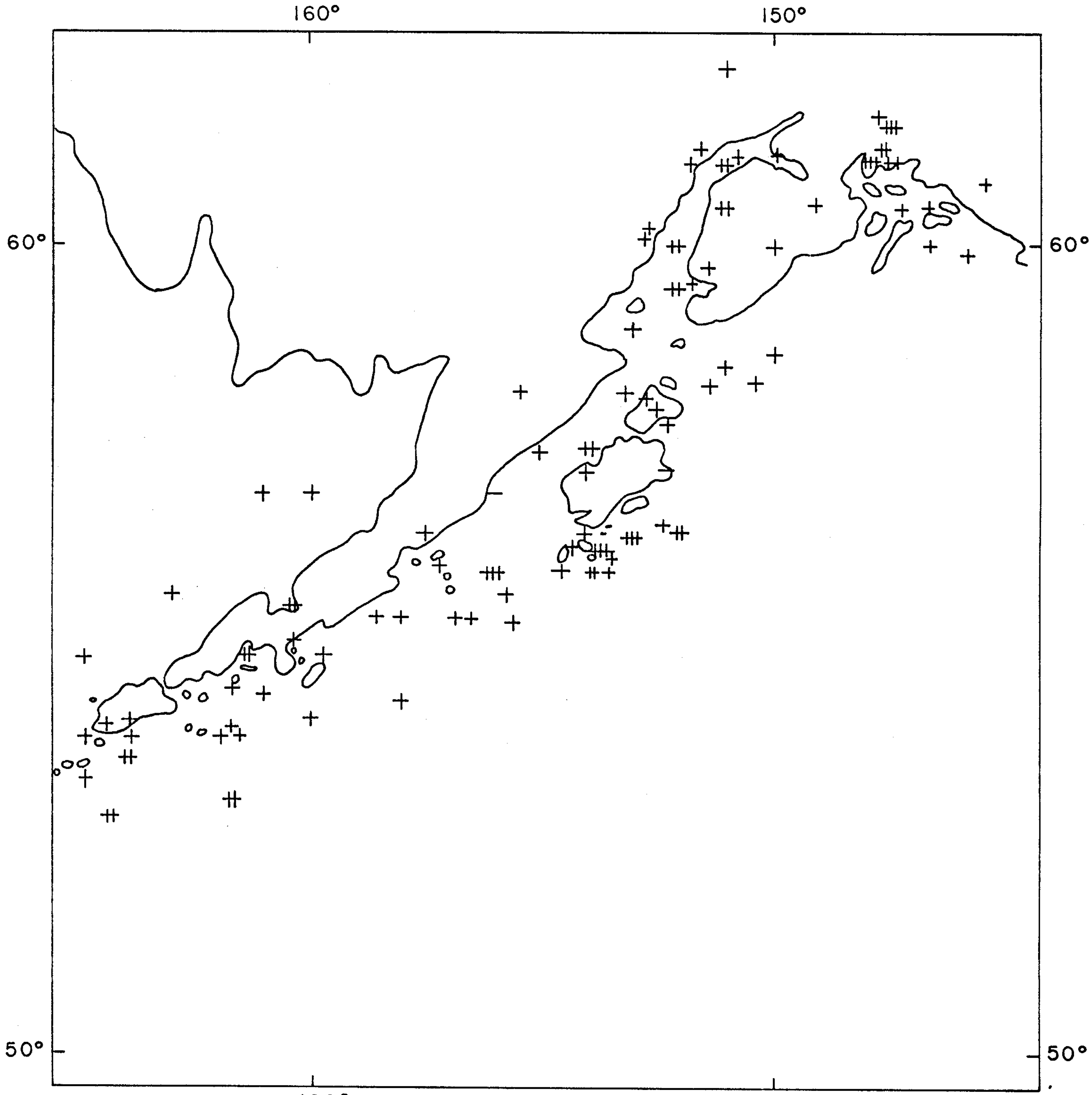
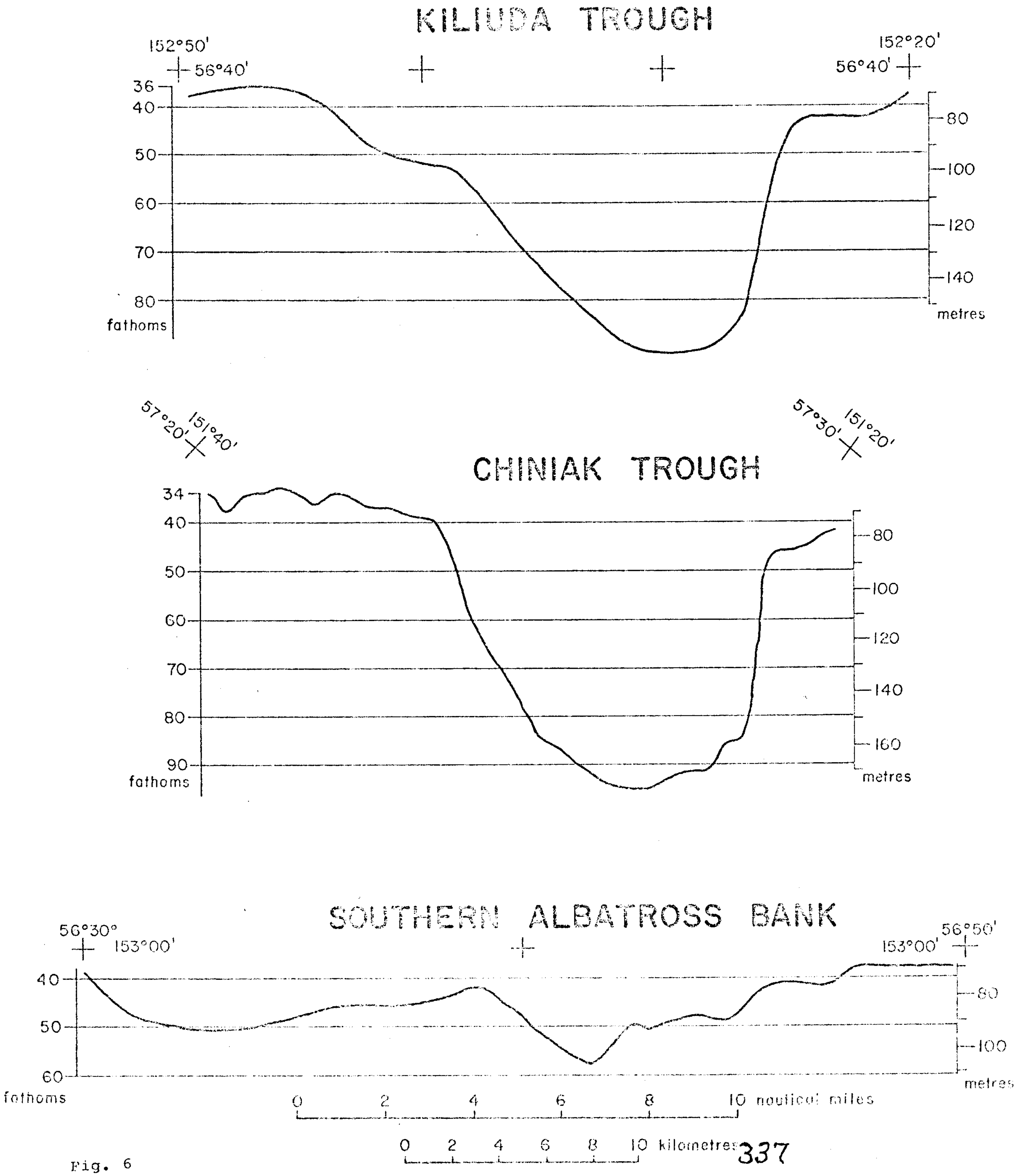


Fig. 2



KILIUDA TROUGH
152°50'
56°40'
152°20'
56°40'
36
40
50
60
70
80
fathoms
80
100
120
140
metres
57°20'
151°40'
57°30'
151°20'
CHINIAK TROUGH
34
40
50
60
70
80
90
fathoms
80
100
120
140
160
metres
SOUTHERN ALBATROSS BANK
56°30°
153°00'
56°50'
153°00'
40
50
60
fathoms
80
100
metres
0 2 4 6 8 10 nautical miles
0 2 4 6 8 10 kilometres

Fig. 6

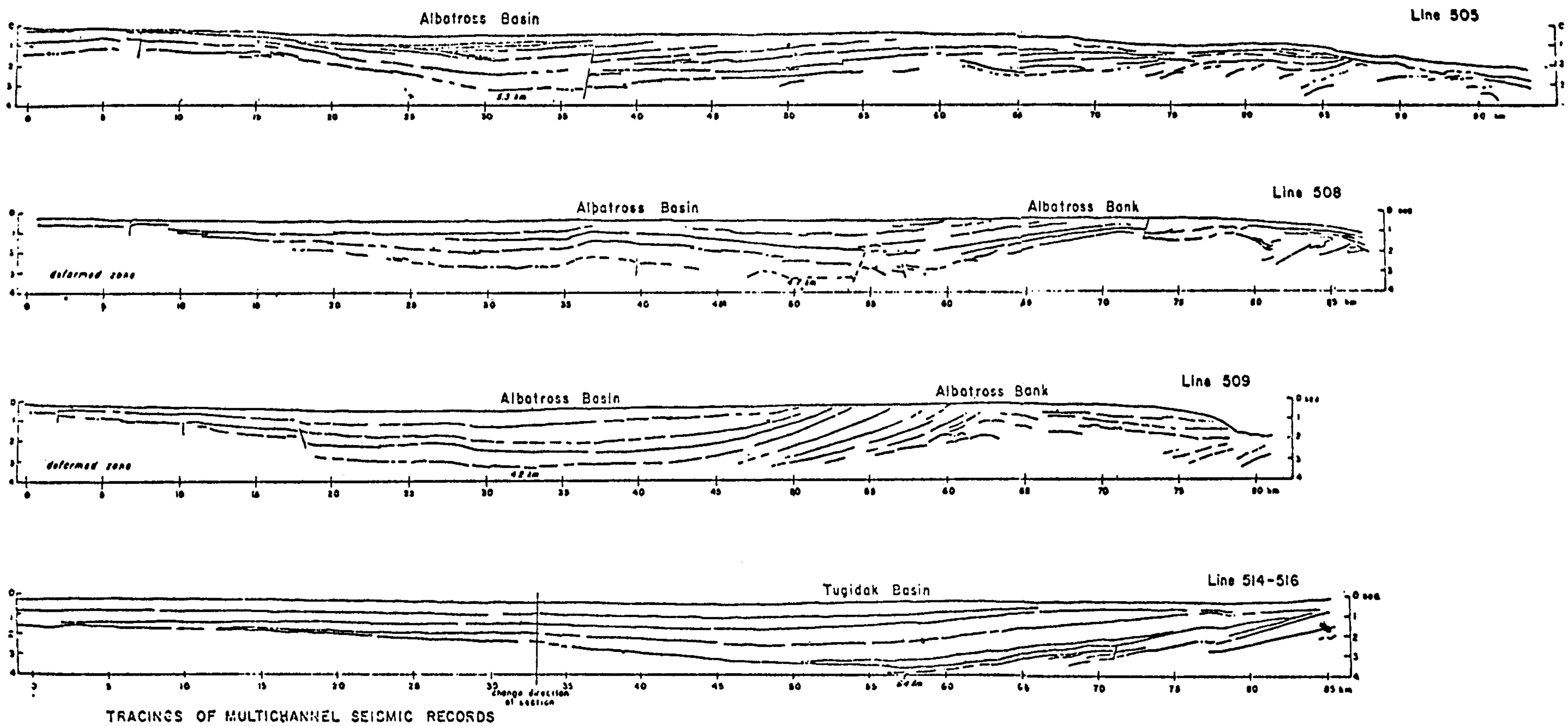


Fig. 5 - Structural profiles across Albatross Bank and Albatross Basin.

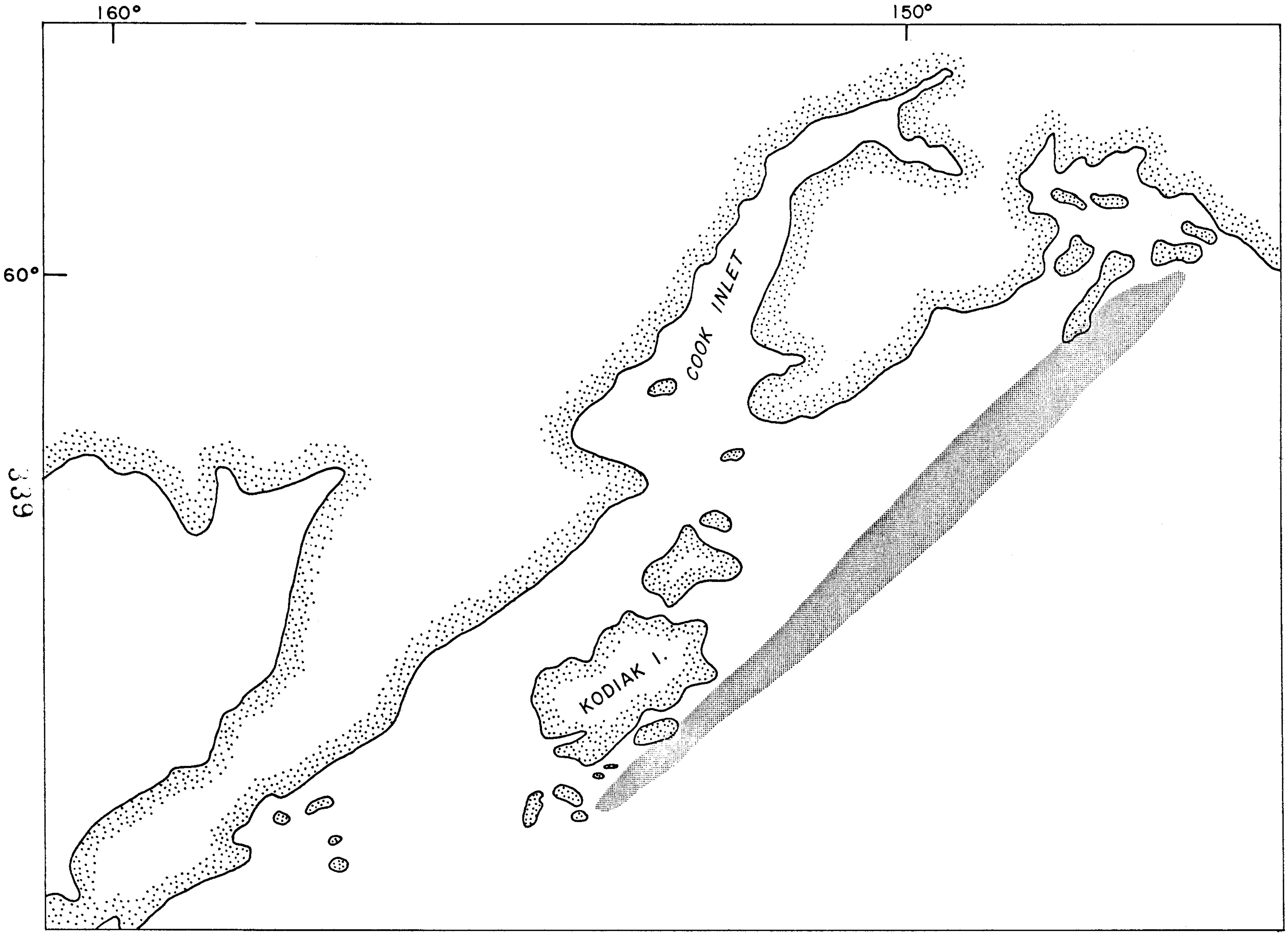


Fig. 8

NOAA Technical Memorandum EDS NGSDC-1

A HISTORICAL SUMMARY OF EARTHQUAKE EPICENTERS IN AND NEAR ALASKA

Herbert Meyers

National Geophysical and Solar-Terrestrial Data Center
Boulder, CO
April 1976

UNITED STATES DEPARTMENT OF COMMERCE
Elliot L. Richardson, Secretary / NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
Robert M. White, Administrator / Environmental Data Service
Thomas S. Austin, Director

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INTRODUCTION

This publication summarizes the Alaska earthquake data file as presently developed by the National Geophysical and Solar-Terrestrial Data Center (NGSDC). This is a growing file and additional data are being added both for current and historical earthquakes as they are prepared for machine processing. It describes data formats, sources used in developing the data file, and data limitations. Included are several tables which summarize the data in usable forms. The publication also is designed to accompany magnetic tapes, microfilm, and printouts produced from the data file.

DESCRIPTION OF FILE

The data file contains information on approximately 10,000 earthquakes, known or suspected explosions, and other earth disturbances for the period 1786 through 1974. The file includes for each event the date, origin time, geographic location, focal depth, and magnitude when available (see fig. 1).

A number of data fields for some events in this file are unfilled because of the limited information available. Information on cultural effects, intensity, and other phenomena associated with the event (such as surface faulting, tsunami generated, etc.) has been included for numerous earthquakes. Reference to *Preliminary Determination of Epicenters* (PDE) reports*, the annual *United States Earthquakes* publications of NOAA, "Seismological Notes" of the *Bulletin of the Seismological Society of America* or the original source is recommended for special studies. Some key studies are listed in the bibliography on page 6.

The quality of epicenter determinations varies significantly with the time period studied. Most epicenters prior to 1961 were located graphically to the nearest ¼ to ½ degree of latitude and longitude. Reliable information on the quality of many epicenter determinations is lacking. Since May 1968, the latitude and longitude values for most events have been listed to three decimal places. This precision is not intended to reflect the accuracy of the location of events except for special epicenter determinations. Where several sources have determined an epicenter for the same earthquake, one solution has been selected as the most reliable. Usually, it is the source believed to contain the best data set for the earthquake. In some cases, data from two sources were combined to provide a more complete data record.

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*The PDE program was initiated in 1937 by the Coast and Geodetic Survey and continued by successor agencies--the National Ocean Survey and Environmental Research Laboratories--both of which are components of the National Oceanic and Atmospheric Administration, and by the U.S. Geological Survey since 1973.

Prior to the Prince William Sound, Alaska, earthquake in March 1964, only 2 permanent seismograph stations were in operation in Alaska.

At the Sitka Observatory, two Bosch-Omori horizontal seismographs were installed in April 1904 and operated until December 1932 when they were replaced with two Wenner horizontal systems. In June 1956, the Wilson-Lamison vertical seismograph was added to improve detection capabilities of local earthquakes and teleseismic *P* waves. The station, which is equipped with a visual recorder and an earthquake alarm device, participates in the Alaska Tsunami Warning System.

The College Observatory was first established at the University of Alaska in November 1935 and was instrumented with two horizontal tilt-compensated McComb-Romberg seismometers of 12 seconds' natural period, with magnetic damping and photographic recording. In January 1948, a three-component short-period moving coil Benioff system was installed at the observatory, and a vertical component Benioff was placed about 3 miles north on rock outcrop to permit operation at higher magnification. The station site is extremely quiet and strategically located for recording local and teleseismic earthquakes, detecting between 20 and 50 every day. Because of the favorable conditions this station has made valuable contributions to the study of both Alaskan and worldwide earthquakes.

In January 1964, this outpost site became a part of the Worldwide Network of Standard Seismograph Stations, operating short- and long-period systems. In July 1964, following the Prince William Sound earthquake, a four-channel United Electro Dynamics strong-motion seismograph system was installed at the College Observatory.

In the late 60's and in the 70's additional seismic nets were established in support of geophysical and environmental studies in Alaska. This permitted greater accuracies in the data and the detection of smaller seismic events than was possible with the limited network in the earlier part of the century.

Magnitudes from a number of different sources are included in the Alaska data file. Gutenberg and Richter (1954) and Richter (1958) discuss the development of the magnitude scale. Many magnitudes published by Gutenberg and Richter (1954) were later revised by Richter (1958). The revised magnitudes are used in the file even though the source is identified as Gutenberg and Richter (1954). The concept of earthquake magnitude is not restricted to one value, as several definitions are possible, depending on which seismic waves are measured. Three different magnitude scales, BODY WAVE (MB), SURFACE WAVE (MS), and LOCAL (ML), are distinguished in this file. In addition, another data field, OTHER MAGNITUDE, has been included when it was unclear which scale was used. Richter (1958) and other modern seismology references provide detailed discussions of this topic. Because of the different methods used, differences between values quoted on different magnitude scales occur. In many cases it is not always obvious which scale has been applied.

A maximum intensity is listed for many of the earthquakes. Each is assigned according to the Modified Mercalli Intensity Scale of 1931 (Wood and Neumann, 1931). Some of these values have been converted from reported intensities on other scales. An abridged version of the Modified Mercalli Intensity Scale of 1931 and a comparison of ratings on the Japanese, Rossi-Forel, and European (Mercalli-Cancani-Sieberg) scales are included in appendix 1. Because of the large distances between populated centers, intensities reported in Alaska often are not good indicators of the severity of the earthquake in the region surrounding the epicenter. Most of the earthquakes in Alaska occur offshore or away from population centers, which limits the completeness of intensity reports.

DATA SOURCES

Preliminary Determination of Epicenters

Under the PDE program, incoming seismic data (i.e., earthquake arrival times) are processed routinely by computer, with external control by a seismologist. Readings from a minimum of five seismograph stations are required for an acceptable solution or epicenter. These locations are published by the USGS in their biweekly and monthly PDE publications as soon as sufficient data have accumulated to insure a reasonable degree of accuracy. The PDE program was begun in 1937 when a few of the larger earthquakes were located. Until 1960, all epicenters were located graphically with an accuracy of about ¼ to ½ degree in latitude and longitude and 50 km in depth. Shallow epicenters were assumed to be 25 km deep. Since 1960 when epicenters began to be computed by electronic means, most PDE determinations are considered accurate to a few tenths of a degree in position and to 25 km in depth. (A complete description of the PDE computer program is provided by Engdahl and Gunst, 1966). Approximately 500 Alaskan earthquakes are added to the file from the PDE program each year. Body-wave magnitudes (MB) have been routinely computed by the Coast and Geodetic Survey and successor organizations as part of the PDE program since April 1963. Surface-wave magnitudes (MS) have been computed as part of the PDE program since May 1968 whenever sufficient data were available. In general, these magnitudes represent an average of individual station values. Significant deviations from a computed average are deleted and a new mean value is then determined. The resultant values are probably accurate to within about 0.3 unit of magnitude.

Seismicity of the Earth and Associated Phenomena

Gutenberg and Richter (1954) describe the data tabulated in their classic reference, *Seismicity of the Earth and Associated Phenomena.*

Approximately 200 earthquake epicenters, covering the period 1899 through 1949, were added to the Alaska data file from this source.

Earthquake History of the United States

This summary of significant earthquakes, revised by Coffman and von Hake (1973), has provided most of the pre-1928 Alaska data now included in the earthquake data file. The geographic locations listed are given to the nearest tenth of a degree and usually represent the place where the highest intensity occurred. Locations prior to 1899 should not be considered to be "epicenters," as instrumental data are not available prior to about 1899. Generally, only those earthquakes between 1786 and 1927 (about 100) in *Earthquake History of the United States* have been incorporated in the data file, because post-1927 data have been included from other, more detailed sources.

United States Earthquakes

Much of the "felt" data incorporated in the Alaska data file (including intensity, associated phenomena, and cultural effects) and some instrumental data have been extracted from the *United States Earthquakes* reports, published annually by the Coast and Geodetic Survey and NOAA from 1928 through 1972 and jointly by NOAA/USGS thereafter.

Other Sources

Other sources utilized in developing the Alaska data file include monthly publications of the Bureau Central International de Séismologie, Strasbourg, France, for the 1950-61 period and *The International Seismological Summary*, Kew, England, for the 1950-59 interval. All abbreviations used to indicate an earthquake source in the data file are listed in appendix 3.

TABULAR SUMMARY OF EARTHQUAKE DATA FILE

Table 1 summarizes earthquakes in Alaska by magnitude and depth distribution per year through 1974. The tabular summary includes the 1786-1899 period, although data on magnitude or depth of focus are not available for this preinstrumental era. The total number of events per year shows significant increases in about 1949 and later years. These increases represent improvements in seismic instrumentation, reporting procedures, and location techniques, rather than a real increase in earthquake occurrences. The seismic magnitude scale was developed for earthquakes in southern California by Prof. Charles F. Richter, California Institute of Technology, Pasadena, in the early 1930's. Later work extended magnitude determinations to earthquakes at greater distances and to earthquakes originating at focal depths in excess of 25 km. Magnitudes for the largest shocks dating back to 1899 were calculated using amplitude data from available seismograms.

Table 2A summarizes all earthquakes in the Alaska file by magnitude for 1° and 10° Marsden Squares (appendix 7) that contain one or more earthquakes. Known tectonic events are counted separately but are included in the total. Also, the maximum magnitude for each 1° Marsden Square is listed. A glance at table 1 shows that the file is fairly complete for magnitudes greater than 7 since 1899. For magnitudes between 6 and 7, the file is fairly complete since about 1928. It is only since about 1963 that the file becomes useful in representing earthquakes with magnitudes less than 6. It should be noted that although table 2A contains all earthquakes in the Alaska file, there are only 29 earthquakes included prior to 1899, none of which has an assigned magnitude. Table 2B is a Marsden Square summary for the years 1963 through 1974, the interval in which the data are fairly homogeneous.

For those earthquakes with more than one magnitude type in the data record, the higher value is used for the count and maximum value in tables 1, 2A, and 2B, and is shown in figures 2 and 3. In these tables, there are numerous earthquakes listed with no given magnitude. It can be assumed that most of those since 1899 are probably less than magnitude 5.5.

TSUNAMIS AND SEICHES IN ALASKA

During recorded history there have been 54 instances where earthquakes have produced tsunamis or seiches in Alaska. Approximately 26 of these earthquakes occurred in or near Alaska, and the remainder occurred in more distant localities. Table 5 lists those earthquakes that have produced tsunamis and seiches in Alaska. The maximum wave height at communities in Alaska experiencing the tsunami is shown in table 6 (also see fig. 4). Two examples of tsunami damage in Alaska are shown in figures 5 and 6.

DATA FORMATS

In addition to offering copies of the Alaska earthquake data file on magnetic tape, NGSDC also can provide computer listings, punched cards, or plots of selected portions of the data file. These usually cover a particular geographical area, bounded by a set of predetermined coordinates or within a certain radius of a set point (see table 3, sample geographic search). Data searches by magnitude, depth of focus, selected earthquake effects, Flinn-Engdahl regions (appendix 2), or other parameters also are provided (see tables 4 and 5).

Appendix 4 contains a description of the 90-character tape format of the earthquake data file. Each data field is explained or a reference is given to another section for additional explanation. The format for punched cards incorporates the data from positions 6 through 85 adjusted to the common 80-column format as shown in appendix 5. Most of the description of the tape format applies to printout versions of the data file (appendix 6).

ACKNOWLEDGMENTS

This study, part of a program for the environmental assessment of the Alaskan Continental Shelf, was supported by the Bureau of Land Management and the Outer Continental Shelf Environmental Assessment Program Office of the National Oceanic and Atmospheric Administration.

All of the computer programs related to the tables and maps in this report were developed by Carl Abston, National Geophysical and Solar-Terrestrial Data Center.

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Table 1 Summary of earthquakes in Alaska by year, magnitude, and depth
(Area covered: 48 -75 N, 165 E-125 W)

YEAR	MAGNITUDES														DEPTHS (KM)			
	MAG NOT GIVEN	LESS THAN 3.5	3.5 TO 3.9	4.0 TO 4.4	4.5 TO 4.9	5.0 TO 5.4	5.5 TO 5.9	6.0 TO 6.4	6.5 TO 6.9	7.0 TO 7.4	7.5 TO 7.9	8.0 TO 8.4	8.5 TO 8.9	TOTAL	0 TO 70	71 TO 300	301 OR MORE	DEPTH NOT GIVEN
1786	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1
1788	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1
1796	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1
1802	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1
1812	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1
1817	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1
1818	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1
1826	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1
1835	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1
1836	2	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	2
1843	3	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	3
1847	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1
1857	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1
1861	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1
1866	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1
1867	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1
1868	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1
1878	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1
1879	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1
1880	2	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	2
1883	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1
1896	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1
1897	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1
1898	2	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	2
1899	3	0	0	0	0	0	0	0	0	0	1	1	1	6	2	0	0	4
1900	1	0	0	0	0	0	0	0	0	0	0	1	0	2	1	0	0	1
1901	2	0	0	0	0	0	0	0	0	0	1	0	0	3	1	0	0	2
1902	0	0	0	0	0	0	0	0	0	0	1	0	0	1	1	0	0	0
1903	3	0	0	0	0	0	0	0	0	0	0	1	0	4	0	1	0	3
1904	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	0	0	0
1905	1	0	0	0	0	0	0	0	0	0	1	0	0	2	1	0	0	1
1906	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	0	0	0
1907	2	0	0	0	0	0	0	0	1	0	1	0	0	4	1	1	0	2
1908	3	0	0	0	0	0	0	0	0	1	0	0	0	4	1	0	0	3
1909	1	0	0	0	0	0	0	0	0	2	0	0	0	3	0	1	0	2
1910	4	0	0	0	0	0	0	0	1	1	0	0	0	6	1	1	0	4
1911	2	0	0	0	0	0	0	0	1	0	0	0	0	3	1	0	0	2
1912	3	0	0	0	0	0	0	1	1	5	1	0	0	11	4	3	0	4
1913	0	0	0	0	0	0	0	0	1	0	0	0	0	1	1	0	0	0
1914	1	0	0	0	0	0	0	0	1	0	0	0	0	2	0	0	0	2
1915	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1
1916	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	1	0	0
1917	2	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	2
1918	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	1
1920	1	0	0	0	0	0	0	2	1	0	0	0	0	4	2	0	0	2
1921	0	0	0	0	0	0	0	0	1	0	0	0	0	1	1	0	0	0
1922	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1
1923	0	0	0	0	0	0	2	0	0	1	0	0	0	3	1	0	0	2
1924	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	1

Table 1 (Continued)

YEAR	MAGNITUDES: MAG NOT GIVEN	LESS THAN 3.5	3.5 TO 3.9	4.0 TO 4.4	4.5 TO 4.9	5.0 TO 5.4	5.5 TO 5.9	6.0 TO 6.4	6.5 TO 6.9	7.0 TO 7.4	7.5 TO 7.9	8.0 TO 8.4	8.5 TO 8.9	TOTAL	DEPTHS (KM): 0 TO 70	71 TO 300	301 OR MORE	DEPTH NOT GIVEN
1925	3	0	0	0	0	0	0	0	0	1	0	0	0	4	0	0	0	4
1926	0	0	0	0	0	0	1	1	1	1	0	0	0	4	1	0	0	3
1927	2	0	0	0	0	0	0	0	0	1	0	0	0	3	1	0	0	2
1928	19	0	0	0	0	0	0	2	2	1	0	0	0	24	5	0	0	19
1929	18	0	0	0	0	0	0	4	1	3	1	0	1	28	7	0	0	21
1930	12	0	0	0	0	1	2	0	1	0	0	0	0	16	0	1	0	15
1931	3	0	0	0	0	0	3	4	0	0	0	0	0	10	2	1	0	7
1932	4	0	0	0	0	0	1	6	4	0	0	0	0	15	10	0	0	5
1933	7	0	0	0	0	1	6	10	4	1	0	0	0	29	15	0	0	14
1934	3	0	0	0	0	0	1	3	4	1	0	0	0	12	6	2	0	4
1935	3	0	0	0	0	0	0	2	2	0	0	0	0	7	3	0	0	4
1936	6	0	0	0	0	0	2	2	0	0	0	0	0	10	1	2	0	7
1937	6	0	0	0	0	1	3	1	0	2	0	0	0	13	2	1	0	10
1938	12	0	0	0	0	2	2	2	0	1	0	0	1	20	3	1	0	16
1939	16	0	0	0	0	0	1	3	2	0	0	0	0	22	3	1	0	18
1940	30	0	0	0	0	1	2	2	2	4	1	0	0	42	7	5	0	30
1941	10	0	0	0	0	1	1	2	4	0	0	0	0	18	2	2	0	14
1942	8	0	0	0	0	0	2	1	1	1	0	0	0	13	0	2	0	11
1943	6	0	0	0	0	0	0	0	0	1	0	0	0	7	1	0	0	6
1944	14	0	0	0	0	0	0	2	1	2	0	0	0	19	2	1	0	16
1945	19	0	0	0	0	0	1	1	1	0	0	0	0	22	3	2	0	17
1946	0	0	0	0	0	0	0	0	4	4	0	0	0	8	4	3	0	1
1947	0	0	0	0	0	0	0	0	0	1	0	0	0	1	1	0	0	0
1948	0	0	0	0	0	0	0	2	3	0	1	0	0	6	2	2	0	2
1949	42	0	0	0	0	0	0	2	1	2	0	1	0	48	3	8	0	37
1950	38	0	0	0	0	0	0	3	4	0	0	0	0	45	2	5	0	38
1951	49	0	0	0	0	0	2	3	0	1	0	0	0	55	11	12	0	32
1952	53	0	0	0	0	3	0	5	3	0	0	0	0	64	12	9	0	43
1953	35	0	0	0	0	0	0	2	3	1	0	0	0	41	2	5	0	34
1954	42	0	0	0	0	0	0	2	4	0	0	0	0	48	5	6	0	37
1955	59	0	0	0	0	0	4	7	10	0	0	0	0	80	4	7	0	69
1956	69	0	0	0	0	0	1	5	8	0	0	0	0	83	5	6	0	72
1957	431	0	0	0	0	2	11	21	24	7	0	1	0	497	7	4	0	486
1958	186	0	0	0	1	3	13	18	8	1	1	0	0	231	8	4	0	219
1959	119	0	0	0	0	3	6	7	3	0	0	0	0	138	6	4	0	128
1960	120	0	0	1	3	6	4	9	4	1	0	0	0	148	51	15	0	82
1961	142	0	0	0	4	5	13	8	2	0	0	0	0	174	161	13	0	0
1962	149	0	0	0	2	3	1	8	5	0	0	0	0	168	151	17	0	0
1963	66	2	24	37	53	21	5	5	2	0	0	0	0	265	225	39	0	1
1964	16	0	132	426	351	167	43	15	9	0	0	0	1	1160	1130	28	0	2
1965	32	0	111	636	576	305	80	16	11	1	1	0	0	1819	1775	43	1	0
1966	8	0	61	234	136	69	18	4	1	1	0	0	0	532	495	36	0	1
1967	32	2	77	181	111	32	20	6	0	0	0	0	0	461	396	63	0	2
1968	332	3	87	159	89	34	7	6	1	1	0	0	0	719	597	122	0	0
1969	418	23	97	157	102	38	13	5	2	1	0	0	0	856	657	196	0	3
1970	43	28	63	112	79	39	14	8	3	1	0	0	0	390	300	90	0	0
1971	78	28	56	109	101	49	18	6	2	2	0	0	0	449	332	117	0	0
1972	140	48	75	102	97	46	16	5	0	0	1	0	0	530	367	163	0	0
1973	107	57	91	94	106	37	16	5	1	0	0	0	0	514	378	136	0	0
1974	96	53	76	116	83	32	18	4	1	0	0	0	0	479	359	120	0	0
TOTAL	3163	244	950	2454	1894	901	353	239	157	56	13	7	4	10445	7541	1302	1	1601

Table 2A. Summary of earthquakes in Alaska by magnitude and 1 and 10 Marsden Squares, 1786-1974[1]

MARSDEN SQUARE	NO MAGNITUDE	UNDER-5.0	5.0-5.4	5.5-5.9	6.0-6.4	6.5-6.9	7.0-7.4	7.5-7.9	8.0-8.4	8.5-8.9	NON-TEC	TOTAL	MAX
15786		3										3	4.9
15787	1	2										3	4.2
15788	8	13	1			1						23	6.6
15789	1		2	1	2							6	6.3
15795							1					1	7.3
15796		1					1					2	7.0
15797	3	4	1	1								9	5.8
15798	4	21	4	1								30	5.7
15799	30	14	6	9	3	1						63	6.5
*TEN DEGREE TOTAL	47	58	14	12	5	2	2	0	0	0	0	140	7.3
15880		1										1	3.8
15890	3	1		2	1	1						8	6.5
15891		1										1	4.4
*TEN DEGREE TOTAL	3	3	0	2	1	1	0	0	0	0	0	10	6.5
16196	1											1	0.0
*TEN DEGREE TOTAL	1	0	0	0	0	0	0	0	0	0	0	1	0.0
16293			1									1	5.4
16296	1											1	0.0
16297	1											1	0.0
16298		2										2	4.6
16299		4										4	4.5
*TEN DEGREE TOTAL	2	6	1	0	0	0	0	0	0	0	0	9	5.4
16386		1										1	4.0
16391	1	1										2	4.7
16397	1	3										4	4.9
16398		2										2	4.2
16399		5										5	4.9
*TEN DEGREE TOTAL	2	12	0	0	0	0	0	0	0	0	0	14	4.9
19305	1											1	0.0
19307	1											1	0.0
19308	2											2	0.0
19309	14	69	7	1	2							93	6.4
19318	1	2										3	4.0
19319	2	8			1							11	6.4
19328		1										1	3.7
19335	1											1	0.0
*TEN DEGREE TOTAL	22	80	7	1	3	0	0	0	0	0	0	113	6.4
19400	14	4	1	1	1	1						22	6.8
19401					1							1	6.0

[1]Magnitude values are available from the year 1899.

Table 2A (Continued)

MARSDEN SQUARE	NO MAGNITUDE	UNDER-5.0	5.0-5.4	5.5-5.9	6.0-6.4	6.5-6.9	7.0-7.4	7.5-7.9	8.0-8.4	8.5-8.9	NON-TEC	TOTAL	MAX
19402	1											1	0.0
19403		1										1	3.9
19410	5	8	2	1	1							17	6.1
19411	1	1	1	1	2	2	2					10	7.0
19420	1	1										2	3.6
19421	5	4			2	2						13	6.7
19422	1	2	1	1	1							6	6.3
19425	1											1	0.0
19430		1										1	4.0
19431	1											1	0.0
19432	1	2			1							4	6.2
19433	2								1			3	8.1
19442	1											1	0.0
19443		1	1		1							3	6.2
19444	2	4				2						8	6.5
19445		1										1	4.6
19446	1											1	0.0
19448	1											1	0.0
19462	1											1	0.0
19465	2	3	2	1	1			1				10	7.6
19466	1	2			1							4	6.2
19468		1										1	4.2
19469	1											1	0.0
19474		1										1	3.7
19476	8	2		1								11	5.6
19477	4	7	3	1		1	1					17	7.1
19478		3			1							4	6.4
19479	1	2										3	4.1
19484	1											1	0.0
19486	6	2	1	1								10	5.6
19487	10	12						1				23	7.9
19488	3	2	1									6	5.0
19489		3										3	4.4
19495	3	1										4	4.8
19496	2	8			1							11	6.0
19497		5	2									7	5.2
19498	4	2		1								7	5.7
19499	6	3										9	4.4
*TEN DEGREE TOTAL	91	89	15	9	14	8	3	2	1	0	0	232	8.1
19559		1										1	4.1
19568		3										3	4.5
19569	1	9	1		1							12	6.0
19570		1										1	4.1
19573	1											1	0.0
19574		1										1	4.5
19576		2										2	4.6
19578			1									1	5.0
19579	2	13	1									16	5.1
19582			1									1	5.3

Table 2A (Continued)

MARSDEN SQUARE	NO MAGNITUDE	UNDER-5.0	5.0-5.4	5.5-5.9	6.0-6.4	6.5-6.9	7.0-7.4	7.5-7.9	8.0-8.4	8.5-8.9	NON-TEC	TOTAL	MAX
19583		1										1	4.9
19584		2										2	4.2
19585		1										1	3.6
19586		1										1	4.4
19587	1	1										2	3.3
19588	1	11	1									13	5.2
19589		22	9	3	1							35	6.2
19590	1	2										3	4.2
19591	3	2					1					6	7.0
19592		12	1		2	1						16	6.8
19593	1	8	3	1	1							14	6.2
19594	1	44	15									60	5.4
19595		54	5	1	2							62	6.2
19596	1	52	6	2	1							62	6.2
19597	5	41	6	4			1					57	7.2
19598	5	50	3	1		1						60	6.6
19599	4	21	2	1	1		1					30	7.0
*TEN DEGREE TOTAL	27	355	55	13	9	2	3	0	0	0	0	464	7.2
19626	1											1	0.0
19634	2											2	0.0
19636			1									1	5.0
19637			1									1	5.1
19638		1										1	4.9
19639			1	1								2	5.5
19640		1										1	4.5
19646	1											1	0.0
19647	1	7										8	4.9
19648	1	7			1							9	6.2
19649		2	1									3	5.1
19650		1										1	4.0
19651				1								1	5.6
19653	2						1					3	7.1
19654		8		1								9	5.7
19655	3	8	1	1		2						15	6.8
19656	4	5	2	1		1	1					14	7.1
19657	4	4										8	4.6
19658	2	3	2	1			1			1		10	8.7
19659	2	3				1						6	6.7
19660		3	1									4	5.0
19661	2	38	7									47	5.3
19662	6	123	30	5	7	2						173	6.6
19663	10	71	12	4	9	3						109	6.7
19664	6	24	5	3	1	3						42	6.5
19665	4	7	2	1								14	5.5
19666	3	7	2	1	1	1	1					16	7.0
19667	4	4	2	2	1	1						14	6.5
19668	5	6										11	4.6
19669		2	1									3	5.1
19670	4	29	5	1								39	5.5

Table 2A (Continued)

MARSDEN SQUARE	NO MAGNITUDE	UNDER-5.0	5.0-5.4	5.5-5.9	6.0-6.4	6.5-6.9	7.0-7.4	7.5-7.9	8.0-8.4	8.5-8.9	NON-TEC	TOTAL	MAX
19671	1	30	15	3								49	5.7
19672	8	47	7	2	1	1						66	6.5
19673	6	37	2	4		1						50	6.5
19674	5	14	1	1	1		1					23	7.0
19675	3	4	1					1				9	7.5
19676	5	5							1			11	8.3
19677		2										2	4.6
19678	1	1										2	4.4
19680	2	31	8	3	2							46	6.3
19681	8	42	5	3	1	2						61	6.7
19682	14	20	7		1	1						43	6.8
19683	4	18		1		1						24	6.8
19684	13	25	4	2								44	5.6
19685	5	6			1							12	6.0
19686	1	5										6	4.8
19687	2	2										4	4.6
19688	1											1	0.0
19689		1										1	4.1
19690	8	12	1									21	5.1
19691	17	24	3		1	1						46	6.7
19692	70	48		1	1	1						121	6.5
19693	43	37	7	2	1		1					91	7.0
19694	5	9										14	4.9
19695	1	3			1							5	6.2
19696		1										1	4.4
19697		1										1	4.7
*TEN DEGREE TOTAL	290	789	137	45	31	22	6	1	1	1	0	1323	8.7
19714	1											1	0.0
19716	1				1							2	6.3
19717	3	5										8	4.9
19718	10	5	1		1	1	1					19	7.0
19719	6	9	3									18	5.0
19720	1											1	0.0
19721			1	1								2	5.6
19722			1									1	5.1
19723		6		1			1					8	7.4
19724	2	3	1									6	5.4
19725	3	2	2									7	5.2
19726	10	20		2		1	1					34	7.3
19727	26	18	6	2	4	3						59	6.7
19728	52	55	10	9	7	6						139	6.8
19729	55	98	16	8	5	2	2					186	7.4
19730	1	5	2	1								9	5.6
19731	2	5	4			2						13	6.6
19732	2	4	1	2								9	5.7
19733	16	46	5	2								69	5.7
19734	14	27	3		3	1	1					49	7.0
19735	9	12	7	2	2		2					34	7.1
19736	24	22	2	2								50	5.8

Table 2A (Continued)

MARSDEN SQUARE	NO MAGNITUDE	UNDER-5.0	5.0-5.4	5.5-5.9	6.0-6.4	6.5-6.9	7.0-7.4	7.5-7.9	8.0-8.4	8.5-8.9	NON-TEC	TOTAL	MAX
19737	26	45	5		3	6						85	6.9
19738	28	21			1	3	1					54	7.0
19739	11	8	4	1	1	2						27	6.7
19740		2				1						3	6.7
19741	7	8	3		1	1		1				21	7.5
19742	8	12	2	2	1							25	6.0
19743	16	19	3	2	1							41	6.0
19744	15	27	8	1	3	1						55	6.9
19745	17	8	1		1		1					28	7.1
19746	8	1		2	1	1						13	6.5
19747	7	1			1							9	6.0
19748	2			1								3	5.8
19749	3	1										4	4.2
19750	4	9	3	1	3							20	6.3
19751	5	4			1	1						11	6.7
19752	5	2										7	4.4
19753	4					1						5	6.7
19754	3											3	0.0
19755	2		1					1				4	7.8
19756	1	1										2	4.2
19757	1	1										2	4.5
19758		2										2	4.3
19759	1											1	0.0
19760	1		1									2	5.3
19761		2		1								3	5.6
19762	3	2										5	4.7
19764		1										1	4.8
19767	1	2										3	4.8
19769		1										1	4.7
19770						1						1	6.7
19771						1						1	6.5
*TEN DEGREE TOTAL	417	522	96	43	41	35	10	2	0	0	0	1166	7.8
19800	2	1	1									4	5.0
19801	1	4	1	1		1	1					9	7.0
19802	1	2	1		1	1						6	6.5
19803	4	1										5	4.3
19804	3	2										5	4.7
19805	6	4	2			1						13	6.7
19806	3	3	5	1		1						13	6.5
19807	12	4	1		1	1						19	6.8
19808	4	9										13	4.6
19809	6	32	2	1	2							43	6.1
19810	20	24	2	4	2					1		53	8.6
19811	18	42	1	2	1							64	6.1
19812	8	6	2		1	2						19	6.5
19813	30	70	15	4	2	2						123	6.7
19814	18	26	11	1	5	1	1					63	7.0
19815	25	66	11	5	5	3			1			116	8.3
19816	52	101	18	7	6	4	3					191	7.3

Table 2A (Continued)

MARSDEN SQUARE	NO MAGNITUDE	UNDER-5.0	5.0-5.4	5.5-5.9	6.0-6.4	6.5-6.9	7.0-7.4	7.5-7.9	8.0-8.4	8.5-8.9	NON-TEC	TOTAL	MAX
19817	56	69	9	11	4	3	1					153	7.1
19818	56	65	21	13	9	4	1					169	7.0
19819	70	142	34	11	6	10	1					274	7.0
19820	43	47	11	2	3							106	6.3
19821	36	32	8	5	2							83	6.2
19822	9	11	1			2						23	6.5
19823	26	28	2	4	3	1						64	6.5
19824	30	21	4	2								57	5.6
19825	24	22	2		2	1						51	6.5
19826	20	8	6		1	1	1					37	7.1
19827	10	5	2		1		1	1				20	7.8
19828	10	11	2				1					24	7.3
19829	8	8	2	1	1		1					21	7.0
19830	9	12	2	1				1				25	7.5
19831	3	2	1		1	1						8	6.7
19832	5	4				1						10	6.5
19833	1	6					1					8	7.0
19834	1	3										4	4.5
19835	1	3										4	4.9
19836						1						1	6.7
19837	3											3	0.0
19838	4							1				5	7.9
19841	1											1	0.0
19848	1											1	0.0
19860	1											1	0.0
19870	3											3	0.0
19890	1											1	0.0
19899	1											1	0.0
*TEN DEGREE TOTAL	646	896	180	76	59	42	13	3	1	1	0	1917	8.6
19900		4										4	4.8
19901		4										4	4.9
19902		11										11	4.5
19903		13	1	1								15	5.7
19904	1	18	2									21	5.3
19905	1	19	5									25	5.2
19906	2	47	1	2	1							53	6.0
19907	2	92	17				1					112	7.3
19908		107	4	2		1						114	6.5
19909	12	19		1	1							33	6.2
19910		4										4	4.9
19911	1	22	1									24	5.1
19912	4	59	4									67	5.4
19913	1	87	11	3	1	1						104	6.5
19914	8	110	49	7	3							177	6.1
19915	10	103	21	5	7		1					147	7.0
19916	8	121	41	5	2	2						179	6.5
19917	10	73	18	3	1	2		1				108	7.7
19918	35	109	23	6	1			1			1	176	7.7
19919	51	82	9	7	6	4	1		1		4	165	8.3

Table 2A (Continued)

MARSDEN SQUARE	NO MAGNITUDE	UNDER-5.0	5.0-5.4	5.5-5.9	6.0-6.4	6.5-6.9	7.0-7.4	7.5-7.9	8.0-8.4	8.5-8.9	NON-TEC	TOTAL	MAX
19920	1	14	1									16	5.1
19921		63	6	1	2			1				73	7.6
19922	7	63	23	13	1	3						110	6.7
19923	7	45	29	16	2		2	1				102	7.7
19924	6	29	13	5	2	1						56	6.5
19925	3	24	14	7	1	1						50	6.9
19926	7	11				1						19	6.5
19927	21	6	2			3						32	6.7
19928	7	9	1	3	1	1						22	6.6
19929	6	7	1									14	5.0
19930	5	3	1	2	1							12	6.2
19931	1	10	5	3	2		1					22	7.1
19932	4	6	2			1						13	6.7
19933	1	1			1							3	6.0
19934	1	3	1									5	5.3
19936	1	2										3	4.7
19937			1									1	5.0
19938		1										1	4.0
19939	1					1						2	6.7
19940	6	1										7	4.2
19941	1											1	0.0
19942		1										1	4.7
19944	1											1	0.0
*TEN DEGREE TOTAL	233	1403	307	92	36	22	6	4	1	0	5	2109	8.3
20006	1											1	0.0
20009		1										1	4.2
20018	1											1	0.0
20029		3										3	4.3
20037	1	1										2	4.7
20038	3	2				1						6	6.5
20039	1	6	2	1		1						11	6.5
20045		1	2									3	5.4
20046					1							1	6.1
20047	1	1	1									3	5.4
20048	2	2	1	1	1							7	6.0
20049	8	2	3		2							15	6.1
20055		10	5	3								18	5.8
20056	4	12	2	2	1	1						22	6.7
20057	2		1									3	5.2
20058		1				1	1					3	7.2
20065				2								2	5.6
20066	1											1	0.0
20075	3											3	0.0
20085				1								1	5.6
20095	1											1	0.0
*TEN DEGREE TOTAL	29	42	17	10	5	4	1	0	0	0	0	108	7.2
22906		1										1	3.6

ble 2 (Continued)

MARSDEN SQUARE	NO MAGNITUDE	UNDER-5.0	5.0-5.4	5.5-5.9	6.0-6.4	6.5-6.9	7.0-7.4	7.5-7.9	8.0-8.4	8.5-8.9	NON-TEC	TOTAL	MAX
22916		1										1	4.1
22925	1		1									2	5.0
22929	1											1	0.0
22938		1										1	4.8
22946		1										1	3.9
22956	1											1	0.0
22958	1											1	0.0
*TEN DEGREE TOTAL	4	4	1	0	0	0	0	0	0	0	0	9	5.0
23005	1											1	0.0
23006	1											1	0.0
23007	1	1				1						3	6.5
23008	2			1								3	5.6
23009		1	1									2	5.1
23014		1										1	4.2
23017			1									1	5.2
23018	1	1		1								3	5.7
23019	2	3										5	3.8
23024		1										1	3.8
23030		1										1	4.2
23034		1										1	3.9
23043		1										1	4.1
23052	2					1						3	6.7
23053	8	8		2		1						19	6.5
23054	2	2	1									5	5.2
23055		1										1	3.5
23056	1											1	0.0
23060		1										1	4.8
23063	1											1	0.0
23065	1	5										6	4.8
23066		1										1	4.6
23075		1			1							2	6.2
23076	2	3				1						6	6.5
23077		1										1	3.7
23085		1										1	4.3
23086		1										1	4.2
*TEN DEGREE TOTAL	25	36	3	4	1	4	0	0	0	0	0	73	6.7
23100	14	13	2	3						1		33	8.6
23101	3	7										10	4.7
23102		11						1	2			14	8.3
23103	1	13	2									16	5.4
23104	3	20										23	4.9
23105	5	44	6		1							56	6.0
23106	16	87	14	5	1		1					124	7.0
23107	30	83	5	2		1						121	6.5
23108	9	35	1	2								47	5.7
23109	14	27	1	1		1	1					45	7.4
23110		7		1	1							9	6.0

Table 2A (Continued)

MARSDEN SQUARE	NO MAGNITUDE	UNDER-5.0	5.0-5.4	5.5-5.9	6.0-6.4	6.5-6.9	7.0-7.4	7.5-7.9	8.0-8.4	8.5-8.9	NON-TEC	TOTAL	MAX
23111		4										4	4.1
23113	1	4										5	4.5
23114		1										1	3.6
23115	1	9										10	4.7
23116	22	34		1								57	5.5
23117	37	46	7	2	4	1	2			1		100	8.5
23118	19	17			2							38	6.2
23119	40	31	2	1								74	5.7
23121		1										1	4.7
23123		2										2	3.7
23124	1	1										2	3.7
23125	2	2										4	4.6
23126	4	2										6	4.2
23127	3	10	1									14	5.1
23128	28	11	1									40	5.0
23129	59	28	1		1							89	6.2
23134	1	1		1								3	5.8
23135	4	3										7	4.4
23136	6	6										12	4.6
23137	8	10		3								21	5.6
23138	22	16	1									39	5.0
23139	60	20	2	2	1							85	6.1
23140	1											1	0.0
23141	1											1	0.0
23142	1											1	0.0
23144	2	2										4	3.6
23145	4											4	0.0
23146	11	12					1					24	7.3
23147	41	46	2	2			2					93	7.4
23148	11	13			1	1						26	6.5
23149	8	10										18	4.4
23152	1											1	0.0
23155	3		1									4	5.3
23157	5	6										11	4.2
23158	12	3										15	4.5
23159	80	12		1								93	5.5
23161	1											1	0.0
23162	1	1										2	3.1
23164		2										2	3.7
23167		1			1							2	6.0
23168	1	4										5	4.9
23169	2	1										3	3.6
23175	1	1										2	3.7
23176		1										1	4.2
23177	1	1										2	3.5
23187		2										2	4.7
23194	1											1	0.0
23195	1	1										2	4.7
*TEN DEGREE TOTAL	603	725	49	27	13	4	7	1	2	2	0	1433	8.6

Table 2A (Continued)

MARSDEN SQUARE	NO MAGNITUDE	UNDER-5.0	5.0-5.4	5.5-5.9	6.0-6.4	6.5-6.9	7.0-7.4	7.5-7.9	8.0-8.4	8.5-8.9	NON-TEC	TOTAL	MAX
23200	23	21			1							45	6.1
23201	43	29	1	1		2						76	6.7
23202	85	49	3		2	2						141	6.5
23203	39	47	3	2								91	5.8
23204		3										3	4.5
23205	1	1										2	4.1
23206	1											1	0.0
23207		1										1	3.9
23208		1										1	4.2
23210	69	45	1	3	2		1					121	7.0
23211	51	30	2	2	2		1					88	7.3
23212	16	14	1	1								32	5.7
23213	1			1								2	5.7
23214		1										1	3.1
23216		1										1	4.7
23220	35	41			1							77	6.0
23221	62	39	1	1								103	5.6
23222	7	12		2	2	1						24	6.9
23223	3	6			3							12	6.0
23224	2	1										3	4.2
23225	3											3	0.0
23226	1	3										4	4.6
23227	2											2	0.0
23229	2	2										4	4.6
23230	93	56	1		1							151	6.2
23231	30	29	3									62	5.4
23232	3	1			1							5	6.2
23233	1	1										2	4.1
23234		1										1	4.3
23235	3											3	0.0
23236	1											1	0.0
23237		1										1	4.3
23240	5	4										9	4.6
23241	2	2							1			5	8.3
23242	4	3										7	4.3
23243	1											1	0.0
23244	2											2	0.0
23246	1											1	0.0
23248		1										1	3.7
23250	65	26					1					92	7.1
23251	2	4			2							8	6.3
23252	5	2			1							8	6.3
23253	2	1										3	4.8
23255	1	5										6	4.1
23256	2	3										5	4.8
23260	1	1										2	3.6
23261	3											3	0.0
23263	3	1										4	3.8
23264	1	1										2	3.8
23265	5											5	0.0
23266	1					1	1					3	7.3

Table 2A (Continued)

MARSDEN SQUARE	NO MAGNITUDE	UNDER-5.0	5.0-5.4	5.5-5.9	6.0-6.4	6.5-6.9	7.0-7.4	7.5-7.9	8.0-8.4	8.5-8.9	NON-TEC	TOTAL	MAX
23267	9	5										14	4.3
23269		1										1	3.7
23275	2	1										3	4.5
23277		2										2	4.4
23279		1										1	4.8
23289		1										1	3.9
*TEN DEGREE TOTAL	694	501	16	13	18	6	4	0	1	0	0	1253	8.3
23311	1	1										2	4.0
23312	1											1	0.0
23321	1											1	0.0
23330	2											2	0.0
23340	2	1		1								4	5.8
23343		1										1	4.3
23345	1				1							2	6.0
23352	2					1						3	6.5
23353		1										1	4.1
23354		4										4	4.9
23356	1											1	0.0
23357	3	2										5	4.5
23358		1										1	4.9
23361		1										1	4.2
23362	2											2	0.0
23363	1			1								2	5.6
23365	1	1										2	4.1
23366	1											1	0.0
23368	1											1	0.0
23370		1										1	4.3
23371		1	1									2	5.2
23372		1										1	4.2
23374	1											1	0.0
23375	1											1	0.0
23380		1										1	4.5
23385		1										1	4.4
*TEN DEGREE TOTAL	22	18	1	2	1	1	0	0	0	0	0	45	6.5
23429	1											1	0.0
23443		2										2	4.5
23463	1											1	0.0
23464	1											1	0.0
23471	1	1			1							3	6.2
23472			1		1	1						3	6.9
23482						1						1	6.5
*TEN DEGREE TOTAL	4	3	1	0	2	2	0	0	0	0	0	12	6.9
23517				1								1	5.6
23523				1								1	5.6
23548				1								1	5.7

Table 2A (Continued)

MARSDEN SQUARE	NO MAGNITUDE	UNDER-5.0	5.0-5.4	5.5-5.9	6.0-6.4	6.5-6.9	7.0-7.4	7.5-7.9	8.0-8.4	8.5-8.9	NON-TEC	TOTAL	MAX
*TEN DEGREE TOTAL	0	0	0	3	0	0	0	0	0	0	0	3	5.7
26528						1						1	6.5
*TEN DEGREE TOTAL	0	0	0	0	0	1	0	0	0	0	0	1	6.5
26609	1											1	0.0
26618				1								1	5.5
*TEN DEGREE TOTAL	1	0	0	1	0	0	0	0	0	0	0	2	5.5
26703		3										3	4.5
26704		3										3	4.7
26705		1										1	4.2
*TEN DEGREE TOTAL	0	7	0	0	0	0	0	0	0	0	0	7	4.7
26821		1										1	3.9
*TEN DEGREE TOTAL	0	1	0	0	0	0	0	0	0	0	0	1	3.9
TOTAL	3163	5550	900	353	239	156	55	13	7	4	5	10445	8.7

Table 2B. Summary of earthquakes in Alaska b magnitude and 1 and 10 Marsden Squares, 1963-1974

MARSDEN SQUARE	NO MAGNITUDE	UNDER-5.0	5.0-5.4	5.5-5.9	6.0-6.4	6.5-6.9	7.0-7.4	7.5-7.9	8.0-8.4	8.5-8.9	NON-TEC	TOTAL	MAX
15786		3										3	4.9
15787		2										2	4.2
15788	2	13	1									16	5.0
15789			1	1								2	5.7
15796		1										1	4.3
15797		4	1	1								6	5.8
15798		19	4									23	5.3
15799		14	4	1	1							20	6.0
*TEN DEGREE TOTAL	2	56	11	3	1	0	0	0	0	0	0	73	6.0
15880		1										1	3.8
15890		1										1	3.2
15891		1										1	4.4
*TEN DEGREE TOTAL	0	3	0	0	0	0	0	0	0	0	0	3	4.4
16293			1									1	5.4
16298		2										2	4.6
16299		4										4	4.5
*TEN DEGREE TOTAL	0	6	1	0	0	0	0	0	0	0	0	7	5.4
16386		1										1	4.0
16391		1										1	4.7
16397		3										3	4.9
16398		2										2	4.2
16399		5										5	4.9
*TEN DEGREE TOTAL	0	12	0	0	0	0	0	0	0	0	0	12	4.9
19309	2	69	7		2							80	6.4
19318		2										2	4.0
19319	2	8										10	4.9
19328		1										1	3.7
*TEN DEGREE TOTAL	4	80	7	0	2	0	0	0	0	0	0	93	6.4
19400		4	1	1								6	5.6
19403		1										1	3.9
19410	1	8	2	1								12	5.7
19411		1		1			1					3	7.0
19420		1										1	3.6
19421		4										4	4.8
19422		2										2	4.7
19430		1										1	4.0
19432		2										2	4.2
19443		1	1									2	5.2
19444		4										4	4.0
19445		1										1	4.6
19465		3	2	1	1			1				8	7.6

Table 2B (Continued)

MARSDEN SQUARE	NO MAGNITUDE	UNDER-5.0	5.0-5.4	5.5-5.9	6.0-6.4	6.5-6.9	7.0-7.4	7.5-7.9	8.0-8.4	8.5-8.9	NON-TEC	TOTAL	MAX
19466	1	2										3	4.6
19468		1										1	4.2
19474		1										1	3.7
19476		2										2	4.8
19477		7	3			1						11	6.7
19478		3			1							4	6.4
19479		2										2	4.1
19486	1	2										3	4.2
19487		12										12	4.7
19488		2	1									3	5.0
19489		3										3	4.4
19495		1										1	4.8
19496		8										8	4.3
19497		5										5	4.4
19498		2										2	4.6
19499		3										3	4.4
*TEN DEGREE TOTAL	3	89	10	4	2	1	1	1	0	0	0	111	7.6
19559		1										1	4.1
19568		3										3	4.5
19569		9	1		1							11	6.0
19570		1										1	4.1
19573	1											1	0.0
19574		1										1	4.5
19576		2										2	4.6
19578			1									1	5.0
19579	2	13	1									16	5.1
19582			1									1	5.3
19583		1										1	4.9
19584		2										2	4.2
19585		1										1	3.6
19586		1										1	4.4
19587	1	1										2	3.3
19588	1	11	1									13	5.2
19589		22	9	2	1							34	6.2
19590		2										2	4.2
19591	1	2										3	3.9
19592		12	1		2	1						16	6.8
19593	1	9	3	1								13	5.8
19594	1	44	15									60	5.4
19595		54	5	1	2							62	6.2
19596	1	52	6	2	1							62	6.2
19597	5	41	6	4								56	5.6
19598	5	50	3	1		1						60	6.6
19599	3	21	2	1	1							28	6.1
*TEN DEGREE TOTAL	22	355	55	12	8	2	0	0	0	0	0	454	6.8
19636			1									1	5.0
19637			1									1	5.1

Table 2B (Continued)

MARSDEN SQUARE	NO MAGNITUDE	UNDER-5.0	5.0-5.4	5.5-5.9	6.0-6.4	6.5-6.9	7.0-7.4	7.5-7.9	8.0-8.4	8.5-8.9	NON-TEC	TOTAL	MAX
19638		1										1	4.9
19639			1	1								2	5.5
19640		1										1	4.5
19647		7										7	4.9
19648		7			1							8	6.2
19649		2	1									3	5.1
19650		1										1	4.0
19651				1								1	5.6
19654		8										8	4.8
19655		8	1	1		1						11	6.8
19656		5	2	1								8	5.7
19657		4										4	4.6
19658		3	2	1								6	5.7
19659		3										3	4.8
19660		3	1									4	5.0
19661		38	7									45	5.3
19662	1	123	30	5	6	2						167	6.6
19663	1	70	10	2	4							87	6.2
19664		24	5	3	1	2						35	6.5
19665		7	1									8	5.0
19666		7	2	1								10	5.6
19667	1	4	2	2	1							10	6.0
19668		6										6	4.6
19669		2	1									3	5.1
19670	3	29	5	1								38	5.5
19671	1	30	15	3								49	5.7
19672	4	47	7	2	1							61	6.3
19673	6	37	2	4		1						50	6.5
19674	2	14	1	1	1							19	6.1
19675	2	4	1									7	5.3
19676	1	5										6	4.8
19677		2										2	4.6
19678		1										1	4.4
19680	1	31	8	3	2							45	6.3
19681	7	42	5	3	1	1						59	6.5
19682	8	20	7			1						36	6.8
19683	1	18		1		1						21	6.8
19684	9	25	4	2								40	5.6
19685	1	6										7	4.6
19686		5										5	4.8
19687		2										2	4.6
19689		1										1	4.1
19690	5	12	1									18	5.1
19691	10	24	3			1						38	6.7
19692	66	48		1								115	5.7
19693	42	37	7									86	5.4
19694	1	9										10	4.9
19695		3										3	4.8
19696		1										1	4.4
19697		1										1	4.7

Table 2B (Continued)

MARSDEN SQUARE	NO MAGNITUDE	UNDER-5.0	5.0-5.4	5.5-5.9	6.0-6.4	6.5-6.9	7.0-7.4	7.5-7.9	8.0-8.4	8.5-8.9	NON-TEC	TOTAL	MAX
*TEN DEGREE TOTAL	173	788	134	39	18	10	0	0	0	0	0	1162	6.8
19717		5										5	4.9
19718		5	1									6	5.0
19719		9	3									12	5.0
19721			1	1								2	5.6
19722			1									1	5.1
19723		6		1								7	5.9
19724		3	1									4	5.4
19725		2	2									4	5.2
19726		19		2								21	5.7
19727	1	18	6	2								27	5.9
19728	2	55	8	5	1							71	6.0
19729	1	98	16	7	3							125	6.3
19730		5	2	1								8	5.6
19731		4	4			2						10	6.6
19732	1	4	1	2								8	5.7
19733	3	46	5	1								55	5.5
19734	1	27	3			1						32	6.5
19735	1	12	7	2								22	5.7
19736	1	22	2	2								27	5.8
19737		45	5			1						51	6.9
19738		21										21	4.9
19739		8	4	1								13	5.5
19740		2										2	4.2
19741	2	8	3			1						14	6.5
19742		12	2	1								15	5.9
19743	1	19	3	2	1							26	6.0
19744	2	27	8	1	1							39	6.0
19745		8	1									9	5.3
19746		1		1								2	5.8
19747		1										1	4.3
19749		1										1	4.2
19750		9	1	1	1							12	6.0
19751		4										4	4.6
19752	3	2										5	4.4
19753	1											1	0.0
19755			1									1	5.2
19756		1										1	4.2
19757		1										1	4.5
19758		2										2	4.3
19760			1									1	5.3
19761		2		1								3	5.6
19762		2										2	4.7
19764		1										1	4.8
19767		2										2	4.8
19769		1										1	4.7
*TEN DEGREE TOTAL	20	520	92	34	7	5	0	0	0	0	0	678	6.9
19800		1	1									2	5.0

Table 2B (Continued)

MARSDEN SQUARE	NO MAGNITUDE	UNDER-5.0	5.0-5.4	5.5-5.9	6.0-6.4	6.5-6.9	7.0-7.4	7.5-7.9	8.0-8.4	8.5-8.9	NON-TEC	TOTAL	MAX
19801		4	1	1		1	1					8	7.0
19802		2	1									3	5.0
19803		1										1	4.3
19804		2										2	4.7
19805		4	1									5	5.2
19806		3	5	1								9	5.5
19807		4	1									5	5.0
19808		9										9	4.6
19809		32	2	1	1							36	6.0
19810	1	24	2	4								31	5.8
19811		42	1	1								44	5.5
19812		6			1							7	6.0
19813	1	70	14	1								86	5.6
19814	2	26	10	1								39	5.5
19815		66	9	2	3							80	6.4
19816	3	101	17	5		1						127	6.5
19817		69	9	7	1		1					87	7.1
19818	1	65	21	13	2							102	6.2
19819	6	142	32	10	4	1	1					196	7.0
19820		46	8	1								55	5.6
19821	1	32	8	3								44	5.7
19822		11	1									12	5.2
19823		28	2	3								33	5.9
19824	2	21	3	1								27	5.6
19825		22	2		1							25	6.1
19826		8	6									14	5.4
19827		5	2									7	5.4
19828		11	2									13	5.1
19829		9	2	1								11	5.5
19830	2	12	2	1								17	5.9
19831		2	1		1							4	6.3
19832		4										4	4.9
19833	1	6										7	4.7
19834		3										3	4.5
19835		3										3	4.9
*TEN DEGREE TOTAL	20	895	166	57	14	3	3	0	0	0	0	1158	7.1
19900		4										4	4.8
19901		4										4	4.9
19902		11										11	4.5
19903		13	1	1								15	5.7
19904		18	2									20	5.3
19905		19	5									24	5.2
19906	2	47	1	2								52	5.6
19907	2	92	17				1					112	7.3
19908		107	4	2		1						114	6.5
19909	1	19										20	4.8
19910		4										4	4.9
19911	1	22	1									24	5.1
19912	3	59	4									66	5.4

Table 2B (Continued)

MARSDEN SQUARE	NO MAGNITUDE	UNDER-5.0	5.0-5.4	5.5-5.9	6.0-6.4	6.5-6.9	7.0-7.4	7.5-7.9	8.0-8.4	8.5-8.9	NON-TEC	TOTAL	MAX
19913		87	11	3	1	1						103	6.5
19914	6	110	49	7	3							175	6.1
19915	3	103	21	5	5							137	6.3
19916	1	121	41	5	2	2						172	6.5
19917		73	18	3								94	5.9
19918	19	109	23	6	1			1			1	160	7.7
19919	3	32	9	2	3	2					4	105	6.8
19920	1	14	1									16	5.1
19921		63	6	1	2							72	6.0
19922	1	63	23	13	1	1						102	6.5
19923		45	29	16	1							91	6.3
19924		29	13	4	1	1						48	6.5
19925		24	14	7	1							46	6.1
19926	1	11										12	4.9
19927		6	1									7	5.4
19928		9	1	2								12	5.7
19929		7	1									8	5.0
19930	2	3	1	2	1							9	6.2
19931		10	5	3	2							20	6.2
19932		6	2									8	5.2
19933		1										1	4.0
19934		3	1									4	5.3
19936		2										2	4.7
19937			1									1	5.0
19938		1										1	4.0
19939	1											1	0.0
19940		1										1	4.2
19942		1										1	4.7
*TEN DEGREE TOTAL	47	1403	306	84	24	8	1	1	0	0	5	1879	7.7
20009		1										1	4.2
20029		3										3	4.3
20037		1										1	4.7
20038		2										2	4.5
20039		6	2									8	5.4
20045		1	2									3	5.4
20046					1							1	6.1
20047	1	1	1									3	5.4
20048		2	1	1	1							5	6.0
20049		2	3									5	5.4
20055		10	5	3								18	5.8
20056	2	12	2	1								17	5.8
*TEN DEGREE TOTAL	3	41	16	5	2	0	0	0	0	0	0	67	6.1
22906		1										1	3.6
22916		1										1	4.1
22925			1									1	5.0
22938		1										1	4.8
22946		1										1	3.9

Table 2B (Continued)

MARSDEN SQUARE	NO MAGNITUDE	UNDER-5.0	5.0-5.4	5.5-5.9	6.0-6.4	6.5-6.9	7.0-7.4	7.5-7.9	8.0-8.4	8.5-8.9	NON-TEC	TOTAL	MAX
*TEN DEGREE TOTAL	0	4	1	0	0	0	0	0	0	0	0	5	5.0
23007	1	1										2	4.1
23009		1	1									2	5.1
23014		1										1	4.2
23018		1										1	4.5
23019		3										3	3.8
23024		1										1	3.8
23030		1										1	4.2
23034		1										1	3.9
23043		1										1	4.1
23053		8		1								9	5.7
23054		2	1									3	5.2
23055		1										1	3.5
23060		1										1	4.8
23065	1	5										6	4.8
23066		1										1	4.6
23075		1										1	4.0
23076		3										3	4.5
23077		1										1	3.7
23085		1										1	4.3
23086		1										1	4.2
*TEN DEGREE TOTAL	2	36	2	1	0	0	0	0	0	0	0	41	5.7
23100		13	2	3								18	5.9
23101		7										7	4.7
23102		11										11	4.9
23103		13	2									15	5.4
23104	1	20										21	4.9
23105	3	44	6		1							54	6.0
23106	13	87	14	5	1							120	6.3
23107	28	83	5	2		1						119	6.5
23108	5	35	1	2								43	5.7
23109	9	27	1									37	5.1
23110		7		1								8	5.5
23111		4										4	4.1
23113		4										4	4.5
23114		1										1	3.6
23115	1	9										10	4.7
23116	13	34		1								48	5.5
23117	29	46	7	2	2	1				1		88	8.5
23118	11	17										28	4.6
23119	31	31	2	1								65	5.7
23121		1										1	4.7
23123		2										2	3.7
23124	1	1										2	3.7
23125	1	2										3	4.6
23126	1	2										3	4.2
23127	2	10	1									13	5.1

Table 2B (Continued)

MARSDEN SQUARE	NO MAGNITUDE	UNDER-5.0	5.0-5.4	5.5-5.9	6.0-6.4	6.5-6.9	7.0-7.4	7.5-7.9	8.0-8.4	8.5-8.9	NON-TEC	TOTAL	MAX
23128	23	11	1									35	5.0
23129	58	28	1									87	5.1
23134		1										1	4.5
23135	3	3										6	4.4
23136	5	6										11	4.6
23137	4	10										14	4.8
23138	13	16	1									35	5.0
23139	56	20	2	1	1							80	6.1
23144	2	2										4	3.6
23145	1											1	0.0
23146	11	12										23	4.6
23147	39	46	2	2								89	5.6
23148	10	13										23	4.3
23149	6	10										16	4.4
23152	1											1	0.0
23155	1		1									2	5.3
23157	4	6										10	4.2
23158	3	3										6	4.5
23159	79	12										91	4.5
23161	1											1	0.0
23162	1	1										2	3.1
23164		2										2	3.7
23167		1										1	3.5
23168	1	4										5	4.9
23169	2	1										3	3.6
23175	1	1										2	3.7
23176		1										1	4.2
23177	1	1										2	3.5
23187		2										2	4.7
23194	1											1	0.0
23195	1	1										2	4.7
*TEN DEGREE TOTAL	482	725	49	20	5	2	0	0	0	1	0	1284	8.5
23200	16	21										37	4.6
23201	36	29	1	1								67	5.6
23202	82	49	3		1	1						136	6.5
23203	34	47	3	1								85	5.6
23204		3										3	4.5
23205		1										1	4.1
23207		1										1	3.9
23208		1										1	4.2
23210	59	45	1	2								107	5.6
23211	45	30	2	2								79	5.5
23212	13	14	1									28	5.0
23214		1										1	3.1
23216		1										1	4.7
23220	34	41										75	4.6
23221	59	39	1	1								100	5.6
23222	3	10		1								14	5.6
23223	1	6										7	4.9

Table 2B (Continued)

MARSDEN SQUARE	NO MAGNITUDE	UNDER-5.0	5.0-5.4	5.5-5.9	6.0-6.4	6.5-6.9	7.0-7.4	7.5-7.9	8.0-8.4	8.5-8.9	NON-TEC	TOTAL	MAX
23224		1										1	4.2
23226		3										3	4.6
23229		2										2	4.6
23230	88	56	1									145	5.0
23231	24	29	3									56	5.4
23232	1	1										2	3.9
23233		1										1	4.1
23234		1										1	4.3
23237		1										1	4.3
23240	3	4										7	4.6
23241	2	2										4	4.4
23242	2	3										5	4.3
23243	1											1	0.0
23244	2											2	0.0
23248		1										1	3.7
23250	63	26					1					90	7.1
23251	1	4										5	4.2
23252	2	2										4	4.4
23253	1	1										2	4.8
23255		5										5	4.1
23256		3										3	4.8
23260	1	1										2	3.6
23263		1										1	3.8
23264		1										1	3.8
23266	1											1	0.0
23267	9	5										14	4.3
23269		1										1	3.7
23275	1	1										2	4.5
23277		2										2	4.4
23279		1										1	4.8
23289		1										1	3.9
*TEN DEGREE TOTAL	584	499	16	8	1	1	1	0	0	0	0	1110	7.1
23311		1										1	4.0
23340	2	1		1								4	5.8
23343		1										1	4.3
23345					1							1	6.0
23353		1										1	4.1
23354		4										4	4.9
23356	1											1	0.0
23358		1										1	4.9
23361		1										1	4.2
23362	1											1	0.0
23363	1											1	0.0
23365	1	1										2	4.1
23370		1										1	4.3
23371		1	1									2	5.2
23372		1										1	4.2
23380		1										1	4.5
23385		1										1	4.4

Table 2B (Continued)

MARSDEN SQUARE	NO MAGNITUDE	UNDER-5.0	5.0-5.4	5.5-5.9	6.0-6.4	6.5-6.9	7.0-7.4	7.5-7.9	8.0-8.4	8.5-8.9	NON-TEC	TOTAL	MAX
*TEN DEGREE TOTAL	6	16	1	1	1	0	0	0	0	0	0	25	6.0
23443		2										2	4.9
23471		1										1	3.9
23472			1									1	5.3
*TEN DEGREE TOTAL	0	3	1	0	0	0	0	0	0	0	0	4	5.3
26703		3										3	4.5
26704		3										3	4.7
26705		1										1	4.2
*TEN DEGREE TOTAL	0	7	0	0	0	0	0	0	0	0	0	7	4.7
26821		1										1	3.9
*TEN DEGREE TOTAL	0	1	0	0	0	0	0	0	0	0	0	1	3.9
TOTAL	1366	5533	868	268	85	32	6	2	0	1	5	8174	8.5

Table 3. Sample geographical search of data file

RADIUS SEARCH 230KM AROUND SEWARD, ALASKA (60.1N, 149.5W MAGNITUDE = 6.0+

SOURCE	YEAR	MO	DA	HR	MN	SEC	LAT	LONG	DEPTH (KM)	---MAGNITUDES--- BODY	SURF.	OTHER	LOCAL	INT MAP	INT MAX	PHENOM DTSVNO	RN	CE	Q/S	MAR	DG	DIST (KM)
EQN	1909	09	19	20	00	00.0Z	60.600N	149.270W				7.40					014	F		231	09	57
G-R	1911	09	22	05	01	24.0	60.500N	149.000W	060			6.90PAS			VIII	QS	014	D		231	09	52
G-R	1912	01	31	20	11	48.0	61.000N	147.500W	080			7.25PAS			IV		002	F		231	17	148
G-R	1928	06	21	16	27	13.0	60.000N	146.500W	025A			7.00PAS			VI		002	D		231	06	167
G-R	1931	12	24	03	40	40.0	60.000N	152.000W	100			6.25PAS			IV		002	F	BBA	232	02	139
G-R	1932	09	14	08	43	23.0	61.000N	148.000W	050			6.25PAS			V		002	F		231	18	129
G-R	1933	01	04	03	59	28.0	61.000N	148.000W	025A			6.25PAS			VI		002	D		231	18	129
G-R	1933	04	27	02	36	04.0	61.250N	150.750W	025A			7.00PAS			VII		002	D		232	10	145
G-R	1933	06	13	22	19	47.0	61.000N	151.000W	025A			6.25PAS					002	F		232	11	129
G-R	1933	06	19	18	47	43.0	61.250N	150.500W	025A			6.00PAS					002	F		232	10	139
G-R	1934	05	04	04	36	07.0	61.250N	147.500W	080			7.20PAS			VI		002	D		231	17	168
G-R	1934	06	02	16	45	29.0	61.250N	147.000W	025A			6.25PAS					002	F		231	17	187
G-R	1934	06	18	09	13	50.0	60.500N	151.000W	080			6.75PAS			V		014	D	AAA	232	01	94
G-R	1934	08	02	07	13	08.0	61.500N	147.500W	025A			6.00PAS			V		002	F		231	17	190
G-R	1940	10	11	07	53	10.0	59.500N	152.000W	025A			6.00PAS					002			196	92	155
G-R	1941	07	30	01	51	21.0	61.000N	151.000W				6.25PAS			VI		002	D		232	11	129
G-R	1942	12	05	14	28	40.0	59.500N	152.000W	100			6.50PAS					002		BBB	196	92	155
G-R	1943	11	03	14	32	17.0	61.750N	151.000W	025A			7.30PAS			V		002	F		232	11	201
G-R	1945	11	03	22	09	03.0	58.500N	151.000W	050			6.75PAS					013			196	81	197
G-R	1946	01	12	20	25	37.0	59.250N	147.250W	050			7.20PAS			IV		015	F		195	97	158
G-R	1949	09	27	15	30	45.0	59.750N	149.000W	050			7.00PAS			V	Q	014	F		195	99	48
ISS	1951	06	25	16	12	37.0	61.100N	150.100W	128			6.25PAS			V		002	F		232	10	116
USE	1954	10	03	11	13	46.0	60.500N	151.000W	100			6.75PAS			VIII		014	D		232	01	94
USE	1958	01	24	23	17	29.0	60.000N	152.000W	060			6.50PAS			IV		002	F		232	02	139
ISS	1959	12	26	18	19	08.0	59.740N	151.380W				6.25PAS					014	F		196	91	112
CGS	1961	09	05	11	34	37.3	60.000N	150.600W	043			6.13PAS			VI		014	D		232	00	62
CGS	1962	05	10	00	03	40.2	62.000N	150.100W	072			6.00BRK			V		001	F	020	232	20	214
CGS	1963	06	24	04	26	37.9	59.500N	151.700W	052	5.70MB		6.75PAS			VII		014	D	014	196	91	140
CGS	1964	03	28	03	36	14.0S	61.040N	147.730W	033G		8.3MS	8.50PAS		USE	X	UTS	002	C	181	231	17	142
CGS	1964	03	28	04	54	07.9	59.800N	149.400W	025	6.10MB							014		025	195	99	33
CGS	1964	03	28	06	43	57.4	58.300N	151.300W	025	6.10MB							013		031	196	81	225
CGS	1964	03	28	07	10	21.4	58.800N	149.500W	020	6.10MB		6.20PAS					015	F	053	195	89	145
CGS	1964	03	28	09	52	55.7	59.700N	146.600W	030	5.50MB		6.20PAS					015	F	056	195	96	168
CGS	1964	03	28	14	47	37.1	60.400N	146.500W	010	5.70MB		6.30PAS					002	F	061	231	06	169
CGS	1964	03	28	14	49	13.7	60.400N	147.100W	010	5.80MB		6.50PAS					002	F	028	231	07	137
CGS	1964	03	28	20	29	08.5	59.800N	148.700W	040	5.80MB		6.60PAS					014	F	081	195	98	55
CGS	1964	03	30	07	09	34.0	59.900N	145.700W	015	5.60MB		6.20PAS					015	F	080	195	95	213
CGS	1964	04	03	22	33	42.2	61.600N	147.600W	040	5.70MB		6.00PAS			V		002	D	080	231	17	196
CGS	1964	04	20	11	56	41.6	61.400N	147.300W	030	5.70MB		6.50PAS					002	F	087	231	17	188
CGS	1964	04	21	05	01	35.7	61.500N	147.400W	040	5.40MB		6.00PAS					002	F	066	231	17	193
USE	1968	04	23	20	29	14.5	58.700N	150.000W	023	6.30MB		6.13PAS					015	F	058	196	80	158
CGS	1968	11	15	00	07	09.7	58.326N	150.367W	026	5.10MB		6.38PAS					015		063	196	80	204
USE	1968	12	17	12	02	15.0P	60.200N	152.800W	086	5.90MB		6.50PAS			VI		002	F	101	232	92	163
USE	1970	01	16	08	05	39.6	60.300N	152.700W	091D	5.60MB		6.00PAS			V		002	F	078	232	02	179

NOTE. Magnitude values are generally accurate to within 0.3 unit. Geographic positions prior to 1961 are generally accurate to no better than ¼ or ½ degree.

Table 4. List of Alaskan earthquakes with magnitudes 6.0 and greater
(Area covered: 48°-75° N, 165 E-125° W)

ALASKA EARTHQUAKES MAG = 6.0+

SOURCE	YEAR	MO	DA	HR	MN	SEC	LAT	LONG	DEPTH (KM)	BODY	SURF.	OTHER	LOCAL	INT MAP	INT MAX	PHENOM DTSVNO	RN	CE	Q/S	MAR	DG	DIST (KM)
EQH	1899	09	04	00	22	00.0Z	60.000N	142.000W	025A			8.30PAS			XI	UT	002	D		231	02	
CFR	1899	09	10	17	04	00.0	60.000N	142.000W	025A			7.80CFR					002	F		231	02	
EQH	1899	09	10	21	40	00.0	60.000N	140.000W				8.60PAS			XI	UTS	019	D		231	00	
EQH	1900	10	09	12	28	00.0	60.000N	142.000W	025A			8.30PAS			VIII		002	D		231	02	
CFR	1901	12	31	09	02	00.0	52.000N	177.000W	025A			7.80PAS					007			198	27	
CFR	1902	01	01	05	20	00.0	55.000N	165.000W	025A			7.80PAS					009			197	55	
CFR	1903	06	02	13	17	00.0	57.000N	156.000W	100			8.30PAS					012			196	76	
G-R	1904	08	27	21	56	06.0	64.000N	151.000W	025A			8.30CFR			VI		001	D		232	41	
G-R	1905	02	14	08	46	36.0	53.000N	178.000W	025A			7.90CFR					007			198	38	
G-R	1906	08	17	00	10	42.0	51.000N	179.000E	025A			8.30CFR					006			199	19	
G-R	1907	08	22	22	24	00.0	57.000N	161.000W	120			6.50PAS					011		CCB	197	71	
G-R	1907	09	02	16	01	30.0	52.000N	173.000E	025A			7.75PAS					005			199	23	
G-R	1908	05	15	08	31	36.0	59.000N	141.000W	025A			7.00PAS			VI		019	F		195	91	
C-R	1909	09	08	17	49	48.0	52.500N	169.000W	090			7.40PAS					009	F		197	29	
EQH	1909	09	19	20	00	00.0Z	60.600N	149.270W				7.40					014	F		231	09	
G-R	1910	05	13	07	58	06.0	57.000N	160.000W	100			6.75PAS					011		CCC	197	70	
G-R	1910	09	09	01	13	18.0	51.500N	176.000W	025			7.10PAS					007			198	16	
G-R	1911	09	22	05	01	24.0	60.500N	149.000W	060			6.90PAS			VIII	QS	014	D		231	09	
G-R	1912	01	04	15	46	54.0	52.000N	179.000W	025A			7.00PAS					007			198	29	
G-R	1912	01	31	20	11	48.0	61.000N	147.500W	080			7.25PAS			IV		002	F		231	17	
G-R	1912	03	11	10	17	30.0	51.000N	131.000W				6.50PAS					022			194	11	
G-R	1912	06	07	09	55	54.0	59.000N	153.000W	025A			6.40PAS			V		002	F		196	93	
G-R	1912	06	10	16	06	06.0	59.500N	153.000W	025A			7.00PAS					002	F		196	93	
G-R	1912	07	07	07	57	36.0	64.000N	147.000W	025A			7.40PAS			IX		001	F		231	47	
G-R	1912	11	07	07	40	24.0	57.500N	155.000W	090			7.50PAS			V		012	F		196	75	
G-R	1912	12	05	12	27	36.0	57.500N	154.000W	090			7.00PAS					013			196	74	
G-R	1913	03	31	03	41	06.0	51.000N	179.000W	060			6.90PAS					007			198	19	
G-R	1914	07	21	22	31	18.0	49.000N	130.000W				6.50PAS					025			158	90	
G-R	1916	04	18	04	01	48.0	53.250N	170.000W	170			7.50PAS					009			198	30	
G-R	1918	12	06	08	41	05.0	49.750N	126.500W				7.00PAS			V		025	F		157	96	
G-R	1920	03	29	05	07	53.0	51.000N	129.000W				6.40PAS					022			193	19	
G-R	1920	07	07	18	41	29.0	61.000N	140.000W	025A			6.00PAS					018			231	10	
G-R	1920	11	16	08	30	57.0	72.500N	128.000W	050			6.50PAS					675			265	28	
G-R	1921	04	10	13	40	16.0	54.000N	134.000W	025A			6.50PAS					022			194	44	
G-R	1923	05	04	16	26	39.0	55.500N	156.500W	025A			7.10PAS					017			196	56	
G-R	1924	03	30	00	08	56.0	50.000N	130.250W				6.00PAS					025			194	00	
G-R	1925	08	19	12	07	27.0	55.250N	168.000E				7.20PAS					004			200	58	
G-R	1926	10	13	19	08	07.0	52.000N	176.000W	025A			7.10PAS					007			198	26	
G-R	1926	10	30	19	41	55.0	48.500N	129.000W				6.10PAS					025			157	89	
G-R	1926	11	01	01	39	18.0	48.750N	128.500W				6.60PAS					025			157	88	
G-R	1927	10	24	15	59	55.0	57.500N	137.000W	025A			7.10PAS			VI		020	D		194	77	
G-R	1928	02	21	13	49	04.0	67.000N	172.000W	025A			6.90PAS					670			234	72	
G-R	1928	02	24	14	10	23.0	67.000N	171.000W	025A			6.25PAS					672			234	71	
G-R	1928	02	26	01	13	10.0	68.000N	172.000W	025A			6.50PAS					672			234	82	
G-R	1928	05	01	18	54	41.0	67.000N	172.000W	025A			6.25PAS					670			234	72	
G-R	1928	06	21	16	27	13.0	60.000N	146.500W	025A			7.00PAS			VI		002	D		231	06	

Table 4 (Continued)

SOURCE	YEAR	MO	DA	HR	MN	SEC	LAT	LONG	DEPTH (KM)	MAGNITUDES BODY	MAGNITUDES SURF.	MAGNITUDES OTHER	MAGNITUDES LOCAL	INT MAP	INT MAX	PHENOM DTSVNO	RN	CE	Q/S	MAR	DG	DIST (KM)
G-R	1929	01	21	10	30	53.0	64.000N	148.000W	025A			6.25PAS			VI		001	F		231	48	
G-R	1929	03	01	07	31	13.0	51.500N	130.750W				6.10PAS					022			194	10	
G-R	1929	03	07	01	34	39.0	51.000N	170.000W	050			8.60CFR				T	009	F		198	10	
G-R	1929	05	26	22	39	54.0	51.000N	131.000W				7.00PAS			VII	T	022	D		194	11	
G-R	1929	07	03	00	53	00.0	62.500N	149.000W	025A			6.25PAS					001	F		231	29	
G-R	1929	07	04	04	28	35.0	64.000N	148.000W	025A			6.50PAS					001			231	48	
G-R	1929	07	05	14	19	02.0	51.000N	178.000W	025A			7.00PAS					007	F		198	18	
G-R	1929	07	07	21	23	12.0	52.000N	178.000W	025A			7.30PAS					007	F		198	28	
G-R	1929	09	17	19	17	34.0	51.000N	131.000W				6.30PAS					022			194	11	
G-R	1929	12	17	10	58	30.0	52.500N	171.500E	025A			7.60PAS					005			199	21	
G-R	1930	12	06	07	03	28.0	53.000N	172.000W	080			6.50PAS					007		CCC	198	32	
G-R	1931	03	29	17	24	58.0	51.000N	170.000W	025A			6.00PAS					009			198	10	
EQH	1931	05	30	10	00	00.0Z	53.000N	173.000E				6.00PAS			VI		005	D		199	33	
G-R	1931	08	14	16	12	03.0	52.500N	168.000W	025A			6.00PAS					009			197	28	
G-R	1931	12	24	03	40	40.0	60.000N	152.000W	100			6.25PAS			IV		002	F	BBA	232	02	
G-R	1932	01	13	16	17	27.0	52.000N	179.000W	025A			6.00PAS					007			198	29	
G-R	1932	03	08	04	29	30.0	51.500N	178.000W	025A			6.00PAS					007			198	18	
G-R	1932	03	25	23	54	51.0	62.500N	153.000W	025A			6.00PAS					001			232	23	
G-R	1932	03	25	23	58	31.0	62.500N	152.500W	025A			6.90PAS			VII		001	D		232	22	
G-R	1932	04	29	18	18	23.0	51.500N	178.000W	025A			6.25PAS					007			198	18	
G-R	1932	06	03	07	52	39.0	62.500N	153.000W	025A			6.00PAS					001			232	23	
G-R	1932	08	12	03	23	57.0	52.250N	169.000W	025A			6.75PAS					009			197	29	
G-R	1932	09	14	08	43	23.0	61.000N	148.000W	050			6.25PAS			V		002	F		231	18	
G-R	1932	10	16	12	08	01.0	54.250N	160.000W	050			6.75PAS					012			197	40	
G-R	1932	10	30	20	46	56.0	55.000N	159.750W	025A			6.75PAS					012			196	59	
G-R	1933	01	04	03	59	28.0	61.000N	148.000W	025A			6.25PAS			VI		002	D		231	18	
G-R	1933	04	27	02	36	04.0	61.250N	150.750W	025A			7.00PAS			VII		002	D		232	10	
G-R	1933	04	27	11	55	38.0	52.500N	167.000W	025A			6.00PAS					009			197	27	
G-R	1933	05	01	18	49	47.0	51.750N	173.000W	025A			6.50PAS					007			198	13	
G-R	1933	06	13	22	19	47.0	61.000N	151.000W	025A			6.25PAS					002	F		232	11	
G-R	1933	06	19	18	47	43.0	61.250N	150.500W	025A			6.00PAS					002	F		232	10	
G-R	1933	06	28	23	34	58.0	53.500N	165.000W	025A			6.00PAS					009	F		197	35	
G-R	1933	07	19	10	45	29.0	51.750N	174.000W	025A			6.00PAS					007			198	14	
G-R	1933	07	19	10	53	53.0	51.750N	174.000W	025A			6.00PAS					007			198	14	
G-R	1933	07	19	13	32	21.0	51.750N	174.000W	025A			6.25PAS					007			198	14	
G-R	1933	07	19	14	59	52.0	51.750N	174.000W	025A			6.25PAS					007			198	14	
G-R	1933	07	22	20	55	13.0	53.000N	169.500W	025A			6.75PAS					009			197	39	
G-R	1933	09	24	15	19	41.0	51.750N	177.000W	070			6.75PAS					007		AAA	198	17	
G-R	1933	10	14	22	19	01.0	53.750N	164.000W	025A			6.25PAS					010			197	34	
G-R	1933	11	02	12	26	54.0	52.000N	176.000W	025A			6.50PAS					007			198	26	
G-R	1934	05	04	04	36	07.0	61.250N	147.500W	080			7.20PAS			VI		002	D		231	17	
G-R	1934	05	14	22	12	46.0	57.750N	152.250W	060			6.50PAS			VI		013	D		196	72	
G-R	1934	06	02	16	45	29.0	61.250N	147.000W	025A			6.25PAS					002	F		231	17	
G-R	1934	06	18	09	13	50.0	60.500N	151.000W	080			6.75PAS			V		014	D	AAA	232	01	
G-R	1934	07	20	02	10	44.0	52.000N	173.000W	025A			6.00PAS					007			198	23	
G-R	1934	07	28	21	36	57.0	55.500N	156.750W	025A			6.75PAS					017			196	56	
G-R	1934	08	02	07	13	08.0	61.500N	147.500W	025A			6.00PAS			V		002	F		231	17	
G-R	1934	11	05	23	02	20.0	52.000N	175.000W	025A			6.50PAS					007			198	25	
G-R	1935	01	23	07	24	00.0	52.250N	169.500W	025A			6.75PAS					009	F		197	29	
G-R	1935	02	22	17	05	54.0	52.250N	175.000E	025A			6.90PAS					006			199	25	
G-R	1935	09	04	01	27	39.0	63.750N	152.500W	025A			6.25PAS					001			232	32	

Table 4 (Continued)

SOURCE	YEAR	MO	DA	HR	MN	SEC	LAT	LONG	DEPTH (KM)	BODY	SURF.	OTHER	LOCAL	INT MAP	INT MAX	PHENOM DTSVNO	RN	CE	Q/S	MAR	OG	DIST (KM)
G-R	1935	09	24	22	12	15.0	49.500N	130.000W				6.20PAS					025			158	90	
G-R	1936	04	23	23	14	21.0	50.250N	179.000E	025A			6.25PAS					006			199	09	
G-R	1936	12	21	19	03	13.0	52.500N	131.500W				6.00PAS					022			194	21	
G-R	1937	07	18	01	01	15.0	54.000N	166.500W	070			6.25PAS					009		CCB	197	46	
G-R	1937	07	22	17	09	29.0	64.750N	146.750W	025A			7.30PAS			VIII		001	D		231	46	
G-R	1937	09	03	18	48	12.0	52.500N	177.500W	080			7.30PAS					007	F		198	27	
G-R	1938	03	22	15	22	14.0	52.250N	132.000W				6.30PAS					022			194	22	
G-R	1938	07	24	13	12	13.0	53.500N	167.000W	050			6.25PAS					009			197	37	
G-R	1938	11	10	20	18	43.0	55.500N	158.000W	025A			8.70CFR			VI	T	012	F		196	58	
G-R	1938	11	17	03	54	34.0	55.500N	158.500W	025A			7.20PAS					012			196	58	
G-R	1939	02	24	14	15	45.0	53.000N	164.500W	070			6.25PAS					010	F	CCA	197	34	
G-R	1939	07	14	08	31	40.0	53.750N	169.000E	060			6.50PAS					004			200	39	
G-R	1939	07	18	03	26	38.0	49.000N	129.250W				6.50PAS					025			157	99	
G-R	1939	08	20	07	17	26.0	54.000N	164.000W	075			6.25PAS			V		010	F	CCB	197	44	
G-R	1939	08	21	15	19	03.0	51.500N	177.000E				6.00PAS					006			199	17	
G-R	1940	02	07	17	16	02.0	51.500N	175.000E	070			7.00PAS					006		AAA	199	15	
G-R	1940	02	12	09	17	46.0	55.000N	161.500W	025A			6.75PAS			V		012	F		197	51	
G-R	1940	04	16	06	07	43.0	52.000N	173.500E	025A			7.10PAS					005			199	23	
G-R	1940	04	16	06	43	07.0	52.000N	173.500E	025A			7.20PAS					005			199	23	
G-R	1940	05	29	01	57	52.0	67.000N	135.000W				6.25PAS					679			230	75	
G-R	1940	06	05	11	01	10.0	67.500N	136.000W				6.50PAS					677			230	76	
G-R	1940	07	14	05	52	53.0	51.750N	177.500E	080			7.75PAS					006		AAA	199	17	
G-R	1940	08	22	03	27	18.0	53.000N	165.500W	025A			7.10PAS					009			197	35	
G-R	1940	10	11	07	53	10.0	59.500N	152.000W	025A			6.00PAS					002			196	92	
G-R	1941	04	01	10	40	59.0	56.000N	153.500W				6.50PAS					013			196	63	
G-R	1941	07	30	01	51	21.0	61.000N	151.000W				6.25PAS			VI		002	D		232	11	
G-R	1941	08	04	10	53	09.0	53.250N	179.000E	070			6.75PAS					006		BBB	199	39	
G-R	1941	08	06	06	15	06.0	55.750N	163.000W	150			6.75PAS					010		AAA	197	53	
G-R	1941	09	28	05	34	12.0	56.500N	157.500W	100			6.50PAS					012		CCB	196	67	
G-R	1941	11	06	12	29	46.0	54.000N	161.500W	025A			6.00PAS					012			197	41	
G-R	1942	03	19	11	59	19.0	50.500N	131.000W				6.00PAS					025			194	01	
G-R	1942	09	09	01	25	26.0	53.000N	164.500W	080			7.00PAS					010		BBB	197	34	
G-R	1942	12	05	14	28	40.0	59.500N	152.000W	100			6.50PAS					002		BBB	196	92	
G-R	1943	11	03	14	32	17.0	61.750N	151.000W	025A			7.30PAS			V		002	F		232	11	
G-R	1944	02	03	12	14	59.0	60.500N	137.500W				6.50PAS					018			230	07	
G-R	1944	07	27	00	04	23.0	54.000N	165.500W	070			7.10PAS					009		BBB	197	45	
G-R	1944	08	10	01	52	50.0	51.250N	131.000W				6.25PAS					022			194	11	
G-R	1944	08	14	11	07	23.0	59.000N	155.000W	100			6.25PAS					002		BBB	196	95	
G-R	1944	12	12	04	17	10.0	51.500N	179.500E	025A			7.00PAS					006			199	19	
G-R	1945	08	02	20	44	45.0	54.000N	133.000W				6.25PAS					022			194	43	
G-R	1945	11	03	22	09	03.0	58.500N	151.000W	050			6.75PAS					013			196	81	
G-R	1946	01	12	20	25	37.0	59.250N	147.250W	050			7.20PAS			IV		015	F		195	97	
G-R	1946	02	04	03	44	48.0	53.000N	176.000W	160			6.75PAS					007		CCA	198	36	
G-R	1946	04	01	12	28	54.0	52.750N	163.500W	050			7.40PAS			VI	T	017	C		197	23	
OTT	1946	06	23	17	13	19.0	49.900N	125.300W				7.30PAS		USE	VIII		025	D		157	95	
G-R	1946	07	12	21	56	27.0	53.500N	169.000W	100			6.75PAS					009		CCC	197	39	
G-R	1946	10	30	07	47	34.0	54.250N	164.000W	050			6.90PAS					010			197	44	
G-R	1946	11	01	11	14	24.0	51.500N	174.500W	040			7.00PAS					007			198	14	
G-R	1946	12	25	11	13	10.0	51.500N	180.000E	090			6.50PAS					006		CCC	199	19	
G-R	1947	10	16	02	09	47.0	64.500N	147.500W	050			7.00PAS			VIII		001	D		231	47	
CGS	1948	01	16	11	08	30.0	52.000N	172.000E	100			6.70PAS					005			199	22	

Table 4 (Continued)

SOURCE	YEAR	MO	DA	HR	MN	SEC	LAT	LONG	DEPTH (KM)	BODY	SURF.	OTHER	LOCAL	INT MAP	INT MAX	PHENOM DTSVNO	RN	CE	Q/S	MAR	DG	DIST (KM)
G-R	1948	05	14	22	31	43.0	54.500N	161.000W	025A			7.50PAS					012			197	41	
CGS	1948	05	26	09	16	42.0	56.000N	156.000W				6.00PAS					012			196	66	
G-R	1948	08	19	13	50	46.0	63.000N	150.500W	100			6.25PAS					001		BBB	232	30	
CGS	1948	12	12	13	17	18.0	52.000N	178.000E				6.63PAS					006			199	28	
G-R	1948	12	23	08	41	17.0	55.500N	166.000E	060			6.75PAS					004			200	56	
G-R	1949	02	02	17	41	29.0	53.000N	173.000W	220			7.00PAS					007		BBA	198	33	
G-R	1949	08	22	04	01	11.0	53.750N	133.250W	025A			8.10PAS				T	022	D		194	33	
CGS	1949	08	23	20	24	32.0	53.000N	132.000W				6.25PAS					022	F		194	32	
CGS	1949	08	25	04	14	28.0	51.500N	179.000W				6.75PAS					007			198	19	
G-R	1949	09	27	15	30	45.0	59.750N	149.000W	050			7.00PAS			V	Q	014	F		195	99	
G-R	1949	10	31	01	39	31.0	56.000N	136.000W				6.25PAS					020	F		194	66	
ISS	1950	03	27	13	04	02.0	53.300N	172.200E				6.75PAS					005			199	32	
ISS	1950	05	25	08	34	37.0	65.500N	151.500W				6.00PAS					676	F		232	51	
ISS	1950	07	12	11	09	10.0	52.500N	167.500W				6.25PAS					009			197	27	
ISS	1950	08	26	04	39	27.0	65.000N	162.000W				6.50PAS			V		676	F		233	52	
ISS	1950	09	02	02	47	13.0	52.500N	170.000W				6.38PAS					009			198	20	
ISS	1950	09	16	21	58	17.0	52.000N	177.100E	096			6.60PAS					006			199	27	
ISS	1950	11	22	10	16	26.0	51.400N	176.000W				6.75PAS					007	F		198	16	
ISS	1951	01	13	21	15	45.0	52.100N	177.500W				6.38PAS					007	F		198	27	
G-R	1951	02	13	22	12	57.0	56.000N	156.000W				7.00PAS					012			196	66	
ISS	1951	06	25	16	12	37.0	61.100N	150.100W	128			6.25PAS			V		002	F		232	10	
ISS	1951	11	08	13	45	08.0	55.600N	160.400W				6.25PAS					012			197	50	
ISS	1952	01	12	20	11	37.0	52.500N	167.500W				6.50PAS					009			197	27	
ISS	1952	01	21	03	42	55.0	52.500N	167.500W				6.75PAS					009			197	27	
USE	1952	03	09	20	00	17.0	59.500N	136.000W				6.00PAS			V		019	F		194	96	
ISS	1952	03	22	18	15	42.0	51.500N	173.500W				6.38PAS					007			198	13	
ISS	1952	07	07	02	52	59.0	54.200N	164.500W				6.25PAS					010			197	44	
ISS	1952	11	29	23	46	27.0	56.300N	153.800W				6.75PAS					013			196	63	
ISS	1952	12	04	03	51	40.0	52.000N	178.200E	128			6.00BRK					006			199	28	
ISS	1952	12	07	00	50	17.0	52.500N	174.200E				6.25PAS			VI		005	F		199	24	
ISS	1953	01	05	07	48	20.0	53.000N	171.500E				7.10PAS					005	F		199	31	
ISS	1953	01	11	22	53	30.0	65.300N	133.200W				6.50PAS					677			230	53	
ISS	1953	02	25	21	16	12.0	56.000N	156.200W				6.75PAS					012			196	66	
ISS	1953	06	15	17	47	14.0	56.300N	153.800W				6.50PAS					013			196	63	
ISS	1953	06	16	19	48	25.0	55.600N	160.400W	033			6.38PAS					012			197	50	
ISS	1953	12	04	14	54	48.0	49.500N	129.000W				6.00PAS					025			157	99	
ISS	1954	03	28	20	36	21.0	51.600N	175.800E				6.13PAS					006			199	15	
USE	1954	04	17	20	10	37.0	51.500N	179.000W				6.75PAS					007	F		198	19	
CGS	1954	06	17	01	42	22.0	56.000N	154.500W				6.50PAS					013			196	64	
ISS	1954	08	05	08	49	53.0	51.700N	175.800E	064			6.00PAS					006			199	15	
USE	1954	10	03	11	18	46.0	60.500N	151.000W	100			6.75PAS			VIII		014	D		232	01	
CGS	1954	12	30	11	32	28.0	53.000N	168.000W	060			6.63PAS					009	F		197	38	
USE	1955	01	13	02	03	43.0	53.000N	167.500W				6.90PAS					009	F		197	37	
USE	1955	01	13	02	35	45.0	53.000N	167.500W				6.50PAS					009	F		197	37	
ISS	1955	03	01	04	42	58.0	65.300N	132.900W				6.75PAS			IV		677	F		230	52	
CGS	1955	03	14	13	12	04.0	52.500N	173.500W	100			6.50PAS					007			198	23	
USE	1955	04	28	19	04	59.0	51.000N	178.500W				6.50PAS					007	F		198	18	
CGS	1955	06	02	00	18	56.0	51.500N	180.000E				6.75PAS					006			199	19	
CGS	1955	06	02	02	02	10.0	51.500N	180.000E				6.00PRA					006			199	19	
CGS	1955	06	05	01	53	16.0	51.500N	180.000W				6.25PAS					007			198	19	
CGS	1955	06	20	12	07	25.0	51.500N	180.000W				6.75PAS					007			198	19	

Table 4 (Continued)

SOURCE	YEAR	MO	DA	HR	MN	SEC	LAT	LONG	DEPTH (KM)	MAGNITUDES BODY	SURF.	OTHER	LOCAL	INT MAP	INT MAX	PHENOM DTSVNO	RN	CE	Q/S	MAR	DG	DIST (KM)
ISS	1955	07	03	14	26	34.0	51.600N	177.600E	033			6.50PAS					006			199	17	
CGS	1955	07	04	14	19	44.0	51.000N	177.000E				6.63PAS					006			199	17	
ISS	1955	07	19	23	52	23.0	56.500N	153.000W				6.00PAS					013			196	63	
CGS	1955	07	26	04	04	18.0	56.500N	153.000W				6.00PAS					013			196	63	
CGS	1955	07	27	18	19	08.0	56.500N	153.000W				6.25PAS					013			196	63	
ISS	1955	09	13	02	00	40.0	52.000N	176.000W				6.00PAS					007			198	26	
CGS	1955	10	09	23	13	32.0	50.500N	176.000E				6.00PAS					006			199	06	
ISS	1955	11	15	10	06	47.0	55.400N	155.600W				6.50PAS					017			196	55	
CGS	1956	01	14	14	08	41.0	51.500N	173.000W				6.00PAS					007			198	13	
CGS	1956	02	19	02	18	00.0	52.000N	131.500W				6.75PAS					022			194	21	
ISS	1956	04	18	11	00	22.0	51.800N	177.700W	033			6.50PAS					007			198	17	
CGS	1956	04	22	17	21	53.0	54.000N	162.000W				6.00PAS					012			197	42	
ISS	1956	06	04	07	09	19.0	52.100N	170.600W				6.25PAS					009			198	20	
CGS	1956	06	28	22	58	50.0	48.750N	129.250W				6.37PAS					025			157	89	
ISS	1956	08	24	04	27	34.0	52.740N	172.600E				6.50PAS					005			199	22	
ISS	1956	08	30	04	24	26.0	53.800N	164.020W	033			6.00PAS					010			197	34	
ISS	1956	10	19	20	47	31.0	52.270N	177.400E				6.75PAS					006			199	27	
USE	1956	11	17	20	27	15.0	54.500N	134.000W				6.50PAS			IV		022	F		194	44	
ISS	1956	12	03	07	20	06.0	52.640N	168.610W				6.63PAS					009			197	28	
ISS	1956	12	08	16	10	25.0	51.370N	179.170W				6.50PAS					007			198	19	
CGS	1956	12	21	08	58	53.0	51.000N	131.000W				6.75PAS					022			194	11	
CGS	1957	01	02	00	39	22.0	53.000N	168.500W				6.63PAS					009			197	38	
CGS	1957	01	02	02	17	35.0	52.500N	168.000W				6.75PAS					009			197	28	
CGS	1957	01	02	03	12	52.0	53.000N	168.000W				6.63PAS					009			197	38	
CGS	1957	01	02	03	48	44.0	53.000N	168.000W				7.00PAS					009			197	38	
ISS	1957	01	02	10	49	32.0	52.580N	168.530W				6.50PAS					009			197	28	
ISS	1957	01	09	07	52	56.0	52.660N	167.500W				6.50PAS					009			197	27	
CGS	1957	01	25	03	36	47.0	51.500N	177.000W				6.50PAS					007			198	17	
ISS	1957	02	21	14	30	11.0	53.020N	171.270W	126			6.75PAS					009			198	31	
USE	1957	03	09	14	22	27.5	51.300N	175.800W				8.30PAS			VIII	T V	007	D		198	15	
CGS	1957	03	09	20	39	16.0	52.300N	169.000W				7.10PAS					009			197	29	
CGS	1957	03	10	03	06	10.5	51.600N	174.400W				6.63PAS					007	F		198	14	
CGS	1957	03	10	15	26	23.5	51.500N	173.600W				6.75BRK					007	F		198	13	
ISS	1957	03	11	03	12	43.0	51.200N	176.700W				6.37PAS					007	F		198	16	
ISS	1957	03	11	09	58	44.0	52.740N	168.410W				6.88PAS					009			197	28	
ISS	1957	03	11	14	55	19.0	51.510N	178.750W				6.75PAS					007	F		198	18	
CGS	1957	03	11	15	35	53.0	51.100N	179.000W				6.50PAS					007	F		198	19	
CGS	1957	03	12	07	28	48.0	51.700N	174.100W				6.37PAS					007	F		198	14	
ISS	1957	03	12	07	39	17.0	51.470N	178.190W				6.37PAS					007	F		198	18	
ISS	1957	03	12	11	44	54.0	51.390N	176.900W				7.30PAS					007	F		198	16	
CGS	1957	03	13	15	42	04.0	51.300N	178.500W				6.75PAS					007	F		198	18	
ISS	1957	03	14	14	47	45.0	51.320N	176.440W				7.20PAS					007	F		198	16	
CGS	1957	03	15	02	52	38.0	53.000N	167.000W				6.75PAS					009			197	37	
ISS	1957	03	16	02	34	15.0	51.570N	178.860W				6.75PAS					007	F		198	18	
CGS	1957	03	17	22	44	44.0	54.000N	166.000W				6.50PAS					009			197	46	
CGS	1957	03	18	02	24	39.0	52.500N	171.000W				6.20UPP					009			198	21	
CGS	1957	03	19	12	50	51.0	51.500N	175.000W				6.75PAS					007	F		198	15	
ISS	1957	03	22	14	21	10.0	53.740N	165.660W	020			7.00PAS					009			197	35	
ISS	1957	03	24	08	22	22.0	50.890N	130.360W				6.88PAS					025			194	00	
CGS	1957	03	29	05	10	28.0	53.500N	167.000W				6.50PAS					009			197	37	
ISS	1957	03	29	22	49	51.0	52.760N	168.490W				6.13PAS					009			197	28	

Table 4 (Continued)

SOURCE	YEAR	MO	DA	HR	MN	SEC	LAT	LONG	DEPTH (KM)	MAGNITUDES BODY	MAGNITUDES SURF.	MAGNITUDES OTHER	MAGNITUDES LOCAL	INT MAP	INT MAX	PHENOM DTSVNO	RN	CE	Q/S	MAR	DG	DIST (KM)
ISS	1957	03	30	09	17	00.0	51.950N	175.160W				6.20UPP					007	F		198	15	
ISS	1957	03	31	10	08	28.0	51.510N	178.470W				6.10UPP					007	F		198	18	
ISS	1957	04	04	00	13	04.0	58.170N	155.040W	089			6.00UPP			IV		012	F		196	85	
CGS	1957	04	05	02	49	39.0	52.000N	172.500W				6.50PAS					007			198	22	
ISS	1957	04	10	11	30	00.0	55.960N	153.860W				7.10PAS					017			196	53	
ISS	1957	04	15	21	33	06.0	52.070N	167.040W				6.43UPP					009			197	27	
CGS	1957	04	19	15	44	53.0	51.500N	168.500W				6.70UPP					009			197	18	
CGS	1957	04	19	22	19	26.0	52.000N	166.500W				7.30PAS					009			197	26	
ISS	1957	05	22	13	29	48.0	50.460N	176.900W				6.50PAS					007			198	06	
CGS	1957	05	24	03	36	33.0	53.000N	167.500W				6.13BRK					009			197	37	
ISS	1957	05	31	22	17	09.0	51.190N	179.240W				6.00UPP					007			198	19	
ISS	1957	06	11	23	53	56.0	51.590N	176.040W				6.05MOS					007			198	16	
CGS	1957	06	13	10	40	38.0	51.500N	175.000W				6.75PAS					007			198	15	
ISS	1957	06	14	06	24	25.0	51.950N	176.110W	040			6.25BRK					007			198	16	
CGS	1957	06	15	18	18	20.0	52.000N	171.000W				6.00BRK					009			198	21	
ISS	1957	06	29	07	48	15.0	51.710N	166.640W				6.30UPP					016			197	16	
CGS	1957	07	03	12	24	37.0	50.500N	179.000W				6.13PAS					007			198	09	
ISS	1957	07	23	00	45	10.0	51.360N	177.190W				6.38PAS					007			198	17	
ISS	1957	07	25	07	42	24.0	51.220N	177.210W				6.25PAS					007			198	17	
CGS	1957	09	02	14	20	13.0	51.500N	168.000W				6.18UPP					009			197	18	
ISS	1957	10	23	05	56	56.0	52.530N	169.690W	038			6.25PAS					009			197	29	
CGS	1957	11	20	12	40	23.0	54.000N	165.000W				6.37BRK					009			197	45	
CGS	1957	11	23	00	58	36.0	53.000N	167.500W				6.15MAT					009			197	37	
ISS	1958	01	13	00	02	27.0	52.370N	176.730E	121			6.50UPP					006			199	26	
USE	1958	01	24	23	17	29.0	60.000N	152.000W	060			6.50PAS			IV		002	F		232	02	
CGS	1958	02	12	23	43	45.0	52.000N	175.000W				6.00PAS					007			198	25	
CGS	1958	02	22	10	50	23.0	50.500N	175.000W				6.75PAS					007			198	05	
CGS	1958	03	03	16	18	17.0	55.500N	166.500E				6.38PAS					004			200	56	
ISS	1958	03	13	22	20	00.0	50.240N	172.950W				6.20UPP					007			198	02	
ISS	1958	03	20	01	38	05.0	50.490N	172.840W				6.50PAS					007			198	02	
ISS	1958	04	07	15	30	40.0	66.030N	156.590W				7.30PAS		USE	VIII		676	D		232	66	
USE	1958	04	13	09	07	24.0	66.000N	156.000W				6.75PAS			V		676	F		232	66	
ISS	1958	05	10	22	54	39.0	65.230N	152.010W				6.38PAS			V		676	F		232	52	
ISS	1958	05	11	05	23	55.0	65.100N	151.940W				6.38PAS			V		676	F		232	51	
ISS	1958	05	12	05	38	18.0	52.210N	169.540W				6.40QUE					009			197	29	
CGS	1958	05	26	10	56	30.0	53.000N	169.500W				6.13PAS					009			197	39	
ISS	1958	05	30	18	04	53.0	52.730N	168.620W				6.13PAS					009			197	28	
ISS	1958	06	04	14	29	54.0	52.690N	167.220W	019			6.13PAS					009			197	27	
CGS	1958	06	08	00	38	52.0	53.000N	167.000W				6.63PAS					009			197	37	
ISS	1958	06	12	20	53	01.0	52.980N	166.970W				6.50PAS					009			197	26	
CGS	1958	07	01	05	53	07.0	51.500N	176.500W				6.00PAS					007			198	16	
USE	1958	07	10	06	15	51.0	58.600N	137.100W				7.90PAS			XI	T	019	C		194	87	
CGS	1958	07	17	20	59	17.0	51.000N	177.500W				6.00BRK					007			198	17	
CGS	1958	07	21	14	37	18.0	51.500N	178.000W				6.25BRK					007			198	18	
ISS	1958	08	13	20	12	59.0	50.390N	177.750W				6.38PAS					007			198	07	
ISS	1958	08	14	14	55	12.0	51.590N	175.390W				6.50PAS					007			198	15	
ISS	1958	08	16	13	17	54.0	51.430N	176.110W				6.13PAS					007			198	16	
CGS	1958	09	24	03	44	14.0	59.500N	143.500W				6.25PAS					015			195	93	
CGS	1958	10	01	17	47	15.0	53.000N	165.500W				6.25PAS					009			197	35	
ISS	1958	10	29	07	44	10.0	51.490N	179.410E				6.25PAS					006			199	19	
USE	1958	12	22	02	41	29.0	66.000N	147.000W				6.00PAS					676	F		231	67	

Table 4 (Continued)

SOURCE	YEAR	MO	DA	HR	MN	SEC	LAT	LONG	DEPTH (KM)	----------MAGNITUDES---------- BODY	SURF.	OTHER	LOCAL	INT MAP	INT MAX	PHENOM DTSVNO	RN	CE	Q/S	MAR	DG	DIST (KM)
CGS	1959	02	06	14	33	02.0	51.000N	175.500W	060			6.00PAS					007			198	15	
ISS	1959	02	17	12	03	04.0	51.100N	171.230W				6.13PAS					009			198	11	
CGS	1959	04	19	15	03	26.0	58.000N	152.500W				6.25PAS					013			196	82	
CGS	1959	04	22	10	55	05.0	54.000N	167.000W				6.00PAS					009			197	47	
ISS	1959	05	12	04	57	39.0	55.150N	168.240E	017			6.50PAS					004			200	58	
ISS	1959	05	12	21	59	56.0	51.210N	176.950W				6.00PAS					007			198	16	
CGS	1959	07	13	12	28	45.0	52.000N	172.500W				6.50PAS					007			198	22	
ISS	1959	12	14	22	00	51.0	52.450N	168.210W				6.00PAS					009			197	28	
ISS	1959	12	18	16	24	50.0	52.560N	168.390W				6.50PAS					009			197	28	
ISS	1959	12	26	18	19	08.0	59.740N	151.380W				6.25PAS					014	F		196	91	
CGS	1960	02	26	23	29	25.0	51.500N	178.000W				6.13PAS					007	F		198	18	
CGS	1960	05	13	16	07	14.0	55.000N	161.500W				6.25PAS			IV		012	F		197	51	
CGS	1960	06	17	16	35	32.0	52.500N	173.500W				6.13PAS					007	F		198	23	
CGS	1960	06	22	23	28	50.0	52.000N	173.000W				6.13PAS					007			198	23	
CGS	1960	06	29	17	07	00.0	53.000N	168.500W				6.30QUE					009			197	38	
CGS	1960	07	03	20	20	46.0	50.500N	177.000W				6.88PAS					007	F		198	07	
CGS	1960	07	04	04	28	33.0	52.000N	131.500W				6.63PAS					022			194	21	
CGS	1960	07	04	13	10	05.0	52.000N	131.000W				6.00PAS					022			194	21	
CGS	1960	08	04	07	34	48.5	51.200N	179.000E	020			6.13PAS					006	F		199	19	
CGS	1960	09	01	15	37	14.4	56.300N	153.700W	024			6.13PAS					013			196	63	
CGS	1960	10	01	16	10	55.6	51.600N	172.400W	046			6.50PAS					007			198	12	
CGS	1960	10	14	21	19	11.4	51.900N	172.100W	050			6.50PAS					007			198	12	
CGS	1960	11	13	09	20	32.3	51.400N	168.800W	032			7.00PAS					009			197	18	
CGS	1960	12	01	20	43	45.5	49.000N	129.300W	015			6.00BRK					025			157	99	
CGS	1961	01	05	14	06	25.9	51.800N	176.300W	037			6.75PAS					007	F		198	16	
CGS	1961	01	20	17	09	15.7	56.600N	152.300W	046			6.38PAS					013			196	62	
CGS	1961	01	31	00	48	36.5	56.000N	153.900W	026			6.25PAS					013			196	63	
CGS	1961	02	27	13	06	35.3	52.700N	168.800W	056			6.10QUE					009			197	28	
CGS	1961	03	28	12	29	12.7	51.700N	176.200W	060			6.25PAS					007	F		198	16	
CGS	1961	05	17	19	29	19.3	52.200N	173.900E	021			6.00PAS					005	F		199	23	
CGS	1961	08	08	12	18	23.1	51.200N	170.700W	033N			6.13PAS					009			198	10	
CGS	1961	09	04	09	49	13.5	51.600N	178.200W	040			6.25BRK					007			198	18	
CGS	1961	09	05	11	34	37.3	60.000N	150.600W	043			6.13PAS			VI		014	D		232	00	
CGS	1961	12	30	00	39	27.1	52.300N	177.600E	056			6.75PAS					006			199	27	
CGS	1962	05	10	00	03	40.2	62.000N	150.100W	072			6.00BRK			V		001	F	020	232	20	
CGS	1962	05	10	05	12	15.9	52.400N	170.900W	043			6.00BRK					009		023	198	20	
CGS	1962	06	14	07	51	53.3	54.400N	169.100E	030			6.13PAS					004		069	200	49	
CGS	1962	06	14	07	55	51.8	54.300N	169.200E	060			6.00PAS					004		021	200	49	
CGS	1962	07	16	12	54	40.6	62.300N	153.100W	039			6.00PAL			V		001	D		232	23	
CGS	1962	08	18	16	43	54.3	62.300N	152.500W	032			6.13PAS			V		001	F	050	232	22	
CGS	1962	08	18	17	46	14.9	62.300N	152.500W	032			6.38PAS			V		001	F	038	232	22	
USE	1962	08	31	17	02	44.4	51.300N	179.700W	032			6.75PAS					007	F		198	19	
CGS	1962	09	01	03	46	05.0	51.300N	179.700W	025			6.50PAS					007	F	037	198	19	
CGS	1962	09	01	07	51	08.2	51.300N	179.900W	042			6.50PAS					007		037	198	19	
CGS	1962	12	21	08	42	48.3	52.400N	168.500W	033			6.50PAS				Q	009		037	197	28	
CGS	1962	12	22	15	20	31.0	52.500N	168.800W	047			6.25PAS					009		029	197	28	
CGS	1962	12	26	22	25	15.5	53.900N	168.700E	033			6.50PAS					004		048	200	38	
CGS	1963	01	28	13	00	48.1	54.700N	161.700W	014			6.50PAS					012		121	197	41	
CGS	1963	03	24	21	35	23.2	51.300N	178.100W	047			6.00PAS					007		088	198	18	
CGS	1963	04	02	16	16	55.3	53.100N	171.700W	140			6.38PAS					009		105	198	31	
CGS	1963	04	29	21	44	17.2	51.300N	178.700E	056	5.90MB		6.00PAS					006		110	199	18	

Table 4 (Continued)

SOURCE	YEAR	MO	DA	HR	MN	SEC	LAT	LONG	DEPTH	---------MAGNITUDES---------				INT	INT	PHENOM	RN	CE	Q/S	MAR	DG	DIST
									(KM)	BODY	SURF.	OTHER	LOCAL	MAP	MAX	DTSVNO						(KM)
CGS	1963	05	02	23	13	09.4	63.100N	149.900W	079	6.10MB							001		019	231	39	
CGS	1963	05	12	20	08	40.8	57.300N	154.000W	060	6.10MB							013	F	126	196	74	
CGS	1963	06	24	04	26	37.9	59.500N	151.700W	052	5.70MB		6.75PAS			VII		014	D	014	196	91	
CGS	1964	02	06	13	07	25.2	55.700N	155.800W	033	5.60MB		6.88PAS			V		017	D	066	196	55	
CGS	1964	03	28	03	36	14.0S	61.040N	147.730W	033G		8.3MS	8.50PAS		USE	X	UTS	002	C	181	231	17	
CGS	1964	03	28	04	54	07.9	59.800N	149.400W	025	6.10MB							014		025	195	99	
CGS	1964	03	28	06	43	57.4	58.300N	151.300W	025	6.10MB							013		031	196	81	
CGS	1964	03	28	07	10	21.4	58.800N	149.500W	020	6.10MB		6.20PAS					015	F	053	195	89	
CGS	1964	03	28	08	33	47.0	58.100N	151.100W	025	5.60MB		6.50PAS					013	F	050	196	81	
CGS	1964	03	28	09	01	00.5	56.500N	152.000W	020	6.00MB		6.20PAS					013	F	060	196	62	
CGS	1964	03	28	09	52	55.7	59.700N	146.600W	030	5.50MB		6.20PAS					015	F	056	195	96	
CGS	1964	03	28	10	35	38.9	57.200N	152.400W	033	6.00MB		6.30PAS					013	F	035	196	72	
CGS	1964	03	28	12	20	49.3	56.500N	154.000W	025	6.10MB		6.50PAS					013	F	061	196	64	
CGS	1964	03	28	14	47	37.1	60.400N	146.500W	010	5.70MB		6.30PAS					002	F	061	231	06	
CGS	1964	03	28	14	49	13.7	60.400N	147.100W	010	5.80MB		6.50PAS					002	F	028	231	07	
CGS	1964	03	28	20	29	08.6	59.600N	148.700W	040	5.80MB		6.60PAS					014	F	081	195	98	
CGS	1964	03	30	02	18	06.3	56.600N	152.900W	025	5.80MB		6.60PAS					013	F	075	196	62	
CGS	1964	03	30	07	09	34.0	59.900N	145.700W	015	5.60MB		6.20PAS					015	F	080	195	95	
CGS	1964	04	03	22	33	42.2	61.600N	147.600W	040	5.70MB		6.00PAS			V		002	D	080	231	17	
CGS	1964	04	04	17	40	08.6	56.300N	154.400W	025	5.70MB		6.50PAS					013	F	078	196	64	
CGS	1964	04	04	17	59	43.3	56.400N	154.500W	025	5.50MB		6.10PAS					013	F	048	196	64	
CGS	1964	04	05	01	22	13.3	56.200N	153.500W	025	5.40MB		6.00PAS					013	F	065	196	63	
CGS	1964	04	12	01	24	31.2	56.600N	152.200W	022	5.60MB		6.25PAS					013	F	095	196	62	
CGS	1964	04	16	19	26	57.4	56.400N	152.900W	030	5.50MB		6.63PAS					013	F	087	196	62	
CGS	1964	04	20	11	56	41.6	61.400N	147.300W	030	5.70MB		6.50PAS					002	F	087	231	17	
CGS	1964	04	21	05	01	35.7	61.500N	147.400W	040	5.40MB		6.00PAS					002	F	066	231	17	
CGS	1964	08	02	08	36	16.9	56.200N	149.900W	031	5.40MB		6.00PAS					015	F	037	195	69	
CGS	1964	12	13	00	33	24.7	64.900N	165.700W	015	5.40MB		6.00PAL			VI		676	C	046	233	45	
CGS	1965	02	04	05	01	21.8	51.300N	178.600E	040	6.00MB		7.75PAS			VI	T	006	D	071	199	18	
CGS	1965	02	04	06	04	57.7	51.700N	174.900E	035	6.10MB		6.10BRK					005		028	199	14	
CGS	1965	02	04	08	40	40.9	51.300N	179.500E	040	6.40MB		6.88PAS					006		054	199	19	
CGS	1965	02	04	12	06	04.3	52.600N	172.100E	025	5.80MB		6.50PAS					005		056	199	22	
CGS	1965	02	04	14	18	27.9	53.000N	171.000E	030	5.70MB		6.25PAS					005		055	199	31	
CGS	1965	02	04	15	51	25.5	53.100N	170.800E	040	5.70MB		6.25PAS					005		052	199	30	
CGS	1965	02	05	06	33	49.5	51.500N	175.100E	025	5.70MB		6.38PAS					006		047	199	15	
CGS	1965	02	05	09	32	09.3	52.300N	174.300E	041	5.90MB		6.50PAS					005		065	199	24	
CGS	1965	02	06	01	40	33.2	53.200N	161.900W	033	6.40MB		6.63PAS					017	F	077	197	31	
CGS	1965	02	06	08	46	51.2	51.900N	174.000E	030	6.00MB							005		036	199	14	
CGS	1965	02	06	14	11	10.1	51.700N	174.200E	038	6.00MB							005		033	199	14	
CGS	1965	02	06	16	50	28.6	53.300N	161.800W	033	6.10MB		6.50PAS			IV		017	F	089	197	31	
CGS	1965	02	07	02	17	09.2	51.400N	173.400E	040	6.00MB							005		050	199	13	
CGS	1965	02	07	09	25	51.1	51.400N	179.100E	030	5.30MB		6.25PAS					006		039	199	19	
CGS	1965	02	12	00	55	06.2	52.200N	172.800E	025	5.50MB		6.00PAS					005		040	199	22	
CGS	1965	02	15	01	25	08.3	51.400N	179.400E	042	5.80MB		6.00BRK					006		022	199	19	
CGS	1965	02	17	10	18	51.3	51.800N	176.600E	044	5.60MB		6.50PAS					006		021	199	16	
CGS	1965	02	18	23	13	36.3	51.400N	179.100E	028	5.40MB		6.00PAS					006	F	029	199	19	
CGS	1965	03	17	14	27	12.4	52.800N	171.900E	023	6.00MB							005	F	023	199	21	
CGS	1965	03	30	02	27	07.2	50.600N	177.900E	051	7.30MB		7.13PAS				T	006	F	026	199	07	
CGS	1965	04	04	13	30	37.8	51.900N	175.200E	040	5.70MB		6.00PAS					006		057	199	15	
CGS	1965	05	23	23	46	12.0	52.200N	175.000E	022	6.10MB		6.00PAS					006		025	199	25	
CGS	1965	06	23	11	09	15.7	56.500N	152.800W	033	5.70MB		6.38PAS					013		112	196	62	

Table 4 (Continued)

SOURCE	YEAR	MO	DA	HR	MN	SEC	LAT	LONG	DEPTH (KM)	MAGNITUDES BODY	SURF.	OTHER	LOCAL	INT MAP	INT MAX	PHENOM DTSVNO	RN	CE	Q/S	MAR	DG	DIST (KM)
CGS	1965	07	02	20	58	40.3	53.100N	167.600W	060	6.70MB		6.90PAS			VI	T	009	D	156	197	37	
CGS	1965	07	29	08	29	21.2	50.900N	171.400W	022	6.30MB		6.75PAS					016	F	133	198	01	
CGS	1965	09	04	14	32	46.7	58.200N	152.700W	010	6.20MB		6.88PAS					013	F	137	196	82	
CGS	1965	09	18	20	46	36.5	59.400N	145.200W	005	5.30MB		6.00PAL					015		089	195	95	
CGS	1965	10	01	08	52	04.4	50.100N	178.200E	023	6.30MB		6.50PAS					006	F	148	199	08	
CGS	1965	12	22	19	41	23.1	58.400N	153.100W	051	6.50MB		6.88PAS			V		013	D	142	196	83	
CGS	1966	01	22	14	27	07.9	56.000N	153.700W	033	5.80MB		6.00PAS					013		123	196	63	
CGS	1966	04	16	01	27	13.5	56.900N	153.600W	023	5.70MB		6.25PAS					013		144	196	63	
CGS	1966	05	19	07	06	24.4	54.100N	164.100W	009	5.10MB		6.00PAS			IV		010	F	042	197	44	
CGS	1966	06	02	03	27	50.0	51.100N	176.000E	016	5.90MB		6.00PAS					006		141	199	16	
CGS	1966	07	04	18	33	37.1	51.900N	179.800E	015	6.00MB		6.88PAS					006	F	170	199	19	
CGS	1966	08	07	02	13	04.7	50.600N	171.200W	033	6.20MB		7.00BRK					016	F	189	198	01	
CGS	1967	01	18	08	18	22.0	52.534N	168.202W	033N	5.80MB		6.00PAS					009		182	197	28	
CGS	1967	01	28	13	52	58.2	52.375N	169.515W	043D	5.90MB		6.38PAS					009	F	208	197	29	
CGS	1967	01	28	16	31	22.6	52.272N	169.303W	045G	5.30MB		6.10UPP					009		120	197	29	
CGS	1967	01	28	17	42	01.8	52.401N	169.386W	050D	5.60MB		6.00PAS					009		152	197	29	
CGS	1967	05	27	17	22	58.5	51.866N	176.124E	032D	5.70MB		6.00PAS					006		229	199	16	
USE	1967	07	01	23	10	07.2P	54.400N	158.000W	033	6.20MB					IV		017	F	109	196	48	
USE	1968	04	23	20	29	14.5	58.700N	150.000W	023	6.30MB		6.13PAS					015	F	058	196	80	
CGS	1968	08	22	14	00	06.8	53.013N	171.047E	033	5.40MB	6.0MS						005		061	199	31	
USE	1968	10	29	22	16	15.6	65.400N	150.100W	007	6.00MB	6.5MS	6.80PAS	7.10MLCGS		VIII		676	D	105	232	50	
CGS	1968	11	15	00	07	09.7	58.326N	150.367W	026	5.10MB		6.38PAS					015		063	196	80	
CGS	1968	12	14	09	59	02.3	51.479N	175.745E	033N	5.20MB	5.8MS	6.25PAS					006		068	199	15	
CGS	1968	12	15	02	14	17.5	51.645N	175.796E	033N	5.70MB	6.2MS	6.38PAS					006		062	199	15	
CGS	1968	12	15	02	28	32.4	51.723N	175.779E	033N	5.40MB	6.1MS						006		041	199	15	
USE	1968	12	17	12	02	15.0P	60.200N	152.800W	086	5.90MB		6.50PAS			VI		002	F	101	232	02	
CGS	1969	01	20	14	20	11.5	54.362N	166.029E	023	6.10MB	5.6MS						004		134	200	46	
USE	1969	05	14	19	32	54.2	51.300N	179.900W	021	6.20MB	7.0MS	6.80BRK	6.50MLCGS		V		007	D	139	198	19	
USE	1969	06	22	10	45	24.5	51.500N	179.900W	056	6.10MB		5.25BRK					007	F	106	198	19	
CGS	1969	09	12	08	57	07.3	51.219N	179.154W	048	6.00MB	6.6MS	6.20PAS	6.30MLCGS				007	F	137	198	19	
CGS	1969	10	02	22	06	00.0A	51.417N	179.182E	001	6.50MB	5.0MS				I	E	006	F	159	199	19	
CGS	1969	10	21	20	53	47.5	51.306N	179.235W	048	5.90MB	5.4MS	6.00PAS					007		155	198	19	
USE	1969	10	31	11	33	04.8	51.300N	179.000W	049	6.00MB	6.3MS	6.30PAS			IV		007	F	091	198	19	
USE	1969	11	24	22	51	50.1	56.200N	153.600W	033N	5.50MB	5.7MS	5.70BRK	6.00MLCGS		IV		013	F	113	196	63	
USE	1970	01	15	08	05	39.5	60.300N	152.700W	091D	5.60MB		6.00PAS			V		002	F	078	232	02	
USE	1970	02	27	07	07	58.1	50.100N	179.600W	020	6.00MB	5.9MS	5.90PAS			III		007	F	092	198	09	
USE	1970	02	28	10	52	31.2	52.700N	175.100W	162	6.10MB		6.10PAS			III		007	F	110	198	25	
USE	1970	03	11	22	38	34.6	57.500N	153.900W	029	6.00MB	6.0MS	6.50PAS	6.40MLCGS		V		013	F	075	196	73	
USE	1970	03	19	23	33	29.1	51.300N	173.800E	016D	5.80MB	6.2MS	6.50PAS					005	F	150	199	13	
USE	1970	04	11	04	05	41.1	59.700N	142.700W	007	5.20MB	6.2MS	6.20PAS	5.80MLCGS		III		015	F	072	195	92	
USE	1970	04	16	05	33	17.5	59.600N	142.600W	007	5.50MB	6.8MS	6.80PAS	6.20MLCGS		IV		015	F	120	195	92	
USE	1970	04	19	01	15	46.8	59.600N	142.800W	020G	5.80MB	6.0MS	5.50BRK	5.80MLCGS				015	F	110	195	92	
CGS	1970	04	26	14	20	30.5	52.972N	171.455E	041	5.80MB	5.7MS	6.00PAS					005		122	199	21	
CGS	1970	06	24	13	09	08.3	51.753N	131.024W	012	5.60MB	7.0MS	6.50PAS					022		081	194	11	
CGS	1970	08	18	17	52	06.3	60.700N	145.384W	016	5.60MB	5.9MS	6.00PAS	5.90MLCGS		IV		002	F	082	231	05	
USE	1970	12	01	21	09	37.2M	51.400N	175.300W	036	5.60MB	5.8MS	6.00PAS			II		007	F	136	198	15	
NOS	1971	01	25	16	08	15.1	51.465N	177.693W	038	5.90MB	6.3MS	6.30PAS			IV		007	F	175	198	17	
NOS	1971	02	01	05	19	23.4	51.670N	172.947W	040	5.50MB	5.8MS	6.00PAS					007		119	198	12	
NOS	1971	02	07	02	29	28.2	51.356N	176.718W	050	6.00MB		6.50PAS			V		007	D	133	198	16	
NOS	1971	03	13	23	51	35.5	50.603N	129.947W	033N	5.70MB	6.1MS						025		124	193	09	
NOS	1971	05	02	06	08	27.3	51.433N	177.213W	043	6.00MB	7.1MS	6.80PAS			IV	T	007	F	204	198	17	

Table 4 (Continued)

SOURCE	YEAR	MO	DA	HR	MN	SEC	LAT	LONG	DEPTH (KM)	MAGNITUDES BODY	SURF.	OTHER	LOCAL	INT MAP	INT MAX	PHEN DTSV	CM NO	RN	CE	Q/S	MAR	DG	DIST (KM)
NOS	1971	06	11	13	58	37.7	51.487N	176.084E	032	5.90MB	6.5MS	6.10PAS			IV			006	F	118	199	16	
ERL	1971	07	25	15	41	21.3	52.151N	173.095E	028	5.80MB	6.3MS	6.00PAS			I			005	F	129	199	23	
ERL	1971	11	06	22	00	00.1A	51.472N	179.107E	002	6.80MB	5.7MS	7.40PAS			IV		E	006	F	315	199	19	
ERL	1971	11	22	00	46	11.1	52.269N	174.317E	043	5.60MB	5.5MS	6.00PAS			IV			005	F	156	199	24	
ERL	1971	12	05	05	50	05.8	49.625N	129.450W	005	5.60MB	6.0MS							025		056	157	99	
ERL	1972	03	20	23	31	48.8	51.290N	179.220W	046	6.00MB	5.4MS	5.20BRK			IV			007	F	[illegible]	198	19	
ERL	1972	03	24	03	38	27.1	56.142N	157.180W	069D	6.00MB					IV			012	F	175	196	67	
ERL	1972	07	23	19	13	09.0	50.149N	129.273W	033N	5.90MB	6.4MS							025		104	193	09	
ERL	1972	07	30	21	45	14.1	56.820N	135.685W	025G	6.50MB	7.6MS	7.50PRU				TS		019	D	103	194	65	
ERL	1972	08	03	04	40	54.9	51.199N	178.119W	049	5.80MB	6.2MS	6.10PAS			VI			007	D	080	198	18	
ERL	1972	08	04	11	38	08.3	56.205N	135.342W	020	5.60MB	5.8MS	6.00PAS			V			019	F	075	194	65	
ERL	1973	05	29	06	14	22.3	54.011N	163.760W	030D	6.00MB	5.5MS	5.30BRK			V			010	F	095	197	43	
ERL	1973	07	01	13	33	34.6	57.840N	137.330W	033N	6.10MB	6.7MS	6.70PAS			V			020	D	116	194	77	
ERL	1973	07	03	16	59	35.1	57.980N	138.021W	033N	6.00MB	6.0MS	6.40PAS			V			020	F	124	194	78	
GS	1973	11	06	09	36	05.0	51.619N	175.404W	034	5.80MB	6.4MS	6.20PAS	5.70MLAOK		IV			007	F	172	198	15	
GS	1973	11	06	18	26	35.1	51.579N	175.247W	041	5.90MB	6.3MS	6.20PAS			IV			007	F	183	198	15	
GS	1973	12	29	08	20	16.2	54.640N	168.735E	033N	5.50MB	6.0MS							004		132	200	48	
GS	1974	02	06	04	04	07.2	53.799N	164.672W	002	5.90MB	6.5MS	6.30PAS			V			010	F	118	197	34	
GS	1974	04	06	03	56	01.8	55.120N	160.443W	040D	6.00MB	5.3MS				V			012	F	190	197	50	
GS	1974	08	01	05	07	59.0	56.516N	152.315W	010	5.20MB	6.1MS							013		64	196	62	
GS	1974	08	01	05	55	38.2	56.670N	152.105W	033N	5.70MB	6.3MS							013		94	196	62	
GS	1974	08	01	07	59	56.3	56.632N	152.265W	033N	5.20MB	6.0MS							013		59	196	62	

NOTE. Magnitude values are generally accurate to within 0.3 unit. Geographic positions prior to 1961 are generally accurate to no better than ¼ or ½ degree.

Table 5. Earthquakes that produced tsunamis and seiches in Alaska
(Area covered: 48°-75° N, 165 E-125° W)

SOURCE	YEAR	MO	DA	HR	MN	SEC	LAT	LONG	DEPTH (KM)	---------MAGNITUDES--------- BODY	SURF.	OTHER	LOCAL	INT MAP	INT MAX	PHENOM DTSVNO	RN	CE	Q/S	MAR	CG	DIST (KM)
EQH	1788	07	22	00	00	00.0Z	55.000N	161.000W								T	012	C		197	51	
* HIG	1792																					
+ HIG	1827																					
o HIG	1845																					
+ HIG	1856	07	29																			
HIG	1868	08	13	16	45	00.0	18.500S	071.000W								T	00			343	81	
* HIG	1874																					
EQH	1878	08	29	00	00	00.0Z	54.000N	167.000W								T	009	D		197	47	
+ HIG	1883	10	06														00			001		
EQH	1899	09	04	00	22	00.0Z	60.000N	142.000W	025A			8.30PAS			XI	UT	002	D		231	02	
EQH	1899	09	10	21	40	00.0	60.000N	140.000W				8.60PAS			XI	UTS	019	D		231	00	
EQH	1901	12	30	00	00	00.0Z	60.500N	151.000W								T V	014	F		232	01	
o HIG	1905	07	04																			
EQH	1908	02	14	11	25	00.0Z	61.000N	146.250W							V	TQ	002	D		231	16	
G-R	1911	09	22	05	01	24.0	60.500N	149.000W	060			6.90PAS			VIII	QS	014	D		231	09	
EQH	1925	02	23	23	55	00.0Z	62.000N	146.000W							VII	T	001	D		231	26	
** G-R	1929	03	07	01	34	39.0	51.000N	170.000W	050			8.60CFR				T	009	F		198	10	
** G-R	1929	05	26	22	39	54.0	51.000N	131.000W				7.00PAS			VII	T	022	D		194	11	
* HIG	1936	10	27																			
G-R	1938	11	10	20	18	43.0	55.500N	158.000W	025A			8.70CFR			VI	T	012	F		196	58	
G-R	1944	12	07	04	35	42.0	33.750N	136.000E	025A			8.30PAS				T	233	C		131	36	
G-R	1946	04	01	12	28	54.0	52.750N	163.500W	050			7.40PAS			VI	T	017	C		197	23	
G-R	1949	08	22	04	01	11.0	53.750N	133.250W	025A			8.10PAS				T	022	D		194	33	
G-R	1949	09	27	15	30	45.0	59.750N	149.000W	050			7.00PAS			V	Q	014	F		195	99	
G-R	1952	03	04	01	22	43.0	42.500N	143.000E	025A			8.60PAS			IX	T	224	C		166	23	
G-R	1952	11	04	16	58	26.0	52.750N	159.500E	025A			8.40PAS				T	219	D		201	29	
ISS	1953	11	25	17	48	54.0	33.900N	141.500E	033			8.25PAS				T	229	C		130	31	
BCI	1956	03	30	06	11	01.0	54.500N	159.000E								T	218			201	49	
USE	1957	03	09	14	22	27.5	51.300N	175.800W				8.30PAS			VIII	T V	007	D		198	15	
USE	1958	07	10	06	15	51.0	58.600N	137.100W				7.90PAS			XI	T	019	C		194	87	
ISS	1958	11	06	22	58	08.0	44.380N	148.580E	032			8.70PAS				T	221	D		166	48	
ISS	1958	11	12	20	23	29.0	44.150N	148.820E				7.30PAS				T	221	F		166	48	
CGS	1959	05	04	07	15	42.0	52.500N	159.500E	060			8.00PAS			III	T	219	C		201	29	
CGS	1960	05	22	19	11	17.0	39.500S	074.500W				8.50PAS				T	134	C		415	94	
CGS	1962	12	21	08	42	48.3	52.400N	168.500W	033			6.50PAS				Q	009		037	197	28	
CGS	1963	10	13	05	17	57.1	44.800N	149.500E	060							T	221		075	166	49	
CGS	1964	03	28	03	36	14.0S	61.040N	147.730W	033G		8.3MS	8.50PAS		USE	X	UTS	002	C	181	231	17	
CGS	1965	02	04	05	01	21.3	51.300N	178.600E	040	6.00MB		7.75PAS			VI	T	006	D	071	199	18	
CGS	1965	03	30	02	27	07.2	50.600N	177.900E	051	7.30MB		7.13PAS				T	006	F	026	199	07	
CGS	1965	07	02	20	58	40.3	53.100N	167.600W	060	6.70MB		6.90PAS			VI	T	009	C	156	197	37	
CGS	1966	10	17	21	41	54.7	10.700S	078.800W	024	6.30MB						T	115		164	343	08	
CGS	1968	04	01	00	42	04.2	32.500N	132.200E	033							T	236		133	131	22	
CGS	1968	05	16	00	48	55.4	40.840N	143.222E	007		7.9MS					T	229	C	115	166	03	
CGS	1968	05	16	10	36	29.9	41.285N	142.974E	033N	4.40MB						T	224	F	007	166	12	
CGS	1968	08	01	20	19	21.9	16.522N	122.201E	037	5.90MB	7.3MS					T	249	C	114	060	62	
CGS	1969	08	11	21	27	39.4*	43.545N	147.353E	028	7.10MB	7.8MS	7.80PAS			VII	T	221	D	022	166	37	

See footnotes at end of table.

Table 5 (Continued)

SOURCE	YEAR	MO	DA	HR	MN	SEC	LAT	LONG	DEPTH (KM)	MAGNITUDES BODY	SURF.	OTHER	LOCAL	INT MAP	INT MAX	PHENOM DTSVNO	RN	CE	Q/S	MAR	DG	DIST (KM)
CGS	1969	11	22	23	09	37.2	57.760N	163.541E	033N	6.30MB	7.3MS	7.10PAS				T	218		231	200	73	
NOS	1971	05	02	06	08	27.3	51.433N	177.213W	043	6.00MB	7.1MS	6.80PAS			IV	T	007	F	204	198	17	
ERL	1971	07	14	06	11	29.1	05.474S	153.885E	047		7.9MS	7.80BRK				T	190	C	115	320	53	
ERL	1971	07	26	01	23	21.3	04.940S	153.173E	048	6.30MB	7.9MS				VI	T	190	D	121	320	43	
ERL	1971	12	15	08	29	55.3	55.996N	163.295E	033N	6.10MB	7.8MS	7.30PAS				T T	219		200	200	53	
ERL	1972	07	30	21	45	14.1	56.820N	135.685W	025G	6.50MB	7.6MS	7.50PRU				TS	019	D	103	194	65	
ERL	1973	02	28	06	37	49.5	50.486N	156.584E	027D	6.30MB	7.2MS	7.10PAS			II	T	221	F	178	201	06	
ERL	1973	06	17	03	55	02.9	43.233N	145.785E	048D	6.50MB	7.7MS	7.70PAS			VIII	T	224	C	201	166	35	

**Tsunami generated, but not in Alaska.

*Tsunami caused by landslide, perhaps not earthquake-related.

°Tsunami caused by icefall, perhaps not earthquake-related.

+Tsunami caused by volcano eruption, perhaps not earthquake-related.

NOTE: Magnitude values are generally accurate to within 0.3 unit. Geographic positions prior to 1961 are generally accurate to no better than ¼ or ½ degree.

Table 6. Maximum tsunami wave heights recorded in Alaska

Source: *Catalog of Tsunamis in Alaska* (Cox and Pararas-Carayannis, 1976)

Place of observation	Geographic coordinates N lat	Geographic coordinates W long	Maximum wave height	Date (local) of tsunami[1] (month-day-year)			
	° '	° '	m				
Adak I.							
Sweeper Cove	51 52	176 38	4.0	12-07-44(0)	03-04-52(0)	11-04-52(0)	03-30-56(0)
				03-09-57(I)	11-07-58(0)	11-13-58(0)	05-22-60(0)
				12-20-62(I,?)	10-17-66(0)	03-27-64(I)	05-16-68(0)
				11-23-69(0)	05-01-71(I)	07-26-71(0)	12-15-71(0)
Afognak I.	58 15	152 30	-	03-27-64(I)			
Attu I.							
Massacre Bay	52 50	173 14E	3.2	12-07-44(0)	03-04-52(0)	11-04-52(0)	11-26-53(0)
				03-30-56(0)	03-09-57(I)	11-07-58(0)	11-13-58(0)
				05-04-59(0)	05-22-60(0)	10-12-63(0)	02-03-65(I)
				03-29-65(I)	10-17-66(0)	03-27-64(I)	04-01-68(0)
				05-16-68(0)	08-02-68(0)	08-12-69(0)	11-23-69(0)
				07-14-71(0)	07-26-71(0)	12-15-71(0)	02-28-73(0)
				06-17-73(0)			
Cape Yakataga	60 04	142 26	3.7	03-27-64(I)			
Cook Inlet	59 22	153 25	-	12-30-01(I,V,?)			
Controller Bay							
Bering River	60 11	144 15	1	09-10-1899(I,L)			
Cordova	60 33	145 45	4.2	03-27-64(I)			
Golden	60 58	147 59	-	09-21-11(I,?)			
Juneau	58 18	134 25	1.1	11-04-52(0)	03-27-64(I)	07-30-72(I)	

[1]See definitions of letters in parentheses at end of table.

Table 6 (Continued)

Place of observation	Geographic coordinates N lat (° ')	Geographic coordinates W long (° ')	Maximum wave height (m)	Date (local) of tsunami[1] (month-day-year)			
Kenai Peninsula							
Seldovia	59 26	151 43	1.2	03-27-64(I)			
Port Graham	59 26	151 50	7.5-9	10-06-1883(I,V)			
Ketchikan	55 21	131 39	0.6	08-21-49(I)	03-27-64(I)		
Kodiak I.							
Kaguyak	56 52	153 46	9±	03-27-64(I)			
Kodiak	57 47	152 47	6.1	08-13-1868(0)	05-22-60(0)	03-27-64(I)	
Old Harbor	57 12	153 18	9.2	03-27-64(I)			
Three Saints Bay	57 06	153 28	-	07-22-1788(I)	1827 (?S)		
Womens Bay	57 43	152 31	6.1	11-04-52(0)	03-09-57(I)	03-27-64(I)	
Lituya Bay	58 37	137 40	525	09-10-1899(I, L)	1874(I,?)	10-27-36(I,L)	07-09-58(I,L)
Lynn Canal	58 10	134 58	0.3	09-03-1899(I,?S)			
Passage Canal							
Whittier	60 47	148 41	9.2	03-27-64(I)			
Prince William Sound							
Chenega	60 17	148 05	16.2	03-27-64(I)			
Resurrection Bay							
Seward	60 07	149 27	7.0	11-10-38(I)	09-27-49(I,?)	11-04-52(0)	03-27-64(I)
Sanak Is.	54 25	162 40	-	07-22-1788(I)			
Shemya I.	52 43	174 07E	10	02-03-65(I)	11-23-69(0)	12-15-71(0)	02-28-73(0)
Shumagin Is.							
Chernabura I.	54 47	159 33	-	1792(I,V,?)			
Unga I.	55 11	160 30	-	07-22-1788(I)			

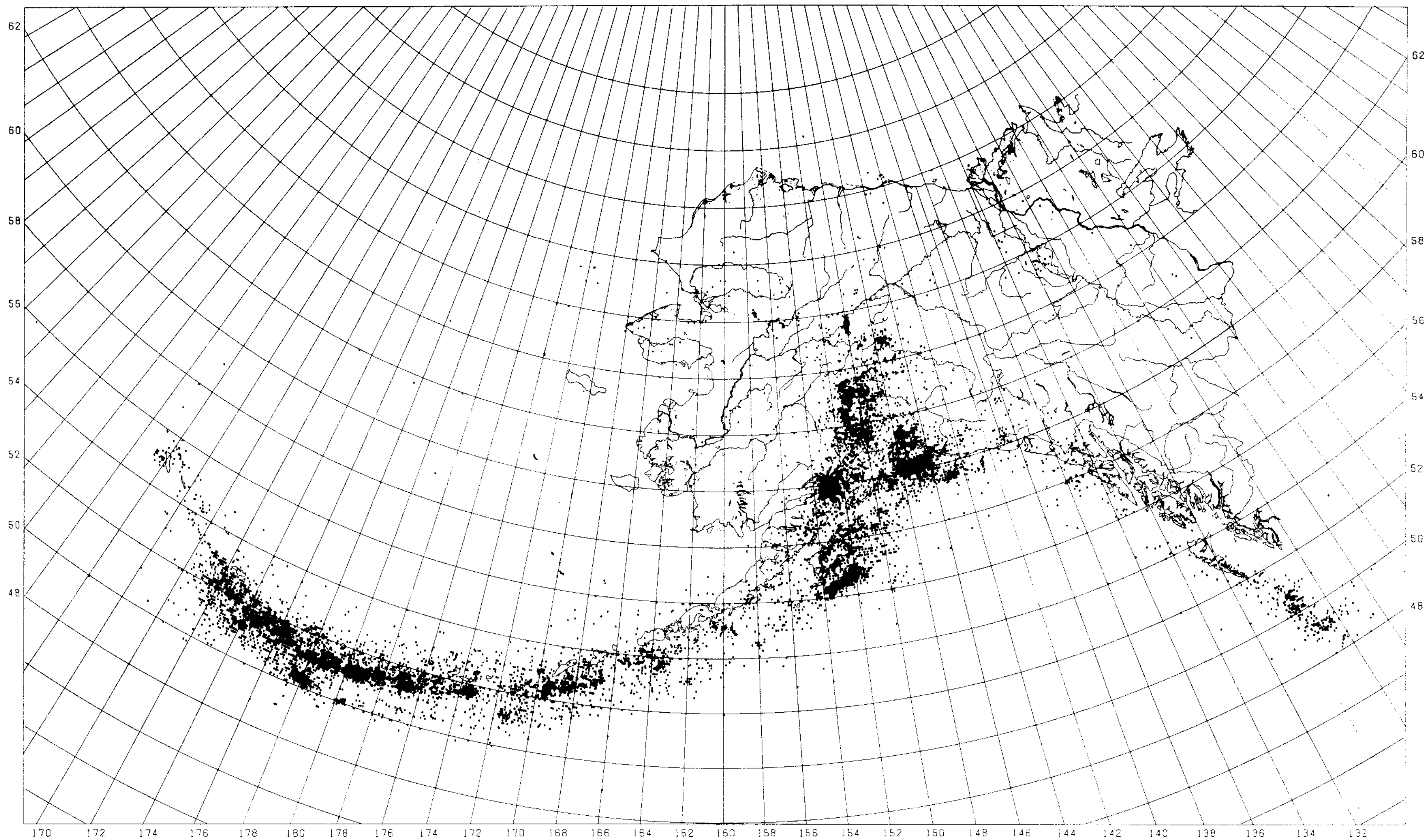
[1]See definitions of letters in parentheses at end of table.

Table 6 (Continued)

Place of observation	Geographic coordinates N lat	W long	Maximum wave height	Date (local) of tsunami[1] (month-day-year)			
	° '	° '	m				
Sitka	57 03	135 20	2.4	11-10-38(I)	04-01-46(I)	08-21-49(I,?)	03-04-52(0)
				11-04-52(0)	03-09-57(I)	07-09-58(I)	05-22-60(0)
				03-27-64(I)	05-16-68(0)	07-30-72(I)	
Snug Harbor	60 06	152 35	0.1	10-17-66(0)			
Unalaska I.	53 53	166 32	0.4	08-29-1878(I)	07-02-65(I)		
Dutch Harbor	53 54	166 31	0.8	11-10-38(I)	03-04-52(0)	11-04-52(0)	03-30-56(0)
				03-09-57(I)	05-22-60(0)	03-27-64(I)	05-16-68(0)
				12-15-71(0)			
Makushin	53 46	166 59	-	08-29-1878(I)			
Unimak I. Scotch Cap	52 24	164 48	30	04-01-46(I)	03-09-57(I)		
Unimak Strait	54 20	164 50		07-26-1856(I,V)			
Valdez Inlet, Valdez	61 07	146 16	6.1	09-10-1899(I, L)	02-14-08(I, ?S)	02-23-25(I)	03-27-64(I)
Wells Bay	60 54	147 29	-	09-21-11(I,?)			
Yakutat Bay	59 40	140 00	35	1845(I,IF)	09-10-1899(I)	07-04-05(I,IF)	
Yakutat	59 33	139 44	2.2	04-01-46(I)	11-04-52(0)	03-09-57(I)	07-09-58(I)
				05-22-60(0)	03-27-64(I)		

I = Tsunami origin in Alaska
0 = Tsunami origin outside Alaska
V = Volcanic generated
IF = Icefall generated
L = Landslide generated
? = Questionable tsunami
?S = Questionable tsunami; probably a seiche
______ = Earthquake that generated maximum wave height tabulated

EARTHQUAKES IN AND NEAR ALASKA (THRU 1974)

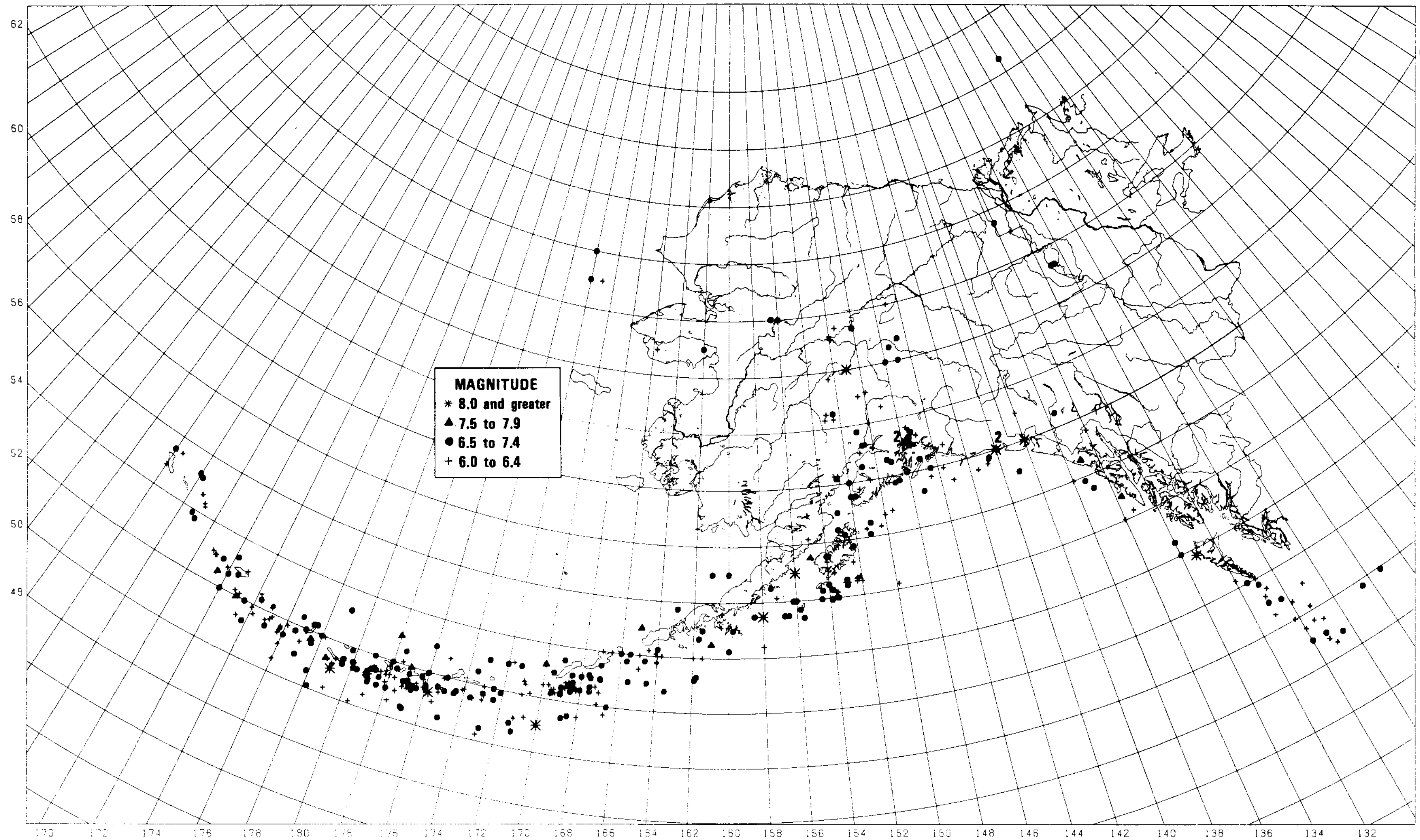


NOAA/EDS/National Geophysical and Solar-Terrestrial Data Center

Only earthquakes within Lat. 48° – 75° N, Long. 165° E – 125° W are shown on map.

Figure 1. Earthquakes in and near Alaska (thru 1974)

MAJOR EARTHQUAKES IN ALASKA (1899-1974)



NOAA/EDS/National Geophysical and Solar-Terrestrial Data Center

Only earthquakes within Lat. 48° – 75° N, Long. 165° E – 125° W are shown on map.

Figure 2. Major earthquakes in Alaska, 1899-1974

MAXIMUM EARTHQUAKE MAGNITUDE PER 1° SQUARE, 1899-1974

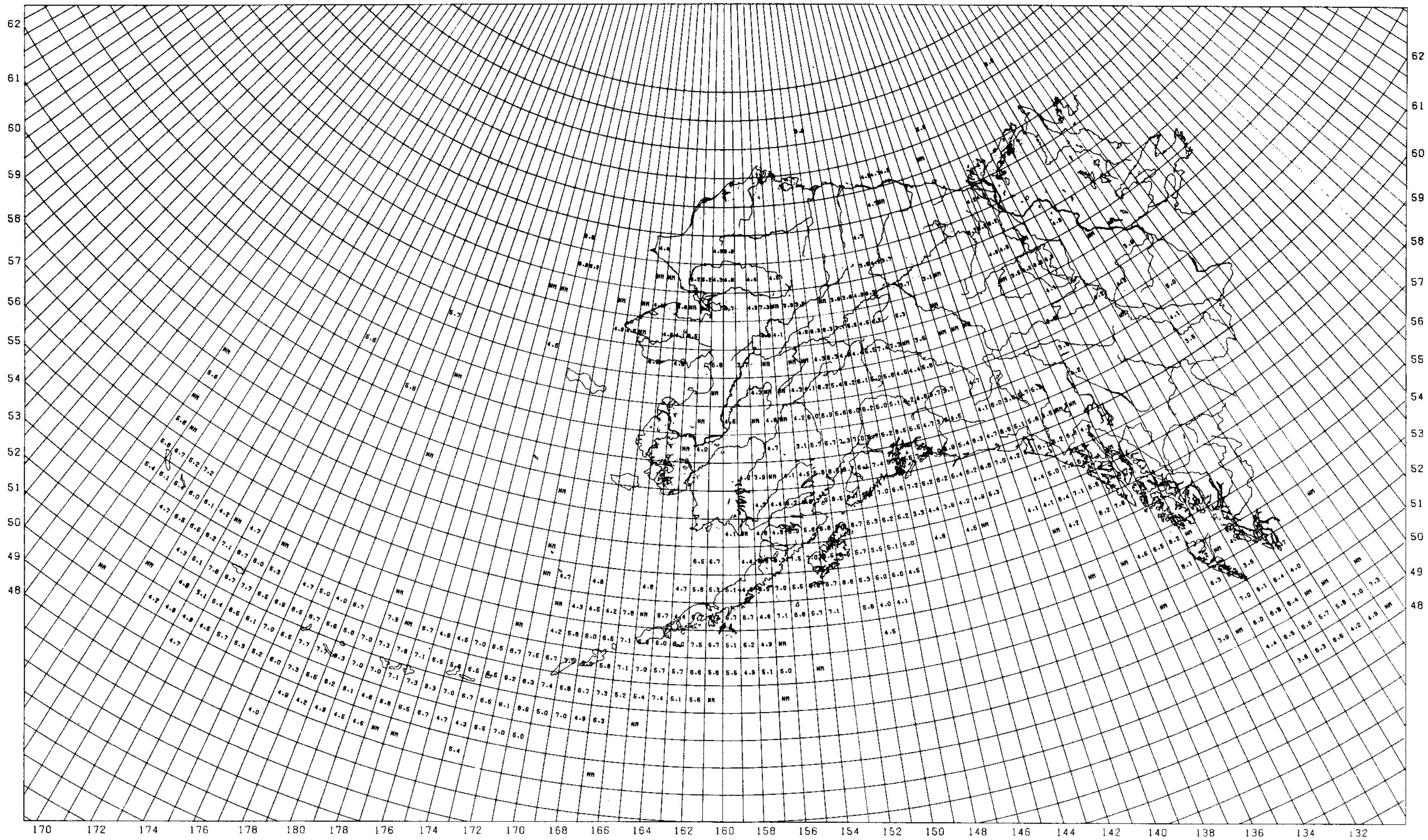
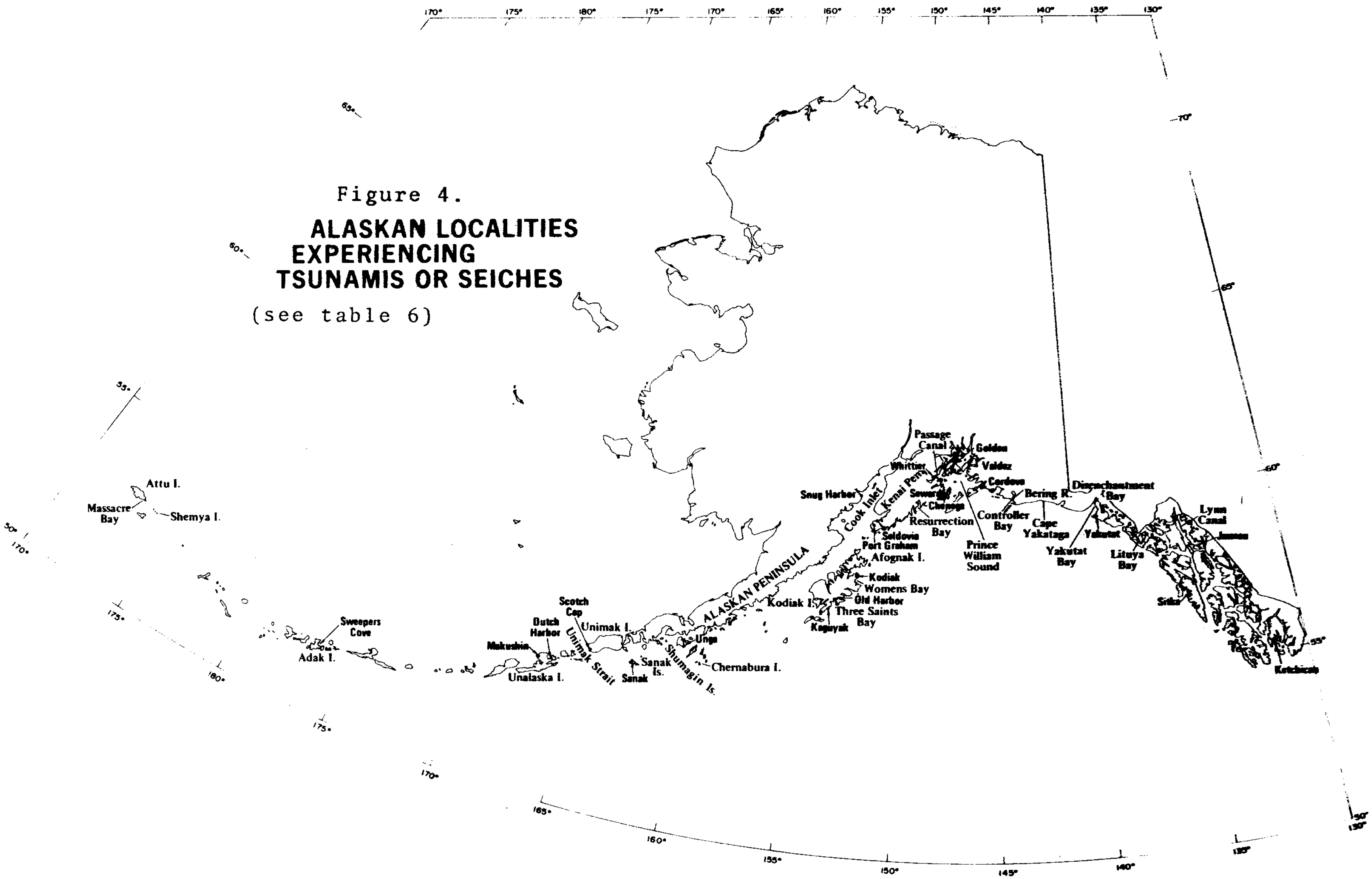


Figure 3. Maximum earthquake magnitude per 1° square, 1899-1974

Figure 4.

ALASKAN LOCALITIES EXPERIENCING TSUNAMIS OR SEICHES

(see table 6)



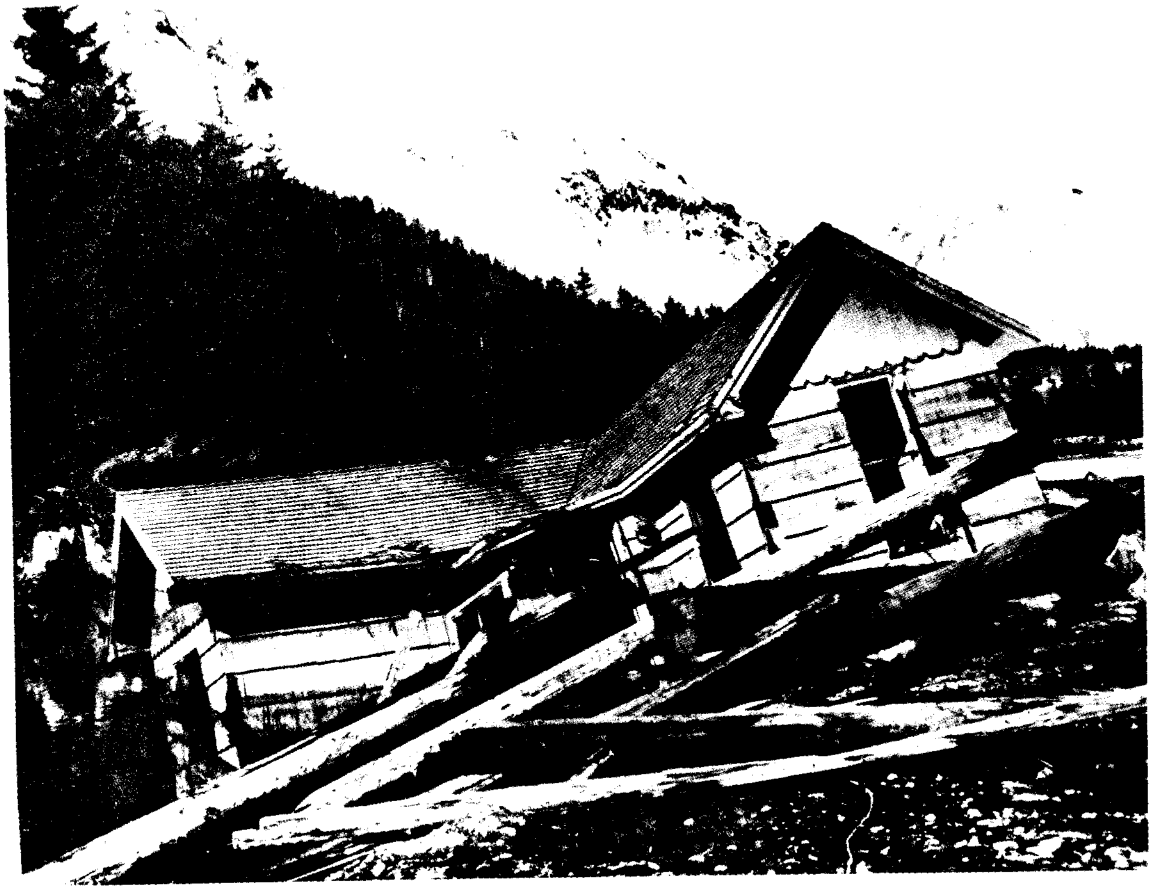


Figure 5. Seward (Alaska) residence severely damaged by tsunami of March 27, 1964. The tsunami caused heavy damage at many other port towns in southern Alaska.

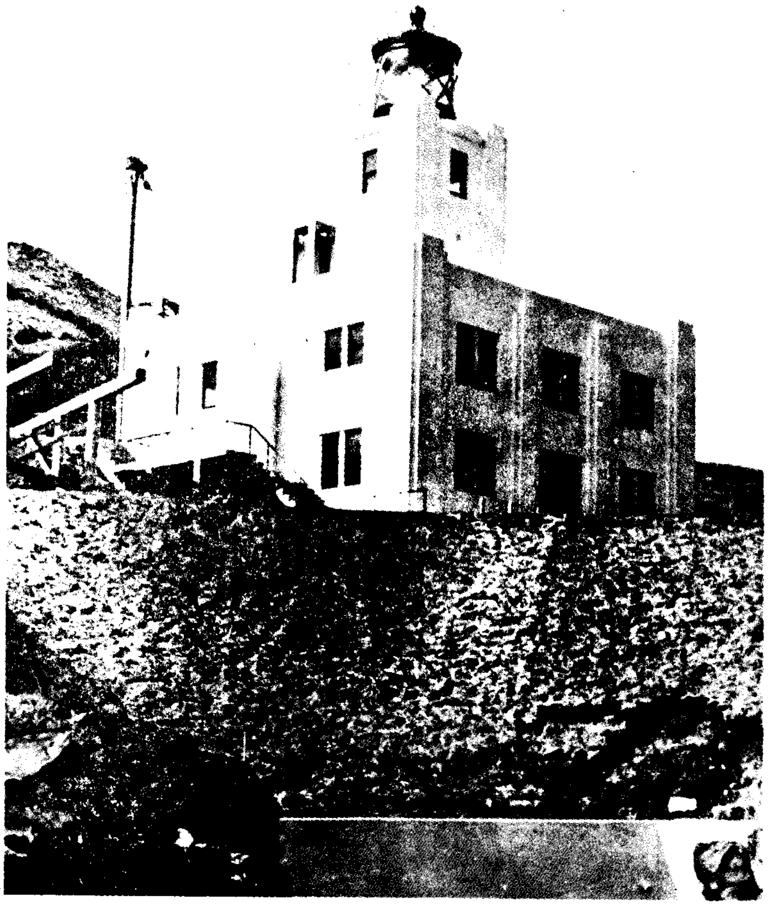


Figure 6. Scotch Cap Lighthouse (Alaska) before and after (bottom) tsunami of April 1, 1946. The five occupants of the lighthouse were never found. The lighthouse was located high on a cliff just a few miles from the epicenter of the earthquake (off Unimak Island).

APPENDIX 1

MODIFIED MERCALLI INTENSITY SCALE OF 1931
(Abridged)

I. Not felt except by a very few under especially favorable circumstances.

II. Felt only by a few persons at rest, especially on upper floors of buildings. Delicately suspended objects may swing.

III. Felt quite noticeably indoors, especially on upper floors of buildings, but many people do not recognize it as an earthquake. Standing motorcars may rock slightly. Vibration like a passing truck. Duration estimated.

IV. During the day felt indoors by many, outdoors by few. At night, some awakened. Dishes, windows, doors disturbed; walls make creaking sound. Sensation like heavy truck striking building. Standing motorcars rocked noticeably.

V. Felt by nearly everyone, many awakened. Some dishes, windows, etc., broken; a few instances of cracked plaster; unstable objects overturned. Disturbances of trees, poles, and other tall objects sometimes noticed. Pendulum clocks may stop.

VI. Felt by all; many frightened and run outdoors. Some heavy furniture moved; a few instances of fallen plaster or damaged chimneys. Damage slight.

VII. Everybody runs outdoors. Damage *negligible* in buildings of good design and construction; *slight* to *moderate* in well-built ordinary structures; *considerable* in poorly built or badly designed structures; some chimneys broken. Noticed by persons driving motorcars.

VIII. Damage *slight* in specially designed structures; *considerable* in ordinary substantial buildings, with partial collapse; *great* in poorly built structures. Panel walls thrown out of frame structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned. Sand and mud ejected in small amounts. Changes in well water. Persons driving motorcars disturbed.

IX. Damage *considerable* in specially designed structures; well-designed frame structures thrown out of plumb; *great* in substantial buildings, with partial collapse. Buildings shifted off foundations. Ground cracked conspicuously. Underground pipes broken.

X. Some well-built wooden structures destroyed; most masonry and frame structures destroyed with their foundations; ground badly cracked. Rails bent. Landslides considerable from river banks and steep slopes. Shifted sand and mud. Water splashed (slopped) over banks.

APPENDIX 1 (Cont.)

XI. Few, if any, (masonry) structures remain standing. Bridges destroyed. Broad fissures in ground. Underground pipelines completely out of service. Earth slumps and land slips in soft ground. Rails bent greatly.

XII. Damage *total*. Waves seen on ground surfaces. Lines of sight and level distorted. Objects thrown upward into air.

USA Modified Mercalli, 1931 (MM)	Japanese, 1950 (JMA)	Rossi-Forel, 1873 (RF)	European (Mercalli-Cancani-Sieberg), 1917
I	0	I	I
II	I	I-II	II
III	II	III	III
IV	II-III	IV-V	IV
V	III	V-VI	V
VI	IV	VI-VII	VI
VII	IV-V	VIII-	VII
VIII	V	VIII+ - IX-	VIII
IX	V-VI	IX+	IX
X	VI	X	X
XI	VII		XI
XII			XII

APPENDIX 2

FLINN-ENGDAHL REGIONS

1	CENTRAL ALASKA
2	SOUTHERN ALASKA
3	BERING SEA
4	KOMANDORSKY ISLANDS REGION
5	NEAR ISLANDS, ALEUTIAN ISLANDS
6	RAT ISLANDS, ALEUTIAN ISLANDS
7	ANDREANOF ISLANDS, ALEUTIAN IS.
8	PRIBILOF ISLANDS
9	FOX ISLANDS, ALEUTIAN ISLANDS
10	UNIMAK ISLAND REGION
11	BRISTOL BAY
12	ALASKA PENINSULA
13	KODIAK ISLAND REGION
14	KENAI PENINSULA, ALASKA
15	GULF OF ALASKA
16	ALEUTIAN ISLANDS REGION
17	SOUTH OF ALASKA
18	SOUTHERN YUKON TERRITORY, CANADA
19	SOUTHEASTERN ALASKA
20	OFF COAST OF SOUTHEASTERN ALASKA
21	WEST OF VANCOUVER ISLAND
22	QUEEN CHARLOTTE ISLANDS REGION
23	BRITISH COLUMBIA
24	ALBERTA PROVINCE, CANADA
25	VANCOUVER ISLAND REGION
26	OFF COAST OF WASHINGTON
27	NEAR COAST OF WASHINGTON
28	WASHINGTON-OREGON BORDER REGION
29	WASHINGTON
30	OFF COAST OF OREGON
31	NEAR COAST OF OREGON
32	OREGON
33	WESTERN IDAHO
34	OFF COAST OF NORTHERN CALIFORNIA
35	NEAR COAST OF NORTHERN CALIF.
36	NORTHERN CALIFORNIA
37	NEVADA
38	OFF COAST OF CALIFORNIA
39	CENTRAL CALIFORNIA
40	CALIFORNIA-NEVADA BORDER REGION
41	SOUTHERN NEVADA
42	WESTERN ARIZONA
43	SOUTHERN CALIFORNIA
44	CALIFORNIA-ARIZONA BORDER REGION
45	CALIFORNIA-MEXICO BORDER REGION
46	W. ARIZ. - MEXICO BORDER REGION
47	OFF W. COAST OF BAJA CALIFORNIA
48	BAJA CALIFORNIA
49	GULF OF CALIFORNIA
50	NORTHWESTERN MEXICO
51	OFF COAST OF CENTRAL MEXICO
52	NEAR COAST OF CENTRAL MEXICO
53	REVILLA GIGEDO ISLANDS REGION
54	OFF COAST OF JALISCO, MEXICO
55	NEAR COAST OF JALISCO, MEXICO
56	NEAR COAST OF MICHOACAN, MEXICO
57	MICHOACAN, MEXICO
58	NEAR COAST OF GUERRERO, MEXICO
59	GUERRERO, MEXICO
60	OAXACA, MEXICO
61	CHIAPAS, MEXICO
62	MEXICO-GUATEMALA BORDER REGION
63	OFF COAST OF MEXICO
64	OFF COAST OF MICHOACAN, MEXICO
65	OFF COAST OF GUERRERO, MEXICO
66	NEAR COAST OF OAXACA, MEXICO
67	OFF COAST OF OAXACA, MEXICO
68	OFF COAST OF CHIAPAS, MEXICO
69	NEAR COAST OF CHIAPAS, MEXICO
70	GUATEMALA
71	NEAR COAST OF GUATEMALA
72	HONDURAS
73	EL SALVADOR
74	NEAR COAST OF NICARAGUA
75	NICARAGUA
76	OFF COAST OF CENTRAL AMERICA
77	OFF COAST OF COSTA RICA
78	COSTA RICA
79	NORTH OF PANAMA
80	PANAMA-COSTA RICA BORDER REGION
81	PANAMA
82	PANAMA-COLOMBIA BORDER REGION
83	SOUTH OF PANAMA
84	YUCUTAN PENINSULA
85	CUBA REGION
86	JAMAICA REGION
87	HAITI REGION
88	DOMINICAN REPUBLIC REGION
89	MONA PASSAGE
90	PUERTO RICO REGION
91	VIRGIN ISLANDS
92	LEEWARD ISLANDS
93	BRITISH HONDURAS
94	CARIBBEAN SEA
95	WINDWARD ISLANDS
96	NEAR NORTH COAST OF COLOMBIA
97	NEAR COAST OF VENEZUELA
98	TRINIDAD
99	NORTHERN COLOMBIA
100	LAKE MARACAIBO
101	VENEZUELA
102	NEAR WEST COAST OF COLOMBIA
103	COLOMBIA
104	OFF COAST OF ECUADOR
105	NEAR COAST OF ECUADOR
106	COLOMBIA-ECUADOR BORDER REGION
107	ECUADOR
108	OFF COAST OF NORTHERN PERU
109	NEAR COAST OF NORTHERN PERU
110	PERU-ECUADOR BORDER REGION
111	NORTHERN PERU
112	PERU-BRAZIL BORDER REGION
113	WESTERN BRAZIL
114	OFF COAST OF PERU
115	NEAR COAST OF PERU
116	PERU
117	SOUTHERN PERU
118	PERU-BOLIVIA BORDER REGION
119	NORTHERN BOLIVIA
120	BOLIVIA
121	OFF COAST OF NORTHERN CHILE
122	NEAR COAST OF NORTHERN CHILE
123	NORTHERN CHILE
124	CHILE-BOLIVIA BORDER REGION
125	SOUTHERN BOLIVIA
126	PARAGUAY
127	CHILE-ARGENTINA BORDER REGION
128	JUJUY PROVINCE, ARGENTINA
129	SALTA PROVINCE, ARGENTINA
130	CATAMARCA PROVINCE, ARGENTINA
131	TUCUMAN PROVINCE, ARGENTINA
132	SANTIAGO DEL ESTERO PROV., ARG.
133	NORTHEASTERN ARGENTINA
134	OFF COAST OF CENTRAL CHILE
135	NEAR COAST OF CENTRAL CHILE
136	CENTRAL CHILE
137	SAN JUAN PROVINCE, ARGENTINA
138	LA RIOJA PROVINCE, ARGENTINA
139	MENDOZA PROVINCE, ARGENTINA
140	SAN LUIS PROVINCE, ARGENTINA
141	CORDOBA PROVINCE, ARGENTINA
142	URUGUAY
143	OFF COAST OF SOUTHERN CHILE
144	NEAR COAST OF SOUTHERN CHILE
145	S. CHILE-ARGENTINA BORDER REGION
146	ARGENTINA
147	TIERRA DEL FUEGO
148	FALKLAND ISLANDS REGION

149	DRAKE PASSAGE
150	SCOTIA SEA
151	SOUTH GEORGIA ISLAND REGION
152	SOUTH GEORGIA RISE
153	SOUTH SANDWICH ISLANDS REGION
154	SOUTH SHETLAND ISLANDS
155	ANTARCTIC PENINSULA
156	SOUTHWESTERN ATLANTIC OCEAN
157	WEDDELL SEA
158	OFF W. COAST OF N. ISLAND, N.Z.
159	NORTH ISLAND, NEW ZEALAND
160	OFF E. COAST OF N. ISLAND, N.Z.
161	OFF W. COAST OF S. ISLAND, N.Z.
162	SOUTH ISLAND, NEW ZEALAND
163	COOK STRAIT, NEW ZEALAND
164	OFF E. COAST OF S. ISLAND, N.Z.
165	NORTH OF MACQUARIE ISLAND
166	AUCKLAND ISLANDS REGION
167	MACQUARIE ISLANDS REGION
168	SOUTH OF NEW ZEALAND
169	SAMOA ISLANDS REGION
170	SAMOA ISLANDS
171	SOUTH OF FIJI ISLANDS
172	WEST OF TONGA ISLANDS
173	TONGA ISLANDS
174	TONGA ISLANDS REGION
175	SOUTH OF TONGA ISLANDS
176	NORTH OF NEW ZEALAND
177	KERMADEC ISLANDS REGION
178	KERMADEC ISLANDS
179	SOUTH OF KERMADEC ISLANDS
180	NORTH OF FIJI ISLANDS
181	FIJI ISLANDS REGION
182	FIJI ISLANDS
183	SANTA CRUZ ISLANDS REGION
184	SANTA CRUZ ISLANDS
185	NEW HEBRIDES ISLANDS REGION
186	NEW HEBRIDES ISLANDS
187	NEW CALEDONIA
188	LOYALTY ISLANDS
189	LOYALTY ISLANDS REGION
190	NEW IRELAND REGION
191	NORTH OF SOLOMON ISLANDS
192	NEW BRITAIN REGION
193	SOLOMON ISLANDS
194	DENTRECASTEAUX ISLANDS REGION
195	SOLOMON ISLANDS REGION
196	WEST NEW GUINEA REGION
197	NEAR N. COAST OF WEST NEW GUINEA
198	NEW GUINEA REGION
199	ADMIRALTY ISLANDS REGION
200	NEAR NORTH COAST OF NEW GUINEA
201	WEST NEW GUINEA
202	NEW GUINEA
203	BISMARCK SEA
204	AROE ISLANDS REGION
205	NEAR S. COAST OF WEST NEW GUINEA
206	NEAR SOUTH COAST OF NEW GUINEA
207	EAST NEW GUINEA REGION
208	ARAFURA SEA
209	WEST CAROLINE ISLANDS
210	SOUTH OF MARIANA ISLANDS
211	SOUTH OF HONSHU, JAPAN
212	BONIN ISLANDS REGION
213	VOLCANO ISLANDS REGION
214	WEST OF MARIANA ISLANDS
215	MARIANA ISLANDS REGION
216	MARIANA ISLANDS
217	KAMCHATKA
218	NEAR EAST COAST OF KAMCHATKA
219	OFF EAST COAST OF KAMCHATKA
220	NORTHWEST OF KURIL ISLANDS
221	KURIL ISLANDS
222	KURIL ISLANDS REGION
223	EASTERN SEA OF JAPAN
224	HOKKAIDO, JAPAN REGION
225	OFF COAST OF HOKKAIDO, JAPAN
226	NEAR WEST COAST OF HONSHU, JAPAN
227	HONSHU, JAPAN
228	NEAR EAST COAST OF HONSHU, JAPAN
229	OFF EAST COAST OF HONSHU, JAPAN
230	NEAR S. COAST OF HONSHU, JAPAN
231	SOUTH KOREA
232	SOUTHERN HONSHU, JAPAN
233	NEAR S. COAST OF SOUTHERN HONSHU
234	EAST CHINA SEA
235	KYUSHU, JAPAN
236	SHIKOKU, JAPAN
237	SOUTHEAST OF SHIKOKU, JAPAN
238	RYUKYU ISLANDS
239	RYUKYU ISLANDS REGION
240	EAST OF RYUKYU ISLANDS
241	PHILIPPINE SEA
242	NEAR SOUTHEASTERN COAST OF CHINA
243	TAIWAN REGION
244	TAIWAN
245	NORTHEAST OF TAIWAN
246	SOUTHWESTERN RYUKYU ISLANDS
247	SOUTHEAST OF TAIWAN
248	PHILIPPINE ISLANDS REGION
249	LUZON, PHILIPPINE ISLANDS
250	MINDORO, PHILIPPINE ISLANDS
251	SAMAR, PHILIPPINE ISLANDS
252	PALAWAN, PHILIPPINE ISLANDS
253	SULU SEA
254	PANAY, PHILIPPINE ISLANDS
255	CEBU, PHILIPPINE ISLANDS
256	LEYTE, PHILIPPINE ISLANDS
257	NEGROS, PHILIPPINE ISLANDS
258	SULU ARCHIPELAGO
259	MINDANAO, PHILIPPINE ISLANDS
260	EAST OF PHILIPPINE ISLANDS
261	BORNEO
262	CELEBES SEA
263	TALAUD ISLANDS
264	NORTH OF HALMAHERA
265	NORTHERN CELEBES
266	MOLUCCA PASSAGE
267	HALMAHERA
268	CELEBES
269	MOLUCCA SEA
270	CERAM SEA
271	BURU
272	CERAM
273	SOUTHWEST OF SUMATRA
274	SOUTHERN SUMATRA
275	JAVA SEA
276	SUNDA STRAIT
277	JAVA
278	BALI SEA
279	FLORES SEA
280	BANDA SEA
281	TANIMBAR ISLANDS REGION
282	SOUTH OF JAVA
283	BALI ISLAND REGION
284	SOUTH OF BALI ISLAND
285	SUMBAWA ISLAND REGION
286	FLORES ISLAND REGION
287	SUMBA ISLAND REGION
288	SAWU SEA
289	TIMOR
290	TIMOR SEA
291	SOUTH OF SUMBAWA ISLAND
292	SOUTH OF SUMBA ISLAND
293	SOUTH OF TIMOR
294	BURMA-INDIA BORDER REGION
295	BURMA-EAST PAKISTAN BORDER REG.
296	BURMA
297	BURMA-CHINA BORDER REGION
298	SOUTH BURMA
299	SOUTHEAST ASIA
300	HAINAN ISLAND

301 SOUTH CHINA SEA
302 EASTERN KASHMIR
303 KASHMIR-INDIA BORDER REGION
304 KASHMIR-TIBET BORDER REGION
305 TIBET-INDIA BORDER REGION
306 TIBET
307 SZECHWAN PROVINCE, CHINA
308 NORTHERN INDIA
309 NEPAL-INDIA BORDER REGION
310 NEPAL
311 SIKKIM
312 BHUTAN
313 INDIA-CHINA BORDER REGION
314 INDIA
315 INDIA-EAST PAKISTAN BORDER REG.
316 EAST PAKISTAN
317 EASTERN INDIA
318 YUNNAN PROVINCE, CHINA
319 BAY OF BENGAL
320 KIRGIZ-SINKIANG BORDER REGION
321 SOUTHERN SINKIANG PROV., CHINA
322 KANSU PROVINCE, CHINA
323 NORTHERN CHINA
324 KASHMIR-SINKIANG BORDER REGION
325 TSINGHAI PROVINCE, CHINA
326 CENTRAL RUSSIA
327 LAKE BAIKAL REGION
328 EAST OF LAKE BAIKAL
329 EASTERN KAZAKH SSR
330 ALMA-ATA REGION
331 KAZAKH-SINKIANG BORDER REGION
332 NORTHERN SINKIANG PROV., CHINA
333 USSR-MONGOLIA BORDER REGION
334 MONGOLIA
335 URAL MOUNTAINS REGION
336 WESTERN KAZAKH SSR
337 EASTERN CAUCASUS
338 CASPIAN SEA
339 UZBEK SSR
340 TURKMEN SSR
341 IRAN-USSR BORDER REGION
342 TURKMEN-AFGHANISTAN BORDER REG.
343 TURKEY-IRAN BORDER REGION
344 N.W. IRAN-USSR BORDER REGION
345 NORTHWESTERN IRAN
346 IRAN-IRAQ BORDER REGION
347 WESTERN IRAN
348 IRAN
349 NORTHWESTERN AFGHANISTAN
350 SOUTHWESTERN AFGHANISTAN
351 EASTERN ARABIAN PENINSULA
352 PERSIAN GULF
353 SOUTHERN IRAN
354 WESTERN PAKISTAN
355 GULF OF OMAN
356 NEAR COAST OF WEST PAKISTAN
357 SOUTHWESTERN RUSSIA
358 RUMANIA
359 BULGARIA
360 BLACK SEA
361 CRIMEA REGION
362 WESTERN CAUCASUS
363 GREECE-BULGARIA BORDER REGION
364 GREECE
365 AEGEAN SEA
366 TURKEY
367 TURKEY-USSR BORDER REGION
368 SOUTHERN GREECE
369 DODECANESE ISLANDS
370 CRETE
371 EASTERN MEDITERRANEAN SEA
372 CYPRUS
373 DEAD SEA REGION
374 JORDAN - SYRIA REGION
375 IRAQ
376 PORTUGAL
377 SPAIN
378 PYRENEES
379 NEAR SOUTH COAST OF FRANCE
380 CORSICA
381 CENTRAL ITALY
382 ADRIATIC SEA
383 YUGOSLAVIA
384 WEST OF GIBRALTAR
385 STRAIT OF GIBRALTAR
386 BALEARIC ISLANDS
387 WESTERN MEDITERRANEAN SEA
388 SARDINIA
389 TYRRHENIAN SEA
390 SOUTHERN ITALY
391 ALBANIA
392 GREECE-ALBANIA BORDER REGION
393 MADEIRA ISLANDS REGION
394 CANARY ISLANDS REGION
395 MOROCCO
396 ALGERIA
397 TUNISIA
398 SICILY
399 IONIAN SEA
400 MEDITERRANEAN SEA
401 NEAR COAST OF LIBYA
402 NORTH ATLANTIC OCEAN
403 NORTH ATLANTIC RIDGE
404 AZORES ISLANDS REGION
405 AZORES ISLANDS
406 CENTRAL MID-ATLANTIC RIDGE
407 NORTH OF ASCENSION ISLAND
408 ASCENSION ISLAND REGION
409 SOUTH ATLANTIC OCEAN
410 SOUTH ATLANTIC RIDGE
411 TRISTAN DA CUNHA REGION
412 BOUVET ISLAND REGION
413 SOUTHWEST OF AFRICA
414 SOUTHEASTERN ATLANTIC OCEAN
415 EASTERN GULF OF ADEN
416 SOCOTRA REGION
417 ARABIAN SEA
418 LACCADIVE ISLANDS REGION
419 NORTHEASTERN SOMALIA
420 NORTH INDIAN OCEAN
421 CARLSBERG RIDGE
422 MALDIVE ISLANDS REGION
423 LACCADIVE SEA
424 CEYLON
425 SOUTH INDIAN OCEAN
426 CHAGOS ARCHIPELAGO REGION
427 MASCARENE ISLANDS REGION
428 ATLANTIC-INDIAN RISE
429 MID-INDIAN RISE
430 SOUTH OF AFRICA
431 PRINCE EDWARD ISLANDS REGION
432 CROZET ISLANDS REGION
433 KERGUELEN ISLANDS REGION
434 AMSTERDAM-NATURALISTE RIDGE
435 SOUTHEAST INDIAN RISE
436 KERGUELEN-GAUSSBERG RISE
437 SOUTH OF AUSTRALIA
438 SASKATCHEWAN PROVINCE, CANADA
439 MANITOBA PROVINCE, CANADA
440 HUDSON BAY
441 ONTARIO
442 HUDSON STRAIT REGION
443 NORTHERN QUEBEC
444 DAVIS STRAIT
445 LABRADOR
446 EAST OF LABRADOR
447 SOUTHERN QUEBEC
448 GASPE PENINSULA
449 EASTERN QUEBEC
450 ANTICOSTI ISLAND, CANADA
451 NEW BRUNSWICK
452 NOVA SCOTIA

APPENDIX 2 CONTINUED

453	PRINCE EDWARD ISLAND, CANADA
454	GULF OF ST. LAWRENCE
455	NEWFOUNDLAND
456	MONTANA
457	EASTERN IDAHO
458	HEBGEN LAKE REGION
459	YELLOWSTONE NATIONAL PARK, WYO.
460	WYOMING
461	NORTH DAKOTA
462	SOUTH DAKOTA
463	NEBRASKA
464	MINNESOTA
465	IOWA
466	WISCONSIN
467	ILLINOIS
468	MICHIGAN
469	INDIANA
470	SOUTHERN ONTARIO
471	OHIO
472	NEW YORK
473	PENNSYLVANIA
474	NORTHERN NEW ENGLAND
475	MAINE
476	SOUTHERN NEW ENGLAND
477	GULF OF MAINE
478	UTAH
479	COLORADO
480	KANSAS
481	IOWA-MISSOURI BORDER REGION
482	MISSOURI-KANSAS BORDER REGION
483	MISSOURI
484	MISSOURI-ARKANSAS BORDER REGION
485	EASTERN MISSOURI
486	NEW MADRID, MISSOURI REGION
487	CAPE GIRARDEAU, MISSOURI REGION
488	SOUTHERN ILLINOIS
489	SOUTHERN INDIANA
490	KENTUCKY
491	WEST VIRGINIA
492	VIRGINIA
493	CHESAPEAKE BAY REGION
494	NEW JERSEY
495	EASTERN ARIZONA
496	NEW MEXICO
497	TEXAS PANHANDLE REGION
498	WEST TEXAS
499	OKLAHOMA
500	CENTRAL TEXAS
501	ARKANSAS-OKLAHOMA BORDER REGION
502	ARKANSAS
503	LOUISIANA-TEXAS BORDER REGION
504	LOUISIANA
505	MISSISSIPPI
506	TENNESSEE
507	ALABAMA
508	WESTERN FLORIDA
509	GEORGIA
510	FLORIDA-GEORGIA BORDER REGION
511	SOUTH CAROLINA
512	NORTH CAROLINA
513	OFF EAST COAST OF UNITED STATES
514	FLORIDA PENINSULA
515	BAHAMA ISLANDS
516	E. ARIZ. - MEXICO BORDER REGION
517	MEXICO-NEW MEXICO BORDER REGION
518	TEXAS-MEXICO BORDER REGION
519	SOUTHERN TEXAS
520	TEXAS GULF COAST
521	CHIHUAHUA, MEXICO
522	NORTHERN MEXICO
523	CENTRAL MEXICO
524	JALISCO, MEXICO
525	VERA CRUZ, MEXICO
526	GULF OF MEXICO
527	GULF OF CAMPECHE
528	BRAZIL
529	GUYANA
530	SURINAM
531	FRENCH GUIANA
532	EIRE
533	UNITED KINGDOM
534	NORTH SEA
535	SOUTHERN NORWAY
536	SWEDEN
537	BALTIC SEA
538	FRANCE
539	BAY OF BISCAY
540	NETHERLANDS
541	BELGIUM
542	DENMARK
543	GERMANY
544	SWITZERLAND
545	NORTHERN ITALY
546	AUSTRIA
547	CZECHOSLOVAKIA
548	POLAND
549	HUNGARY
550	NORTHWEST AFRICA
551	SOUTHERN ALGERIA
552	LIBYA
553	UNITED ARAB REPUBLIC
554	RED SEA
555	WESTERN ARABIAN PENINSULA
556	CENTRAL AFRICA
557	SUDAN
558	ETHIOPIA
559	WESTERN GULF OF ADEN
560	NORTHWESTERN SOMALIA
561	OFF S. COAST OF NORTHWEST AFRICA
562	CAMEROON
563	RIO MUNI
564	CENTRAL AFRICAN REPUBLIC
565	GABON
566	CONGO
567	REPUBLIC OF THE CONGO
568	UGANDA
569	LAKE VICTORIA REGION
570	KENYA
571	SOUTHERN SOMALIA
572	LAKE TANGANYIKA REGION
573	TANZANIA
574	NORTHWEST OF MALAGASAY REPUBLIC
575	ANGOLA
576	ZAMBIA
577	MALAWI
578	SOUTHWEST AFRICA
579	BOTSWANA REPUBLIC
580	RHODESIA
581	MOZAMBIQUE
582	MOZAMBIQUE CHANNEL
583	MALAGASAY REPUBLIC
584	REPUBLIC OF SOUTH AFRICA
585	LESOTHO
586	SWAZILAND
587	OFF COAST OF SOUTH AFRICA
588	NORTHWEST OF AUSTRALIA
589	WEST OF AUSTRALIA
590	WESTERN AUSTRALIA
591	NORTHERN TERRITORY, AUSTRALIA
592	SOUTH AUSTRALIA
593	GULF OF CARPENTERIA
594	QUEENSLAND, AUSTRALIA
595	CORAL SEA
596	SOUTH OF SOLOMON ISLANDS
597	NEW CALEDONIA REGION
598	SOUTHWEST OF AUSTRALIA
599	OFF SOUTH COAST OF AUSTRALIA
600	NEAR SOUTH COAST OF AUSTRALIA
601	NEW SOUTH WALES, AUSTRALIA
602	VICTORIA, AUSTRALIA
603	NEAR S.E. COAST OF AUSTRALIA
604	NEAR EAST COAST OF AUSTRALIA

605 EAST OF AUSTRALIA
606 NORFOLK ISLAND REGION
607 NORTHWEST OF NEW ZEALAND
608 BASS STRAIT
609 TASMANIA REGION
610 SOUTHEAST OF AUSTRALIA
611 NORTH PACIFIC OCEAN
612 HAWAII REGION
613 HAWAII
614 CAROLINE ISLANDS REGION
615 MARSHALL ISLANDS REGION
616 ENIWETOK ATOLL REGION
617 BIKINI ATOLL REGION
618 GILBERT ISLANDS REGION
619 JOHNSON ISLAND REGION
620 LINE ISLANDS REGION
621 PALMYRA ISLAND REGION
622 CHRISTMAS ISLAND REGION
623 ELLICE ISLANDS REGION
624 PHOENIX ISLANDS REGION
625 TEKELAU ISLANDS REGION
626 NORTHERN COOK ISLANDS
627 COOK ISLANDS REGION
628 SOCIETY ISLANDS REGION
629 TUBUAI ISLANDS REGION
630 MARQUESAS ISLANDS REGION
631 TUAMOTU ARCHIPELAGO REGION
632 SOUTH PACIFIC OCEAN
633 LOMONOSOV RIDGE
634 ARCTIC OCEAN
635 NEAR NORTH COAST OF GREENLAND
636 EASTERN GREENLAND
637 ICELAND REGION
638 ICELAND
639 JAN MAYEN ISLAND REGION
640 GREENLAND SEA
641 NORTH OF SVALBARD
642 NORWEGIAN SEA
643 SVALBARD REGION
644 NORTH OF FRANZ JOSEF LAND
645 FRANZ JOSEF LAND
646 NORTHERN NORWAY
647 BARENTS SEA
648 NOVAYA ZEMLYA
649 KARA SEA
650 NEAR COAST OF WESTERN SIBERIA
651 NORTH OF SEVERNAYA ZEMLYA
652 SEVERNAYA ZEMLYA
653 NEAR COAST OF CENTRAL SIBERIA
654 EAST OF SEVERNAYA ZEMLYA
655 LAPTEV SEA
656 EASTERN RUSSIA
657 E. RUSSIA-N.E. CHINA BORDER REG.
658 NORTHEASTERN CHINA
659 NORTH KOREA
660 SEA OF JAPAN
661 NEAR E. COAST OF EASTERN RUSSIA
662 SAKHALIN ISLAND
663 SEA OF OKHOTSK
664 EASTERN CHINA
665 YELLOW SEA
666 OFF COAST OF EASTERN CHINA
667 NORTH OF NEW SIBERIAN ISLANDS
668 NEW SIBERIAN ISLANDS
669 EAST SIBERIAN SEA
670 NEAR N. COAST OF EASTERN SIBERIA
671 EASTERN SIBERIA
672 CHUKCHI SEA
673 BERING STRAIT
674 ST. LAWRENCE ISLAND REGION
675 BEAUFORT SEA
676 ALASKA
677 NORTHERN YUKON TERRITORY, CANADA
678 QUEEN ELIZABETH ISLANDS
679 NORTHWEST TERRITORIES, CANADA
680 WESTERN GREENLAND
681 BAFFIN BAY
682 BAFFIN ISLAND REGION
683 SOUTHEAST CENTRAL PACIFIC OCEAN
684 EASTER ISLAND CORDILLERA
685 EASTER ISLAND REGION
686 WEST CHILE RISE
687 JUAN FERNANDEZ ISLANDS REGION
688 EAST OF NORTH ISLAND, N.Z.
689 CHATHAM ISLANDS REGION
690 SOUTH OF CHATHAM ISLANDS
691 SOUTH PACIFIC CORDILLERA
692 SOUTHERN PACIFIC OCEAN
693 EAST CENTRAL PACIFIC OCEAN
694 NORTHERN EASTER I. CORDILLERA
695 WEST OF GALAPAGOS ISLANDS
696 GALAPAGOS ISLANDS REGION
697 GALAPAGOS ISLANDS
698 SOUTHWEST OF GALAPAGOS ISLANDS
699 SOUTHEAST OF GALAPAGOS ISLANDS
700 SOUTH OF TASMANIA
701 WEST OF MACQUARIE ISLAND
702 BALLENY ISLANDS REGION
703 ANDAMAN ISLANDS REGION
704 NICOBAR ISLANDS REGION
705 OFF W. COAST OF NORTHERN SUMATRA
706 NORTHERN SUMATRA
707 MALAY PENINSULA
708 GULF OF SIAM
709 AFGHANISTAN
710 WEST PAKISTAN
711 SOUTHWESTERN KASHMIR
712 INDIA-WEST PAKISTAN BORDER REG.
713 CENTRAL KAZAKH SSR
714 SOUTHEASTERN UZBEK SSR
715 TADZHIK SSR
716 KIRGIZ SSR
717 AFGHANISTAN-USSR BORDER REGION
718 HINDU KUSH REGION
719 TADZHIK-SINKIANG BORDER REGION
720 NORTHWESTERN KASHMIR
721 FINLAND
722 NORWAY-USSR BORDER REGION
723 FINLAND-USSR BORDER REGION
724 WESTERN RUSSIA
725 WESTERN SIBERIA
726 CENTRAL SIBERIA
727 VICTORIA LAND, ANTARCTICA
728 ROSS SEA
729 ANTARCTICA

APPENDIX 3

CODES OF DATA SOURCES

ADK Adak, AK, USA
AEC U.S. Atomic Energy Commission
AGS Alaska Seismic Studies, USGS-NCER, Menlo Park, CA, USA
ALG Algiers, Algeria
ALI Alicante, Spain
ALM Almeria, Spain
ALQ Albuquerque, NM, USA
APA Apatity, RSFSR, USSR
API Apia, Samoa Is.
ATH Athens Observatory, Greece
BCI Bureau Central International de Séismologie, Strasbourg, France
BLA Blacksburg, VA, USA
BNS Bensberg, Federal Republic of Germany
BOG Bogota, Colombia
BRA Bratislava, Czechoslovakia
BRK Berkeley (Haviland), CA, USA
BSS *Bulletin of the Seismological Society of America*
BUC Bucharest, Romania
BUL Bulawayo, Rhodesia
CAN Canberra, Australian Capital Territory, Australia
CAR Caracas, Venezuela
CFR Charles F. Richter (see Richter, 1958, in References)
CGS Coast and Geodetic Survey
CHC Chapel Hill, NC, USA
CLL Collmberg, German Democratic Republic
DJA Djakarta, Java, Indonesia
EQH *Earthquake History of the United States* (see References)
ERL Environmental Research Laboratories
GIA Geophysical Institute University of Alaska, Fairbanks, AK, USA
G-R Gutenberg-Richter (see Gutenberg and Richter, 1954, in References)
GOL Golden (Bergen Park), CO, USA
GS U.S. Geological Survey, Denver, CO, USA
HEL Helsinki, Finland
HRB Hurbanovo, Czechoslovakia
HVO Hawaiian Volcano Obsy., Hawaii National Park, HI, USA
ISK Istanbul-Kandilli, Turkey
ISS International Seismological Summary, Kew, England, UK
IST Istanbul, Turkey
JER Jerusalem, Israel
JMA Japan Meteorological Agency, Tokyo, Japan
JOH Johannesburg, South Africa
KAR Karachi, Pakistan
KEW Kew, England, UK
KIR Kiruna, Sweden
LEM Lembang, Java, Indonesia
LIS Lisbon, Portugal
LJU Ljubljana, Yugoslavia
LWI Lwiro, Zaire
MAL Malaga, Spain
MAN Manila, Philippines
MAT Matsushiro, Honshu, Japan
MER Merida, Mexico
MOS Moscow, RSFSR, USSR
MOX Moxa, German Democratic Republic
NCE National Center for Earthquake Research (NCER), Menlo Park, CA, USA
NES Northeastern Seismological Association, Weston, MA, USA
NOS National Ocean Survey
NOU Noumea, New Caledonia
NRR North Reno, NV, USA
OAX Oaxaca, Mexico
OBM Ulan Bator, Mongolia
OTT Ottawa, Ontario, Canada
OXF Oxford, MS, USA
PAL Palisades, NY, USA
PAS Pasadena, CA, USA
PDE *Preliminary Determination of Epicenters*
PEK Peking, China
PET Petropavlovsk, RSFSR, USSR
PMG Port Moresby, Papua

APPENDIX 3 (Cont.)

PMR	Palmer, AK, USA
PRA	Praha (Prague), Czechoslovakia
PRU	Pruhonice, Czechoslovakia
QUE	Quetta, Pakistan
RAC	Raciborz, Poland
REY	Reykjavik, Iceland
RIV	Riverview, New South Wales, Australia
RMP	Rome (Monte Porzio Catone), Italy
ROM	Rome, Italy
SAN	Santiago, Chile
SEA	Seattle, WA, USA
SHI	Shiraz, Iran
SHL	Shillong, India
SLM	St. Louis, MO, USA
SNM	Socorro, NM, USA
SSS	San Salvador, El Salvador
STR	Strasbourg, France
STU	Stuttgart, Federal Republic of Germany
SYK	Sykes (see References)
TAC	Tacubaya, Mexico
TEH	Teheran, Iran
TOC	Tocklai, India
TRI	Trieste, Italy
TRN	Trinidad, Trinidad, W.I.
TUL	Tulsa, OK, USA
UCC	Uccle, Belgium
UGL	Uglegorsk, RSFSR, USSR
UPP	Uppsala, Sweden
USE	*United States Earthquakes*
VIC	Victoria, British Columbia, Canada
WAR	Warsaw, Poland
WEL	Wellington, New Zealand
YSS	Yuzhno-Sakhalinsk, RSFSR, USSR
ZUR	Zurich, Switzerland

APPENDIX 4

TAPE FORMAT

Tape Position	*Field*	*Comments*
1-3	10° Marsden Square number	See appendix 7.
4-5	1° Marsden Square number	Do.
6-8	Data source (see appendix 3)	Publication from which all or most of the data were obtained.
9	Blank	
10-11	First two digits of year	Examples "16', "17", "18", or "19"; combine with positions 16-17.
12-17	Date (UT/GMT)	Positions 12-13 day, 14-15 month, and 16-17 year.
18-24	Origin time (UT/GMT)	Computed, or observed if controlled explosion with shot timed. Positions 18-19 hour, 20-21 minute, and 22-24 second. Implied decimal between positions 23 and 24.
25-30	Geographic latitude (decimal degrees)	Usually given to three decimal places, although this degree of accuracy is not necessarily applicable. N/S in position 30. Implied decimal between positions 26 and 27.
31-37	Geographic longitude (decimal degrees)	Usually given to three decimal places. E/W in position 37. Implied decimal between positions 33 and 34.
38-40	Focal depth (km)	See also position 73.
41-43	Body-wave (MB) average	Implied decimal between positions 41 and 42. Value as determined by PDE program.
44-45	"MB"	
46-48	Isoseismal map	Three-letter abbreviation indicating the publication of an isoseismal (intensity) map. USE, *United States Earthquakes;* EQN, *Earthquake Notes;* PDE, *Preliminary Determination of Epicenters;* WEL, Wellington, N.Z.; NTR, *Nature* magazine.

Tape Position	*Field*	*Comments*
49	Intensity	Maximum Modified Mercalli Scale or converted to MM Scale. 1-9 = I-IX, X = X, E = XI, T = XII. See appendix 1.
	<u>Associated Phenomena</u>	
50	Diastrophism code	F = Surface faulting U = Uplift/subsidence D = Faulting and uplift/subsidence.
51	Tsunami code	T = Tsunami generated Q = Possible tsunami.
52	Seiche code	S = Seiche Q = Possible seiche.
53	Volcanism code	V = Earthquake associated with volcanism.
54	Nontectonic code	R = Rockburst C = Coal bump or rockburst in coal mine M = Meteoritic source E = Explosion, accidental, controlled or suspected explosion I = Collapse L = Lights or other such visual phenomena seen.
55	Waves generated code	T = T-wave A = Acoustic wave G = Gravity wave B = Both A & G.
56-58	Flinn-Engdahl geographic region number	As described by Flinn et al. (1974). See Bibliography and appendix 2.
59-60	Surface-wave (MS) average value	Implied decimal between positions 59 and 60. Value determined by PDE program. (IASPEI formula used).
61-62	"MS"	
63	Component Z or H (not used at present)	

Tape Position	*Field*	*Comments*
64	Cultural effects	C, D, F, or H in position 64 indicates reported Casualties, Damage or Felt information, or earthquake Heard. The notations listed here provide a brief summary of the earthquake effects on population and buildings. Casualty, damage, or felt reports associated with a particular earthquake do not imply that the effects were noted at the epicentral position. Especially with offshore earthquakes, the maximum intensity may be reported at some distance from the source of the shock. An "F" in this position, with no accompanying intensity (position 49) is likely associated with an intensity of I-III on the Modified Mercalli Scale.
65	Blank	
66-68	Other magnitude	Value obtained from various sources; unspecified magnitude type but generally MS (implied decimal between positions 66 and 67). Fractions have been converted to decimal numbers: $6\frac{1}{4}$ = 6.25. For ranges, median values are listed: $6\frac{1}{2}$ - $6\frac{3}{4}$ = 6.63.
69-71	Authority for magnitude in positions 66-68	See source codes in appendix 3.
72	Special event designator	X = International Data Exchange (IDE) earthquake.
73	Depth control designator	A = Assigned D = Restrained depth based on 2 or more reported *pP*'s identified as such G = Depth restrained by geophysicist

Tape Position	*Field*	*Comments*
73 (cont.)	Depth control designator (cont.)	N = Held at 33 km (normal depth), when data not sensitive to depth for a shallow focus. S = Depth control aided by use of *S*-phase data.
74-76	Quality/number of stations	Number of *P* and/or *P'* arrivals used in hypocenter solution. Also quality indicators described below.

Quality Indicators

Source	Style	Probable Limits of Error		
G-R (Gutenberg-Richter)	3-letter combination	Epicenter deg.	Origin time sec.	Depth km.
	A-Very accurate	1	5	30
	B-Good	2	8	50
	C-Fair	3	12	80
	D-Poor	-	-	-
MOS (Moscow)	2-letter or letter/symbol combination in positions 74 and 76	A-Best accuracy (epicenter/depth) B- N- V- *-Lowest accuracy.		
PAS (Pasadena)	Single-letter designator in position 74	A-Specially investigated B-Epicenter probably within 5 km, origin time to nearest second C-Epicenter probably within 15 km, origin time to a few seconds D-Epicenter not known within 15 km, rough location.		
BRK (Berkeley), WEL (Wellington, N.Z.)	Single-letter designator in position 75	A-Best accuracy (epicenter) B- C- D-Lowest accuracy.		

Tape Position	*Field*	*Comments*
77	Authority for time and coordinates/other quality indicators	blank = Authority same as source (positions 6-8).
		* = Assigned tc solutions for which poor azimuth, depth control, and other factors contribute to a less reliable solution.
		A = Parameters of explosion supplied by U.S. Atomic Energy Commission (AEC)/Energy Research and Development Administration (ERDA).
		B = Parameters of epicenter supplied by University of California, Berkeley.
		C = Parameters of epicenter supplied by Commission de Energie Atomique, Paris, France.
		E = Some or all parameters of explosion (controlled or accidental) supplied by any group or individual other than AEC/ERDA.
		G = Parameters of epicenter supplied by the U.S. Geological Survey for any area other than Island of Hawaii.
		H = Parameters of epicenter supplied by the USGS Hawaiian Volcano Observatory.
		J = Parameters of epicenter supplied by St. Louis University.
		L = Parameters of epicenter supplied by Lamont-Doherty Geological Observatory, Palisades, NY.
		M = Hypocenter based on macroseismic information.
		P = Parameters of epicenter supplied by California Institute of Technology, Pasadena.
		R = Parameters of epicenter supplied by University of Nevada, Reno.
		S = An NEIS solution based on use of dense local networks, a local crustal model, or other methods not routinely applied by NEIS (USGS).

Tape Position	*Field*	*Comments*
77 (cont.)	Authority for time and coordinates/other quality indicators (cont.)	U = Parameters of epicenter supplied by University of Utah, Salt Lake City. V = Parameters of epicenter supplied by Virginia Polytechnic Institute and State Univ., Blacksburg. W = Parameters of epicenter supplied by University of Washington, Seattle. X = No time reported. Z = Noninstrumental.
78-80	Local magnitude	Implied decimal between positions 78 and 79.
81-82	Scale for positions 78-80	Generally ML.
83-85	Authority for value 78-80	See source codes in appendix 3.
86-90	Blank	

Blocking Factor: 50 records (90 characters each) per tape block. A sample list of a block (50 records) of a geographically sorted tape follows:

Appendix 4 (Cont.)

15786CGS	19280570173832148450N126659W003490MB		025		057	1
15786CGS	19130869161216948483N126474W033460MB		025		N024	2
15786CGS	19011069171111348506N126485W023470MB		025		031	3
15787GS	19281074093839448174N127684W033420MB		025		N 10*	4
15787ISS	19220951101657048000N127000W		025			5
15787CGS	19141066180218048900N127000W033410MB		025		008	6
15788GS	19220874130134548937N128603W033440MB		025		N 13*	7
15788PDE	19220753101739048500N128000W		025			8
15788PDE	19220753103720048500N128000W		025			9
15788BCI	19290658190518048500N128000W		025		*	10
15788ERL	19250373155321148952N128927W033420MB		025		N011*	11
15788ERL	19301271074509948946N128812W033420MB		025		N010*	12
15788G-R	19011126013918048750N128500W		025	660PAS		13
15788CGS	19050454193457048000N128000W		025			14
15788CGS	19130457034400048500N128000W		025			15
15788CGS	19160463165411848100N128600W033		025		006	16
15788CGS	19140664014652448800N128400W033		025		008	17
15788CGS	19020965113749948300N128100W033460MB		025		009	18
15788CGS	19020965140237348400N128200W033430MB		025		013	19
15788CGS	19020965154225648300N128400W033440MB		025		012	20
15788CGS	19020965154339648200N128500W033470MB		025		011	21
15788CGS	19020965180119548300N128300W033440MB		025		013	22
15788CGS	19020965194125648400N128300W033490MB		025		011	23
15788CGS	19020965211643748400N128200W033400MB		025		010	24
15788CGS	19020965212716648400N128200W026500MB		025		014	25
15788CGS	19030965044236148400N128200W012460MB		025		012	26
15788CGS	19111162214520548900N128800W033		025		021	27
15788CGS	19171168211134748979N128882W010440MB		025		031	28
15788CGS	19221168115925848968N128729W044400MB		025		011*	29
15789ERL	19201171212442648755N129520W033550MB		02557MS		N104	30
15789ERL	19251171234012148777N129377W033510MB		025		N042	31
15789G-R	19310530102153048500N129000W		025	540PAS		32
15789G-R	19301026194155048500N129000W		025	610PAS		33
15789CGS	19050454192600048000N129000W		025			34
15789CGS	19280656225850048750N129250W		025	637PAS		35
15795OTT	19230646171319049900N125300W	USE8	.025	D 730PAS		36
15796GS	19200774191559049916N126521W033400MB		025		N 12*430MLNEW	37
15796G-R	19061218084105049750N126500W	5	025	F 700PAS		38
15797GS	19130773025930149115N127840W033480MB		025		N011*	39
15797BCI	19251254013137049250N127000W		025			40
15797ERL	19050772101638449545N127213W027580MB		02557MS	F 550BRK	067	41
15797NOS	19100371153828749320N127391W033500MB		025		N040	42
15797CGS	19300349202828049000N127500W		025			43
15797CGS	19090464004653249100N127500W033410MB		025		008	44
15797CGS	19310565032042049300N127800W011470MB		025		020	45
15797CGS	19291061140012049400N127600W056		025			46
15797CGS	19091267183149749200N127700W033400MB		025		016	47
15798GS	19300574005956049063N128386W033480MB		02542MS		N 17	48
15798GS	19130773025939149027N128008W033530MB		02551MS		N072	49
15798GS	19170874213612649113N128403W033470MB		025		N 17	50

10445

10445

APPENDIX 5

PUNCHED CARD FORMAT

Card column	*Field**
1-3	Data source (appendix 3)
4	Blank
5-6	First two digits of year
7-12	Date (UT/GMT)
13-19	Origin time (UT/GMT)
20-25	Geographic latitude
26-32	Geographic longitude
33-35	Focal depth (km)
36-38	Body-wave (MB) average value
39-40	"MB"
41-43	Isoseismal map
44	Intensity (appendix 1)
45	Diastrophism code
46	Tsunami code
47	Seiche code
48	Volcanism code
49	Nontectonic code
50	Waves generated code
51-53	Flinn-Engdahl geographic region number (appendix 2)
54-55	Surface-wave (MS) average value
56-57	"MS"
58	Component Z or H (not used at present)

*Refer to Tape Format (appendix 4) for description of Field and Codes.

Column	*Field*
59	Cultural effects
60	Blank
61-63	Other magnitude
64-66	Authority
67	Special event designator
68	Depth control designator
69-71	Number of *P* and/or *P'* arrivals used in hypocenter solution or quality indicator(s)
72	Authority/quality indicators
73-75	Local magnitude
76-77	Scale
78-80	Authority

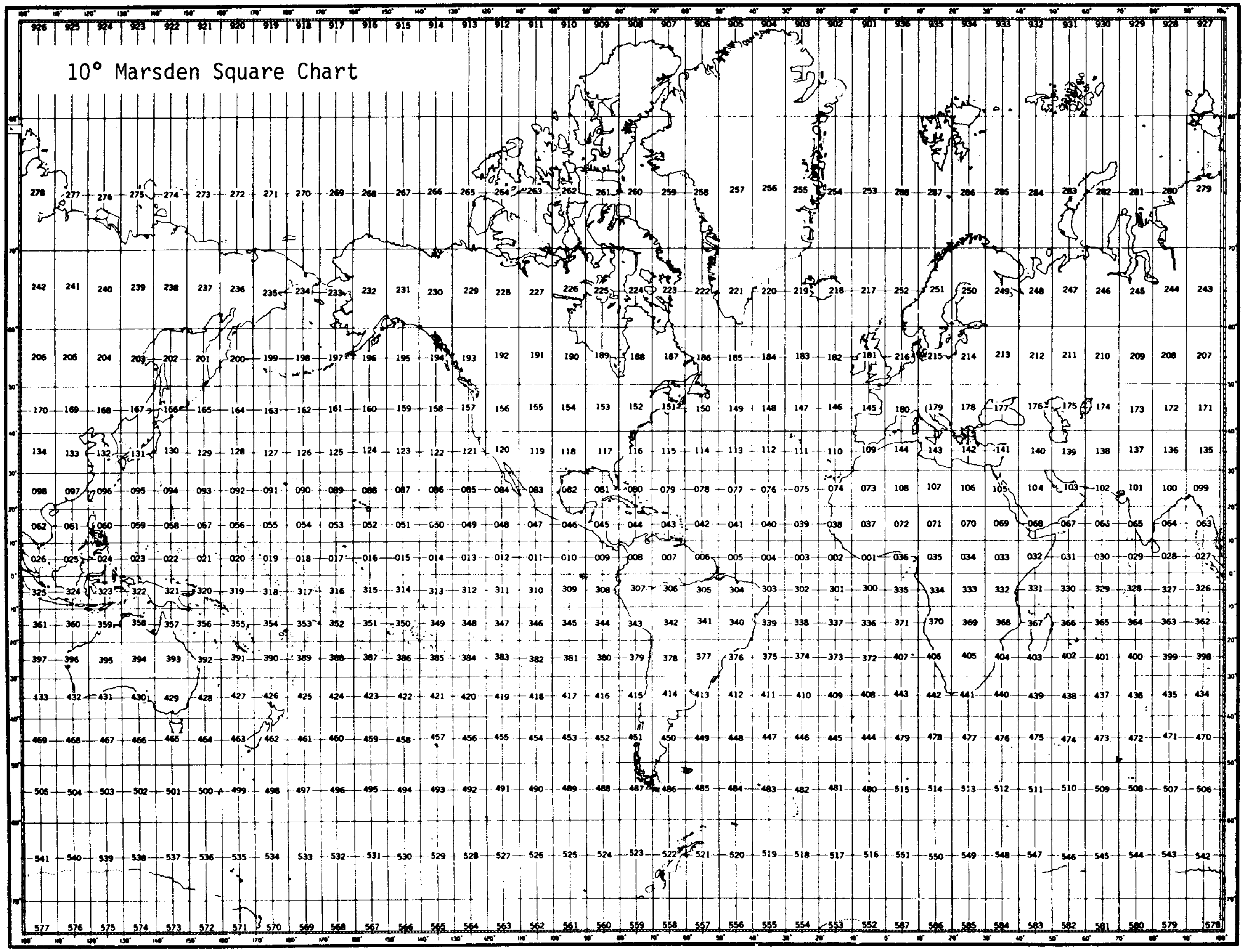
APPENDIX 6

PRINTOUT FORMAT

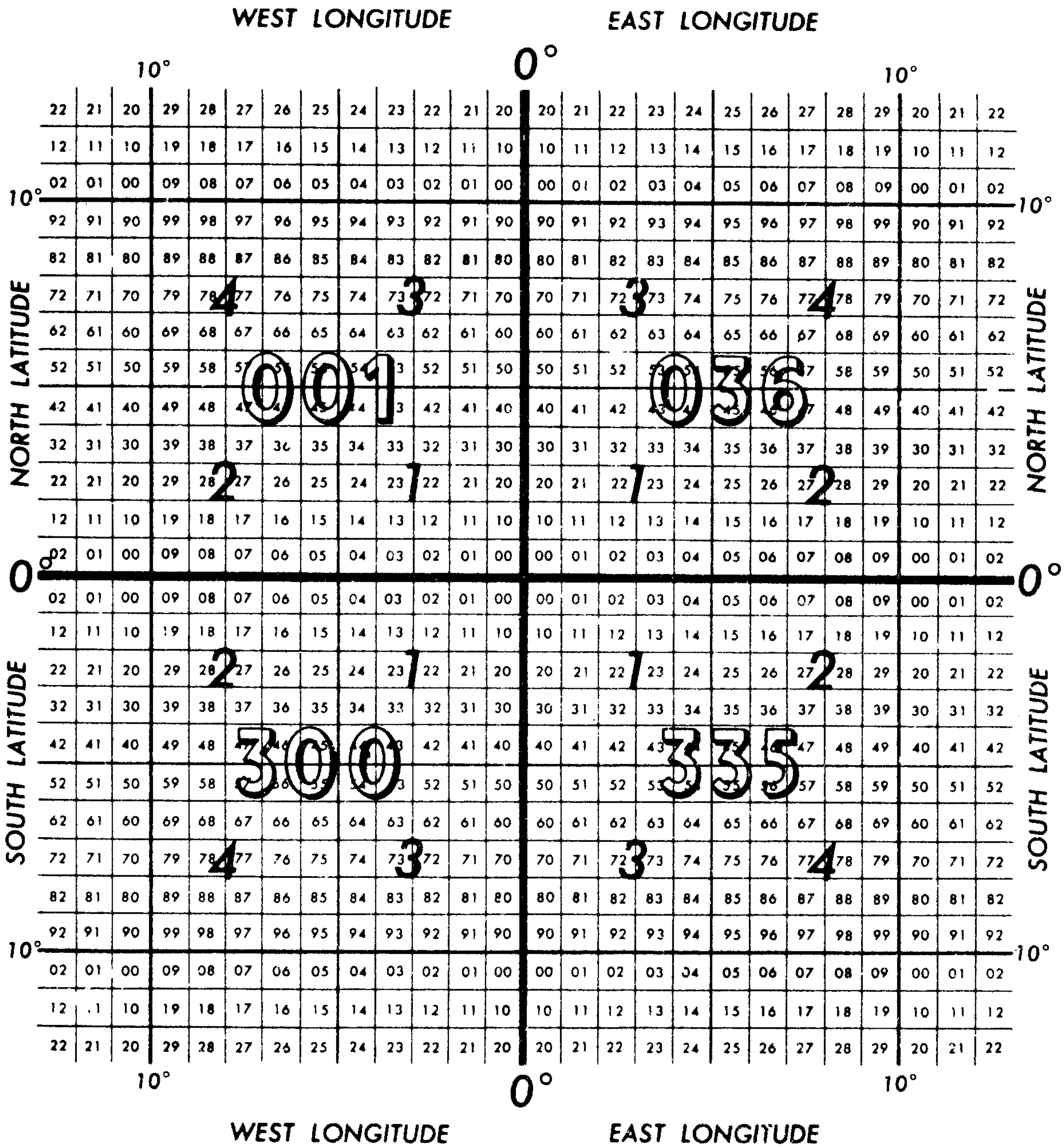
Field	*Description**
SOURCE	Data source (appendix 3).
YEAR, MO, DA	Date (UT/GMT).
HR, MN, SEC	Origin time (UT/GMT). Letter or symbol following time is quality and code for time and coordinates (all position 77 of tape format).
LAT, LONG	Geographic latitude and longitude.
DEPTH	A, G, D, or N following value designates depth control factor.
MAGNITUDES	Body- and surface- (SURF.) wave values as determined by PDE programs. Authority for other magnitudes and local magnitudes according to "Source Codes" (appendix 3).
INT MAP	Intensity (isoseismal) map published.
INT MAX	Maximum intensity (appendix 1).
PHENOM DTSVNO	Associated phenomena: Diastrophism, Tsunami, Seiche, Volcanism, Nontectonic, and Waves Generated.
RN	Flinn-Engdahl geographic region number (appendix 2).
CE	Cultural effects.
Q/S	Quality/number of stations.
MAR DG	Marsden (10°) square and 1° subsquare number (appendix 7).
DIST	On radius searches, the distance in km between the earthquake location and the designated point.

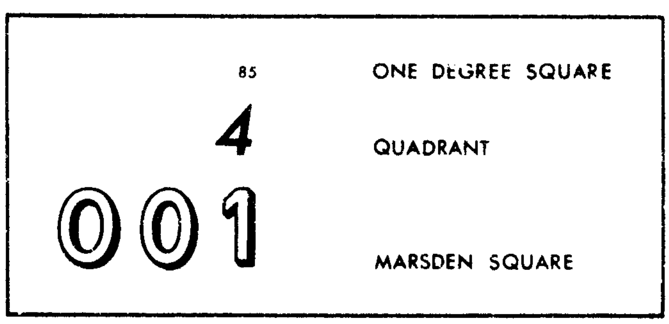
*See Tape Format (appendix 4) for explanation of codes.

APPENDIX 7. MARSDEN SQUARE CHARTS



1° MARSDEN SQUARE CHART





QUARTERLY REPORT

Contract no. 03-6-022-35126
Research unit no. 407
Reporting period: 1 Jan. -
31 March 1976.
Number of pages:________

A STUDY OF BEAUFORT SEA COASTAL EROSION

NORTHERN ALASKA

Robert Lewellen
P.O. Box 1068
Littleton, Colorado 80120

31 March 1976

I. TASK OBJECTIVES.

Search, evaluate, and synthesize existing literature and data on erosional and depositional rates and patterns of sediments along the Alaskan sea coasts. Compile maps of erosional and depositional rates and patterns.

Evaluate present rates of change in coastal morphology, with particular emphasis on rates and patterns of man-induced changes. Locate areas where coastal morphology is likely to be changed by man's activities and evaluate the effect of these changes, if any. The relative susceptibility of different coastal areas will be evaluated.

II. FIELD OR LABORATORY ACTIVITIES.

A. Ship or Field Trip Schedule.

1. Dates, name of vessel, aircraft, NOAA or chartered, (none required for this project).

B. Scientific Party.

1. Names, affiliation, role, (not applicable).

C. Methods.

1. Field sampling or laboratory analysis. Methods include the use of published and unpublished materials documents, and data, sequential aerial photography and standard air photo mensurational techniques.

D. Sample localities/ship or aircraft tracklines. The temporal sampling scheme is a function of when sequential aerial photography or ground measurements exist. This coverage is adequate.

E. Data collected or analyzed.

1. Number and types of samples/observations. Numerous observations are currently being processed, but will not be available until the next quarterly report.

2. Number and types of analyses. (all are aerial photography measurements except for a few ground measurements).

3. Miles of trackline. (not applicable to this project).

III. RESULTS.

No results are available for this report.

IV. PRELIMINARY INTERPRETATION OF RESULTS. The coastline is definitely eroding in permafrost terrain; and in other cases permafrost is rapidly aggrading in areas of recent deposition.

V. PROBLEMS ENCOUNTERED/RECOMMENDED CHANGES. (none).

VI. ESTIMATE OF FUNDS EXPENDED. (approximately $8900).

1. Adequate information exists on the coastal erosion of Northern Alaska. The information has not been compiled in final form or published completely. The information exists principally on the sequential aerial photography which has been taken by various agencies and individuals since 1945. Additional information exists in a few selected publications.

2. Periodically, along the coast from Point Barrow to Demarcation Point, where sequential coverage permits, changes will be measured from the aerial photography.

3. This project involves a lot of time interpreting the photography, and differs from the other projects in that it is merely a laboratory study. There are no logistical or equipment requirements, and nothing required for the data on sample exchange interfaces or sample archival requirements.

4. The project was finally approved 1 October 1975 with the receipt of the signed contract dated 26 September 1975 from the U. S. Government.

5. From 1 October to 1 January 1976, 406 man-hours were spent on the project. This effort consisted of extracting old maps, field notes and photographs from the files, determining which of the data to utilize, and ordering it geographically and by time. The satellite photography does not have the required resolution. The imagery being obtained by the U. S. Geological Survey team at Barrow has not been examined as of the date of this report.

COAST AND GEODETIC SURVEY HYDROGRAPHIC CHARTS:

9464
9465
9466
9467
9468
9469
9470
9471
9472
9473
9474
9475
9476
9477
9478

U.S. GEOLOGICAL SURVEY TOPOGRAPHIC SERIES (1/250,000).

Barrow
Meade River
Teshekpuk
Harrison Bay
Beechey Point
Flaxman Island
Mt. Michelson
Barter Island
Demarcation Point

Note: All of these 1/250,000 quadrangles are now available on the 1/63,360 scale topographic maps. There are about 48 of these maps which cover the shoreline from Point Barrow to Demarcation Point.

6. To date, 204 observations or measurements have been made off of the aerial photography. The mean thaw-season shoreline erosion rate has been determined as 2.03 meters for the 204 observations. The standard deviation is 1.63 meters. The rates range from stable or zero to 10.4 meters per thaw season. Spits, shoals, barriers, bars, etc. are being formed in many areas.

7. Lewellen is currently working out on the ice off Prudhoe Bay.

QUARTERLY REPORT

Contract no. 03-6-022-35126
Research unit no. 407
Reporting period: 1 Oct. - 31 Dec. 1975.
Number of pages: 4

A STUDY OF BEAUFORT SEA COASTAL EROSION NORTHERN ALASKA

Robert Lewellen
P.O. Box 1068
Littleton, Colorado 80120

1 January 1976

I. TASK OBJECTIVES.

Search, evaluate, and synthesize existing literature and data on erosional and depositional rates and patterns of sediments along the Alaskan sea coasts. Compile maps of erosional and depositional rates and patterns.

Evaluate present rates of change in coastal morphology, with particular emphasis on rates and patterns of man-induced changes. Locate areas where coastal morphology is likely to be changed by man's activities and evaluate the effect of these changes, if any. The relative susceptibility of different coastal areas will be evaluated.

II. FIELD OR LABORATORY ACTIVITIES.

A. Ship or Field Trip Schedule.

1. Dates, name of vessel, aircraft, NOAA or chartered, (none required for this project).

B. Scientific Party.

1. Names, affiliation, role, (not applicable).

C. Methods.

1. Field sampling or laboratory analysis. Methods include the use of published and unpublished materials documents, and data, sequential aerial photography and standard air photo mensurational techniques.

D. Sample localities/ship or aircraft tracklines. The temporal sampling scheme is a function of when sequential aerial photography or ground measurements exist. This coverage is adequate.

E. Data collected or analyzed.

1. Number and types of samples/observations. Numerous observations are currently being processed, but will not be available until the next quarterly report.

2. Number and types of analyses. (all are aerial photography measurements except for a few ground measurements).

3. Miles of trackline. (not applicable to this project).

III. <u>RESULTS</u>.

No results are available for this report.

IV. <u>PRELIMINARY INTERPRETATION OF RESULTS</u>. The coastline is definitely eroding in permafrost terrain; and in other cases permafrost is rapidly aggrading in areas of recent deposition.

V. <u>PROBLEMS ENCOUNTERED/RECOMMENDED CHANGES</u>. (none).

VI. <u>ESTIMATE OF FUNDS EXPENDED</u>. (approximately $5000).

1. Adequate information exists on the coastal erosion of Northern Alaska. The information has not been compiled in final form or published completely. The information exists principally on the sequential aerial photography which has been taken by various agencies and individuals since 1945. Additional information exists in a few selected publications.

2. Periodically, along the coast from Point Barrow to Demarcation Point, where sequential coverage permits, changes will be measured from the aerial photography.

3. This project involves a lot of time interpreting the photography, and differs from the other projects in that it is merely a laboratory study. There are no logistical or equipment requirements, and nothing required for the data on sample exchange interfaces or sample archival requirements.

4. The project was finally approved 1 October 1975 with the receipt of the signed contract dated 26 September 1975 from the U. S. Government.

5. From 1 October to 1 January 1976, 406 man-hours were spent on the project. This effort consisted of extracting old maps, field notes and photographs from the files, determining which of the data to utilize, and ordering it geographically and by time. The satellite photography does not have the required resolution. The imagery being obtained by the U. S. Geological Survey team at Barrow has not been examined as of the date of this report.

COAST AND GEODETIC SURVEY HYDROGRAPHIC CHARTS:

9464
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9466
9467
9468
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U.S. GEOLOGICAL SURVEY TOPOGRAPHIC SERIES (1/250,000).

Barrow
Meade River
Teshekpuk
Harrison Bay
Beechey Point
Flaxman Island
Mt. Michelson
Barter Island
Demarcation Point

Note: All of these 1/250,000 quadrangles are now available on the 1/63,360 scale topographic maps. There are about 48 of these maps which cover the shoreline from Point Barrow to Demarcation Point.

★U.S. Government Printing Office: 1976-679-581/463 Region 8