United States
Department of the Interior
Geological Survey

DISTRIBUTION OF GAS-CHARGED SEDIMENTS IN NORTON BASIN, NORTHERN BERING SEA

by

Mark L. Holmes and Devin R. Thor

OPEN FILE REPORT 80-

April 1980

DISTRIBUTION OF GAS-CHARGED SEDIMENTS IN NORTON BASIN, NORTHERN BERING SEA

M. L. Holmes and D. R. Thor

ABSTRACT

Seismic reflection records from Norton Sound and Chirikov basin contain numerous zones of anomalous acoustic responses caused by gas in the subsurface sediment layers. These acoustic anomalies have been detected using sound sources ranging in size and power from 3.5 kHz transducers to 1326 cubic inch air gun arrays. The frequency and distribution of these zones suggest that up to 7000 km^2 of the northern Bering Sea (Norton basin) may be underlain by gas-charged sediment. Much of the gas is of shallow biogenic origin, having been generated in buried peat deposits. Compressional velocity is about 1.5 km/see in these layers, or 7 per cent below the velocity in gas free areas as determined from seismic refraction studies. Seismic velocity beneath a large gas seep south of Nome decreases to about 1.2 km/see in the interval from 250-440 m below the sea floor. Here, thermogenic gases of deeper origin are migrating upwards along a system of basin margin faults.

INTRODUCTION

Discovery of the submarine seepage of natural gas south of Nome, Alaska, in 1976 (Cline and Holmes, 1977) prompted a comprehensive review of seismic reflection data from the Norton basin area (Fig. 1). The same types of anomalous acoustic responses associated with the seep zone (Cline and Holmes, 1977; Holmes and Cline, 1978; Nelson et al., 1978) were first encountered by Grim and McManus (1970) in the course of a high-resolution seismic study of the northern Bering Sea in 1967. They interpreted the zones of acoustically impenetrable sea floor on their sparker records as representing a Yukon River deposit very near the surface of the present-day seafloor. The highly reflective nature of this surficial deposit was thought to cause the sudden termination of deeper reflectors observed along portions of the seismic track (Grim and McManus, 1970). Air gun reflection records collected in Chirikov basin during a cruise by NOAA (then ESSA) in 1968 (Walton et al., 1969) also crossed a few of these reflector termination anomalies.

Cline and Holmes (1977) first suggested that these acoustic responses were caused by the presence of bubble phase gas in the near-surface sediment; Holmes and Cline (1978), Nelson et al. (1978), and Kvenvolden et al. (1979) presented detailed analyses of the deep penetration and high resolution seismic reflection records collected over the seep zone and the geochemistry of sediment samples from Norton Sound and Chirikov basin on USGS cruises in 1977 and 1978.

The main objective of this study was to determine the geographic extent and distribution of zones showing anomalous acoustic responses on seismic reflection records from Norton Sound and Chirikov basin. Certain characteristics of these acoustic anomalies could then be analyzed to determine the most probable cause of the anomaly (gas, change in sediment type, etc.). Seismic records used for this study were collected aboard U.S. Geological Survey and University of Washington research vessels during the past 12 years along some 27,000 km of trackline (Fig. 2). Sound sources used in these geophysical studies included medium- and high-resolution sparker, 40 to 1300 cubic inch air gun, Uniboom, and subbottom profilers.

GEOLOGIC SETTING

The floor of the northern Bering Sea is a broad, shallow epicontinental shelf (Fig. 1). Water depths in Chirikov basin in the western part of the survey area range from 20-50 m. Norton Sound is bounded on the north by Seward Peninsula, on the east by the Alaska mainland, and on the south by the Yukon Delta. Water- depths in Norton Sound range from 10-25 m. The surficial sediment of Norton Sound is primarily derived from the Yukon River and consists of coarse silt to very fine sand underlain by organic rich, nonmarine, peaty mud. Surficial sediment in Chirikov basin consists mostly of glacial gravel and transgressive fine sand (Nelson and Hopkins, 1974; McManus et al., 1974).

DESCRIPTION AND CAUSE OF ACOUSTIC ANOMALIES

Figures 3 and 4 show the locations of acoustically anomalous zones along more than 20,000 km of seismic reflection lines in Norton basin. The distribution of the many crossings of these zones suggests that they occur in large patches beneath much of the sea floor of Norton Sound; the total area may be as much as 7000 km^2. Two distinct types of acoustic anomalies were observed on the seismic reflection records: Reflector pull-downs and reflector terminations (Holmes and Cline, 1978). Reflector pull-downs similar to those shown in Fig. 5 have been observed and described by several other investigators from both deep and shallow water areas where gas had accumulated in the subsurface strata (Lindsey and Craft, 1973; Cooper, 1978). The low compressional velocity in gas-charged horizons causes the recorded time section (seismic record) to be distorted relative to the true depth section. The greater travel time through the gassy sediment produces a zone of pulled down reflectors beneath it on the seismic record. The gas does not necessarily have to be in the free state (bubble phase) to produce this phenomenon; gas-water or oil-water solutions have compressional velocities less than water alone (Craft, 1973), although, the decrease is much greater if gas is present in the sediment interstices. The strong horizontal reflector exhibiting a 180° phase shift which is associated with the observed pull-downs (Fig. 5) could be the result of reflections from interfaces between gas-charged zones and strata where water alone fills the pore spaces. The decrease in both compressional velocity and density due to the presence of gas in the sediment results in a large negative reflection coefficient at the top of tine gas-charged layer (Craft, 1973; Savit, 1974) . Such a condition would produce acoustic responses similar to the strong horizontal reflectors above the reflector pull-downs (Fig. 5).

Crossings of the acoustic anomaly associated with the gas seep south of Nome are shown in Figs. 5 and 6. The anomaly covers an area of about 50 km^2; it is characterized by a sudden termination of subbottom reflectors, and by a dramatic pull-down of the reflectors at its margins (Fig. 6). The depth to the top of the feature causing the anomalous acoustic signature appears to be quite shallow, on the order of 50-200 m. In places the surface of the acoustically opaque zone rises abruptly to within a few meters of the sea floor (Nelson et al., 1978). These zones may indicate the locations of the active seeps (Kvenvolden et al., 1979).

Calculations by Cline and Holmes (1977, 1978) indicated that the concentrations of the low molecular weight hydrocarbons which had accumulated in the sediment beneath the seep zone were far below theoretical saturation va ues. This finding was in conflict with *the* seismic reflection data, wh ch strongly suggested the presence of bubble phase gas in the sediment. The paradox was resolved by the recent discovery that the seep consists primarily of CO_2 rather than hydrocarbons, and that CO_2 is present in the free state in the sediment interstices (Kvenvolden *et* al., 1979).

Examples of other reflector termination anomalies observed on air gun records in Norton basin (Fig. 7) are quite different from the one associated with the gas seep. They exhibit only slight reflector pull-downs *at* their margins, and lack the dramatic "wipe-out" appearance of the seep anomaly. Low frequency reflections at 0.6, 0.9, and 1.2 seconds can be traced across the acoustic anomaly zone (Fig. 7); these reflectors show distinct pull-down relative to the corresponding reflectors in the normal section. The attenuation of all but the low frequency energy is a distinctive characteristic of the reflector termination zones (Figs. 3 and 4).

Other indirect evidence indicating abnormally low compressional velocities in these shallow zones is provided by the multichannel seismic reflection data collected by the USGS in August 1978. An oscillographic camera is used to monitor the signal from the hydrophone streamer every 50 shots. A "normal" shot record is shown in Figure 8. This is not a "gather" in the true sense of the word, but merely a recording' of the output from each of the 24 *streamer* channels for one shot from the 1326 cubic inch (21.71) air gun array. Refracted arrivals (head waves), the water wave, and reflected arrivals are clearly visible. In sharp contrast is a shot record over the gas seep reflector termination zone (Fig. 9). Little reflected energy is returned to the streamer over the gas-charged zone. Severe attenuation of the reflected arrivals is apparent, and the only arrival beyond trace 22 is the direct water wave (D). This phenomenon can easily be explained by invoking the model of near-surface gas-charged sediment; attenuation of the reflected arrivals, especially the high frequencies, will be pronounced (Mavko and Nur, 1979), as in the case of Figure 9.

Anomalous acoustic responses were also observed on mini-sparker and Uniboom reflection records (Grim and McManus, 1970; Nelson et al., 1978; Kvenvolden et al., 1979). Small reflector pull-downs observed on the air-gun records usually appear as abrupt reflector terminations on the high resolution profiles. Anomalies on Uniboom and mini-sparker records characteristically are near the surface (10 meters or less) and in some cases the top of anomalies are in the energy pulse of the record. Core-sample gas analysis substantiates that the top of gas-charged sediment zone is within a couple tens of centimeters of the surface (Kvenvolden et al., in press). The thickness of these near-surface gas zones is unknown, because only the top of the zone acts as a reflector, no energy is returned from lower reflectors. A minimum thickness of 5 m is set by the continuously high gas contents in a 5-m-long core.

Figure 10 shows a portion of a mini-sparker (800 joules) record over an anomaly approximately 20 km east of the Norton basin gas seep. The near surface zone of diffractions (point source reflectors) was at first thought to be related to the acoustic anomaly; this diffraction layer is commonly observed on high-resolution records over the reflector wipe-outs. However, careful examination of the seismic data (Fig. 10) shows that the diffractions are also present outside of the acoustic anomaly zones. The presence of gas in the near-surface sediment apparently attenuates energy reflected from deeper horizons in the gas-charged zone, thereby making the zone of diffractions more apparent on records over the gas-charged zones. The patches of diffracted arrivals observed on the high resolution records in Norton Sound and Chirikov basin are probably caused by coarse sediment (cobbles and pebbles) buried in or a few meters beneath the Holocene section.

The extensive reflector termination anomalies observed throughout Norton basin (Figs. 3 and 4) are probably caused by a subsurface accumulation of gas in sufficient quantity that scattering and attenuation of the seismic signal, even from large sources, is almost complete. The drastic reduction in apparent amplitude of both the reflected and direct arrivals was observed over virtually all of the reflector termination anomalies crossed in the course of the geophysical surveys. It is indicative of an unusually low impedance mismatch at the sea floor; the most likely explanation is the presence of free (bubble-phase) gas in the sediment.

Geochemical analyses by Kvenvolden and others (979) have shown that biogenic methane and thermogenic carbon dioxide are present at saturation volumes in near-surface sediment at many station sites in Norton basin. At many of the sampled sites, but not all, acoustic anomalies are associated with known saturated gas conditions.

Reflector Pull-Down Analysis

In an effort to gain more quantitative estimates of the velocity changes due to the presence of gas, a method was developed for computing the compressional velocity in gas-charged zones over which single channel seismic reflection records show a distinct pull-down of reflectors. Compressional velocity data obtained from sonobuoy refraction profiles (Holmes and Fisher, 1979) were first used to construct an average thickness versus reflection time curve for the "normal" gas-free section in Norton basin.

The next step was to carefully measure reflection times to several marker horizons which can be traced across a pull-down zone. The reflection times measured from the single channel seismic sections were first corrected for source to receiver offset using the formula

$$T_v^2 = T_r^2 - \frac{x^2}{V_o^2}$$

where T_r = apparent reflection time from the record, x = source to receiver offset, V_o = compressional velocity just beneath the sea floor (1.60 kn/see), and T_v = corrected (normal incidence) reflection time.

The depth to a given reflector could then be determined using the equation for the depth (thickness) versus reflection time curve derived from the sonobuoy measurements:

$$D = 0.80 T_v + 0.167 T_v^2$$

It was then possible to construct average velocity curves for both the normal zones and the gas-charged zones:

$$\bar{V}^2 = \frac{4 D^2 + x^2}{T_v^2}$$

where T_v = corrected vertical reflection time to a given reflector in the normal zone and to that same reflector in the pulled-down (gas-charged) section. These average velocity curves can then be used to compute interval velocities in each zone.

In actual practice, reflectors were picked at time ncrements of O. see, and these intervals were carried through the entire chain of calculations. Figure 11 is an examp'e of such an analysis of the pull-down zone over the gas seep shown in Figure 6. The analysis extends only to a subbottom depth of 640 m; the extent and character of the acoustically anomalous zone beneath the seep area prevents accurate picking of pulled-down reflectors below that depth. However, the general trend of the average and interval velocity curves for the gas-charged zone beneath the seep suggest that the *entire* section above basement (about 1.3 km) probably contains enough gas to significantly lower compressional velocity.

The interval velocity curve can also be used as a qualitative indicator of gas concentration in the sedimentary section. Figure 11 snows that compressional velocity reaches a minimum of 1.21-1.24 km/sec between 250-440 m subbottom depth. This represents a decrease of about 35 per cent from the velocity one would expect at that depth in a normal sedimentary section. if the interval velocity curve could be constructed for the entire section down to basement, it might exhibit several minima similar to the one shown in Figure 11. These minima are probably an expression of a change in sediment or rock type which allows gas to be concentrated in those horizons.

POSSIBLE SOURCES OF GAS

The distribution of acoustic anomalies (Figs. 3 and 4) suggests that near-surface accumulations of gas are most common in the central part of Norton basin northwest of the Yukon River delta. The apparent gas-free zones along the southern and eastern shores of Norton Sound (Fig. 3) are due to the absence of data from these very shallow water areas. Such is not the case for western Norton basin, however. Seismic reflection coverage is good (Fig. 2); there are simply few occurrences of acoustic anomalies.

The possible sources of the gas are still being investigated. The gas seep south of Nome is the only well-substantiated source of low molecular weight hydrocarbon gases and carbon dioxide indicative of a deep thermogenic origin (Cline and Holmes, 1978; Nelson et al., 1978; Kvenvolden et al., 1979.

Carbon isotope measurements on the CO_2 and CH_4 components yielded $\delta^{13}C$ values (relative to PDB) of -.27% and -3.6%, respectively (Kvenvolden et al., 1979). Holmes and Cl ine(1979) have *used* these data to estimate the source depth of these seep gases. ,4 $\delta^{13}C$ value of -3.6% is characteristic of methane from a depth of about 2500 m (Gal imov, 1969). This greatly exceeds basement depth (850-1450 m) beneath the seep, suggesting that the gas has migrated to the seep area from the deeper central portion of Norton basin. The southerly dip of beds and unconformities as well as numerous faults observed on the reflection records over the seep also support such an interpretation.

The location of many of the other reflector termination zones, especially in Norton Sound, coincides with known occurrences of buried tundra-derived peat deposits which were formed during low sea-level stands in the Quaternary (Nelson and Creager, 1977). Biogenic methane and carbon dioxide generated in these peat beds could cause the observed anomalous acoustic responses (Kvenvolden et al. , in press); the peat layers themselves could also act to trap upward migrating petroleum-derived gases. A velocity analysis simi ar to the one previously discussed for *the* seep zone was performed for an acoustic anomaly associated with a suspected peat deposit, Although the reflector termination anomalies usually associated with this type of gas accumulation make it difficult to trace reflector pull-downs, preliminary results suggest that the gas has accumulated in near surface horizons up to a few tens of meters thick. Compressional velocity in these layers is approximately 1.5 km/see, or about 7 percent less than in the surrounding gas-free sediment.

The absence of acoustic anomalies(gas-charged sediment) in western Chirikov basin is probably due to the different types of Quaternary deposits. Chirikov basin was extensively glaciated during the Pleistocene (Grim and McManus, 1970); the boundary between the glaciated and unglaciated terrain corresponds closely with the eastern limit of acoustic anomalies in Figs. 3 aiid 4. The Quaternary glacial and glacio-marine sediments deposited in Chirikov basin do not have a high potential for biogenic gas generation because advance and retreat of the ice sheets evidently destroyed or prevented the growth of tundra-derived peats common to Norton Sound. Also, the relatively thin Tertiary sedimentary section beneath Chirikov basin has not attained sufficient thickness to subject the basal sediments to the temperatures and pressures required for the generation of hydrocarbon gases.

SUMMARY

The distribution of acoustic anomalies indicates that almost 7000 km^2 of seafloor in Norton Sound and Chirikov basin is underlain by sediments containing sufficient gas to affect sound transm ssion through these zones. A method of indirectly determining compressional velocity in the gas-charged zones gave values from 7 to 35 per cent ower than would be expected in the case of gas-free sediment. The cause of one of he anomal ies, that associated with the Norton basin gas seep, is we 1 documented. Here thermogenic gases are seeping to the surface along a system of basic margin faults. Although other undiscovered seeps of the thermogenic gas may exist in Norton Sound or Chirikov basin, most of the acoustic anomal ies in this area are probably caused by biogenic gases generated in buried peat layers. Further detailed processing and analysis of the seismic data will possibly permit quantitative estimates to be made of the amounts of gas present in these acoustically anomalous zones.

REFERENCES

Cline, J.D., and Holmes, M.L. (1977) Submarine seepage of natural gas in Norton Sound, Alaska. Science 198, 1149-1153.

_____ (1978) Anomalous gaseous hydrocarbons in Norton Sound: Biogenic or thermogenic? Proceedings, Offshore Technology Conference, Houston, p. 81-86.

Cooper, A.K. (1978) Hydrocarbon prospects for the frontier abyssal areas of the Bering Sea. The Oil and Gas Journal, Oct. 23, p. 196-201.

Craft, Cl. (1973) Detecting hydrocarbons--for years the goal of exploration geophysicists. The Oil and Gas Journal, Feb. 19, p. 122-125.

Galimov, E.M. (1969) Isotopic composition of carbon in gases of the crust. International Geology Review 11, 109,2-1104.

Grim, P_?.S., and McManus, D.A. (1970) A shallow seismic-profiling survey of the northern Bering Sea. Marine Geology 8, 293-320.

Holmes, M.L., and Cline, J.D. (1978) Geological setting of the Norton basin gas seep. Proceedings, Offshore Technology Conference, Houston, p. 73-80.

_____ (1979) Source depth and geologic setting of the Norton basin gas seep. Journal of Petroleum Technology 31, 1241-1248.

Holmes, M.L., and Fisher, M.A. (1979) Sonobuoy refraction measurements from Norton basin, northern Bering Sea. Program, Amer. Assoc. Petroleum Geologists Annual Convention, Houston, p. 104 (abs).

Kvenvolden, K.A., Nelson, C.H., Thor, D.R., Larsen, M.C., Redden, G.D., and Rapp, J.B. (1979) Biogenic and thermogenic gas in gas-charged sediment of Norton Sound, Alaska. Proceedings, Offshore Technology Conference, Houston, p. 479-486.

Lindsey, J.P., and Craft, C.I. (1973) How hydrocarbon reserves are estimated from seismic data. World Gil, Aug. 1, p. 23-25.

Mavko, G,M., and Nur, A., (1979) Wave attenuation in partially saturated rocks. Geophysics 44:161-178.

McManus, D.A., Venkatarathnam, K., Hopkins, D.M., and Ne son, C.H. (1974) Yukon River sediment on the northernmost Bering Sea shelf. Journal of Sedimentary Petrology 44, 1052-1060.

Nelson, C.H., Hopkins, D.M., and Scholl, D.W. (1974) Cenozoic sedimentary and tectonic history of the Bering Sea. In D.W. Hood and E.J. Kelley (eds.) Oceanography of the Bering Sea, University of Alaska, Inst. Marine Sciences, p. 485-516.

Nelson, C.H., and Creager, J.S. (1977) Displacement of Yukon-derived sediment from Bering Sea to Chukchi Sea during Holocene time. Geology 5, 141-146.

Nelson, C.H., Kvenvolden, K., and Clukey, E.C. (1978) Thermogenic gases in near-surface sediments of Norton Sound, Alaska. Proceedings, Offshore Technology Conference, Houston, p. 2623-2633.

Savit, C.H. 974) Bright spot in the energy picture. Ocean Industry, Feb., p 60-65.

Walton, F.W. Perry, R.B., and Greene, H.G. (1969) Se smic reflection profiles, northern Bering Sea. Environmental Science Services Administration Operational Data Report C &GSDR-8, 26 p.

FIGURE CAPTIONS

FIGURE 1. Location map of study area showing Norton Sound, Chirikov basin, and the Norton basin gas seep (Cline and Holmes, 1977; Holmes and Cline, 1979).

FIGURE 2. Seismic reflection tracklines in the northern Bering Sea. Cruise dates and sound sources used are also shown.

FIGURE 3. Location of anomalous near-surface acoustic responses observed on single channel air-gun and minisparker seismic reflection records from Norton Sound and Chirikov basin. Also shown are the locations of the Norton basin gas seep (Cline and Holmes, 1977), and the seismic record sections shown in Figures 5,6,7,10.

FIGURE 4. Location of anomalous near-surface acoustic responses observed on Uniboom reflection records from Norton Sound and Chirikov basin.

FIGURE 5. Seismic reflection record across the Norton basin gas seep zone. Location of line shown in Figure 3. Tnis record shows two types of acoustic anomalies indicative of gas in the sediment: Reflector terminations and reflector pull-downs.

FIGURE 6. Single channel reflection record across the Norton basin gas seep area. Location of line shown in Figure 3. Reflector termination zone and marginal pull-downs are clearly shown.

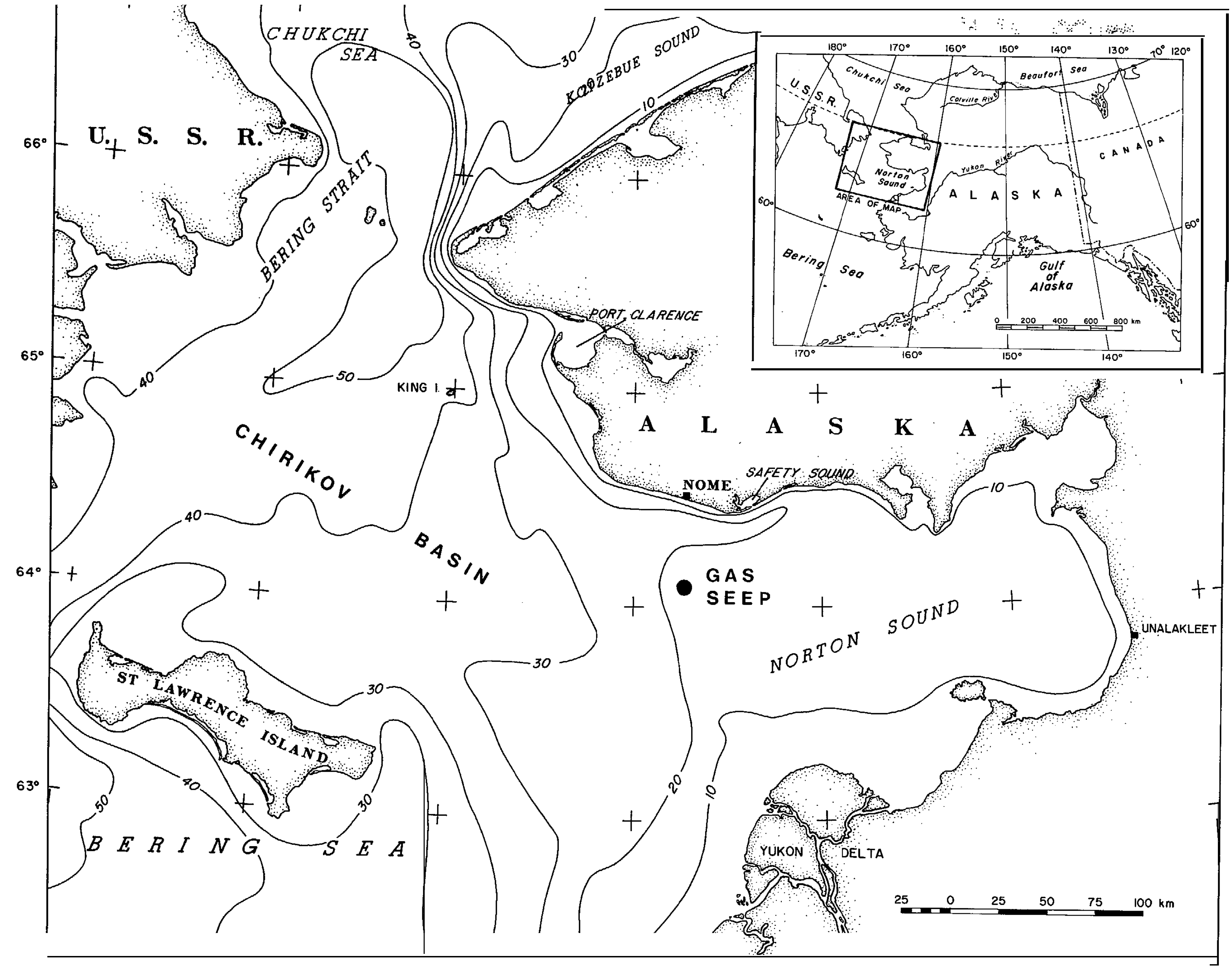
FIGURE 7. Single channel seismic reflection record from eastern Norton basin showing "normal" reflector zones and typical reflector termination anomalies. Location of line is shown in Figure 3.

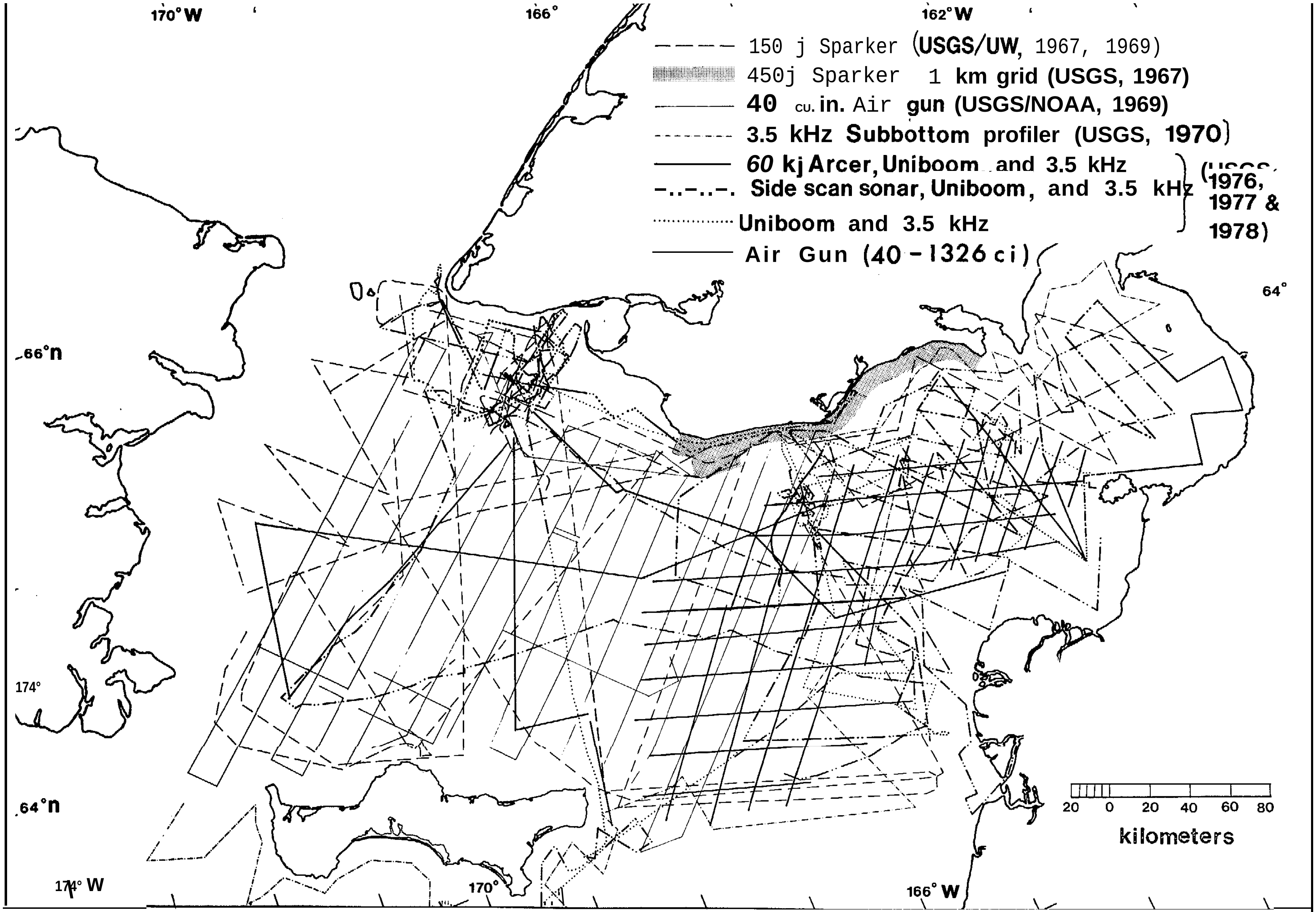
FIGURE 8. Multichannel shot record over "normal" reflector sequence shown in Figure 7. Refracted headwaves (H), and reflected arrivals (R) are clearly visible.

FIGURE 9. Multichannel shot record over the gas seep reflector termination anomaly shown in Figure 6. All arrivals are markedly attenuated due to gas in the near surface sediment. Amplifier settings slightly higher than in Figure 8.

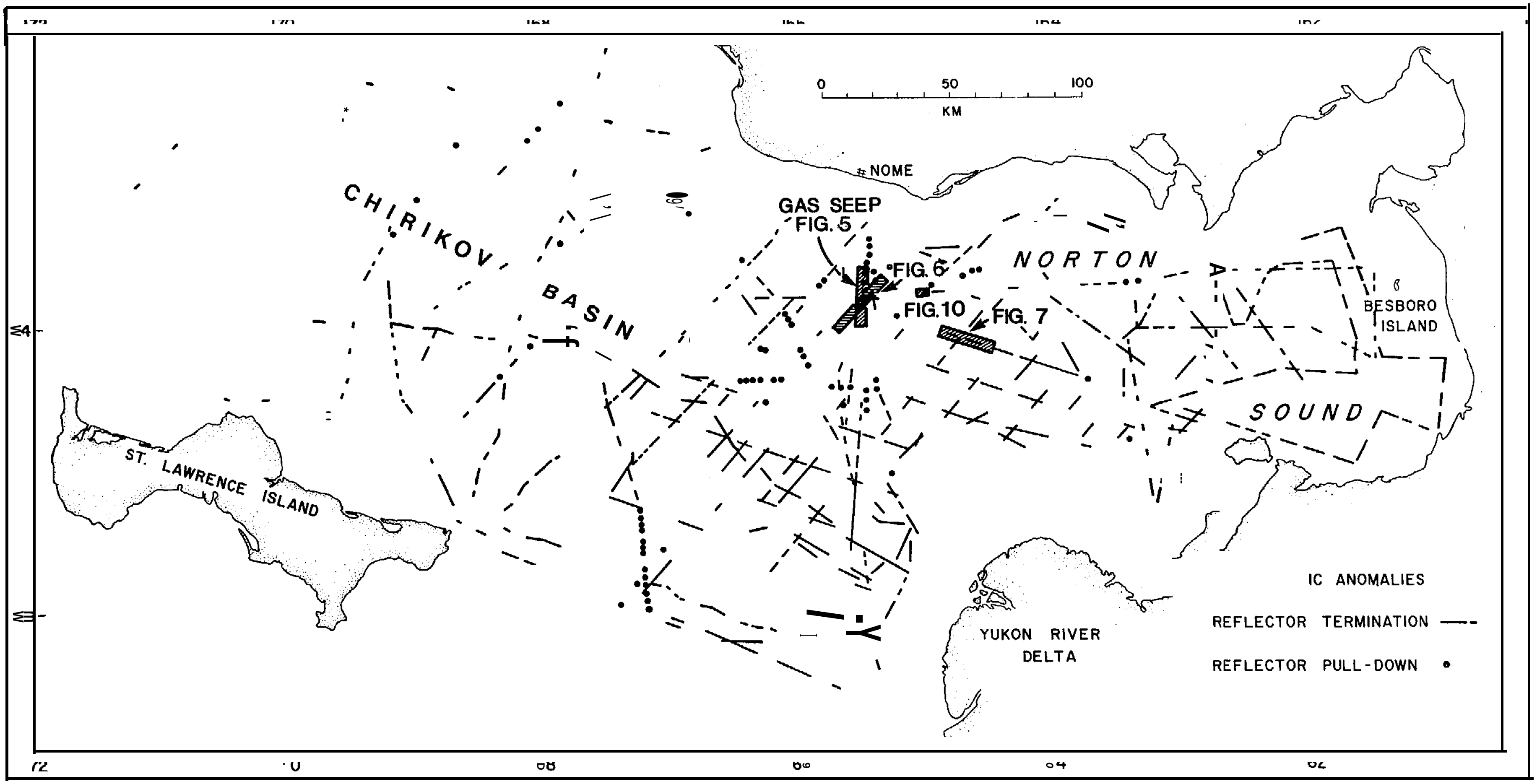
FIGURE 10. Minisparker (800 joules) record from Norton basin showing reflector termination anomaly with near-surface diffractions. Location of line is shown in Figure 3.

FIGURE 11. Velocity analysis of reflector pull-down zone beneath the Norton basin gas seep (Fig. 6). The two right hand curves show average and interval velocity versus depth in the gas-free reflector sequence outside the seep zone. The two curves on the left are for the gas-charged section beneath the seep itself.

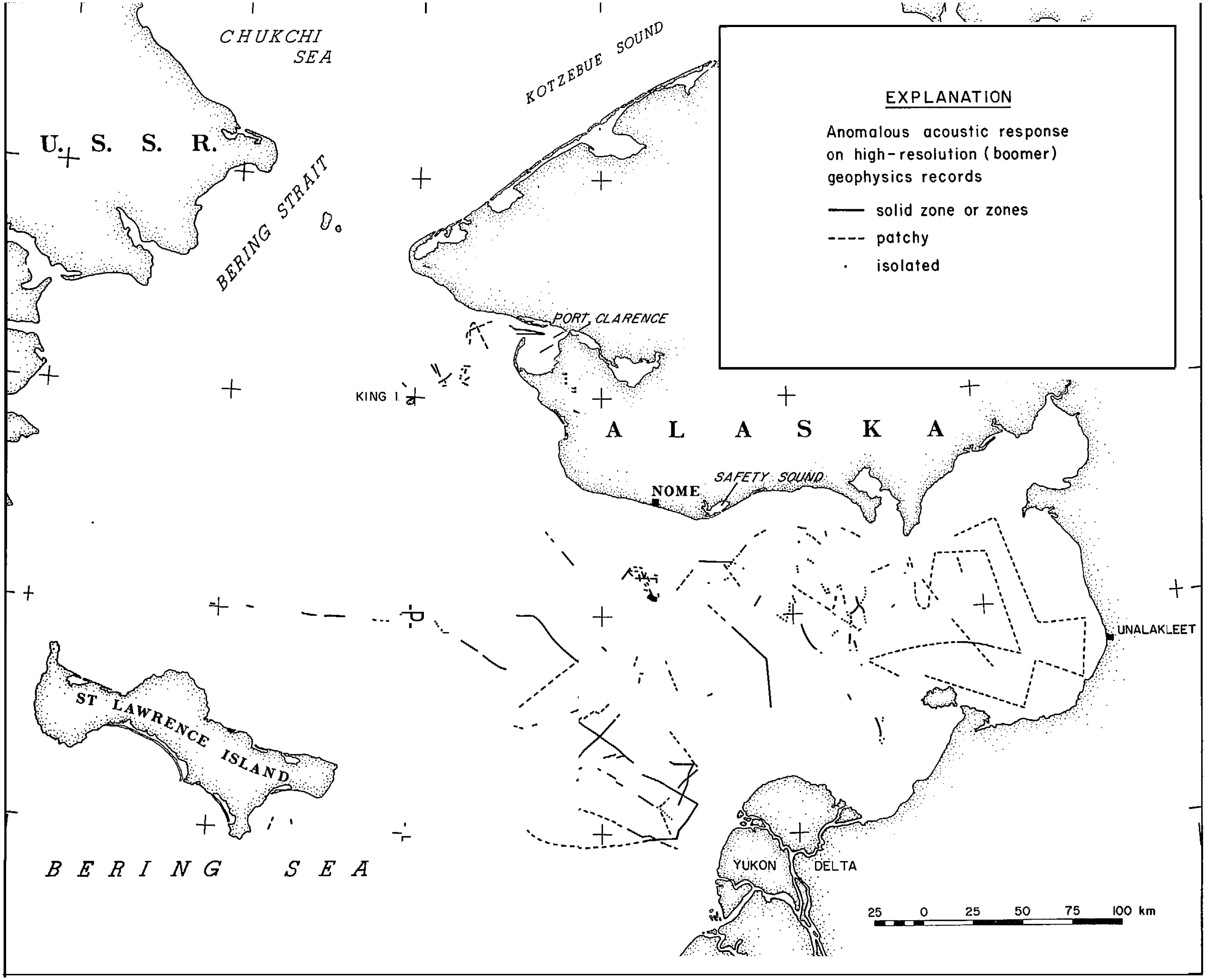

CHUKCHI SEA
KOTZEBUE SOUND
U. S. S. R.
BERING STRAIT
KING I.
CHIRIKOV BASIN
ALASKA
PORT CLARENCE
NOME
SAFETY SOUND
GAS SEEP
NORTON SOUND
UNALAKLEET
ST LAWRENCE ISLAND
BERING SEA
YUKON DELTA
66°
65°
64°
63°
10
20
30
40
50
25 0 25 50 75 100 km
U.S.S.R.
Chukchi Sea
Beaufort Sea
Colville River
Yukon River
CANADA
Norton Sound
AREA OF MAP
Bering Sea
Gulf of Alaska
0 200 400 600 800 km
180°
170°
160°
150°
140°
130°
120°
70°
60°

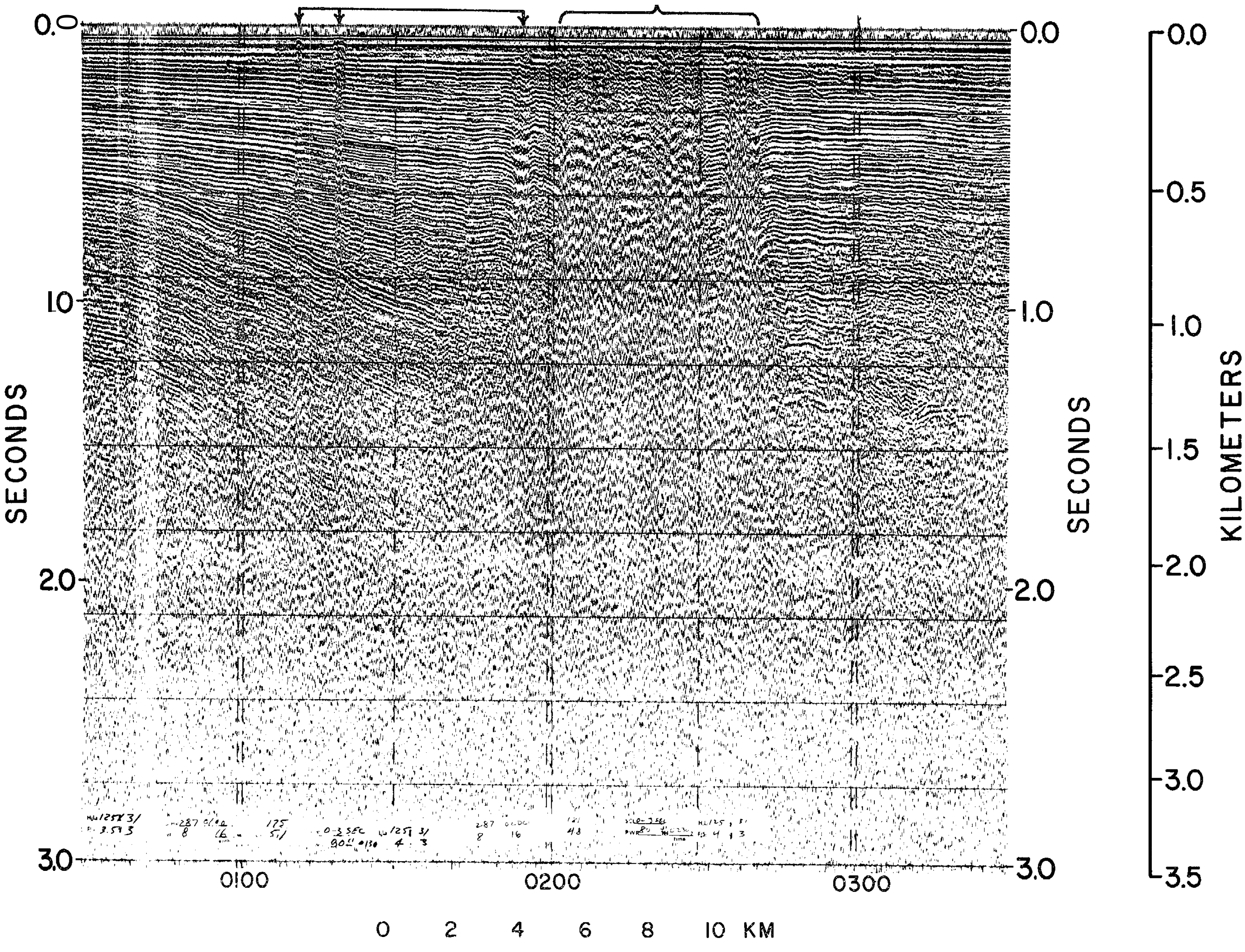


170° W
166°
162° W
150 j Sparker (USGS/UW, 1967, 1969)
450j Sparker 1 km grid (USGS, 1967)
40 cu. in. Air gun (USGS/NOAA, 1969)
3.5 kHz Subbottom profiler (USGS, 1970)
60 kj Arcer, Uniboom and 3.5 kHz
Side scan sonar, Uniboom, and 3.5 kHz
Uniboom and 3.5 kHz
(USGS, 1976, 1977 & 1978)
Air Gun (40 - 1326 ci)
64°
66°n
174°
64°n
174° W
170°
166° W
20 0 20 40 60 80
kilometers

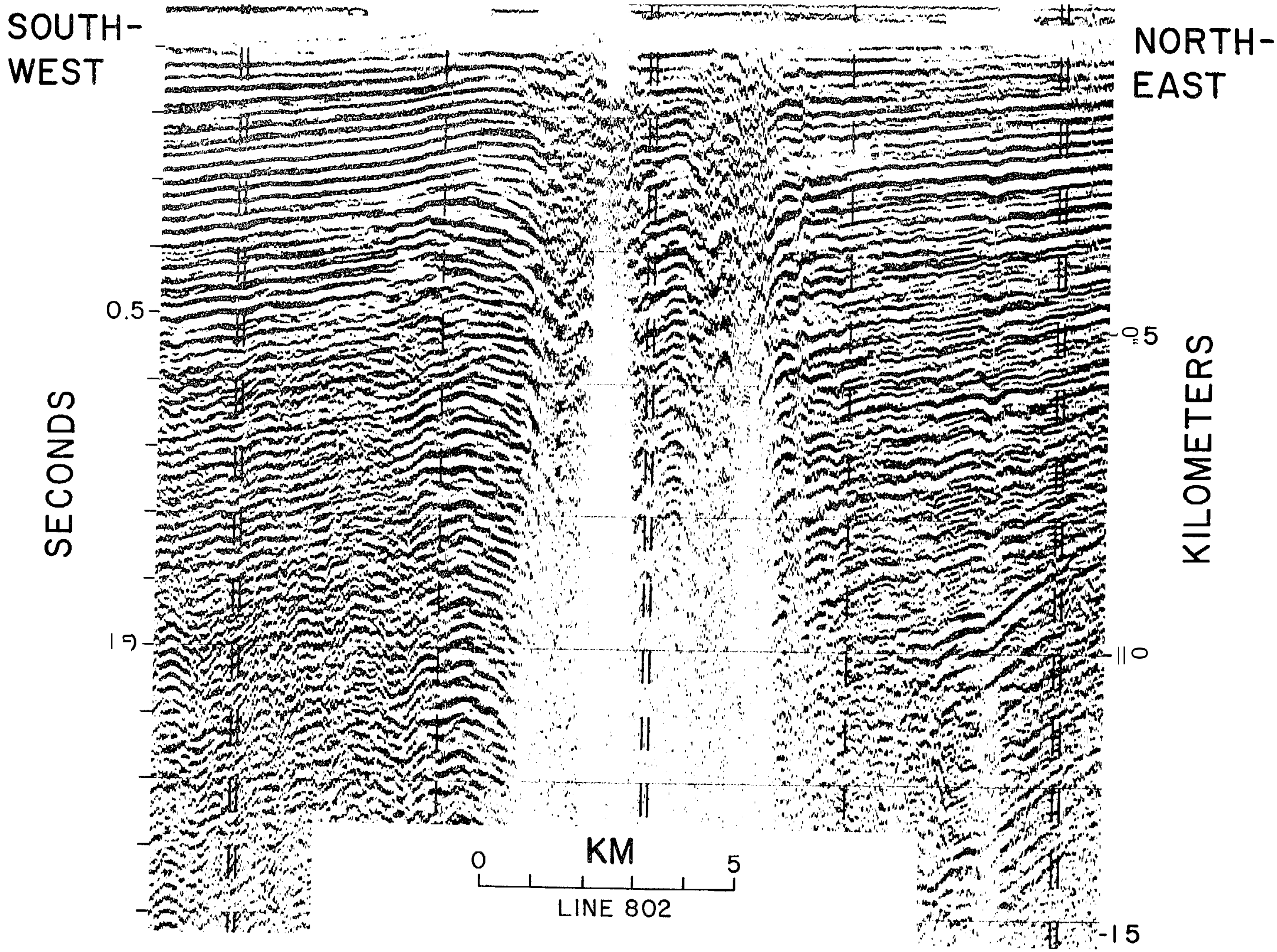


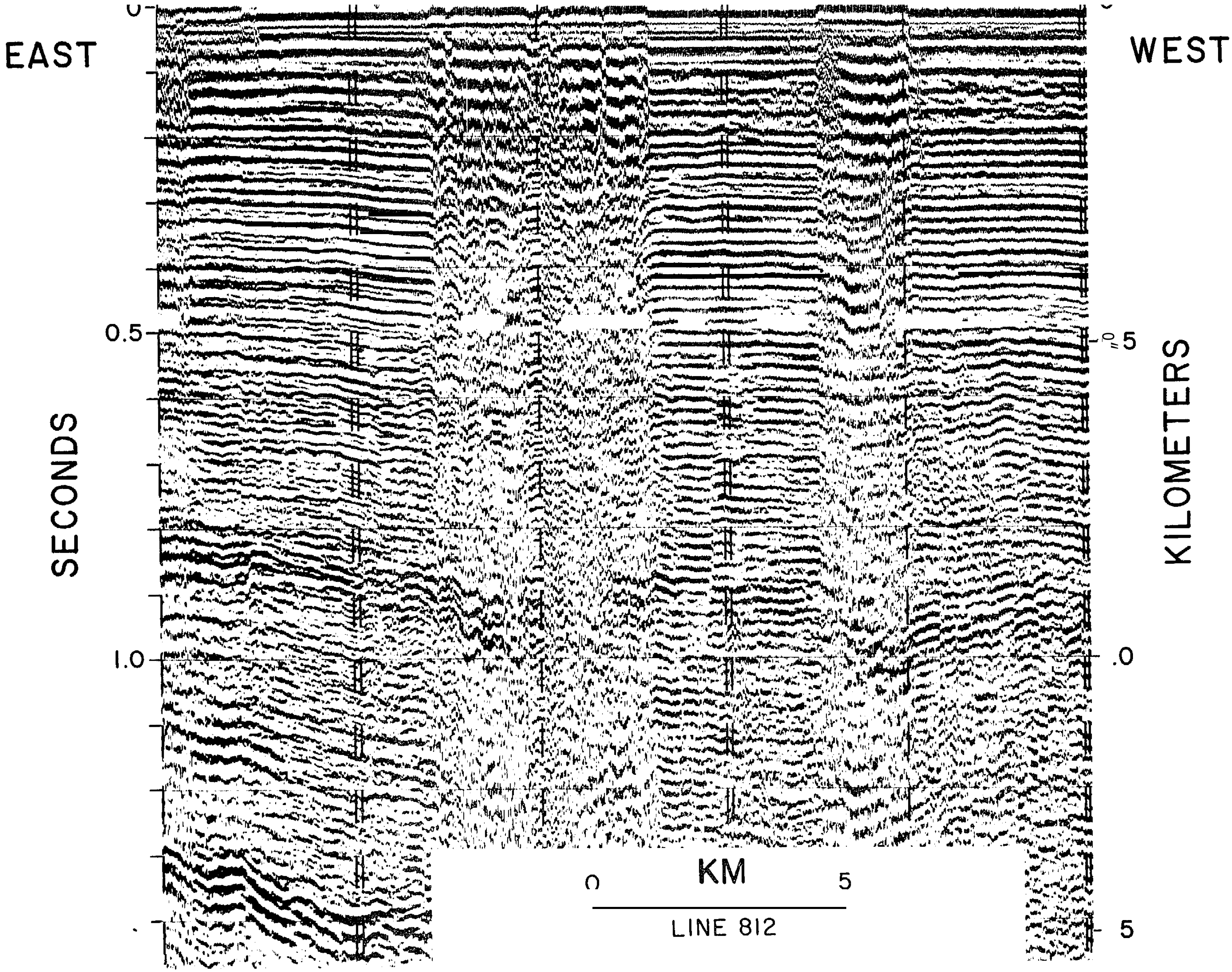
0 50 100
KM
NOME
GAS SEEP
FIG. 5
FIG. 6
FIG. 10
FIG. 7
NORTON
SOUND
BESBORO
ISLAND
CHIRIKOV
BASIN
ST. LAWRENCE ISLAND
YUKON RIVER
DELTA
IC ANOMALIES
REFLECTOR TERMINATION
REFLECTOR PULL-DOWN


EXPLANATION
Anomalous acoustic response on high-resolution (boomer) geophysics records
solid zone or zones
patchy
isolated
CHUKCHI SEA
KOTZEBUE SOUND
U. S. S. R.
BERING STRAIT
PORT CLARENCE
KING I.
A L A S K A
SAFETY SOUND
NOME
UNALAKLEET
ST LAWRENCE ISLAND
YUKON
DELTA
BERING SEA
66°
65°
64°
63°
25 0 25 50 75 100 km



SECONDS
0.0
1.0
2.0
3.0
0100
0200
0300
0 2 4 6 8 10 KM
KILOMETERS
0.5
1.5
2.5
3.5

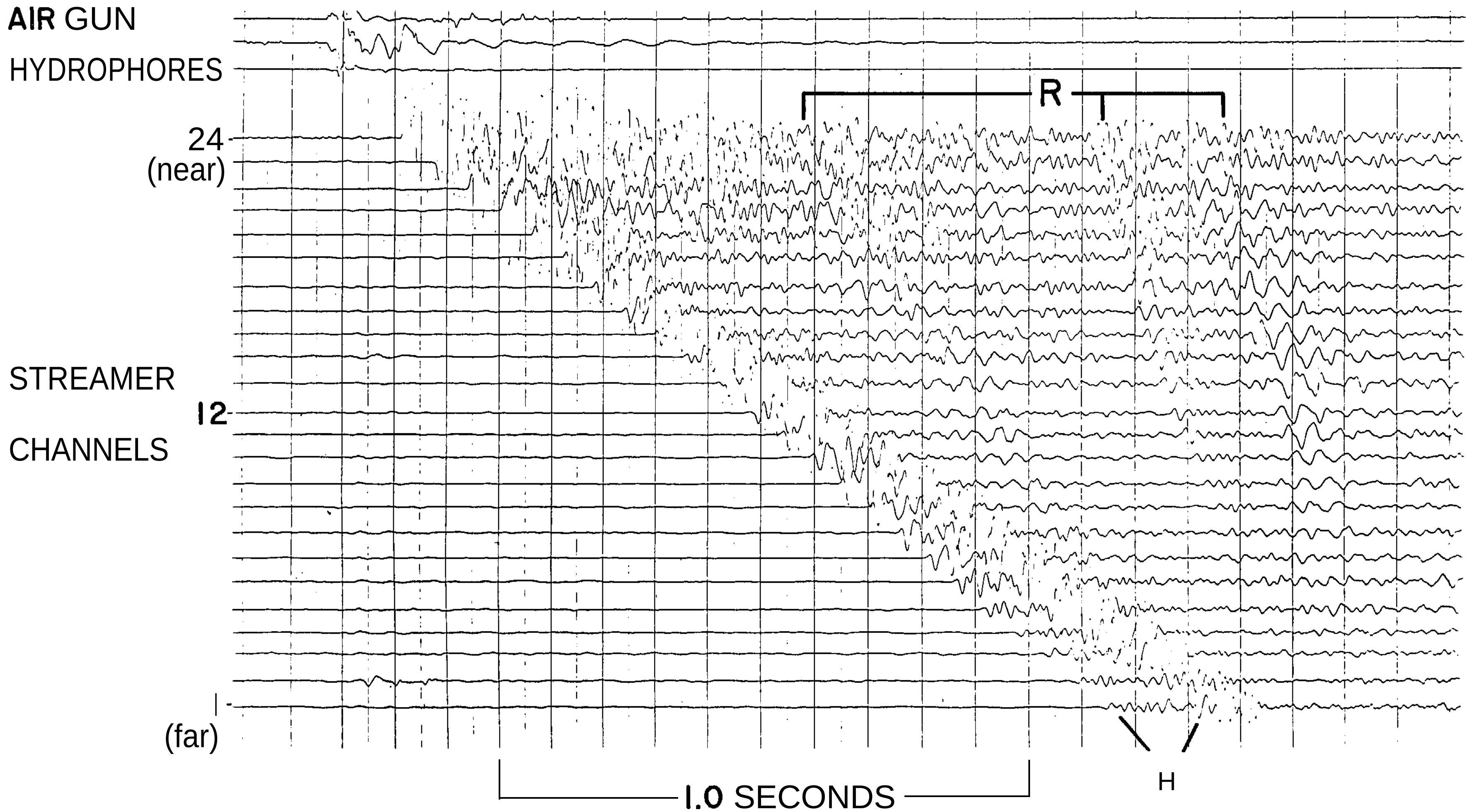

SOUTH-
WEST
NORTH-
EAST
0.5
1.5
SECONDS
0.5
0
-1.5
KILOMETERS
0
KM
5
LINE 802



EAST
WEST
SECONDS
KILOMETERS
0
0.5
1.0
.5
.0
5
0
KM
5
LINE 812

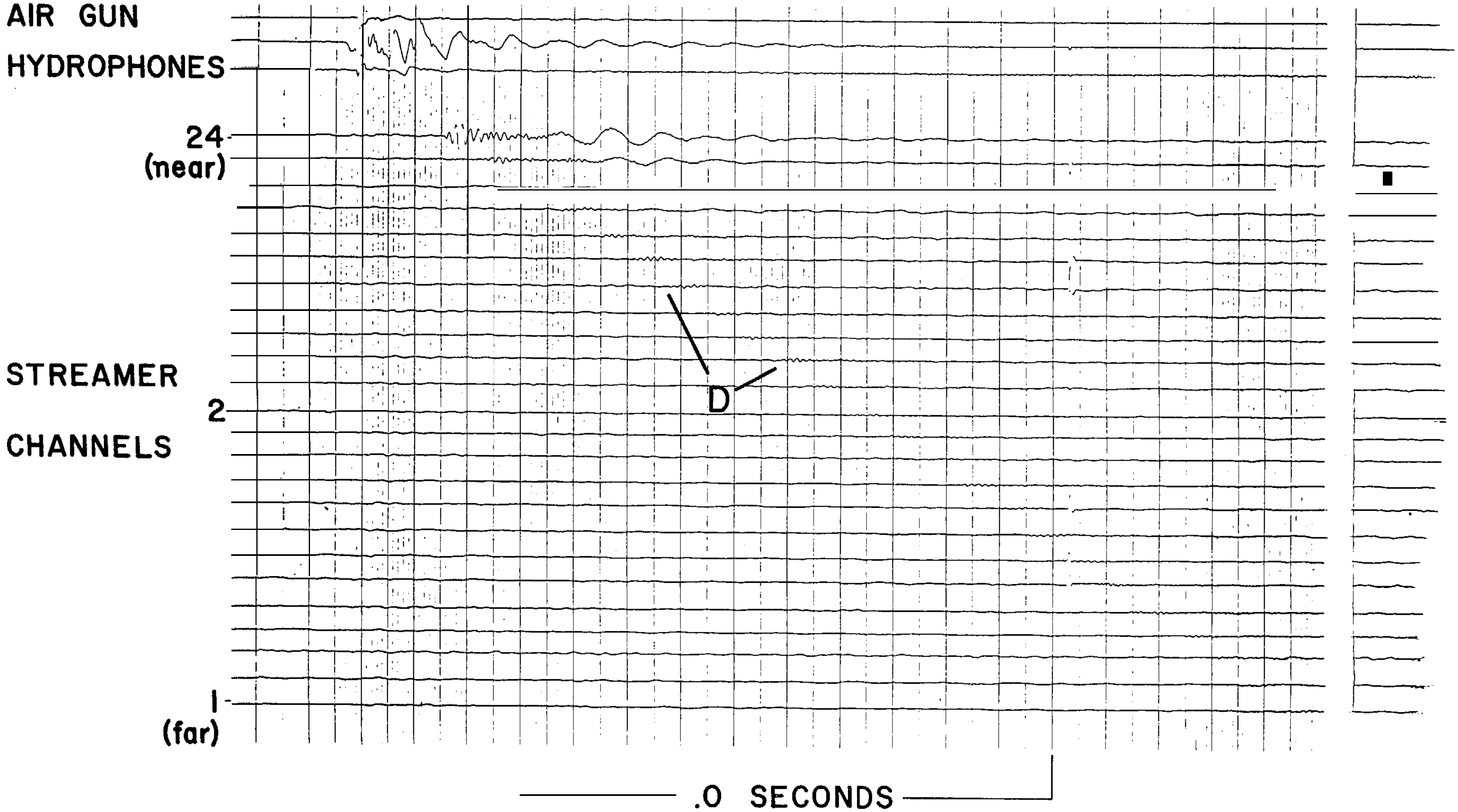
SHOT RECORD

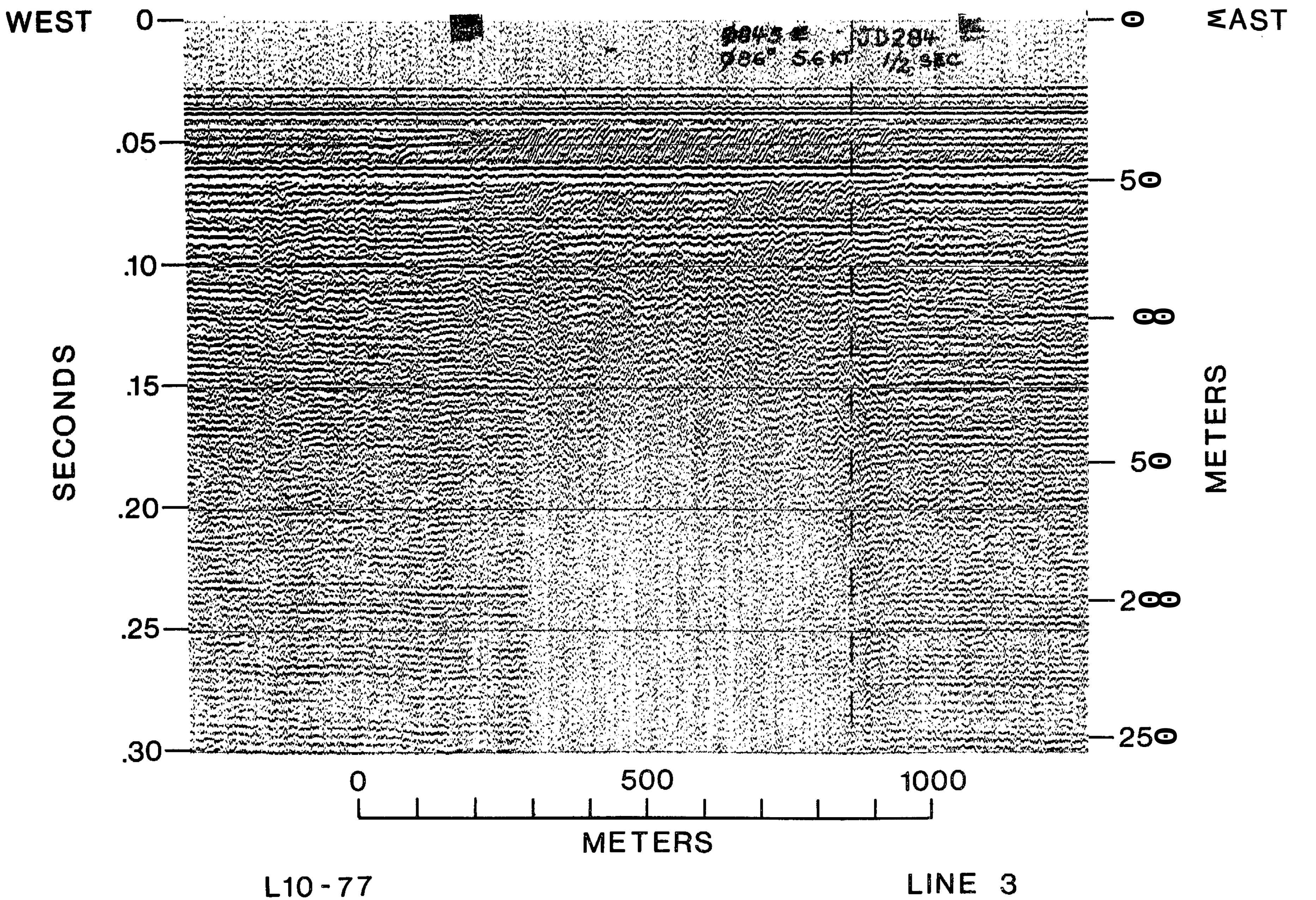
CRUISE : L4-78-BS
DATE / TIME: 225 / 0404
LINE : 812



SHOT RECORD

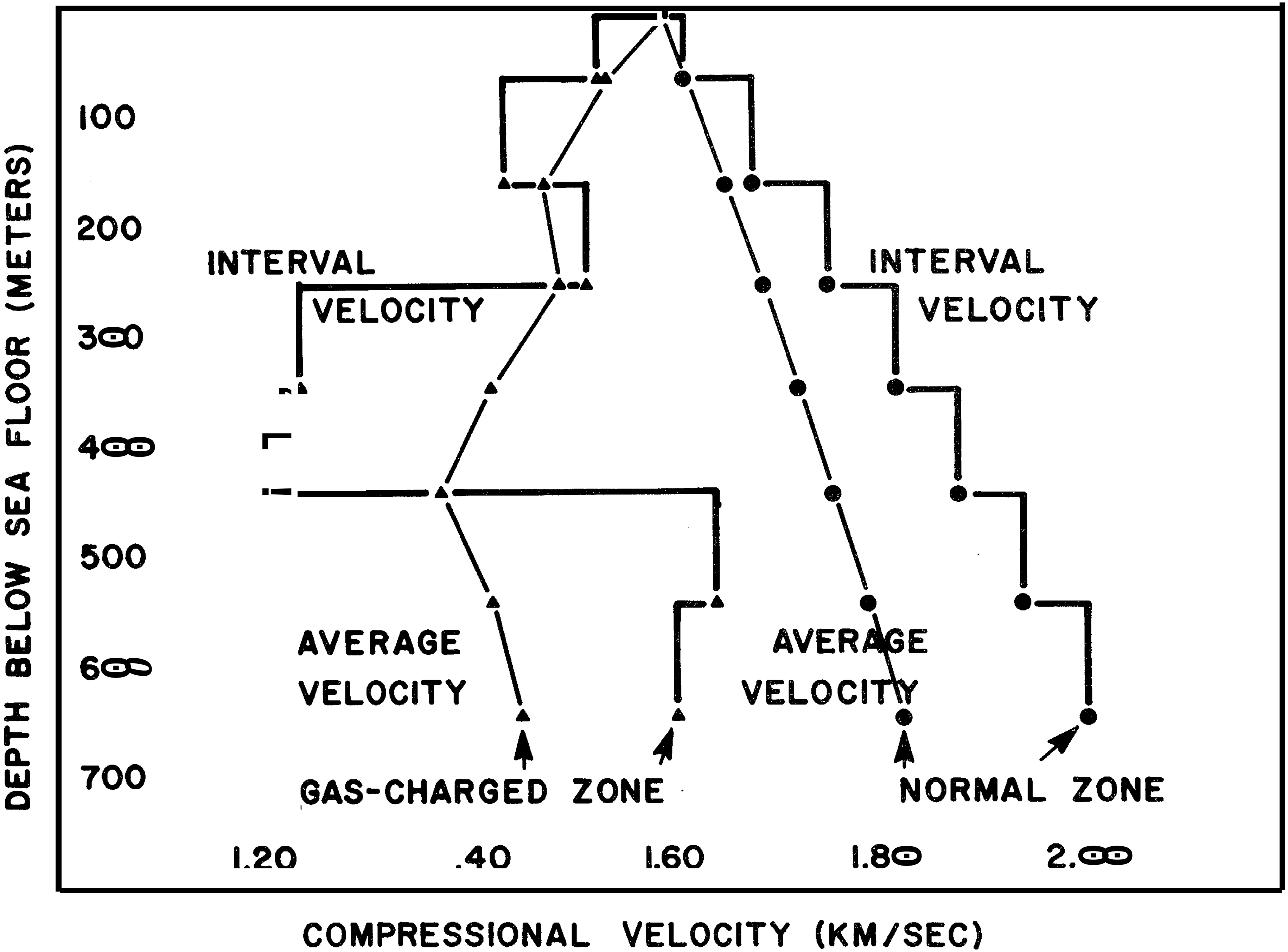
CRUISE: L4-78-BS
DATE / TIME: 220 / 0254
LINE: 802





WEST
EAST
SECONDS
0
.05
.10
.15
.20
.25
.30
METERS
0
50
100
150
200
250
0
500
1000
METERS
L10-77
LINE 3
JD284
1/2 SEC

GAS SEEP PULL-DOW NALYSIS



Sources of papers included in this volume, indicated in right margin:

Sedimentary processes and potential hazards on the sea floor of Northern Bering Sea (EBS)
by: M.C. Larsen, C-H. Nelson, and D.R. Thor

Interplay of physical and biological sedimentary structures of the Bering epicontinental shelf (EBS
by: C. H. Nelson, R.W. -Rowland, S.W. Stoker, B.R. Larsen

Ripples and sand waves in Norton Basin; bedform activity, and scour potential
by: C. H. Nelson, M.E. Field, D.A. Cacchione, D.E. Drake, and T. H. Nilsen

Graded storm sand layers offshore from the Yukon delta, Alaska
by: C. H. Nelson

Ice gouging on the subarctic Bering shelf (EBS)
by: D. R. Thor and C. H. Nelson

Liquefaction potential of the Yukon prodelta, Bering Sea (OTC)
by: E. C. Clukey, D.A. Cacchione, C.H. Nelson

Surface and subsurface faulting in Norton Sound and Chirikov Basin, Alaska
by: J. L. Johnson and M. L. Holmes

Hydrocarbon gases in near-surface sediment of northern Bering Sea (.Norton Sound and Chirikov Basin) (EBS)
by: K. A. Kvenvolden, G. D. Redden, D. R. Thor, and C. H. Nelson

Introduction to papers from Holocene Marine Sedimentation in the North Sea Basin (HMS)
by: C. H. Nelson

Late Pleistocene-Holocene transgressive sedimentation in deltaic and non-deltaic areas of the Bering epicontinental shelf (HMS)
by: C. H. Nelson

Microfaunal analysis of late Quaternary deposits of the northern Bering Sea (HMS)
by: K. McDougall

Sedimentary structures on a delta-influenced shallow shelf, Norton Sound, Alaska (HMS)
by: J. D. Howard, C. H. Nelson

Linear sand bodies in the Bering Sea epicontinental shelf (HMS)
by: C.H. Nelson, W. R. Dupré, M.E. Field, and J. D. Howard

Depositional and erosional features of the inner shelf, northeastern Bering Sea (HMS
by: R. Hunter, D. R. Thor, and M. L. Swisher

Velocity and bottom-stress measurements in the bottom boundary layer, outer Norton Sound, Alaska (HMS
by: D. A. Cacchione, D. E. Drake, P. Wiberg.

Geotechnical characteristics of bottom sediments in the northern Bering Sea (HMS
by: H. W. Olsen, E. C. Clukey, and C. H. Nelson

Distribution of gas-charged sediment in Norton Basin, northern Bering Sea (HMS
by: M. L. Holmes and D. R. Thor

APPENDIX

Following is a list of papers included in this volume. Following the paper name, in parenthesis, is the name of the journal or book in which the paper can be found, when published, in the near future. If no journal or book name follows the paper title, this indicates that the paper appears only in this open file report.

Abbreviations used:

EBS- The Eastern Bering Shelf: Its Oceanography and Resources, Hood, D.W., editor. (in press).

OTC- Offshore Technology Conference, Proceedings, Houston, TX., paper 3773.

HMS - Holocene Marine Sedimentation in the North Sea Basin, Nio, S.C., Schattenhelm, R.T., and Van Weering, T.C.E., 'editors, International Association of Sedimentologists Special Publication, Blackwell Scientific publications, London. **(in press)**.

U.S. DEPARTMENT OF THE INTERIOR
March 3, 1849