WHOI-80-2

# Woods Hole Oceanographic Institution

WOODS HOLE OCEANOGRAPHIC INSTITUTION
1930 - 1980

# REMOTE ACOUSTIC SENSING OF OCEANIC FLUID AND BIOLOGICAL PROCESSES

by

M. H. Orr

June 1980

TECHNICAL REPORT

*Prepared for the Office of Naval Research under Contract N00014-77-C-0196; NR 083-004, for the National Oceanic & Atmospheric Administration under Grants NA79AA-D-00030 (Ocean Dumping Program) and NA79AA-D-00102 (Office of Sea Grant) and for the National Science Foundation under Grant OCE 77-08682.*

*Approved for public release; distribution unlimited.*

WOODS HOLE, MASSACHUSETTS 02543

WHOI-80-2

# REMOTE ACOUSTIC SENSING OF OCEANIC FLUID AND BIOLOGICAL PROCESSES

by

M. H. Orr

WOODS HOLE OCEANOGRAPHIC INSTITUTION
Woods Hole, Massachusetts 02543

June 1980

TECHNICAL REPORT

*Prepared for the Office of Naval Research under Contract N00014-77-C-0196; NR 083-004, for the National Oceanic & Atmospheric Administration under Grants NA79AA-D-00030 (Ocean Dumping Program) and NA79AA-D-00102 (Office of Sea Grant) and for the National Science Foundation under Grant OCE 77-08682.*

Approved for Distribution Earl E. Hays
Earl E. Hays, Chairman
Department of Ocean Engineering

# Remote Acoustic Sensing of Oceanic Fluid and Biological Processes*

M. H. Orr†

Abstract--High frequency acoustic backscattering systems are being used in monostatic modes to evaluate the use of acoustic techniques to detect and study a variety of fluid processes in the oceanic environment. A short outline of those research programs actively evaluating and using acoustic techniques is presented, followed by a detailed review of this investigator's program. This program uses a multifrequency high frequency acoustic system to study a variety of processes including turbulent mixing, air-sea interactions, internal waves, interleaving water masses, natural particulate dispersion and distribution, the dispersion of particulates associated with deep ocean disposal of industrial chemical waste, and biological response to a variety of stimulae including fluid motion, predators, and oceanographic instrumentation. Graphic acoustic data records of several of the above phenomena are described.

## INTRODUCTION

REMOTE acoustic sensing of atmospheric fluid processes has, during the past 15 years, developed into an active research discipline (BROWN and HALL, 1978). There are a large number of applied and basic atmospheric research groups using the acoustic technique in both the monostatic and bistatic modes of operation. These groups study both fluid and biological processes.

---

* This contribution was delivered as an invited paper at a NOAA workshop: Ocean Acoustic Remote Sensing Workshop, Mayflower Park Hotel, Seattle, Washington, U.S.A., January 21-25, 1980. (W.H.O.I. Technical Report 80-2).

† Woods Hole Oceanographic Institution, Woods Hole, Massachusetts 02543 U.S.A. Woods Hole Oceanographic Institution Contribution No. 4559.

In contrast, the number of researchers actively using or evaluating the use of high frequency remote acoustic sensing to study oceanic fluid processes is quite limited. They are divided among several groups in the United States and Canada. Some activity in the Soviet Union also results in an occasional publication (ANDREYOVA and MAKSHTAS, 1977). The potential for using high frequency acoustics as a remote sensor for small scale fluid processes in the ocean has been recognized since at least the mid-1950's (FRASSETTO, BACKUS, and HAYS, 1962; EDGERTON, 1966; CUSHING, LEE, and RICHARDSON, 1956; SCHROEDER and SCHROEDER, 1964). Although a few people actively pursued the potential, the oceanographic community has not adopted the technique as a tool.

As an indication of the diversity of the high frequency remote acoustic sensing research groups' oceanic activities, a list of their respective interests follows. R. DAVIS and L. REGIER (1979) (Scripps Institution of Oceanography) and R. HILL (1979) (The Naval Research Laboratory) are independently modifying and evaluating the use of an Ametek Straza Doppler Shear Measurement acoustic system with the aim of measuring the water column shear from a moving ship in the upper 100-200 m of the ocean. J. PIJANOWSKI (1979) (NOAA National Ocean Survey) is evaluating a Thomson/CSF Doppler current meter, to be used in the same manner as the Ametek Straza instrument. In addition, J. EDWARD (1979) (General Electric) is developing a system (Quo Vadis) which is being adapted to measure shear using a correlation technique. The acoustic doppler and correlation systems are in a developmental and evaluation stage and are not yet used routinely in oceanographic experiments to measure shear.

At the Marine Physical Laboratory of the Scripps Institution of Oceanography (FISHER and SQUIER, 1975; SQUIER, WILLIAMS, BURKE and FISHER, 1976) have developed and used a narrow-beam 87.5 kHz echo sounder and detected the internal wave motion of multiple acoustic backscattering layers. This work has been followed by several subsequent investigations at the Marine Physical Laboratory.

G.T. KAYE has evaluated the use of acoustic systems in a monostatic pulsed backscattering mode to detect thermal structure and internal wave activity in the water column. Both an 8 kHz array on a submersible barge (KAYE and ANDERSON, 1979) and an 87 kHz transducer mounted on FLIP (KAYE, 1979) were used during the experiments. The general conclusions of the work were that acoustic systems can be used to detect internal waves and that thermal microstructure in the ocean environment can be detected. The 8 kHz acoustic detection of thermal microstructure was thought to be limited by biological backscattering contamination. The internal waves were detected by backscattering from biological scatterers which were acting as passive tracers for the water column motion.

R. PINKEL (Scripps Institution of Oceanography, Marine Physical Laboratory) has used the narrow beam 87 kHz echo sounder aboard FLIP in a doppler range gated mode to look horizontally outward to detect internal waves (PINKEL, 1979). He is replacing the 87 kHz unit with a three-axis, narrow beam, high power (32 kw) system which operates over the 65-90 kHz range. With this system, he has achieved the ability to measure doppler signals at ranges of 1.6 km. The three-axis system will be used to measure, among other things, the isotropy and frequency vs. wavenumber dependence of the internal wave fields in the immediate vicinity of FLIP.

A towed two frequency (20, 200 kHz) acoustic system has been used by J. PRONI (National Oceanic and Atmospheric Administration, Atlantic Meteorological and Oceanography Laboratory) to perform remote acoustic sensing of the ocean (PRONI and APEL, 1975; PRONI, 1978). He has detected internal waves and interleaving water masses (NEWMAN, PRONI and WALTER, 1977). He also uses his system to study the dispersion of particulates released during the ocean disposal of dredge spoils, sewage sludge, and industrial chemical wastes (PRONI, NEWMAN and SELLERS, 1976; PRONI, NEWMAN, RONA, DRAKE, BERBERIAN, LAUFER, and SELLERS, 1976).

D. FARMER (Institute of Ocean Sciences, Sidney, Canada) and J. D. SMITH (University of Washington) have been using commercially available fathometer systems in conjunction with standard oceanographic instrumentation to study fluid processes associated with a tidal flow across a sill in Knight Inlet, British Columbia (FARMER and SMITH, 1978). The fluid system is two-layer with fresh water over salt water. Their acoustic data is quite striking, revealing internal waves, shear instabilities, and hydraulic jumps in the vicinity of the sill.

The relationship between 12 kHz acoustic backscattering layers and the passage of internal wave packets have also been discussed in the literature (CURTIN and MOOERS, 1975).

The research program of this investigator has used a four-frequency towed acoustic system operated in a monostatic pulsed mode to study a variety of fluid and, on occasion, biological processes in the estuary, shelf, and open ocean (ORR and HESS, 1978a; ORR and HESS, 1978b; HAURY, BRISCOE, and ORR, 1979). The acoustic system (HESS and ORR, 1979) was developed at the Woods Hole Oceanographic Institution and has been used to study:

(1) sewage sludge and particulate distribution in Boston Harbor,

(2) fluid processes such as internal waves, shear instabilities, air-sea interactions, shelf-slope frontal zone, interleaving water masses, and

hydraulic jump and lee wave formation across sills, and

(3) the seasonal dispersion properties of particulates released or formed during industrial chemical and sewage sludge disposal at Deep Water Dumpsite 106 (DWD 106). The research has been conducted in Boston Harbor, Massachusetts Bay on the eastern continental shelf of the United States, in Puget Sound, Washington on the west coast, and in the open ocean.

## EXPERIMENTAL CONSIDERATIONS

The W.H.O.I. acoustic system operates simultaneously on four frequencies, selectable from the following frequencies or bandwidths: 15-45 kHz, 78 kHz, 200 kHz, 357 kHz, and 520 kHz. Any frequencies in the 5-800 kHz band can be utilized if the transducers are available. There is a dead band at 455 kHz ± 20 kHz. A four-frequency operating system was chosen to allow the remote determination of the dominant backscattering mechanism which allows one to detect a particular fluid process. Theoretical considerations (WESTON, 1958; TATARSKII, 1961; MUNK and GARRETT, 1973; PRONI and APEL, 1975; ORR and HESS, 1978b) indicate that the dominant mechanisms anticipated for the oceanic environment are:

(1) backscattering from laminae or isotropic temperature fluctuations which are developed during turbulent mixing events,

(2) backscattering from temperature steps or gradients, and

(3) backscattering from particulate distributions (either animate or inanimate) associated with varying water masses. For example, nearly neutrally buoyant particles, when falling through the water column, could have a tendencey to collect at density discontinuities associated with temperature or salinity steps in the water column. Consequently, an acoustic backscattering system would be able to map the location of the

density step and associated thermal step and the step's response to internal wave activity and mixing processes.

The wavelength dependence for the backscattered acoustic intensity for each of the above backscattering mechanisms is:

| | Wavelength Dependence |
|---|---|
| (1) for turbulent mixing areas | |
| (a) isotropic temperature fluctuations | $\lambda^{-1/3}$ |
| (b) laminae temperature fluctuations | $\lambda^{-2}$ |
| (2) for thermal gradients | $\lambda^{2}$ |
| (3) for backscattering from large numbers of particles in a scattering volume | $\lambda^{-6}$ |

The target strength of the backscattering from each of the above mechanisms (using numbers for temperature fluctuations, thermal gradients, and particle concentrations which are representative of oceanic conditions) varies from greater than -60 dB to less than -130 dB. This entire backscattering target strength range is detectable with high frequency acoustic systems. It is, however, detectable with a range dependence. The -60 dB target strengths should be detectable to ranges in excess of 100 m depending upon the characteristics of the high frequency acoustic backscattering system being used.

The frequency variability of the backscattered pressure signal as a function of backscattering mechanism is shown in Figure 1. This figure indicates that an acoustic system operating over the frequency range of 20 to 600 kHz should be able to identify which of the above backscattering mechanisms is the source of the backscattered acoustic energy provided only one backscattering mechanism is operational or dominant at a particular time.

It has been of concern that the dominant interference to the detection of fluid processes by physical backscattering mechanisms may come from biological scatterers which range in size from less than 1 mm to greater than meters. This is the case in many situations; not, however, to the detriment of using acoustics as a remote sensor of fluid processes. If the biological scatterers are neutrally buoyant as in the case of small phyto- and zooplankton, they act as acoustically detectable passive tracers whose motion mirrors the motion of the water column and the variability of water mass type. When the biology responds to strong thermal or density structure in the water column and group themselves near these features, the ability to acoustically detect short period internal waves or interleaving water masses is often striking. There are situations, as illustrated later in this paper, where the biology can respond to a variety of stimulations in a nonpassive manner.

The WHOI acoustic systems as mentioned operates in a monostatic pulsed mode at four frequencies. The transducers are mounted in a hydrodynamic body which is towed from a boom on the side of a ship. The tow body depth is set at 1-3 m depth depending on the sea state and ship speed. All four frequencies are operated at the same time and can provide data to ranges in excess of ≈100 m. The maximum range achievable depends upon the strength of the backscattering mechanisms, the energy content in the acoustic pulse, the transmit and receive beamwidth of the acoustic transducer, the receive sensitivity of the transducer, the attenuation of the acoustic frequency of interest, the flow noise of the hydrodynamic body and the ship's noise level at the frequencies of interest. The acoustic data is displayed on graphic acoustic records, recorded on 7 track analog tape and as deemed necessary digitized and stored on 9 track digital tape for subsequent analysis. Graphic acoustic records are produced on board ship to provide real time shipboard qualitative information concerning the distribution and position of the scatterers in the water column.

A graphic acoustic record is created in the following manner: A short acoustic pulse is repeatedly projected downward perpendicular to the water surface. The acoustic energy reflected by various scatterers distributed throughout the water column is detected, amplified, and then plotted with a graphic recorder. The graphic recorder displays a varying gray level proportional to the reflected signal level from the transducer depth (usually 1-3 m below the surface) to the maximum depth plotted. The display plots many backscattered signals side by side and allows the eye to discern variations in gray scale as a function of time and interpret the records in terms of the presence or absence of scatterers in the water column.

Figure 2 is an example of a grey scale acoustic record. It should be noted that the darkness of the record at a given point in time and depth is dependent on the pressure amplitude of the scattered sound from that depth. Time progresses from left to right and the depth scale is noted from the top to the bottom of the record. In this case particles are the dominant scatterers in the water column. For a constant particle concentration as a function of depth, the intensity of the reflected sound would decrease with increasing depth due to attenuation and transmission loss. The time varying gain normally used in acoustic systems can compensate for transmission loss, but not usually attenuation loss. The darkness at a given depth of any area of the graphic record that is not totally black is roughly proportional to the square root of the number of particles at that depth. Equal gray scales at different depths do not imply that the particle concentration is the same at those depths unless proper electronic time varying gain compensation have been used.

## RESULTS

The remainder of the paper will be used to illustrate the types of phenomena which have been detected with the W.H.O.I. high frequency acoustic backscattering system. The data will illustrate the ability of the acoustic systems to detect a variety of fluid processes and to detect the vertical and horizontal dispersion of particulates in the open ocean. The illustrations will progress from the eastuary zone to the open ocean.

Boston Harbor. The particle distribution in Boston Harbor has been studied for the past two years with the object of determining the distribution of particle concentrations in and outside the harbor (FITZGERALD, MILLIMAN, ORR, AND BOTHNER, 1979). Large quantities of particles are released from the Deer Island municipal waste treatment plant's settling tanks. The release occurs at the beginning of ebb tide. The acoustic system has been used as part of this study to detect the particles at release, to determine both the areal extent (in the vertical and horizontal) of the plume and the tidal variability of the particle burden at 24-hour anchor stations. The acoustic system has been quite helpful in determining the particle depth distribution and areal extent of the plume such that water samples could be obtained from areas of highest particle contrast. Mixing mechanisms at the salt water interface which exists near the harbor entrance have also been identified. Figure 2 is representative of the acoustic records obtained near the Deer Island outfall. It shows a plume of materials rising from the outfall and the particle distribution in the immediate vicinity of the outfall. During surveys of the particle distribution in Boston Harbor, the acoustic system has discovered previously unknown locations where broken sewage pipes were releasing material into the harbor.

Massachusetts Bay. Short period internal waves are known to propagate through Massachusetts Bay. They are generated on the incoming tide by the propagation of a lee wave across Stellwagen Bank (HAURY, BRISCOE, and ORR, 1979), as shown in Figure 3. The acoustic system was used during an interdisciplinary experiment to detect the internal wave field and to remotely determine the biological response to its passage.

A typical acoustic record taken over Stellwagen Bank during the passage of the lee wave is shown in Figure 4. The backscattered signal (200 kHz, monostatic pulsed mode) is reflected from a region of high shear and turbulent mixing (arrow 1). Temperature records obtained with a CTD (arrow 2) showed a high variability when the heavy acoustic scattering areas came to the CTD's depth of deployment. The acoustic records show areas of distinct shear instabilities (arrow 3) and the development of "cats eye" type turbulent mixing areas (arrow 4). The acoustic backscattering is thought to be from temperature fluctuations caused by mixing in a high shear zone. Atmospheric acoustics researchers (BROWN and HALL, 1978) have concluded that the same backscattering mechanism allows detection of mixing events in the first 1-3 km of the atmosphere.

The distinction between biological scattering and backscattering from high shear areas is brought out in Figure 5. An internal wave field (wavelength approximately 200 m) propagating through Massachusetts Bay is shown. Two backscattering mechanisms allow the detection of the internal wave: (1) backscattering from particulates (arrow 2) which, in this case, are biological organisms, zooplankton, which appear to respond to the short period internal wave field as passive traces on the water column, and (2) backscattering from temperature fluctuations which develop in an area of high shear (arrow 4). Note that the heavy acoustic scattering area which marks the discontinuity between the mixed layer and the temperature gradient below it does not appear until the vertical displacement of the water column is near its maximum. At this point the diffuse, but narrow in vertical extent, scattering appears and becomes more intense as one proceeds to the rear of the lobe. The acoustic system is detecting a mixing area and it is believed that the intensity of the signal is proportional to both the energy dissipation rates and the cell size of the dissipation.

One of the goals of the research program has been to obtain collaborative and simultaneous data from free-fall CTD fine and microstructure devices such that acoustic backscattering levels can be compared to theoretically predicted backscattering levels using structure factors determined from the *in situ* measurements. Also, the threshold levels, in terms of dissipation rates, at which the turbulence can be acoustically detected need to be determined. With proper calibration, it is anticipated that the acoustic systems could be used to remotely estimate dissipation rates. This goal is proving elusive due to the transient nature of the acoustically detectable turbulence and the difficulties of placing *in situ* measuring instruments into the areas of mixing at the same time acoustic records are being obtained.

In several instances during the Massachusetts Bay experiment, large scale Kelvin-Helmholtz shear instabilities were detected in association with the internal wave fields. The most spectacular event is shown in Figure 6. The diagonal lines are caused by acoustic backscattering from a yo-yo CTD which was being lowered and raised from a drifting research vessel. The density profiles calculated from the CTD measurements are overlain on the acoustic records (HAURY, BRISCOE, and ORR, 1979). The data was taken in the first lobe of an internal wave field which was passing the drifting ship. The down-thrust of the internal wave was seen as the vertical displacement of point scatterers (arrow 1). The increase in a diffuse acoustic backscattering (arrow 2) started near the base of the mixed layer. The density profile becomes quite ragged as the diffuse acoustic backscattering area takes on the characteristic form of Kelvin-Helmholtz shear instabilities. Note the strong density inversions (arrow 3) corresponding to the regions where the cold dense water below the mixed layer has been thrust into the mixed layer water. The large scale shear instabilities (arrow 4) are being outlined by small scale shear instabilities (arrow 5) which evidently have large enough temperature variability and the correct cell size (approximately 3.5 mm) for backscattering of a 200 kHz pulse ($\lambda \approx 7.5$ mm).

An example of short period internal wave breakdown as it approached shallow water is displayed in Figure 7. The symmetric wave field outlined by the dark scattering areas associated with shear near the mixed layer boundary is seen to break down in the fourth lobe (arrow 2) into an area of heavy mixing which appears to be caused by large scale instabilities overrunning one another (arrow 3). In addition, an area where an entire lobe (arrow 4) is overturning is outlined. This overturning has the potential of forming interleaving water masses as the cold water in the lobe is thrust over the warm water in the mixed layer. Indeed, such a sequence (Figure 8, bracket 1) was observed in another Massachusetts Bay internal wave train where layered acoustic scattering zones were detected as an internal wave field overturned. Unfortunately, no XBT data was obtained during the acoustic observations (Figure 8) to provide the magnitude of the temperature variability associated with layered structure.

Interleaving Water Masses. The acoustic systems have detected interleaving water masses and internal waves both on the outer continental shelf and in the open ocean. The open ocean data appears to be dominated by acoustic backscattering from biological organisms (particulates) whose neutral or nearly neutral buoyancy allows them to act as passive tracers of water mass motion. As an example of interleaving water mass detection with a 200 kHz acoustic system, data obtained in April 1978 at Deep Water Dumpsite 106 (depths > 1700 m, Figure 9) are displayed. An XBT taken on the same day as the acoustic record, XBT #54, is shown in Figure 10. Warm water (arrow 1) overlays a layer of cold water (arrow 2) followed by a layer of warm water (arrow 3) (Figure 10). The three layers of water are clearly distinguishable in the acoustic record as pointed to by arrows 1', 2', and 3' (Figure 11).

Internal Wave Spectra. During the JASIN experiment (Joint Air-Sea Interaction Experiment), July-September 1978, acoustic data were obtained during box tows which involved other ships moving in formation with appropriate navigation. One (the ATLANTIS II) carried CLAYTON PAULSON's (Oregon State University) thermistor string. The internal wave spectra (energy density vs. wavenumber) calculated from the digitized acoustic records obtained during one of the box tows is shown in Figure 12. This spectra is being intercompared with the towed thermistor string data of PAULSON to determine the accuracy of the acoustic data. The main point to notice in the spectra is the sharp cut-off at a wavelength of approximately 1 km and the relatively high energy density for the experiment area. A rough intercomparison with PAULSON's data indicates that the acoustic data has the right appearance and the energy density is of the same order of magnitude; more detailed intercomparison remains to be performed. Similar experiments have been performed with the Naval Research Laboratory (NRL) thermistor string group. In that case, the data were taken from the same ship, thus cross-correlation between the acoustic time series of the vertical displacement of the scattering surfaces and the vertical displacement of the isothermal surfaces detected by the thermistor chain can be calculated. This information will be used to further determine the utility of using remote acoustic sensing systems to detect fluid processes in the ocean. Acoustic data taken in a variety of places in the world's oceans are presently being digitized to determine the variability of the internal wave energy density spectra as a function of geographic location.

At this point, a small but representative portion of the work in fluid processes has been covered.

Ocean Dumping of Industrial Chemical Wastes. The NOAA Ocean Dumping Program has been studying the impact of the disposal of industrial chemical wastes at DWD 106 for the past several years. A significant problem in studying wastes in the open ocean is to determine the position of the waste field, its horizontal and vertical distribution as a function of time, and the effects of shear on the dispersion of the plumes such that meaningful chemical and biological samples can be obtained both within and outside the contaminated water column. If the industrial chemical wastes either form or have particles associated with them, acoustic systems can be used to trace the particle dispersion such that the plume can be tracked and water samples, etc. can be taken from depths which correspond to the distribution of the waste fields.

Acoustic data has been taken during the past three years, and indicates that the vertical distribution of the waste fields is seasonally dependent (ORR, BAXTER II, and HESS, 1979). That is, during the summer months there exists a sharp seasonal thermocline in the top 10-20 m of the water column which acts as an effective barrier to the penetration of the acoustically detected particulate phase of the waste field. During the winter months, the mixed layer is approximately 100-120 m in thickness and consequently the particulate phase of the wastes are distributed throughout this portion of the ocean in discrete patches. During the springtime, the shallow seasonal thermocline is being re-established and the penetration of the particulate phase of the waste field is effectively limited by the density discontinuities. These characteristics are exhibited in the acoustic data obtained during summer, winter, and springtime water conditions (Figures 13-15). Both the summertime (Figure 13) and the springtime (Figure 14) water conditions are characterized by the shallow seasonal thermocline (white arrow 1) and particle distributions which are limited in their vertical extent (white arrow 2). The wintertime condition (Figure 15) has a deep mixed layer and the corresponding greater vertical distribution of the particles (arrow 1). An analog trace of the backscattered acoustic pressure signal (Figure 16) indicates the variable distribution of the particles within a small plume which ranged from 90-110 m in vertical depth. These analog records are being digitized to determine dispersion rates; however, the problem is not easily solved due to the need for precise navigation, knowledge concerning shear, and the ability to monitor a specific plume for extended periods.

The effects of shear on the horizontal and vertical distribution of sewage sludge particles is shown in Figure 17. Note the assymetric distribution of particles in the plume due to the effects of shear. The water sampling ambiguities without acoustic guidance should be apparent. To be able to measure shear in the water column over small vertical segments (approximately 1-3 m) is necessary such that intelligent planning for ocean dumping sampling may be made on board ship. Good candidates for these shear measurements are either the acoustic doppler and correlation systems mentioned earlier or R. Drever and T. Sanford's (University of Washington) expendable shear probes (DREVER and SANFORD, 1979).

Biological Interaction. The study of biological interaction with fluid processes such as internal waves indicates, as previously discussed, that the biology which is detected most readily with 200 kHz acoustic systems responds as a passive tracer to the water motion. The biology detected with the 200 kHz systems has on occasion, however, exhibited marked mobility in response to the presence of predators (ORR, in preparation). These predator prey responses have been observed both in Massachusetts Bay and Puget Sound. They are rarely observed, but are interesting.

The Puget Sound data obtained during June 1979 (Figure 18) shows several scattering layers (arrow 1) which were detected for extended periods of time. They are seen to exhibit internal wave motions (arrow 4). On two occasions the scattering layer was observed to move vertically (arrow 2) in response to a dense school of heavy scatterers (predators) which was moving through the area (arrow 3). Due to the heavy scattering from the predator school, the response of the prey cannot be distinguished in their presence. Also due to the lack of doppler information the direction of motion of the predators cannot be determined. However, following the predator school's acoustic detection approximately 1 minute passed before the biology returned to their original layered configuration. This type of event happened twice on the record shown. This active predator-prey interaction suggests that biological mechanisms for the avoidance of oceanographic instrumentation nets could also exist, as has been suspected by many biologists. Again in Puget Sound, the active avoidance of Dr. Michael Gregg's (University of Washington) fine and microstructure measuring free-fall vehicle was observed on two successive drops (Figure 19). The backscattering from the vehicle (arrow 2) can be seen to begin at the same time that the backscattering layer (arrow 1) dissociates (arrow 3). Before the vehicle returns to the surface, and at a range of approximately 15 m, the scatterers return to their original configuration. The vehicle happened to fall in the beam of the acoustic system. It did not return to the surface in the beam, hence the scatterers were not seen to disperse during the vehicle's ascent.

The potential of using acoustic systems to evaluate fish stock and zooplankton biomass has been recognized by the European community (CUSHING, 1962) and active research and applied programs in that community are both assessing and actively using the technique. The U. S. program is small with research being conducted primarily on the west coast. Those researchers known to be active and their respective locations are, on the west coast (THRONE, THOMAS, ACKER, and JOHNSON, 1979; SMITH, 1978; HOLLIDAY and PIEPER, 1978; GREENBLATT, and PINKEL, 1978; GREENLAW, 1978), in the Great Lakes (HUANG and CLAY, 1979; McNAUGHT, BUZZARD, and LEVINE, 1975), and on the east coast (SUOMALA, 1975).

The vertical resolution of a narrow beam 200 kHz acoustic backscattering system is displayed in Figure 20. The data was taken in Massachusetts Bay in a water depth of ≃80 m. A high speed recording of the 200 kHz signal which emphasizes the 5 m of space above the bottom shows demersal fish within a few centimeters (arrows 2 and 3) and two meters (arrow 1) from the bottom. Acoustic systems such as this have the capability of counting individual fish and separating the size of fish by the amplitude of the backscattered signal (ORR, HAYS and HESS, 1978).

## CONCLUSION

A short outline of the research programs and objectives of those groups which are actively involved in the use or evaluation of high frequency acoustic backscattering as a remote sensor of fluid processes has been presented. A general overview of the results of this investigator's research program has been presented to illustrate or call attention to the potential of using high frequency acoustic backscattering systems in the study of:

I. A variety of fluid processes:
   A. internal waves
   B. fronts
   C. mixing
   D. interleaving water masses

II. Particulate distributions:
   A. natural in both estuary, shelf, and open ocean environment
   B. manmade in both estuary, shelf, and open ocean environment
      1. dredge spoils
      2. industrial chemical wastes
      3. sewage sludge

III. Biology
   A. Fish stock assessment
   B. zooplankton biomass assessment
   C. predator-prey interactions
   D. biological avoidance of oceanographic instrumentation
   E. biological response to fluid processes

High frequency acoustic backscattering techniques have the potential for becoming a valuable tool in oceanographic research. The systems can be used in both a complementary format with standard oceanographic instrumentation and in some situations in a stand-alone format. The technique, if applied, should not be done in the black box format common to the use of XBT's or CTD's. Dedicated research groups individually addressing all or one of the research areas listed above must be formed and staffed with individuals (scientists, engineers, and technicians) capable of understanding the physical processes (fluid dynamics) to be studied and the technical capabilities and limitations of the instruments being used. The groups should have not only superior acoustic systems but also high resolution CTD's and shear measuring devices available to them. In addition, laboratory studies of the backscattering mechanism must be simultaneously pursued with ocean going work to allow adequate understanding of the acoustic backscattering mechanisms and the physical processes involved.

Open ocean data acquisition with acoustic systems is done in a continuously varying environment and the researcher must be alert and have the depth of knowledge as indicated above to allow anticipation of the fluid processes occurring in the research area and to make the necessary alteration of the research instruments' configurations to take advantage of the varying oceanic conditions. If research using high frequency acoustic systems as a remote sensor is attempted in the black box format, i.e., giving an instrument with a few knobs to turn to inexperienced technicians or scientists, the technique in a quantitative format in all likelihood will lead to extreme frustration and eventual abandonment by the oceanographic community.

Acknowledgements--The W.H.O.I. acoustic system was designed by FREDERICK R. HESS and, under his guidance, constructed and maintained by BRIAN BARDSLEY and DONALD CROWELL. Data reduction and analysis has been performed by LINCOLN BAXTER II and STANLEY BERGSTROM. ELIZABETH PRATT has supervised the preparation of the figures. SUSAN SMITH has prepared this manuscript. Support for the work described in this text has come from the Naval Ocean Research and Development Agency, the National Oceanic and Atmospheric Administration Ocean Dumping Program, the National Oceanic and Atmospheric Administration Sea Grant Program, and the National Science Foundation.

## REFERENCES

ANDREYOVA, I.B. and Ya. P. MAKSHTAS (1977) Internal waves and sound scattering layers in the thermocline. Oceanology, 17, 287-289.

BROWN, E.H. and F.F. HALL, JR. (1978) Advances in atmospheric acoustics. Review of Geophysics and Space Physics, 16, 47-110.

CURTIN, T. B. and C.N.K. MOOERS (1975) Observation and interpretation of high frequency internal wave packet and surface slick pattern. Journal of Geophysical Research, 30, 882-894.

CUSHING, D. H., A.J. LEE, and I.D. RICHARDSON (1956) Echo traces associated with thermoclines. Journal of Marine Research, 15, 1-13.

CUSHING, D. H. (1973) The Detection of Fish. Pergamon Press, New York, NY.

DAVIS, R. and REGIER, L. (1979) Personal communication from F. H. FISHER, Scripps Institution of Oceanography.

DREVER, R. G. and SANFORD, T. B. (1979) An expendable temperature and velocity profiler (XTVP) in Proceedings of a Workshop on Near Surface Ocean Experimental Technology, 6-8 November 1979, at Naval Ocean Research and Development Activity, Bay St. Louis, Missouri.

EDGERTON, H. E. (1966) Sonic detection of a fresh water-salt water interface. Science, 154, 1555.

EDWARDS, J. A. (1979) Remote measurement of water currents using correlation sonar. Journal of the Acoustical Society of America, 66, S-57.

FARMER, D. and J. D. SMITH (1978) Nonlinear internal waves in a fjord. In: Hydrodynamics of Fjords and Estuaries, J. C. NIHOUS, editor. Elsevier Press, 465-493.

FISHER, F. H. and SQUIER, E. D. (1975) Observation of acoustic layering and internal waves with a narrow-beam 87.5-kHz echo sounder. Journal of the Acoustical Society of America, 58, 1315-1317.

FITZGERALD, M., J. MILLIMAN, M. H. ORR, and M. BOTHNER (1979) Source and fate of urban estuarine sediments - Boston Harbor. Presented at Geological Society of America Annual Meeting.

FRASSETTO, R., R. H. BACKUS, and E. E. HAYS (1962) Sound scattering layers and their relation to thermal structure in the Strait of Gibraltar. Deep-Sea Research, 9, 69-72.

GREENBLATT, P., R. PINKEL (1978) Measurement of zooplankton patchiness with a 87.5 kHz sonar system. Journal of the Acoustical Society of America, 64 (S97).

GREENLAW, C. (1978) Quantitative acoustic estimation of zooplankton distribution. Journal of the Acoustical Society of America, 64 (S94).

HAURY, L. R., M. G. BRISCOE, and M. H. ORR (1979) Tidally-generated internal wave packets in Massachusetts Bay, U.S.A.; Preliminary physical and biological results. Nature, 278, 312-317.

HESS, F. R. and M. H. ORR (1979) A towed multifrequency high frequency sonar system for scattering and ocean dynamics studies. W.H.O.I. Technical Memorandum 79-76.

HILL, R. (1979) Personal communication.

HOLLIDAY, D. V. and R. E. PIEPER (1978) Volume scattering strengths and plankton distribution at acoustic frequencies between 0.5 and 3 MHz. Journal of the Acoustical Society of America, 64 (S94). (This meeting had several individuals discussing biological backscattering and should be referred to for a complete bibliography.)

HUANG, K. and C.S. CLAY (1979) Backscattering cross-sections of live fish: PDF and aspect. Manuscript may be obtained from C. S. CLAY, Geophysical and Polar Research Center, University of Wisconsin, Madison, Wisconsin 53706.

KAYE, G.T. (1979) Acoustic remote sensing of high frequency internal waves. Journal of Geophysical Research, 84, 7017-7022.

KAYE, G.T. and V.C. ANDERSON (1979) Scattering from oceanic microstructure: Detection with a large aperature array. Journal of the Acoustical Society of America, 66, 842-849.

McNAUGHT, D.C., M. BUZZARD, and S. LEVINE (1975) Zooplankton production in Lake Ontario as influenced by environmental perturbations. EPA-660/ 3-75-021, National Environmental Research Center, EPA, Corvallis, Oregon 97330.

MUNK, W.H. and C. GARRETT JR. (1973) Internal wave breaking and microstructure. Boundary-Layer Meteorology, 4, 37-45.

ORR, M.H. and F.R. HESS (1978a) Remote acoustic monitoring of industrial chemical waste released at Deep Water Dumpsite 106. Journal of Geophysical Research, 83, 6145-6154.

ORR, M.H. and F.R. HESS (1978b) Remote acoustic monitoring of natural suspensate distributions, active suspensate resuspension, and slope-shelf water intrusions. Journal of Geophysical Research, 83, 4062-4068.

ORR, M.H., E.E. HAYS, and F.R. HESS (1978) Acoustic detection of demersal fish to within fifteen centimeters of the bottom in eighty meters of water. Journal of the Fisheries Research Board of Canada, 35, 1155-1156.

ORR, M.H., L. BAXTER II, and F.R. HESS (1979) Remote acoustic sensing of the particulate phase of industrial chemical wastes and sewage sludge: Report on the seasonal variability of the dispersion of the particulate phase as observed from three cruises, July 1977, January-February, 1978, and April 1978. W.H.O.I. Technical Memorandum 79-38.

ORR, M.H. (1980, in preparation) Remote acoustic detection of predator-prey interaction, active biological evasion of oceanographic instrumentation, and the response of biological organisms to fluid processes on the continental shelves of the United States of America.

NEWMAN, F.C., J.R. PRONI and D.J. WALTER (1977) Acoustic imaging of the New England shelf-slope water mass interfaces, Nature, 269, 790-791.

PEYNEAUD, F. and J. PIJANOWSKI (1979) An Acoustic Doppler Current Meter. Presented at 11th Annual Offshore Technology Conference, April 1979.

PINKEL, R. (1979) Doppler sonar measurements from FLIP. Journal of the Acoustical Society of America, 66, S-57.

PRONI, J.R. and J.R. APEL (1975) On the use of high frequency acoustics for the study of internal waves and microstructure. Journal of Geophysical Research, 80, 1147-1151.

PRONI, J.R., F.C. NEWMAN, C. PARKER (1976) Acoustic Tracking of Ocean-Dumped Sewage Sludge, Science, 193, 1005-1007.

PRONI, J.R., F.C. NEWMAN, D.C. RONA, D.E. DRAKE, G.A. BERBERIAN, C.A. LAUTER JR, R.L. SELLERS (1976) On the use of acoustics for studying suspended oceanic sediment and for determining the onset of the shallow thermocline, Deep-Sea Research, 23, 831-837.

PRONI, J.R., F. OSTAPOFF, and R.L. SELLERS (1978) Acoustic observations of high frequency near surface internal wave groups in the deep ocean during GATE. Deep-Sea Research, 25, 299-307.

SCHROEDER, R. and H. SCHROEDER (1964) On the use of the echo sounder in lake investigations. Mem. Inst. Ital. Idrobiol., 17, 167-188.

SMITH, P.E. (1978) Precision of sonar mapping for pelagic fish assessment in the California Current, J. Cons. Int. Explor. Mer., 38(1), 33-40.

SQUIER, E.D., R.B. WILLIAMS, S.P. BURKE and F.H. FISHER (1976) High Resolution, Narrow Beam Echo Sounder, Marine Physical Laboratory of the Scripps Institution of Oceanography, SIO Ref. 76-8.

SUOMALA, J.B. (1975) The application of hydroacoustic methods for aquatic biomass measurements. The Charles Stark Draper Laboratory, Cambridge, Massachusetts, U.S.A., Report C-4528.

TATARSKII, V.I. (1961) Wave Propagation in a Turbulent Medium. Translated by R.A. SILVERMAN, Dover, NY, U.S.A.

THORNE, R.E., G.L. THOMAS, W.C. ACKER, and L. JOHNSON (1979) Two applications of hydroacoustic techniques to the study of fish behavior around coastal power stations. Washington Sea Grant Program, University of Washington, WSG 79-2.

WESTON, D.E. (1958) Observations on a scattering layer at the thermocline. Deep-Sea Research, 5, 44-50.

# FIGURE CAPTIONS

Fig. 1 Plot of pressure amplitude variability vs. frequency for four backscattering mechanisms which are considered to be important to the detection of oceanic fluid processes. The plot shows only the dependence of the backscattered acoustic pressure as a function of frequency. It does not include such considerations as variability of particle size distribution, wave number variability of cell sizes during turbulent mixing events or length scales in fine or microstructure steps. Each of these variables will further alter the frequency dependence of the acoustic backscattering.

Fig. 2 Acoustic record (200 kHz) of particles rising from the Deer Island outfall and their distribution throughout the water column in the immediate vicinity. Arrow 1 points to the outfall, the dark areas near the surface (arrow 2) are the result of backscattering from the particles in the water. Particles falling out of the plume can be seen in the area of arrow 3.

Fig. 3 Temporal development of a short period internal wave field in Massachusetts Bay. The figure and identification of the generation mechanisms is from Dr. Melbourne Briscoe (HAURY, BRISCOE, and ORR, 1979). (A) The outflowing tide across Stellwagen Bank produces a lee wave which is held in position until the tide slacks. (B) At that time, the lee wave propagates westward across Stellwagen Bank, forming a short period internal wave which then propagates across Massachusetts Bay (C,D).

Fig. 4 Acoustic record (200 kHz) of a short period internal wave forming from a lee wave propagating across Stellwagen Bank. The acoustic backscattering from arrow 1 is thought to be from temperature fluctuations in the vicinity of a high shear zone created during the passage of the lee wave. Note the formation of shear instabilities (arrow 3) and cats eye-like structure (arrow 4). The horizontal line was caused by backscattering from a CTD (arrow 2) held at constant depth during the lee wave passage.

Fig. 5 A 200 kHz acoustic record of an internal wave packet. The period of the waves are doppler shifted by the ship's speed of about 2.5 knots (128 cm $s^{-1}$) as it travelled from the rear to the front of the packet parallel to the packet's propagation direction ($240^{\circ}$); left to right in figure). The seasonal thermocline is displaced by 30 m (arrow 1) and the stratified point scatterers (zooplankton) at 30 to 40 m are displaced more than 20 m (arrow 2 and 3). The heavy acoustic backscattering in the vicinity of arrow 4 and extending in an oscillatory pattern throughout the figure is caused by turbulent mixing near the thermocline. The asymmetry of the wave field, with narrow troughs and broad crests, is determined by the depth of the mixed layer. Similar asymmetrical waves have been observed acoustically in the lower atmosphere. The heavy scattering near 75 m is probably caused by euphausiid and mysid shrimp. The oscillations in bottom depth (arrows 5 and 6) are due to variations in the travel time of the sound pulses resulting from the thermal structure within the internal wave field; that is, the water column above arrow 6 is mostly cold (slower speed of sound).

Fig. 6 The 200 kHz acoustic record of Kelvin-Helmholtz shear instabilities associated with an internal wave packet detected in Massachusetts Bay on the 30th of August 1977. This record shows several overturning events; the direction of overturning (left to right) is opposite that of packet propagation. Superimposed are the corroborating density profiles obtained by repeated vertical casts of a CTD. The instrument's path is seen as the oblique traces.

Fig. 7 A short period internal wave breaking down as it approached shallow water on the western side of Massachusetts Bay. The internal wave field is travelling to the left in the figure with the first lobe noted with arrow 1. The fourth peak (arrow 2) of the internal wave field is seen to be breaking down. The acoustic record indicates that nearly 15 m of the water column is undergoing mixing. Shear instabilities (arrow 3) can be seen in the area of heavy mixing. A second region (arrow 4) reveals an entire lobe of the internal wave field in a classical breaking wave configuration. This configuration would suggest the possibility of the formation of interleaving water masses as a result of the overturn (see the next figure).

Fig. 8 The formation of interleaving acoustic scattering areas (bracket 1) in the area of internal wave breakdown in western Massachusetts Bay. This is a process often mentioned in the theoretical internal wave literature, here shown clearly by the acoustic backscattering technique.

Fig. 9 Chart showing the position of DWD 106 as referenced to the east coast of the United States of America.

Fig. 10 An XBT sequence indicating the thermal structure of the springtime water at DWD 106. Of particular interest is XBT #54. The layered structure in the water column is noted by arrows 1, 2 and 3.

Fig. 11 An acoustic record taken at DWD 106 during a chemical waste disposal monitoring operation. The particulate phase of the chemical waste can be seen distributed in the first 15 m of the water column and on the first density interface, see arrows 1, 2 and 3. The interleaving water masses followed during the experiment and described in the text are illustrated by arrows 1', 2' and 3'. Note the internal waves and the lack of vertical coherence between the layer at 25-30 m in depth and the layer at 7-15 m in depth.

Fig. 12 Energy density spectra vs. wavenumber calculated from nine hours of acoustic backscattering data obtained during a box tow at the JASIN (Joint Air-Sea Interaction) experiment site on September 3, 1978. The acoustic backscattering surface was displaced on occasion by as much as 20 m and appeared to outline the vertical displacement of the base of the mixed layer.

Fig. 13 Summertime 200 kHz acoustic backscattering record showing the base of the seasonal mixed layer as outlined by particles from a duPont acid iron waste field (arrows 1 and 2). Note that a small number of particles are outlining a second density gradient (arrow 3). The entire waste field was being perturbed by a cycloidal internal wave during the data acquisition period. The internal wave was being Doppler shifted by a moving vessel. The difficulty in sampling the water column as a result of the varied spatial distribution of the waste, the thinness of the particle layers, and the influence of the internal wave field on the particle distribution should be apparent.

Fig. 14 A multilayered springtime water mass similar to that previously discussed in Figure 11. In this case the penetration of particulates released during an industrial chemical waste disposal operation was limited by the first density discontinuity (white arrow 1, 2). Note the shallow penetration of the waste plumes over a period of more than one hour following the release of the waste.

Fig. 15 Vertical dispersion of a chemical waste plume in wintertime water conditions. The depth of the mixed layer was from 80-120 m during the experiment period. In this case, arrow 1, the waste plume was observed to be distributed over the first 75 m of the water column, or nearly 5 times as deep as during the spring and summer month data previously described.

Fig. 16 A representative data set of analog acoustic signals backscattered from a particle cloud during the winterime water conditions (depth range 75-110 m). The amplitude of the acoustic signal, i.e., the amount of horizontal offset to the right, is representative of the number of particles in the cloud. Note that the amplitude is quite variable for the 12 seconds of data shown in the figure. The difficulty of sampling the cloud with ship-launched equipment in the horizontal and vertical should not be underestimated. Even though the acoustics can readily detect the particles, in this case a cloud approximately 50 m in width, the chances of positioning a ship over the cloud a second time with Loran C without knowing water shear are very small.

Fig. 17 An example of the effects of shear on the horizontal dispersion of sewage sludge. Two crossings nearly perpendicular to a barge disposal track acoustically detected the particle plume to a depth of 60 m. At a depth of 15 m the shape of the sinking particle plume was distorted by shear in the water column. This effect was noted during both crossings of the waste plume.

Fig. 18 A 200 kHz record of backscattering from biological layers (arrow 1). Schools of predators (arrows 3, 200 kHz record)(see 20 kHz record, arrow 1') were detected in the water column. In the vicinity of the predators, the distribution of the layers of zooplankton is seen to be altered in the vertical. This altered distribution is interpreted to be a response of the prey to the predators. The scattering voids in the vicinity of the predators (arrow 2) are conspicuous. The analog acoustic signals recorded on magnetic tape can be analyzed to determine if the number of zooplankton have decreased after the passage of the predators.

Fig. 19 A 357 kHz acoustic backscattering record showing a layered scattering zone (arrow 1). A free fall oceanographic instrument (M. GREGG, University of Washington) was released and, at a depth of approximately 16 m (arrow 2), was acoustically detected as it drifted beneath the acoustic transducer. At the same time, the acoustic scattering layer disappeared (arrow 3), having moved away from the descending instrument package. Once the package was a safe distance away, ≃ 15 m, the scatterers returned to a layered structure configuration (arrow 4). It is believed that the scatterers, as observed with the acoustic system, were moving away from the descending instrument when they detected it below them. The similarity in the scattering void area as observed in this record and Figure 18 should be noted.

Fig. 20 High speed recording of 200 kHz data showing individual demersal fish to within 10 cm of the ocean floor (arrow 2). The presence of scatterers closer than 10 cm to the bottom are observed in the record (arrow 3). The easily resolved fish 2 m from the ocean floor are indicated (arrow 1).

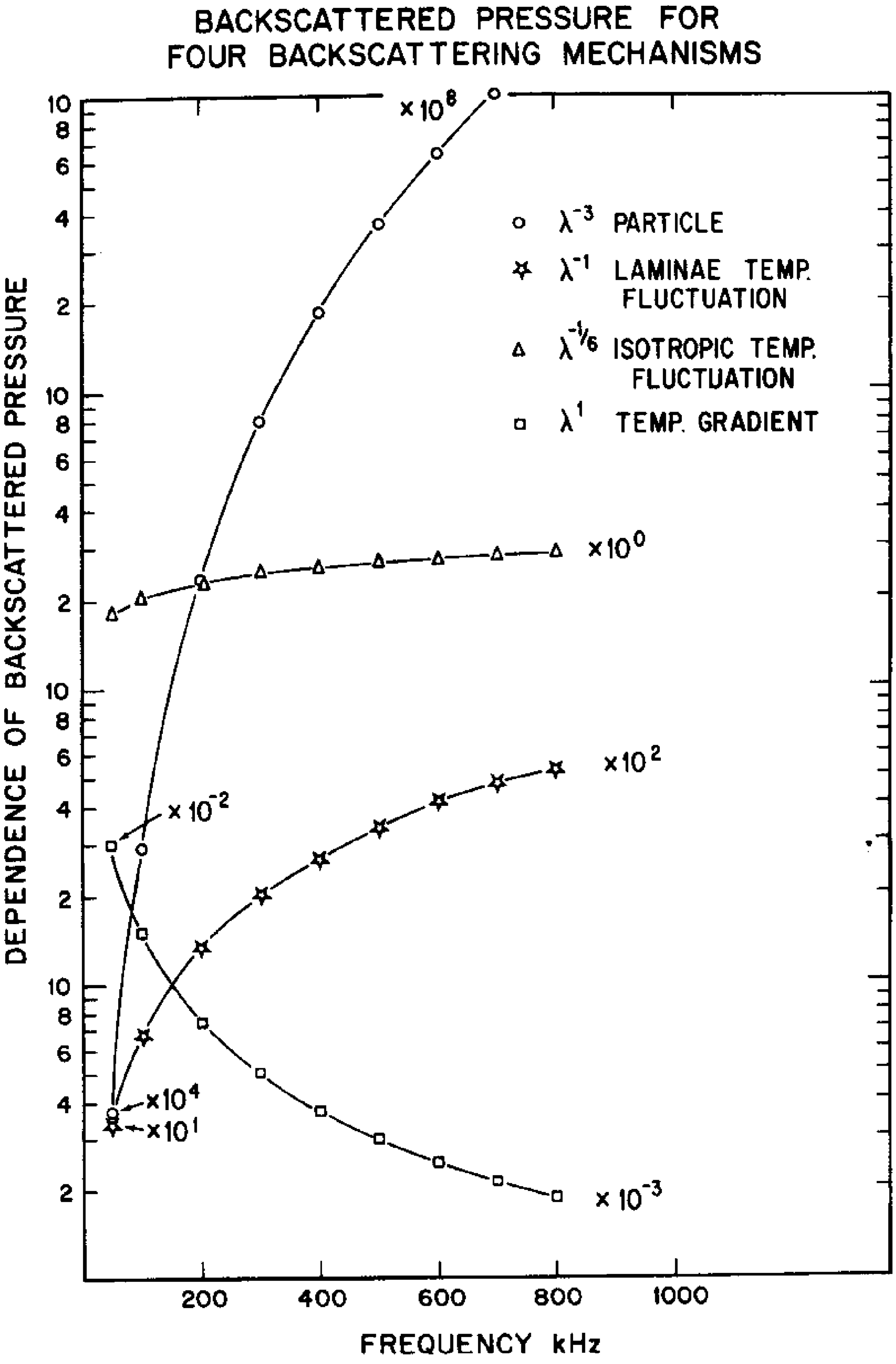

BACKSCATTERED PRESSURE FOR
FOUR BACKSCATTERING MECHANISMS
DEPENDENCE OF BACKSCATTERED PRESSURE
FREQUENCY kHz
200
400
600
800
1000
10
8
6
4
2
○ λ^-3 PARTICLE
✡ λ^-1 LAMINAE TEMP. FLUCTUATION
△ λ^-1/6 ISOTROPIC TEMP. FLUCTUATION
□ λ^1 TEMP. GRADIENT
×10^8
×10^0
×10^2
×10^-2
×10^4
×10^1
×10^-3

Fig. 1

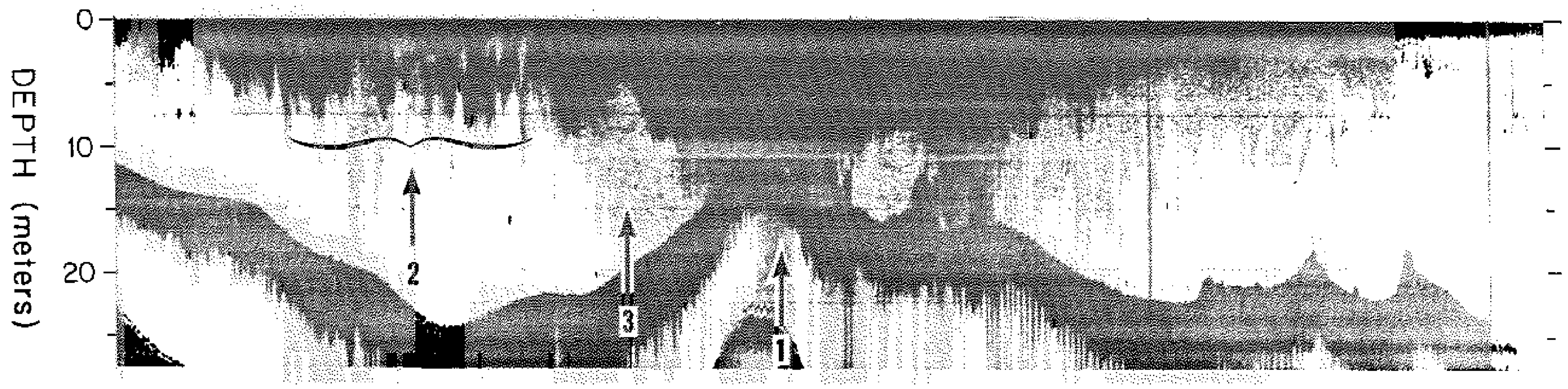


Fig. 2

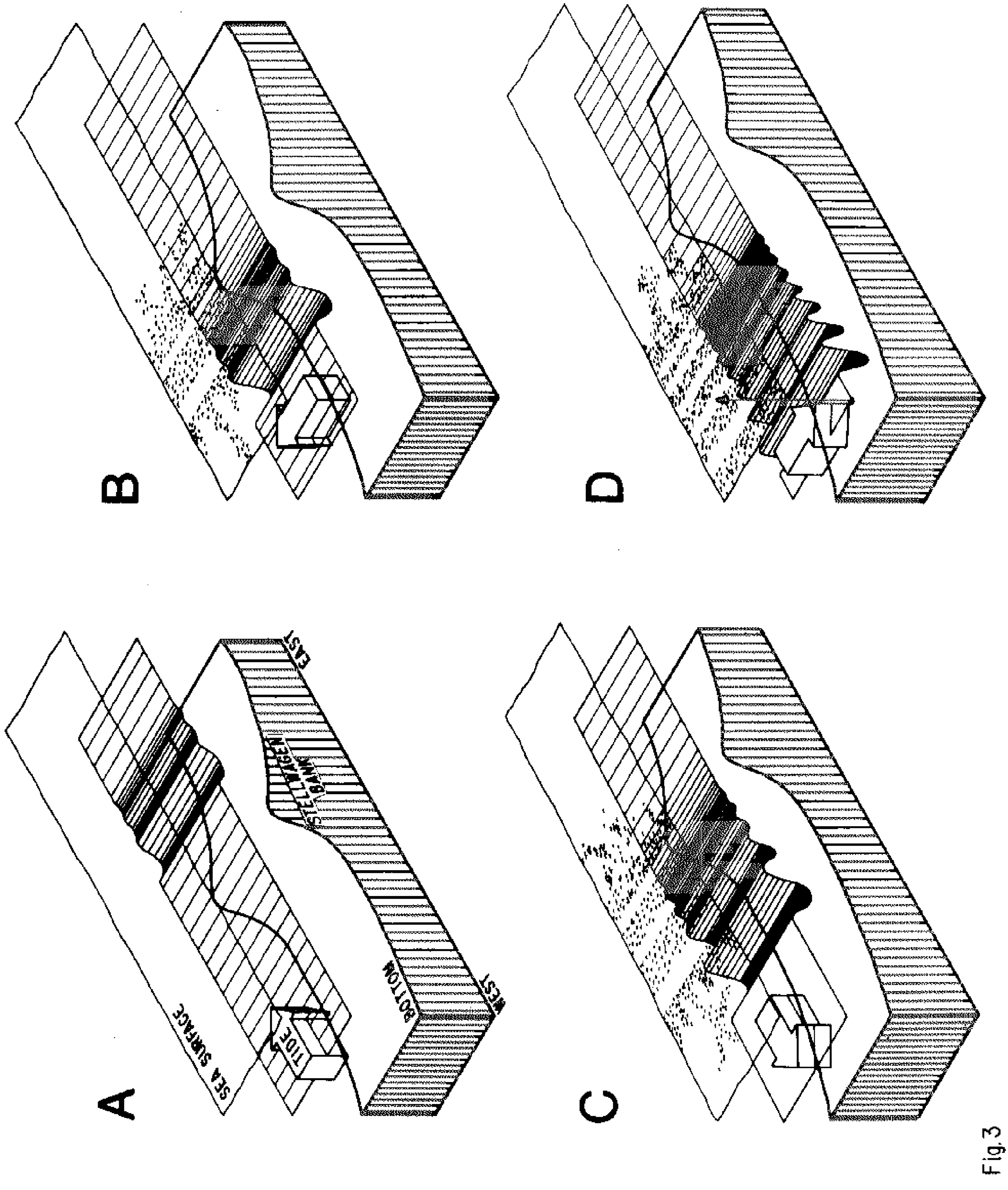


Fig.3

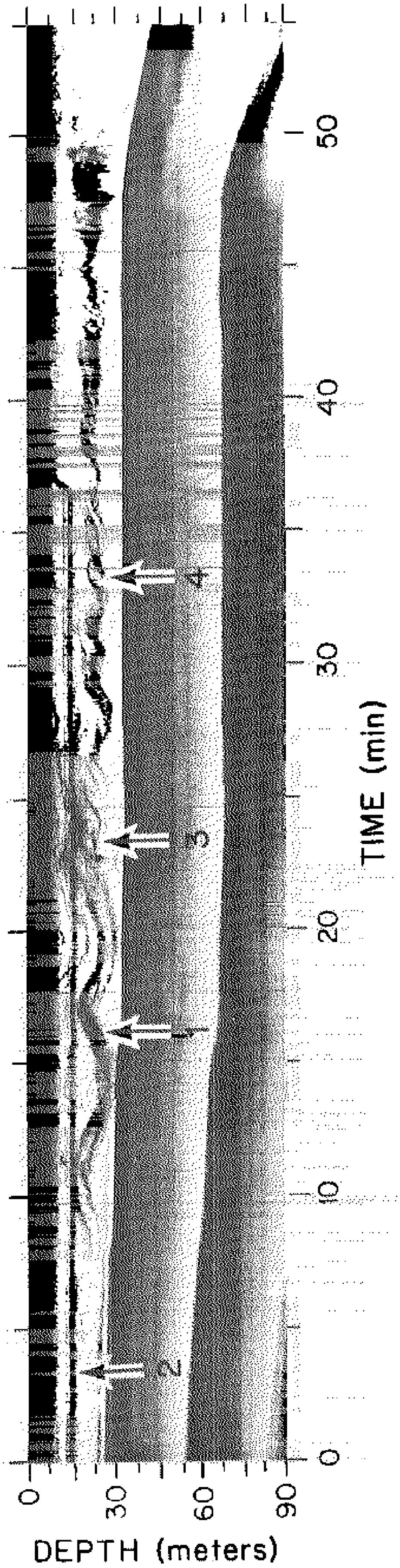


Fig. 4

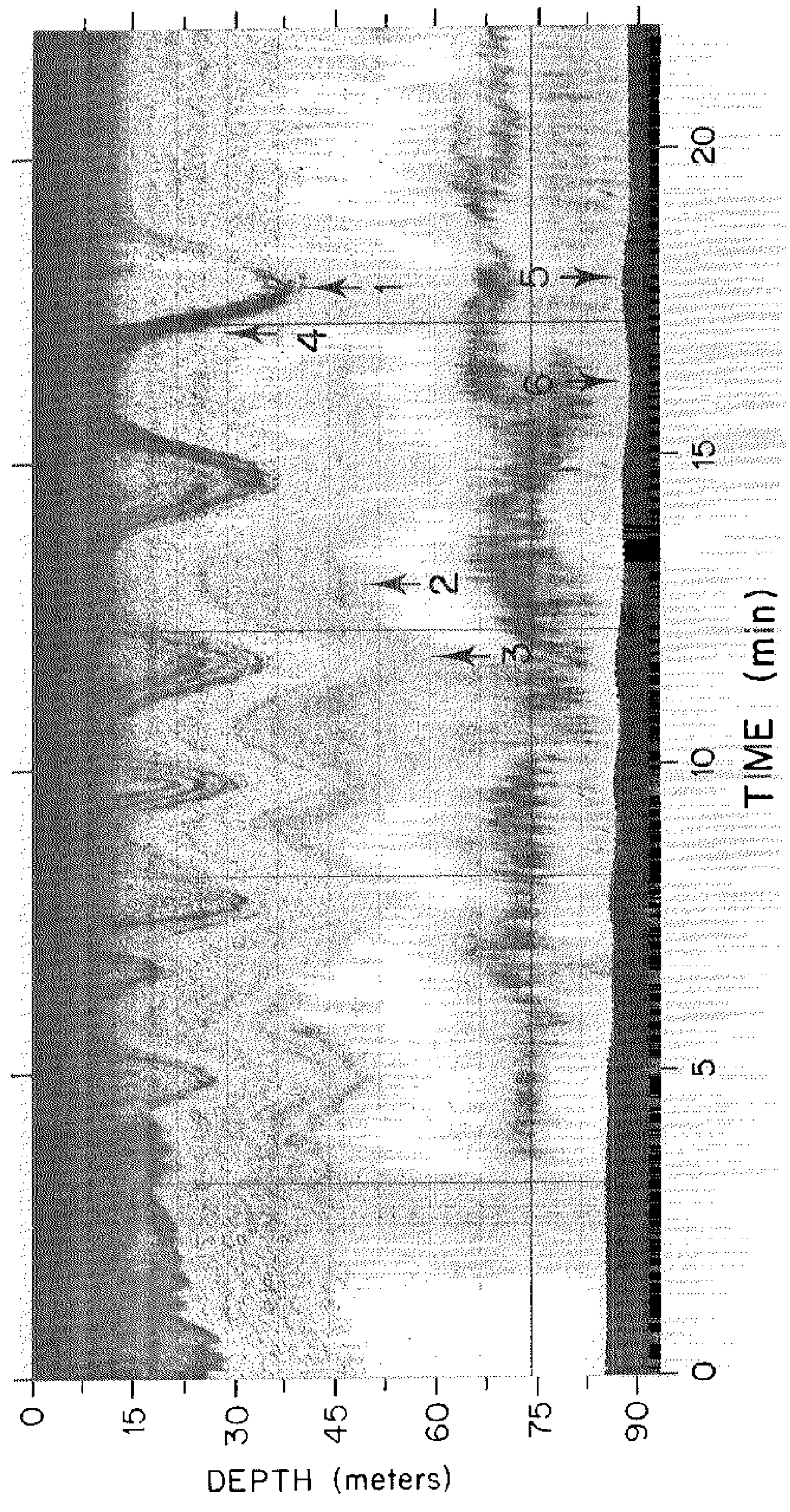


Fig. 5

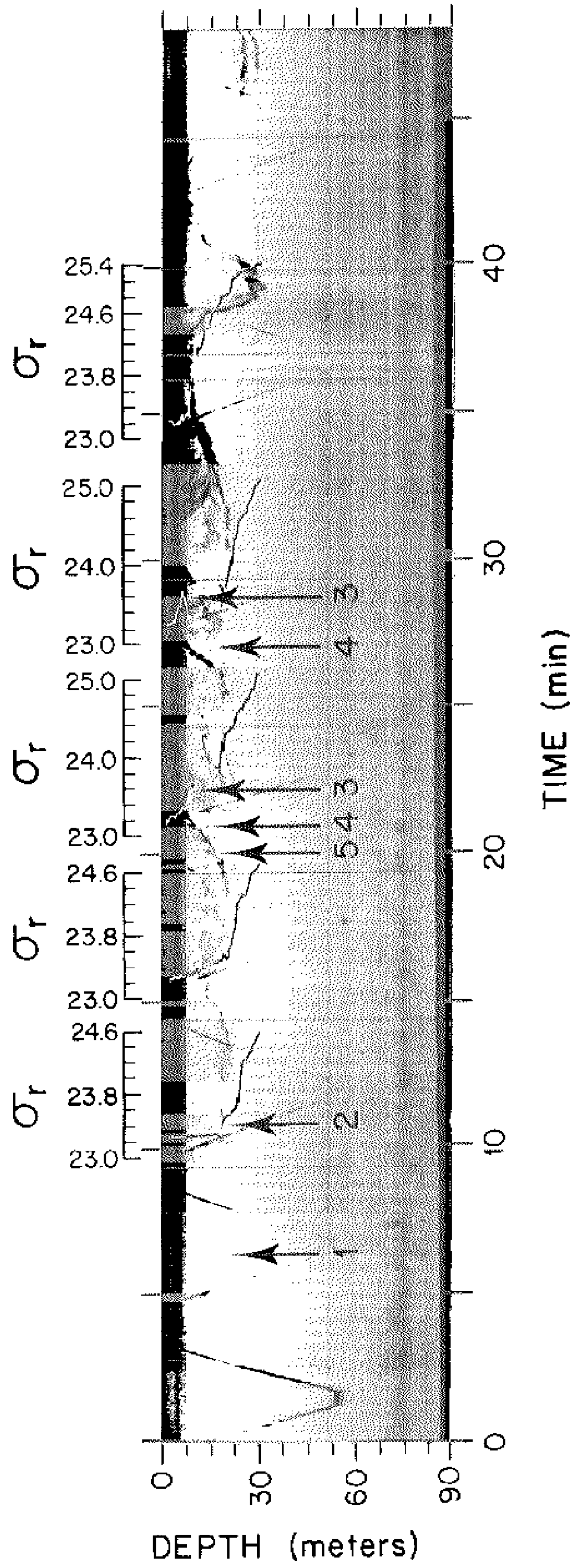

σr
25.4
24.6
23.8
23.0
σr
25.0
24.0
23.0
σr
25.0
24.0
23.0
σr
24.6
23.8
23.0
σr
24.6
23.8
23.0
1
2
5 4 3
4 3
0
30
60
90
DEPTH (meters)
0
10
20
30
40
TIME (min)

Fig. 6

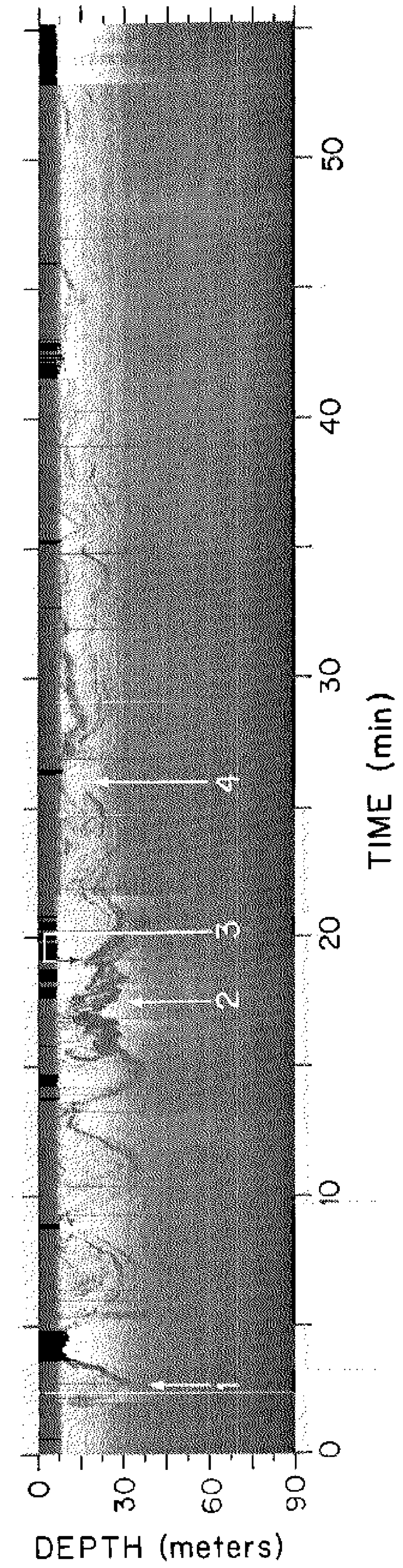


Fig. 7

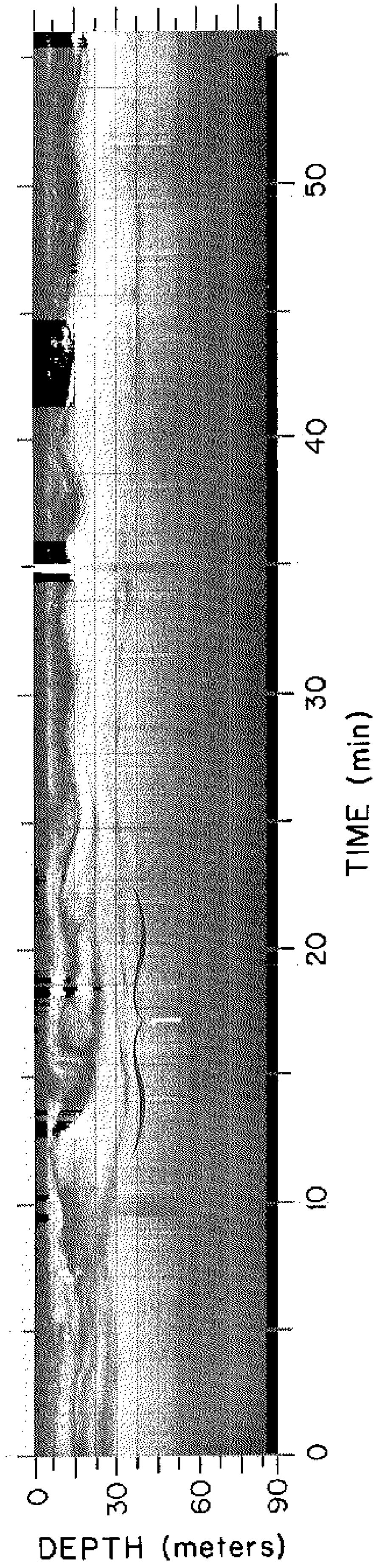


Fig. 8

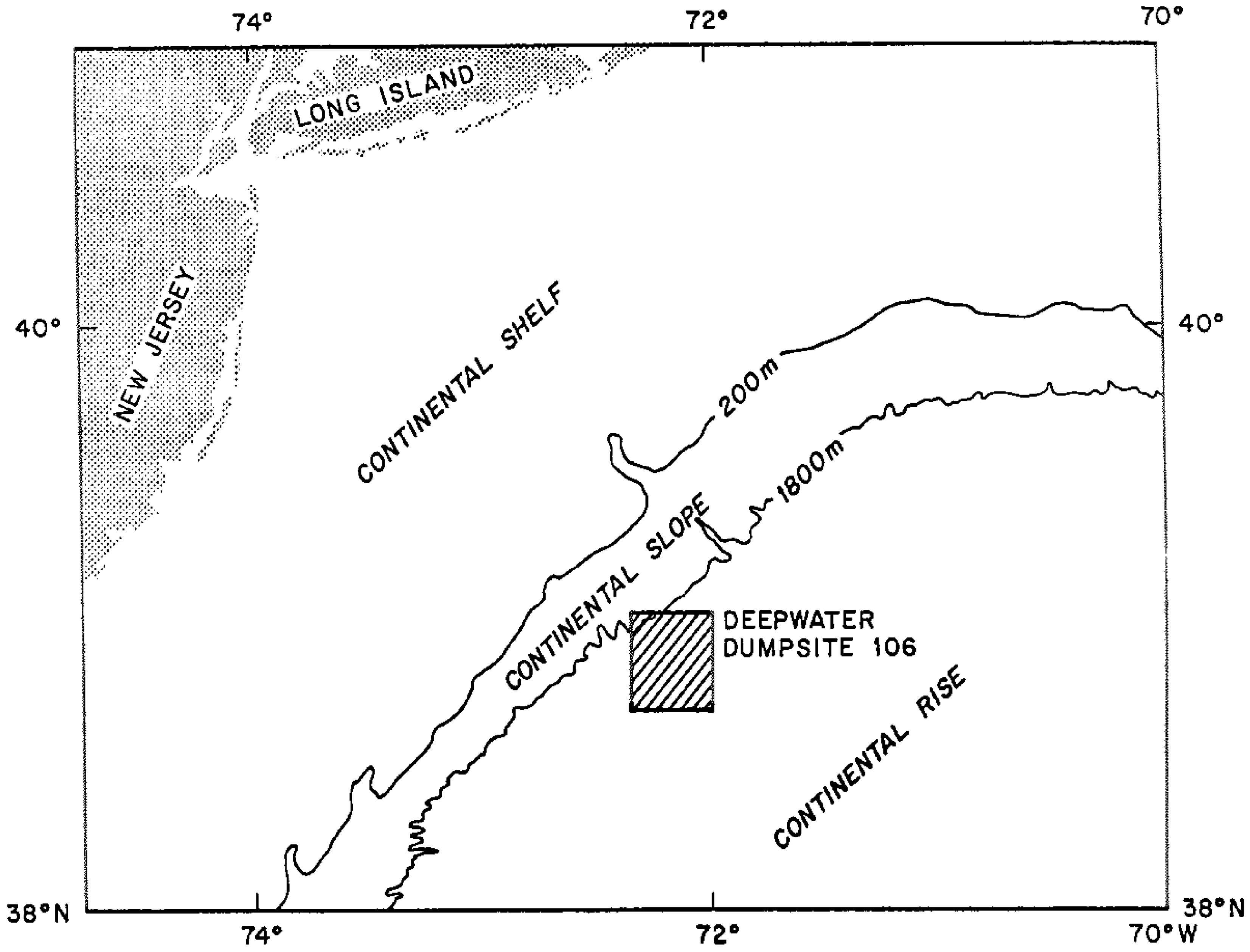
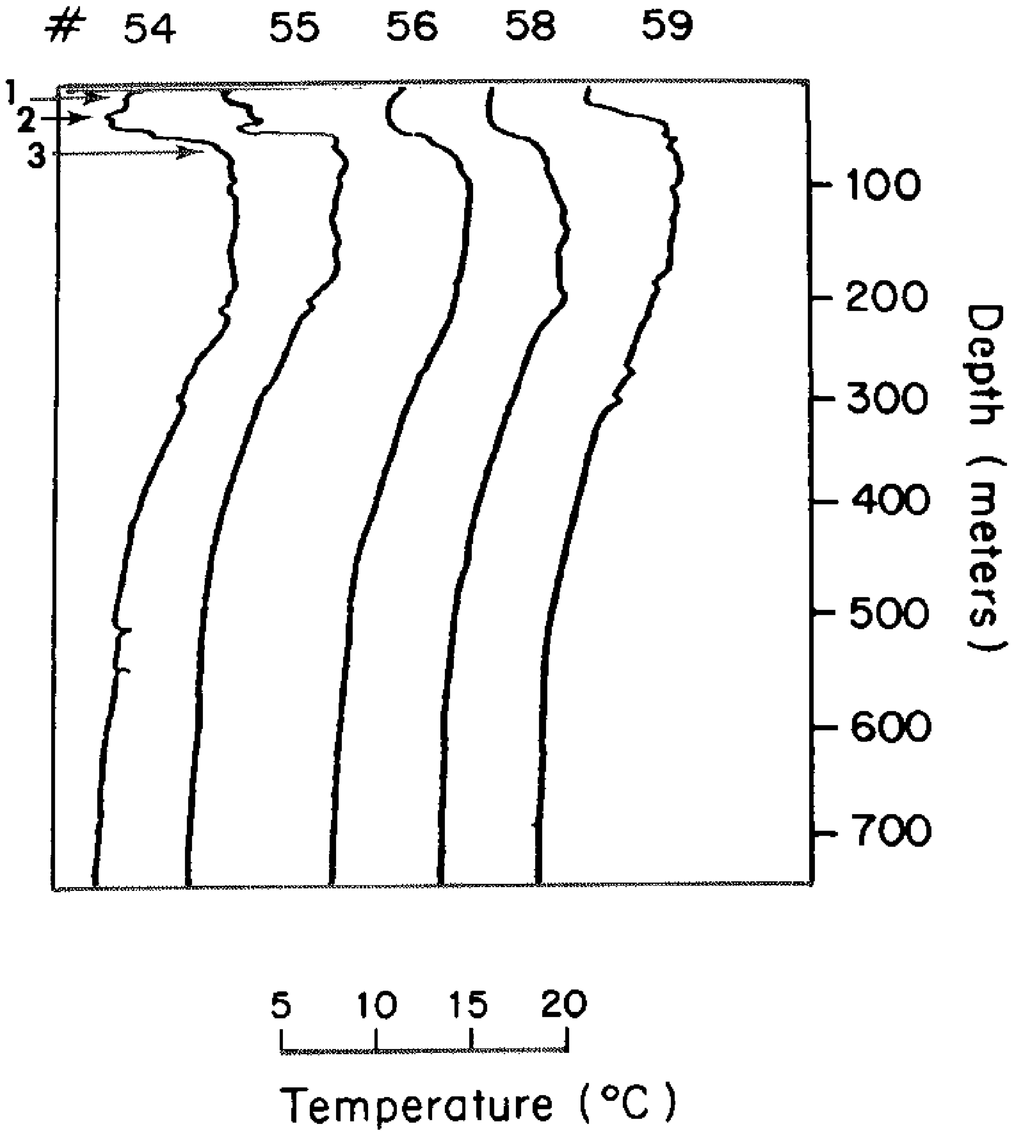

74°
72°
70°
40°
40°
LONG ISLAND
NEW JERSEY
CONTINENTAL SHELF
200m
1800m
CONTINENTAL SLOPE
DEEPWATER
DUMPSITE 106
CONTINENTAL RISE
38°N
38°N
74°
72°
70°W

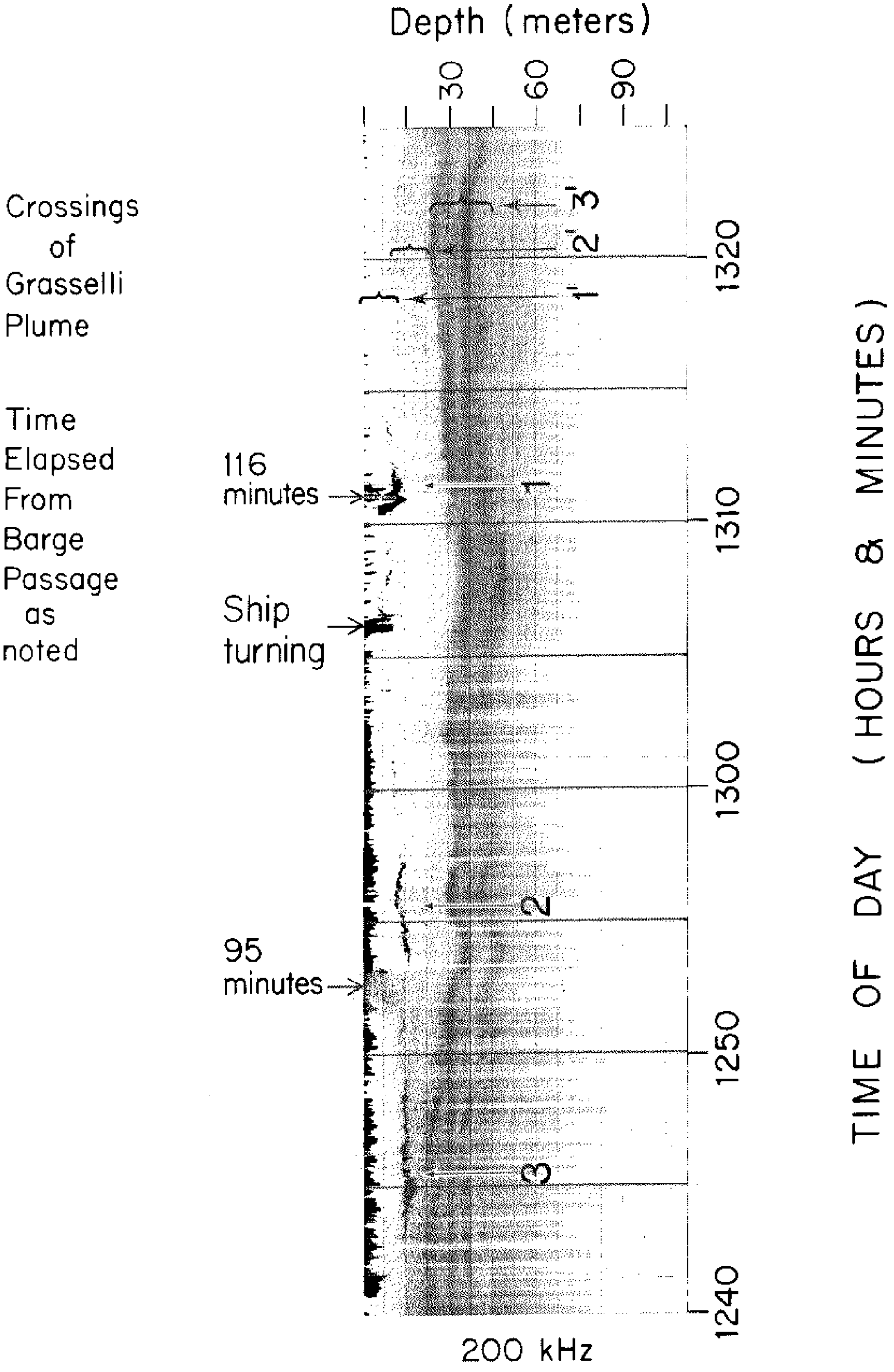
Fig. 9



At 600 meter depth
all traces read approximately
5°C

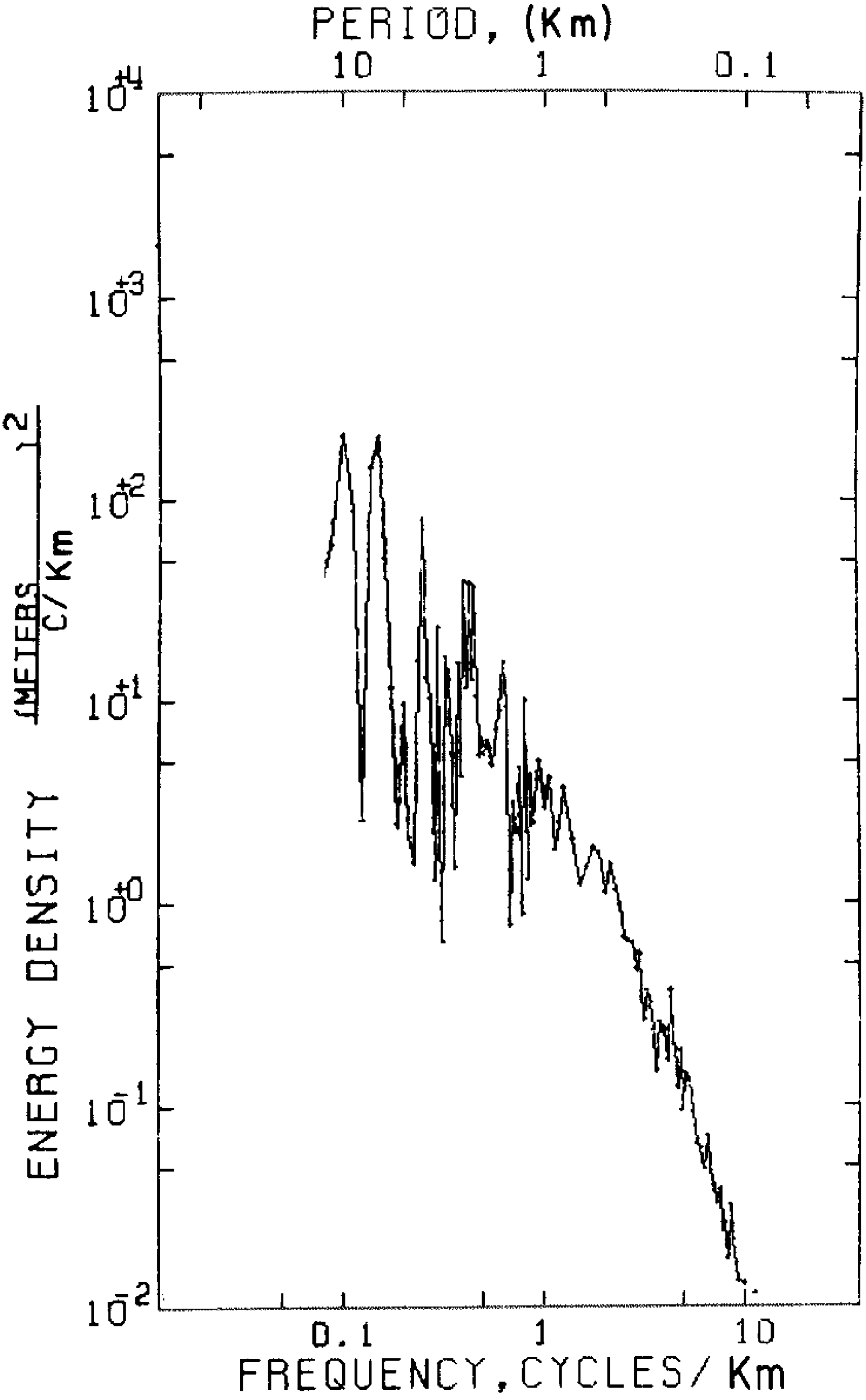
#54 = April 10 2330Z
#55 = April 11 0350Z
#56 = April 11 0612Z
#58 = April 11 0828Z
#59 = April 11 1735Z

Fig. 10



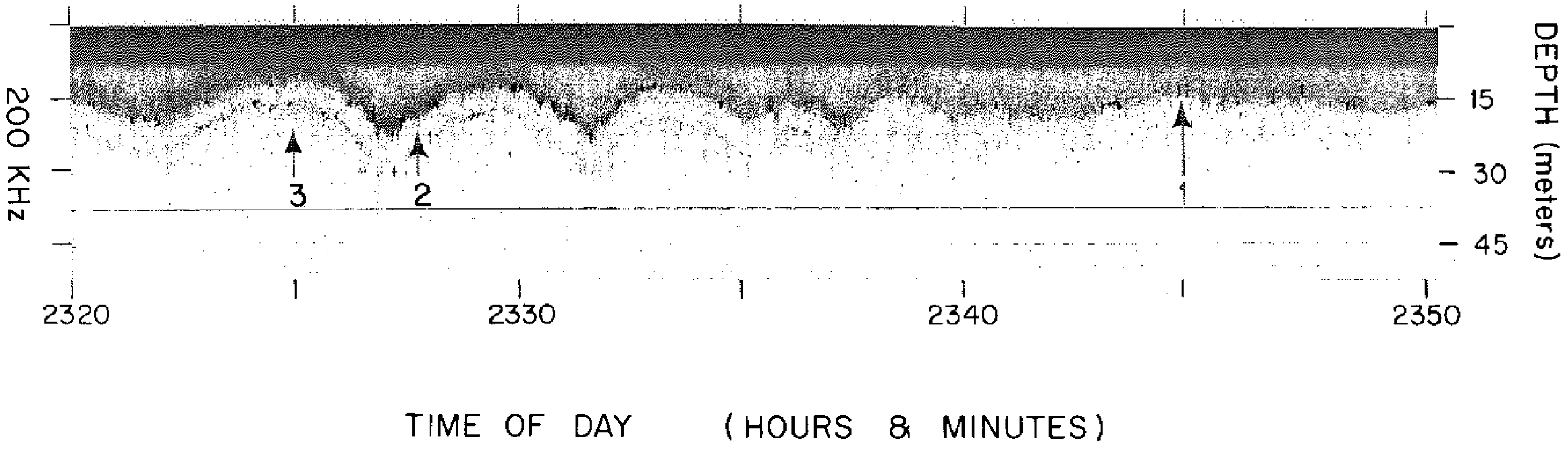
MT MITCHELL 10 APRIL 1978

Fig. 11



**SEPT. 3, 1978**

Fig. 12



ALBATROSS IV 26 JULY 1977 Edge Moor Waste

riding an internal wave
8 hours after barge passage

Fig. 13

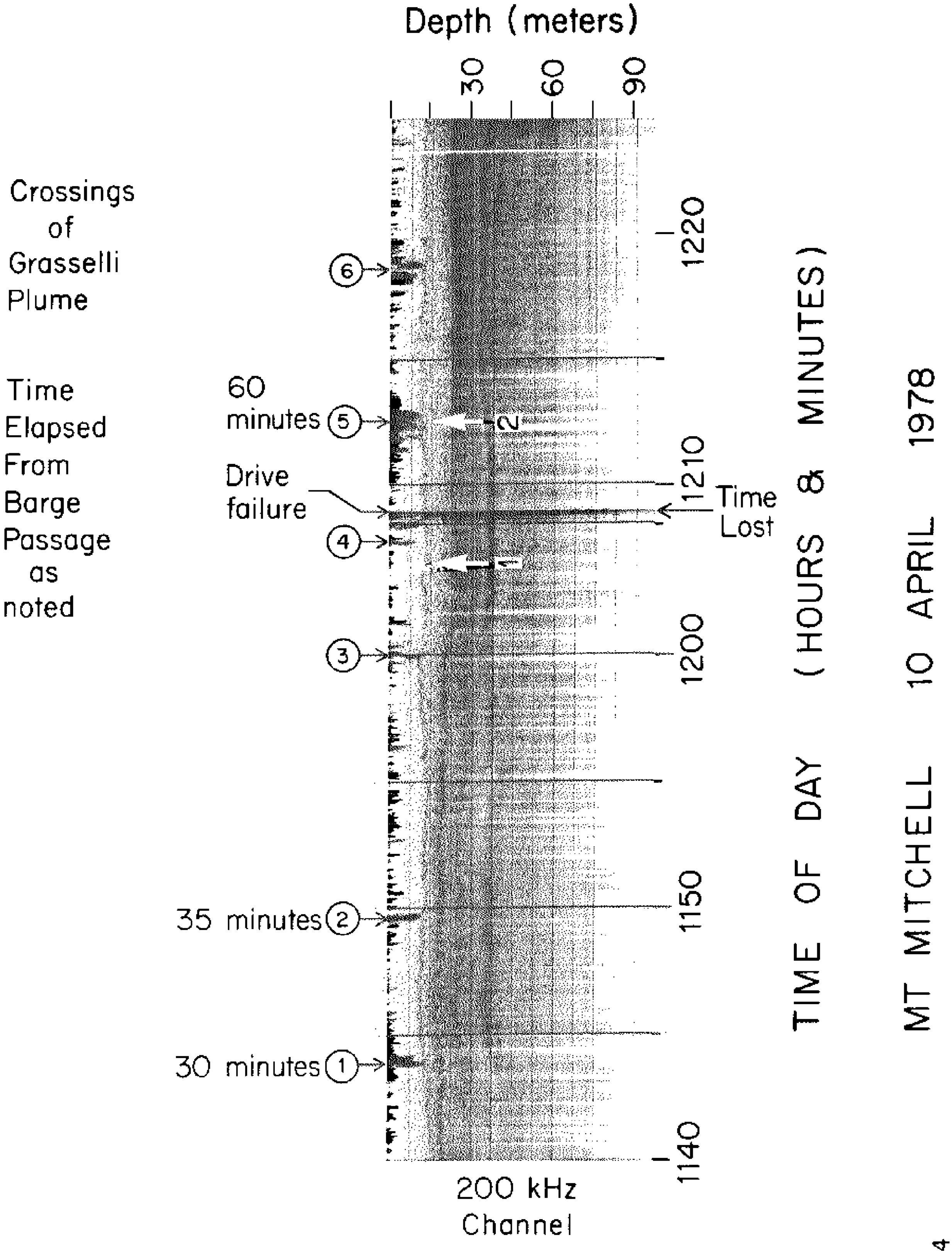
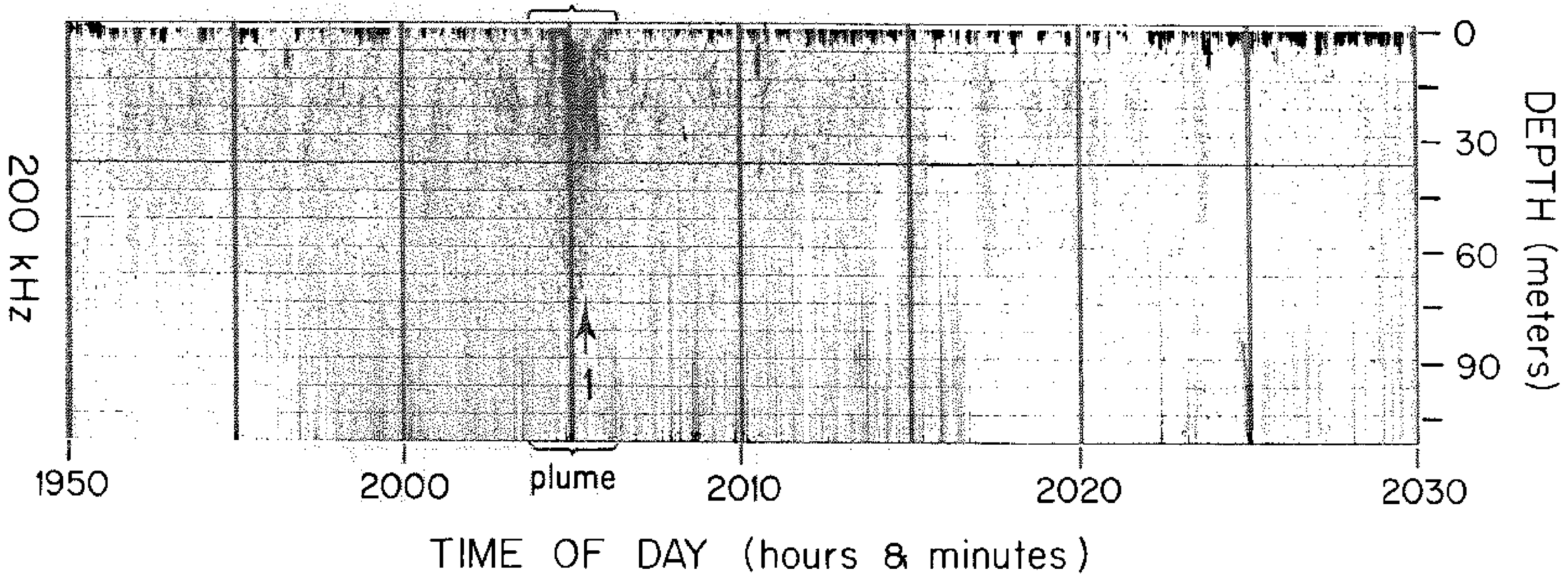

Depth (meters)
30
60
90
Crossings of Grasselli Plume
Time Elapsed From Barge Passage as noted
⑥
60 minutes ⑤
2
Drive failure
Time Lost
④
1
③
35 minutes ②
30 minutes ①
1220
1210
1200
1150
1140
200 kHz Channel
TIME OF DAY (HOURS & MINUTES)
MT MITCHELL 10 APRIL 1978

Fig. 14


ALBATROSS IV 2 FEB 1978

Edge Moor Waste
about 6.6 hours after barge passage

Fig. 15

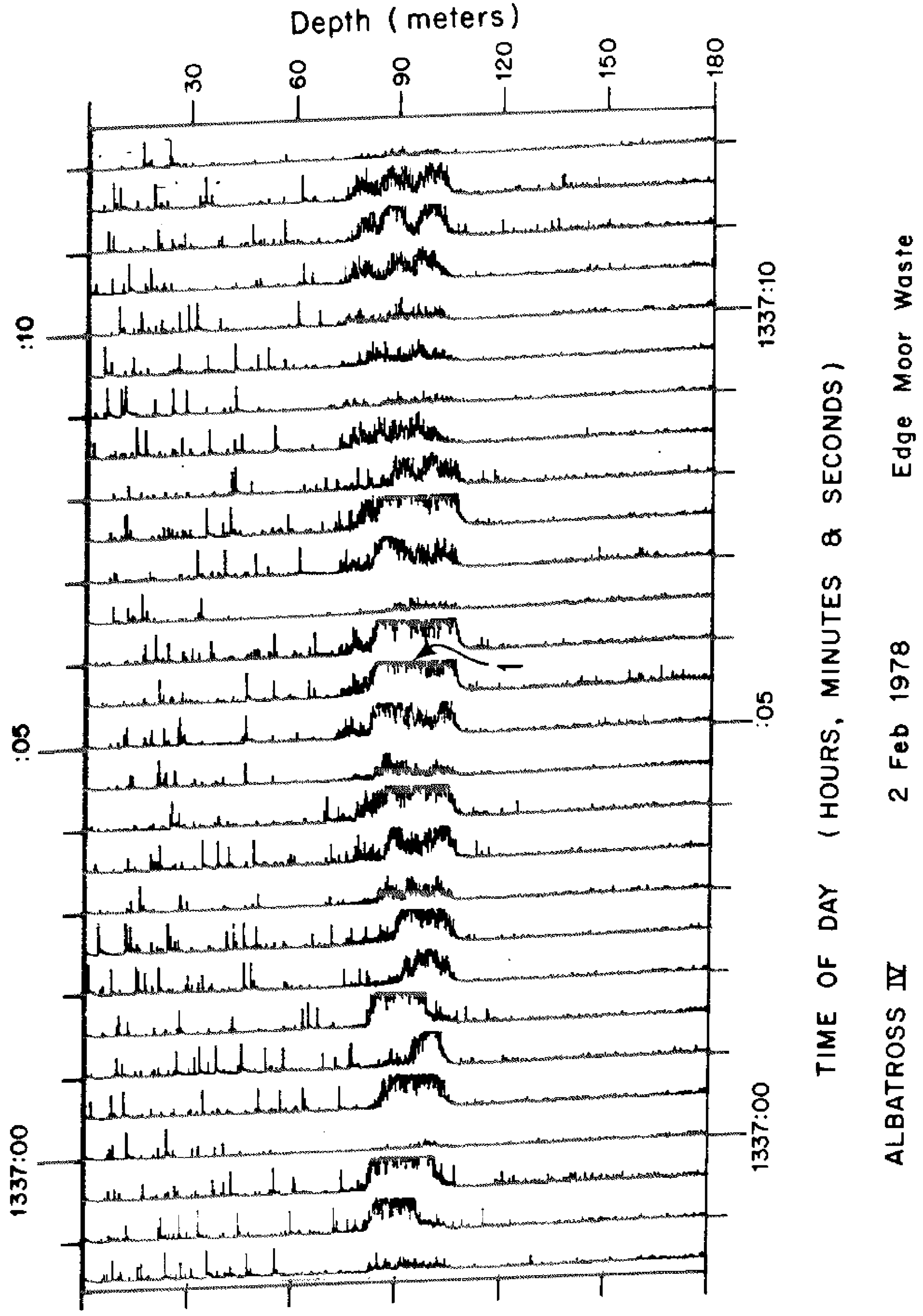
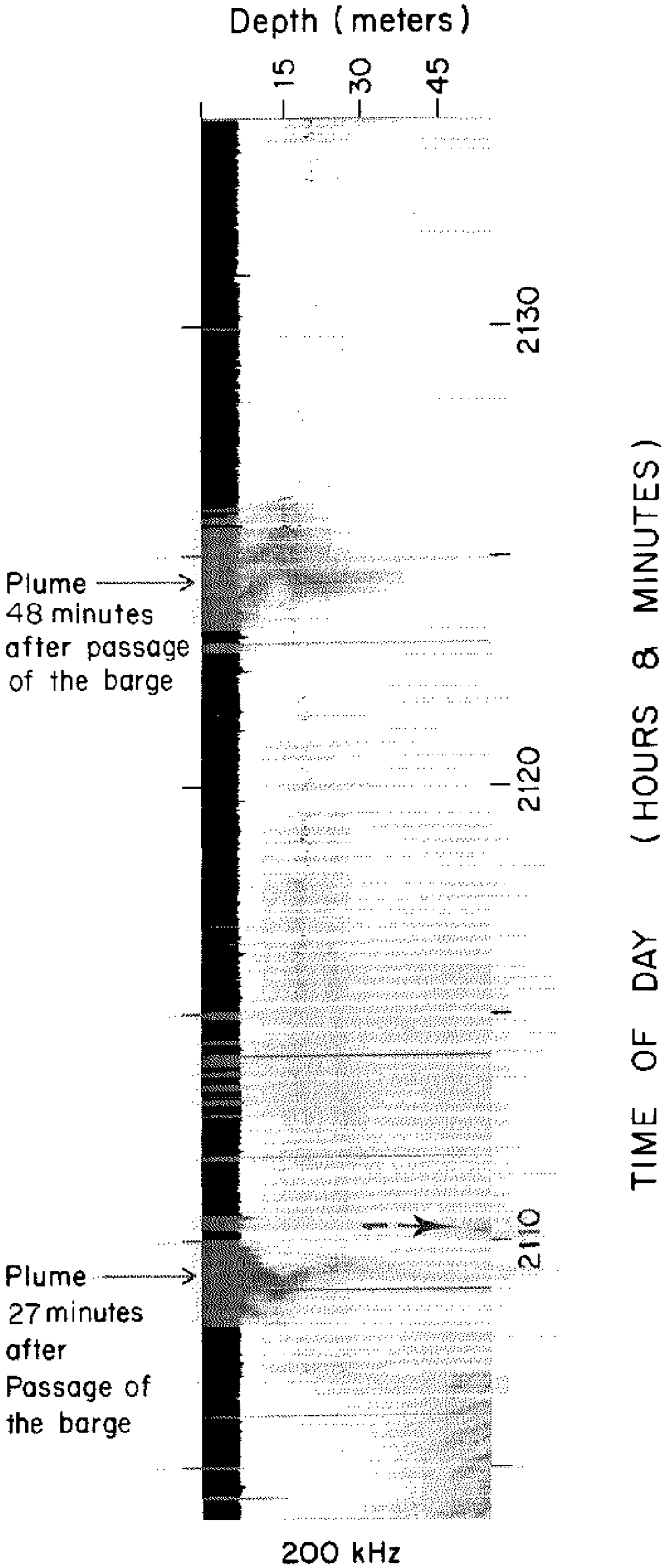
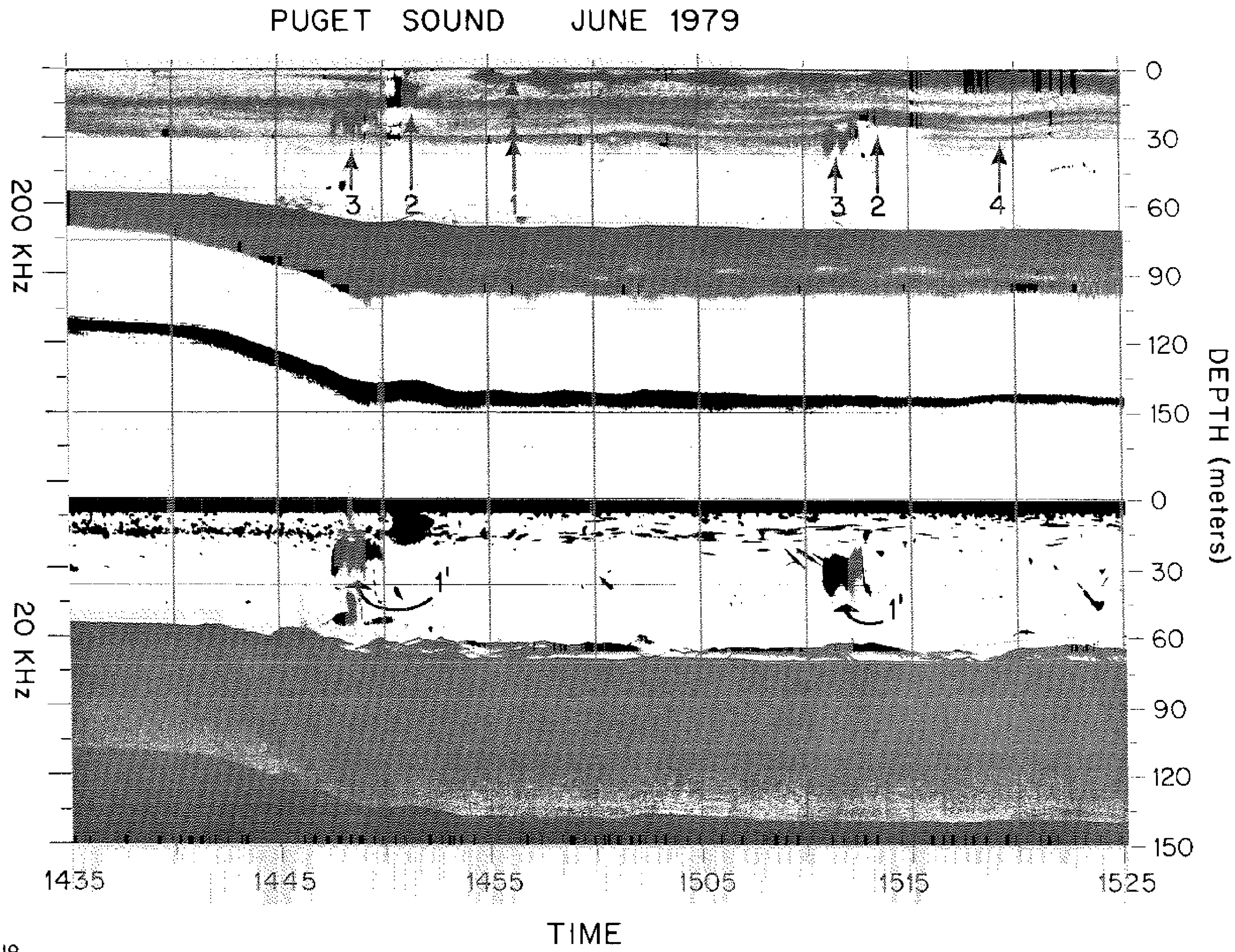

Depth ( meters)
30
60
90
120
150
180
1337:00
:05
:10
1337:00
:05
1337:10
1
TIME OF DAY (HOURS, MINUTES & SECONDS)
ALBATROSS IV 2 Feb 1978 Edge Moor Waste

Fig. 16



PEIRCE 23 July 1977 Sewage Sludge Dump

Fig.17



PUGET SOUND JUNE 1979

Fig. 18

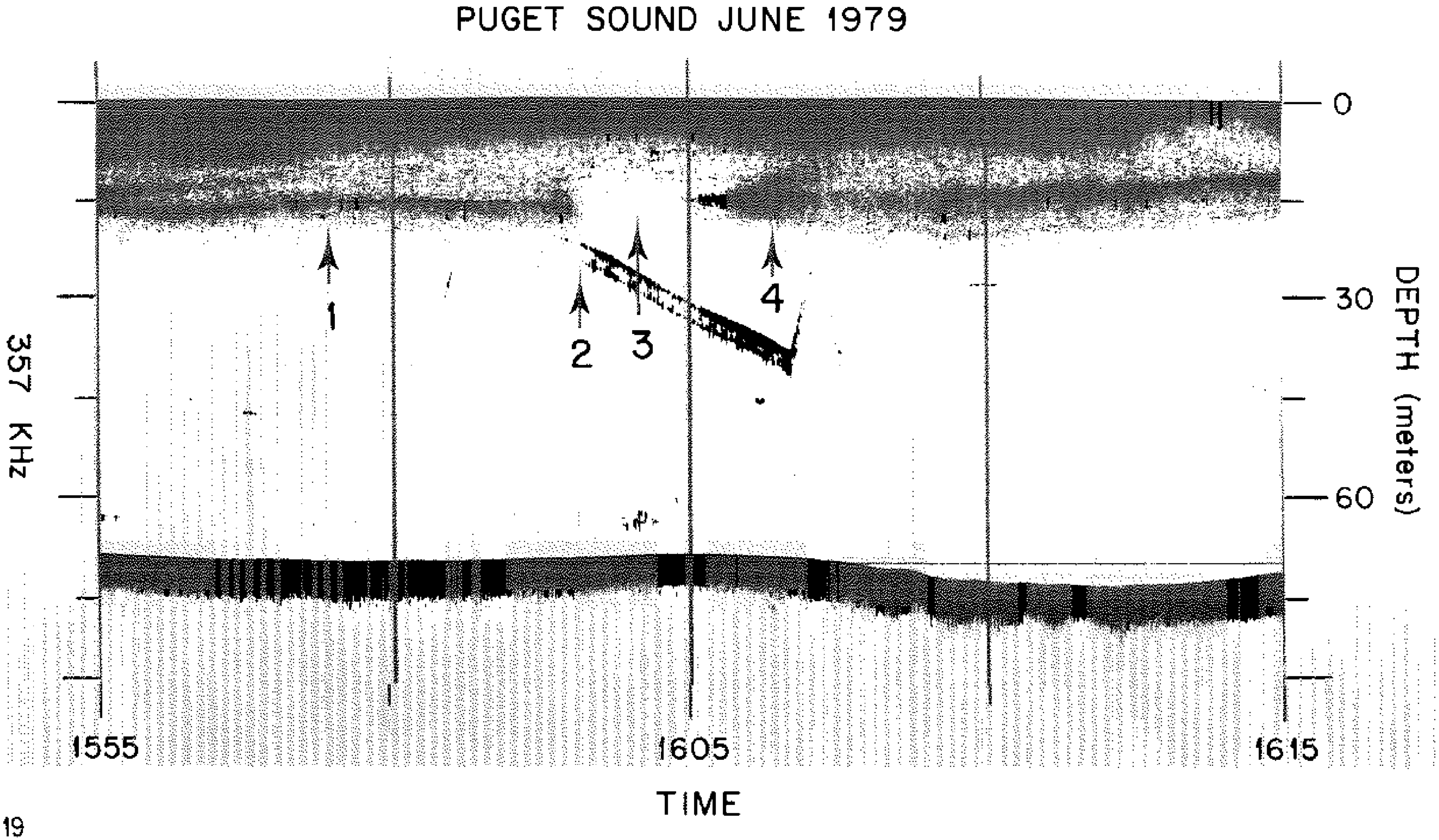

PUGET SOUND JUNE 1979
357 KHz
DEPTH (meters)
0
30
60
1
2
3
4
1555
1605
1615
TIME

Fig.19

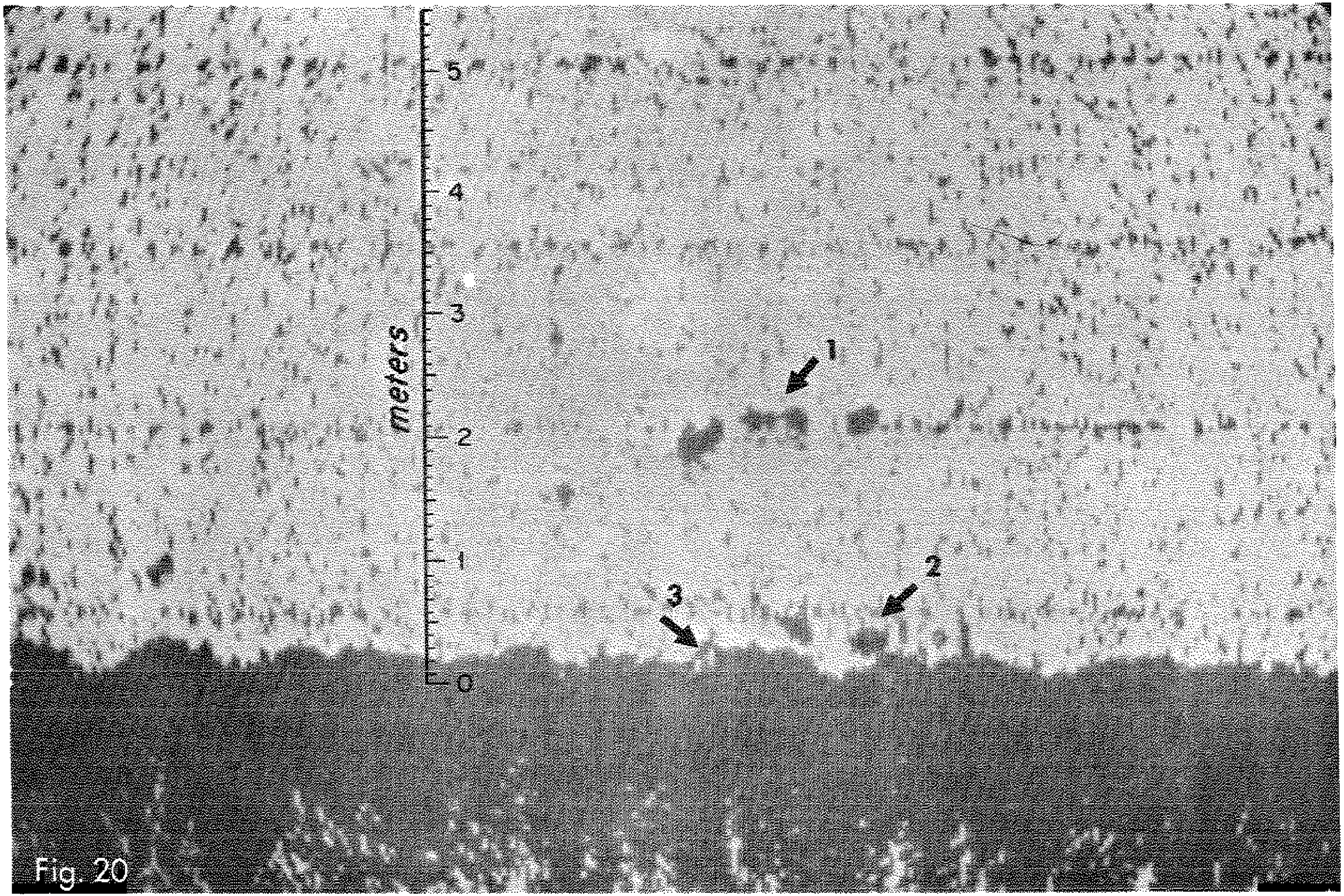


Fig. 20

May 1980

# DISTRIBUTION FOR SEA GRANT REPORTS

| No. of Copies | Address |
|---|---|
| 3 | National Sea Grant Depository<br>Pell Marine Science Library<br>University of Rhode Island<br>Kingston, RI 02881 |
| 5 | Office of Sea Grant<br>6010 Executive Blvd.<br>Rockville, MD 20852 |
| 25 | NOAA<br>Library & Information Serv. Div. OA/D825<br>6009 Executive Blvd.<br>Rockville, MD 20852 |
| 1 | *Sea Grant Today*<br>Editor, Food Science and Technology<br>VPI & SU<br>Blacksburg, VA 24061 |

## REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS
BEFORE COMPLETING FORM

1. REPORT NUMBER
WHOI-80-2

2. GOVT ACCESSION NO.

3. RECIPIENT'S CATALOG NUMBER

4. TITLE (and Subtitle)
REMOTE ACOUSTIC SENSING OF OCEANIC FLUID AND BIOLOGICAL PROCESSES

5. TYPE OF REPORT & PERIOD COVERED
Technical

6. PERFORMING ORG. REPORT NUMBER

7. AUTHOR(s)
M. H. Orr

8. CONTRACT OR GRANT NUMBER(s)
N00014-77-C-0196; NA79AA-D-00030; NA79AA-D-00102; OCE77-08682.

9. PERFORMING ORGANIZATION NAME AND ADDRESS
Woods Hole Oceanographic Institution
Woods Hole, MA 02543

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
NR 083-004

11. CONTROLLING OFFICE NAME AND ADDRESS
NORDA
National Space Technology Laboratory
Bay St. Louis, MS 39529

12. REPORT DATE
June 1980

13. NUMBER OF PAGES
51

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)

15. SECURITY CLASS. (of this report)
Unclassified

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

1. Fluid Processes
2. Biological Processes
3. Acoustic backscattering

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

High frequency acoustic backscattering systems are being used in monostatic modes to evaluate the use of acoustic techniques to detect and study a variety of fluid processes in the oceanic environment. A short outline of those research programs actively evaluating and using acoustic techniques is presented, followed by a detailed review of this investigator's program. This program uses a multifrequency high frequency acoustic system to study a variety of processes including turbulent mixing, air-sea interactions (Cont. on back)

Woods Hole Oceanographic Institution
WHOI-80-2

REMOTE ACOUSTIC SENSING OF OCEANIC FLUID AND BIOLOGICAL PROCESSES by M. H. Orr. 51 pages. June 1980. Prepared for the Office of Naval Research under Contract N00014-77-C-0196; NR 083-004, for the National Oceanic and Atmospheric Administration under Grants NA79AA-D-00030 (Ocean Dumping Program) and NA79AA-D-00102 (Office of Sea Grant) and for the National Science Foundation under Grant OCE 77-08682.

High frequency acoustic backscattering systems are being used in monostatic modes to evaluate the use of acoustic techniques to detect and study a variety of fluid processes in the oceanic environment. A short outline of those research programs actively evaluating and using acoustic techniques is presented, followed by a detailed review of this investigator's program.. This program uses a multifrequency high frequency acoustic system to study a variety of processes including turbulent mixing, air-sea interactions, internal waves, interleaving water masses, natural particulate dispersion and distribution, the dispersion of particulates associated with deep ocean disposal of industrial chemical waste, and biological response to a variety of stimulae including fluid motion, predators, and oceanographic instrumentation. Graphic acoustic data records of several of the above phenomena are described.

1. Fluid Processes
2. Biological Processes
3. Acoustic Backscattering

I. Orr, M. H.
II. N00014-77-C-0196; NR 083-004
III. NA79AA-D-00030
IV. NA79AA-D-00102
V. OCE 77-08682

This card is UNCLASSIFIED

Woods Hole Oceanographic Institution
WHOI-80-2

REMOTE ACOUSTIC SENSING OF OCEANIC FLUID AND BIOLOGICAL PROCESSES by M. H. Orr. 51 pages. June 1980. Prepared for the Office of Naval Research under Contract N00014-77-C-0196; NR 083-004, for the National Oceanic and Atmospheric Administration under Grants NA79AA-D-00030 (Ocean Dumping Program) and NA79AA-D-00102 (Office of Sea Grant) and for the National Science Foundation under Grant OCE 77-08682.

High frequency acoustic backscattering systems are being used in monostatic modes to evaluate the use of acoustic techniques to detect and study a variety of fluid processes in the oceanic environment. A short outline of those research programs actively evaluating and using acoustic techniques is presented, followed by a detailed review of this investigator's program.. This program uses a multifrequency high frequency acoustic system to study a variety of processes including turbulent mixing, air-sea interactions, internal waves, interleaving water masses, natural particulate dispersion and distribution, the dispersion of particulates associated with deep ocean disposal of industrial chemical waste, and biological response to a variety of stimulae including fluid motion, predators, and oceanographic instrumentation. Graphic acoustic data records of several of the above phenomena are described.

1. Fluid Processes
2. Biological Processes
3. Acoustic Backscattering

I. Orr, M. H.
II. N00014-77-C-0196; NR 083-004
III. NA79AA-D-00030
IV. NA79AA-D-00102
V. OCE 77-08682

This card is UNCLASSIFIED

Woods Hole Oceanographic Institution
WHOI-80-2

REMOTE ACOUSTIC SENSING OF OCEANIC FLUID AND BIOLOGICAL PROCESSES by M. H. Orr. 51 pages. June 1980. Prepared for the Office of Naval Research under Contract N00014-77-C-0196; NR 083-004, for the National Oceanic and Atmospheric Administration under Grants NA79AA-D-00030 (Ocean Dumping Program) and NA79AA-D-00102 (Office of Sea Grant) and for the National Science Foundation under Grant OCE 77-08682.

High frequency acoustic backscattering systems are being used in monostatic modes to evaluate the use of acoustic techniques to detect and study a variety of fluid processes in the oceanic environment. A short outline of those research programs actively evaluating and using acoustic techniques is presented, followed by a detailed review of this investigator's program.. This program uses a multifrequency high frequency acoustic system to study a variety of processes including turbulent mixing, air-sea interactions, internal waves, interleaving water masses, natural particulate dispersion and distribution, the dispersion of particulates associated with deep ocean disposal of industrial chemical waste, and biological response to a variety of stimulae including fluid motion, predators, and oceanographic instrumentation. Graphic acoustic data records of several of the above phenomena are described.

1. Fluid Processes
2. Biological Processes
3. Acoustic Backscattering

I. Orr, M. H.
II. N00014-77-C-0196; NR 083-004
III. NA79AA-D-00030
IV. NA79AA-D-00102
V. OCE 77-08682

This card is UNCLASSIFIED

Woods Hole Oceanographic Institution
WHOI-80-2

REMOTE ACOUSTIC SENSING OF OCEANIC FLUID AND BIOLOGICAL PROCESSES by M. H. Orr. 51 pages. June 1980. Prepared for the Office of Naval Research under Contract N00014-77-C-0196; NR 083-004, for the National Oceanic and Atmospheric Administration under Grants NA79AA-D-00030 (Ocean Dumping Program) and NA79AA-D-00102 (Office of Sea Grant) and for the National Science Foundation under Grant OCE 77-08682.

High frequency acoustic backscattering systems are being used in monostatic modes to evaluate the use of acoustic techniques to detect and study a variety of fluid processes in the oceanic environment. A short outline of those research programs actively evaluating and using acoustic techniques is presented, followed by a detailed review of this investigator's program.. This program uses a multifrequency high frequency acoustic system to study a variety of processes including turbulent mixing, air-sea interactions, internal waves, interleaving water masses, natural particulate dispersion and distribution, the dispersion of particulates associated with deep ocean disposal of industrial chemical waste, and biological response to a variety of stimulae including fluid motion, predators, and oceanographic instrumentation. Graphic acoustic data records of several of the above phenomena are described.

1. Fluid Processes
2. Biological Processes
3. Acoustic Backscattering

I. Orr, M. H.
II. N00014-77-C-0196; NR 083-004
III. NA79AA-D-00030
IV. NA79AA-D-00102
V. OCE 77-08682

This card is UNCLASSIFIED