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UNITED STATES
DEPARTMENT OF THE INTERIOR
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REFRACTION STUDIES BETWEEN ICY BAY AND KAYAK ISLAND EASTERN GULF OF ALASKA

OPEN-FILE REPORT 77-550

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

Menlo Park, California
July 1977

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ABSTRACT

Results of five seismic refraction lines shot by the U.S. Geological Survey in the Gulf of Alaska between Icy Bay and Kayak Island indicate the following: 1) The continental shelf is underlain by as much as 11 km of sedimentary rock of probable Tertiary age with refraction velocities ranging from 1.2 - 5.5 km/sec; 2) a section approximately 5 km thick with velocities of 4.1 - 5.5 km/sec that could represent the early Tertiary Orca Group is present in the western part of the study area but not in the eastern part; and 3) consistent basement velocities of approximately 7.0 km/sec could indicate oceanic crust underlying the continental margin.

INTRODUCTION

This report describes five seismic refraction lines acquired during the 1974 U. S. Geological Survey cruise aboard the University of Washington research vessel THOMAS G. THOMPSON in the eastern Gulf of Alaska between Icy Bay and Kayak Island (Fig. 1). The length of the refraction line totals approximately 500 km (including reversals). The primary purpose of the cruise was to delineate the overall structural framework of the eastern Gulf of Alaska continental shelf by single channel seismic reflection, seismic refraction, high resolution sparker, gravity, and magnetic methods in anticipation of offshore oil and gas lease sales. Data and results of the cruise are available in various publications (Bruns and Plafker, 1975a and b, 1976; Plafker and others, 1975; Carlson and others, 1975; Carlson and Molnia, 1975; Molnia and Carlson 1975 a and b, Molnia and others, 1976; von Huene and others, 1975; Core and others, 1975).

Refraction lines A, C and D are located seaward of Icy Bay (Fig. 1) in an area of relatively simple geologic structure, and when combined with the refraction lines of Shor (1965), they form a refraction transect across the continental shelf. Lines E and H were shot near Kayak Island in a zone characterized by more complex geologic structure,a shelf edge arch, and a deep shelf basin behind the arch (Bruns and Plafker, 1975b, 1976).

STRATIGRAPHIC SUMMARY

The eastern Gulf of Alaska forms a complex continental margin basin which onshore consists of over 10 km of marine and nonmarine terrigenous clastic rocks that are intercalated with subordinate mafic volcanic and volcaniclastic rocks and with minor coal. These rocks are also presumed to underlie much of the contiguous continental shelf. Tertiary rocks are bordered on the north and are in part underlain by highly deformed, metamorphosed, and intruded Cretaceous and older bedded sedimentary and volcanic rocks. Recent summaries of the onshore geology of the province have been made by Plafker (1967, 1971, 1974) and Plafker and others 1975).

On the basis of induration and hence perhaps velocity, the Tertiary sequence can be broadly divided into a lower unit of well-indurated, intensely deformed rocks of early Tertiary (mainly Paleocene and Eocene) age, and an upper unit of mainly middle and late Tertiary (and locally Pleistocene) age that is notably less deformed and indurated.

On the basis of fossils and gross lithologic characteristics, three major subdivisions of Tertiary rocks are believed to correspond to major changes in the depositional environment of the basin. These are: (1) the Paleocene through lower Oligocene, (2) the middle Oligocene through lower Miocene, and (3) the middle Miocene through Pleistocene. The changes in depositional environment are characteristically gradational and appear to be time-transgressive in different parts of the basin.

Lower Tertiary Sequence

The oldest Tertiary rocks consist of complexly intertonguing, deep-water marine pillow lava, tuff, and tuffaceous sandstone and siltstone that comprise the Orca group and its equivalents in the Katalla district and the "unnamed siltstone" unit of the Yakataga and Malaspina districts (place names are shown on figure 1). These rocks are inferred to be of Paleocene and possibly earliest Eocene age on the basis of their stratigraphic position, the few diagnostic fossils collected from them, and their relationship to radiometrically dated plutonic rocks that intrude them.

The lower units appear to grade upward and laterally towards the northeast into rocks characterized by abundant intertonguing arkosic, pebbly, and coal-bearing sandstone that is commonly calcareous; the sandstone also is zeolitized in many places. Their fauna and flora suggest that they were deposited during late Paleocene to late Eocene and possibly early Oligocene time in a subtropical to temperate environment. Rocks of this age include the Kushtaka Formation and perhaps the lower Tokun Formation of the Katalla District and the Kulthieth Formation in the Yakataga and Malaspina districts.

All the early Tertiary sedimentary rocks are characteristically hard, dense, and intensely deformed. Although many of the cleaner sandstones appear porous and friable in outcrop, surface samples that have been examined microspically have negligible porosity.

In outcrop the Orca group is estimated to be at least 5,000 m thick in the Katalla district and thins to the east.

Middle Tertiary Sequence

The lower Tertiary rocks are overlain unconformably by a marine sequence consisting predominantly of interbedded concretionary mudstone and siltstone with subordinate sandstone. This sequence is characterized locally by the presence of interbedded aquagene tuff, agglomerate, glauconitic sandstone, and pillow lavas. The middle Tertiary sequence, which includes the Katalla, upper Tokun(?), and Poul Creek Formations, was deposited during Oligocene and early Miocene time in temperate water. Intermittent submarine volcanic activity is recorded by mafic flow and pyroclastic rocks throughout much of these units. The mudstone and siltstone are richly organic Katalla, Yakataga, and Malaspina districts, an the sequence there contains many petroliferous beds and oil and gas seeps. The sandstone-"shale" (actually mainly siltstone and mudstone) ratio of these units is 30 percent or less; most of the thicker sandstone beds are concentrated near the base.

The middle Tertiary sequence extends offshore at least to the continental margin where approximately 2,000 m of middle Tertiary rocks were penetrated in a well drilled by the Tenneco Oil Company near Middleton Island (Fig. 1). The sequence probably crops out on the sea floor between Kayak and Middleton Island, but is not known to be exposed elsewhere in the offshore parts of the basin.

Upper Tertiary and Pleistocene Sequence

Marine clastic rocks of Miocene to Pleistocene age that locally are characterized by abundant glacial detritus lie on the temperate-water sequence with local unconformity. The sequence consists mainly of rocks of the Yakataga Formation--fossiliferous thick-bedded mudstone, muddy sandstone, conglomeratic sandy mudstone (marine "tillite"), and minor conglomerate.

On the basis of the megafauna, the base of the sequence is probably of early middle Miocene age in the Yakataga and Malaspina districts and possibly as old as late Oligocene in the Katalla district (Plafker and Addicott, 1976).

The composite onshore outcrop thickness of the Yakataga Formation is about 5,000 m. The sandstone content of the formation ranges from as much as 55 percent in sections on the mainland near the northern margin of the basin to as little as 9 percent at Middleton Island near the edge of the continental shelf.

Based on its onshore distribution and the character of near-surface reflectors over adjacent offshore areas, the Yakataga Formation is inferred to underlie most of the continental shelf in the area of the refraction survey. Extrapolation of data from onshore sections and wells and offshore seismic reflection data suggests that the depositional axis of the Yakataga Formation in the area east of Kayak Island is probably offshore and within 15 to 30 km of the coast.

Much of the continental shelf is mantled with a veneer of unconsolidated Holocene, and possibly late Pleistocene, deposits (Molnia and Carlson, 1975a). Bottom sediments on the shelf include submarine moraines of poorly sorted till and their closely associated fluvioglacial outwash fans of sand and gravel near the present major glaciers. In addition, mud and silt that were discharged into the sea by streams have been widely dispersed offshore by current and wave action.

VELOCITIES FROM WELL LOGS

Sonic velocity logs from the Middleton Island, the Malaspina Unit No. 1A, the Chaix Hills No. 1A, and the Riou Bay No. 1 wells (locations shown on figure 1) have been used to derive velocity/depth curves for the part of the sedimentary sequence penetrated by these wells (Fig. 2).

The Middleton Island well penetrated the Katalla and Tokun Formation (Oligocene to Eocene or older). The Malaspina well penetrated the Yakataga and Kulthieth Formations (Pleistocene(?) to probable Eocene). The Chaix Hills wells penetrated the Yakataga and Poul Creek Formations (Miocene rocks to Oligocene). The Riou Bay well spudded in Holocene deposits and bottomed in the lower Yakataga Formation (Pleistocene to Middle(?) Miocene). The Riou Bay and Malaspina wells are located in relatively simple structural settings; the Chaix Hills and Middleton Island wells are in structurally complex settings.

In general, the velocity data of figure 2 do not show any apparent relationship of interval velocity to rock age or lithology. Velocities in the Malaspina and Riou Bay wells appear to be somewhat similar. The plots from these two wells indicate a gradual increase of velocity with depth, approaching a velocity of about 4 km/sec at a depth somewhere below 4 km. Velocities in the Middleton Island well are slightly higher than those in the Malaspina and Riou Bay wells to a depth of about 3 km; below 3 km, the velocity increases rapidly. The interval velocity at about 3.7 km in the Middleton Island well is over 5 km/sec. Interval velocities in the Chaix Hills well are generally about 4-5 km/sec at depths below about 1 km. These higher velocities suggest uplift and erosion of approximately 2 km of section at this locality and possible tectonic compaction of the sequence, as would be expected from the well location on the south limb of an overturned, faulted anticline. Interval velocities measurements from rocks of the Orca Group are not available. These velocities might be expected to be high (~5 km/sec) considering the intense deformation and mild metamorphism that these older Tertiary rocks have experienced.

In general, the wells suggest that mid-Miocene and younger rocks have velocities of about 4 km/sec or less, while the early Tertiary rocks can have velocities greater than 4 km/sec.

FIELD PROCEDURES

Field procedures for the marine refraction survey involved deploying one or two sonobuoys at the start of each refraction line and "shooting away", at speeds of about 15 km/hr, with a 300 cu. in. air gun at intervals of 5-30 seconds. Energy from the air gun source was insufficient at a distance of 1-2 kilometers and shooting was continued using chemical explosives at intervals of 1-30 minutes. Upon loss of radio signal from the sonobuoy or loss of energy from the chemical explosives (usually a distance of about 50 km) the refraction line would be terminated. The ship would then turn 180^{o} and return along the same general course, at which time sonobuoys would again be deployed for the reverse line.

The sonobuoy (product of Select International) detects the seismic arrivals with its hydrophone, amplifies this signal, modulates an FM transmitter and telemeters the seismic signal to a recording system aboard ship via an FM radio link. The recording system includes a high sensitivity-low noise-solid state receiver for each channel, antialiasing filters for digital recording, broad band data for analog recording and monitoring, and a special water break filter amplifier for the accurate determination of the direct water arrival. Figure 3 is a generalized flow diagram from energy source to real-time paper record.

Navigational control was provided by satellite and Loran A. Due to the Alaska current gyre (influencing the free-floating sonobuoys), and lack of more precise navigational aids, the attempt to spatially re-run a refraction trackline within an accuracy of about a kilometer proved unsuccessful. Table 1 lists the minimum and maximum deviations for each of the five "reversed" refraction lines and the locations of the sonobuoys deployed during the survey.

The general shooting configuration is shown in figure 4. A facsimile of a part of a seismic refraction record is shown as figure 5. The Galvo-camera produces a 15.24 cm wide continuous photographic record at a uniform rate of 15.24 cm/sec. Timing lines are marked across the seismogram at intervals of 0.01 seconds.

A preliminary interpretation was done aboard ship as the records were being recorded. This involved an immediate cursory examination of the records as to signal-to-noise ratios to determine the charge size needed for the next shot and the plotting of the direct water wave as a function of the refracted arrival for on-the-spot checks.

Environmental considerations limited the charge size to about 110 kilograms of chemical explosive. In addition, to avoid possible fish kill, explosion depth of the charges was adjusted to prevent detonation at the sea floor or within schools of fish detected in the water column, and shotpoints were delayed or cancelled if possible marine life could not be avoided.

RESULTS

The approximate locations of the five seismic refraction lines are shown in figure 1. Disparities in locations between the forward and reversed sections of the lines are listed in Table 1. Seismic events were picked to the nearest 5 milliseconds and plotted as a function of the direct "water arrival". The observed points were then fit by eye to straight line segments. Depths to refracting horizons were calculated by a standard time-intercept method in areas of gentle or no dip. For areas where significant dip was indicated by the data, the graphical method of Slotnick (1950) was employed.

Refraction Line A

Refraction line A is located seaward of the continental shelf in water depths between 500 and 2,000 m (Fig. 1). The results from this line are shown in figure 6 with refracted events plotted as a function of the direct water wave travel time. Excluding the water column (velocity of 1.5 km/sec), three layers with velocities of about 3.4, 4.2, and 7.0 km/sec were recorded. The uppermost layer (velocity 3.4 km/sec) is represented by two distinct points near the west end of the line; near the east end of the line, the layer either was not recorded or may be represented as a first arrival only along a very short segment of the travel-time plot as indicated in figure 6. The intermediate layer (4.2 km/sec) was clearly recorded from at least four shotpoints while shooting away from both the east and west sonobuoys. The equal apparent velocities recorded on both the forward and reversed segments of the profile indicate that this layer is flat lying. The deepest layer (velocity 7.0 km/sec) is represented by an apparent velocity of 6.9 km/sec in shooting from east to west and 7.1 km/sec shooting in the reversed direction. This small difference in apparent velocity may be due to random error or can be explained by a westward dip of about one-half of a degree. Assuming horizontal layers, the depths to the tops of the 3.4, 4.2, and 7.0 km/sec layers are calculated to be 1.35, 2.3, and 6.5 km respectively (fig. 11).

Refraction Line C

Refraction Line C is located on the continental shelf seaward of Icy Bay in water depths of about 100 m (fig. 1). A plot of refracted arrivals as a function of the direct water wave arrival is shown in figure 7. Excluding the water column (velocity 1.5 km/sec), three velocity layers were defined. The shallowest layer has an apparent velocity of 2.7 km/sec on the west and 2.5 km/sec on the east. Our interpretation is that this difference is not due to dip, but is probably due to lateral velocity variations in a thin, flat layer that averages about 2.6 km/sec. Again as on line A, a flat lying intermediate layer with a velocity of 4.2 km/sec was clearly recorded on both the forward and reversed segments of the line. It is possible, as suggested by the results of lines A and D, that a layer with a velocity of about 3.5 km/sec lies between the 2.6 and 4.2 km/sec layers, but no arrivals were found to substantiate this. In shooting from the west, a deep layer with an apparent velocity of 7.0 km/sec was recorded from six shotpoints. On the reversed segment of the line these arrivals did not appear. The results of lines A and D suggest however that the apparent velocity of 7.0 km/sec represents a flat laying layer with a true velocity of 7.0 km/sec. Assuming that the layers are horizontal, the depths to the tops of the 2.6, 4.2, and 7.0 km/sec. layers are calculated to be 0.5, 1.6, and 9.8 km respectively (fig. 11).

Refraction Line D

Refraction line D is located on the continental shelf, about 10 km seaward of line C, in water depths between 100 and 200 m. A plot of refracted arrivals as a function of the direct water wave arrival is shown in figure 8. Excluding the water column (velocity 1.5 km/sec), the data suggest four horizontal layers with velocities of 2.5, 3.3, 4.25, and 7.0 km/sec. This line differs from lines A and C in that the 4.2 km/sec is overlain by two discreet lower velocity layers instead of only a single layer. This difference may be a result of the higher resolution obtained along line D as a result of the many closely spaced shotpoints at the southeast end of the line.

It is possible that on all three lines (A, C, and D), closer spaced shotpoints might show that the sediments overlying the 4.2 or 4.25 km/sec layer simple increase in velocity with depth rather than comprising discreet layers. This is suggested by the fact that the first arrivals at the southeast end of line D could be fitted to a curve as well as straight line segments. This latter interpretation is attractive in that most of the well data also (fig. 2) show a continuous increase in velocity with depth.

If we assume a simple, horizontal four layer solution on line D, depths to the tops of the 2.5, 3.3, 4.25 and 7.0 km/sec layers are calculated to be 0.25, 0.9, 2.0, and 8.5 km respectively (fig. 11). Except for the 7.0 km/sec layer, these depths agree quite well with depths obtained on line C for similar velocity layers. The depth to the 7.0 km/sec layer indicates dip landward from line A to line C of this layer (Fig. 11).

Refraction Lines E and H

Refraction lines E and H are located on the continental shelf about 15-20 km east-southeast of Kayak Island (fig. 1). Line E is about 10 km shoreward of H. The profiles are discussed together not only because of their geographic proximity, but also because of the similarity of results, and the fact that only parts of various refractors were recorded on each line and a consistent interpretation requires that they be interpreted in conjunction with one another. A plot of refracted arrivals as a function of the direct water arrival for line E is shown in figure 9 and for line H in figure 10.

A thin upper layer with an apparent velocity varying from 2.3 to 2.6 km/sec was recorded on both lines. The changes in apparent velocity were interpreted as representing local velocity variations in the near surface sediments rather than dip. The average velocity for this shallowest layer was assumed to be 2.4 km/sec (fig. 11). On line E a second layer with an average velocity of 3.6 km/sec (apparent velocity 3.5 km/sec at the west sonobuoy and 3.7 km/sec at the east sonobuoy) was recorded. This layer is calculated to be about 2.5 km thick with an easterly dip of about 0.8 degree (fig. 11). On line H this same depth interval appears to be represented by two layers with average velocities of 3.2 km/sec (apparent velocities 3.1 and 3.3 km/ sec) and 4.1 km/sec (apparent velocities 4.0 and 4.2 km/sec). The total thickness of the 3.2 and 4.1 km/sec layers is about 3.5 km. The situation is similar for the deeper part of the section. On line H a layer with an apparent velocity of 5.2 km/sec appears on both the forward and reversed segments of the line. On line E, the section of the time-distance plot that corresponds to approximately the same depth interval shows two layers. The upper layer is represented by apparent velocities of 4.6 km/sec (west sonobuoy) and 4.8 km/sec (east sonobuoy, fig. 9). Its true velocity is calculated to be about 4.7 km/sec. The other layer with an apparent velocity of 5.4 km/sec was recorded only at the west sonobuoy; its true velocity was assumed to be about 5.5 km/sec.

Considering the above results it is possible that the velocity layering for lines E and H is similar, and that closer shotpoint spacing would show a continuous increase in velocity with depth from about 2.0 km/sec at the water bottom to perhaps 5.5 km/sec at a depth of 10 km.

The deepest layer penetrated on line E is represented by an apparent velocity of 7.0 km/sec which was recorded only at the west sonobuoy. On line H this layer appears to be represented by an apparent velocity of 7.2 km/sec. If we assume that these velocities represent a layer with a true velocity of 7.0 km/sec, its depth would be about 10.8 km beneath line E and 10.3 km beneath line H. The slightly greater depth calculated beneath line E, compared to that calculated for line H, may be due to dip, but could also reflect inaccuracies in velocities used in the calculation for line H.

Except for the 4.7 km/sec layer on line E and the 5.2 km/sec layer on line H, the layering appears to be nearly horizontal. However, the time-intercept of the 4.7 km/sec layer on line E at the west sonobuoy is about 1.7 sec whereas at the east sonobuoy it is about 2.55 sec. This large difference in intercept-times together with the nearly equal apparent velocities of 4.6 and 4.8 km/sec on the forward and reversed segments of the lines suggests that thehorizon may be vertically offset by as much as 1 km. A similar line of reasoning suggests vertical offset of about 0.5 km on the 5.2 km/sec layer of line H.

It should be noted that in shooting to the east sonobuoy on line E, an anomalous apparent velocity of 6.4 km/sec was recorded from the results of three shotpoints. Although the energy was strong, the authors were unable to relate this segment of the time-distance plot to any of the previously discussed refractors on either line E or H. Multichannel seismic reflection data shows this area has a complex geologic structure; this complexity is likely also reflected in the lower crust. Therefore, although this apparent velocity could be due to a change in lithology, it could also be due to a change in dip of the deep refractors beneath the west end of line E.

DISCUSSION

The marine refraction results are summarized in figure 11. The deepest layer penetrated on all five of the refraction lines has a seismic velocity of about 7.0 km/sec. This velocity is comparable to lower crustal velocities measured in other refraction studies in the Gulf of Alaska near Kodiak Island (Shor and von Huene, 1972), near Dixon Entrance (Johnson and others, 1972,) and between Icy Bay and Dry Bay to the east, (Shor , 1965). The 7.0 km/sec velocity appears to be typical of the transition zone between oceanic and continental crust in the Gulf of Alaska. It is also within the range of typical oceanic crustal velocities as discussed by Worzel (1974), and could represent generally oceanic crust underthrusting the coast at a relatively shallow angle as is suggested by the oceanic magnetic data in this region (Naugler and Wageman, 1973; Taylor and O'Neill, 1974). Lines A, C, and D show a thickening of the overlying sedimentary rocks from about 6 km at the shelf edge to at least 10 km near the coast, and Shor (1965) on a refraction line from Icy Bay to the shelf edge, indicates that there may be over 12 km of sedimentary section overlying the lower crustal layer. Lines E and H indicate a somewhat thicker overlying sedimentary sequence than is present near Icy Bay.

Velocities on lines A, C, and D above the 7.0 km/sec layer are about 4.2 km/sec. Velocities on lines E and H are substantially higher ranging from 5.2 - 5.5 km/sec. Comparison of these velocities suggests that there is a distinct difference in the underlying geology of the two areas, and by comparisons with velocities seen in wells, the 5.2 - 5.5 km/sec velocities could indicate either truncation of the higher velocity section towards the east or an eastward decrease in structural deformation within the section. Plafker (1971) notes that in outcrop the deformed metamorphosed rocks of early Tertiary age thin from west to east, and the lack of higher velocity rocks in the eastern lines may indicate that the early Tertiary rocks are not present in substantial thickness offshore. Alternatively, Plafker (1974) and Bruns and Plafker (1975 a and b, 1975) note that Kayak and Wingham Islands as well as the contiguous continental shelf shows greater structural complexity west of Icy Bay than to the east, which suggests that the higher velocities measured in lines E and H may be due to greater deformation of the rocks underlying this part of the continental shelf.

SUMMARY

The initial layer on all profiles indicates water and thin unconsolidated sediments with a velocity of 1.5 km/sec. In the area offshore of Icy Bay maximum velocities of about 4.2 km/sec for the sedimentary section suggest a thickness of up to 10 km of clastic sedimentary rocks with velocity increasing primarily as a function of depth of burial. Velocity discontinuities within this clastic sequence may be due to the presence of regional unconformities rather than to major lithologic contrasts. These sediments probably correlate with a sequence of late Tertiary age rocks that are exposed onshore and have been penetrated in exploratory wells.

In the area southeast of Kayak Island, velocities of 4.7 to 5.5 km/sec in the lower half of the sedimentary section indicate a distinctly different unit or, possibly the same unit which has undergone a much greater amount of deformation and (or) maximum depth of burial. These higher velocities most probably reflect the presence of the early Tertiary Orca Group.

Beneath the sedimentary section rock velocities were measured or inferred to be, 7.0 km/sec on all 5 profiles. These velocities are typical of lower crustal velocities across the continental margin in other areas of the Gulf of Alaska, and probably indicate oceanic crust beneath the continental margin. On a short segment of profile E, east of Kayak Island, an anomolous unreversed velocity of 6.4 km/sec may indicate a sliver of buried continental crust or a granitic pluton, although it could also be caused by an abrupt change in dip of the deep reflectors.

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TABLE 1

PROFILE	MINIMUM DIST. (KM)	MAXIMUM DISTANCE (KM)	SONOBUOY LOCATIONS			
			WEST		EAST	
			LATITUDE (N)	LONGITUDE (W)	LATITUDE (N)	LONGITUDE (W)
A	0	5.6	59° 18.2'	142° 25.7'	59° 06.5'	141° 48.5'
C	2.8	5.6	59° 41.3'	142° 01.8'	59° 42.1'	141° 14.0'
D	0	4.6	59° 40.0'	142° 16.0'	59° 21.1'	141° 32.2'
E	0	6.5	59° 47.0	144° 16.5'	59° 44.3'	143° 14.0'
H	0	14.8	59° 43.1'	144° 24.5'	59° 37.0'	143° 39.5'

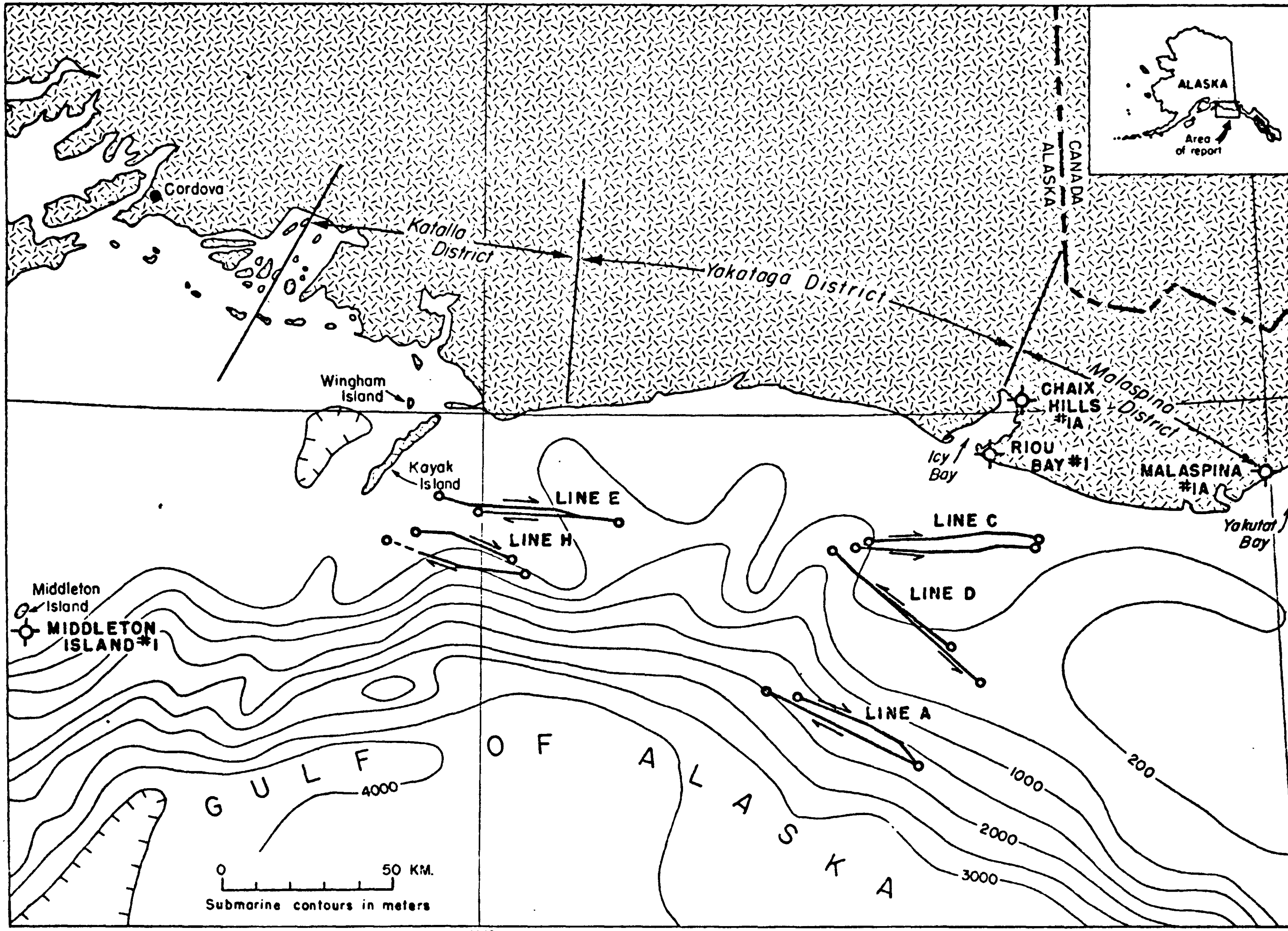

Figure 1. Map of study area showing location of refraction lines, selected wildcat wells, and geographic features referred to in the text.

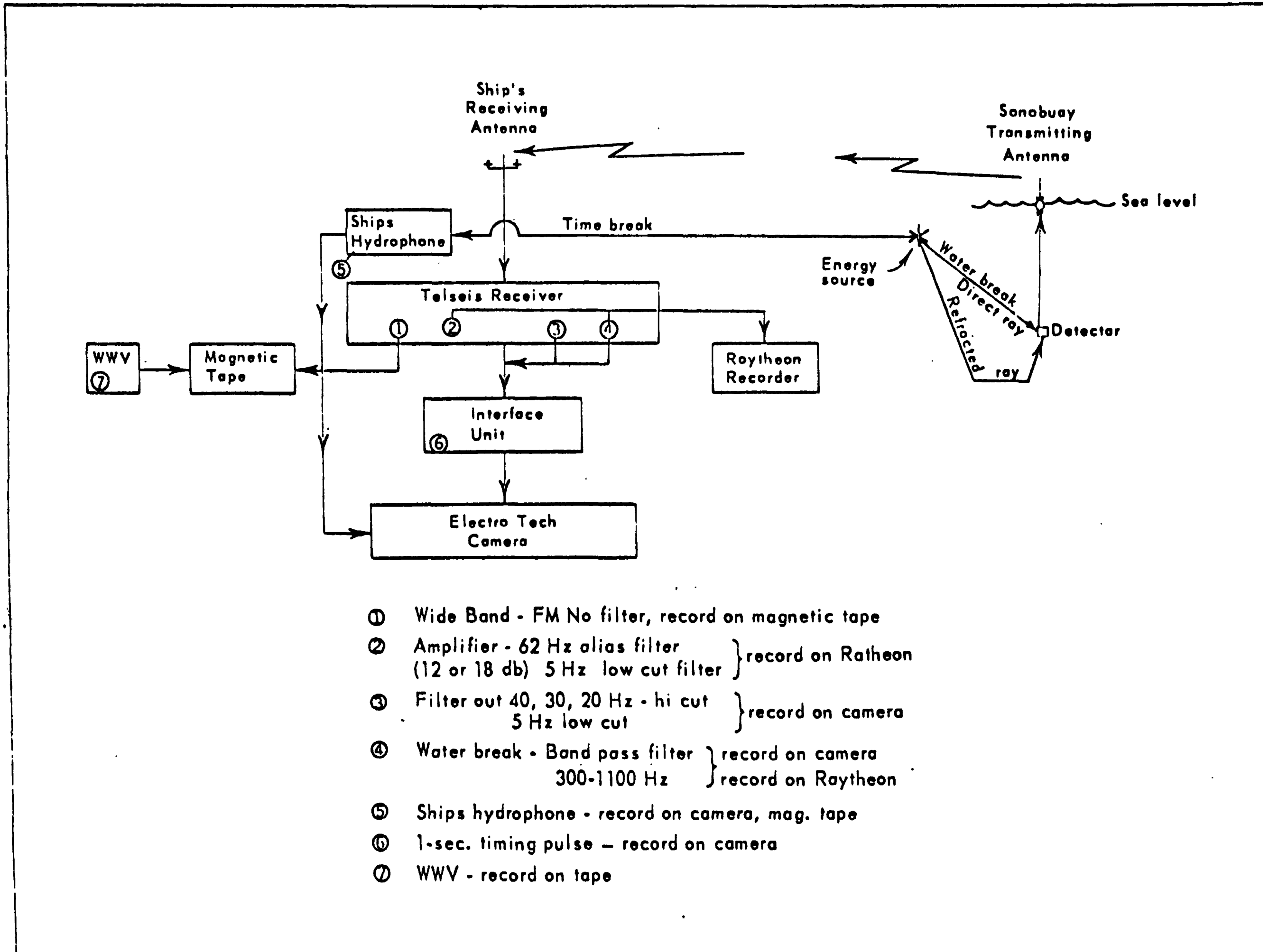

Figure 3. Flow diagram showing configuration of seismic refraction transmission.

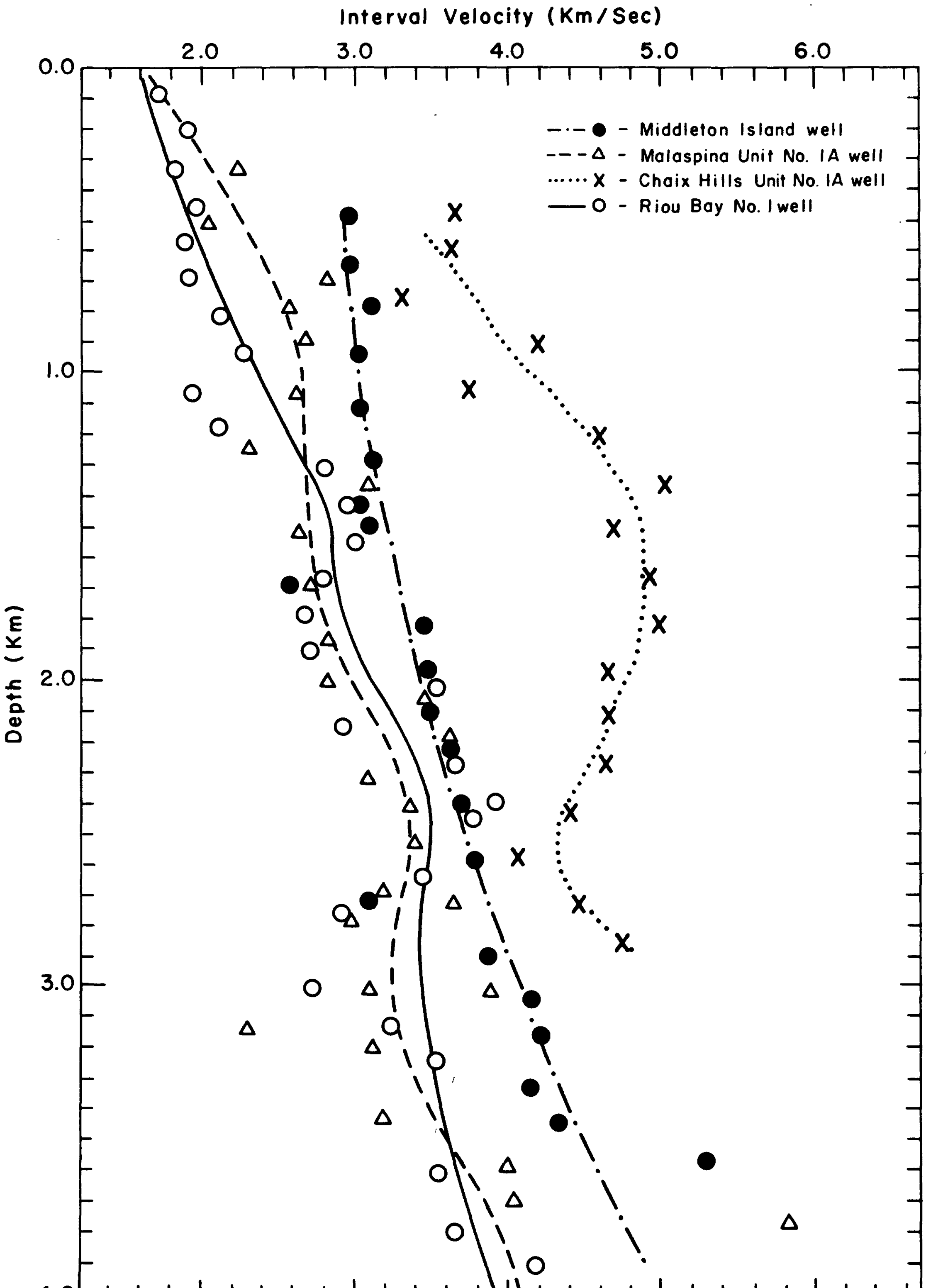

Figure 2. Interval velocity plotted as a function of depth for selected wells in the Gulf of Alaska Tertiary Province (GATP).

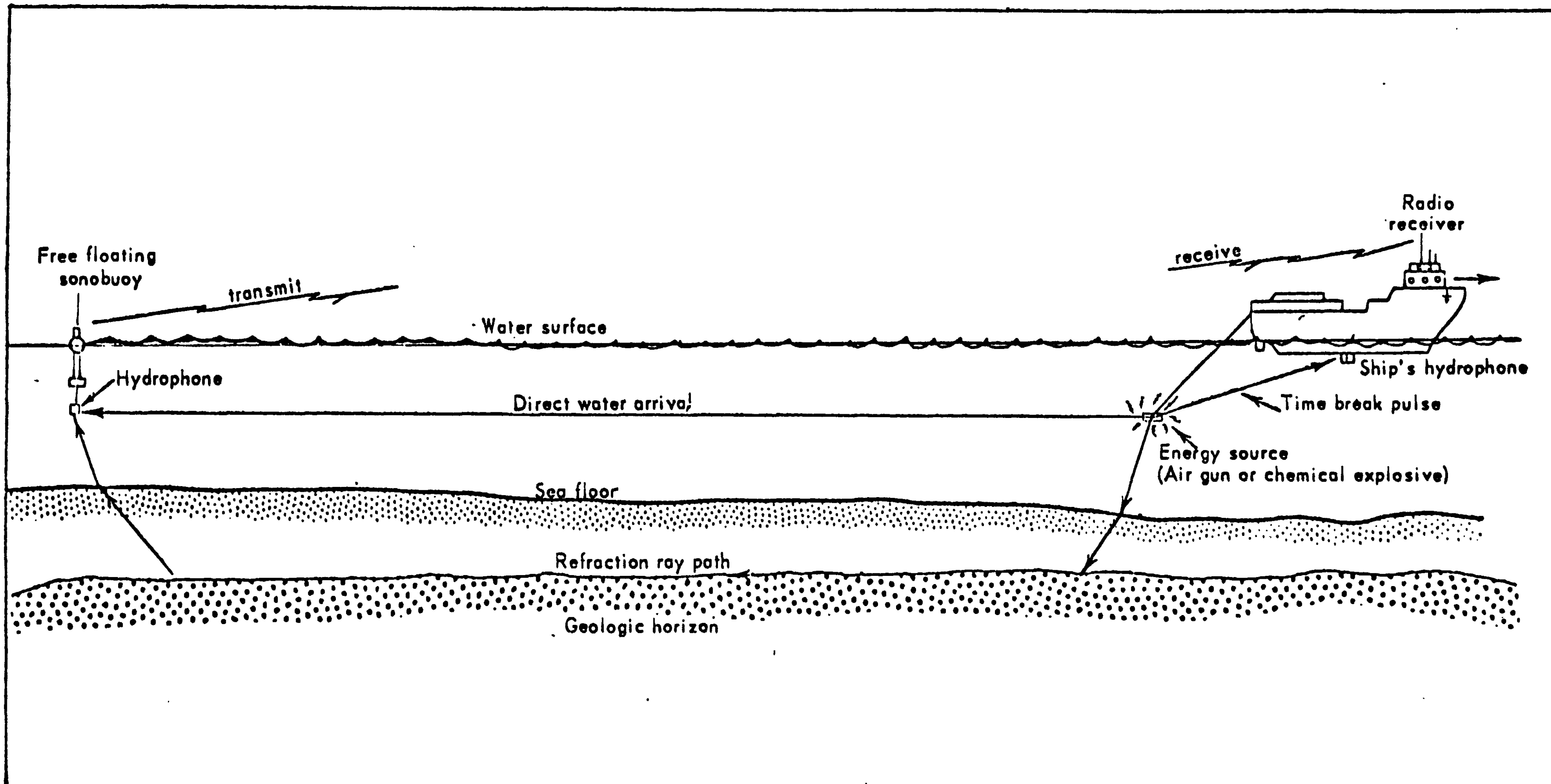

Figure 4. Diagram showing the general shooting configuration used for the refraction survey.

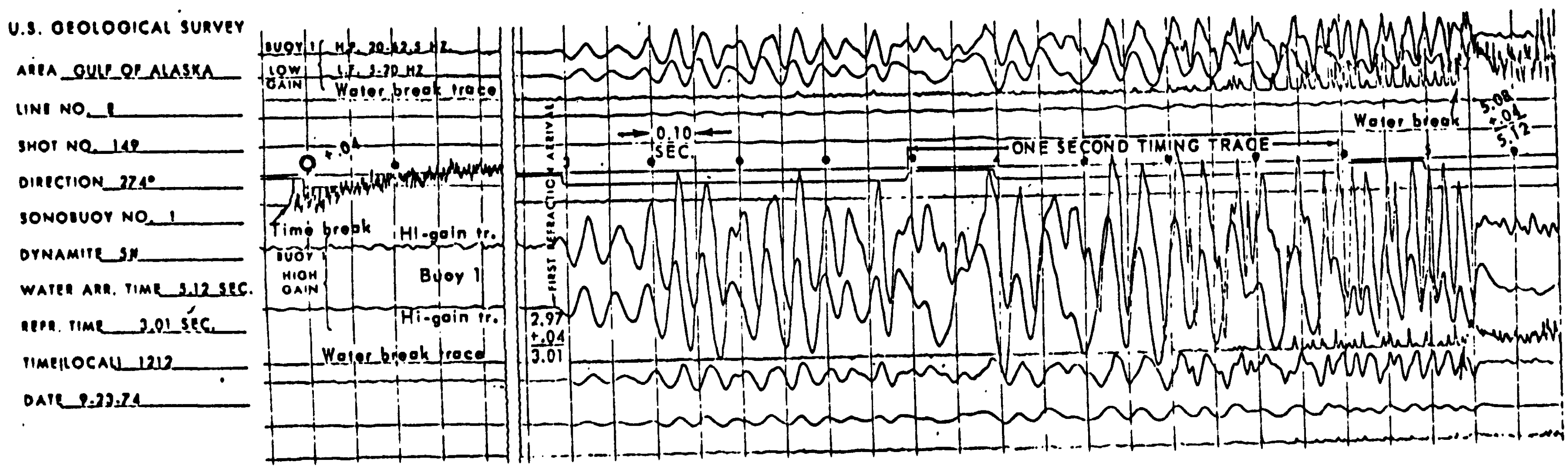

Figure 5. Sample seismic record from the Galvocamera.

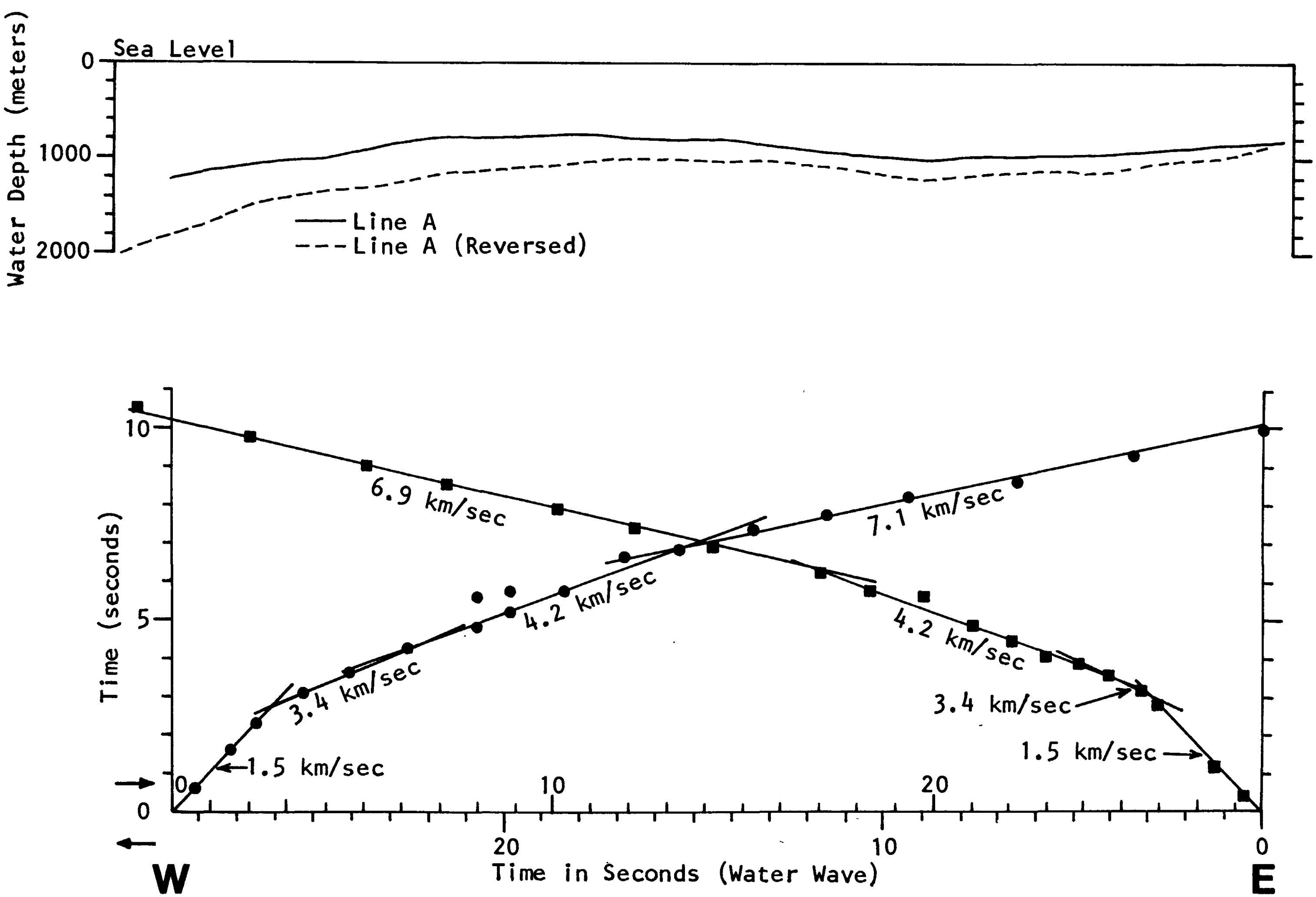

Figure 6. Plot of refracted arrivals as a function of the direct water wave arrivals for refraction line A.

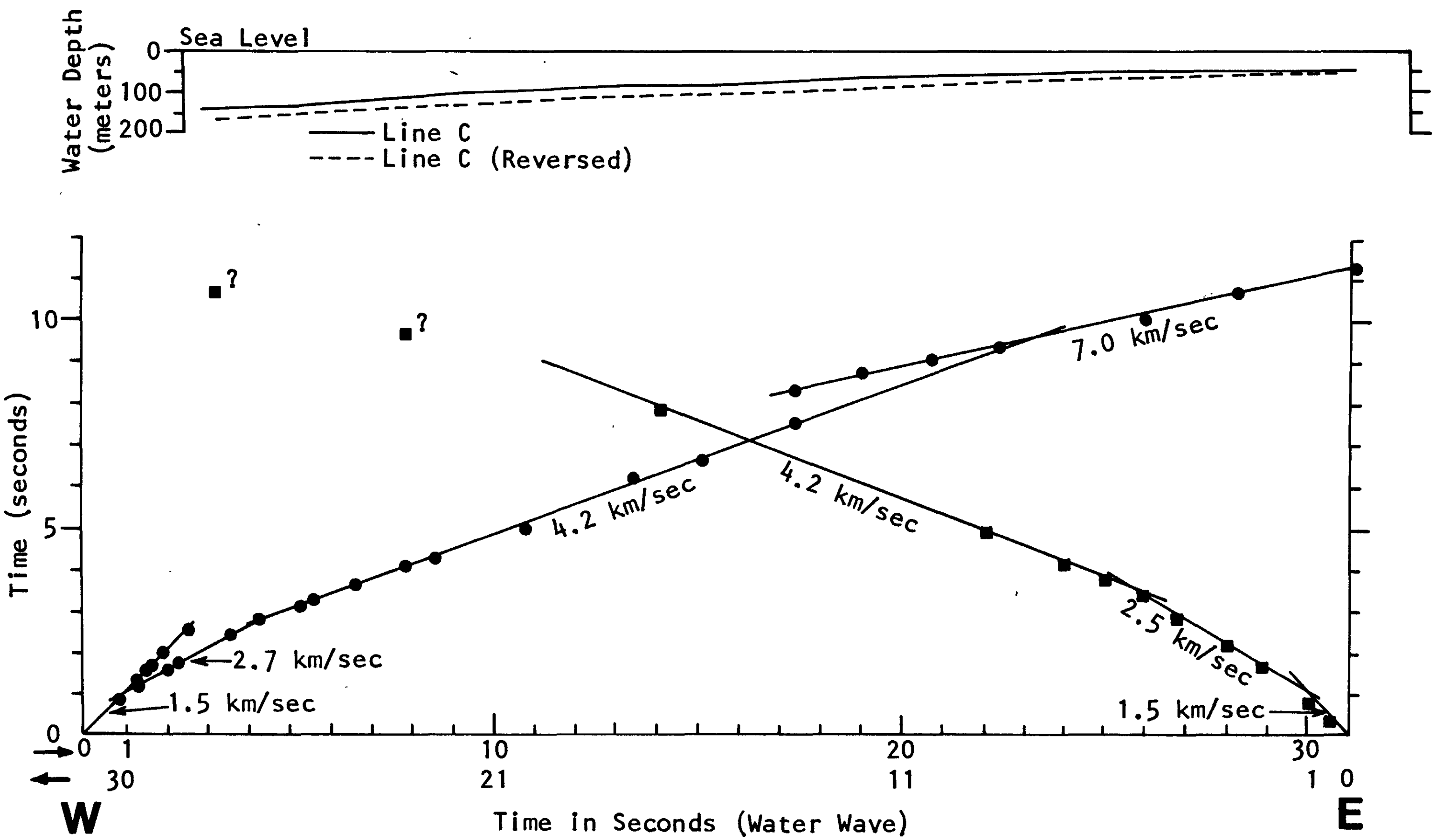

Figure 7. Plot of refracted arrivals as a function of the direct water wave arrivals for refraction line C.

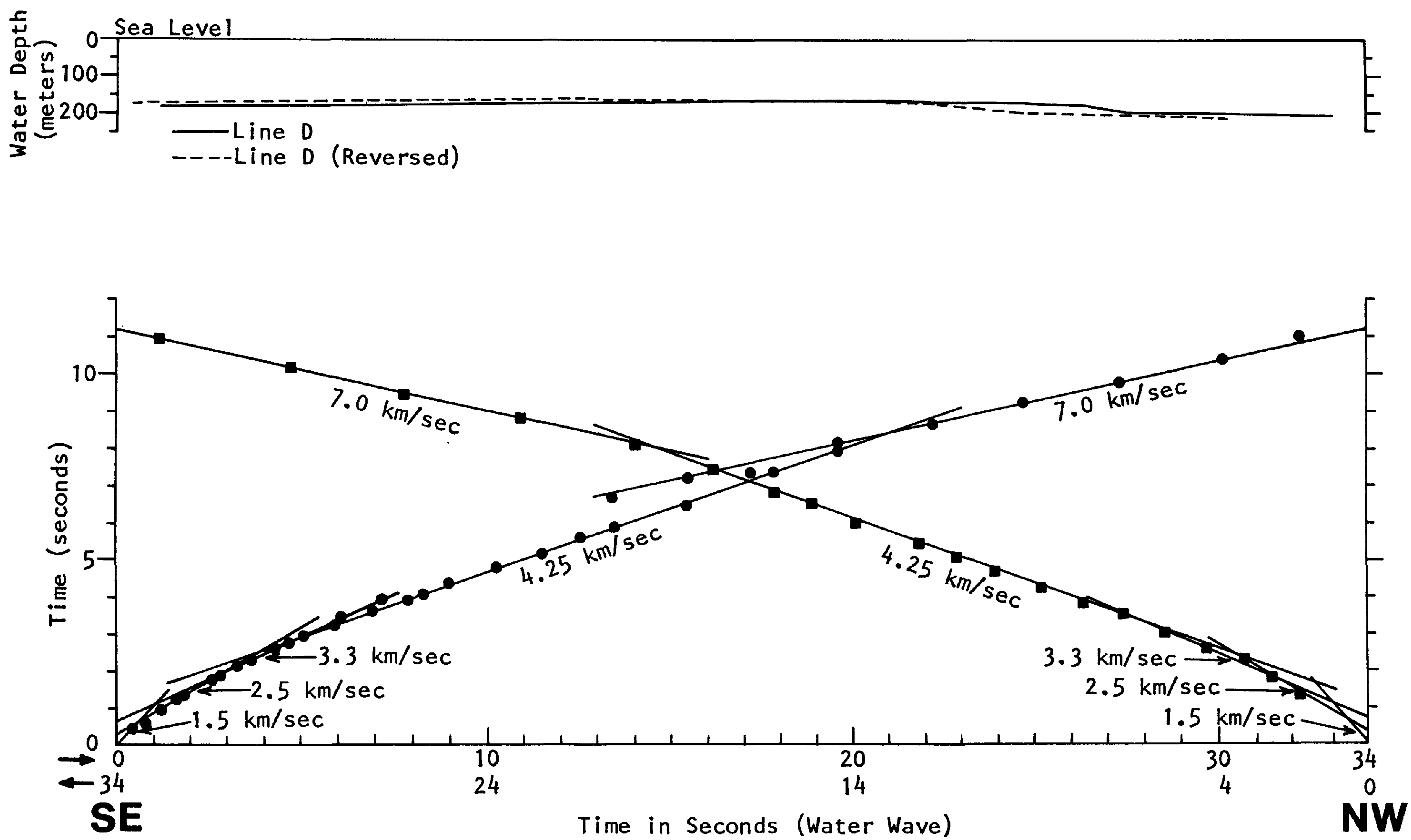

Figure 8. Plot of refracted arrivals as a function of the direct water wave arrivals for refraction line D.

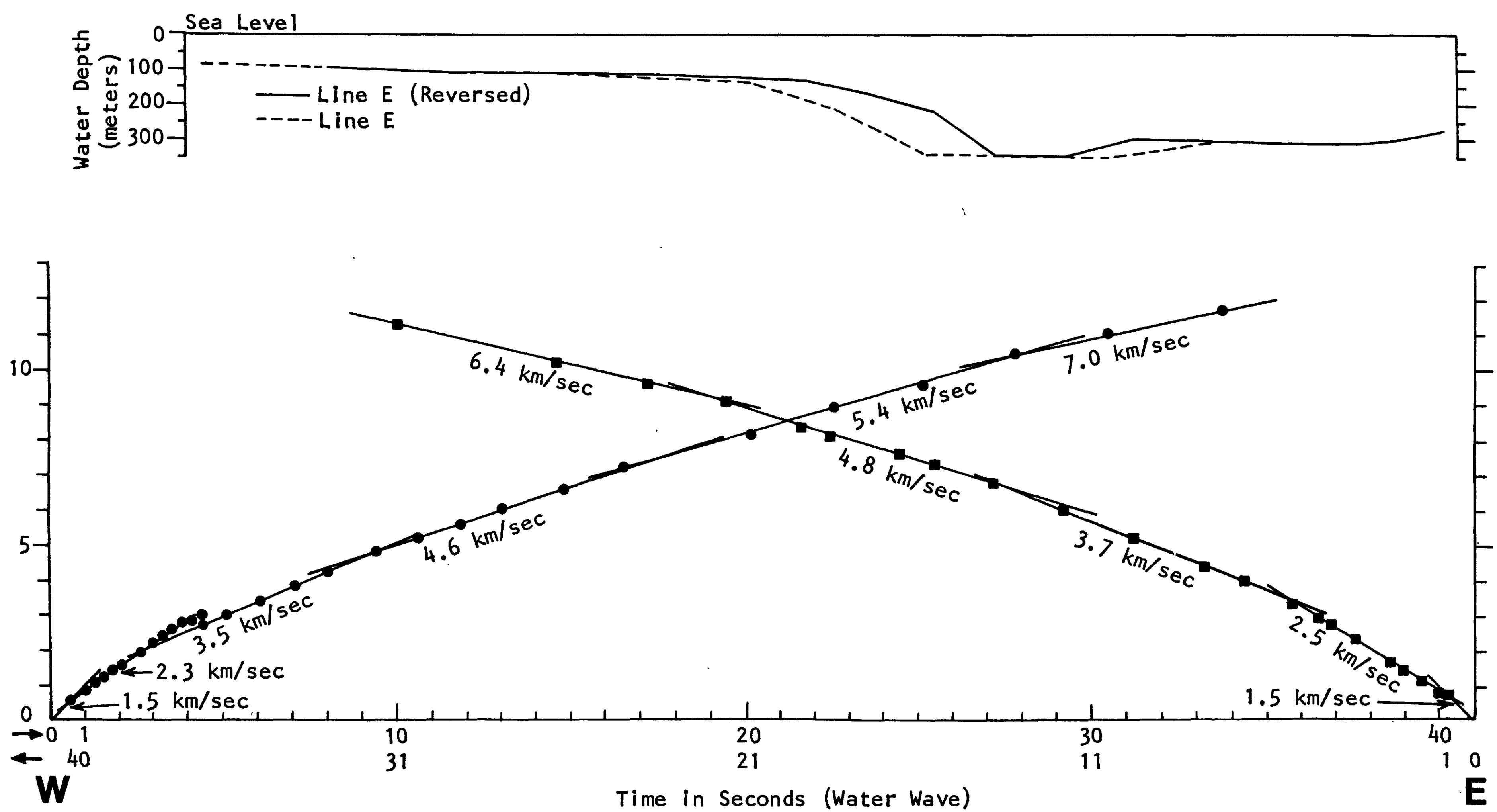

Figure 9. Plot of refracted arrivals as a function of the direct water wave arrivals for refraction line E.

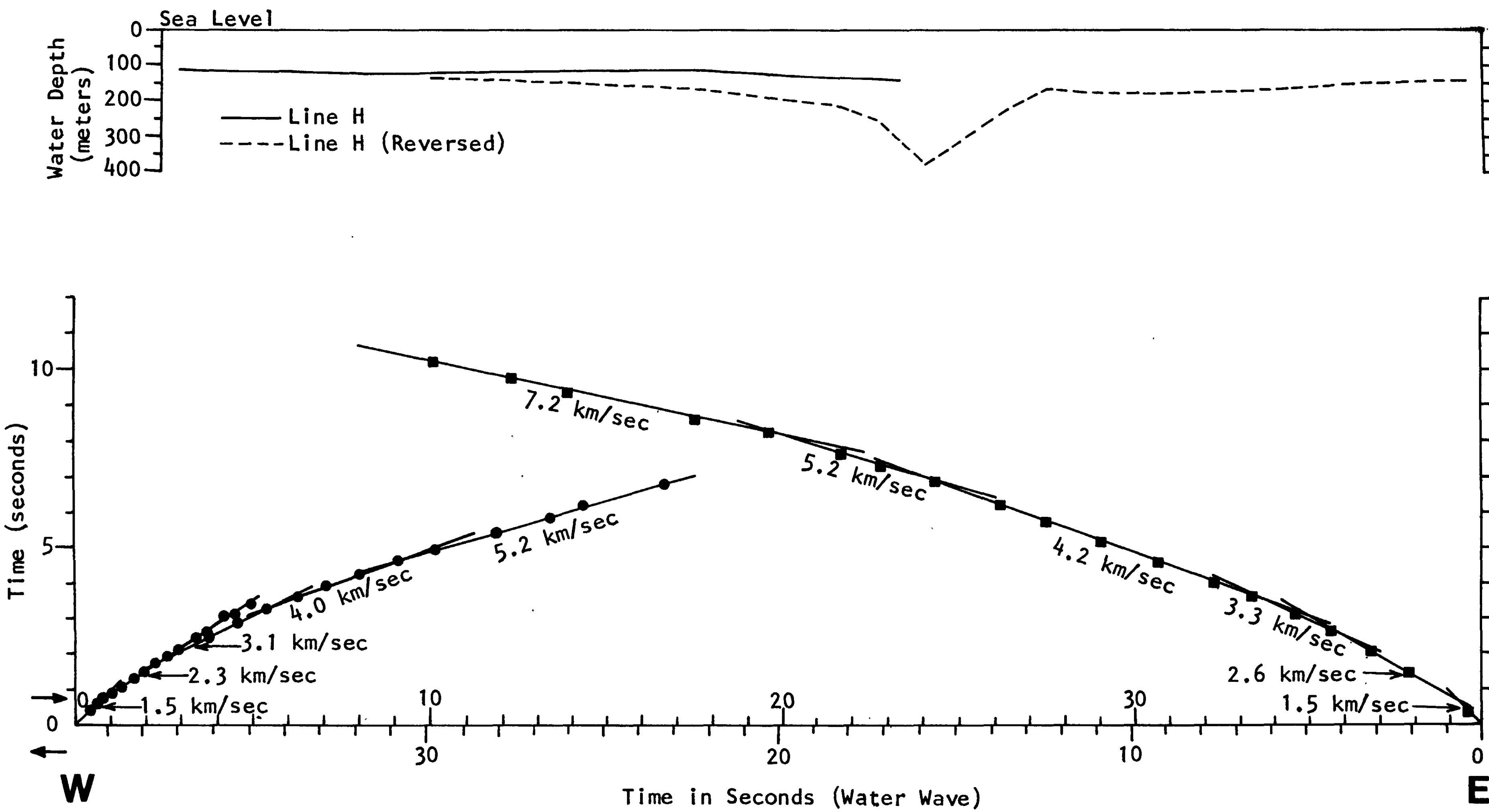

Figure 10. Plot of refracted arrivals as a function of the direct water wave arrivals for refraction line H.

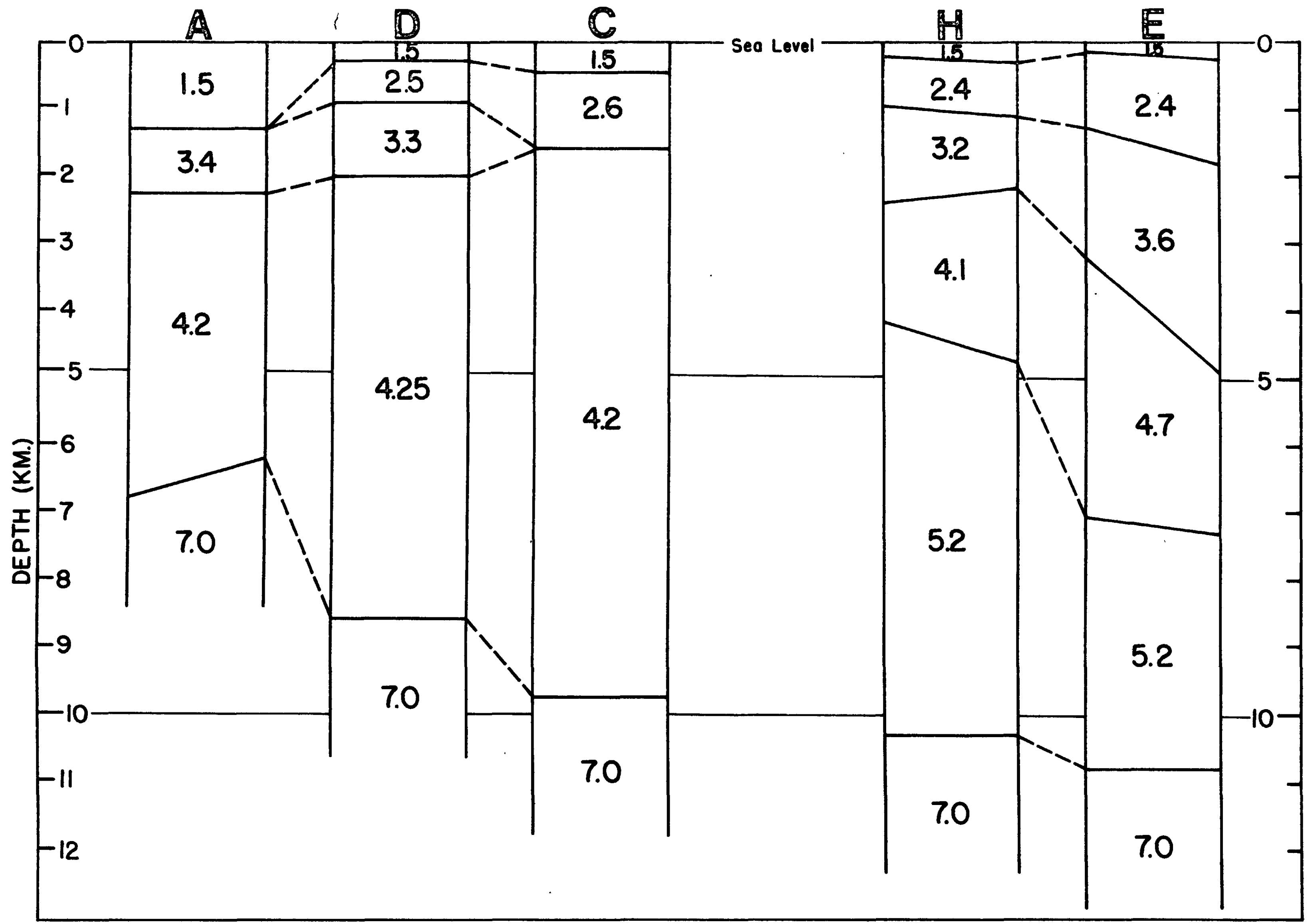

Figure 11. Velocity layers determined for refraction lines A, D, C, H, and E (see fig. 1 for locations). Numerals in columns indicate velocity in km/sec; the eastern ends of the refraction lines are to the right.