Bolt Beranek and Newman Inc.

Report No. 5586

Investigations of the Potential Effects of Underwater Noise from Petroleum Industry Activities on Migrating Gray Whale Behavior

Phase II: January 1984 Migration

August 1984

Prepared for:
U.S. Department of Interior
Minerals Management Service
Alaska OCS Office

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INVESTIGATIONS OF THE POTENTIAL EFFECTS OF UNDERWATER NOISE FROM PETROLEUM INDUSTRY ACTIVITIES ON MIGRATING GRAY WHALE BEHAVIOR

Phase II: January 1984 Migration

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The research has been performed through support from Dr. Cleveland J. Cowles, Alaska OCS Office of the Minerals Management Service. Mr. Gordon Reetz of the Pacific OCS Office of MMS also provided valuable help during both phases of this work. Many others showed interest and provided support to the project. The following is an attempt to summarize those contributions, all of which were very important to the performance of the various tasks.

The National Marine Fisheries Service and the U.S. Fish and Wildlife Service extended the required permits for performing the acoustic stimulus research. Without those permits, we would not have been able to develop further confidence in our earlier findings by adding to the statistical data base.

The tape recordings used in the playback experiments were obtained by the MMS for this project in 1982 from the Naval Ocean Systems Center and Polar Research Laboratories. The willingness of those organizations to assist this project in that way is appreciated.

The single air gun used during the field work was leased from Western Geophysical and was operated from a geophysical survey air compressor loaned at no cost to the project by Price Compressor, Inc. The equipment was mounted onboard M.V. CHEYENNE ARROW owned and operated by Logan and Logan, Inc. and chartered by BBN. The availability of these major elements to the project was essential to resolving an answer to the question regarding gray whale response to air guns.

Dr. Marianne Riedman was retained under this contract to provide sea otter behavioral observation services during the

field research effort. Her assistance through application of her observational skills, analysis and preparation of her report (Appendix D) were very helpful and necessary to the completion of this effort.

The enthusiastic support of Mr. Russell Nilson, owner and operator of R.V. VARUA, the acoustic research vessel, and his skill in operating his vessel in highly variable sea conditions is particularly appreciated.

There were several scientists who provided needed advice and support at various times and at various levels of effort. They are:

Ms. Lisa Ballance; field observer

Ms. Jane Clark; field observer

Mr. Donald Croll; field observer

Ms. Jo Guerrero; data entry services

Ms. Linda Guinee; field observer and data analysis

Dr. Roger Payne; whale behavioral research procedures

Ms. Victoria Rowntree; field observer and data analysis.

Their contributions to the project were essential to the successful completion of the work.

The history of marine seismic exploration in California could not have been completed within the constraints of this project without the willing cooperation and interested assistance of Mr. Charles Darden of the International Association of Geophysical Contractors (Denver) and Dr. Robert Gaal of the California State Lands Commission (Long Beach). Dr. Michael Loughridge and his staff at the National Geophysical Data Center in

Boulder, Colorado, also provided support and quick response to our request. We are particularly grateful for their contributions.

Within BBN, the dedication and skills of Mr. Rafal Mlawski in the installation, maintenance, and operation of the acoustic systems on board R.V. VARUA were very important to the project. Dr. Robert Pyle provided dedicated use of his talents in applying the BBN computer to the detailed development and analysis of whale tracks and behavioral data. His valuable contributions were essential to the completion of the analysis of the field data. Mr. Creighton Gogos, also of BBN was the key individual in the assembly, test, installation, and operation of the single air gun system on board the air gun charter vessel. His skills were essential to the successful completion of the air gun experiments.

The word processing talents and patience which Ms. Judy Russo applied to the typing of this complex report, as well as Report No. 5366, are especially appreciated.

Finally, the authors of this report had the following project responsibilities:

Mr. Charles I. Malme	Chief Project Scientist and Principal Investigator for Acoustics
Mr. Paul R. Miles	Project Coordination, acoustics, and seismic survey history
<u>Consultants to BBN:</u>	
Dr. Christopher W. Clark	Co-Principal Investigator for whale behavioral research
Dr. Peter Tyack	Co-Principal Investigator for whale behavioral research
Mr. James E. Bird	Literature Survey and assistant regarding whale behavioral research.

All of these staff members contributed to various aspects of the required data analysis, interpretation, and reporting.

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1. SUMMARY

The applied research discussed in detail in this report supplements the work performed during the 1983 southbound and northbound migrations of the gray whale, Eschrichtius robustus, in the Monterey, California region. The objective of both phases has been to determine the degree of behavioral response of migrating gray whales to acoustic stimuli associated with oil and gas exploration and development activities. The results of that earlier work were presented in Bolt Beranek and Newman Inc. Report No. 5366* This companion document extends the 1983 research effort, adding to the statistical data base through measurements of behavioral response of the January 1984 southbound gray whale population to the same acoustic stimuli used in 1983 and to the operation of a single air gun. The playback sounds consisted of tape recordings of underwater acoustic signatures of a drilling platform, drillship, production platform, semisubmersible drilling rig and a helicopter overflight. Analysis and interpretation of the resulting 1984 data both support and strengthen the findings of the 1983 research effort.

This report, as well as the previously referenced report by BBN on the same subject of gray whale behavioral response to acoustic stimuli, establishes that gray whales respond to industrial waterborne sounds depending on the characteristics of the signal and the signal-to-background noise conditions. The degree of response has been quantified in detail, varying in level of statistical significance. We must caution the reader that the term "significant" as used here does not imply a biologically significant effect on the population or a large or

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*Malme, C.I., P.R. Miles, C.W. Clark, P. Tyack, and J. Bird (November 1983), "Investigations of the Potential Effects of Underwater Noise From Petroleum Industry Activities on Migrating Gray Whale Behavior," Final Report for the Period 7 June 1983 - 31 July 1983.

violent reaction to a given stimulus. Significance indicates that a statistically measurable change in behavior has been demonstrated. Indeed, the measurable reactions usually consist of rather subtle short term changes in speed and/or heading of the whale(s) under observation. These changes often become evident only after careful computer-aided statistical analysis of the optical tracking data.

Behavioral Observation Results

The main data collection and analysis effort of the study centered on whale group track analysis. However, a concerted effort was made to note whale group behaviors such as surface activity, milling, and breaching during control and experimental conditions so that any potential relationship to industrial sound exposure level could be determined. No significant differences in the occurrences of any of these behaviors were observed when comparing control and experimental conditions.

Track Analysis Results

A computer-implemented track analysis program was established to analyze the theodolite data for any possible changes in distance from shore, speed, linearity of track, orientation toward the sound source, and course heading of the whale group. The results of this program were cumulative track frequency distributions which were statistically analyzed to determine significant differences between experimental and control conditions.

Migrating whales were found to respond to the presence of a noise source by small course changes at some distance from the source. This "detection" reaction often occurred at ranges where the estimated level of the noise source was equal to the local ambient noise level. In the test area this corresponded to ranges of 2 to 3 km. The result of these small course changes, as the whales approached the sound source, was an increase in the distance between the whales and the source at the closest point of approach. This "avoidance" behavior resulted in a lower sound level exposure than would have occurred had the whale maintained the original course.

The distribution of distances between the source and the migrating whale tracks was statistically analyzed by comparing the track density distributions under experimental conditions with the track density distributions for the corresponding control conditions. This procedure resulted in obtaining a "probability of avoidance" distribution which showed the change in track density near the source as a function of distance from the source. By converting the distribution of range values to a distribution of sound exposure levels, using measured sound propagation characteristics for the test area, a set of sound exposure characteristics were obtained which permitted prediction of the probability that migrating whales would avoid a region of high noise level. These sound exposure characteristics thus are specific for the industrial noise sources used in the experiments but are not site-specific. thus, if the expected range of sound exposure levels can be predicted for a proposed drilling site, the potential impact zone for migrating gray whales can be estimated.

Probability of Avoidance Levels

The probability of avoidance analysis procedure showed that avoidance behavior began at sound exposure levels of around 110 dB (re 1µPa) for the playback signals and was greater than 80% for regions with signal levels higher than 130 dB. Some variation among the various playback stimuli was observed with the drillship producing the greatest avoidance and the production platform the lowest, for levels between 110 and 125 dB. However, for levels between 125 and 130 dB, the reactions to all playback signals were comparable. For the 100 cu. in. air gun, the threshold of avoidance behavior was 164 dB (effective pulse pressure re 1µPa). Levels of 180 dB were observed to produce nearly complete avoidance of the area. The air gun pulse rate was 6/min.

Effective Range of Operating Sources

An estimate of the effective range of the original noise sources (from which the tape recorded signals were obtained) was made by assuming operation in the test area. The effective range for a 50% probability of avoidance for most of the playback sources was estimated as less than 100 m. The effective range for the drillship was estimated as 1.1 km and for the air gun, 400 m. Based on data obtained previously* for a 4000 cu. in. seismic array, the effective range for broadside sound exposure geometry is 2.5 km. These effective ranges are based on sound propagation in the test area off Soberanes Point, California. Application of these estimates to other areas should not be made without following the procedures discussed in this report.

Seismic Exploration History

A compilation of the history of marine seismic exploration in the California region was performed with the objective of determining whether or not such industrial activity coincided with the presence of whales and has impacted gray whale migration habits in that area. A detailed discussion of the results of that effort, together with a summary of gray whale migration

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*BBN Report 5366, Section 8.

characteristics in California is given in Appendix A of this report.

A questionnaire was distributed to 53 organizations, discussions were held with the California State Lands Commission and a file search was performed at the National Geophysical Data Center. That effort resulted in a compilation of data representing 431,475 line miles of seismic surveys accomplished in the 1964 to 1983 period. Approximately 50% of those surveys were performed during the California migration season. An estimated 99% of that work used "nonexplosive" techniques employing such devices as air guns and sparkers. Explosives, such as dynamite, were used almost exclusively between about 1945 when the marine seismic survey work commenced and the mid-1960's. Very little seismic survey summary information was received for that early period.

The degree of detail of survey dates and locations of survey activity provided by respondents to the inquiry was insufficient to permit a rigorous statistical treatment of survey activity and gray whale census data. A comparison of the growth in gray whale population, detailed by Reilly (1981) and others with the rate of increase in survey activity seems to indicate that no long-term relationship is evident between population size and seismic survey activity.

Most census work, including shore monitoring and aerial reconnaissance indicates that over 90% of the migrating gray whale population travels within three nautical miles from shore except when travelling across mouths of embayments or running from point-to-point or cape-to-cape. This has been a consistent pattern since early records were kept in the mid-1800's. There is not quantitative evidence that the whales either have or are changing their migration corridors to deep ocean areas to avoid seismic survey activity. Marine seismic surveys are now moving further offshore onto the outer continental shelf (OCS). As shown in the body of this report and in the previous BBN report on the same subject (BBN Report No. 5366), observed short-term behavioral response of migrating gray whales to seismic survey sounds occurs for distances, between the seismic system and whales, which are shorter than 5 km, or 2.7 nautical miles. Most OCS seismic work is now occurring at distances exceeding 6 nm from shore. Therefore, it appears that even short-term behavioral response to present and future seismic survey activity will be minimal.

Also, a specific task requiring sea otter (Enhydra lutris nereis) behavioral observations during the acoustic stimulus experiments was performed. The report of that work is contained in Appendix D. It was demonstrated that the behavior density and distribution of sea otters were not influenced by the underwater playback of industrial sounds or by the air gun experiments.

2. BACKGROUND

This report presents the procedures and results of research applied by Bolt Beranek and Newman Inc. (BBN) and its whale behavioral consultant staff to a study of gray whale (Eschrichtius robustus) behavioral response to various underwater acoustic stimuli associated with oil and gas exploration and development. The work performed under Minerals Management Service Contract No. 14-12-0001-29033 represents a continuation of similar field measurements, data analysis, and interpretation performed in January, April and May 1983 and reported previously in BBN Report No. 5366.* The purpose of the additional research was to develop a larger statistical data base than previously acquired regarding gray whale behavioral response to acoustic stimuli. During January 1983, playback of taped sounds was performed in the presence of southbound migrating gray whales near Monterey, California. In April and early May of 1983, while some limited playback work was performed, the research concentrated upon determination of gray whale response to air gun array and single air gun impulsive sounds. That effort was applied to the mother/calf pair portion of the northbound migration of gray whales. Therefore, it was felt that additional data regarding gray whale response to air gun sounds should be performed in association with the general southbound 1984 population. Playback experiments were also performed during the same January 1984 migration period.

In preparation for continuation of the field measurements it was necessary to apply for extension of the permits obtained from

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*C.I. Malme, P.R. Miles, C.W. Clark, P. Tyack, J. Bird, "Investigations of the Potential Effects of Underwater Noise from Petroleum Industry Activities on Migrating Gray Whale Behavior," BBN Report No. 5366, November 1983.

National Marine Fisheries Service (NMFS) and the U.S. Fish and Wildlife Service (USFWS) to perform research which could impact endangered species (gray whale and sea otter, respectively). NMFS Permit #400 was extended to allow for the additional acoustic stimulus research in association with migrating gray whales. USFWS Permit #PRT 2-9740 was extended as well since the gray whale reserch was to be performed in an area which is inhabited by sea otters.

In the previous research effort in 1983, a team of sea otter observers was stationed on shore to determine the degree of response of the sea otter population to the acoustic stimuli used during the gray whale research. The results of that first year effort demonstrated that there were no observable sea otter behavioral responses to the playbacks and air gun sounds. As a result of that work, a single sea otter observer (Dr. Marianne Riedman) was stationed on shore during the January 1984 experiments. Her report covering that work is contained in Appendix D.

Included in the extension of the applied research outlined above was a request by MMS for BBN to develop a history of marine seismic survey operations off the coast of California and to relate that history to the observed migration history of the gray whale in California waters. The results of that work are detailed in Appendix A.

3. EXPERIMENTAL PROCEDURE

3.1 Overall

The field work was performed in the same area as in 1983, utilizing two shore-based observation teams (four observers per site) located at the same sites occupied in January 1983, a sound playback and acoustic monitor research vessel and an air gun vessel. Figures 3.1 and 3.2 outline the positioning of shore sites and research vessels. In Fig. 3.1, the R.V. VARUA was stationed at S1 during the air gun tests and at S2 during playback of sounds associated with oil and gas development activities. The nearby locations of the air gun vessel, M.V. CHEYENNE ARROW are also noted, located about 4 km, 2 km, and 0.5 km from position S1. The migration corridor of the southbound gray whales was expected to be centered at about 1.5 to 2 km from shore or near positions S1 and S2. At the conclusion of the air gun experiments, the air gun vessel headed along the dashed track (1/11/84) with the air gun operating, providing an opportunity for obtaining acoustic propagation loss data associated with the measurement site. Figure 3.2 provides another chart of the air gun vessel tracks on a larger scale to include an 8 mile (15 km) traverse of the air gun sound source. Experience from the 1983 series of experiments demonstrated that it was not necessary to operate the single air gun at larger distances from the expected location of migrating whales.

The acoustic field procedures used were the same as those used in 1983. The single air gun (a 100 cu. in. unit operated at 4500 psi) was pulsed every 10 seconds during the various tests. The taped playback signatures consisted of:

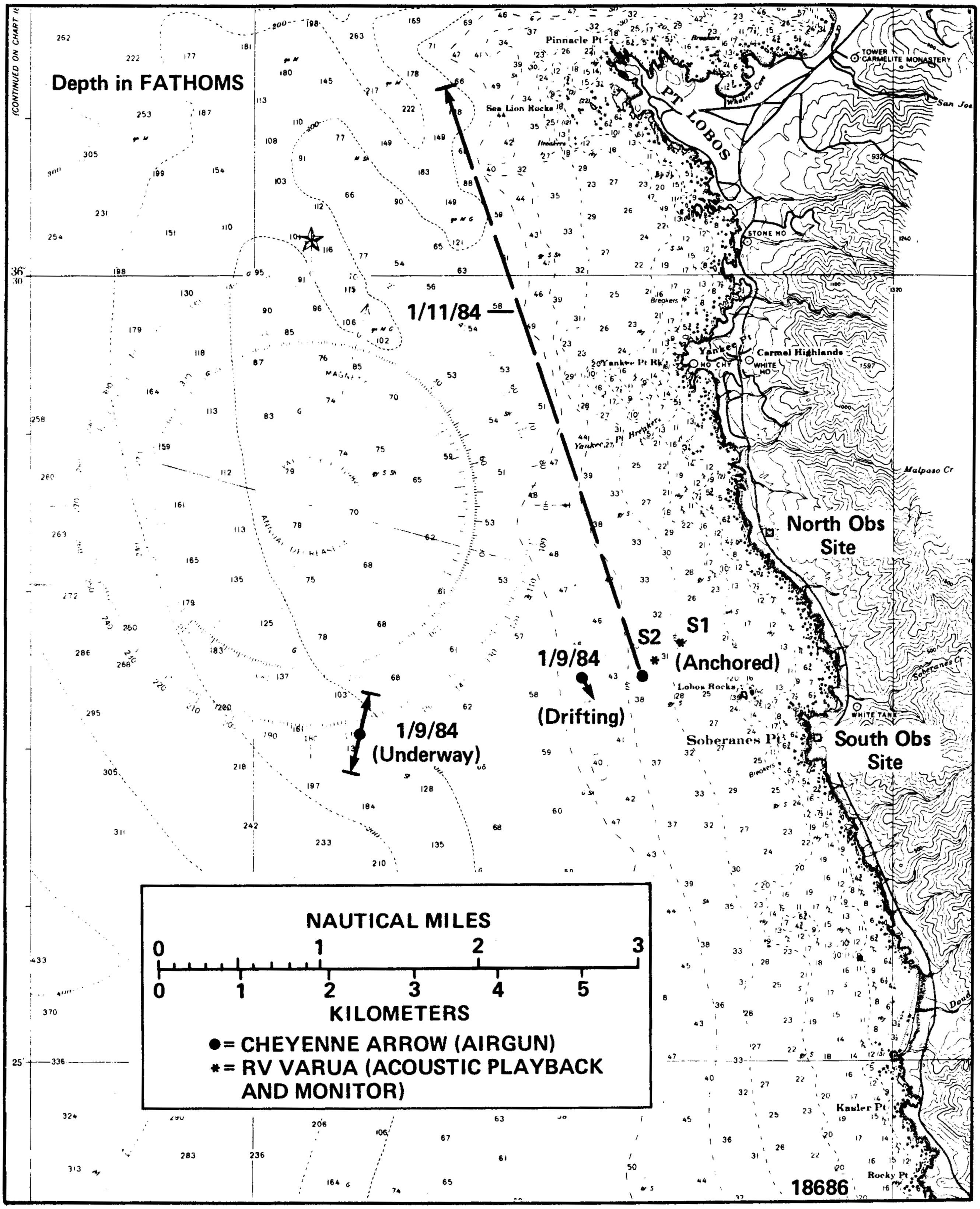


FIG. 3.1. ACOUSTIC STIMULUS VESSEL POSITIONS AND GRAY WHALE OBSERVATION SITES FOR JANUARY 1984 SOUTHBOUND MIGRATION.

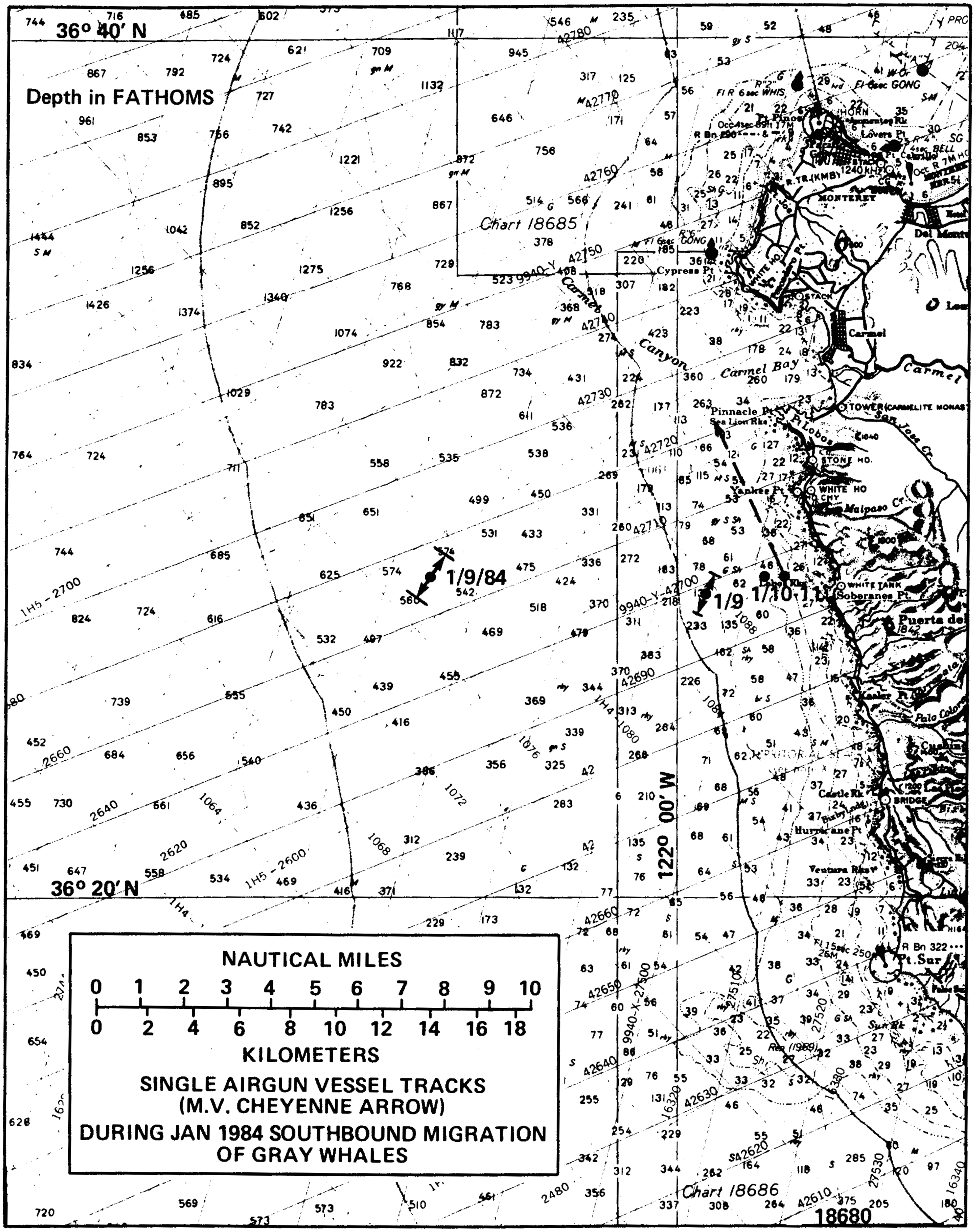


FIG. 3.2. TRACKS AND LOCATIONS OF THE SINGLE AIR GUN VESSEL DURING THE JANUARY 1984 SOUTHBOUND MIGRATION OF GRAY WHALES.

- Drilling Platform (HOLLY) (DP)
- Drillship (EXPLORER) (DS)
- Production Platform (SPARK) (PP)
- Helicopter Overflight (Bell #212) (H)
- Semisubmersible Drill Rig (OCEAN VICTORY) (SS).

The same tapes used in 1983, and obtained from Naval Ocean Systems Center and Polar Research Laboratories through MMS, were used in this series of tests. During 1983, sounds from killer whales (Orcinus orca) were also used during the playback tests. That natural sound playback was not used in 1984 since sufficient data were acquired during the earlier tests.

The shore-based observers operated blind to the extent that they did not know either the timing of playbacks or the playback signature being used. No-playback periods were interleaved with playback periods and several days of control observations both with and without research vessels present provided whale behavioral data during normal ambient noise conditions.

Measurement of the natural uncontrolled background noise environment of the migrating gray whales was also obtained for various periods throughout each day to develop information regarding the statistical variability of the ambient noise. Major contributions to the ambient noise were determined to be surf and wave noise, sounds from shrimp and sea lions, and ship traffic offshore.

The shore crews obtained continuous theodolite track information on whale groups as they passed through the measurement area, logged behavioral information such as aerial activity, milling and social activity, and obtained regular theodolite position information on the positions of the research vessels.

3.2 Behavior Monitoring

The basic objective of the research was to determine the potential influence of underwater industrial noise associated with offshore oil and gas exploration and development on the behavior of migrating gray whales. The experimental procedure established a controlled noise field in the test area and conducted behavioral observations of whales migrating through the test area. The goal of the field work was to obtain behavioral response data which would then be related to quantified sound exposure levels. The determination of response to industrial noise depended on comparisons between observations under normal (undisturbed) and experimental (potentially disturbed) conditions. Therefore, there were no differences in the behavioral observation techniques or efforts employed during the normal and experimental aspects of the project.

A set of behavioral assays were selected in order to assess the level of response to any of the experimental sound exposures. The behaviors that were simultaneously monitored were swimming pattern, and the occurrence of any other visible surface activities such as breaching, rolling, etc.

Behavioral monitoring was done simultaneously with theodolite tracking such that any observable behaviors were noted along with time and position. Observations were made using either the unaided eye, hand held binoculars (x8), dual Bausch and Lomb spotting scopes (x15 and x22), or the theodolite eyepiece (x20). In a few cases behaviors could be associated with a specific individual within the group based on markings that were specific to that group member, for example, if there were differences in the degree of mottling on the back or distinctive white spots on or near the dorsal ridge.

3.2.1 Whale position tracking

The method of using a theodolite to track whales from a shore station was first developed by Roger Payne and has since been used frequently to follow whales and porpoises (e.g., Würsig, 1976, Clark and Clark, 1980, Tyack, 1981). By this method, one measures the horizontal angle from the whale to a fixed landmark for azimuth, and measures the vertical angle of depression from the horizon to the whale for derivation of range. Since the altitudes of the transit stations used in this study were low relative to the ranges of the whales observed, precision of measuring the vertical angle was critical. (See Appendix E for theodolite tracking system error analysis.)

The model of theodolite used in this project was Topcon Model DT-20. The theodolites had electronic digital angle measurement with a visual numeric readout. Angles were measured with a precision of at least 20 seconds of arc. The actual precision of our localization of southbound whales is discussed in Appendix E.

As soon as a new group of whales was sighted from the North transit station, it was given a unique group letter for the day. Each time a whale within the group was located by the theodolite operator, a notetaker recorded the time of the observation, the group letter, the vertical and horizontal bearings to the whale, group size and any displays observed. Observers also made an effort to count the number of whales within the group. Bearings indicating the positions of boats in the study area were also noted. As a boat or group of whales passed into the field of vision of another transit station, observers at both stations would communicate group letters or other identifiers for whales or boats by CB radio, and attempt to take simultaneous sightings on them.

3.2.2 Track and position data analysis

Conversion of Bearing Data

All transit sightings of whales and boats were entered into an Apple II^{+} computer using the editor for Apple Pascal or directly into the BBN PDP-20 computer. A separate file was made for each day's records from each transit station. Data from each sighting were entered on one line per sighting for the following variables:

TIME GROUP LETTER GROUP SIZE VERTICAL BEARING

HORIZONTAL BEARING BEHAVIOR

These data were then converted into position in rectangular coordinates, in units of meters, with the Soberanes transit station as the origin, with true North as the positive x axis and West as the positive y axis. The transit bearings were converted into rectangular coordinates using an iterative correction for the curvature of the earth developed by J. Wolitzky (Würsig, 1976). A correction for refraction of light was found to be unnecessary for the ranges at which whales were typically tracked, but the tidal excursion was large enough that the altitude of the station was corrected for tidal fluctuations.

After the field season was over, the Apple II^{+} files of rectangular coordinates were transferred to BBN System G, a DEC PDP-20 computer using the program PTERM.

3.2.3 Track data

Each point along the track of each whale group was checked after processing by a RATFOR program developed by R.W. Pyle which sorted entries into tracks of each group and listed the apparent speed between points. All points with unrealistically high speeds were labelled not to be used in tracks unless they represented almost simultaneous sightings of different whales within a group. The criterion for high speeds was dependent on group size as follows:

Group Size	Maximum Acceptable Speed
1	18 km/hr
2	24 km/hr
3	30 km/hr
4	36 km/hr

These maximum speed limits assume worst case conditions of 100 m error between two sightings and that any two individuals within a group could be separated by as much as 100 m along the x-axis. There were few such points in typical tracks and most were easily determined to be isolated erroneous data.

No effort was made to select tracks that were strictly linear, since track deflection was a critical response measure. A small percentage of groups yielded a series of points requiring unreasonably high speeds to be fitted to a track, but in which it was impossible to determine unambiguously which one or two points were in error. These groups were not used in the track analysis.

If a group was sighted less than three times over an interval of < 15 min. or tracked over a distance of < 100 m, its sightings were not used for tracks. In addition, if there was a gap in sighting a group of > 20 min., the track was terminated before the gap.

3.2.4 Plots

Plots of selected tracks were made using DISSPLA software and a Nicolet-Zeta 2300X plotter. The coastline of the study area was digitized using a Calcomp 9000 digitizing tablet; the coastline and position of the playback stimulus source were plotted along with the tracks of whales.

3.2.5 Track deflection program

A track deflection program was developed by R.W. Pyle and P. Tyack. This program was written in RATFOR and run on the PDP-20 computer at BBN. The program uses DISSPLA software to generate plots of cumulative track density distributions.

3.2.6 Other behaviors

At the same time that the theodolite positions were being recorded, other behaviors were noted. These included: breaching, vertical flukes, fluke outs, underwater blowing, head ups, rolling, spyhopping, direction of movement (other than direction of migration), milling, groups joining, and groups splitting (see Sec. 6.2 for further description).

Consistent observations on the various behaviors were difficult because the groups were 1 to 4 km off shore and there were usually many groups in the area at any one time. Breaching, direction of movement, milling, splitting, and joining and general surface activity were relatively easy to observe but noting specific surface active behaviors was often problematical.

3.3 Acoustic Instrumentation, Measurement, and Analysis Procedures

This section describes the instrumentation and procedures used to obtain the required physical and acoustic data. The field measurements employed two types of sound sources during the whale behavior observations, a broadband projector for playback and a 100 cu. in. air gun. For the playback work, the goal was to simulate as closely as possible the sound fields produced by a representative range of offshore oil and gas industry activities. This required the following considerations:

- Provision for establishing a calibrated relationship between the playback sound field and the sound field existing around the actual industry activity being simulated.
- Measurement of the acoustic propagation conditions at the playback site.
- Measurement of the ambient noise levels at the playback site during the observation period.

Similar considerations applied to the observations using the air gun source in that acoustic propagation data and ambient noise data were required. The effective acoustic output level and spectra of a 100 cu. in. air gun were measured during the April-May 1983 field period. The data obtained were used to derive sound propagation and pulse pressure scaling relationships for the observation area. Additional measurements were required during the January 1984 field period to verify that the previously obtained data and the resulting sound pressure scaling equations remained relevant. These equations would then permit estimation of the sound exposure for whales migrating through the observation area. Knowledge of the sound source level of the air gun (L_S) also permits estimation of the sound levels that would be produced for air gun operation in other areas, providing the sound transmission-loss characteristics (TL) for the area in question are known.

The instrumentation for the principal measurements was installed on the VARUA, a 73-ft (93-ft OA) brigantine. Sonobuoy measurements were also made to obtain data from an extended measurement baseline. The air gun source was handled from the CHEYENNE ARROW, a 140-ft cargo/supply vessel normally chartered by the oil industry.

3.3.1 Acoustic environmental measurements

Navigation

The radar on the VARUA was used for determining the location of the vessel relative to the local coastline. It was also used to determine ranges to the air gun vessel and ranges to passing ships which were contributing to the local ambient noise level. An optical rangefinder was used for range measurements under 400 m. Theodolite sightings from shore provided the final input data to the whale/sound-source range computation for the data analysis.

A recording fathometer was used for determining the water depth during anchoring and sound measurement procedures.

Physical Measurements

The variation of water temperature and salinity with depth was measured with a Beckman Model RS5-3 conductivity, temperature, and salinity probe. This instrument provided a salinity measurement based on the temperature and conductivity data. Measurements were made at selected depths down to 40 m. The measured data were then used to calculate the sound velocity profile.

Wave and swell height were estimated visually.

Ambient Noise Measurements

A standard hydrophone system that combined an ITC Type 6050C hydrophone with a low-noise preamplifier and tape-recorder was used to obtain ambient noise data. The hydrophone sensitivity and electrical noise-floor characteristics are shown in Fig. 3.3. The acoustic noise measurement system block diagram is shown in Fig. 3.4. Overall frequency response of the measurement system was generally flat from 20 Hz to 15 kHz. All components of the system were battery operated during ambient noise measurement. Cable fairings and a support float system were used to minimize strumming and surge noise effects on the ambient measurement hydrophone.

Sonobuoy Measurements

An AN/SSQ-57A sonobuoy was used to obtain sound level data during a playback experiment. This buoy was released from the VARUA and allowed to drift with the along-shore tidal current. The drift rate was estimated based on observations at the VARUA position and calibrated by correlation techniques during data analysis. The rate at which the playback signal level decreased with increasing range was then measured and compared with the predicted values based on the previously derived sound propagation equation.

An equalizer circuit was used to correct the low-frequency de-emphasis of the sonobuoy as shown in Fig. 3.4. The resulting receiver channel response was flat within ±1 dB from 10 Hz to 20 kHz with a sensitivity of -115 dB re $|v|$ μPa.

Transmission Loss Verification

The transmission loss information obtained during the 1983 field season was checked by measurements using the air gun source. Data were obtained for several ranges extending from

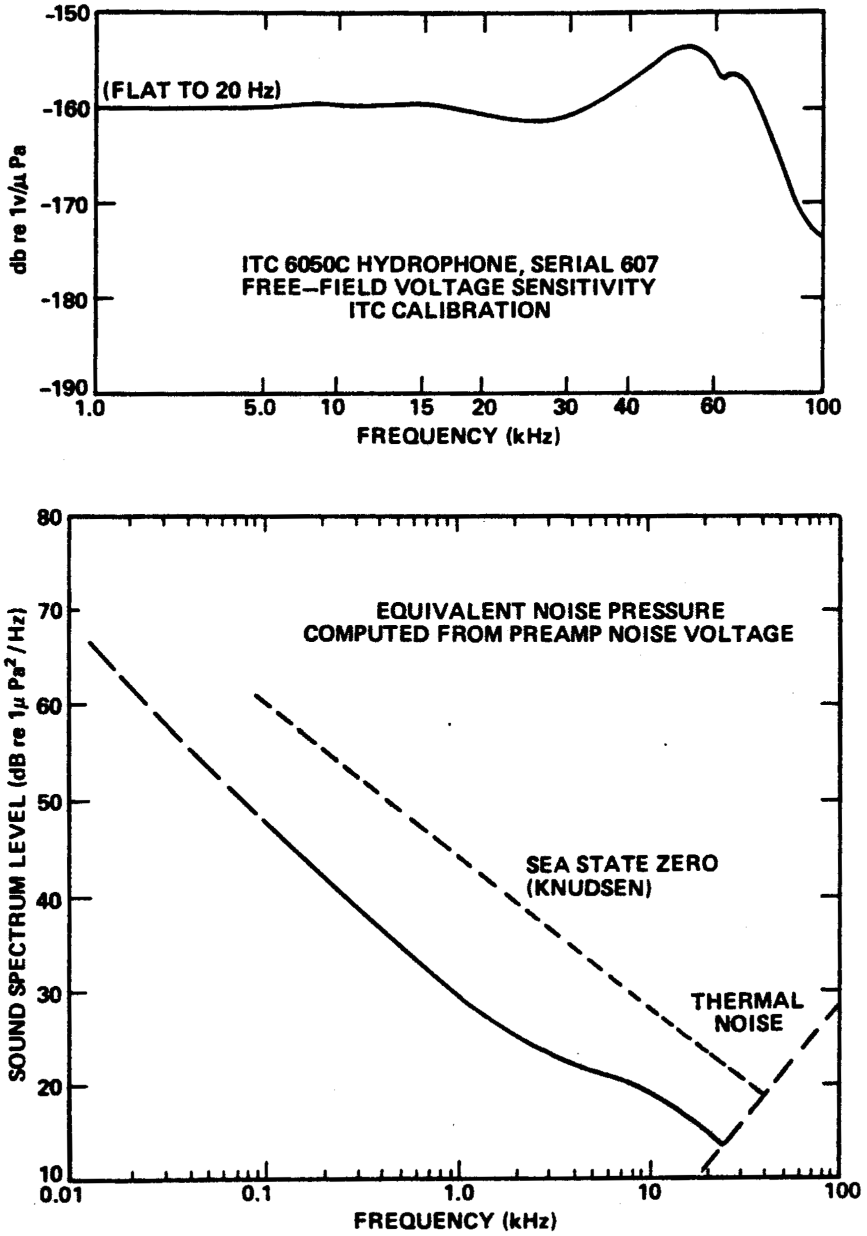
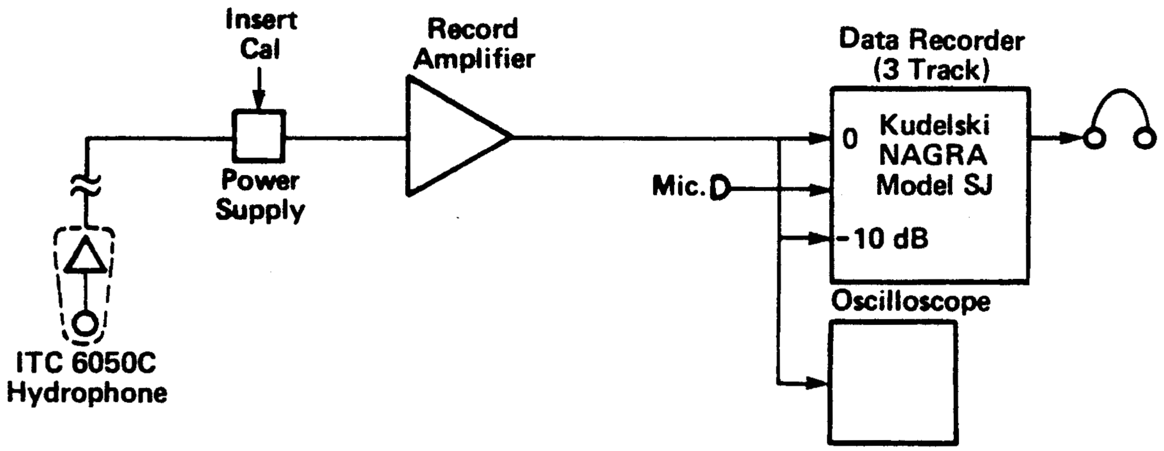
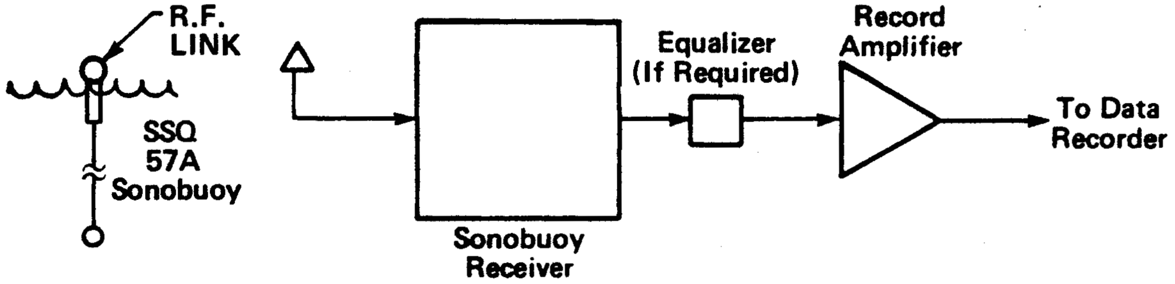


FIG. 3.3. MEASUREMENT HYDROPHONE CHARACTERISTICS.



GENERAL PURPOSE ACOUSTIC MEASUREMENT SYSTEM



SONOBUOY MEASUREMENT SYSTEM

FIG. 3.4. ACOUSTIC MEASUREMENT SYSTEMS.

300 m to 15.5 km. In addition, a transmission loss measurement run was made to determine transmission loss along the migration route from the VARUA position to a position 7.4 km north - off Pt. Lobos.

3.3.2 Acoustic playback procedure

Projector System

The acoustic playback system was designed to provide sound levels and frequency response capable of realistically simulating the designated range of petroleum industry activities. In order to keep the system within the required operational constraints, a compromise was necessary in the achievable low frequency response of the projector system. During the previous playback work, a USN/USRD Type J-13 projector was used which provided useful frequency response down to 50 Hz. Since many of the industrial noise stimuli used in the playback study have significant noise contributions below 50 Hz, an effort was made to improve the low frequency output of the playback system by using two J-13 projectors.

Because of the required broad frequency range needed to reproduce the industrial noise spectra, three sound projectors were used. In addition to the two low frequency projectors, a USN/USRD Type F-40 projector was used to provide high frequency sound above 2 kHz. Electrical equalization and cross-over networks were used to enable all of the projectors to be driven from a Crown 300-watt power amplifier. As a result of the use of two low frequency projectors and the electronic equalization network, the useful response of the system was made to extend from 32 Hz to 20 kHz. The playback system and its response curve are shown in Fig. 3.5.

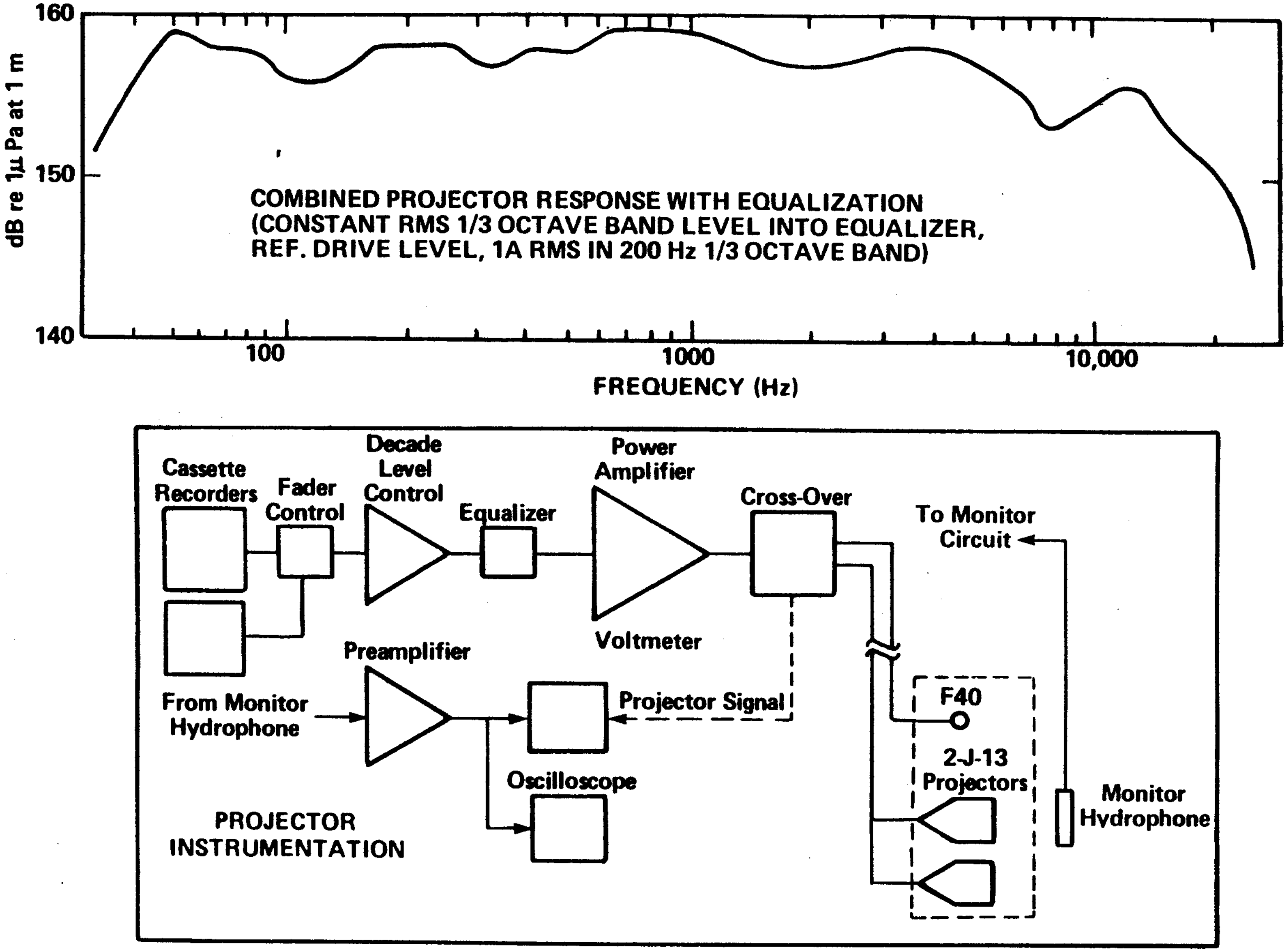


FIG. 3.5. PLAYBACK INSTRUMENTATION.

The three projectors were mounted in a support frame to maintain correct acoustic alignment of the radiating surfaces and to facilitate handling. The assembly similar to that shown in Fig. 3.6 of Report 5366 was lowered to a depth of 15 m with the cargo boom on the VARUA. A "wind vane" was also mounted on the projector assembly to keep the J-13 projector pointed away from the current. This facilitated operation during high tidal current conditions by minimizing drag forces on the projector piston which could cause signal distortion.

A reference monitor hydrophone (ITC Type 6050C) was mounted at a distance of 6 m from the projector system to maintain calibration of the projected sound levels.

During a playback sequence, a pre-recorded industrial noise or control stimulus on a cassette tape was used to generate a test signal. Two cassette recorders coupled to a fader control (previously shown in Fig. 3.5) permitted uninterrupted continuous sound for as long as desired. Playback periods of 2 to 2.5 hrs were generally used.

Stimuli Projection and Monitoring

The acoustic levels reported for the original sources of the playback stimuli varied over a wide range. Playback at source levels designed to reproduce the original signal levels was not feasible for some stimuli because of the high acoustic power required. For other stimuli, the original sound levels were low enough so that reproduction of the original level could result in whale behavioral reaction in close proximity to the VARUA. The presence of the VARUA would be a potential confounding factor in interpreting the results for the lower level stimuli.

Thus, to provide a potential behavioral reaction zone at some distance from the VARUA for all of the playback sequences, the output level of the projector system was set to provide a source level which was 55 to 60 dB above the measured ambient noise level in the dominant bandwidth of the stimulus. An effective range of 2 to 3 km was obtained to the zone where the playback level became approximately equal to the ambient noise level in the dominant band of the stimulus. This procedure produced an acoustic test zone where any behavioral reaction of the migrating whales would probably occur within visual range of the observation stations but also at some distance from the VARUA.

The sound levels used were subsequently scaled to levels reported for the actual sources and range corrections were derived by using the transmission loss characteristics measured at the test site. This procedure is described in detail in Sec. 8.

Selection and Level Calibration

Five petroleum industry development and production noise examples were used for the playback stimuli. Descriptive information for these test examples is contained in Table 3.1.

As shown in the table, the acoustic recording used for each of the test stimuli was obtained at various ranges from the respective source. Hence, to standardize the playback comparison process, we corrected the reported acoustic level data to an equivalent 100 m range from the source. Since the water depth and sound propagation characteristics differed for the various sources, we considered that correction to a 100 m range represented a smaller potential error than correction to the usual 1 m range. In each case measured transmission loss data were used, if available, or the best estimate of transmission loss was used based on stated range and water depth values. In deriving the appropriate comparison with the projected playback level, a 100 m sound level estimate was also used. Thus, we were able to derive a scaling factor for the playback level which

TABLE 3.1. PLAYBACK STIMULI INFORMATION.

Stimulus (Code)	Original Recording Dist. Meters	Dominant Frequencies Hz	Reported Level dB//µPa	Est. 100 m Level dB//µPa	Playback 100 m Level dB//µPa	Difference (PB-Orig) dB	Data Ref.
Drilling Platform (HOLLY)	30	5 (t)	119	109	-	-	Gales
		13 (t)	107	97	-	-	p. 66
		80-315 (st)	99	89	125	36	
DRILLSHIP (DS)	185	278 (t)	123	126	122	-4	Greene
(EXPLORER II)		50-315 (bb)	133	136	127	-9	p. 322
Production Platform (PP)	9	20 (t)	134	118	93	25	Gales
(SPARK)		63-250 (st)	125	109	123	14	p. 64
Helicopter (H)	152	20 (t)	114	118*	99	-19	Greene
(Bell 212)	(altitude)	32 (t)	99	103*	113	10	P. 311
		50-200 (st)	99	103*	116	13	
Semisubmersible Rig (SS)	12	28 (t)	129	111	105	-6	Gales
(OCEAN VICTORY)		63-250 (st)	119	101	123	22	p. 65

Key:

(t) tonal, (bb) broadband, (st) summed tonals.

*These values are for a flyover at 100 m altitude. Estimate based on relationships developed for aircraft-underwater sound transmission in deep water. In shallow water, levels would be higher, depending on the acoustic properties of the bottom material. Values assume a receiver position near the surface. (Barger and Sachs) allowed us to compensate for local transmission loss characteristics and for differences between acoustic levels from the actual sources and the achievable levels from the playback projector. Table 3.1 shows the differences in levels between the playback stimuli and the reported values as corrected to an equivalent 100 m range. We wished to operate at a relatively constant signal-to-noise ratio (S/N) at the source to have a uniform exposure region for all test stimuli. Thus, as shown in the table, the projected level was louder than the actual source for some stimuli, and quieter than the actual source for others.

Table 3.1 lists the maximum measured levels for the stimuli when they were originally recorded. These sound levels are based on the reported data for the actual tape dubs used. The reference cited was used as the basis for establishing the original sound field level because of the difficulty in recovering and preserving a calibration chain through the dubbing and playback process. The original data were used to determine the dominant spectrum components of the original sound field and the frequency region of the principal output. Because of the low frequency limitation of the J-13 projectors below 32 Hz, it was not possible to reproduce the required levels for sources with very low dominant frequencies. In this case, the degree to which the frequency response above 32 Hz matched the original source was examined independently by comparison of this part of the playback spectrum with the comparable part of the reported original source spectrum. This is shown as the "summed tonal level" value in Table 3.1.

The sound level output produced during playback is compared with the original sound source values in the last column of the table. The comparison shows that, while low frequency components are often appreciably reduced on playback, the components above 32 Hz are generally greater than their original levels. The exception to this is the drillship stimulus where the achievable level is below that of the actual source at all frequencies. The procedure for scaling level differences between playback and actual sources will be discussed in Sec. 8 using the measured TL and ambient noise data for the observation site.

Playback Schedule Considerations

The playback schedule which was designed for the five sound stimuli in the repertoire involved requirements to:

- Maximize the number of different sequences presented each day in order to obtain a sufficient data base for each type of sound and in order to average out fluctuations in environmental conditions that could potentially influence behavior of the whales.
- Provide a sufficiently long exposure period for each sequence so that a large number of whales swimming at 6 to 9 km/hr would traverse a pre-exposure zone, a test zone, and a recovery zone within visual range of the observation sites.
- Provide a no-playback interval between test sequences to minimize the number of whales exposed to two different types of test stimuli.
- Provide a no-playback control period at least as long as the playback for each block of playback stimuli and, in addition, provide at least one full day of control with the VARUA present without playback.

The schedule was organized into three 2 to 2.5 hr playback periods separated by 0.5 hr quiet periods. This permitted 2 to 3 playback sequences per day depending on whether or not a no-playback control sequence was included (see Table 4.3 in Sec. 4).

All of the tests were performed using a double-blind method in which observers knew nothing of the playback schedule and playback personnel did not know of potential whale responses. Three blocks of five stimuli each were completed in an 8-day period which included a boat present control day and a boat absent weather day. The stimuli schedule within each block was designed to keep the number of presentations as balanced as possible at any given time in case the weather precluded any further work.

3.3.3 Air gun source measurements

Three days of observations were made with an air gun source vessel present. The purpose of these observations was to determine the sound levels for which behavioral changes may occur for whales in the southbound migration. The data obtained would be compared to that obtained for the mother-calf phase of the northbound migration during April-May 1983.

The results obtained during the 1983 measurements showed that behavioral changes were not observed at ranges greater than 1 to 2 km for mother-calf pairs. Thus, a preliminary set of measurements were scheduled for the southbound migration where the air gun range would be gradually decreased from 8 miles (15.5 km) to a position near the center of the migration zone. Following this test, two days of observations were made with the air gun vessel anchored near the VARUA. These tests provided measurement geometry very similar to that used for the playback observations and permitted use of the same statistical testing procedures for both playback and air gun data.

3.4 Statistical Analysis Procedures

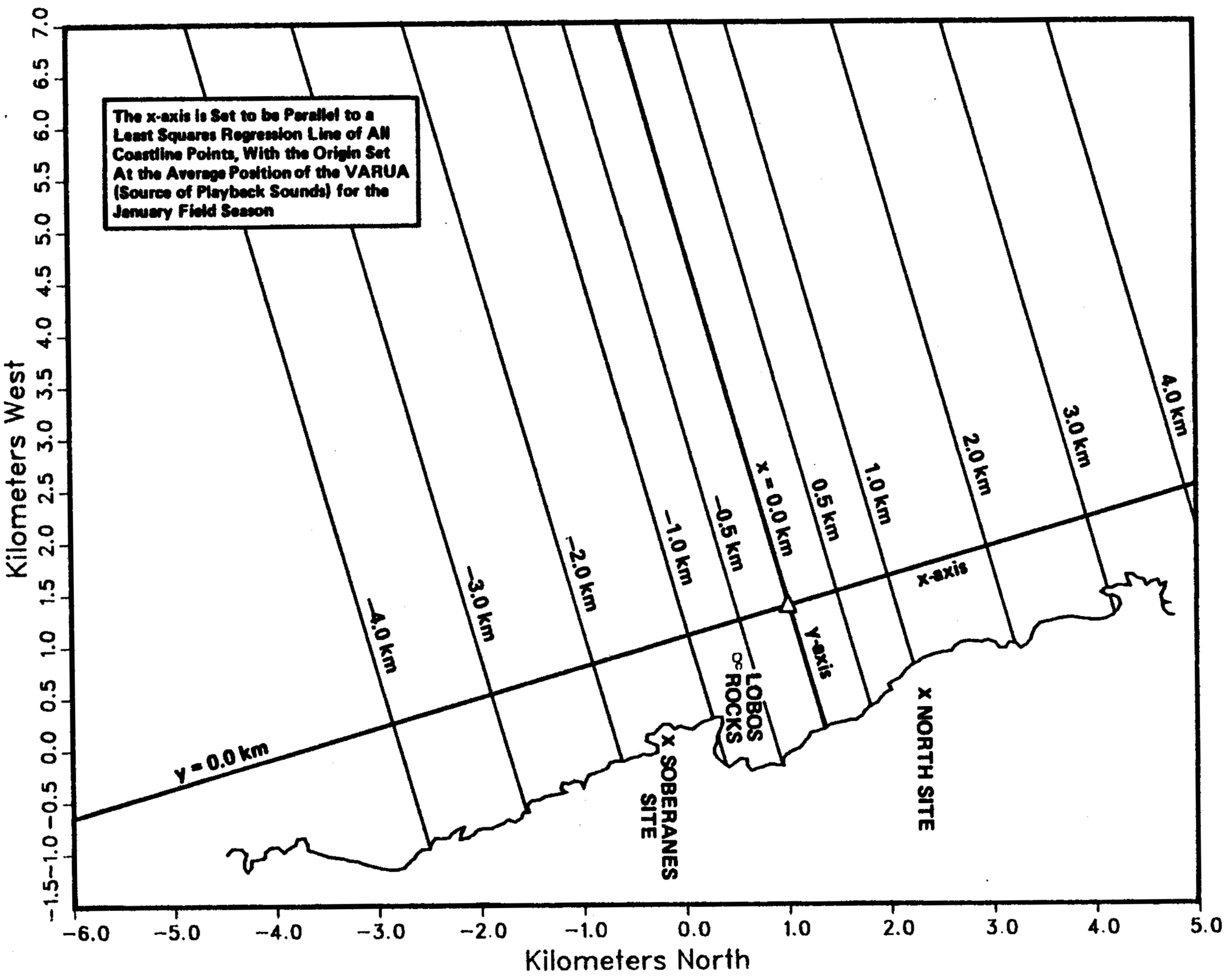
This section summarizes the procedures used to study the swimming behavior of the whales under control and acoustic experimental conditions.

3.4.1 Analysis procedure for track data

The track deflection program developed for last year's analysis was used again in this year's analysis of the track data. Since this program is the principle tool for statistical analysis of the experimental results, we will review it briefly here.

The primary motivation in the analysis scheme is to compare swimming patterns during a variety of acoustic experimental conditions with patterns observed during control conditions. To this end we first devised a two-dimensional caretsian coordinate system with its origin at the average playback position of the VARUA (the sound source) and its x-axis a line parallel to the linear regression of the coastline inthe observation area. A series of grid lines projecting perpendicular to the x-axis were then established at 4.0, 3.0, 2.0, 1.0, 0.5, 0.0, -0.5, -1.0, -2.0, -3.0, and -4.0 km from the VARUA (see Fig. 3.6).

For each whale group that crosses one of these grid lines, the track deflection program calculates the group's distance from the x-axis (D_y) and its distance offshore (D_s). For each whale group that crosses an adjacent pair of grid lines (referred to as a grid interval), the program calculates the group's cumulative speed (s) (total distance travelled between grids divided by time), milling index (MI), course bearing (CB), and VARUA bearing (VB). Cumulative frequency distributions for all six of these measures are then described by pooling the data for all tracks



The x-axis is Set to be Parallel to a Least Squares Regression Line of All Coastline Points, With the Origin Set At the Average Position of the VARUA (Source of Playback Sounds) for the January Field Season

FIG. 3.6. GRID COORDINATE SYSTEM FOR TRACK DEFLECTION PROGRAM.

observed under the same condition. Typical distribution plots are shown in Fig. 3.7 and in Appendix B.

The net result is that a set of cumulative frequency distributions are calculated for D_y and D_s at each grid line and for S, MI, CB, and VB at each adjacent pair of grid lines. Data gathered under similar conditions (e.g., Drillship playback) are then tested for homogeneity by comparing every possible pair of distributions within the same type of track measure. For example, the D_y distribution at the 4.0 km grid is compared to the D_y distributions at the 3.0, 2.0, 1.0, 0.5, 0.0, -0.5, -1.0, -2.0, -3.0, -4.0 grids. Comparisons of D_y, D_s, S, and MI distributions are made by testing the significance of the maximum difference between pairs of distributions (Kolmogorov-Smirnov two sample test) or the sum of the squared differences between pairs of distributions (Cramer-von Mises two sample test). Comparisons of CB distributions are made by testing the significance of the sum of the squared differences between pairs of distributions (Watson U^2 test). Comparisons between VB distributions for different grid intervals are meaningless since the angle to the VARUA is always different for any pair of grid intervals. The results of these testing procedures indicate whether there are significant differences within the track data for that condition. Such information is improtant for interpreting the results of comparisons between an experimental condition and its control.

In order to test for the significance of the differences between swimming patterns under different acoustic conditions, the cumulative distributions for the two conditions were compared at the same grid lines or grid intervals. For each pair of distributions from the two conditions (e.g., D_y at 1.0 km for Drillship vs D_y at 1.0 km for control), the program calculates both the maximum difference and the sum of the squared differences

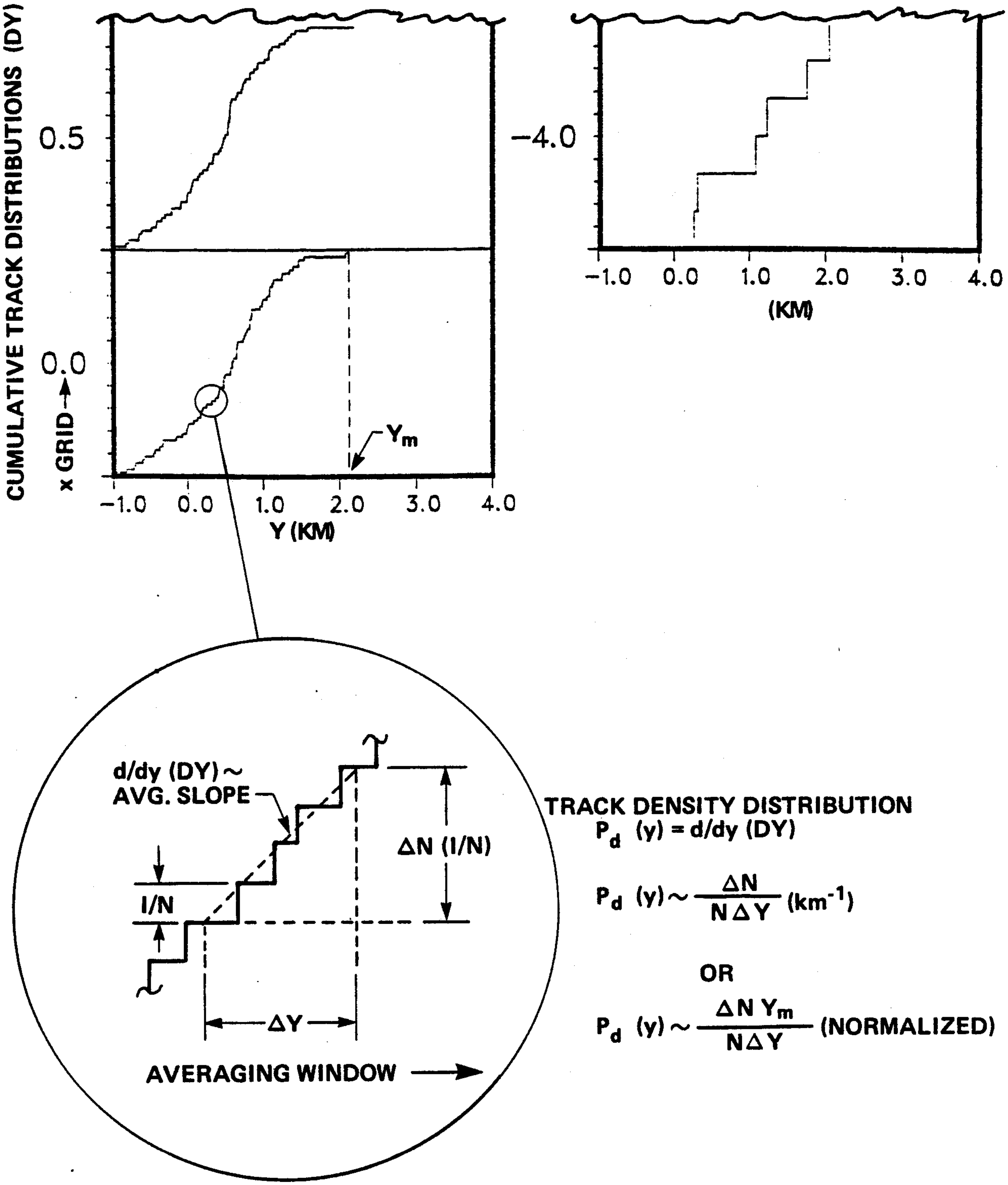


FIG. 3.7. PROCEDURE FOR OBTAINING AN APPROXIMATE TRACK DENSITY DISTRIBUTION FROM THE CUMULATIVE DISTRIBUTION.

in their distributions. These results are then compared to values in look-up tables for the Kolmogorov-Smirnov test (Siegel 1956) and the Cramer-von Mises test (Anderson and Darling 1952), and the significance of the differences in the two distributions is determined. The Watson U^2 test (Zar 1974) was used to test for the significance of differences in Course bearing and VARUA bearing distributions.

3.4.2 Development of an approximate track density calculation

If the cumulative track distributions were continuous functions of the distance offshore (y) then differentiation of these functions would yield track probability density functions. Comparison of these functions would provide a more direct measure of a shift in track density due to avoidance than comparison of the distribution functions. Unfortunately, the track distributions have discrete steps so direct differentiation or slope analysis is difficult.

An approximation to the probability density function was derived by the procedure illustrated in Fig. 3.7. The number of track increments contained in a finite "window" along the y direction is proportional to the slope of the cumulative track distribution at the window location. The window must be wide enough so a relatively smooth averaged output is obtained. If the window is made too wide, resolution of small scale density changes is lost. It can be shown that resolution of density changes of a scale equal to one-half of the window width is possible. Accordingly, we tested the results of this approximation using window widths up to 300 m since the day-to-day repositioning accuracy of the playback source was 100 to 150 m. Results using a 200 m window or less were found to give very rough density plots. As a result, a 300 m window-width was used for most of the data.

4. FIELD MEASUREMENTS

Field observations of southbound migrating gray whales during normal or potentially undisturbed days and during periods of acoustic playback and controlled air gun operations are summarized below. Also provided is an itemization of the periods of acoustic stimuli operated from R.V. VARUA and M.V. CHEYENNE ARROW.

4.1 Field Observations in January 1984

We determined that our 1984 field work should be conducted from 8 January to 21 January, based on our literature review of gray whale migration characteristics (Appendix A, Report 5366) and the results of the 1983 January field season. This time period proved to be optimum in terms of the number of whales and the number of groups passing our study site.

As in the January 1983 field season, our study site was located approximately 22 km south of Monterey, California, in the Yankee Point-Granite Canyon area. This area is easily accessible by ground transportation and has served in the past as the research site for the National Marine Fisheries Service in work on gray whale population assessment. The southern-most site was located at Soberanes Point, with a second site 2.4 km to the north (see Fig. 3.1). These sites offered excellent viewing conditions to Yankee Point, 2 km north of north station, and to Kasler Point, 4 km south of Soberanes Station making the total effective viewing area 8.4 km during good or better conditions. Soberanes and north sites, at elevations of 80.4 m and 60.2 m, respectively, allowed reliable theodolite localization of whale groups, The theodolite techniques are discussed in Sec. 3.2 of our previous report referenced above.

Communication between the two sites was by CB radio. A marine-band VHF radio was used for communication between Soberanes and the R.V. VARUA.

Each site was manned by four observers this year, augmented from three used during the 1983 field season. Because of our experiences last year, it was determined that a fourth person was needed for the times when many groups of whales (more than 5) were passing the study site. The fourth observer also provided the capability of sketching maps of the whale group locations, placing them in relation to one another and our "siting landmarks" (Lobos Rocks, VARUA, rock outcroppings onshore, etc.). These maps were, at times, indispensible in determining group identification. The fourth observer also used the tripod-mounted binocular spotting-scopes at each site. These scopes (22x wide-angle and 15x power) facilitated determination of group size, behaviors, and, at times, distinguished individual whales on the basis of morphological characteristics. The recognition of these morphological features allowed more efficient transfer of whale groups whales as they moved from the north station observation area into the Soberanes station observation area.

The responsibilities of the four people were as follows: 1) theodolite (Topcon TC-20) operator, 2) secretary, data recorder, 3) inter-station coordinator (observer and CB operator), and 4) observer-mapper. In practice, the theodolite operator, and inter-station coordinator were second and third observers, and the data recorder, to a lesser extent, a fourth. Positions were rotated periodically so that all personnel were involved in all phases of data collection.

Table 4.1 presents a summary of shore-base observations by date and site. Most observations began between 0745 to 0845 and ended between 1600 to 1700 (PDT). Overall, we had very good viewing conditions (see Table 4.2). We lost no shore-based

TABLE 4.1. SUMMARY OF LAND OBSERVATIONS. 8 JANUARY TO 21 JANUARY 1984.

Date	Obs. Per.	Exp. Boat	No. of Obs.	No. of Groups	No. Whales[1] in Groups	Total No.[2] Whales	Mean Group Size	No. of Theodolite Sightings	Theodolite Sightings per Group	Boats	Tankers	Aircraft	Calves
8 Jan-N	0851-1640	n[3]	4	86	202	195	2.35	254	2.95	1	0	5	0
S	0913-1645		4/5/4[4]	75	156	151	2.08	299	3.99	1			
9 Jan-N	0805-1702	y	4/5/4[5]	91	219	219	2.41	359	3.95	0	1	3	1
S	0825-1703		4/5/4[6]	94	195	195	2.07	420	4.47	1			
10 Jan-N	0745-1650	y	4	86	180	180	2.09	406	4.72	2	0	4	0
S	0745-1654		4/5/4[7]	84	164	164	1.95	332	3.95	2			
11 Jan-N	0749-1702	y	4	97	223	218	2.30	434	4.47	3	5	4	2
S	0802-1700		4	117	246	232	2.10	526	4.50	3			
12 Jan-N	0837-1646	n	3/4[8]	74	167	162	2.26	316	4.27	1	3	5	1
S	0845-1650		4	75	159	149	2.12	303	4.04	1			
13 Jan-N	0755-1656	y	4/5[9]	120	289	276	2.41	539	4.49	0	1	5	0
S	0807-1700		4	110	248	233	2.25	526	4.78	0			
14 Jan-N	0838-1649	Y	4	99	224	224	2.26	446	4.51	3	5	7	2
S	0837-1648		4	100	212	205	2.12	450	4.50	0			
15 Jan-N	0855-1635	y	4	55	119	115	2.16	219	3.98	1	3	5	0
S	0900-1625		4	55	134	128	2.44	242	4.40	0			
16 Jan-N	0903-1600	n	4	81	171	167	2.11	321	3.96	0	1	0	0
S	0920-1515		3/4[10]	56	110	110	1.96	317	5.66	0			
17 Jan-N	0802-1707	y	6/5[11]	106	262	251	2.47	544	5.13	0	0	4	5
S	0815-1707		4/5[12]	103	211	207	2.05	488	4.74	1			

TABLE 4.1. (Cont.) SUMMARY OF LAND OBSERVATIONS. 8 JANUARY TO 21 JANUARY 1984.

Date	Obs. Per.	Exp. Boat	No. of Obs.	No. of Groups	No. Whales[1] in Groups	Total No.[2] Whales	Mean Group Size	No. of Theodolite Sightings	Theodolite Sightings per Group	Boats	Tankers	Aircraft	Calves
18 Jan-N	0809-1612	y	4	81	152	141	1.88	368	4.54	2	1	2	3
S	0808-1634		4/3/4[13]	95	193	174	2.03	440	4.63	1			
19 Jan-N	0807-1613	y	4	69	154	148	2.23	389	5.64	1	0	9	1
S	0809-1619		4	65	121	119	1.86	385	5.92	1			
20 Jan-N	0806-1602	y	4	62	122	111	1.97	324	5.23	1	0	6	0
S	0805-1605		4/5[14]	68	126	123	1.85	414	6.09	0			
21 Jan-N	0941-1507	n	4	51	97	88	1.90	192	3.76	4	0	2	0
S	0936-1510		4	50	91	86	1.82	205	4.10	7			

Footnotes:

[1] Counting whales twice which have split or joined (i.e., Grp. A = 1, Grp. B = 1, Grp. AB = 2, total whales = 4 in 3 Grps.).

[2] Total number of whales irregardless of splits and joins (i.e., Grp. A = 1, Grp. B = 1, Grp. AB = 2, Total Whales = 2).

[3] See Table 4.3 for experimental boat schedule.

[4] Five observers 1100-1300 (approx.)

[5] Five observers 1400-1500.

[6] Five observers 1530-1630 (approx.)

[7] Five observers 1145-1300.

[8] Three observers 0837-0900.

[9] Five observers 1101-end.

[10] Three observers 0920-1046.

[11] Six observers 0802-1030, five observers to end.

[12] Five observers 1550 to end.

[13] Three observers 0840-0910.

[14] Five observers 1446 to end.

TABLE 4.2 SUMMARY OF OBSERVATION CONDITIONS, 8 JANUARY TO 21 JANUARY, BY SITE.

8 Jan-N	Good to fair in a.m. Wind SSE 15, hazy. Wind N 15 by mid-day, p.m. wind E, ENE 8-12, good conditions. By end, fair w/haze. 10-30% clouds, 0% at end.
S	Good to excellent early a.m. Wind S 1-5. Mid, late a.m., early p.m. fair to poor w/haze, w/caps, wind E, NE, NW, N, E 5-15. Good towards end, wind SE 1-5.
9 Jan-N	Good in a.m. Mid-day good-excellent, deteriorating to poor by end. Wind S, SE, SW 1-10, then mid p.m. to NW, NE. 100-10% clouds by mid-day, up to 100% by end.
S	Fair to good a.m., wind NW, NE, SE, SW 3-10. Good early, mid p.m., wind 0. Poor at end w/haze, fog, shifting winds 2-5.
10 Jan-N	Good in a.m., wind E 5-10. Mid-day fair to poor w/haze, fog. Excellent rest of day, wind NW 4-8. 30-50% clouds a.m., 0% mid-day, 70-30% end.
S	Poor in a.m., wind NNE, NW 8-10 w/fog, haze. Wind N, NW 1-10 rest of day. Fair mid-day. Poor towards end w/haze.
11 Jan-N	Good to excellent early, mid a.m., wind NE, E 1-5. Late a.m., early p.m. fair w/haze, w/caps. Good to end. 0-20% clouds all day.
S	Good all day except fair periods late a.m., mid p.m. Wind NE, NW, N 5-15 all day.
12 Jan-N	Fair to poor most of day w/haze, fog. Good early p.m. Light variable wind 0-3. 80-100% clouds all day.
S	Good early a.m., wind NE 1-5 w/some haze. Fair to poor by mid-day. Excellent by mid p.m., wind SW 1-5. Good at end with no wind.
13 Jan-N	Good to excellent all day. Wind N, NW 2-10 all day. 10-90% clouds a.m., 0% by mid-day.
S	Excellent conditions all day. Wind NW, NE 5-10 a.m. No wind in p.m.

TABLE 4.2. (Cont.) SUMMARY OF OBSERVATION CONDITIONS, 8 JANUARY TO 21 JANUARY, BY SITE.

14 Jan-N	Fair early a.m., wind ESE 5. Fair to good rest of day, wind W, SSW, S 3-8. 5-60% clouds a.m., 30-10% p.m.
S	Fair early a.m., wind ESE 3-5. Excellent conditions mid a.m. deteriorating to poor by mid-day. Good all p.m. with wind S, SE 8-15.
15 Jan-N	Fair to poor all day. Wind SE, SW, S 3-10 all day. Some drizzle at mid-day, high swell, w/caps, 100% clouds all day.
S	Fair to poor all day. Wind S, SE 5-20, w/caps, high swell.
16 Jan-N	Excellent in a.m., wind NNW 3. Fair to good mid-day wind N 5-8. Good to excellent rest of day with wind NNW, N 1-5. 10-60% clouds all day.
S	Good to excellent all day. Wind NW 1-10 all day, some w/caps.
17 Jan N	Good to excellent in a.m., wind S 1-3. Good to excellent p.m., wind SW, S 1-5. No wind at end. 10-15% clouds mid p.m., 0% rest of day.
S	V.Good to excellent all day. Wind SE, SW 1-10.
18 Jan N	Good in a.m. and early p.m., with good to excellent conditions to end. Wind E 1-2 a.m., W, NW 1-5 in p.m. 60-20% clouds a.m., 75-10% p.m.
S	Good to excellent all day, wind NW 1-3, slight haze in p.m., no wind.
19 Jan N	Excellent in a.m. with wind E 1-3. Haze/smoke as p.m. progressed, fair, wind NW 5-10. Good late p.m. 0-10% clouds a.m, 0-40% p.m.
S	Good, deteriorating to poor by mid-day with haze, w/caps. Wind up to N 15 by late a.m. Poor to fair conditions with haze, w/caps until late p.m. when good. Wind N, NW 5-20 in p.m.

TABLE 4.2. (Cont.) SUMMARY OF OBSERVATION CONDITIONS, 8 JANUARY TO 21 JANUARY, BY SITE.

20 Jan N	Good in a.m., some haze, no wind. Fair to good mid-day with haze, wind S, SW 3-4. Good to excellent by mid p.m. deteriorating to fair to poor by end with wind NE 1-3. 0-95-0% clouds a.m., 20-40% early, mid p.m., 100% at end.
S	Good, good to fair all day with wind S, SW, W 1-5 with periods of calm. Towards end haze made poor conditions.
21 Jan-N	Fair to poor most of day with wind NE, N 2-8 all day. Haze mid-day. Fair at end. 100% clouds all day.
S	Good early, mid a.m., wind NE, NW 1-7. Poor mid-day w/haze, smoke. Good to fair early p.m., wind N 5-10, deteriorating to poor to fair by end, wind NW, N 4-10.

NOTES: [1] Percent of cloud coverage for the day is given at end
north site viewing conditions.

observation days to adverse weather conditions, and we only had to terminate one day (21 January) because of deteriorating viewing conditions. During January 1983, we lost one complete day and three others had to be terminated because of weather. We achieved a total of 225.4 hrs of field observations during the 1984 field season compared to 209.6 hrs in January 1983.

The peak of the migration passing our study site occurred on 13 January with a maximum of 276 whales, 120 groups (north site) and a minimum of 233 whales, 110 groups (Soberanes). Differences in numbers between North Site and Soberanes reflect variable viewing conditions, groups splitting and joining, and groups not observed. When we compare the total number of groups passing on a day-to-day basis, the totals for the 1984 field season exceed the totals for January 1983 on all days except 16 January (the peak day of 1983). Over the 1984 field season, the total number of whales seen at the observation stations ranged from a high of 2,567 to a low of 2,204, considering the maximum and minimum counts for each day. In 1983, the counts were 1,699 and 1,356, respectively. The number of whale groups ranged from 1,203 to 1,102 in 1984 and were 825 and 695 in 1983, respectively. The actual numbers of whales within visual range probably was above the maximum values. There were 14 observation days in 1984 and 15 days in 1983.

It is of interest to note that in 1984 we observed a total of 15 mother/calf pairs (newborn calves) passing the study site (in January 1983 the number was 7). Mother/calf pairs were observed on seven of the 14 days and were distributed throughout the period of field observations. A high count of five occurred on 17 January. The high count during the January 1983 field season also occurred on 17 January with two mother/calf pairs observed. Most of the mother/calf pairs (12 out of 15) were first observed between late morning and early afternoon (1103 to

1555) and were travelling south approximately 1 km from shore. In 3 of the 15 mother/calf groups there were two larger animals accompanying the calf and in 1 of the remaining 12 there were 3 larger animals accompanying the calf.

During our observations we saw six other species of marine mammals: minke whale (Balaenoptera acutorostrata), common dolphin (Delphinus delphis), Pacific white-sided dolphin (Lagenorhynchus obliquidens), killer whale (Orcinus orca), California sea lion (Zalophus californianus), and sea otter (Enhydra lutris nereis). Two of these species, the Pacific white-sided Dolphin and the California sea lion, were, at times, observed with gray whales.

4.2 Acoustic Stimuli During the Southbound Migration of 1984

In order to obtain a larger data sample from the general southbound population, both single air gun tests and playback experiments were performed in January of 1984. No air gun array was available for tests during this period. The single air gun used this season was the same as that used in May 1983; a 100 cu. in. unit operated at 4500 psi pressure from the M.V. CHEYENNE ARROW (sister ship of M.V. CROW ARROW used last year). The air gun was leased from Western Geophysical, Inc. and operated with a compressor and controller loaned to the project by Price Compressor Co.

Table 4.3 provides the timing details and the experimental conditions for the air gun and playback experiments. The location of research vessels with respect to landmarks and the observation sites is given in Figs. 3.1 and 3.2 in Section 3. As shown in this table, the air gun experiments were performed during the first three days of the field tests, 9 through 11 January. During these days, an average of 206 whales were observed each day by North Site and 197 whales were monitored by

TABLE 4.3. ACOUSTIC STIMULUS SCHEDULE – JANUARY 1984.

Single Air Gun (100 cubic inch; 4500 psi pressure; 10 second pulse interval; vessel: M.V. CHEYENNE ARROW; VARUA monitoring at Station #1)

Date	Time On	Minutes	Comments
1/09/84	0915-1232	(197)	Transect 1 mile long, approx. 8 nm (15 km) from shore
	1337-1500	(83)	Transect 0.5 nm long, approx. 3 nm (5.5 km) from shore
	1530-1705	(95)	Drifting Approx. 1.5 miles (2.8 km) from shore
1/10/84	0850-1200	(190)	Vessel anchored approx. 1 nm from shore.
	1330-1613	(163)	Same
	1633-1700	(27)	Same
1/11/84	0900-1100	(120)	Vessel anchored as on 1/10/84
	1300-1500	(120)	Same
	1700-1842	(102)	Vessel underway from anchorage at 340°T heading for distance 4 nm (7.4 km)

Playback of Taped Sounds* VARUA anchored at Station #2, approx. 1 nm (1.8 km) from shore)

1/13/84	1017-1132	(72)	Control period (NO PLAYBACK)
	1133-1403	(150)	Drilling Platform
	1431-1700	(149)	Drillship

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*Ambient or background noise conditions were measured during intervals between each playback or air gun period lasting for about 30 minutes each.

TABLE 4.3. (Cont.) ACOUSTIC STIMULUS SCHEDULE - JANUARY 1984.

Date	Time On	Minutes	Comments
1/14/84	1117-1315	(118)	Production Platform
	1345-1545	(120)	Helicopter
	1554-1652	(58)	Control Period (NO PLAYBACK)
1/15/84	1005-1145	(100)	Drillship
	1227-1401	(94)	Semisubmersible Rig
	1436-1616	(100)	Production Platform
1/16/84	NONE		Control Period, No VARUA Present (seas too heavy)
1/17/84	0848-1046	(118)	Semisubmersible Rig
	1122-1318	(116)	Drilling Platform
	1345-1545	(120)	Helicopter
1/18/84	NONE 0800-1630	(510)	Control Period (VARUA on station) NO PLAYBACK
1/19/84	0845-1045	(120)	Drilling Platform
	1115-1315	(120)	Drillship
	1345-1545	(120)	Helicopter
1/20/84	0830-1030	(120)	Semisubmersible Rig
	1030-1230	(120)	Control Period (NO PLAYBACK)
	1231-1431	(120)	Production Platform
	1431-1535	(64)	Control Period (NO PLAYBACK)

TABLE 4.3. (Cont.) ACOUSTIC STIMULUS SCHEDULE - JANUARY 1984.

SUMMARY OF PLAYBACK SCHEDULE

Order of Playback	**Date**	**1/13**	**1/14**	**1/15**	**1/16**	**1/17**	**1/18**	**1/19**	**1/20**
1		Contr (72)	PP (118)	DS (100)	N O	SS (118)	Contr (170)	DP (120)	SS (120)
2		DP (150)	H (120)	SS (94)	N	DP (116)	Contr (170)	DS (120)	Contr (120)
3		DS (149)	Contr (58)	PP (100)	E (417)	H (120)	Contr (170)	H (120)	PP (120)

Parenthetical numbers = Time in minutes for each playback.

	Condition	Total Time/Condition
DP	= Drilling Platform (HOLLY)	386 min.
DS	= Drillship (EXPLORER)	369 min.
PP	= Production Platform (SPARK)	338 min.
H	= Helicopter (Bell #212)	360 min.
SS	= Semisubmersible Drill Rig (OCEAN VICTORY)	332 min.
Contr	= Control Period (VARUA at anchor and no playback)	824 min.
None	= No Vessel Present (plus 1/8, 1/12, 1/21)	1713 min.

South Site. The air gun and acoustic playback work was performed over a total of nine days while behavioral observation from the land sites was performed over a 14 day period. Thus, there were five control days available for comparison of behavior with that occurring during acoustic stimulus days.

The degree of exposure of migrating whales to the air gun impulses varied considerably from one test to another. Typical exposure sound levels are presented in Section 5 of this report. As noted in the table, the air gun system was operated at nominal distances of approximately 15 km, 5.5 km, and 2.8 km from the estimated center of the migration corridor while the vessel was either underway or drifting. Previous testing with the air gun in May 1983 demonstrated that these test distances would "bracket" the distances within which some observable behavioral changes could be expected. In addition, a series of tests were performed with the air gun vessel anchored. Because of the nature of air gun useage, these experiments could not be performed on a "blind" basis and shore observers were aware that the air gun was operating.

Playback experiments summarized in Table 4.3 were performed during an eight day period (1/13-1/20). On two of these days no playback experiments were conducted. On one day (1/16), the VARUA could not leave Monterey Harbor because of very heavy sea conditions. Fortunately, the observation conditions on that day were good so additional whale track data could be obtained without any vessel present in the measurement area. The other day (1/18), VARUA was present but did not do any playbacks during the entire day. The shore crews did not know that there were no playbacks being performed, maintaining the requirements of a blind experiment. The summary of the playback schedule at the end of Table 4.3 includes the order of playback for each day as well as the amount of time devoted to each playback condition. A total of approximately six hours of playback time was given to each playback condition and 13.75 hours to control (VARUA present, but no playback). A total of 28.5 hours provided control behavioral data with no vessel present.

Ambient noise conditions were highly variable during the measurement and observation periods due to offshore ship traffic, variable surf conditions, and snapping shrimp noise. More specific comments regarding ambient noise conditions are provided together with specific noise level data in Section 5 of this report.

Acoustic propagation loss or transmission loss data were acquired from operation of the air gun at various distances from the measurement hydrophones on-board R.V. VARUA. The air gun vessel also ran a radial track away from the sound measurement vessel for a distance of about four miles, parallel to shore, as noted in Fig. 3.1. These data were used for comparison with transmission loss data obtained in 1983, confirming the the sound propagation model derived from the 1983 data and presented in BBN Report 5366.

5. ACOUSTIC MEASUREMENTS AND RESULTS

This section contains a description of the acoustic measurements made during the January 1984 field season and a summary of the results obtained. The analytical background of the procedures used was developed in Section 5 of Report 5366. Some of that discussion will be included here to facilitate understanding of the results and minimize the need to refer to the earlier report.

5.1 Air Gun Experiments

The series of tests using a 100 cu. in. air gun operating at 4500 psi were performed in order to obtain data on the behavioral response of migrating gray whales to the high sound levels produced by this source. Additional acoustic transmission loss (TL) data were also obtained for the observation area. This section is concerned with measurements of the air gun source characteristics and the TL measurement results.

5.1.1 Air gun source characteristics

The previous measurements of a single 100 cu. in. air gun (Report 5366, Sec. 5.1.2) showed that the average pulse pressure level was a useful measure of the effective received level of the transient signals from an air gun. This quantity is a measure of the effective energy of a noise pulse in terms of an average pressure level defined as (Urick, 1975, Sec. 4.4)

$$E = \frac{1}{\rho c} \int_0^\infty p^2(t)dt = \frac{\overline{p}^2 T}{2\rho c} \text{ (Joules)} \qquad (1)$$

where

ρc = the specific acoustic impedance of water

$p(t)$ = the original pulse pressure waveform

$\overline{p}$ = the average pulse pressure

T = the effective pulse duration (the time required for $p^2(t)$ to decay to less than 10% of the initial value).

The instrumentation used to analyze air gun signals to obtain the average pulse pressure incorporated a squaring and integrating circuit to provide a voltage output proportional to the integrated acoustic energy of the pulse. The time duration of the signals was determined by digital transient recording of the waveform and visual inspection of the pulse envelope. Figure 5.1 illustrates a typical air gun signature and the analysis procedure. Generally it is more convenient to express acoustic pressure in logarithmic terms. Consequently, the average pulse pressure level is defined as

$$L_{\overline{p}} = 20 \text{ Log}_{10}(\overline{p}/p_{ref}) \text{ dB} \tag{2}$$

where

$P_{ref} = 1\mu$ Pascal.

Air gun signature analysis

A narrowband analyzer was used to obtain analyses of air gun signatures for various ranges. The time waveforms of the pulses were also recorded to obtain peak pressure data and examine time duration as a function of range. Because of multipath transmission, peak pressure values were found to be quite variable. The time duration of the signals was observed to generally increase with range due to reverberation. Occasionally, separate discrete multipath pulses were received.

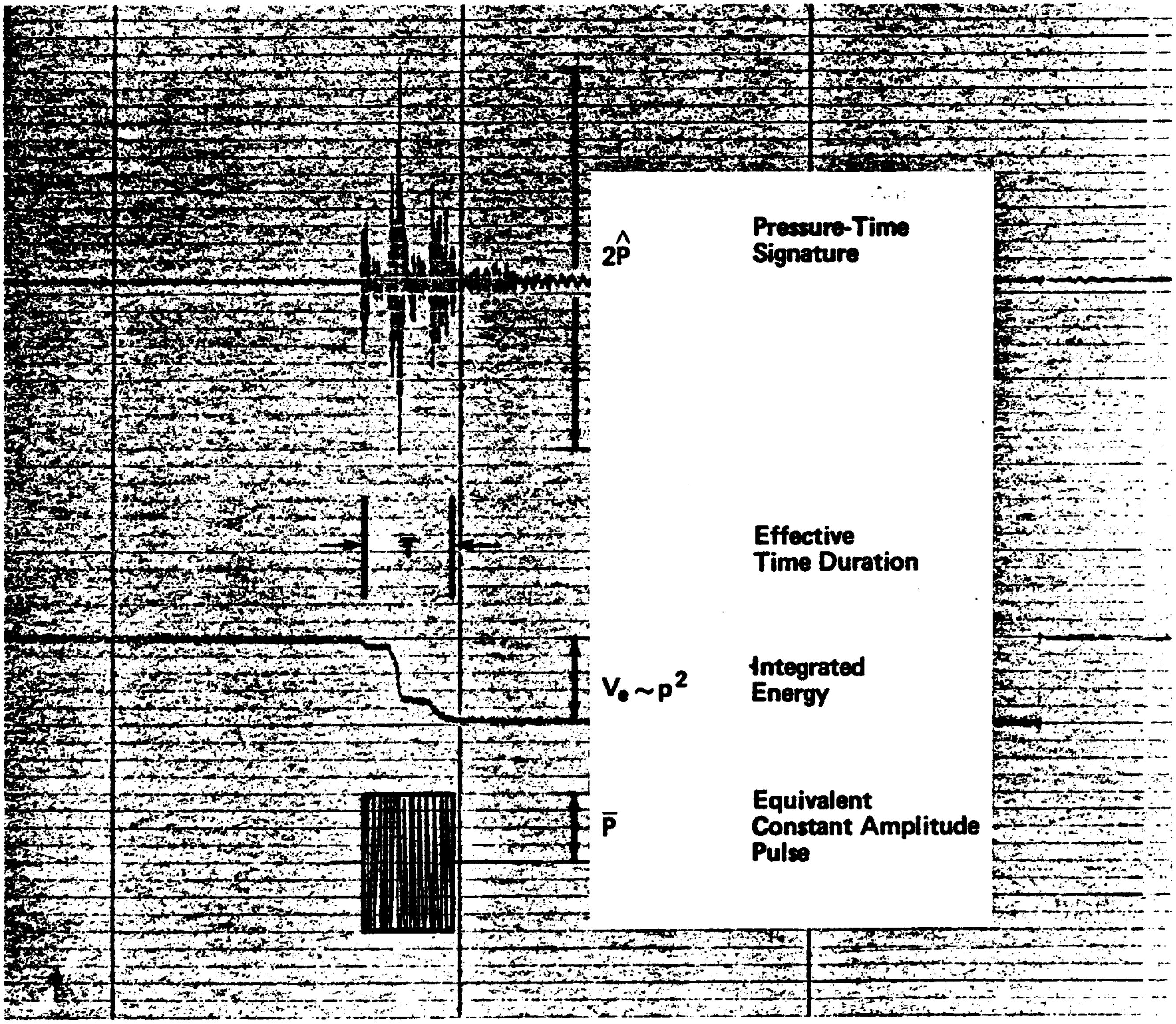

FIG. 5.1. CHART RECORD SHOWING PULSE SIGNATURE AND PULSE ENERGY INTEGRATOR OUTPUTS.

The air gun was operated at ranges of 15.5 km (8 nm) to 360 m. The pressure signature observed at the 360 m range was found to agree quite well with the data obtained during the 1983 tests, also using a 100 cu. in. gun. Thus, closer range tests to obtain reverberation-free signatures were not performed. Figure 5.2 illustrates pressure-time waveforms at ranges of 360 m and 1.1 km. The peak pressures of these signatures can be seen to be 900 Pascal and 200 Pascal, respectively, or in logarithmic form, 179 dB and 166 dB referred to 1 μPa. Narrowband frequency analyses were made of these signatures as shown in Fig. 5.3. The dominant energy of the signals can be seen to be at 100 Hz and below.

5.1.2 Transmission loss measurements

Acoustic transmission loss in shallow water is highly dependent on the acoustic properties of the bottom material since, in most areas, sound energy is transmitted mainly by paths that are multiply reflected from the bottom and surface. The average number of reflections (or "bounces") depends on the water depth, on the acoustic properties of the water column (sound velocity gradient), on acoustic properties of the bottom, and on any directional properties of the source and receiver. In most shallow water areas, the relationship between acoustic pressure and distance from the source (range) has been found to be modeled quite well by considering a spreading loss which is midway between that of unbounded deep water (spherical spreading or 20 log range) and that of ducted horizontal spreading (cylindrical spreading or 10 log range) (Urick, 1975, Sec. 6.6). To the spreading loss must be added a loss due to molecular absorption in the water, a loss due to the scattering and absorption at the surface and bottom, and an energy increase due to the surface and

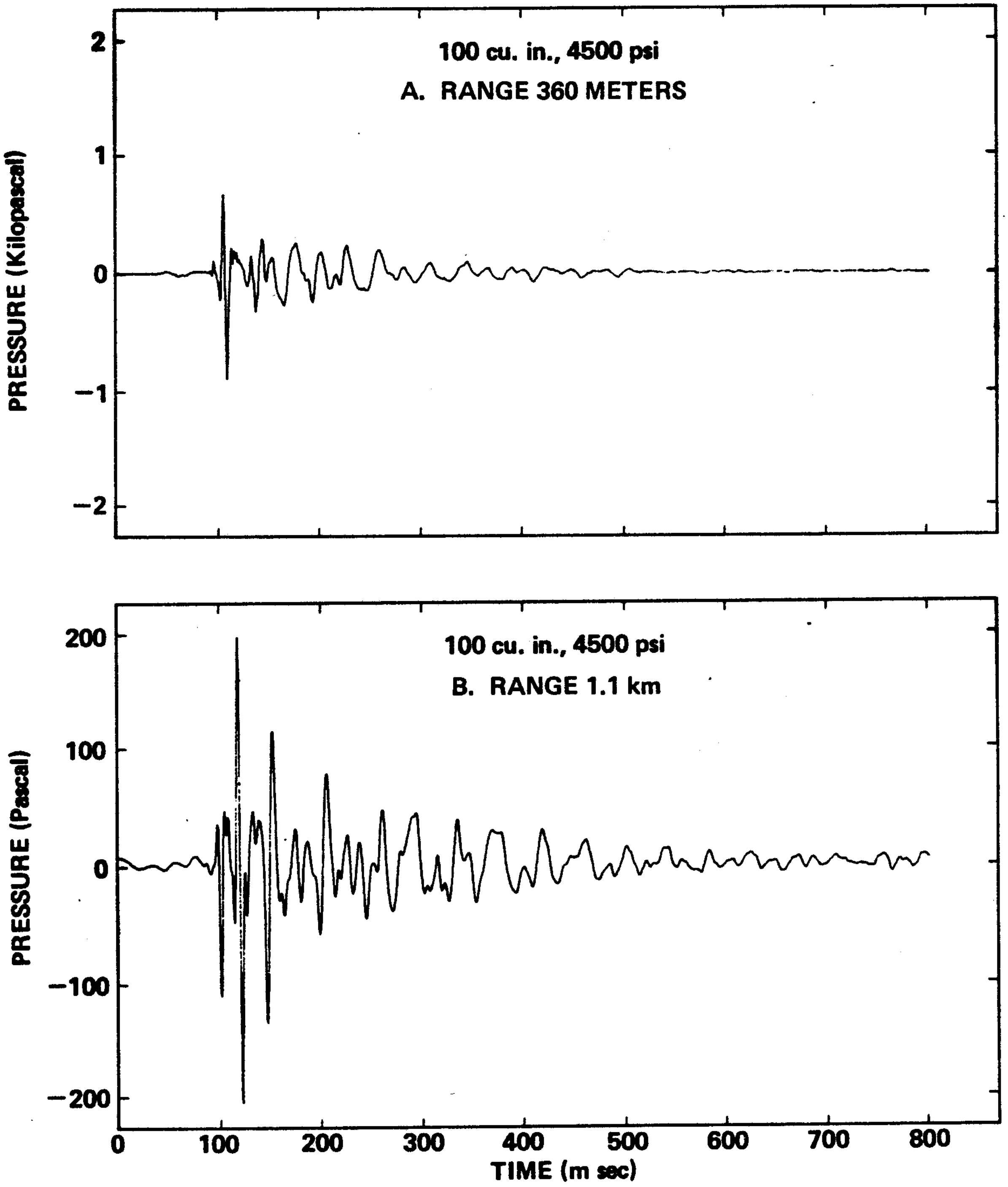

FIG. 5.2. AIR GUN SIGNALS.

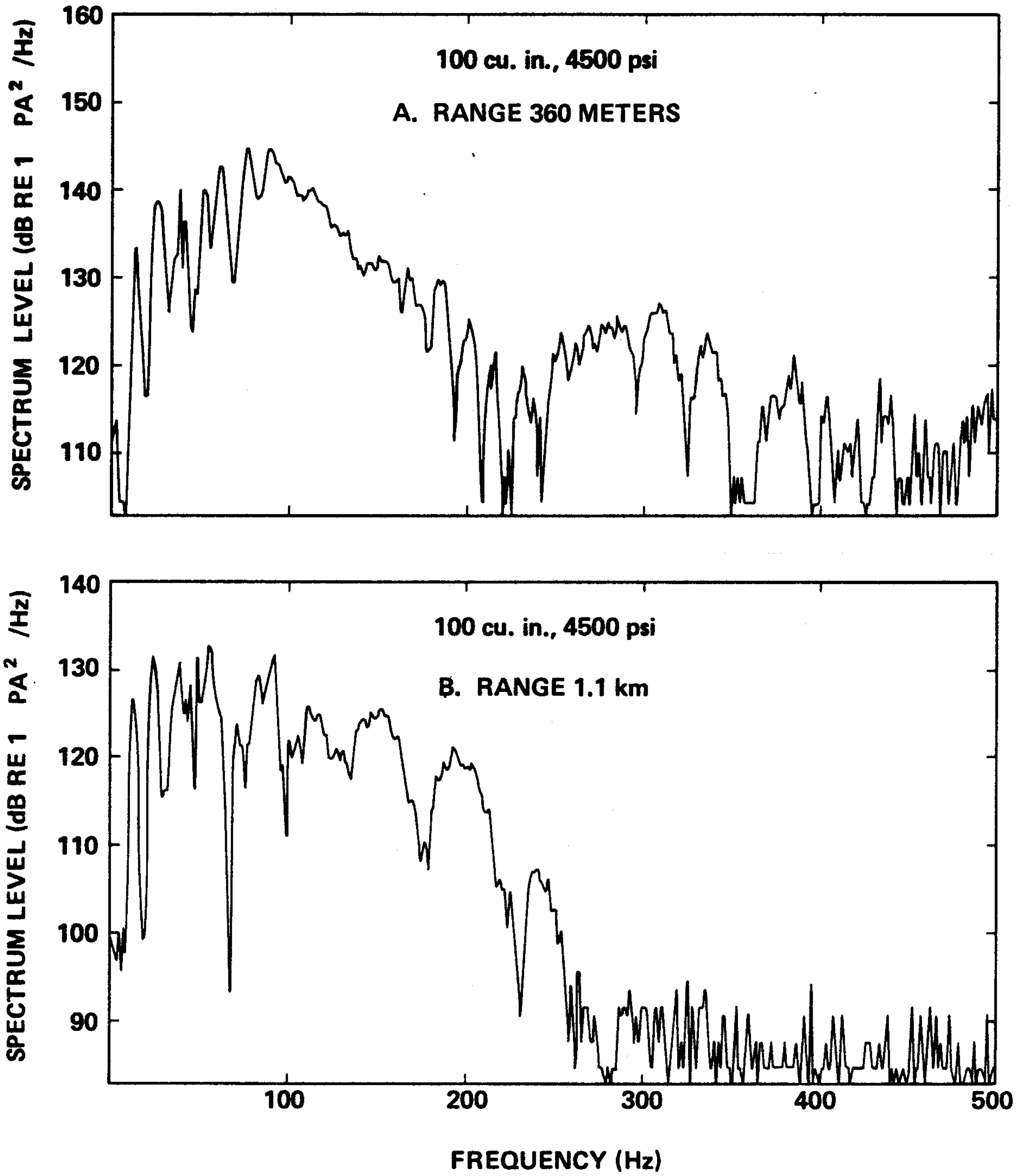

FIG. 5.3. AIR GUN SIGNAL SPECTRA.

bottom "image" sources. The resulting sound propagation model can be expressed in equation form as:

$$L_r = L_s - 15\ \mathrm{Log}(R) - A_v(R) - A_r(R) + I\ (\mathrm{dB}//1\,\mu\mathrm{Pa}) \tag{3}$$

where

L_r = Received level at range R (dB//1 μPa)
L_s = Source level (dB//1 μPa at 1 m)
R = Range in meters
A_v = Molecular (volumetric) absorption (dB per meter)
A_r = Reflection loss at surface and bottom (dB per meter)
I = Change in effective source level due to proximity of surface and/or bottom (dB).

This model was modified to fit the requirements of the measurement area and experimental conditions. Since our primary concern was low frequency sound propagation, we have neglected the volumetric absorption loss as not being significant below 500 Hz for the ranges of interest. Much of the data we obtained was for conditions where the source and receiver were in regions with appreciably different depths; also, for a number of measurements the source depth was a significant fraction of the range. Thus, the number of reflections was not constant with range, and the spreading loss would not be expected to be 15 log(R) for the entire propagation path.

The model was modified by assuming the bottom to be uniformly sloping between the source and receiver. The effective loss per bounce was then determined by considering the total number of bounces to be proportional to R/d(avg) where d(avg) = (source depth, d_s, + receiver depth, d_r)/2. Thus, if A_b is defined as the effective attenuation per bounce, then

Number of bounces (avg) = $2R/(d_s + d_r)$

Total attenuation = $A_b(R/(d_s + d_r))$

where A_b includes the factor of 2 obtained in averaging. Sound spreading loss in the region of the source was assumed to be 20 log(R) out to a range equal to the depth d_s, where bottom reflections would become a significant factor in the received sound. Thus, the propagation model was modified to consider a near-source region and a region where bottom and surface reflections control the propagation. Equation (1) was rewritten as

$$L_r = L_s - 20 \log(d_s) - 15 \log(R/d_s) - A_b(R/(d_s + d_r)) + 6 \text{ dB}. \tag{4}$$

This can be simplified to

$$L_r = L_s - 5 \log(d_s) - 15 \log(R) - A_b(R/(d_s + d_r)) + 6 \text{ dB}. \tag{5}$$

Here, the 6 dB correction term assumes a 3 dB contribution each from surface and bottom source images.

Regression analysis of TL data obtained using air gun sources during the April-May, 1983 field measurements provided an estimate of the effective "loss-per-bounce" coefficient in Eq. (5) for the test area. An estimate of the effective source level of the 100 cu. in. air gun was also obtained. The resulting received sound level equation was

$$L_r = 168 - 5 \log(d_s) - 15 \log(R) - 440(R/(d_s+d_r)) + 6 \text{ (dB//1}\mu\text{Pa)} \tag{6}$$

where R is the distance from the source (km) and d_s, d_r are the source and receiver depths (meters). The received sound level in this case is the effective pulse pressure as defined previously.

Data were obtained during the January, 1984 field measurement to provide verification or, if necessary, modification of Eq. (6). These data were obtained for operation of the air gun during the preliminary 8-mile, 3-mile, and 1-mile transects; during the anchored tests; and during a 7.5 km TL test along the general migration path. The results are shown in Fig. 5.4. The measured data are compared with calculated values using Eq. (6). Good agreement is obtained except for data near the end of the TL track where a slight inshore deviation of the track would have put the source in considerably shallower water (see Fig. 3.1). This would have caused the higher values of TL observed in the data. The anomalously high value of TL observed for the 3-mile transect measurements is unexplained except as an example of the variability of underwater sound propagation.

An extreme example of sound propagation variability was also observed in the 8 mile transect data. The initial air gun signal waveform, received during the first 15 min. of the test is shown in Fig. 5.5(a). In this example two major sound paths are contributing. These two low frequency signals (500 Hz) were preceeded by a weak high frequency precursor (>1 kHz) as shown in Fig. 5.6(a). Within about six air gun pulses (60 sec), the low frequency pulses faded to ambient noise level - a drop in level of more than 25 dB. The only remaining signal was the precursor as shown in Fig. 5.6(b). A radio call to the source vessel confirmed that the air gun was operating normally. The source vessel was requested to reverse course and return along the original track. After a short period of time, the low frequency pulses reappeared in the received signal. However, when the air gun vessel had returned along the track for about 20 min., the

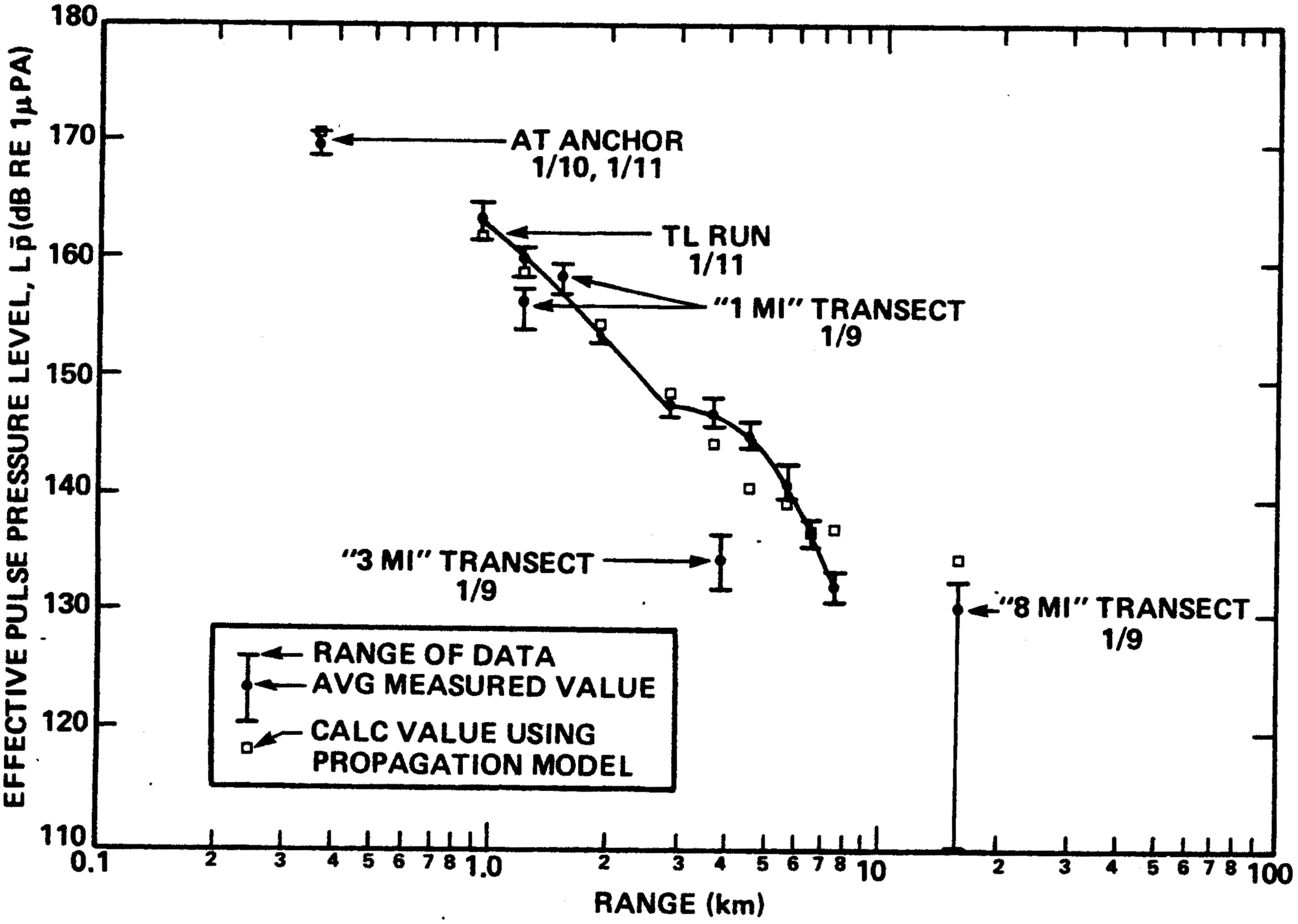

FIG. 5.4. AIR GUN EFFECTIVE PULSE PRESSURE LEVEL VERSUS RANGE IN THE TEST AREA (100 cu. in. 4500 psi).

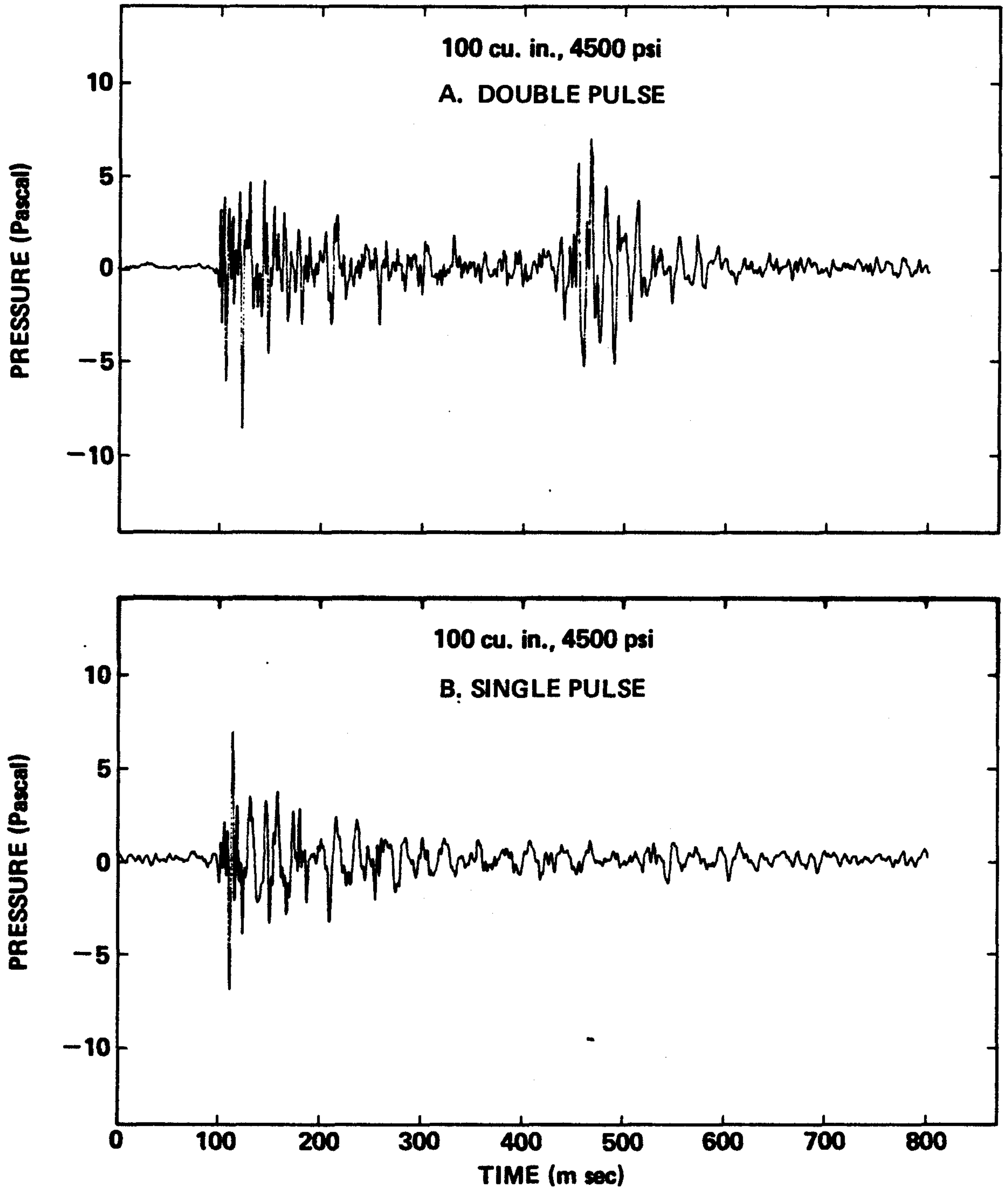

FIG. 5.5. AIR GUN SIGNALS AT 15.5 km RANGE (LOW-FREQUENCY COMPONENTS).

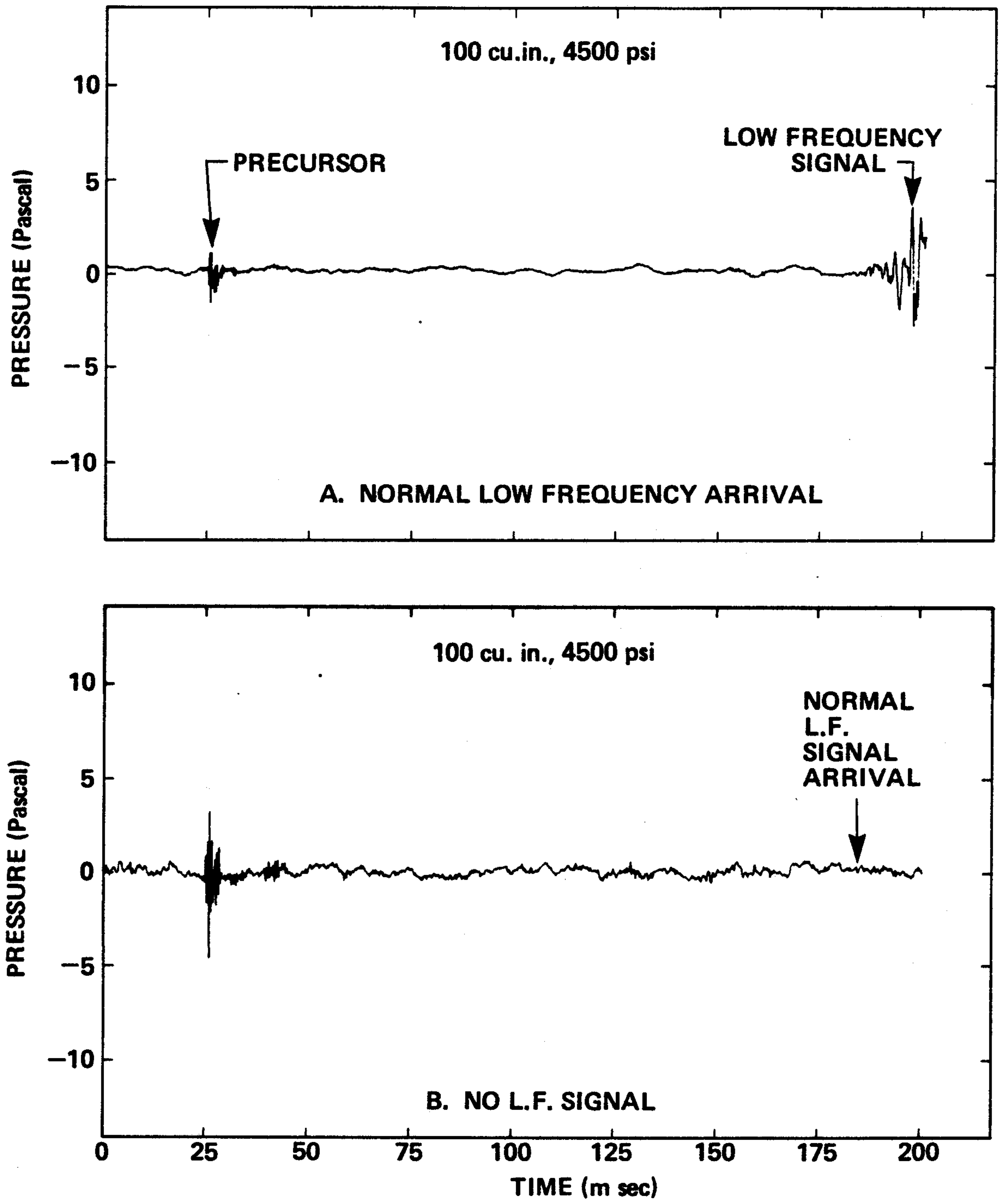

FIG. 5.6. AIR GUN SIGNALS AT 15.5 km RANGE (PRECURSOR COMPONENTS).

double pulse signal shifted to a single pulse as shown in Fig. 5.5(b). This shift again occurred over a relatively short period of time.

Measurements of the sound velocity profile at the VARUA position showed a nearly neutral profile. The extreme variability in propagation conditions for the 8-mile geometry thus were probably caused by rapid changes in bottom and sub-bottom composition between the source and receiver.

The degree of received signal level variability described above was not observed for transmission loss measurements where the air gun was operated nearer to shore along the whale migration corridor, as shown previously in Fig. 5.4.

5.2. Playback Experiments

The results of the playback experiments conducted in January 1983 showed that two types of behavioral reactions occurred. An initial "detection" reaction occurred at ranges where the loudest portion of the playback spectrum approached the ambient noise level in the same frequency band (0 dB S/N). This reaction was generally observed as a change in swimming speed and often a slight change in heading. As a result of this change in swimming pattern, the whales would pass the region of the source at a greater distance than would be the case under control (no playback) conditions. For some playback tests, the change in swimming direction would occur at a relatively close range to the source. In either case, the reaction could be considered as an "avoidance" of the region with loud sound levels. Accordingly, we have analyzed the playback data to provide information not only on the absolute level and spectrum of the reproduced signals but also on their relative level in relation to local ambient noise conditions.

The sound level produced by a playback stimulus at the position of an observed whale was estimated by applying the propagation model described in the preceding section to the area involved. To do this, Eq. (6) was modified by recognizing that $TL = L_s - L_r$, which resulted in the following relationship:

$$TL = 5 \log(d_s) + 15 \log(R) + .44(R/(d_s+d_r)) - 6 \text{ (dB)}. \qquad (7)$$

The reference range has been changed to 1 meter for convenience.

The distance at which the projected signal could potentially be detected was estimated by measuring the local ambient noise spectrum and comparing the noise spectrum with the spectrum of the projected stimulus. This process was complicated by the lack of knowledge of the frequency dependence of the hearing threshold and critical bandwidths of gray whales. Based on available data from other marine mammals and nonmarine mammals, such as Homo sapiens, we made the following assumptions concerning the auditory capabilities of Eschrichtius robustus:

- The hearing threshold is below the general ambient noise level and covers a frequency range at least as broad as the reported vocalization range.
- The critical bandwidths are 1/3 octave or narrower* (Herman and Tavolga, 1980).
- The sensation of loudness or noisiness follows a logarithmic relationship.
- The masking relationships between sounds at different frequencies are similar to those determined for human hearing.

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*A critical bandwidth is defined as the bandwidth of noise at constant spectrum level required to mask a pure tone at the same center frequency and RMS pressure level.

5.2.1 Playback system response measurement

As described previously in Sec. 3.3, the low frequency response of the playback system was improved over that available during the 1983 work by adding a second low-frequency projector. In addition, an equalization network was used to provide a flatter frequency response in the mid-band and high-frequency regions. The accuracy of the playback system was examined by recording the output of the source monitor hydrophone and comparing the spectrum of the reproduced signal with the relative spectrum of the original tape recording. An example of this comparison is shown in Fig. 5.7 for the drillship stimulus. A complete set of comparison spectra is contained in Appendix C for all of the industrial noise stimuli.

5.2.2 Ambient noise measurements

Ambient noise in the test area was influenced by ship traffic at low frequencies and by snapping (pistol) shrimp at high frequencies. A typical example is shown in Fig. 5.8. For the high ambient conditions of 14 January, an oil tanker was passing offshore and the wind speed was about 10 kts. The shrimp noise contribution peaking at about 6.3 kHz can be seen to be appreciable. A comparison with shallow water ambient data reported by Wenz (1962) shows good agreement in the mid-frequency range. The ambient noise spectrum for 17 January was typical for low-wind conditions in the test area. Note that the overall ambient noise levels for the full 25 to 16,000 Hz frequency range differ by only 3 dB from the "noisy" condition to the "quiet" condition. This is a result of the dominance of the shrimp noise which does not change with wind speed.

5.2.3 Determination of playback signal-to-noise ratio

The high frequency ambient noise produced by the shrimp was of concern because of its potential masking effect on the playback

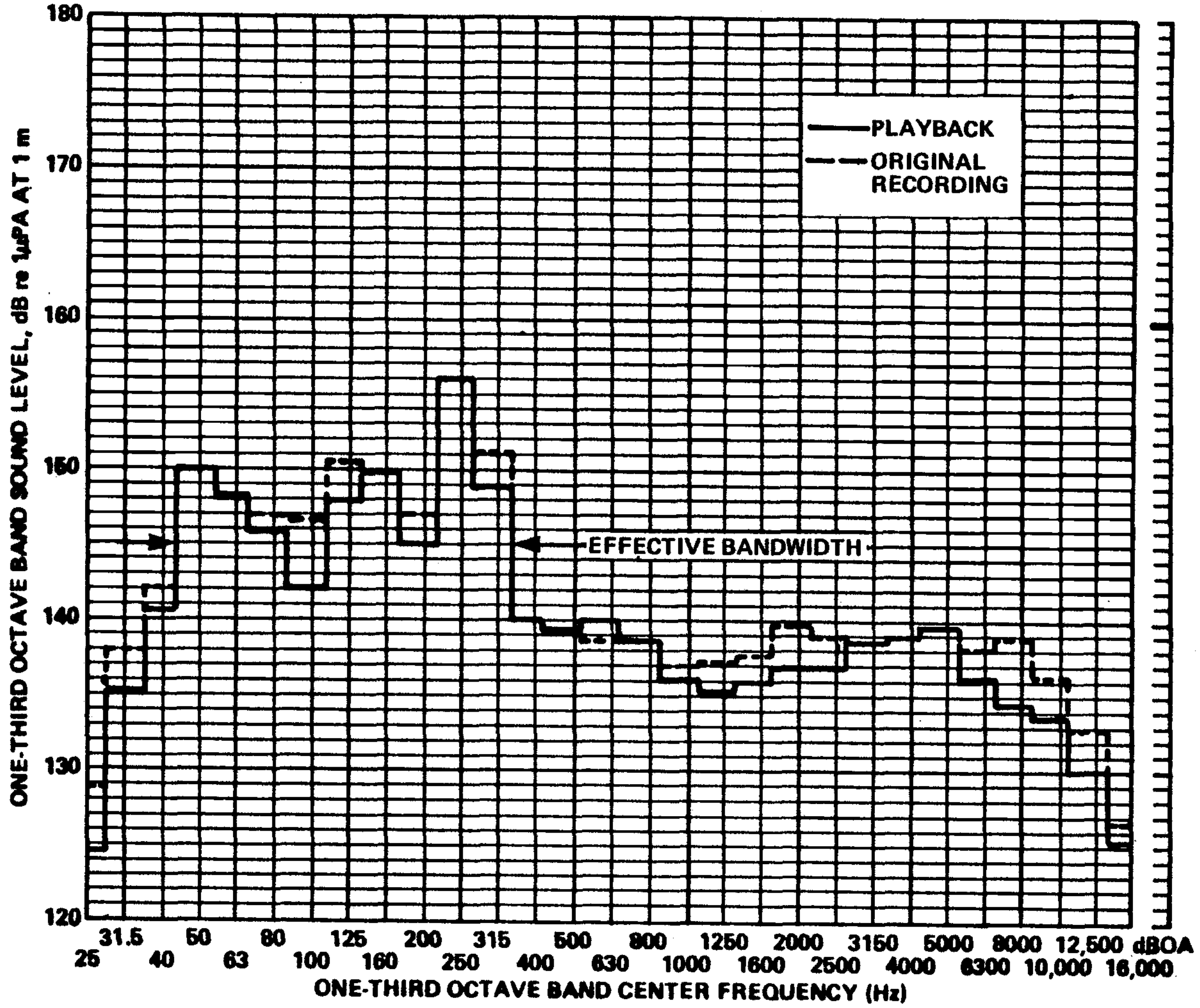


FIG. 5.7. DRILLSHIP ONE-THIRD OCTAVE SPECTRA.

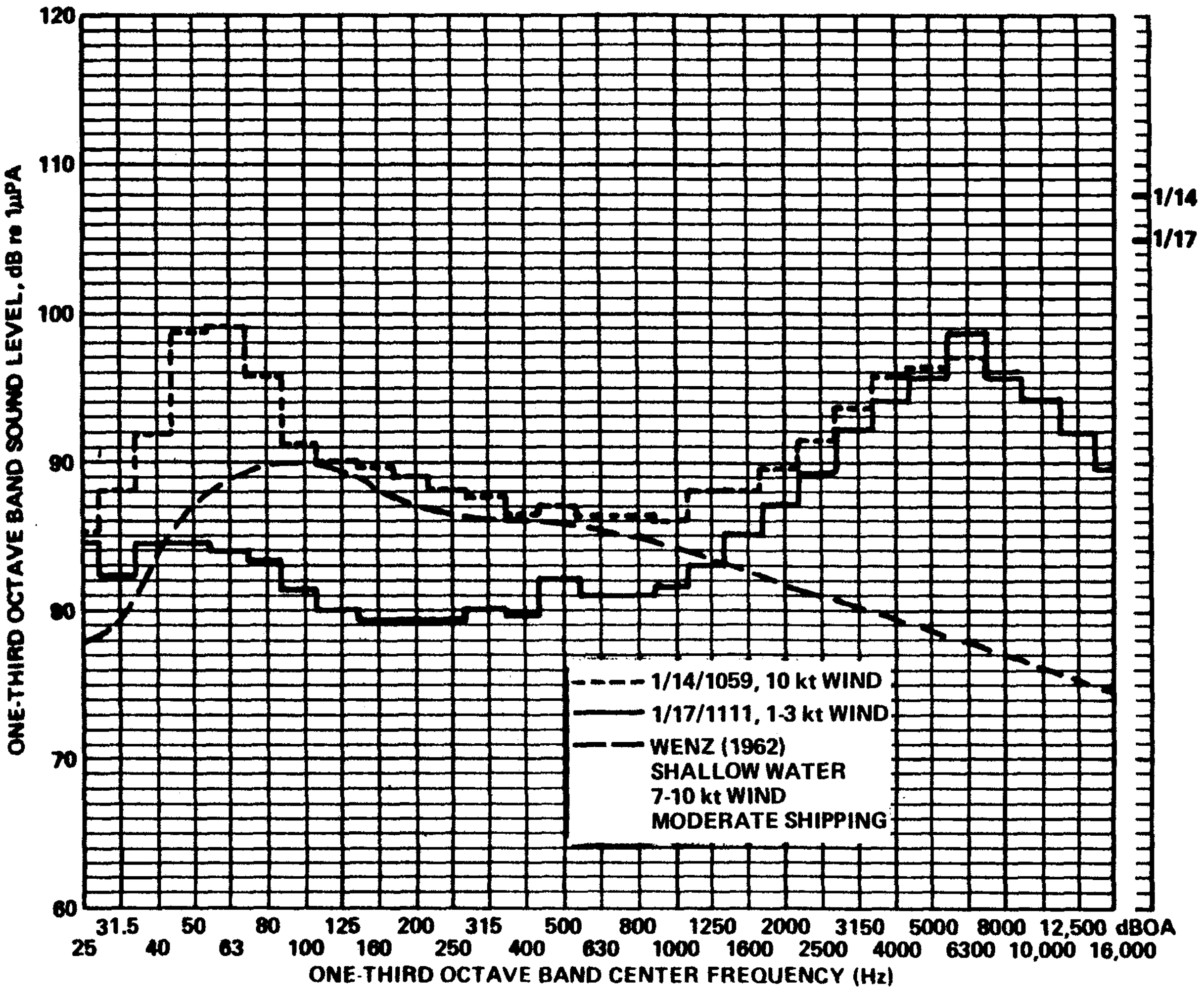


FIG. 5.8. AMBIENT NOISE RANGE DURING PLAYBACK PERIOD.

sound. In human hearing, the masking of one sound by another is greatest when both sounds are within a critical bandwidth. However, upward and downward masking effects do occur. In this case, downward masking is the concern. Fortunately, the dominant spectrum components of the playback stimuli are about one decade lower in frequency than the peak of the shrimp noise. Studies of downward masking by bands of noise (Spieth, 1957) have shown that for human subjects the masking threshold is 40 dB below the peak noise spectrum level, one decade below the noise spectrum peak frequency. In the case of the shrimp noise spectrum, this would imply that a 1/3 octave band signal level of 50 dB or greater at 600 Hz or below would not be masked by the shrimp noise. Fortunately, as was shown in Fig. 5.8, local ambient levels are generally higher than this. Thus, in developing our estimated signal-to-noise (S/N) ratios for the playback stimuli, we have considered that the dominant masking of the playback signal is produced by ambient noise in the same frequency range.

The "available S/N ratio" was estimated for each playback stimulus using the following procedure. The effective signal level for the playback signal was determined by calculating the RMS signal level for the "dominant" bandwidth. Referring back to Fig. 5.7, the dominant signal bandwidth was determined by observing the highest 1/3 octave band level in the signal as measured by the monitor hydrophone, and then including the total number of 1/3 octave bands which had levels within 10 dB of the maximum. The ambient noise spectra measured before and after the playback sequence were averaged and the RMS noise signal for the same dominant bandwidth was calculated. The available S/N ratio was obtained by subtracting the effective masking noise level (dB).

5.2.4 Sonobuoy measurement of playback level vs range

A series of measurements were made using a drifting AN/SSQ-57A sonobuoy (hydrophone depth - 10 m) to determine the effective range of a playback signal. This was done to obtain a check on the accuracy of Eq. (7) when used for predicting the stimulus exposure level versus range. The range of the sonobuoy from the projector was determined by cross-correlating the output of the source monitor hydrophone with the output of the sonobuoy receiver. The time delay of the correlation peak was then converted to a sonobuoy range estimate using the local underwater sound speed.

Figure 5.9 shows the results of these measurements for a sequence using the semisubmersible rig stimulus. The ambient noise levels obtained just after the end of the playback are shown for both the sonobuoy signal and for the ambient noise monitor hydrophone near the VARUA. The two spectra can be seen to agree except at the low frequencies where a line component from a passing ship was stronger near the VARUA. During the playback, when the sonobuoy was at an estimated range of 1.0 km from the VARUA, the ship contribution to the ambient can be seen to be somewhat lower than during the ambient measurement period. The playback signal appears in the 160 to 315 Hz 1/3 octave bands. this is the dominant part of the spectrum for this stimulus (see Fig. C.3 in Appendix C). If we assume that the sonobuoy drift track was along shore at the same depth as the VARUA, Eq. (7) can be used to estimate the expected received levels for the 160 and 250 Hz bands. The resulting estimated levels are compared to the measured levels in Table 5.1(a).

A similar procedure was used for a production platform playback which followed the semisubmersible rig sequence. The results of this measurement are shown in Fig. 5.10. Ambient noise measurements taken before the start of the playback show that the ship noise previously observed had dropped in level but was still loudest at the VARUA position. The playback signal at the sonobuoy position can be seen in the 80 to 250 Hz 1/3 octave bands. The estimated range at this time was 1.5 km. A comparison of estimated and measured playback signal levels is shown in Table 5.1(b). The agreement is not as good as it was for Table 5.1(a). This may be caused by a decrease in the effective TL at low frequencies. The assumption that the sonobuoy continued drifting along the same depth contour after 2 hrs may not be valid. An error in water depth at the receiver would cause an error in calculated TL.

5.2.5 Acoustic exposure estimation

Table 5.1 lists the results of analyzing the playback stimuli and the ambient noise levels at the time of projection according to the procedure discussed in the preceding section. The results are presented in terms of available S/N ratio, 1 m from the projector, and the estimated range for an effective S/N ratio of 0 dB or 10 dB. These ranges are presented both for the entire dominant bandwidth as well as for the highest 1/3 octave band in the respective stimulus. The last measure is appropriate for determining if observed response changes are the result of stimulus detection at low levels.

The TL calculation procedure provided by Eq. (7) was used to obtain the range values given in Table 5.2. To simplify the procedure, a set of fixed-depth values was assumed for the January field period data. Since most of the migration was centered around the same depth contour as the VARUA position, a calculation for TL vs range was made for that depth (64 m), and plotted as shown in Fig. 5.11. Note that the available S/N for the 0 dB maximum range criterion is equal to the TL.

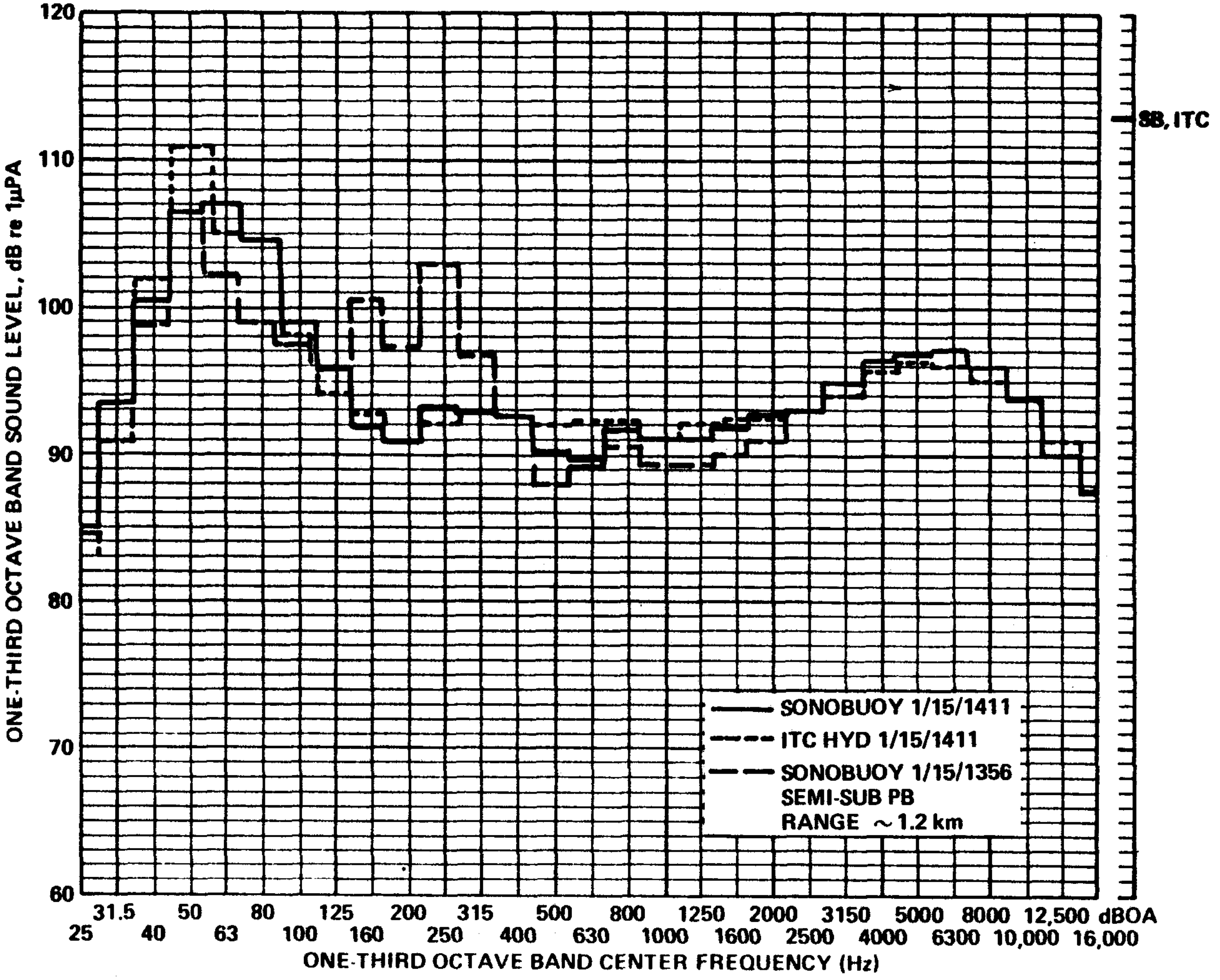


FIG. 5.9. SONOBUOY REMOTE AMBIENT AND SEMISUBMERSIBLE RIG STIMULUS LEVEL MEASUREMENTS.

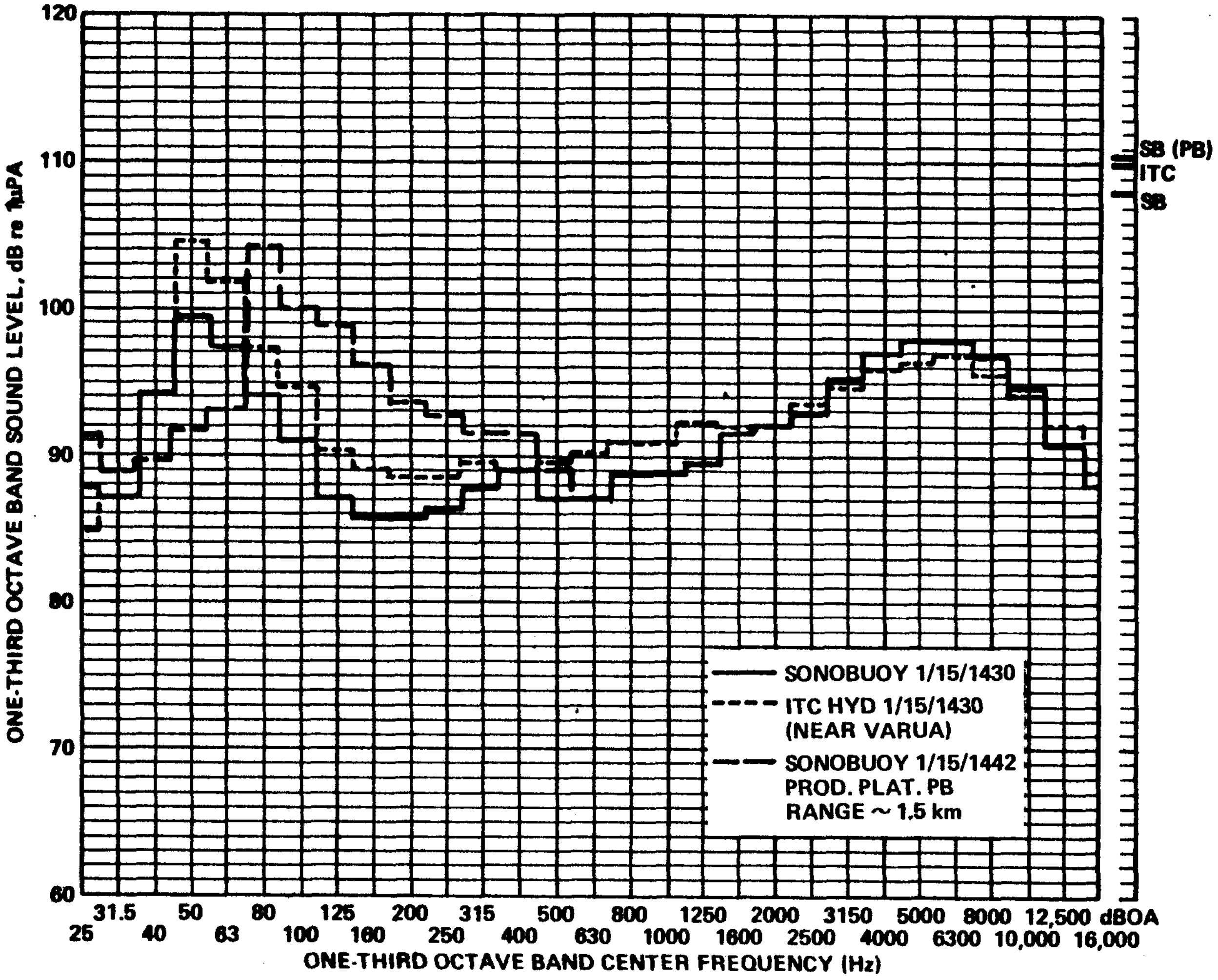


FIG. 5.10. SONOBUOY REMOTE AMBIENT AND PRODUCTION PLATFORM STIMULUS LEVEL MEASUREMENTS.

TABLE 5.1. SONOBUOY SOUND PROPAGATION MEASUREMENTS.

A. Semisubmersible Rig Stimulus Playback

Source Level (1 m)		Range (Meas)	TL (Calc)	Received Level	
1/3 Oct Hz	L_s dB re 1 μPa	km	dB	Calc L_r dB re 1 μPa	Meas. L_r dB re 1 Pa
160	152	1.0	51	101	101
250	153	1.0	51	102	103

B. Production Platform Stimulus Playback

Source Level (1 m)		Range (Meas)	TL (Calc)	Received Level	
1/3 Oct Hz	L_s dB re 1 μPa	km	dB	Calc L_r dB re 1 μPa	Meas. L_r dB re 1 μPa
80	157	1.5	56	101	104
125	151	1.5	56	95	99
250	150	1.5	56	94	93

TABLE 5.2. PLAYBACK SIGNAL/NOISE DATA AND ESTIMATED EFFECTIVE RANGE.

Date/Time		Stim Code	BW_{eff}[1] Hz	L_S dB//µPa	L_N dB//µPa	S/N dB	R_0 km	R_{10} km	B_M Hz	S/N dB	R_0 km	R_{10} km	Est. L_N[2] Variation dB
1/13/84	1133-1403	PD1	80-1.6K[3]	162	100	62	2.4	1.1	125	67	3.3	1.7	10
	1431-1544	DS1	50-315[3]	151	96	55	1.4	0.5	250	59	2.0	0.8	5
	1544-1700	DS1	50-315	153	96	57	1.7	0.6	250	64	2.8	1.3	5
1/14/84	1117-1315	PP1	63-500	163[4]	109	54	1.3	0.4	80	57	1.7	0.6	6
	1345-1545	H1	31.5-135	158	105	53	1.2	0.4	160	58	1.9	0.7	9
1/15/84	1005-1145	DS2	50-315	160	102	58	1.9	0.7	250	64	2.8	1.3	3
	1227-1401	SS1	50-1K	160	108	52	1.1	0.3	250	63	2.6	1.2	3
	1436-1616	PP2	63-500	160	102	58	1.9	0.7	250	62	2.4	1.1	3
1/17/84	0848-1046	SS2	50-1K	157	97	60	2.2	0.9	250	69	3.7	2.0	4
	1122-1318	PD2	80-1.6K	157	95	62	2.4	1.1	250	65	3.0	1.4	6
	1345-1545	H2	31.5-315	157	99	58	1.9	0.7	160	64	2.8	1.3	1
1/19/84	0845-1045	PD3	80-1.6K	159	103	56	1.6	0.5	250	65	3.0	1.4	1
	1115-1315	DS3	50-315	159	102	57	1.7	0.6	250	63	2.6	1.2	3
	1345-1545	H3	31.5-315	160	104	56	1.6	0.6	31.5	61	2.3	1.0	2
1/20/84	0830-1030	SS3	50-1K	161	105	56	1.6	0.6	250	65	3.0	1.4	3
	1231-1431	PP3	63-500	161	103	58	1.9	0.7	80	64	2.8	1.3	1

Notes: [1] Range of 1/3 octave-band center frequencies.

[2] Estimated ambient noise level variation during playback.

[3] Projector not equalized.

[4] Source level 6 dB higher from 1117-1137.

Key:

R_0 = Range to 0 dB S/N

R_{10} = Range to 10 dB S/N

L_S = Source level, 1 m

L_N = Noise level

B_M = 1/3 octave band with highest level in signal.

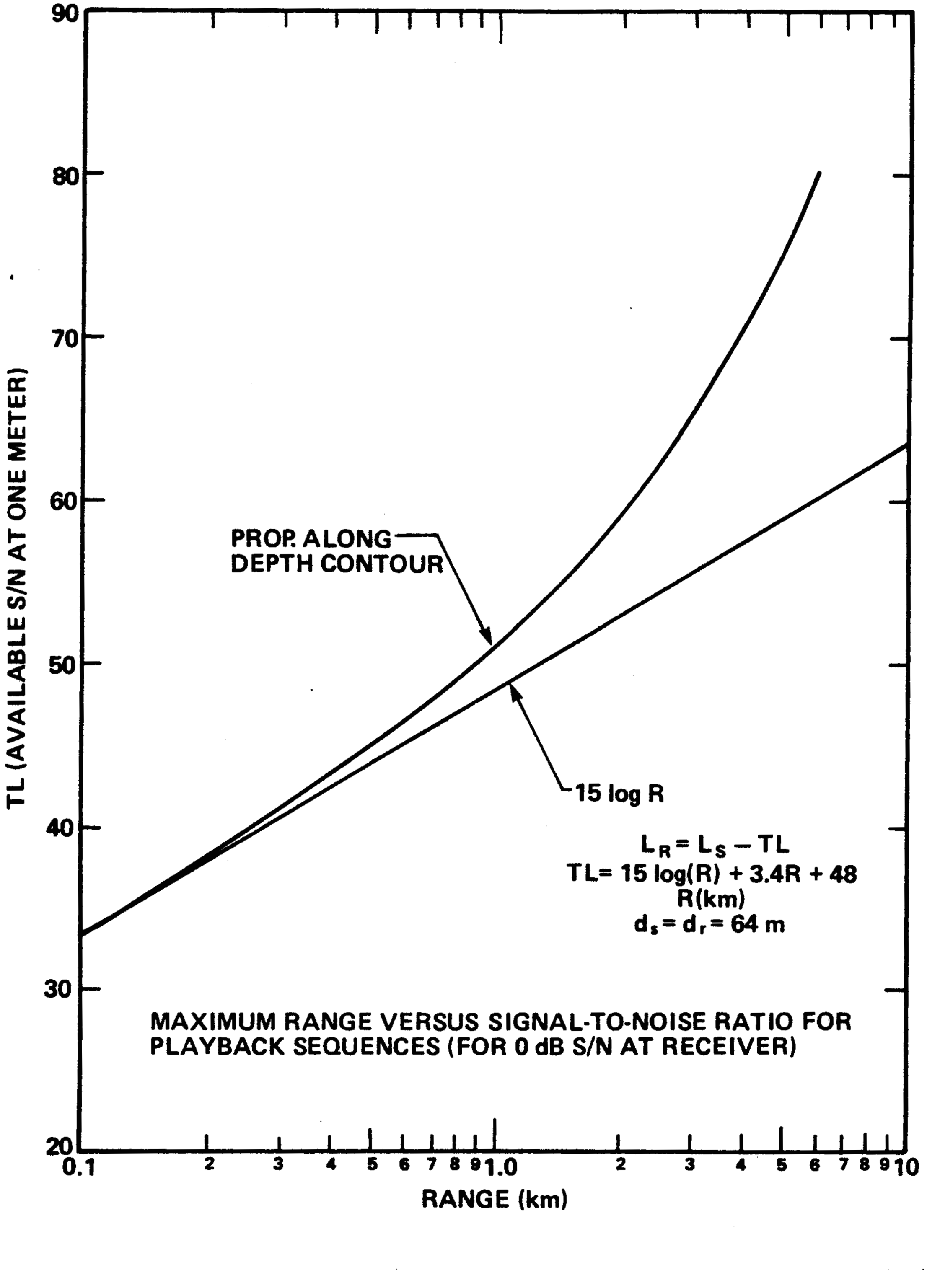


FIG. 5.11. PLAYBACK TRANSMISSION LOSS CHARACTERISTIC.

6. BEHAVIORAL OBSERVATIONS AND ANALYSIS

6.1 Behavioral Observations

The purpose of this section is to present a qualitative description of the southward migration for January 1984. As we emphasized in our 1983 report, knowledge of and familiarity with the normal migratory behavior of gray whales is essential for a proper interpretation of results obtained under potentially disturbed conditions. The following is a characterization of the southward migration and a series of descriptions based on observations made under both undisturbed and potentially disturbed conditions. These descriptions are derived from field notes and daily summaries written in the evening after observations had ended.

6.1.1 Normal migratory behavior

During the southbound migration, whales passed our study sites at speeds of between 5 and 10 km/hr. During the 1984 field season, we did not observe migratory pulses as we had in 1983. Instead, we had the impression that whales were passing in a constant stream, although we were aware of daily fluctuations in the number of whales. Whale groups tended to pass our study site in a corridor 2 to 5 km offshore. We have not quantified the relationship between group size and distance from shore, but last year large groups appeared to migrate further offshore than during this field season.

During the 1984 field season we observed a variety of individual and group behaviors including breaching, rolling, side swimming with pectoral fin extended, milling, and possible surface skim feeding. Since our primary objective was theodolite tracking of whale groups, we could not reliably note all behaviors in a given series (i.e., every time a whale extended a pectoral fin during a 10 min. period of surface activity). However, we are confident that we did note all breaches and surface active behaviors (see Sec. 6.2.1 for a definition of surface active behavior and see Sec. 7.1.5 of Report No. 5366 for definitions of individual behaviors). Although we have not made a quantitive comparison between the number of behaviors seen during the 1984 season and the January 1983 season, it is our overall impression that the two seasons did not differ significantly.

We emphasize that the behaviors described below were rare occurrences during the southward migration. We present them here to illustrate unusual behaviors observed during the southward migration.

6.1.2 Observations under control conditions

The following are narrative descriptions of four groups of whales observed during normal conditions. All whale group positions are approximate within 100 m and all times are given to the nearest minute.

Possible Feeding - 12 January

Group FFF (see Fig. 6.1) was a spread out group of three whales, first observed at 1407 just north of north site. By 1444 the group was 1.5 km south of Soberanes, 2 km offshore. At this point, one whale in the group was seen with its mouth open, skimming the surface. A group of about 20 Pacific white-sided dolphins were observed with this group. These dolphins were presumably a part of a large group (150 to 200) of dolphins offshore of group FFF. The closest point of approach of these dolphins to group FFF occurred during the surface skimming at 1444 (see Fig. 6.1). At 1450, a number of surface active

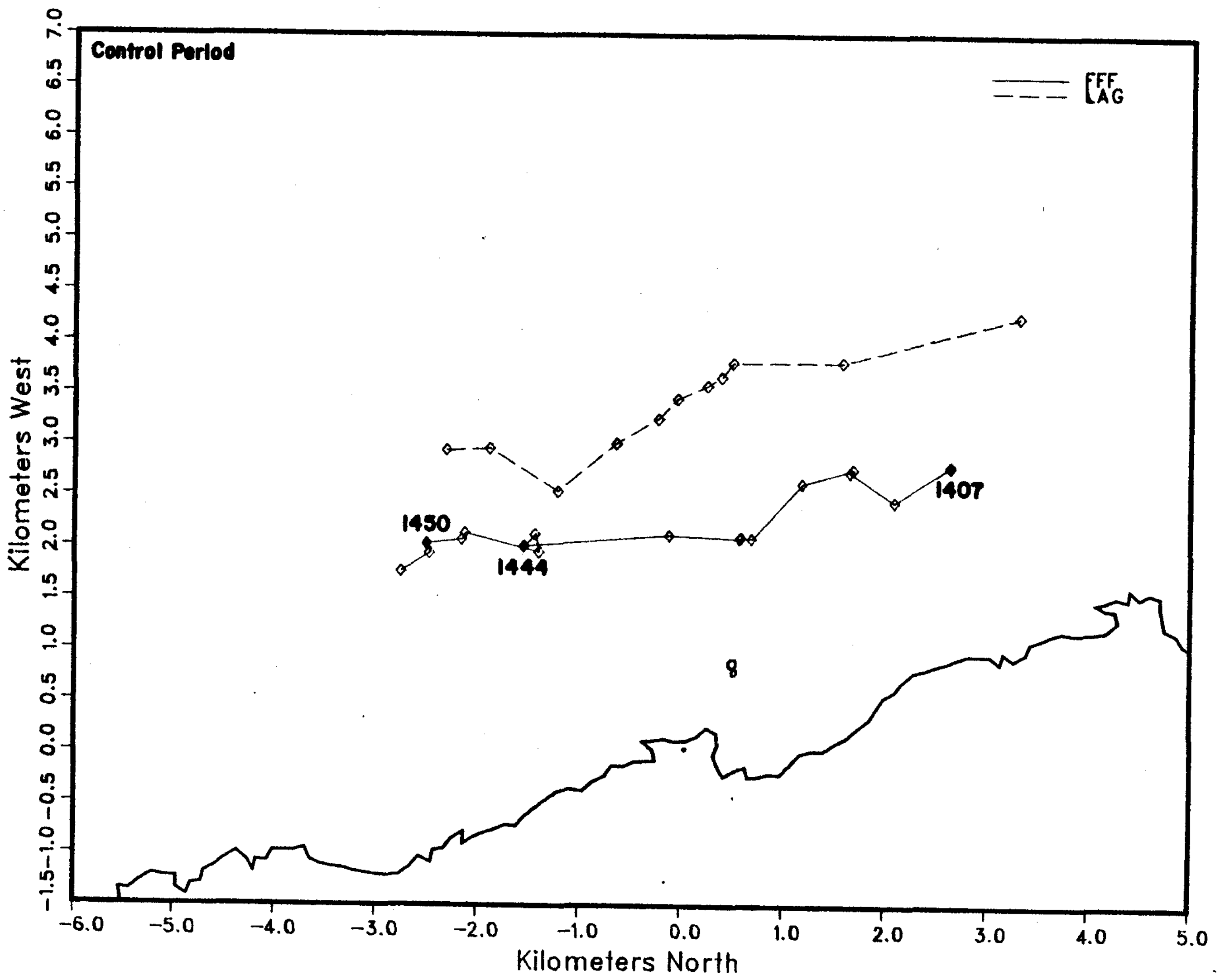


FIG. 6.1. GROUP FFF, POSSIBLE SKIM FEEDING WHALES, 12 JANUARY. THE LARGE GROUP OF PACIFIC WHITE-SIDED DOLPHINS IS MOVING SOUTH TO NORTH OFFSHORE OF GROUP FFF. LOBOS ROCKS ARE INDICATED BY THE TWO SMALL CIRCLES (8).

behaviors were observed, including rolling at the surface with dolphins with fluke tips and pectorals visible (vertical flukes and pectorals). Two members of the group were also seen rolling ventral surface to ventral surface. This surface active behavior continued until 1456. What we believe to be surface skim feeding with dolphins was again observed at 1459 (see Fig. 6.1). This was our last observation of group FFF which was now 2.7 km south of Soberanes and 2 km offshore. This was the first time we have observed surface skimming.

Sexual Activity - 18 January

Sexual activity (2+ whales rolling with penis seen) was an uncommon occurrence during both the January 1983 and the 1984 season. The following is a description of one of two sexually active groups seen during January 1984. Group F (see Fig. 6.2) was first observed at 0833, 1.1 km north of north site and between 2 to 2.5 km offshore. As this group approached north site, observers could distinguish three parts which were noted as subgroups F1, F2, and F3. Interchange between these subgroups and their distance from shore made it difficult to accurately determine total group size. However, subgroup F2 seemed to remain stable throughout our observations and it was determined that it was composed of three adults and one calf. Surface active behaviors were first noted from subgroup F2 at 0844 (see Fig. 6.2) when they were 0.2 km north of north site and 2 km offshore. These behaviors continued until 0907 (see Fig. 6.2) when F2 was 0.8 km north of Soberanes and 2 km offshore. Behaviors included rolling, vertical flukes and pectorals, head-ups, and tail lashes. An extended penis was seen as one whale swam sideways. The three subgroups were quite separated as they approached Soberanes and were followed up to 5 km south of Soberanes.

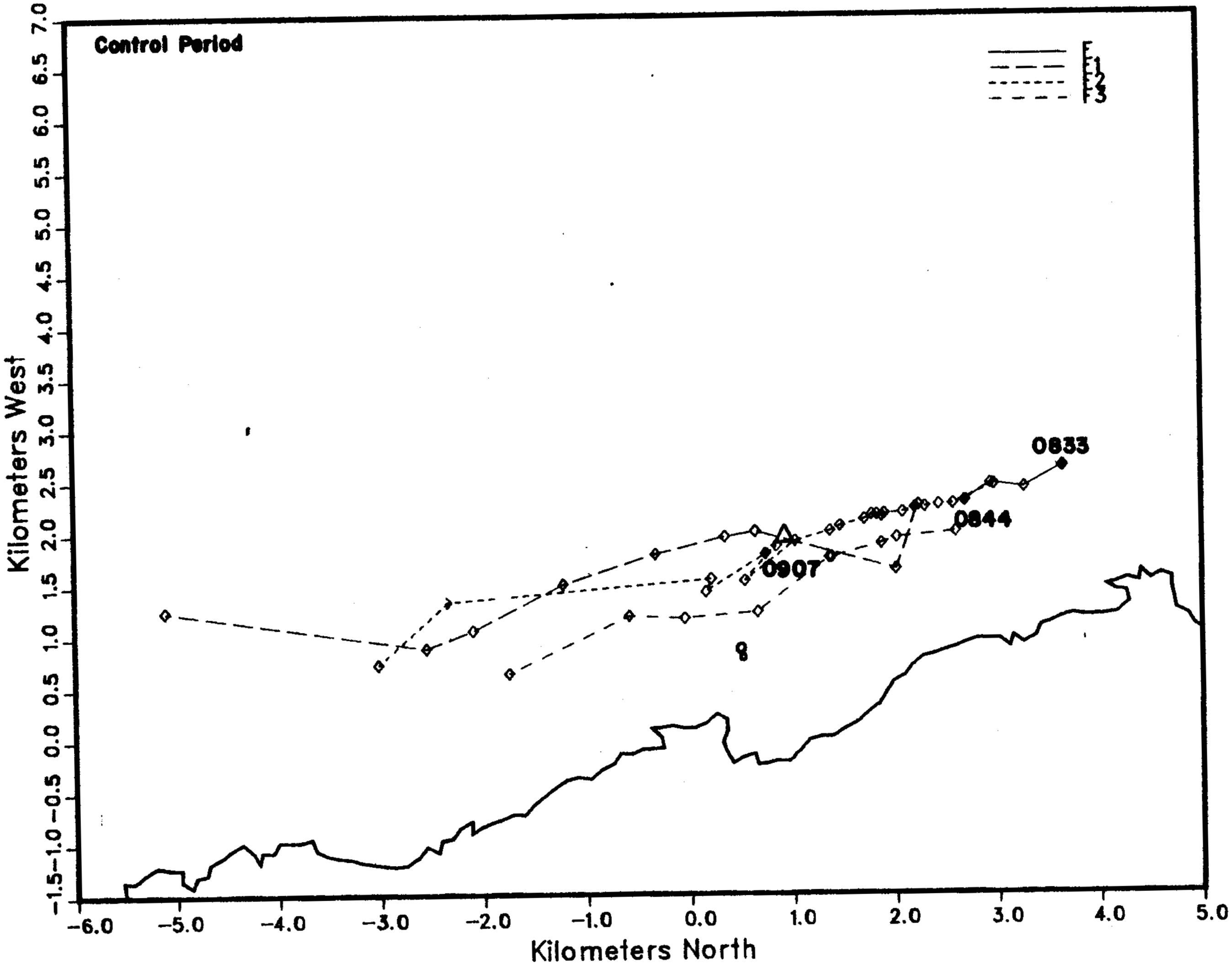


FIG. 6.2 GROUP F AND SUBGROUPS F_1, F_2, AND F_3, 18 JANUARY. THE POSITION OF VARUA IS INDICATED BY Δ.

Milling - 20 January

Although milling was observed during both the current field work and January 1983, the following incident was unusual in the long during of milling observed. Group O, composed of two whales, was first observed at 1015, 0.3 km north of north site and close to shore (see Fig. 6.3). The next sighting of this group occurred at 1040 when it was located 750 m north of Soberanes and 700 m offshore. Although this group was not seen for a 25 min. period, we are confident that it was resighted because all groups passing north site had been accounted for by personnel at Soberanes. Group O stayed in the same general area for over 2 hr., until 1242, when it started to move south again (see Fig. 6.3). It was last seen at 1347, 2 km south of Soberanes moving slowly and still very close to shore. During the entire time that this group was milling, only one surface active behavior (circling with pectoral extended) was recorded. A semisubmersible rig playback was started at 1231. This group spent almost the entire control period in the same general area, only resuming its southward migration shortly after the start of a sound playback.

Whale Group - Boat Interaction - 21 January

Group AA, composed of three whales, was first seen at 1220, 2.5 km offshore and just north of north site (see Fig. 6.4). At 1239, this group started displaying a variety of behaviors including vertical flukes and pectorals, rolling, tail slaps, head-ups, an extended penis. At 1318, a member of the group breached. This was the only time during the 1984 field season that a single breach was integrated with a number of surface active behaviors. During January 1983, such behavior was also observed once. Within minutes after the surface activity started during which, a vertical fluke and an extended penis were seen, a boat approximately 15 m in length approached Group AA. The boat,

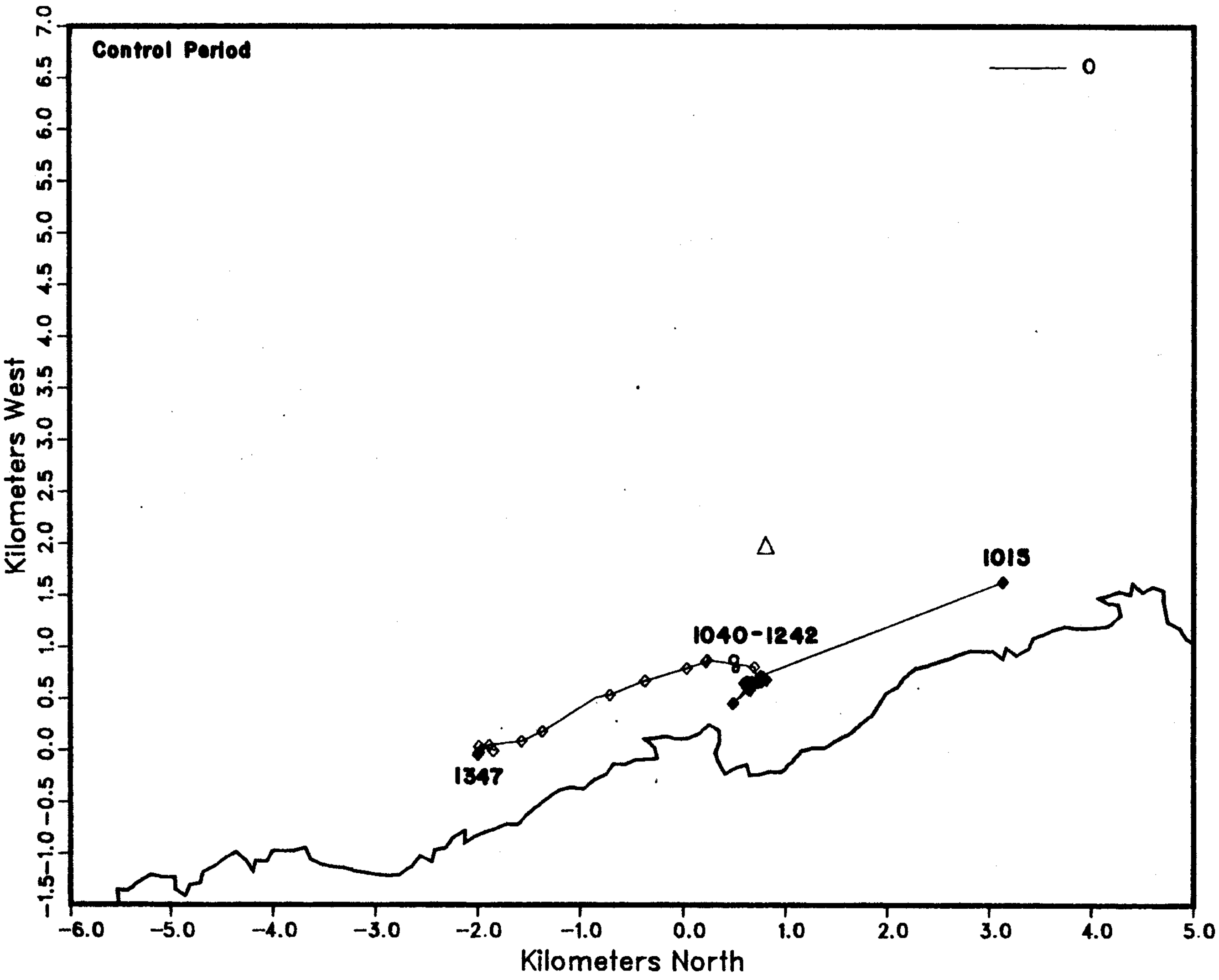


FIG. 6.3. GROUP O MILLING FOR 2+ HR JUST NORTH AND INSHORE OF LOBOS ROCKS, 20 JANUARY.

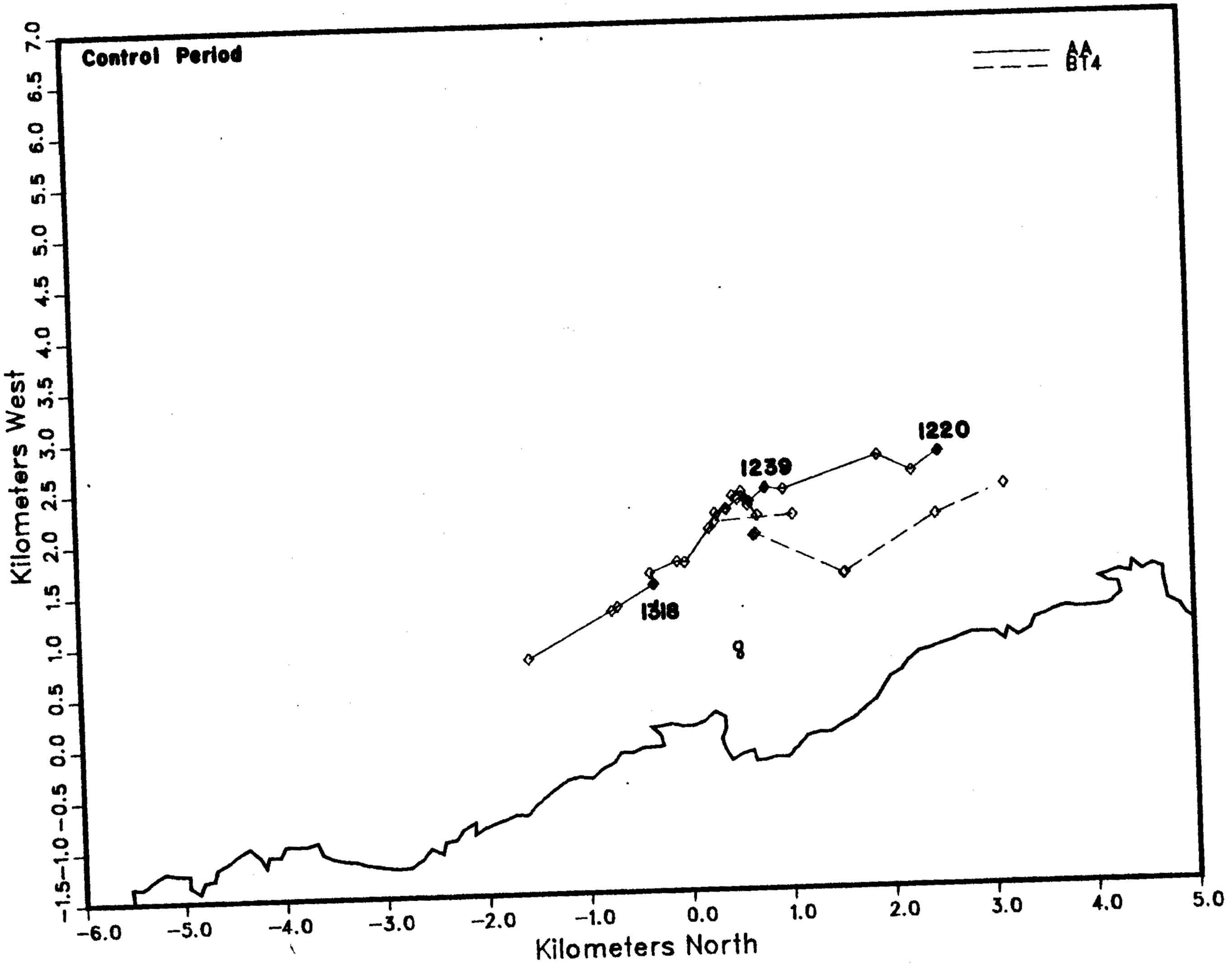


FIG. 6.4. GROUP AA/BOAT INTERACTION 1.5 km OFFSHORE OF LOBOS ROCKS, 21 JANUARY.

not a part of our experimental design, stayed with Group AA for approximately 17 min (see Fig. 6.4). We had the distinct impression that the presence of the boat elicited some of the observed behaviors.

6.1.3 Observations under experimental conditions

Time constraints did not allow us to analyze each group that exhibited unusual behavior during experimental conditions. We have chosen to provide the following three descriptions as examples of uncommon behavior and tried to relate this behavior to received sound level.

Northward Movement - 19 January

Group C, composed of two to three whales, was first sighted at 0811 just north of north site and 2.6 km offshore (see Fig. 6.5). The group was tracked south to a point 1.8 km south of Soberanes and 2.4 km offshore. At approximately this time, the group split and one whale was seen to move north at 0902 (see Fig. 6.5). This single whale from Group C, designated C2 in our notes, continued to move north and was last tracked at 0940 when it was 0.3 km north of Soberanes and 1.9 km offshore. North station had sightings of C2 but did not track it after this point. The other part of Group C, designated C1, continued its southward movement and was last seen at 0912, 3 km south of Soberanes and 2.3 km offshore. A drilling platform playback had started at 0845 and continued until 1045. At the point when Group C2 headed north, the received sound level at the whale was calculated to be 97 dB or 6 dB below the ambient. However, the received level at the whale when it was last spotted with the theodolite was 112 dB or 9 dB above the ambient. If the mean speed of movement of Group C before it separated ($\overline{x}$ = 6.24 km/hr ± 1.759, n = 12) is compared to the mean speed of C2, the northward moving whale ($\overline{x}$ = 3.61 ± 0.994, n = 7), we find that there

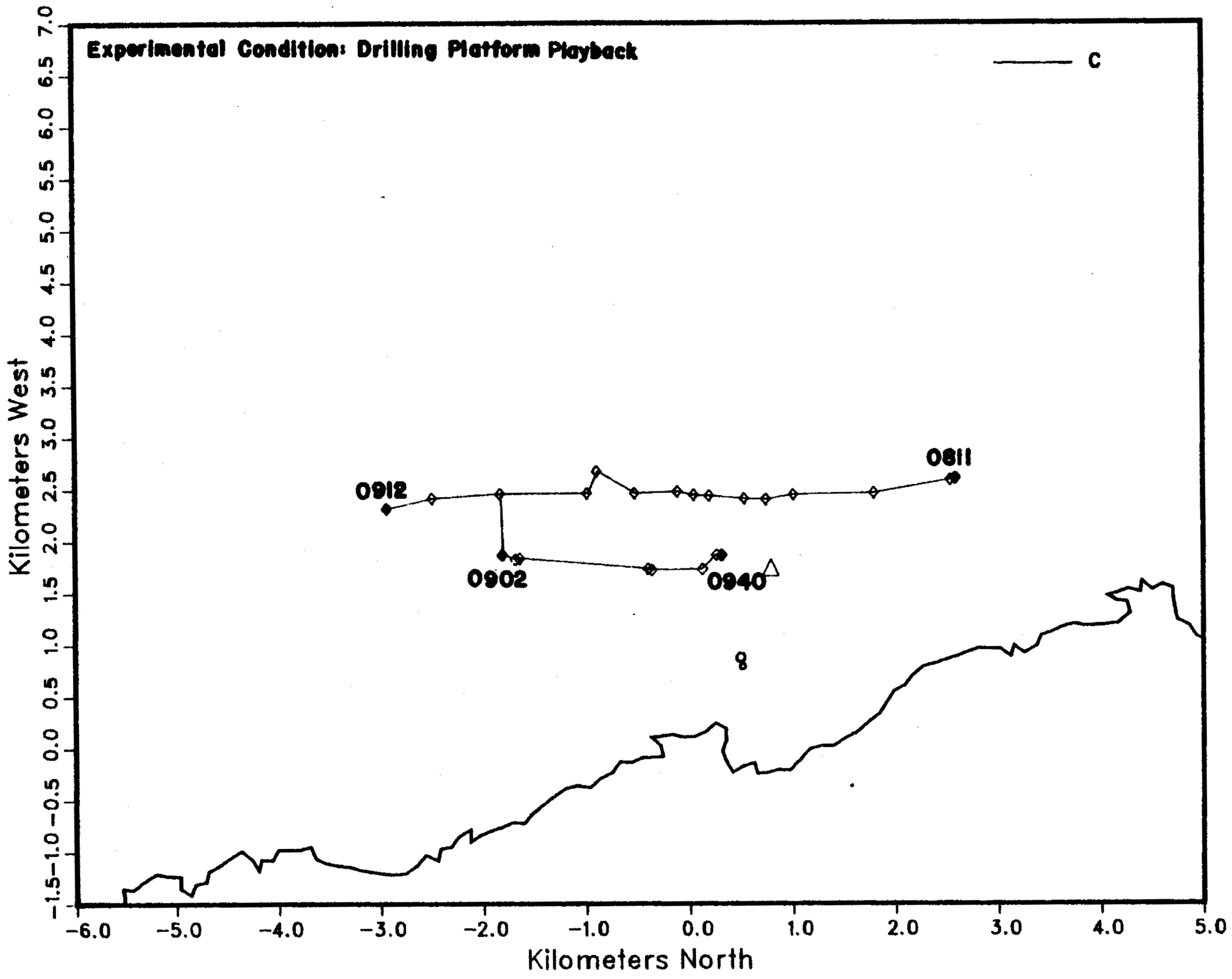


FIG. 6.5. SUBGROUP C_2 SPLITTING FROM GROUP C AND MOVING NORTH, 19 JANUARY.

was a significant drop in speed of the northward moving whale ($T_S = 4.9462$, $p < 0.001$, df = 17). Although the reason for the turn north of C2 is unknown, this whale did slow its speed as it moved north toward the general location of the playback source. The interpretation that an increase in received sound level was responsible for the slower speed must be viewed with caution as not all data on northward moving whales has been analyzed.

Possible Use of a Low Sound Area - 17 January

Group ZZZZ, composed of two whales, was first sighted at 1508, 0.6 km north of north site and 1.7 km offshore (see Fig. 6.6). At this time, a helicopter playback was in progress (1345-1535). Observers at north site noted that one whale was smaller than the other. At 1512, one of the whales breached, 0.2 km north of north site and 1.6 km offshore. At this point, the received sound level at the group was calculated as 99 dB, or in this case, equal to the measured ambient level. At 1529, the group was 1.4 km north of Soberanes and 0.9 km offshore. The received sound level was calculated at 102 dB or 3 dB above the ambient. Our next transit reading of the group was at 1544, 0.6 km north of Soberanes and 0.6 km offshore. This position puts the group just north of a line between Soberanes and the VARUA, with Lobos Rocks in between. The calculated received sound level at this point was 97 dB or 2 dB below ambient. The group stayed in this same general area, milling about, until at least 1623. The group was last seen at 1644, 1 km to the south of Soberanes and very close to shore. Between 1629 and the last sighting at 1644, the group had come inshore by approximately 500 m. It is possible to speculate that the group detected the helicopter playback at the point of the breach and then moved to an area that would lessen the received sound level. However, until in-depth analysis of milling groups during experimental conditions is performed, this interpretation should remain speculative.

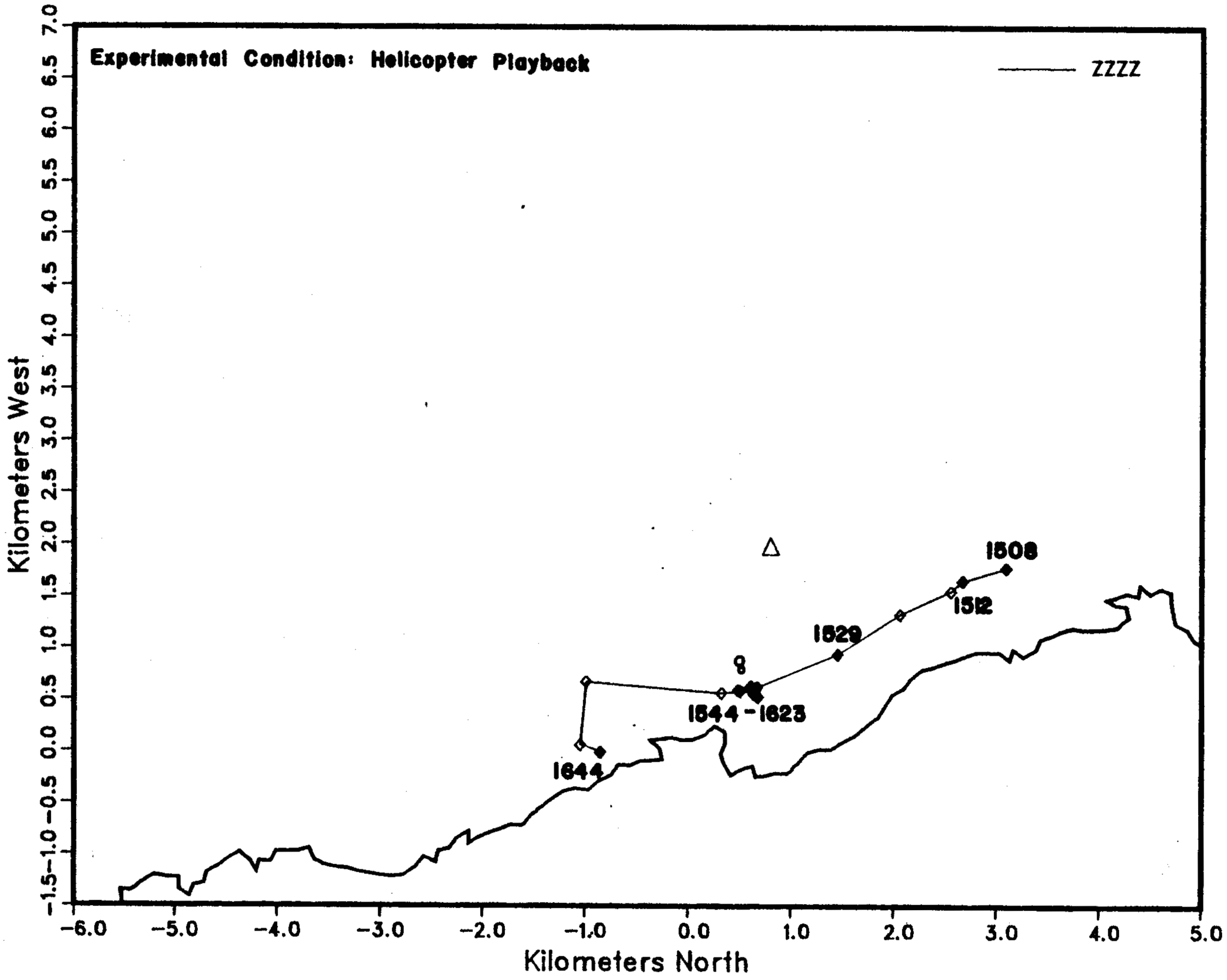


FIG. 6.6. GROUP ZZZZ MILLING JUST NORTH AND INSHORE OF LOBOS ROCKS, 17 JANUARY.

Breaching - 15 January

During the semisubmersible rig playback which started at 1248 and ended at 1356, we observed four different groups breaching. This was an unusually high number of groups breaching in a relatively short period of time. The groups were 5.0 km, 3.8 km, 2.7 km, and 2.5 km from the experimental vessel and therefore were probably not experiencing sound levels above ambient. Thus, these breaching incidents were probably not related to the playback stimulus.

6.2 Behavioral Data Analysis Procedures and Results

In this section we present a quantitative comparison of various classes of behavior during experimental and control conditions.

6.2.1 Definitions of behavioral measures

During the 1984 field season, we were able to distinguish 21 different behaviors. However, since there were very few observations of most behaviors, we reduced the various behaviors into four categories for statistical comparison. The following four categories of behaviors were used in this year's analysis with the original behaviors listed in parenthesis:
1) breach; 2) milling (circling, milling, not moving); 3) surface active (head lunge, head up, lob tail, pectoral extension, roll, surface active, spyhop, tail lash, vertical fluke, unidentified white-water); and 4) change in direction. We chose to consider breaching as separate from other surface active behaviors because breaching only occurred once during bouts of surface active behavior in both years.

Most of the behaviors listed above have been defined in Sec. 7.1.5 of Report No. 5366. Additional definitions include:

a) Head lunge: the head of a whale comes out of the water at 45° to the water's surface while travelling.

b) Lobtail: the whale raises its fluke together with a portion of the tail stock above the water and slaps it down on the surface.

c) Tail lash: the whale raises its fluke (and at times a portion of the tail stock) out of the water and makes a horizontal slashing motion.

For this behavioral analysis, we scored change of direction as movement to the E, W, N, NE, or NW. Other more subtle changes (i.e., SE, SW, etc.) are best determined by the track analysis program (see Sec. 7).

6.2.2 Statistical comparisons of behavioral data

In order to analyze statistically the occurrence of the four categories of behavior during control and experimental conditions we first generated a daily chronological list of the occurrence of four behaviors and separated the time periods by control or playback condition. Each time period associated with a condition was divided into a series of 10 min. intervals. Ten min. periods were chosen by the start time of the condition. During whole-day control periods (8, 12, 16, 18, 21 January), the start time was determined as the earliest time both stations were in operation. When counting the number of ten min. periods, if, at the end of the day or the playback there was a period of less than 10 min., this period was dropped. We only examined whether or not the behavior occurred in the 10 min. period not the number of behaviors by individual groups. (Example: 13 January, drilling platform playback 1133-1403, 15 10-min. periods, two breaching periods, 13 no breaching periods.) If the same behavior was performed by the same group in two adjacent periods, then both of these periods were scored with an occurrence of that behavior type. For directional changes this was not the case. If a group was seen moving north, for example, for more than one 10 min. period (as was the case for a few groups) only the first 10 min. period that the group was observed to move north was scored as a directional change period. See Tables 6.1 and 6.2 for group behavioral summaries during experimental and control conditions.

6.2.3 Industrial noise playback results

In this section, we statistically compare the numbers of intervals with and without behaviors during the five different industrial noise playbacks and during appropriate control conditions. Three different control periods were used. These are labelled #1, #2, and #3 in Table 6.2. The pooled control period #1 was used for data formed by pooling all playbacks while control periods #2 and #3 were used for all other comparisons of playbacks (see Sec. 7.1.1 for a description of these control periods). Statistical tests used were obtained from Sokal and Rohlf (1969).

Breaching

The numbers of ten minute intervals with or without breaches are presented in the first row of Table 6.1.

To determine if the number of breaching periods is independent of playback condition, a R x C test of independence was performed using the G-Test. The results show that breaching periods are independent of playback condition ($G = 6.050$, $0.1 < p < 0.5$, $dF = 4$). Because of this homogeneity between breaching across the five playback conditions, we pooled the data for all experiments as above (18,161) and compared these to the data for control periods #1, #2, and #3 (our industrial playback control periods). There was no significant difference between the ratio of playback breaching periods (18, breach, 157 no breach) and the

TABLE 6.1. GROUP BEHAVIORAL SUMMARY DURING THE VARIOUS EXPERIMENTAL CONDITIONS. (See Sec. 6.2.2 for an explanation of how the numbers were derived.)

	Industrial Noise Playbacks					Single Air Gun Moored		Single Air Gun Transect		Single Air Gun Drifting
Behavior	**P.P.***	**S.S.***	**D.S.***	**D.P.***	**H.***	**10 JAN**	**11 JAN**	**8 N.M.**	**3 N.M.**	**1.5 N.M.**
Breach	1,32	3,29	6,30	6,32	2,34	2,35	3,21	0,19	0,8	2,7
Surface Active	4,29	6,26	1,35	2,36	0,36	1,36	1,23	2,17	2,6	0,9
Direction Change	0,33	1,31	0,36	4,34	1,37	1,37	7,17	6,13	0,8	1,8
Milling	2,31	0,32	2,34	0,38	0,37	0,38	0,24	1,18	2,6	2,7

*P.P. = Production Platform; S.S. = Semisubmersible Rig; D.S. = Drillship; D.P. = Drilling Platform; H = Helicopter.

NOTE: Each entry in the table is in a pair of numbers. The first number indicates the number of ten minute intervals in which the behavior was observed; the second number indicates the number of intervals in which the behavior was not observed.

TABLE 6.2. GROUP BEHAVIORAL SUMMARY DURING THE VARIOUS CONTROL PERIODS.

	Control Periods							
Behaviors	**#1**	**#2**	**#3**	**#4**	**#5**	**8 JAN 0915-1232**	**8 JAN 1337-1500**	**8 JAN 1530-1705**
Breach	12,152	10,106	2,46	1,29	6,86	0,19	1,7	0,9
Surface Active	28,136	20,96	8,40	0,30	13,79	4,15	1,7	0,9
Directional Change	11,153	5,111	6,42	1,29	2,90	0,19	1,7	0,9
Milling	4,160	3,113	1,47	1,29	1,91	2,17	0,8	0,9

NOTE: Each entry in the table is in a pair of numbers. The first number indicates the number of ten minute intervals in which the behavior was observed; the second number indicates the number of intervals in which the behavior was not observed.

ratio of breaching periods during the pooled control period #1 (12 breach, 152 no breach; $G_{ADJ} = 0.600$, $0.1 < p < 0.5$, dF =1). Pooled breaching compared with control period #2 (10,107) showed no statistical difference ($G_{ADJ} = 0.072$, $0.5 < p < 0.9$, dF = 1). There was also no statistical difference between pooled breaching during experiments and control period #3 (2,46) ($G_{ADJ} = 1.186$, $0.1 < p < 0.5$, dF = 1). We conclude that industrial noise playbacks did not affect the incidence of breaching periods.

Surface Active Behavior

The numbers of ten minute intervals with or without surface active behaviors are presented in the second row of Table 6.1. The surface active, no surface active behavior periods were pooled (13,162) and compared to the pooled control period #1 (28,136). There was a significant difference between the number of surface active periods during playback and the number of pooled surface active periods during control period #1 ($G_{ADJ} = 6.620$, $0.01 < p < 0.025$, dF = 1). Most of the surface active behaviors during control period #1 occured on 21 January, when 33.3% of the ten min. periods (11 out of 33) were surface active periods. Our last field day, 21 January, was a Saturday and sea conditions were Beaufort 1. Many small (<10 m) boats were moving through our study site. On more than one occasion, we observed whale/boat interactions where the presence of the boat seemed to alter the group's behavior (see Sec. 6.1 for a narrative description of one such incident).

To determine if the number of surface active behavior periods is independent of playback condition, a R x C test of independence using the G-Test was done. The results show that the surface active behavior periods are not independent of playback condition ($G = 12.536$, $0.01 < p < 0.025$, dF = 4). In order to determine what playback stimulus (or stimuli) caused this heterogeneity, an a posteriori test by STP for homogeneity was done. When Production Platform, Semisubmersible Rig, Drilling Platform and Drillship were tested together they were homogeneous ($G_H = 6.282$, below the x^2 value of 9.488 at the 0.05 level for $dF = 4$). Heterogeneity occurs when the data from the Helicopter playback is added. If the number of surface active behavior periods during the Semisubmersible Rig condition are not included in the test, the results for the remaining four playback types are also homogeneous. This result shows that the number of surface active behaviors during the Semisubmersible Rig condition (6,26) was significantly higher than during the Helicopter condition (0,36). When we plotted the positions of the surface active whale groups on 20 January during the Semisubmersible Rig condition (five out of the six ten min. periods are during this particular playback), none of the groups were experiencing received sound levels over ambient when their surface activity started. This shows that the playback probably was not responsible for the increased surface activity.

Because of this heterogeneity in surface active periods during pooled playback conditions, comparisons were made between the two homogeneous combinations of playbacks. Surface action periods during Production Platform, Semisubmersible Rig, Drillship and Drilling Platform were pooled to form the first combination called SA1 (for Surface Active 1). Surface active periods during Production Platform, Drillship, Drilling Platform, and Helicopter were pooled to form the second combination called SA2 (for Surface Active 2). Surface active periods during SA1 and SA2 were compared to control periods #2 and #3. There was no significant difference in the number of surface active behavior periods between SA1 (13,126) and control period #2 (20,96) ($G_{ADJ} = 2.818$, $0.05 < p < 0.5$, $dF = 0.1$). There was also no significant difference in the number of surface active behavior periods between SA1 and control period #3 (8,40) ($G_{ADJ} = 1.174$,

$0.1 < p < 0.5$, dF = 1). However, when a comparison is made between SA2 (7,136) and control period #2, there was a significant difference in the number of surface active behavior periods (G_{ADJ} = 9.292. $0.001 < p < 0.005$, dF = 1). There was also a significant difference between SA2 and control period #3, although not as great as between SA2 and control period #2 (G_{ADJ} = 4.692, $0.025 < p < 0.05$, dF = 1). The results are difficult to interpret. It is not clear whether or not our control period data base was biased on 21 January because of small boat traffic. More data is needed on surface active behavior during control and experimental conditions to make conclusions regarding the affect of industrial noise playbacks on this behavioral category.

Direction Change

The numbers of ten minute intervals with or without direction change are presented in the third row of Table 6.1. The direction change, no direction change periods were pooled (6,169) and compared to the pooled control period #1 (11,153). There was no significant difference between the number of playback direction change periods and the number of direction changes during control period #1 (G_{ADJ} = 1.290, $0.1 < p < 0.5$, dF = 1).

To determine if the number of direction change periods is independent of playback conditions, a R x C test of independence using the G-Test was performed. The results show that direction change periods are not independent of playback condition (G = 8.654, $0.001 < p < 0.005$, dF = 4). By inspection (see Table 6.1), the relatively higher number of direction change periods during the Drilling Platform playback is responsible for this heterogeneity. When the received sound level at the four whale groups who changed direction is calculated, only two of the groups were experiencing sound levels above ambient and the sound level for one of these groups was only 1 dB above ambient. Group UU2 on 13 January was, however, experiencing received sound levels of 111 dB (11 dB above ambient). Because of this result it is difficult to assign a cause for this relatively large number of direction changes during the Drilling Platform playback condition (or, conversely, the low number of direction change periods during the other four playback conditions). For this reason, comparisons between direction change periods during playbacks with control periods #2 and #3 were not performed.

Milling

The numbers of ten minute intervals with or without milling, are presented in the fourth row of Table 6.1. The milling, no milling periods were pooled (4,171) and compared to the pooled control period #1 (4,160). There was no significant difference between the number of playback milling periods and the number of milling periods during the pooled control period #1 (G_{ADJ} = 0.068, $0.5 < p < 0.9$, dF = 1).

Because of the low number of milling periods during playback conditions and during control periods #2 (3,113) and #3 (1,47), statistical comparisons were not made. Based on our limited number of milling observations during control and experimental conditions, we conclude that industrial noise playbacks did not cause whale groups to mill. More data is needed, however, to reach solid conclusions regarding the effect of industrial noise playbacks on whale groups using milling behavior as an indicator.

6.2.4 Moored air gun results

In this section we statistically compare the numbers of intervals with and without behaviors during the moored air gun experiments and during appropriate control conditions. Two different control conditions were used. These are labelled #4 and #5 in Table 6.2 and are discussed in more detail in Sec. 7.2.1. Control period #4 consists of tracks from control periods during the two days of moored air gun experiments 10 and 11 January 1984. Control period #5 consists of tracks from the two control days (VARUA not present), 8 and 12 January, flanking the air gun experiments.

Breaching

During the moored air gun experiments on 10 January, there were two ten minute intervals with breaches and 35 without breaches. During the experiments on 11 January, there were three intervals with breaches and 21 without. There is no significant difference between the number of breaching periods on 10 January and 11 January ($G_{ADJ} = 0.254$, $0.5 < 0.9$, $dF = 1$). Because of this similarity for breaching during the two moored single air gun experimental days, the data were pooled the data (5 with breaches, 56 without breaches) and compared these values with control period #4. There was no significant difference between the number of moored air gun breaching periods and the number of breaching periods during control period #4 (1,29) ($G_{ADJ} = 0.192$, $0.5 < p < 0.9$, $dF = 1$). There was also no significant difference between the number of moored air gun breaching periods and control period #5 (6,86) ($G_{ADJ} = 0.006$, $0.975 < p < 0.9$, $dF = 1$). We conclude that the moored single air gun did not affect the incidence of breaching periods. However, sample sizes are low.

Surface Active Behavior

The following data cover the number of ten minute periods (surface active, no surface active behavior) for the two days of moored single air gun experiments: 10 January (1,36) and 11 January (1,23). Because of the low number of surface active ten minute periods, a statistical comparison between the two days could not be made. However, by inspection, there is virtually no difference between these two experimental periods so they were pooled for comparison with control periods #4 and #5. A statistical comparison between the pooled, moored single air gun surface active behavior periods (2,59) and control period #4 could not be made because there were no surface active periods during control period #4 (0,30). However, there was a significant difference between the number of moored single air gun surface active periods and the number of surface active periods during control period #5 (13,79) (G_{ADJ} = 4.162, $0.025 < p < 0.05$, dF = 1). A possible interpretation of this result is that surface activity was reduced by the moored single air gun experiments. However, this interpretation requires validation.

Direction Change

The following data present the number of 10 min. periods with or without direction change for the two days of moored single air gun experiments: 10 January (1,36) and 11 January (7,17). There is a significant difference between the number of direction change periods on 10 January and 11 January (G_{ADJ} = 6.814, $0.005 < p < 0.01$): On 11 January there were more whale groups changing direction than on 10 January. In order to attempt to explain this difference, a number of factors were examined.

One possible explanation is differential viewing conditions at North and Soberanes stations. On 10 January, Soberanes had poor to fair viewing condition all day (see Table 4.2). These poor conditions could account for the low number of direction changes observed on 10 January. Another possible explanation is the difference in whale group size for the two days. The mean size of whale groups exposed to moored single air gun experimental conditions on 10 January during the morning experiment (0850-1200) was $\overline{x}$ = 2.58, ±1.283, n = 24. During the 11 January moored single air gun experiment (0900-1100), mean group size was $\overline{x} = 3.04, \pm 1.644, n = 28$; the mean group size on 11 January is significantly greater than the mean group size on 10 January ($T_S = 2.6818$, $0.02 < p < 0.01$, $dF = 50$). We chose to look only at the morning experiments because six out of the seven direction change 10 min. periods occurred during the 0900-1100 experiment on 11 January. Although we have not quantitatively associated direction changing with group size during control periods, it is our impression that larger groups are involved in direction changes more often than smaller groups. The significant difference in direction change 10 min. periods between 10 January and 11 January may possibly be group size related. A third possible explanation is the distance of migrants from shore on the two days. The statistical comparisons between the 10th and the 11th moored single air gun condition showed no significant difference in distance offshore for grid crossings 4.0 to -3.0 (see Sec. 7 for a complete discussion of grid crossings and results of statistical tests). However, an examination of the mean distance from shore for these two days at grid crossings 4.0 to -3.0 shows that on 11 January the whale groups were, on average, 0.1 to 0.2 km closer to shore, an indication that their sound exposure levels would be slightly higher.

A firm conclusion as to the differences in direction change 10 min. periods on these two moored single air gun experiment days is, however, not possible, given the limited amount of data.

Because of the difference in direction change 10 min. periods on 10 and 11 January, each of these days was compared to the two control periods (#4 and #5). The small number of direction change periods on 10 January and control periods #4 (1,29) and #5 (2,90) made statistical comparisons impossible. However, inspection reveals no obvious differences. There is a significant difference between moored single air gun direction change periods on 11 January and control period #4 (1,29) (G_{ADJ} =

5.356, $0.01 < p < 0.025$, dF = 1). The significance level increases when the 11 January data are compared to control period #5 ($G_{ADJ} = 12.302$, $p < 0.001$, dF = 2).

Milling

The low instances of milling 10 min. periods during both control and experimental conditions make statistical comparisons impossible. Milling was not observed during the moored single air gun experiment and when control periods #4 and #5 are pooled, there were only 2, 10 min. milling periods as opposed to 120 no milling periods.

6.2.5 Moving air gun results

Because of the low number of 10 min. periods during both the 1.5 n.m. drifting air gun experiment and the control period (8 January 1530-1705), statistical comparisons could not be made. However, on inspection of the raw data (see Tables 6.1 and 6.2), no trend seems to be evident.

6.3 Summary

The following is a summary of the analysis of the four categories of whale group behavior during the two types of experimental conditions examined.

6.3.1 Industrial noise playback condition

The incidence of breaching and milling periods during the five industrial noise playbacks were not significantly different. There was also no significant difference when these two behavioral categories were compared to the control periods. The milling period sample was, however, very small.

There were significantly more surface active behavior periods during the Semisubmersible Rig playback. This result could not be explained in terms of sound exposure level. When the pooled playbacks without the Semisubmersible Rig data was compared to the control periods #2 and #3, there was a significant lower number of surface active periods. However, when the pooled playbacks with Semisubmersible Rig data (but without Helicopter data) were compared to the two control conditions, no significant difference was found.

The incidence of direction change periods during the five playbacks was significantly different with a high number of direction changes during the Drilling Platform playback. This result could not be explained in terms of sound exposure level. There was no significant difference when the pooled playback, direction change periods was compared to control period #1.

6.3.2 Moored air gun condition

The incidence of breaching periods during the two moored air gun experiments was not significantly different. Also, there was no significant difference in breaching periods when these experimental days were pooled and compared to each of the control periods. There was no difference in the number of surface active periods during the two experimental days. However, in comparing the pooled data to control period #5, there was a significantly lower number of surface active behaviors during experimental conditions.

There were many direction change periods during experimental conditions on 11 January and possible explanations are offered in Sec. 6.2.4.

We observed no milling behavior during the moored single air gun experiments and only two incidents were observed during both control periods.

6.4 Conclusions

The primary data collection and analysis effort of this study was centered on whale group tracks (see Sec. 7). However, an effort was made to note whale group behaviors during control and experimental conditions. Our four behavioral categories proved useful in a preliminary assessment of playbacks on migratory gray whales, and some clear results were obtained for breaching periods. Future studies should examine behavioral patterns under control conditions to determine the extent of diurnal, seasonal, or between season variations. Variation of these behaviors with group size should also be examined.

7. TRACK DATA ANALYSIS PROCEDURES AND RESULTS

The two shore stations were staffed with four observers each, which permitted us to consistently note general group behaviors as well as track group movements with the theodolite. Because of the large number of whales, we did not attempt to gather any data on respiration rates or blow intervals. Despite the efforts at collecting behavioral data, there were relatively few behaviors observed other than swimming (see Sec. 6). Therefore, the major analysis effort is based upon theodolite data which provides information on the swimming patterns or tracks of the whales.

Track data provide a set of points $(x_1, y_1)\ldots\ldots(x_n, y_n)$ associated with time representing the locations at which a group was sighted. From these we calculated six measures of swimming movement following the procedures given in Report No. 5366. These measures were track deflection (D_y), distance from shore (D_{shore}), swimming speed (S), milling index (MI), course bearing (CB), and VARUA bearing (VB).

7.1 Results of Track Deflection Analysis

7.1.1 Description of control and playback periods

As discussed in Sec. 4, the experimental period of this study began with the moving single air gun experiments on 9 January and continued with stationary air gun experiments on 10 and 11 January. This was followed by 15 sound playback experiments conducted from 13 to 20 January. There were three moving air gun experiments conducted at 8, 3, and 1.5 nm from shore and lasting 3.3, 1.4, and 1.5 hrs, respectively. Owing to time constraints on our use of the air gun vessel, the two days following the moving air gun experiments were devoted to moored air gun experiments. Six experiments were run lasting anywhere from 27 min to 3 hrs and 10 min. For the industrial sound playback experiments, three 2 hr playback sessions were performed for each of the five industrial sound stimuli. These playback stimuli were presented according to the schedule in Table 4.3. By this schedule, playbacks were distributed throughout each of six days within the eight day playback period.

The track deflection analysis (see Report 5366, Sec. 7.1.1 for a full description of this program) was designed to separate each track into pre-exposure intervals, when whales are far to the north of the VARUA, exposure intervals of increasing received levels as the whales approach the sound source, decreasing levels as the whales pass the VARUA, and post-exposure intervals as the whales are moving away from and outside of the playback range. The strength of this approach was that each group could serve as its own control since we could compare tracks from the pre-exposure and post-exposure areas with tracks from within the exposure area. With two shorebased observation stations it was hoped that the range over which whales were tracked would be greater than the projection range of the source during industrial sound playback.

However, as will be seen in a later part of this section, responses were observed at the extremes of our observation ranges near the 0 dB S/N level of the playback signal. Thus, the amount of pre-exposure and post-exposure control data within an experimental period was limited by the difficulty of tracking whales at distances of greater than 3 km from either of the observation stations. Table 7.1 shows the total number of tracks at each y grid interval for the various test and control conditions. As Table 7.1 indicates, there were very few track crossings at +4,

TABLE 7.1a. TOTAL NUMBER OF TRACK SAMPLES FOR EACH Y COORDINATE GRID CROSSING PLAYBACK TEST AND CONTROL PERIODS.

Grid Crossing	All Playbacks	Control #1	DP	DS	SS	H	PP	Control #2	Control #3
4	5	3	1	2	1	1	0	0	3
3	53	24	16	12	3	16	6	14	10
2	169	105	46	27	26	42	24	75	30
1	237	184	64	41	43	50	35	128	56
0.5	241	194	70	43	41	50	35	128	56
0	241	191	68	41	40	49	39	133	58
-0.5	237	194	66	34	42	48	40	129	65
-1	210	182	62	12	38	42	33	114	68
-2	118	117	38	3	27	14	26	69	48
-3	35	47	10	1	9	0	13	20	27
-4	12	19	0	0	5	0	5	0	0

TABLE 7.1b. TOTAL NUMBER OF TRACK SAMPLES FOR EACH Y COORDINATE GRID CROSSING AIRGUN TEST AND CONTROL PERIODS.

Grid Crossing	Moored Airgun	Control #4	Control #5	Moving Airgun 8 nm	Moving Airgun Control 8 nm	Moving Airgun 3 nm	Moving Airgun 1.5 nm	Moving Airgun Control 3 nm + 1.5 nm
4	13	7	0	0	0	0	0	0
3	25	16	9	9	1	1	1	4
2	57	27	59	20	9	6	6	14
1	70	29	89	22	12	11	5	20
0.5	73	33	101	22	13	13	5	22
0	67	34	97	24	13	12	7	22
-0.5	70	36	94	24	15	12	7	18
-1	65	35	80	24	17	11	6	13
-2	36	27	49	19	15	1	3	3
-3	8	14	16	7	10	0	0	0
-4	0	4	7	0	0	0	0	0

+3, -3, or -4 km compared to the number of crossings at closer ranges. These small sample sizes at the extremes often precluded the effective use of pre-exposure or post-exposure track data for statistical analysis.

Both for this reason and for comparison of responses under potentially disturbed conditions with those of completely undisturbed migrating whales, five control periods were constructed. These five control periods and the five experimental conditions against which they were compared are given below.

Control Period #1: The track data from the four non-experimental days (12, 16, and 21 January, no boat present; 18 January, boat present but not operating) that were within one day of any of the industrial sound playback experiments were pooled for comparison with the pooled results from those 15 experimental periods.

Control Period #2: The track data for 12, 16, and 21 January (no boat present) were pooled for comparison with each of the five pooled experimental playback types.

Control Period #3: The track data for 18 January (boat present, no experiments) was used for comparison with the pooled data for each of the five experimental playback types.

Control Period #4: The track data from the control periods on 10 and 11 January (boat present, compressors running) were pooled for comparison to the pooled moored air gun experiments on those same dates.

Control Period #5: The track data for 8 and 12 January (no boat present) were pooled for comparison with the pooled moored air gun experiments on 10 and 11 January.

For several of the experimental types there were differences in our estimates of the range to 0 dB S/N. These discrepancies were due to variations in ambient noise conditions during the different experiments. Therefore, a further set of comparisons were made between track data for the same experimental condition on different days. In these cases, we compared the playback periods against matched control periods selected either from before or after the playback or from an adjacent day with an identical time window as the playback period. The notion was that if an effect was observed for a playback with a large broadcast (0 dB S/N) range, then a similar but more confined effect might also be observed for the playback with a small broadcast (0 dB S/N) range. We performed such comparisons for each of two Drillship, Helicopter and Semisubmersible Rig playbacks.

Two matched control periods were constructed for the three moving air gun experiments conducted on 9 January. The control period for the 8 nm experiment was from 8 January, 0900-1200 hrs. The control period for the 3.0 and 1.5 nm experiments was from 8 January, 1300-1600 hrs.

7.1.2 Variations in measures during control conditions

Analysis of Within-day Variation

As mentioned previously, the measure D_y is simply a whale group's distance, Y, from the x-axis, interpolated at each grid line that a whale group crosses. Since the x-axis is set parallel to a linear regression of the coastline, motion in the Y direction constitutes a measure of track deflection. The measure D_{shore}, representing the minimum distance between each grid point (x_{grid}, and y_{grid}) and the shore, was also calculated. This measure was included in order to check whether whales were following the contour of the coastline instead of following a fairly constant course heading.

Since the effects of experimentation are made evident by comparisons with control periods, an exhaustive analysis of those controls was performed. For this, we compared track data between each pair of days when either no experimental boats were present or boats were present but not operating. We also compared morning track data with afternoon track data from the same day in order to test for diurnal effects. These analyses indicate that there are significant day-to-day variations in some of the track scores. We did not find any diurnal effects. The daily variations are most evident in the distances from the x-axis, D_y, and the speeds at which whales were travelling, with D_{shore} values mirroring D_y's and MI and CB showing very little between-day variation. Interestingly enough, day-to-day changes in both distances off shore and speeds were noticed by observers in the field.

As a means of demonstrating between-day variability for the five control days, all possible pairwise combinations of distributions between days were tested. Table 7.2 verbally summarizes the results of these 495 tests.

Overall, whales on 8 January tended to travel further offshore and swim faster than whales on any of the other four control days. Whales on 12 January were further offshore than whales on 16, 18, or 21 January. Whales on 16 January tended to swim faster than whales on 12, 18, or 21 January. In general, differences between days were not restricted to zones in the 1.0 to -1.0 km grid areas but were uniform throughout the entire range of observations. In other words, if whales were swimming rapidly and far offshore at the 3.0 to 4.0 km grid lines they were also swimming rapidly and far offshore at all other grid lines. This result indicates that within any control day all the scores used to characterize group tracks remained relatively stable over the entire tracking range.

TABLE 7.2 COMPARISON OF CONTROL DAY DISTANCE, SPEED MEASURES.

	Reference Control Day			
Jan.	8	12	16	21
12	faster/ further offshore	--	faster/ further inshore	speeds similar/ further inshore
16	faster/ further offshore	slower/ further offshore	--	slower/ D_y's similar
18	faster/ further offshore	speeds similar/ further offshore	faster/ D_y's similar	speeds similar/ D_y's similar
21	faster/ further offshore	faster/ further offshore	faster/ D_y's similar	--

A measure of track stability within a day is gained by a pairwise statistical comparison between that day's distributions at different grid lines or pairs of grid intervals for the same day. Table 7.3 shows a tally of the number of occurrences of significant differences between pairs of distributions for each of the five measures on each of the five control days. The number in the numerator indicates the number of significant test results, while the number in the denominator indicates the total number of tests performed. This represents the results of 995 tests. At the 5% significance level, we should expect, by chance, approximately 50 tests to be significant, when in fact we found 101 significances.

In reviewing where differences within a day's scores occurred, it was found that 69 occurred when one of the distributions was from a distance of greater than ± 3 km from the origin of our coordinate system (i.e., the VARUA playback location). These distances represent the extremes of our observation range where sample sizes are small and sighting errors are greatest thereby producing the greatest variances in all the track scores. Table 7.4 shows the tally of the number of occurrences of significant differences between pairs of distributions when only scores within the ± 3 km grid boundaries are considered. The total of 32 significant differences out of 770 tests is close to the expected number of 38 significant differences due to chance alone (5% x 770).

Thus, within-day variations were not significant for distances of 3 km or less and daily scores for any of the five track measures were very stable throughout this observation range. We emphasize this point of within day stability for control days since it will serve as the backdrop against which all the experimental periods will be compared.

TABLE 7.3. ANALYSIS OF WITHIN-DAY TRACK HOMOGENEITY.

	Five Track Measures				
Date	D_y	D_s	**S**	**MI**	**CB**
8	1/45	7/45	2/36	1/36	4/36
12	15/45	17/45	0/36	0/36	2/36
16	0/36	2/36	6/28	1/28	4/28
18	7/55	12/55	0/45	3/45	15/45
21	0/45	0/45	0/36	2/36	0/36
Totals	23/226	38/226	8/181	7/181	25/181

TABLE 7.4. ANALYSIS OF WITHIN-DAY TRACK HOMOGENEITY @ < ± 3 km.

	Five Track Measures				
Date	D_Y	D_S	S	MI	CB
8	0/36	0/36	2/28	1/28	0/28
12	4/36	2/36	0/28	0/28	2/28
16	0/28	2/28	0/21	1/21	0/21
18	3/45	3/45	0/36	3/36	7/36
21	0/36	0/36	0/28	2/28	0/28
Totals	7/181	7/181	2/136	7/136	9/136

Analysis of Control Period Variation

Control Period #1: Since control days were distributed throughout the period of playback experiments and within day variation was small, all four non-experimental days (12, 16, 18, and 21 January) were pooled. This provided an overall picture of normal migratory tracks during the period when industrial playbacks were conducted. When we tested these pooled data for homogeneity of track measures by making comparisons between distributions at different grid lines or pairs of grid intervals at $\leq$ 3 km, there were a total of 11 significant ($p < 0.05$) differences out of a total of 198 tests as shown below:

Analysis of Control Period #1 Homogeniety

D_y	D_s	S	MI	CB
2/45	6/45	1/36	2/36	6/36

Again, this demonstrates the stability within the pooled data from these four control days, with D_y, Speed, and MI representing the most stable measures.

Figures B.10 and B.11 in Appendix B illustrate the D_y distributions for these pooled data. From these figures a second critical characteristic of control days emerges: distributions of D_y do not display flattening or concavity in their slopes. This indicates that whales were not avoiding the area where the VARUA or Cheyenne Arrow would have been stationed during an experiment. In fact, the primary swimming corridor (the 25% to 75% band in the distributions) is centered at +240 m relative to the position of the VARUA. In other words, when the boats were not present, the majority of whales would swim through the immediate area where the boats were stationed during any of the experiments.

Control Periods #2 and #3: The control period #1 just described was broken into two separate control periods, #2 and #3. Control period #2 consisted of the pooled track data from 12, 16, and 21 January, the three days when no boats were present. Control period #3 consisted of the single day, 18 January, when VARUA was at her usual playback location but no playbacks were run. As was mentioned previously, 18 January track scores were similar to those for the 16 and 21 of January. Variations between distributions within the three pooled days in control #2 are small. The following analysis shows the number of significant differences between pairs of distributions for all grids and for grids ≤ 3 km from the origin.

Analysis of Control Period #2

	D_y	D_s	S	MI	CB
All grids	1/45	16/45	2/36	0/36	2/36
≤ 3 km	1/36	2/36	0/28	0/28	2/28

Again, all of the five measures are stable within the control period #2.

Variations between distributions for 18 January are also small. The following analysis shows the number of significant differences between all pairs of distributions and between pairs at grid lines within ± 3 km of the VARUA.

Analysis of Control Period #3

	D_y	D_s	S	MI	CB
All grids	7/55	12/55	0/45	3/45	15/45
≤ 3 km	3/45	3/45	0/36	3/36	7/45

Except for Compass Bearing (CB), all measures are stable within the Control period #3 at distances of ± 3 km from the VARUA.

Comparison of Control Period #2 and Control Period #3

Since control periods #2 and #3 will be compared with the same experimental periods, they were also compared against each other. The following comparison shows the number of significant differences when all possible pairs of distributions were compared for the two controls.

Comparison Between Control Periods #2 and #3y

	D_Y	D_S	S	MI	CB	VB
All grids	0/10	0/10	1/9	1/9	0/9	0/9

These results indicate that these two control periods are very similar to each other for all six track measures strongly suggesting that whales did not respond to the VARUA when she was on site with no playback equipment operating. Notice that the VARUA bearing (VB) is now included since tracks from different days are now being compared at the same grid lines or grid intervals.

Control Period #4, Air gun Control 10 and 11 January

Four time periods from 10 and 11 January were pooled to make one of the two Air gun Control periods. these times were from 1230-1330 on 10 January, and from 800-900, 1130-1300, and 1530-1700 on 11 January. These control data did not include the 0.5 hour period immediately following an air gun experiment. When we tested for the significance of differences between distributions at different grid lines and grid intervals within these pooled data at $\leq$ 3 km from the origin, a total of 42 out of 156 tests were significant. The following analysis shows the breakdown of these significances by measure type.

Analysis of Control Period #4

	D_y	D_s	S	MI	CB
All grids	23/45	26/45	4/36	6/36	2/36
$\leq$ 3 km	17/36	18/36	0/28	5/28	2/28

This table indicates that D_y and D_s were highly variable within the pooled data. The reason for this is that the distributions for these two measures at grid crossings north of the VARUA were significantly different than the grid crossings south of the VARUA (see Appendix B, Fig. B.18). This point will be discussed when we compare this control period with the results from the air gun experiments conducted on these same days.

Control Period #5; 8 and 12 January Pooled

The two days, 8 and 12 January, that bracketed the three days of air gun experiments, were pooled as a second Air gun Control. When we tested for the significance of differences between distributions at all possible pairwise combinations of grid lines and grid intervals within these pooled data, a total of 20 out of 198 tests were significant. When only data at < 3 km from the origin were considered, a total of 11 out of 156 tests were significant. The following analysis shows the breakdown of these significances by measure type.

Analysis of Control Period #5

	D_y	D_s	S	MI	CB
All grids	2/45	9/45	8/36	1/36	0/36
< 3 km	1/36	1/36	8/28	1/28	0/28

This table indicates that Speed was quite variable within these pooled data. The reason for this is that speeds at grid intervals 1.0 to 0.5 km were slower compared to speeds at all grid intervals south of that. As mentioned previously (see Table 7.2), swimming speeds on 8 January were unusually high throughout all grid intervals. This coupled with the fact that swimming speeds on 12 January were increasing from north to south, resulted in the non-homogeneous distributions for Speed in the pooled data for these two days. In contrast to Speed, all the other four measures were quite stable within Control Period #5.

Comparison of Control Period #4 and Control Period #5

Since Control periods #4 and #5 will be compared with the same experimental period, they were also compared against each other. The following comparison shows the number of significant differences when all possible pairs of distributions were compared for the two controls.

Comparison Between Control Periods #4 and #5

	D_Y	D_S	S	MI	CB	VB
All grids	1/9	1/9	2/8	0/8	1/8	0/8

These results indicate that these two control periods are very similar to each other for all six track measures. Again, notice that the VARUA bearing (VB) is now included since tracks from different days are being compared at the same grid lines or grid intervals.

7.1.3 Pooled responses to all playback stimuli as compared to Control Period #1

Table 7.5 lists the significant differences between the distributions of four track measures after all 15 industrial

TABLE 7.5. POOLED PLAYBACK RESULTS COMPARED WITH CONTROL PERIOD.

Grid Crossing (km)	Track Deflection	Speed	Course Bearing	VARUA Bearing
4	NS			
		NS	NS	NS
3	NS			
		$0.010<p<0.025$	NS	NS
2	NS			
		NS	NS	NS
1	$0.010<p<0.025$			
		NS	NS	$p<0.001$
0.5	$p<0.001$			
		NS	NS	$p<0.001$
0	$p<0.001$			
		NS	NS	NS
-0.5	$p<0.001$			
		NS	NS	$p<0.001$
-1	$p<0.001$			
		NS	NS	$0.02 <p<0.05$
-2	$p<0.001$			
		$0.010<p<0.025$	NS	$0.02 <p<0.05$
-3	NS			
		NS	NS	NS
-4	NS			

Notes: - = No Data

NS = Not Significant

D_y and speed were tested by the Kolmogorov-Smirnov two sample test, while course bearing and VARUA bearing were tested by the Watson's U^2 two sample test. D_y was measured at grid crossings, so D_y statistics are listed on the same line as the grid crossing. The other three measures were obtained from intervals between adjacent grids, so they are listed on the line between those for adjacent grid crossings. NS stands for Not Significant ($p > 0.05$ that samples came from the same population).

playback results were pooled and compared to the Control Period #1. D_y and Speed were tested by the Kolmogorov-Smirnov two sample test, while Course Bearing and VARUA Bearing were tested by the Watson's U^2 two sample test.

Six grid crossings, between +1.0 and -2.0 km, showed significant differences for the D_y measure. Two grid intervals, at 3.0 to 2.0 km and -2.0 to -3.0 km, showed significant differences for Speed. Five grid intervals, between 1.0 to 0.0 km and between -0.5 to -3.0 km, showed significant differences for VARUA Bearing.

The interpretation of the importance of these significant differences is aided by the analysis of the distributions within Control Period #1 as presented in the previous subsection 7.2.2. There, we determined that measures D_y, S, and MI were very stable within Control Period #1. Furthermore, if a similar within-sample analysis is performed on the pooled data for all 15 playback experiments, we find that although measures S and MI are quite stable, the measure of track deflection, D_y, is <u>not</u> stable. In fact, 12 of the 36 intergrid tests of D_y are significant as follows:

Grid Interval	**p Value**
3.0 vs 0.0	$0.010 < p < 0.025$
3.0 vs -0.5	$0.010 < p < 0.025$
3.0 vs -2.0	$0.010 < p < 0.010$
2.0 vs 0.5	$0.005 < p < 0.005$
2.0 vs -0.5	$p < 0.001$
2.0 vs -1.0	$p < 0.001$
2.0 vs -2.0	$p < 0.001$
1.0 vs 0.0	$0.010 < p < 0.025$
1.0 vs -0.5	$0.005 < p < 0.010$
1.0 vs -1.0	$0.001 < p < 0.005$
1.0 vs -2.0	$0.001 < p < 0.005$

These results coupled with the fact that the significant differences for D_y, as presented in Table 7.5, come in clusters, strongly suggest that the differences in D_y between the Control Period #1 and the Pooled experiments are robust and real. These results show that as whales approached the playback area they deflected around the source starting at 3.0 km north of the VARUA.

The importance of the two significant differences in Speed as listed in Table 7.5 are not clear since within the pooled experiments Speed was quite stable. Although whales slow down during industrial playback relative to the control period when they are 3.0 to 2.0 km north and 2.0 to 3.0 km south of the source, they did not slow down relative to other grid intervals during the experiments.

The five significant differences for VARUA Bearing listed in Table 7.5 further reflect the results from the test on D_y. A comparison of the bearings and lengths of the mean vectors for these significant VARUA Bearings are given as follows:

Grid Interval		Control		All Experiments	
		Length	Bearing	Length	Bearing
1.0	0.5	.8527	11°	.8245	20°
0.5	0.0	.7214	17°	.6832	32°
-0.5	-1.0	.0762	165°	.7089	150°
-1.0	-2.0	.8848	168°	.8514	161°
-2.0	-3.0	.9645	174°	.9254	174°

Except for the -0.5 to -1.0 interval, whales were less oriented during the experimental transitions than they were during the control; as exemplified by the lower values of the lengths of the mean vector. The higher values of the bearing angle north of the VARUA and the lower values of the bearing angle south of the VARUA during experiments indicates that the whales were crossing the grid lines further away (in this case offshore) from the VARUA. This last result is identical to the results of the tests of D_Y distributions showing avoidance of the playback area.

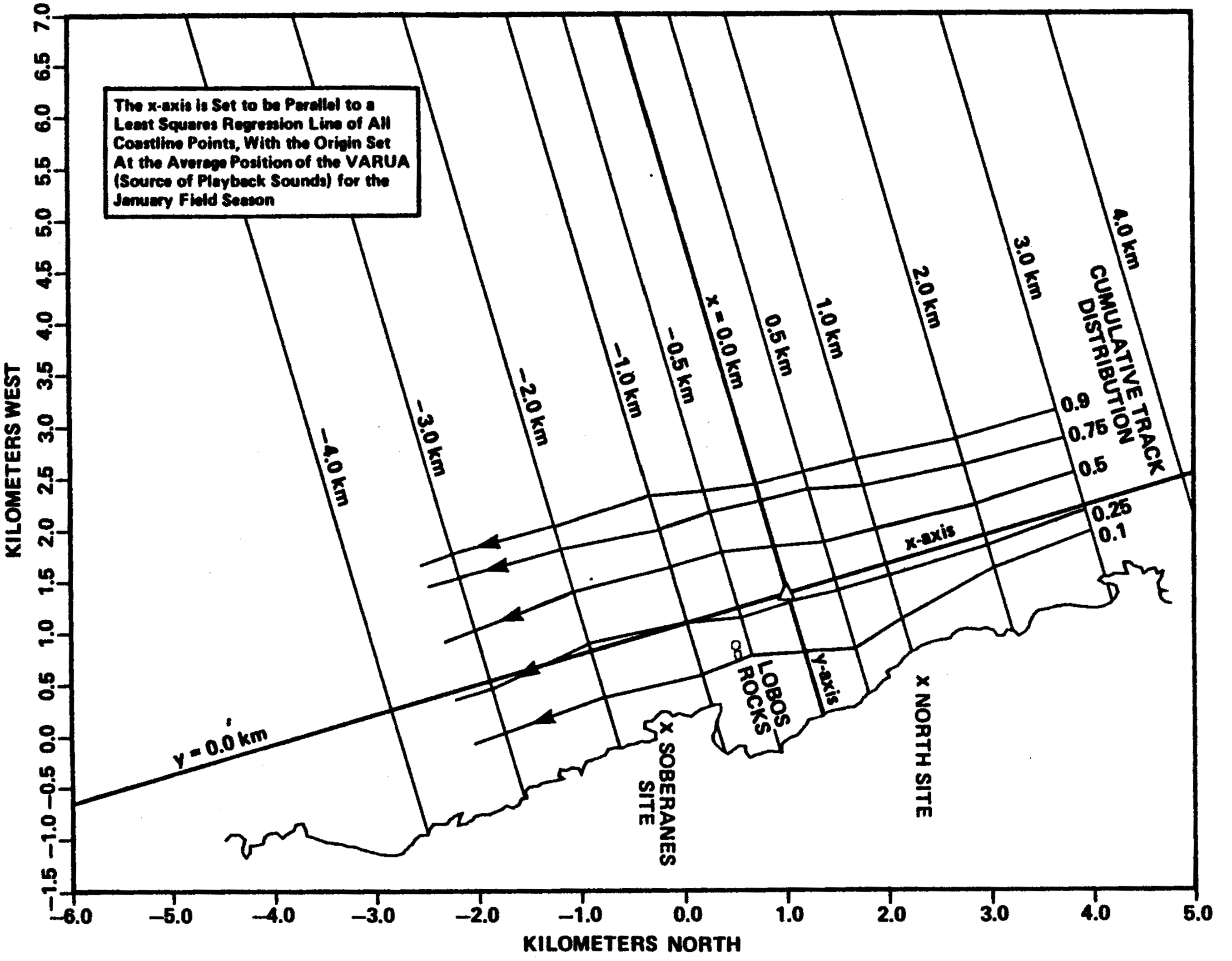
In summary, these results strongly indicate that whales avoided the area of the playback source. This avoidance was evidenced by significant track deflections at ranges of up to 1.0 km north of the source with recovery to normal track courses by 3.0 km south of the source. As whales approach the playback source, they begin to deflect around it starting at about 3 km away. An illustration of this effect is shown in Fig. 7.1 where 10%, 25%, 50%, 75%, and 90% contours of whale tracks are superimposed on a map of the study area.

7.1.4 Responses to playback stimuli, pooled by type, as compared to Control Periods #2 and #3

The above results demonstrate that playback of industrial sounds affects the migratory swimming behavior of gray whales, but these results do not provide insight into how each of the different industrial stimuli affect the whales' behavior. In order to ascertain what effect each of the five industrial sound playback types had on the whales, the results from the three playbacks of the same type were pooled and compared to Control Periods #2 and #3.

Responses to the Drilling Platform Stimulus Condition

Table 7.6a lists the significant differences between the distributions of four track measures when the pooled results from the three Drilling Platform experiments are compared to Control Period #2 (12, 16, and 21 January: no boat present). Table 7.6b lists the significant differences between the distributions of four track measures when the pooled results from the three Drilling Platform experiments are compared to Control Period #3 (18 January, boat present but not operating).



The x-axis is Set to be Parallel to a Least Squares Regression Line of All Coastline Points, With the Origin Set At the Average Position of the VARUA (Source of Playback Sounds) for the January Field Season

FIG. 7.1. CUMULATIVE TRACK DISTRIBUTION CONTOURS, POOLED PLAYBACK DATA.

TABLE 7.6a. DRILLING PLATFORM PLAYBACK COMPARED WITH CONTROL PERIOD 2.

Grid Crossing (km)	Track Deflection	Speed	Course Bearing	VARUA Bearing
4	-	-	-	-
		-	-	-
3	NS			
		$.010<p<.025$	NS	$.02<p<.05$
2	NS			
		NS	NS	NS
1	$.025<p<.050$			
		NS	NS	$.001<p<.002$
0.5	$.001<p<.005$			
		NS	NS	$0.002<p< 0.005$
0	$.010<p<.025$			
		NS	NS	NS
-0.5	$.010<p<.025$			
		NS	NS	$.005<p<.01$
-1	$.005<p<.010$			
		NS	NS	NS
-2	$.010<p<.025$			
		NS	NS	NS
-3	NS			
		-	-	-
-4	-			

TABLE 7.6b. DRILLING PLATFORM PLAYBACK COMPARED WITH CONTROL PERIOD 3.

Grid Crossing (km)	Track Deflection	Speed	Course Bearing	VARUA Bearing
4	NS			
		NS	NS	NS
3	NS			
		NS	NS	NS
2	NS			
		NS	NS	$.02<p<.05$
1	$p<.001$			
		NS	NS	$p<.001$
0.5	$p<.001$			
		NS	NS	$p<.001$
0	$p<.001$			
		NS	NS	NS
-0.5	$.001<p<.005$			
		NS	NS	$.005<p<0.01$
-1	$.001<p<.005$			
		NS	NS	NS
-2	$p<.001$			
		NS	NS	$.02 <p<.05$
-3	$.010<p<.025$			
		-	-	-
-4	-			

Notes: - = No Data

NS = Not Significant

D_y and speed were tested by the Kolmogorov-Smirnov two sample test, while course bearing and VARUA bearing were tested by the Watson's U^2 two sample test. D_y was measured at grid crossings, so D_y statistics are listed on the same line as the grid crossing. The other three measures were obtained from intervals between adjacent grids, so they are listed on the line between those for adjacent grid crossings. NS stands for Not Significant ($p > 0.05$ that samples came from the same population).

Compared to Control Period #2 (see Table 7.6a), six grid crossings, between 1.0 and -2.0 km, showed significant differences for the D_y measure. One grid interval, at 3.0 to 2.0 km, showed a significant difference for speed. Four grid intervals, at 3.0 to 2.0 km, 1.0 to 0.5 km, 0.5 to 0.0 km, and -0.5 to -1.0, showed significant differences for VARUA bearing.

Compared to Control Period #3 (see Table 7.6b), seven grid crossings, from 1.0 km to -3.0 km, showed significant differences for the D_y measure. Five grid intervals from 2.0 to 1.0 km, 1.0 to 0.5 km, 0.5 to 0.0 km, -0.5 to -1.0 km, and -2.0 to -3.0 km, showed significant differences for VARUA bearing.

The interpretation of the importance of these significant differences is aided by the analysis of the distributions within Control Periods #2 and #3 presented in the previous subsection 7.2.2. There we determined that measures D_y, S, and MI were very stable within both Control Period #2 and Control Period #3. Furthermore, if a similar within-sample analysis is performed on the pooled Drilling Platform experimental results, we find that Speed is very stable, but D_y is <u>not</u> stable. In fact, six of the 36 intergrid tests of D_y are significant as follows:

Grid Interval	**Significance Level**
3.0 vs -2.0	$0.025 < p < 0.050$
3.0 vs -3.0	$0.010 < p < 0.025$
2.0 vs -1.0	$0.010 < p < 0.025$
2.0 vs -2.0	$p < 0.001$
2.0 to -3.0	$0.005 < p < 0.010$
1.0 to -3.0	$0.025 < p < 0.050$

Notice that none of these differences occurs within the 1.0 km to -1.0 km zone, indicating that the initial deflection occurred well north (ca 3.0 km) of the VARUA and that whales returned to their normal distribution by about 1.0 km south of the vessel. An indication of the extent of this deflection at the 0.0 km grid line is illustrated in Fig. 7.2, which shows the track density distribution for control and playback conditions. This figure shows peaks at 350 m from VARUA during control and 750 m from VARUA during Drilling Platform playback, indicating that the center of the migratory path shifted 400 m offshore when whales were exposed to Drilling Platform sounds.

These results together with the significant differences for D_y as presented in Tables 7.6a and 7.6b, strongly suggest that differences in D_y between Control Periods #2 and #3 and the pooled Drilling Platform experiments are real.

The importance of the significant difference in Speed as listed in Table 7.6b is not clear since within the pooled Drilling Platform experiments speed was very stable.

The significant differences for VARUA bearing as listed in Tables 7.6a and 7.6b further reflect the test results for D_y. A comparison of the lengths of mean vectors and bearings for these significant VARUA bearings are given as follows:

	Control #2		**Control #3**		**Drilling Platform**	
Grid Interval	**Length**	**Bearing**	**Length**	**Bearing**	**Length**	**Bearing**
3.0 to 2.0	.9707	5°	--	--	.9886	7°
2.0 to 1.0	--	--	.9760	11°	.9526	16°
1.0 to 0.5	.8421	11°	.8767	9°	.8043	25°
0.5 to 0.0	.7086	19°	.7536	13°	.6605	35°
0.0 to -0.5	--	--	.2879	95°	.4124	90°
-0.05 to -1.0	.6804	166°	--	--	.6849	148°

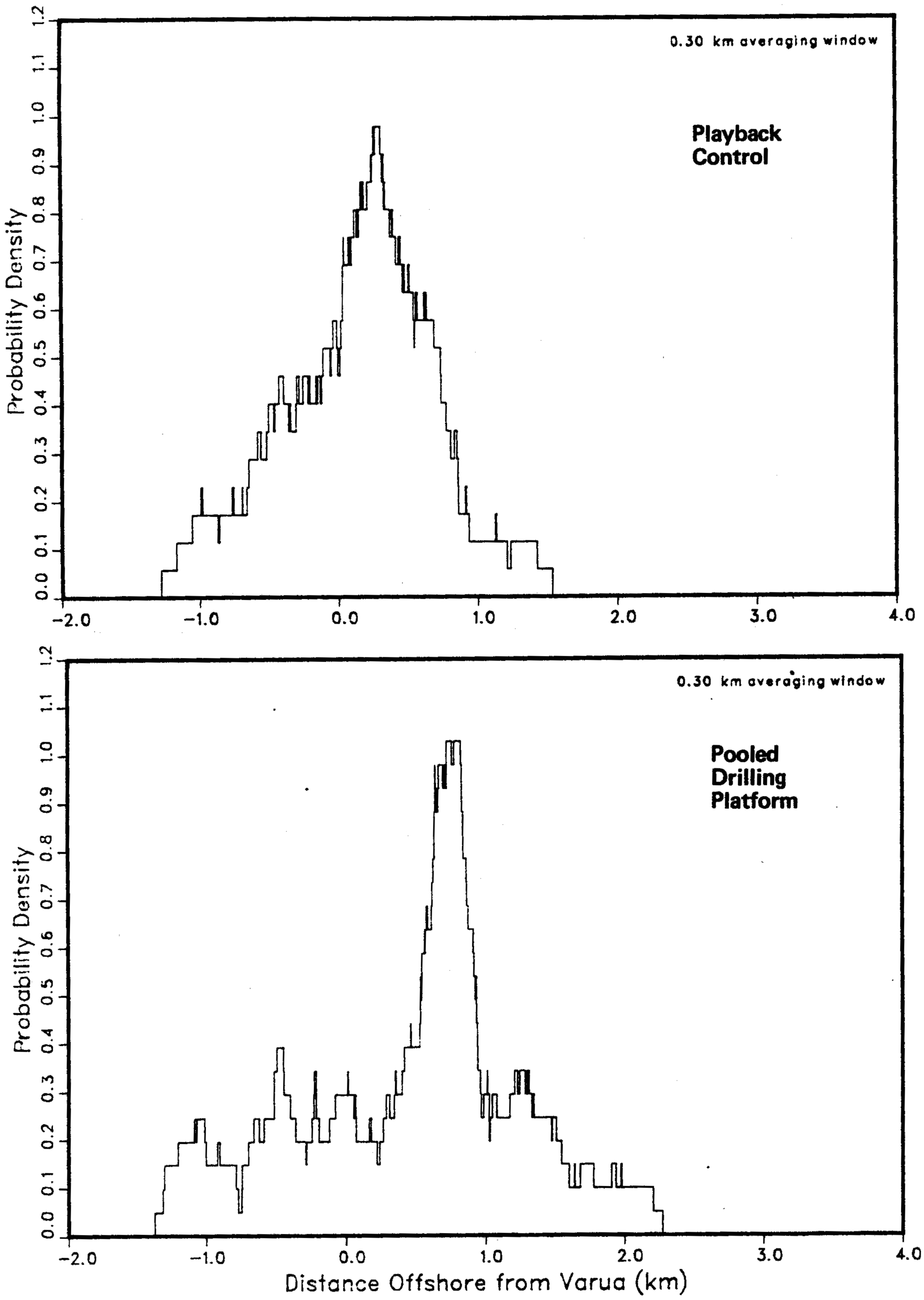


FIG. 7.2. DRILLING PLATFORM AND CONTROL 3 PROBABILITY DENSITY FUNCTIONS.

In six out of the nine grid intervals showing significant difference, whales oriented away from the boat during experiments. The higher values of the bearing angle north of the VARUA and the lower values of the bearing angle south of the VARUA during experiments indicate that the whales were crossing the grid lines further away (in this case offshore) from the VARUA. These last results are identical to the results of the tests of D_y distributions.

These results are quite similar to the results for pooled Drilling Platform obtained last year in January. The 1983 plots of the cumulative distributions for D_y under experimental conditions definitely show a flattening around the 0.0 km mark on the x-axis (see Appendix B, p. B-20 in Report No. 5366). This flattening indicates that whales were avoiding the vicinity of the VARUA starting at around 2.0 km north and persisting until about 1.0 to 2.0 km south of the playback vessel. Similarly, in 1983 there were significant differences in VARUA bearing distributions starting at 3.0 to 2.0 km north and ending at -0.5 to -1.0 km south of the vessel.

In summary, these results strongly indicate that whales avoided the area of the Drilling Platform playback source by moving offshore by several hundred meters. This avoidance was evidenced by significant track deflections at ranges of 1.0 km and VARUA bearing changes at 3.0 km away.

Responses to Drillship Stimulus Condition

Table 7.7a lists the significant differences between the distributions of four track measures when the pooled results from the three Drillship experiments are compared to Control Period #2. Table 7.7b lists the significant differences between the distributions of four track measures when the pooled results from the three Drillship experiments are compared to Control Period #3.

TABLE 7.7a. DRILLSHIP PLAYBACK COMPARED WITH CONTROL PERIOD #2.

Grid Crossing (km)	Track Deflection	Speed	Course Bearing	VARUA Bearing
4	-			
		-	-	-
3	NS			
		NS	NS	NS
2	.010<p<.025			
		NS	NS	NS
1	.000<p<.001			
		NS	NS	p<.001
0.5	.000<p<.001			
		.010<p<.025	NS	.001<p<.002
0	.000<p<.001			
		.010<p<.025	NS	NS
-0.5	.000<p<.001			
		.010<p<.025	NS	p<.001
-1	.000<p<.001			
		NS	NS	.01 <p<.02
-2	NS			
		NS	NS	NS
-3	NS			
		NS	NS	NS
-4	NS			

TABLE 7.7b. DRILLSHIP PLAYBACK COMPARED WITH CONTROL PERIOD #3.

Grid Crossing (km)	Track Deflection	Speed	Course Bearing	VARUA Bearing
4	NS			
		NS	NS	NS
3	NS			
		NS	NS	NS
2	.001<p<.005			
		NS	.001<p<.002	.01<p<.02
1	p<.001			
		NS	NS	p<.001
0.5	p<.001			
		NS	NS	p<.001
0	p<.001			
		NS	NS	NS
-0.5	p<.001			
		.025<p<.050	NS	p<.001
-1	p<.001			
		NS	NS	.001 <p<.002
-2	.010<p<.025			
		NS	NS	NS
-3	NS			
		NS	NS	NS
-4	NS			

Notes: - = No Data

NS = Not Significant

D_y and speed were tested by the Kolmogorov-Smirnov two sample test, while course bearing and VARUA bearing were tested by the Watson's U^2 two sample test. D_y was measured at grid crossings, so D_y statistics are listed on the same line as the grid crossing. The other three measures were obtained from intervals between adjacent grids, so they are listed on the line between those for adjacent grid crossings. NS stands for Not Significant (p > 0.05 that samples came from the same population).

Compared to Control Period #2 (see Table 7.7a), six grid crossings between 2.0 km and -1.0 km showed significant differences for the D_y measure. Three grid intervals, from the 0.5 to 0.0 km interval through the -0.5 to -1.0 km interval, showed significant differences for speed. Four grid intervals, at 1.0 to 0.5 km, 0.5 to 0.0 km, -0.5 to -1.0 km, and -1.0 to -2.0 km intervals, showed significant differences for VARUA bearing.

Compared to Control Period #3 (see Table 7.7b), seven grid crossings between 2.0 km and -2.0 km showed significant differences for the D_y measure. One grid interval, at -0.5 to -1.0 km, showed a significant difference for Speed. One grid interval, at 2.0 to 1.0 km, showed a significant difference for course bearing. Five grid intervals, at 2.0 to 1.0 km, 1.0 to 0.5 km, 0.5 to 0.0 km, -0.5 to -1.0 km, and -1.0 to -2.0 km showed significant differences for VARUA bearing.

The interpretation of the importance of these significant differences is aided by the analysis of the distributions within Control Periods #2 and #3 presented in the previous subsection 7.2.2. There we determined that measures D_y, S, and MI were very stable within both Control Period #2 and Control Period #3. If a similar within-sample analysis is performed on the pooled Drillship experiments, we find that D_y and Speed are very stable within the Drillship experiments. Unfortunately, due to small sample sizes, at distances of < 3 km, the results of these within playback tests only indicate that whales within 3.0 km of the vessel were swimming uniformly. Thus, if whales are responding to the playback at > 3 km and then maintaining their tracks when they are within 3 km of the vessel, the inter-playback tests will not show any significance. In the case of Drillship playback, that is apparently what is happening. If one compares the figures of the distributions for D_y under playback conditions with the figures for either Control #2 or Control #3 (see Appendix B; pp B-12 and B-14 vs B-26), it is apparent that whales are avoiding the vicinity of the vessel. These results strongly suggest that the differences in D_y between Control Periods #2 and #3 and the pooled Drillship experiment are real. A measure of the extent to which whales avoided the playback area is illustrated by comparing the probability density functions for the playback periods with the function for the control period at the closest point of approach (x = 0.0 grid). Figure 7.3 shows these functions have their peaks at 300 m and 1000 m offshore of the VARUA, respectively. In other words, the center of the migratory path shifted offshore by 700 m when whales were exposed to Drillship playback.

The importance of the significant differences in Speed as listed in Tables 7.7a and 7.7b is not clear. During Drillship experiments, whales tended to swim faster as they approached the playback vessel and then slowed down as they swam to the south of the vessel.

The significant differences for VARUA bearing as listed in Tables 7.7a and 7.7b further reflect the test results for D_y. A comparison of the lengths of mean vectors and bearings for these significant VARUA bearings are given as follows.

	Control #2		**Control #3**		**Drilling Platform**	
Grid Interval	**Length**	**Bearing**	**Length**	**Bearing**	**Length**	**Bearing**
2.0 to 1.0	--	--	.9760	11°	.9394	16°
1.0 to 0.5	.8421	11°	.8767	9°	.8091	26°
0.5 to 0.0	.7086	19°	.7536	13°	.6938	44°
-0.05 to -1.0	.6804	166°	.7510	162°	.6934	133°
-1.0 to -2.0	.8651	167°	.9127	170°	.8513	144°

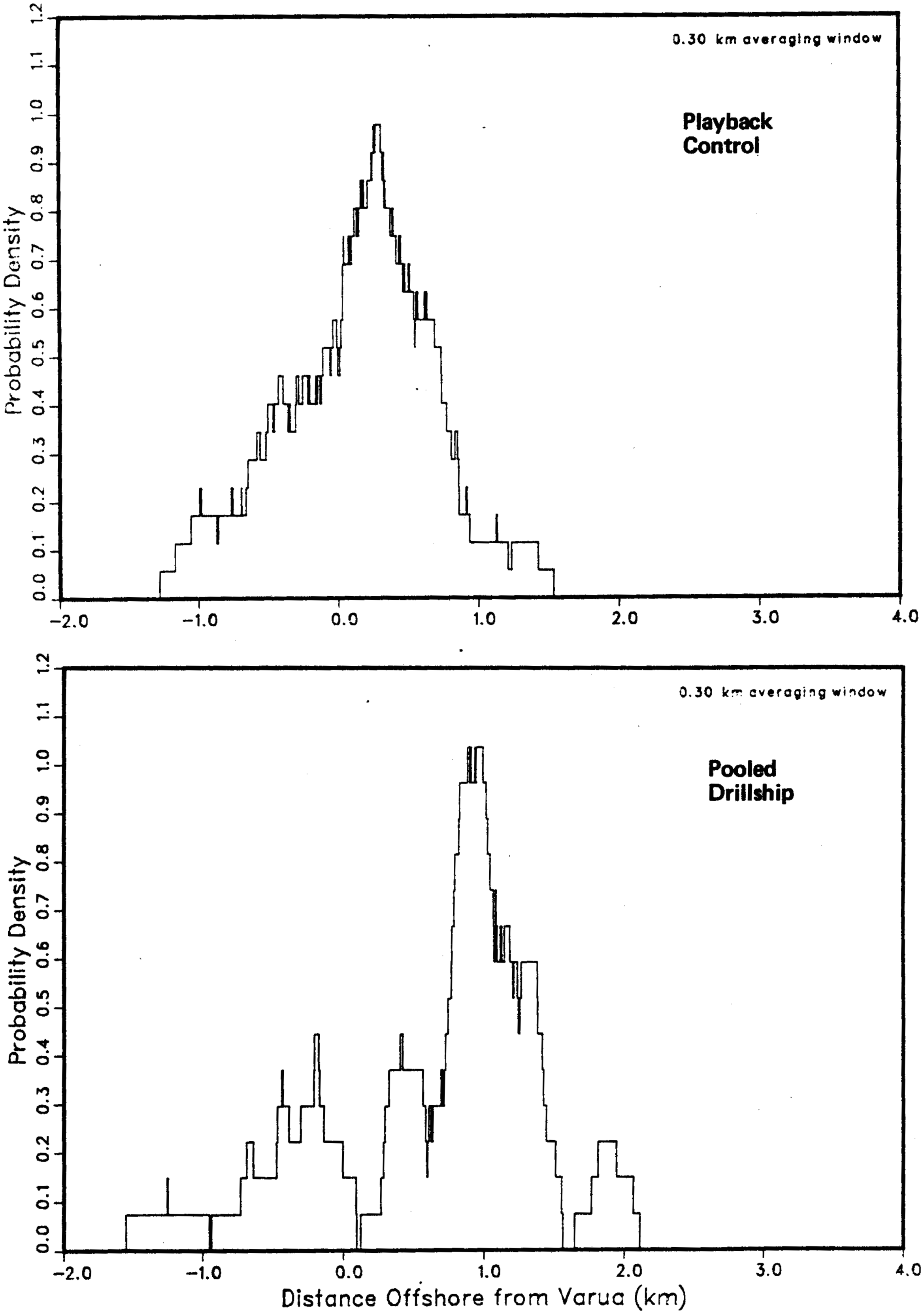


FIG. 7.3. DRILLSHIP AND CONTROL 3 PROBABILITY DENSITY FUNCTIONS.

In eight out of the nine grid intervals showing significance, whales were oriented away from the VARUA during the experiments. The higher values of the bearing angle north of the VARUA and the lower values of the bearing angle south of the VARUA during experiments indicate that the whales were crossing the grid lines further away (in this case offshore) from the VARUA. These last results are identical to the results of the tests of D_y distributions.

These results are not similar to the results obtained in 1983 for pooled Drillship. The 1983 plots of D_y distributions under experimental conditions do not indicate that whales are avoiding the area of the VARUA (see Report 5366, Appendix B, pp. B-9 and B-23). Also, for speed in 1983, whales slowed down as they approached the source whereas in 1984 we found that whales slowed down as they swam away from the source.

Despite the inconsistency in results from the two test periods, the results presented here strongly indicate that whales avoided the area of Drillship playback by moving offshore by several hundred meters. This avoidance was evidenced by significant track deflections and VARUA bearing values at ranges up to 2.0 km north of the source with recovery of normal track courses by 1.0 to 2.0 km south of the playback vessel.

Responses to the Semisubmersible Rig Stimulus Condition

Table 7.8a lists the significant differences between the distributions of four track measures when the pooled results from the three Semisubmersible Rig experiments are compared to Control Period #2. Table 7.8b lists the significant differences between the distributions of four track measures when the pooled results from the three Semisubmersible Rig experiments are compared to Control Period #3.

TABLE 7.8a. SEMISUBMERSIBLE PLAYBACK COMPARED WITH CONTROL PERIOD 2.

Grid Crossing (km)	Track Deflection	Speed	Course Bearing	VARUA Bearing
4	-			
		-	-	-
3	NS			
		.010<p<.025	NS	NS
2	NS			
		NS	NS	NS
1	NS			
		NS	NS	NS
0.5	NS			
		NS	NS	NS
0	NS			
		NS	NS	NS
-0.5	NS			
		NS	NS	NS
-1	NS			
		NS	NS	NS
-2	NS			
		NS	NS	NS
-3	NS			
		NS	NS	NS
-4	NS			

TABLE 7.8b. SEMISUBMERSIBLE PLAYBACK COMPARED WITH CONTROL PERIOD 3.

Grid Crossing (km)	Track Deflection	Speed	Course Bearing	VARUA Bearing
4	NS			
		NS	NS	NS
3	NS			
		NS	NS	NS
2	NS			
		NS	NS	NS
1	NS			
		NS	NS	NS
0.5	NS			
		NS	NS	NS
0	NS			
		NS	NS	NS
-0.5	NS			
		NS	NS	NS
-1	NS			
		NS	NS	NS
-2	NS			
		NS	NS	.02 <p<.05
-3	NS			
		NS	NS	NS
-4	NS			

Notes: - = No Data

NS = Not Significant

D_y and speed were tested by the Kolmogorov-Smirnov two sample test, while course bearing and VARUA bearing were tested by the Watson's U^2 two sample test. D_y was measured at grid crossings, so D_y statistics are listed on the same line as the grid crossing. The other three measures were obtained from intervals between adjacent grids, so they are listed on the line between those for adjacent grid crossings. NS stands for Not Significant ($p > 0.05$ that samples came from the same population).

Compared to Control Period #2 (see Table 7.8a), only one grid interval, at 3.0 to 2.0 km, showed a significant difference for Speed.

Compared to Control Period #3 (see Table 7.8b), only one grid interval, at -2.0 to -3.0 km, showed a significant difference for VARUA bearing.

These results coupled with the fact that Speed within the pooled Semisubmersible Rig data was very stable indicate that the whales did not show any observable responses to Semisubmersible Rig playbacks. We did not observe any of the changes in Speed noted in 1983 when whales slowed down as they approached the source. Although none of the tests for track deflections was significant, deflection around the source was observed. The extent of this deflection at the 0.0 km grid line is clearly illustrated in Figure 7.4. This shows that during semisubmersible rig playback, whales diverted around the source by deflecting both inshore and offshore by about 350 m.

In summary, these results demonstrate that whales avoided the immediate area of the playback when Semisubmersible Rig sounds were projected by moving offshore and inshore of the source by several hundred meters.

Responses to the Helicopter Stimulus Condition

Table 7.9a lists the significant differences between the distributions of four track measures when the pooled results from the three Helicopter experiments are compared to Control Period #2. Table 7.9b lists the significant differences between the distributions of four track measures when the pooled results from the three Helicopter experiments are compared to Control Period #3.

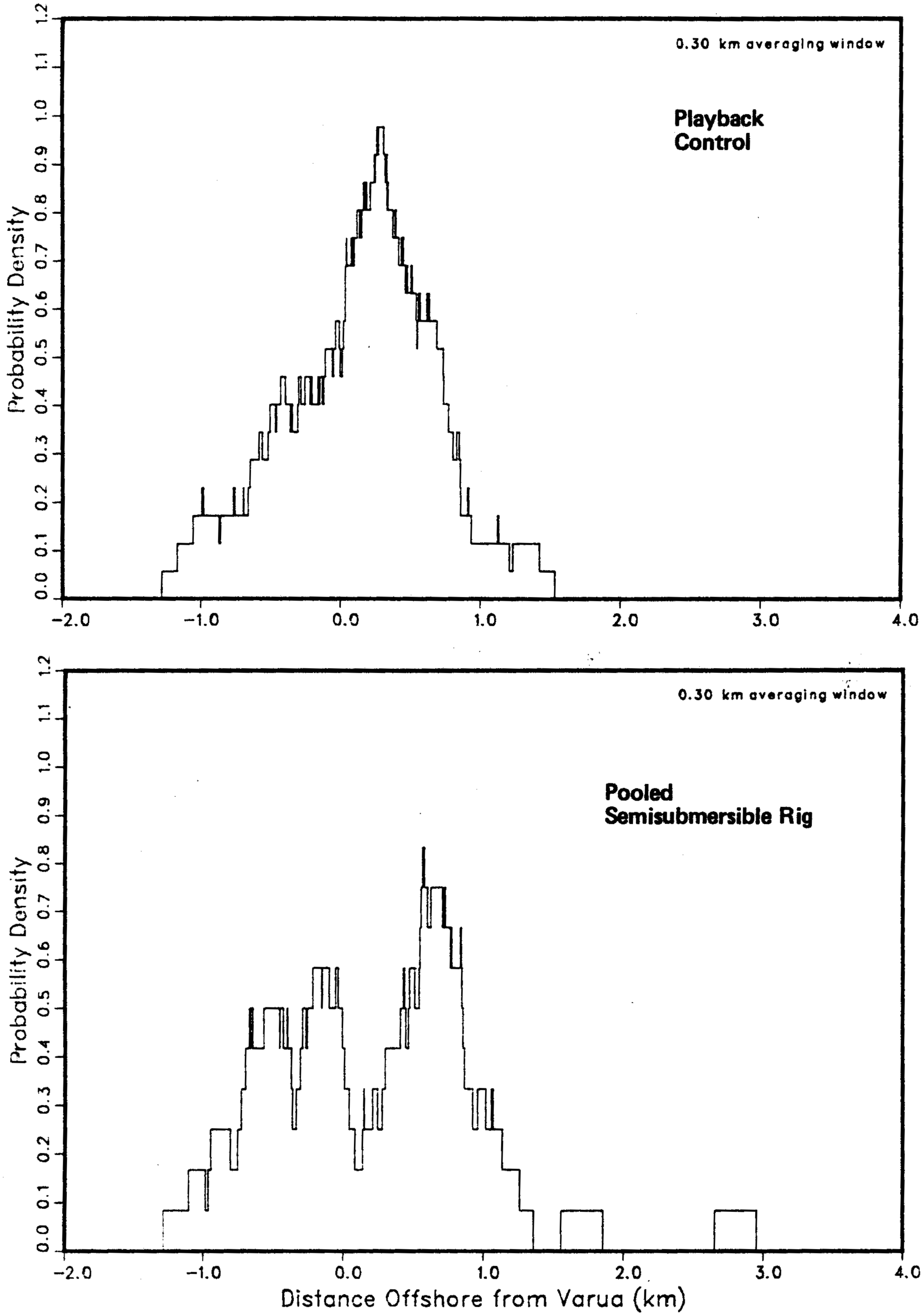


FIG. 7.4. SEMISUBMERSIBLE RIG AND CONTROL 3 PROBABILITY DENSITY FUNCTIONS.

TABLE 7.9a. HELICOPTER PLAYBACK COMPARED WITH CONTROL PERIOD 2.

Grid Crossing (km)	Track Deflection	Speed	Course Bearing	VARUA Bearing
4	-			
		-	-	-
3	$.025<p<.050$			
		NS	$0.02<p<0.05$	$0.01<p<0.02$
2	NS			
		NS	NS	NS
1	NS			
		NS	NS	NS
0.5	NS			
		NS	NS	$.01<p<.02$
0	NS			
		NS	NS	NS
-0.5	NS			
		NS	NS	$.02<p<.05$
-1	$.010<p<.025$			
		NS	NS	$.005<p<.01$
-2	$p<.001$			
		-	-	-
-3	-			
		-	-	-
-4	-			

TABLE 7.9b. HELICOPTER PLAYBACK COMPARED WITH CONTROL PERIOD 3.

Grid Crossing (km)	Track Deflection	Speed	Course Bearing	VARUA Bearing
4	NS			
		NS	NS	NS
3	NS			
		NS	NS	NS
2	NS			
		NS	$0.02<p<0.05$	NS
1	NS			
		NS	NS	NS
0.5	NS			
		NS	NS	NS
0	NS			
		NS	NS	NS
-0.5	NS			
		NS	NS	NS
-1	$.010<p<.025$			
		NS	NS	$.002<p<.005$
-2	$p<.001$			
		-	-	-
-3	-			
		-	-	-
-4	-			

Notes: - = No Data

NS = Not Significant

D_y and speed were tested by the Kolmogorov-Smirnov two sample test, while course bearing and VARUA bearing were tested by the Watson's U^2 two sample test. D_y was measured at grid crossings, so D_y statistics are listed on the same line as the grid crossing. The other three measures were obtained from intervals between adjacent grids, so they are listed on the line between those for adjacent grid crossings. NS stands for Not Significant ($p > 0.05$ that samples came from the same population).

Compared to Control Period #2 (see Table 7.9a), three grid crossings, at 3.0, -1.0, and -2.0 km, showed significant differences for the D_y measure. One grid interval at 3.0 to 2.0 km showed a significant difference for course bearing. Four grid intervals, at 3.0 to 2.0 km, 0.5 to 0.0 km, -0.5 to -1.0 km, and -1.0 to -2.0 km, showed significant differences for VARUA bearing.

Compared to Control Period #3 (see Table 7.9b), two grid crossings, at -1.0 km and -2.0 km showed significant differences for D_y. One grid interval, at 2.0 to 1.0 km, showed a signficant difference for course bearing. One grid interval, at -1.0 to -2.0 km showed a significant difference for VARUA bearing.

As mentioned previously, we know that both track deflection, D_y, and course bearing, CB, were very stable within both Control Periods #2 and #3. When a similar within-sample analysis is performed on the pooled Helicopter experiments, we find that the CB distribution at 3.0 to 2.0 km is significantly different than the distributions at 1.0 to 0.5 km and -1.0 to -2.0 km. That is, CB is quite stable except for the 3.0 to 2.0 km interval where sample sizes are small. However, D_y is <u>not</u> stable. In fact, 12 of the 36 inter-grid tests of D_y are significant as follows:

Grid Interval	**Significance Level**
3.0 to 0.0	$0.025 < p < 0.050$
3.0 to -0.5	$0.001 < p < 0.005$
3.0 to -1.0	$0.001 < p < 0.005$
3.0 to -2.0	$p < 0.001$
2.0 to -1.0	$0.005 < p < 0.010$
1.0 to -0.5	$0.010 < p < 0.025$
1.0 to -1.0	$0.001 < p < 0.005$
1.0 to -2.0	$p < 0.001$
0.5 to -1.0	$0.025 < p < 0.050$
0.0 to -2.0	$p < 0.001$
-0.5 to -2.0	$0.001 < p < 0.005$
-1.0 to -2.0	$0.010 < p < 0.025$

These results together with the significant differences for D_y as presented in Tables 7.9a and 7.9b suggest that the differences in D_y at -1.0 to -2.0 km are real. The significant differences at 3.0 km is based upon small sample sizes (16 for experiments, 14 for control) and, therefore, is probably a result of sampling error. Also, it was detected in only those tests comparing Helicopter to Control Period #2. In looking at the distribution figures and track plots for pooled Helicopter (see Appendix B; pp B-7 and B-22), one can see that whales began avoiding the immediate vicinity of the VARUA at about 0.5 km. This avoidance becomes more pronounced at the -0.5 km and -1.0 km grids. An indication of this avoidance at the 0.0 km grid line is illustrated in Figure 7.5. This figure shows that the peaks for both the control and playback periods are the same indicating the center of the migratory path does not change during playback of Helicopter sounds. However, there is a noticeable avoidance of the immediate vicinity of the playback source as evidenced by the low probability values at the position of the VARUA.

The two significant differences for course bearing (one for each test) are not particularly convincing. They do not occur at similar grid intervals in the two tests and for one of them (Control #2), the sample sizes are quite small (13 and 14, respectively). The significant difference at interval 2.0 to 1.0 km when Helicopter is compared to Control #3 is based on the length of the mean vector (.9906 for the control vs .9760 for Helicopter) since bearings for both conditions are identical (187°).

The significant differences in VARUA bearing as listed in Tables 7.9a and 7.9b partially reflect the test results of D_y. A comparison of the lengths of mean vectors and the bearings for these significant VARUA bearings are given as follows.

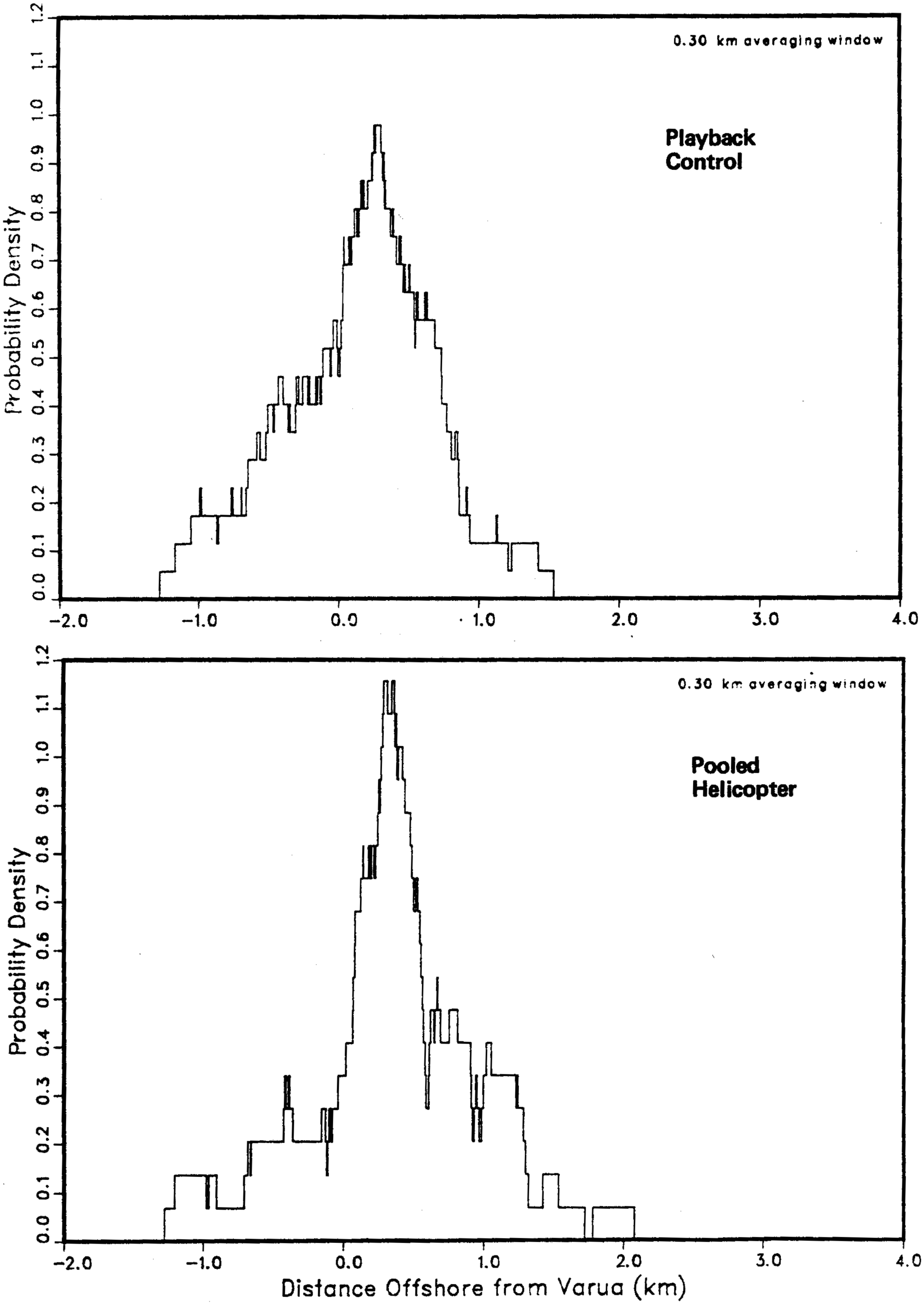


FIG. 7.5. HELICOPTER AND CONTROL 3 PROBABILITY DENSITY FUNCTIONS.

	Control #2		Control #3		Helicopter	
Grid Interval	Length	Bearing	Length	Bearing	Length	Bearing
3.0 to 2.0	.9707	5°	--	--	.9812	8°
0.5 to 0.0	.7086	19°	--	--	.7807	32°
-0.5 to -1.0	.6804	166°	--	--	.7975	150°
-1.0 to -2.0	.8651	167°	.7510	162°	.9695	138°

Interestingly enough, whales were more oriented during all the Helicopter intervals than any of the control intervals. However, the bearing angles for Helicopter were always higher north of the VARUA and lower south of the VARUA indicating that whales were crossing the grid lines further away (in this case, offshore) from the VARUA. These results are similar to the results of the tests on D_y distributions except that tests for VARUA bearing indicate that the track deflections started in the 0.5 to 0.0 km interval rather than at 1.0 km.

These results are similar to the results for pooled Helicopter playback obtained in 1983. Cumulative distribution plots for D_y under the Helicopter condition in 1983 showed that whales were distributed further offshore than under the control condition, particularly for those grids south of the playback source (see Report No. 5366, Appendix B, pp. B-11 and B-29).

In summary, these results indicate that whales avoided the area of Helicopter playback by deflecting around the source. This deflection was observed at about 0.5 km north of the source but persisted for up to 2.0 km south of it.

Responses to Production Platform Stimulus Conditions

Table 7.10a lists the significant differences between the distributions of four track measures when the pooled results from the three Production Platform experiments are compared to Control Period #2. Table 7.10b lists the significant differences between the distributions of four track measures when the pooled results from the three Production Platform experiments are compared to Control Period #3.

Compared to Control Period #2 (see Table 7.10a), four grid intervals, at 2.0 to 1.0 km, 1.0 to 0.5 km, -1.0 to -2.0 km, and -2.0 to -3.0 km, showed significant differences for Speed. One grid interval, at 1.0 to 0.5 km, showed a significant difference for VARUA bearing.

Compared to Control Period #3, (see Table 7.10b), five grid crossings, at 1.0 km, 0.5 km, 0.0 km, -0.5 km, and -2.0 km, showed significant differences for D_y. Three grid intervals, at 2.0 to 1.0, -2.0 to -3.0, and -3.0 to -4.0 km showed significant differences for Speed. One grid interval at -2.0 to -3.0 km showed a significant difference for Compass bearing. One grid interval, at 1.0 to 0.5 km, showed a significant difference for VARUS bearing.

As mentioned previously, we already know that D_y, Speed, and course bearing were very stable within the Control Periods #2 and #3. When a similar within-sample analysis is performed on the pooled Production Platform results, we find that D_y, Speed, and CB are also very stable. As with the pooled Drillship experiments, sample sizes were very small at distances of greater than 2.0 km from the source. Therefore, if whales are responding to playbacks at 3.0 km from the source, the within-sample tests would not detect the response. If the D_y distributions for pooled Production Platform are examined and compared with the Control Periods #2 and #3, one will notice that in both pairs of figures,

TABLE 7.10a. PRODUCTION PLATFORM PLAYBACK COMPARED WITH CONTROL PERIOD 2.

Grid Crossing (km)	Track Deflection	Speed	Course Bearing	VARUA Bearing
4	NS			
		-	-	-
3	NS			
		NS	NS	NS
2	NS			
		$.010<P<.025$	NS	NS
1	NS			
		$.001<P<.005$	NS	$.02<p<.05$
0.5	NS			
		NS	NS	NS
0	NS			
		NS	NS	NS
-0.5	NS			
		NS	NS	NS
-1	NS			
		$.010<P<.025$	NS	NS
-2	NS			
		$.025<p<.050$	NS	NS
-3	NS			
		NS	NS	NS
-4	NS			

TABLE 7.10b. PRODUCTION PLATFORM PLAYBACK COMPARED WITH CONTROL PERIOD 3.

Grid Crossing (km)	Track Deflection	Speed	Course Bearing	VARUA Bearing
4	-			
		-	-	-
3	NS			
		NS	NS	NS
2	NS			
		$0.010<p<0.025$	NS	NS
1	$0.010<p<0.005$			
		NS	NS	$0.010<p<0.02$
0.5	$0.025<p<0.050$			
		NS	NS	NS
0	$0.010<p<0.025$			
		NS	NS	NS
-0.5	$0.025<p<0.050$			
		NS	NS	NS
-1	NS			
		NS	NS	NS
-2	$0.025<p<0.050$			
		$0.025<p<0.050$*	$0.02<p<0.050$	NS
-3	NS			
		$0.025<p<0.050$*	NS	NS
-4	NS			

Notes: * = Small sample size

- = No Data

NS = Not Significant

D_y and speed were tested by the Kolmogorov-Smirnov two sample test, while course bearing and VARUA bearing were tested by the Watson's U^2 two sample test. D_y was measured at grid crossings, so D_y statistics are listed on the same line as the grid crossing. The other three measures were obtained from intervals between adjacent grids, so they are listed on the line between those for adjacent grid crossings. NS stands for Not Significant ($p > 0.05$ that samples came from the same population) while "________" means that there were no data for that grid crossing or grid interval.

Production Platform distributions are shifted offshore (to the right) starting at around 1.0 km north of the VARUA and continuing to 2.0 km south of the vessel.

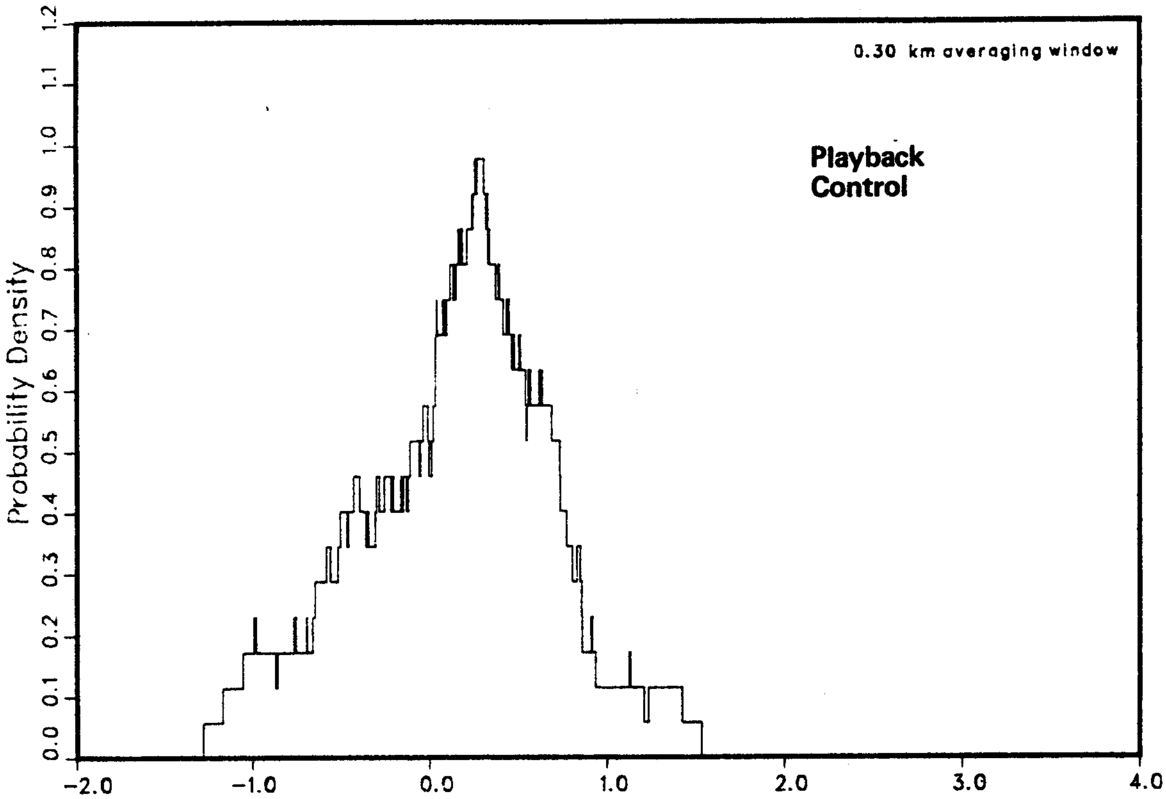
Thus, although there were no significant track deflections when Production Platform distributions were compared to Control Period #2, there were differences which were consistent with the significant results from testing PP distributions against Control Period #3. These results indicate that the significant differences in D_y between Control Period #3 and PP are real.

A further indication of deflection at the 0.0 km grid is illustrated in Figure 7.6. This figure clearly shows that whales were deflecting inshore by 500 m and offshore by 250 m during playback of Production Platform.

The importance of the significant differences in Speed as listed in Tables 7.10a and 7.10b is not easy to interpret. All seven tests were consistent in that significant control period intervals had speeds that were always faster than the experimental intervals. In other words, whales slowed down as they approached the source starting at 2.0 to 1.0 km, then swam at normal speeds as they passed the VARUA and again slowed down as they left the observation area. Considering that the significant differences appear near the ends of the observation area, there is the possibility that several of these differences are due to sampling error.

The importance of the one significant difference in course bearing at -2.0 to -3.0 km is not clear. Sample sizes at these ranges were small (12 and 27, respectively), so there is a good possibility that the difference is a result of sampling error.

The significance of the VARUA bearing at 1.0 to 0.5 km as listed in both Tables 7.10a and 7.10b is consistent with the



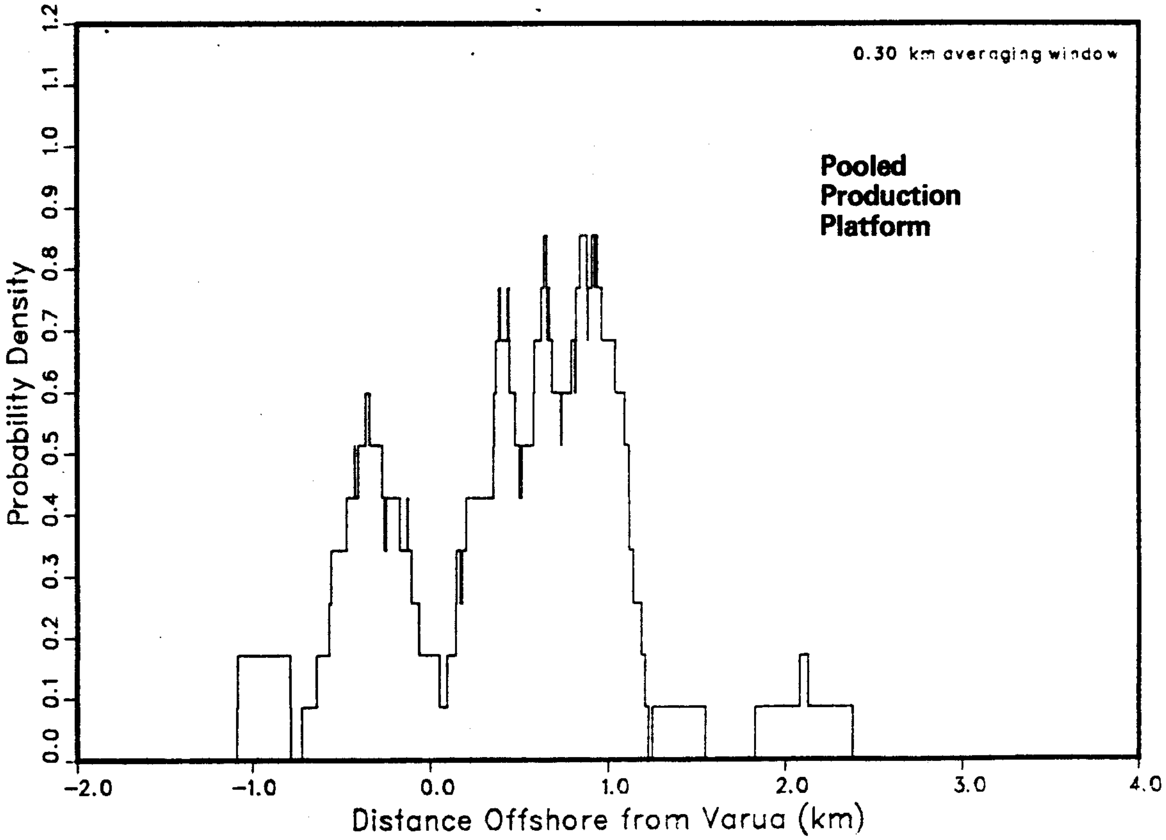


FIG. 7.6. PRODUCTION PLATFORM AND CONTROL 3 PROBABILITY DENSITY FUNCTIONS.

results for D_y. A comparison of lengths of mean vectors and bearings at this interval are:

	Control #2		Control #3		Production Platform	
Grid Interval	Length	Bearing	Length	Bearing	Length	Bearing
1.0 to 0.5	.8421	11°	.8767	9°	.8385	19°

These values indicate that whales were more oriented away from the VARUA during playbacks than during the control periods. This result is further illustrated in the track plots for Production Platform (see Appendix B). In this plot one can see tracks deflect around the VARUA at about 0.5 km north of her with the deflection persisting for several kilometers to the south.

These results are quite similar to the results for pooled Production Platform obtained in 1983. Cumulative distribution plots for D_y under those conditions in 1983 showed that whales were distributed further offshore than under the control conditions. Also, the deflection tended to persist for several kilometers south of the source (see Report No. 5366, Appendix B, pp. B-12 and B-32).

In summary, these results indicate that whales avoided the area of Production Platform playback by moving inshore and offshore of the source by several hundred meters. This deflection was first observed at about 1.0 km north of the playback source and persisted for several kilometers south of it. There was some evidence that whales slowed down as they approached and left the playback area.

Many of these results, based on comparing pooled data for similar types of industrial sound stimuli, have been consistent with the results when all 15 playbacks were pooled and compared with the pooled Control Periods #2 and #3. In general, whales responded similarly to playback of Drilling Platform, Drillship, Helicopter, and Production Platform by deflecting around the source. Whales showed a similar but much more reduced response to Semisubmersible Rig sound playback. Differences between responses to the different types of playback stimuli are observed in the distance north of the source at which whales begin to move offshore, the distance they are displaced offshore, and the distance south of the source that they maintain this offshore course.

7.1.5 Comparisons between responses to playback of similar stimuli types

We compared responses to two playback experiments of similar playback types in an effort to determine whether the whales' responses were graded relative to the received levels and/or ambient noise conditions associated with that experiment. These intra-playback comparisons were made only if there were sufficient differences between ambient conditions for two playbacks of the same stimulus type. (See Table 5.2)

On this basis, comparisons were made between Drilling Platform experiments #2 and #3, Helicopter experiments #2 and #3, and Semisubmersible Rig experiments #2 and #3.

Comparison of Responses to Drilling Platform #2 and #3

Table 7.11a lists the significant differences between Drilling Platform #2 and its matched control period; 18 January, 1122-1318. Table 7.11b lists the significant differences between Drilling Platform #3 and its matched control period, 18 January, 0845-1045.

TABLE 7.11a. RESPONSE FOR PLAYBACK DP2 COMPARED WITH CONTROL PERIOD.

Grid Crossing (km)	Track Deflection	Speed	Course Bearing	VARUA Bearing
4	-			
		-	-	-
3	NS			
		NS	NS	NS
2	NS			
		NS	NS	NS
1	NS			
		$.000<p<.001$	NS	NS
0.5	NS			
		$.010<p<.025$	NS	NS
0	NS			
		$.001<p<.005$	NS	NS
-0.5	NS			
		NS	NS	NS
-1	NS			
		NS	NS	NS
-2	NS			
		NS	NS	NS
-3	NS			
		NS	NS	NS
-4	NS			

TABLE 7.11b. RESPONSE FOR PLAYBACK DP3 COMPARED WITH CONTROL PERIOD.

Grid Crossing (km)	Track Deflection	Speed	Course Bearing	VARUA Bearing
4	-			
		-	-	-
3	NS			
		NS	NS	NS
2	NS			
		NS	NS	NS
1	$.05<p<.10$			
		NS	NS	$.02<p<.05$
0.5	$.05<p<.10$			
		NS	NS	$.01<p<.02$
0	$.05<p<.10$			
		NS	NS	NS
-0.5	NS			
		NS	NS	NS
-1	NS			
		NS	NS	NS
-2	NS			
		NS	NS	NS
-3	NS			
		NS	NS	NS
-4	NS			

Notes: - = No Data

NS = Not Significant

D_y and speed were tested by the Kolmogorov-Smirnov two sample test, while course bearing and VARUA bearing were tested by the Watson's U^2 two sample test. D_y was measured at grid crossings, so D_y statistics are listed on the same line as the grid crossing. The other three measures were obtained from intervals between adjacent grids, so they are listed on the line between those for adjacent grid crossings. NS stands for Not Significant ($p > 0.05$ that samples came from the same population) while "________" means that there were no data for that grid crossing or grid interval.

Compared to its control period (see Table 7.11a), Drilling Platform #2 showed significant differences for speed at grid intervals 1.0 to 0.5 km, 0.5 to 0.0 km, and 0.0 to -0.5 km (see Appendix B). When Drilling Platform #3 was compared to its control period, significant differences in VARUA Bearing were found at grid intervals 1.0 to 0.5 km and 0.5 to 0.0 km (See Appendix B). Furthermore, there were three grid crossings for which D_y distributions were different from Drilling Platform #3 control at the $0.05 < p < 0.10$ level. These occurred at the 1.0 km, 0.5 km, and 0.0 km grids.

Comparisons Within Test and Control Periods

Both Speed and VARUA bearing were stable within either control periods. For Drilling Platform #2, the D_y distribution at 3.0 km and 2.0 km were different from the distribution at -2.0 km. Speed distributions at the 3.0 to 2.0 km grid interval were different from all intervals between 1.0 and -1.0 km. These differences are listed as follows:

Drilling Platform #2

Grid Crossing Compared	**D_y**
3.0 vs -2.0	$0.025 < p < 0.050$
2.0 vs -2.0	$0.050 < p < 0.10$

Grid Intervals Compared	**Speed**
3.0 to 2.0 vs 1.0 to 0.5	$0.005 < p < 0.010$
3.0 to 2.0 vs 0.5 to 0.0	$0.050 < p < 0.10$
3.0 to 2.0 vs 0.0 to -0.5	$0.010 < p < 0.025$
3.0 to 2.0 vs -0.5 to -1.0	$0.050 < p < 0.10$

For Drilling Platform #3, the D_y distributions at 2.0 km were different from the distributions at 0.0 km, -0.5 km, and -1.0 km. These differences are listed as follows:

Drilling Platform #3

Grid Crossings Compared	D_y
2.0 vs 0.0	$0.05 < p < 0.10$
2.0 vs -0.5	$0.025 < p < 0.05$
2.0 vs -1.0	$0.05 < p < 0.10$

These results suggest that the significant changes in Speed under Drilling Platform #2 condition and the significant differences in VARUA bearing under Drilling Platform #3 condition are real. In evaluating possible intra-playback differences for the Drilling Platform playbacks, we would expect to find a graded response based on D_y distributions. This expectation is based upon the results presented earlier for Drilling Platform which demonstrated that whales responded to Drilling Platform playback by deflecting around the source.

The only evidence indicating a graded effect comes from the analysis of the within-playback D_y distributions during Drilling Platform playbacks #2 and #3. Here we find that during Drilling Platform #2, when the estimated range for 0 dB S/N for the peak 1/3 octave band was 3.0 km and the range for 0 dB S/N for broadband was 2.4, there was a hint of a response between 3.0 and 2.0 km. During Drilling Platform #3, where again the estimated range for 0 dB S/N for the peak 1/3 octave band was 3.0 km but the range for broadband was 1.6 km, there was an apparent response between 2.0 km and 1.0 km. We must caution that this coincidence between response and the 0 dB S/N range for broadband energy level of the playback is not strong, is based on small sample sizes, and is subject to possible sampling errors.

Comparison of Responses to Semisubmersible Rig Playback #2 and #3

There were no significant differences between Semisubmersible Rig #2 and its matched Control period; 18 January, 0848-1046. There were three significant differences between Semisubmersible Rig #3 and its matched control period; 20 January, 1100-1230: Speed at the -3.0 to -4.0 km grid interval ($].025 < p < 0.050$), Course bearing at the -1.0 to -2.0 km grid interval ($0.02 < p < 0.05$), and VARUA bearing at the 0.0 to -0.5 km grid interval ($0.02 < p < 0.05$). All three were based on very small sample sizes.

Therefore, we conclude that we did not observe any graded responses to these two Semisubmersible Rig playbacks.

Comparison of Responses to Helicopter Playback #2 and #3

There were three significant differences between Helicopter #2 and its matched control period; 18 January, 1345-1545. These differences were: D_y at the -1.0 km grid ($0.025 < p < 0.05$), Speed at the -0.5 to -1.0 km grid interval ($0.005 < p < 0.010$) and VARUA bearing at the 0.5 to 0.0 km grid interval ($0.02 < p < 0.05$). There was one significant difference between Helicopter #3 and its matched control period; 18 January, 1345-1545. This difference was for VARUA bearing at the -0.5 to -1.0 km grid interval and was based upon observations showing that whales were more oriented toward the VARUA and closer to her during experiment than during the control. Therefore, we conclude that we did not observe any graded responses to these two Helicopter playbacks.

7.1.6 Response to moored air gun condition

Table 7.12a lists the significant differences between the distributions of four track measures when the pooled results from moored air gun experiments were compared to Control Period #4 (this was the control constructed from time periods on the same days as the moored air gun experiments but when the gun was not operating). Table 7.12b lists the significant differences between the distributions of four track measures when the pooled results from moored air gun experiments were compared to Control Period #5 (8 and 12 January pooled).

Compared to Control Period #4 (see Table 7.12a), three grid crossings, at 3.0 km, 2.0 km and 1.0 km, showed significant differences for the D_y measure. One grid interval, at 4.0 to 3.0 km, showed a significant difference for Speed. One grid interval, at 0.5 to 0.0 km, showed a significant difference for Compass bearing. Two grid intervals, at 1.0 to 0.5 km and 0.5 to 0.0 km, showed significant differences for VARUA bearing. When the Cramer von Mises test was used for these tests, there was one additional significance found for D_y at the 0.5 km grid crossing.

Compared to Control Period #5 (see Table 7.11b), one grid crossing at 0.0 km showed a significant difference for D_y. One grid interval, at 0.0 to -0.5 km, showed a significant difference for Speed. Two grid intervals, at 2.0 to 1.0 and 1.0 to 0.5 km showed significant differences for Compass bearing. Two grid intervals, at 1.0 to 0.5 km and 0.5 to 0.0 km, showed significant differences for VARUA bearing.

The interpretation of these significant differences is aided by the analysis of the distributions within Control Periods #4 and #5 presented in the previous subsection 7.3.2. There it was shown that for Control Period #4, D_y distributions north of the VARUA were significantly different from distributions south of the

TABLE 7.12a. MOORED AIRGUN COMPARED WITH CONTROL PERIOD 4.

Grid Crossing (km)	Track Deflection	Speed	Course Bearing	VARUA Bearing
4	NS			
		0.025<p<0.050	NS	NS
3	0.025<p<0.050			
		NS	NS	NS
2	0.010<p<0.025			
		NS	NS	NS
1	0.025<p<0.050			
		NS	NS	p<0.001
0.5	NS			
		NS	0.02<p<0.05	0.02<p<0.05
0	NS			
		NS	NS	NS
-0.5	NS			
		NS	NS	NS
-1	NS			
		NS	NS	NS
-2	NS			
		NS	NS	NS
-3	NS			
		NS	NS	NS
-4	NS			

TABLE 7.12b. MOORED AIRGUN COMPARED WITH CONTROL PERIOD 5.

Grid Crossing (km)	Track Deflection	Speed	Course Bearing	VARUA Bearing
4	NS			
		NS	NS	NS
3	NS			
		NS	NS	NS
2	NS			
		NS	0.02<p<0.050	NS
1	NS			
		NS	0.02<p<0.05	0.001<p<0.002
0.5	NS			
		NS	NS	p<0.001
0	0.025<p<0.050			
		0.001<p<0.005	NS	NS
-0.5	NS			
		NS	NS	NS
-1	NS			
		NS	NS	NS
-2	NS			
		NS	NS	NS
-3	NS			
		NS	NS	NS
-4	NS			

Notes: - = No Data

NS = Not Significant

D_y and speed were tested by the Kolmogorov-Smirnov two sample test, while course bearing and VARUA bearing were tested by the Watson's U^2 two sample test. D_y was measured at grid crossings, so D_y statistics are listed on the same line as the grid crossing. The other three measures were obtained from intervals between adjacent grids, so they are listed on the line between those for adjacent grid crossings. NS stands for Not Significant ($p > 0.05$ that samples came from the same population) while "________" means that there were no data for that grid crossing or grid interval.

VARUA. Specifically, whales were swimming fairly normal tracks north of the VARUA and Cheyenne Arrow but then moved offshore once they passed the two boats. For Control Period #5, D_y was very stable but Speed was variable. This variability in speed distribution was primarily due to the fact that whales were swimming faster on 8 January than on 12 January. When a similar within-sample analysis is performed on the Moored Air gun results, we find that D_y distributions at 4.0 km, 3.0 km, and 2.0 km are significantly different than distributions at 0.5 km, 0.0 km, -0.5 km, -1.0 km, and -2.0 km. An inspection of the D_y distributions shown in Appendix B (p. B-32), reveals that distributions at 4.0 km, 3.0 km, and 2.0 km were fairly normal but that by 1.0 km a flattening of the distribution at around 250 m west of the x-axis is beginning to be evident. This flattening persists through the -2.0 km distribution. Thus, variability within D_y for Control Period #4 represents a change in distributions starting at the 0.0 grid crossing, while variability within D_y for the Moored Air gun experiments represents a change in distributions starting at the 2.0 km grid line.

An indication of the extent of the deflation at the 0.0 km grid line is illustrated in Figure 7.7. This figure clearly shows that whales were avoiding the area of the vessels by moving inshore by 1000 m and offshore by 200 m during the moored airgun experiments.

These results together with the significant differences for D_y as presented in Tables 7.12a and 7.12b, suggest that the differences in D_y between Control Periods #4 and #5 and the Moored Air gun experiments are real.

The importance of the significant differences in Speed are not as clear. The significant difference at the 4.0 to 3.0 km grid interval is based on sample sizes of only 11 and 6. The

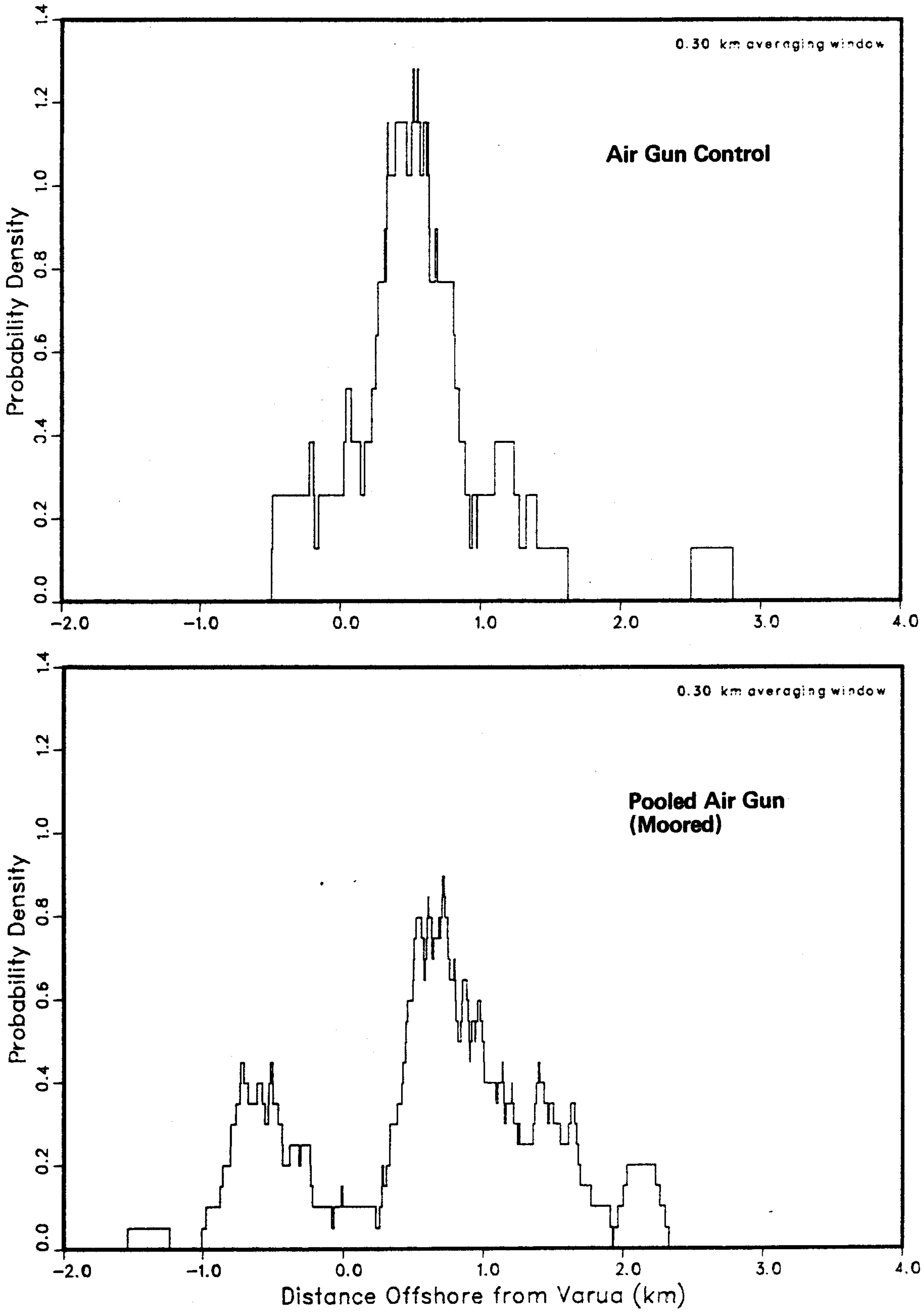


FIG. 7.7. MOORED AIR GUN AND CONTROL 4 PROBABILITY DENSITY FUNCTIONS.

errors at these distances combined with the small sample sizes makes it likely that this difference is a result of sampling error. The significant difference at the 0.0 to -0.5 km grid interval when Moored Air gun is compared to Control Period #5 is interesting in light of the fact that whales during the experiments were swimming faster as they approached the air gun but swimming slower once they had passed the gun.

The significant differences for Course bearing and VARUA bearing as listed in Tables 7.12a and 7.12b further reflect the test results for D_y indicating that whales deflect around the vessels during air gun activity. A comparison of lengths of mean vectors and bearings for the significant Course and VARUA bearing are given as follows:

Course Bearing

	Control #4		**Control #5**		**Moored Air gun**	
Grid Interval	**Length**	**Bearing**	**Length**	**Bearing**	**Length**	**Bearing**
2.0 to 1.0	--	--	.9725	183°	.9730	188°
1.0 to 0.5	--	--	.9703	183°	.9514	190°
0.5 to 0.0	.9801	194°	--	--	.9496	188°

VARUA Bearing

	Control #4		**Control #5**		**Moored Air gun**	
Grid Interval	**Length**	**Bearing**	**Length**	**Bearing**	**Length**	**Bearing**
1.0 to 0.5	.9098	15°	.8745	22°	.7878	32°
0.5 to 0.0	.8313	42°	.7883	34°	.6262	46°

In six out of the seven grid intervals showing significant differences, whales were more oriented away from the vessels during the experiments than during the controls. This difference is made evident by length of mean vectors for control conditions being greater than vectors for the Moored Air gun condition.

The higher values of the bearing angle, except during Control #4 at 0.5 to 0.0 km, indicate that whales were crossing the grid lines further away (in this case, both further inshore and further offshore) from the vessels during the experiments than during the control periods.

In summary, these results indicate that whales showed a brief avoidance to the immediate vicinity of the vessels when no air gun was operating (Control #4) and these deflections persisted for about 1.0 km. A much stronger response similar to that observed during Drilling Platform playback was observed when the moored air gun was operating. During these experiments, whales avoided the playback area by moving further offshore and inshore of the vessels. This avoidance response was first detected at 2.0 km north of the vessels and persisted until the whales were at least 2.0 km south of them.

7.1.7 Responses to Moving Air gun experiments

On 9 January, the Cheyenne Arrow proceeded along transects at 8, 3, and 1.5 nm (see figure). These Moving Air gun experiments lasted only for 2 hr 45 min., 1 hr, and 1 hr, respectively. Because of these very short experimental periods, the number of whales tracked was low and consequently the analytical procedures are limited by reduced sample sizes. Furthermore, the track deflection program was designed for stationary sound sources located at the origin of the coordinate system. The sensitivity of both the track deflection and VARUA bearing measures are based on this assumption about source location so they will be insensitive and difficult to interpret for a moving sound source. Since the grid crossing system tallies up data at presumably set ranges from the source, the grid intervals also cannot be interpreted for a moving source. With these caveats we present the following summaries of our results for these three Moving Air gun transects.

Responses to Moving Air gun at 8 nm (15.5 km)

Table 7.13a lists the significant differences for four track measures when distributions for Moving Air gun at 8 nm were compared with the distribution for its matched control period; 8 January, 900-1200. All differences occurred at the extremes of the observation ranges for this data where sample sizes were small. The two significant differences for Course bearing are based upon data that show whales better oriented during the moving air gun than during the control, but with mean bearing angles away from the x-axis. Therefore, we conclude that we did not observe any response to the moving air gun at 8 nm.

Responses to Moving Air gun at 3 nm (5.6 km)

Table 7.13b lists the significant differences for four track measures when distributions for Moving Air gun at 3 nm were compared with the distributions for its matched control period; 8 January, 1300-1600. The Speed difference is due to higher speeds during the 8 January control period. The Course bearing difference is due to whales being better oriented during the Moving Air gun experiment but with a bearing angle away from the x-axis. Therefore, we conclude that we did not observe any response to the moving air gun at 3 nm.

TABLE 7.13a. RESPONSES TO MOVING AIRGUN AT 8 NM COMPARED WITH CONTROL PERIOD.

Grid Crossing (km)	Track Deflection	Speed	Course Bearing	VARUA Bearing
4				
3	NS			
		-	-	-
2	NS			
		NS	$0.02<p<0.05$	NS
1	NS			
		NS	NS	NS
0.5	NS			
		NS	NS	NS
0	NS			
		NS	NS	NS
-0.5	NS			
		NS	NS	NS
-1	NS			
		NS	NS	NS
-2	NS			
		$0.025<p<0.05$	$0.02 <p<0.05$	NS
-3	NS			
		NS	NS	NS
-4	NS			

TABLE 7.13b. RESPONSES TO MOVING AIRGUN AT 3 NM COMPARED WITH CONTROL PERIOD.

Grid Crossing (km)	Track Deflection	Speed	Course Bearing	VARUA Bearing
4	-			
3	NS			
		-	-	-
2	NS			
		NS	NS	NS
1	-			
		NS	$0.02<p<0.05$	NS
0.5	NS			
		NS	NS	NS
0	NS			
		NS	NS	NS
-0.5	NS			
		$0.025<p<0.050$	NS	NS
-1	NS			
		NS	NS	NS
-2	NS			
		-	-	-
-3	-			
		-	-	-
-4	-			

Notes: - = No Data

NS = Not Significant

D_y and speed were tested by the Kolmogorov-Smirnov two sample test, while course bearing and VARUA bearing were tested by the Watson's U^2 two sample test. D_y was measured at grid crossings, so D_y statistics are listed on the same line as the grid crossing. The other three measures were obtained from intervals between adjacent grids, so they are listed on the line between those for adjacent grid crossings. NS stands for Not Significant ($p > 0.05$ that samples came from the same population).

Responses to Moving Air gun t 1.5 nm (2.8 km)

Table 7.13c lists the significant differences for four track measures when distributions for Moving Air gun at 1.5 nm were compared with the distributions for its matched control period; 8 January, 900-1200. All the Speed differences were due to higher swimming speeds during the 8 January control period. The VARUA bearing difference is due to whales being better oriented and closer to the VARUA during the Moving Air gun experiment than during the control. Therefore, we conclude that we did not observe any responses to the Moving Air gun at 1.5 nautical miles.

TABLE 7.13c. RESPONSES TO MOVING AIRGUN AT 1.5 NM COMPARED WITH CONTROL PERIOD.

Grid Crossing (km)	Track Deflection	Speed	Course Bearing	VARUA Bearing
4	-			
		-	-	-
3	NS			
		NS	NS	NS
2	NS			
		$0.025<p<0.050$	NS	$0.02<p<0.05$
1	NS			
		NS	NS	NS
0.5	NS			
		$0.010<p<0.025$	NS	NS
0	NS			
		$0.005<p<0.010$	NS	NS
-0.5	NS			
		$0.010<p<0.025$	NS	NS
-1	NS			
		NS	NS	NS
-2	NS			
		-	-	-
-3	-			
		-	-	-
-4	-			

Notes: - = No Data

NS = Not Significant

D_y and speed were tested by the Kolmogorov-Smirnov two sample test, while course bearing and VARUA bearing were tested by the Watson's U^2 two sample test. D_y was measured at grid crossings, so D_y statistics are listed on the same line as the grid crossing. The other three measures were obtained from intervals between adjacent grids, so they are listed on the line between those for adjacent grid crossings. NS stands for Not Significant ($p > 0.05$ that samples came from the same population) while "________" means that there were no data for that grid crossing or grid interval.

8. INTERPRETATION AND APPLICATION OF RESULTS

The acoustic and behavioral results presented in the previous sections can be used to estimate the possible influence of industrial noise on gray whale behavior in other areas. To do this requires application of acoustic scaling relationships, measurement of acoustic environmental factors, and consideration of the whale activity that may be impacted.

In this section, a method of predicting gray whale response to high industrial noise levels is developed. Procedures for applying this method to generalized source locations are presented.

8.1 The Influence of Playback and Air Gun Sound Levels on Migration Behavior

The data presented in Sec. 7 showed that gray whales detected several of the playback stimuli at ranges where the level of the dominant part of the playback signal was comparable to the ambient noise level in the same frequency range (0 dB S/N). Analysis of the track and speed distributions showed that the principal reaction was a small change in swim direction and a drop in speed. The change in swim direction generally caused the whales to pass the vicinity of the sound source at a greater distance than would have occurred otherwise. This avoidance reaction thus results in a reduction of the sound exposure for the whales as they pass the source. The avoidance distance presumably is a function of the loudness and degree of unpleasantness (noisiness) of the sound. It is also likely to be a function of whether or not the sound might have a threat significance to the whales (such as orca sounds).

Some detailed tracks showing response of whale groups to various stimuli are illustrated in Figs. 8.1 through 8.3. The contours are not concentric because of the dependence of sound

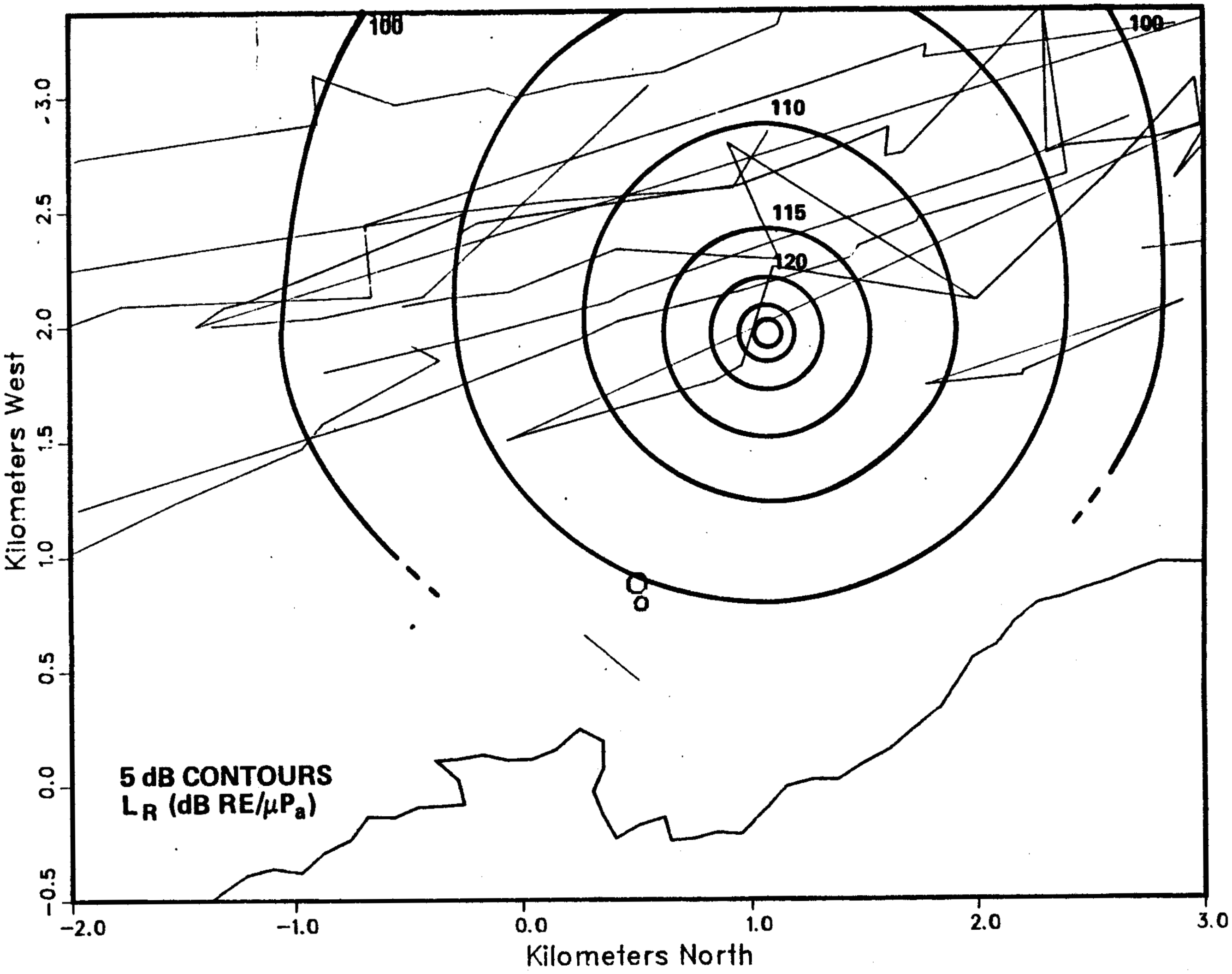


FIG. 8.1. DRILLSHIP PLAYBACK TRACK PLOT.

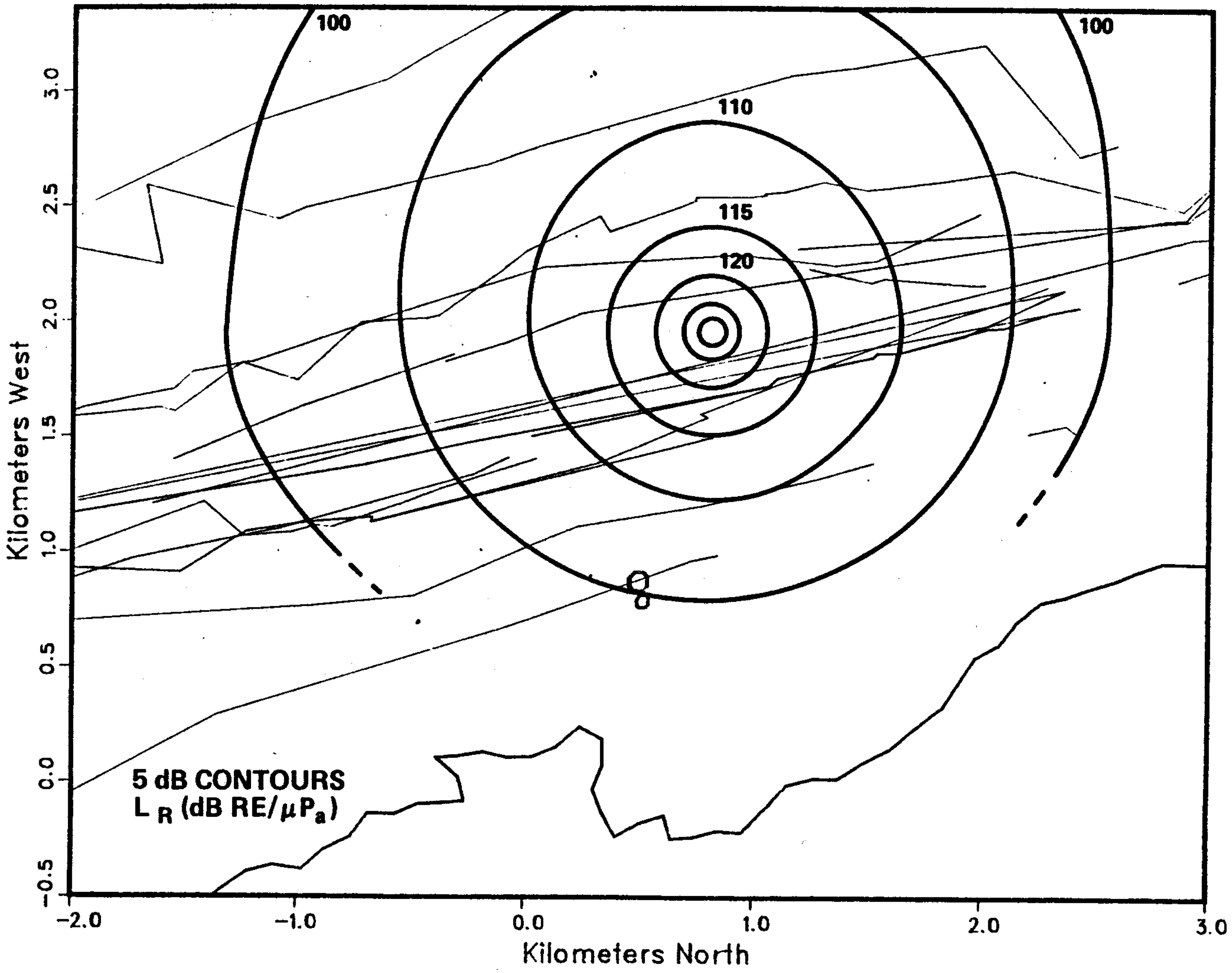


FIG. 8.2. SEMISUBMERSIBLE RIG PLAYBACK TRACK PLOT.

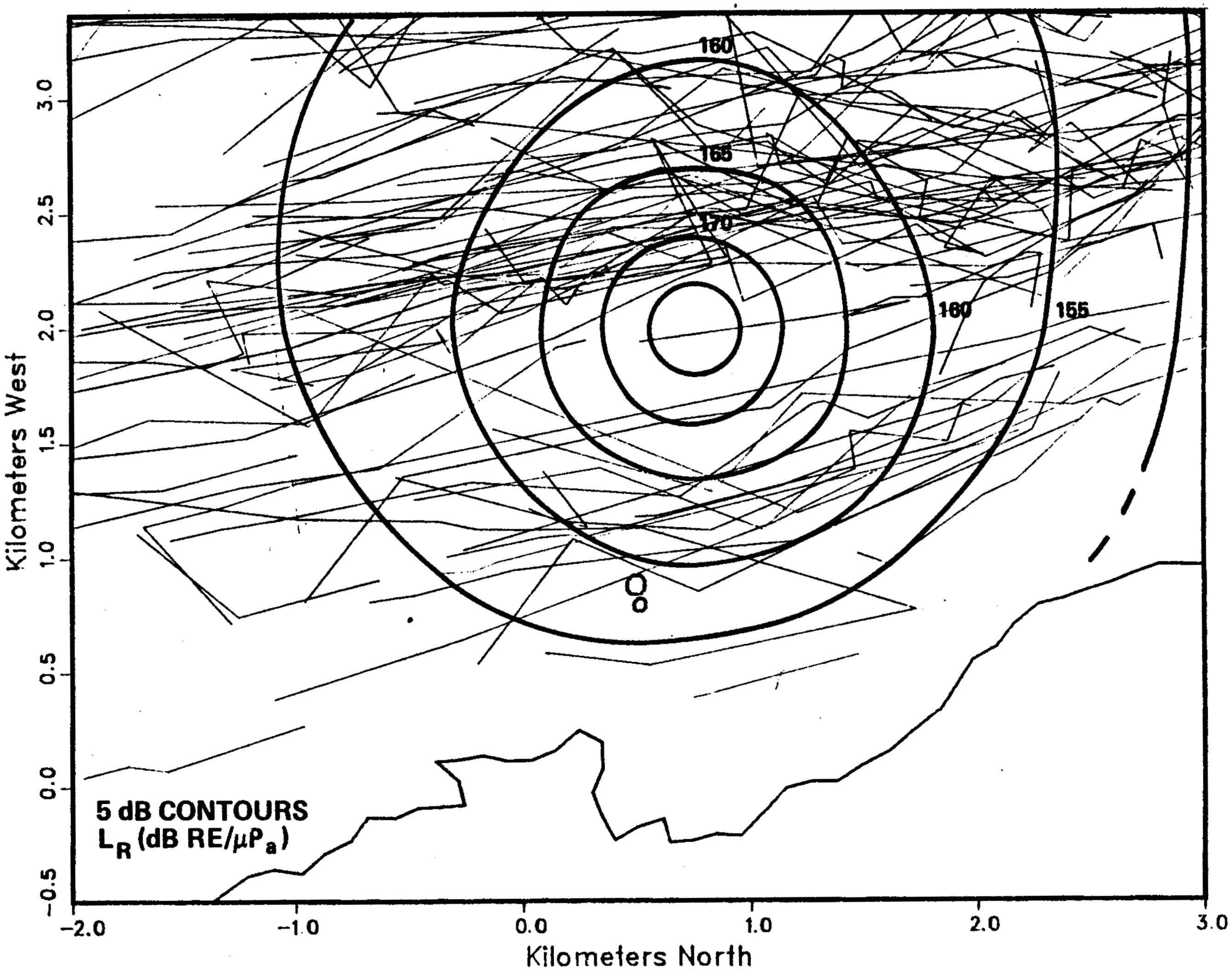


FIG. 8.3. MOORED AIR GUN TEST TRACK PLOT.

transmission on bottom depth in addition to range. The bottom is non-uniformly sloping to seaward in the test area. Figure 8.1 shows the track plots near the source area for a drillship playback period. Several tracks show course changes at some distance from the source. A similar plot for a semisubmersible rig stimulus playback is shown in Fig. 8.2. In this example, an observable gap in track density can be seen near the source, and some whales are seen to move offshore when they are approximately 1 km north of the source. No significant deflection can be observed in the tracks that pass close to the source on the shoreward side. The track data shown in Fig. 8.3 for the moored air gun test demonstrate a more dramatic avoidance of the source area. Only one track can be seen passing inside the 180 dB effective peak pressure level contour.

8.2 Sound Avoidance Analysis

The track data shown in Figs. 8.1 through 8.3 could be used to develop plots showing track density versus sound level for the various stimuli used. However, this information can be obtained more conveniently by using the cumulative track distributions described in Sec. 3.4. Not only is track deflection easy to visualize and interpret, but the track deflection score D_y was one of the most sensitive for statistical analysis. The distance by which the whales avoid the sound source can be estimated by comparing the cumulative track distributions for a given stimulus condition with the distributions for the control condition with VARUA present but no sound projection. Since for most tracks the point of closest approach to the source occurs along the $x = 0$ grid line (see Fig. 3.4), only the distribution of track crossings along this line needs to be considered in making the avoidance determination. Cumulative track distributions for the pooled drillship playback and for the pooled air gun experiments are conveniently compared with the appropriate control conditions by using a direct overlay procedure as illustrated in Figs. 8.4 and 8.5. The influence of the high sound levels near the source can be seen as a shift in the distribution near the source region (x = 0.5 - 0 coordinates).

8.2.1 Probability of avoidance calculations

The approximate track density function for the playback control condition and each of the pooled playback stimuli were determined using the procedure described in Sec. 3.4.2. A "probability of avoidance" estimate was then made using the relationship

$$P_{a(y)} = \left(P_c(y) - P_s(y)\right)/P_c(y) \tag{8}$$

The Probability of Avoidance is thus defined as the difference between the track density under control conditions, $P_c(y)$, and the track density under experimental conditions, $P_s(y)$, normalized by the control condition track density. Thus, if for a given value of y, the density during experimental conditions was the same as during control conditions, the probability of avoidance at that point would be 0. Conversely, if no tracks were found near the same y value under experimental conditions, the probability of avoidance would be 1.

The procedures described previously in Section 3.4 were used to obtain track density plots for the playback and air gun tests using the summed cumulative track distributions. These tracks, shown previously in Figs. 7.3 through 7.8 were then compared with corresponding density distributions for control periods to obtain the probability of avoidance for each stimulus.

The probability of avoidance plots for the playback and air gun tests are shown in Figs. 8.6 through 8.11. The control, test, and avoidance densities are shown in each figure for

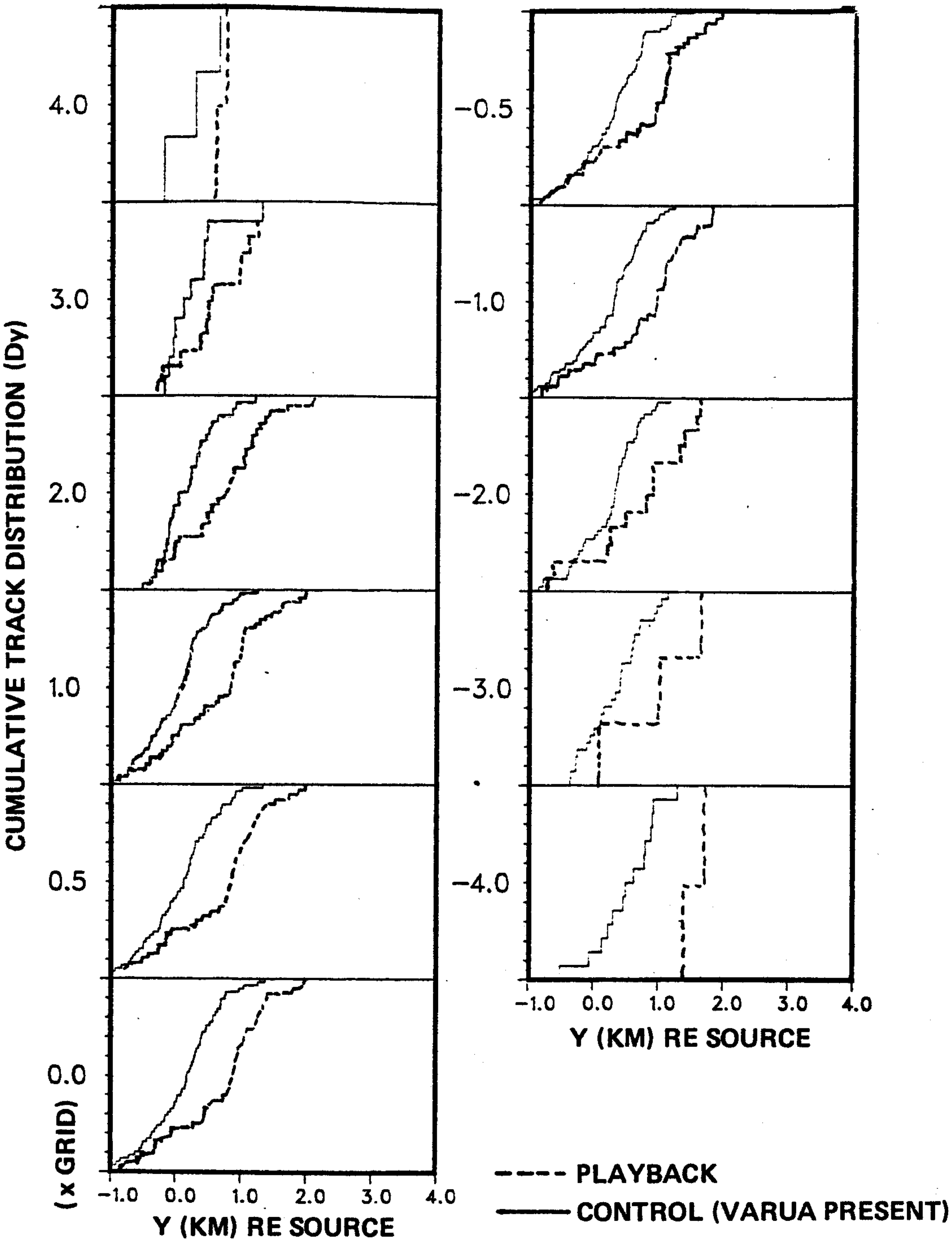


FIG. 8.4. TRACK DISTRIBUTION COMPARISON, POOLED DRILLSHIP PLAYBACK VERSUS CONTROL.

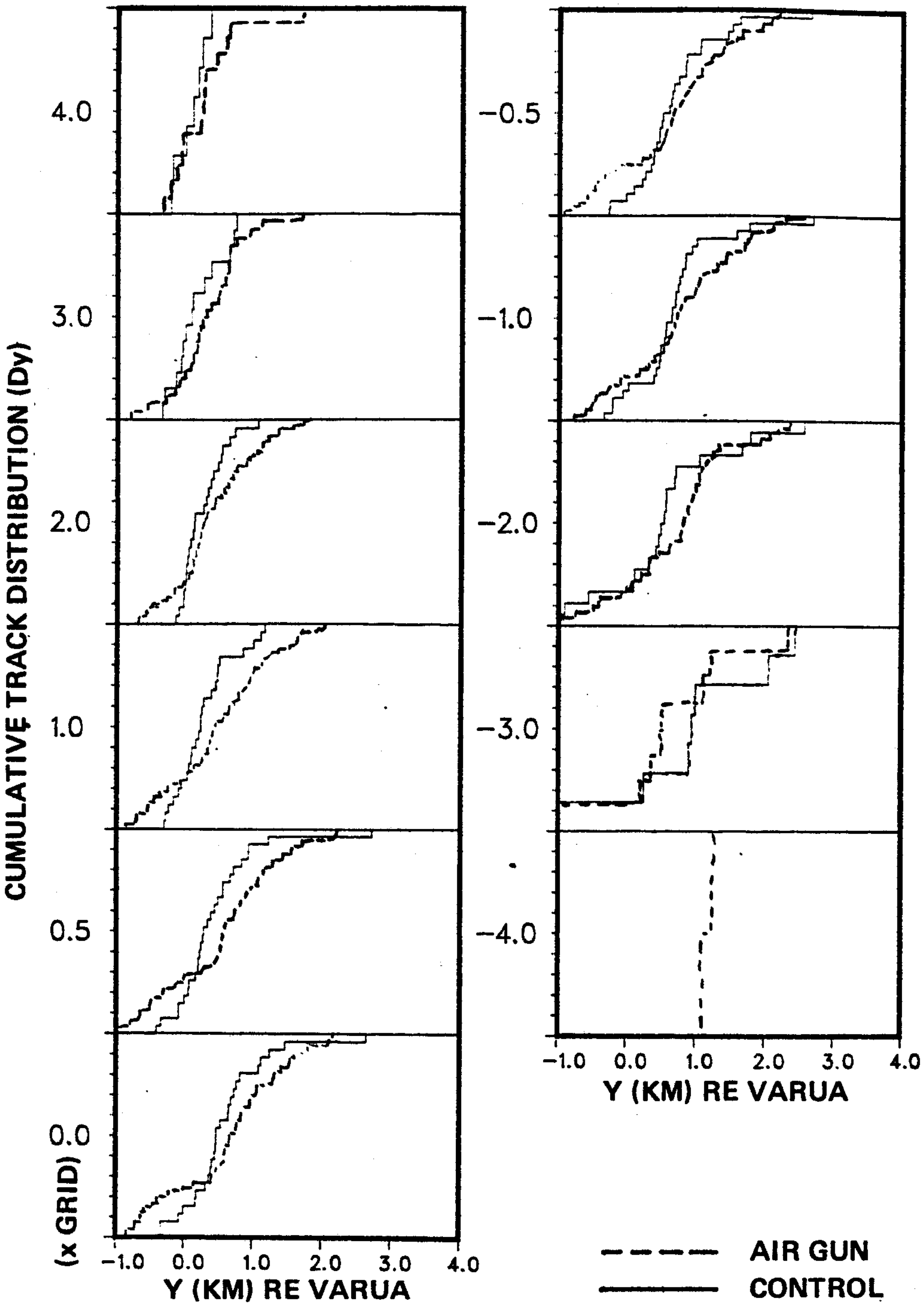


FIG. 8.5. TRACK DISTRIBUTION COMPARISON, MOORED AIR GUN VERSUS CONTROL.

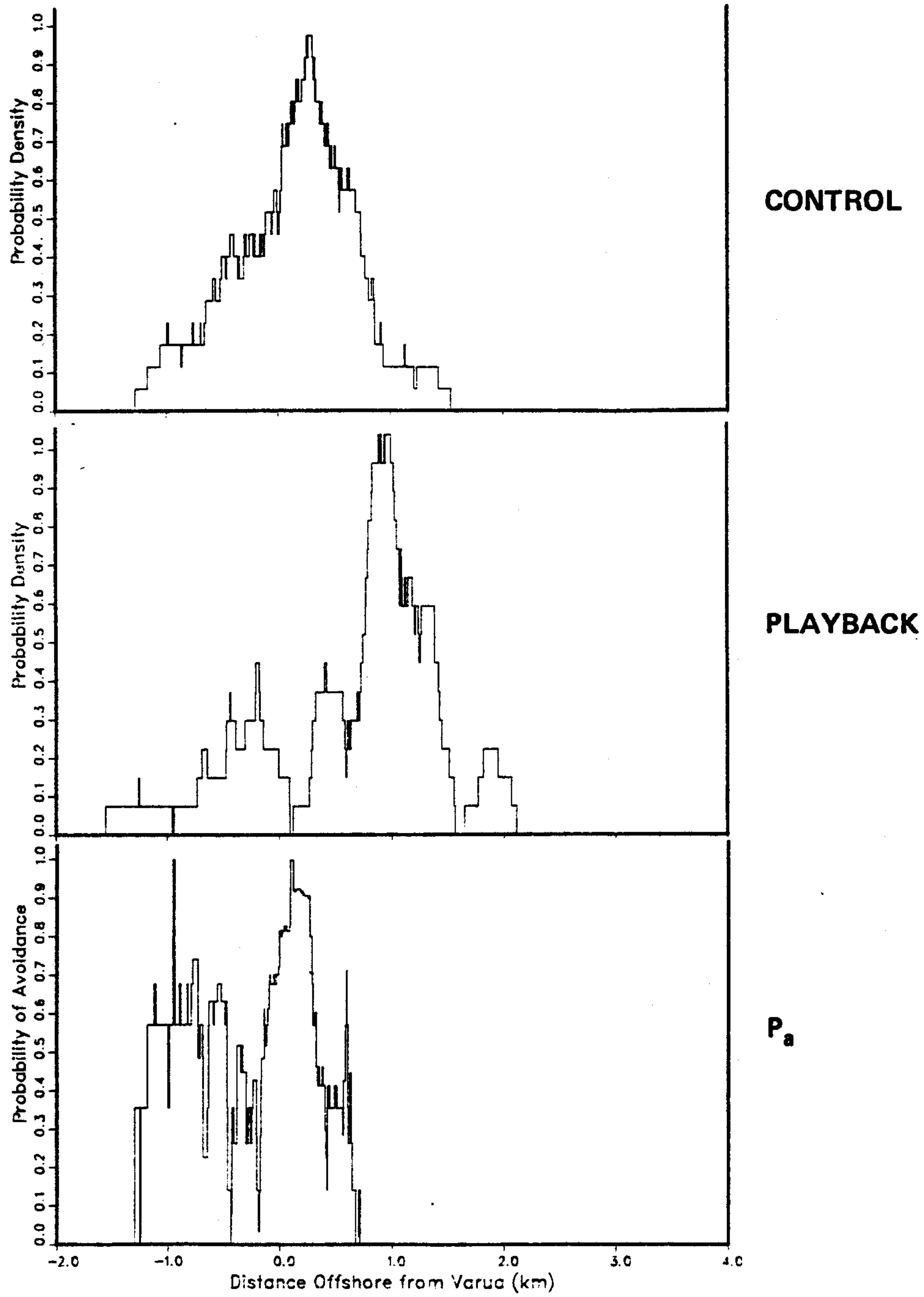


FIG. 8.6. DRILLSHIP AVOIDANCE ANALYSIS.

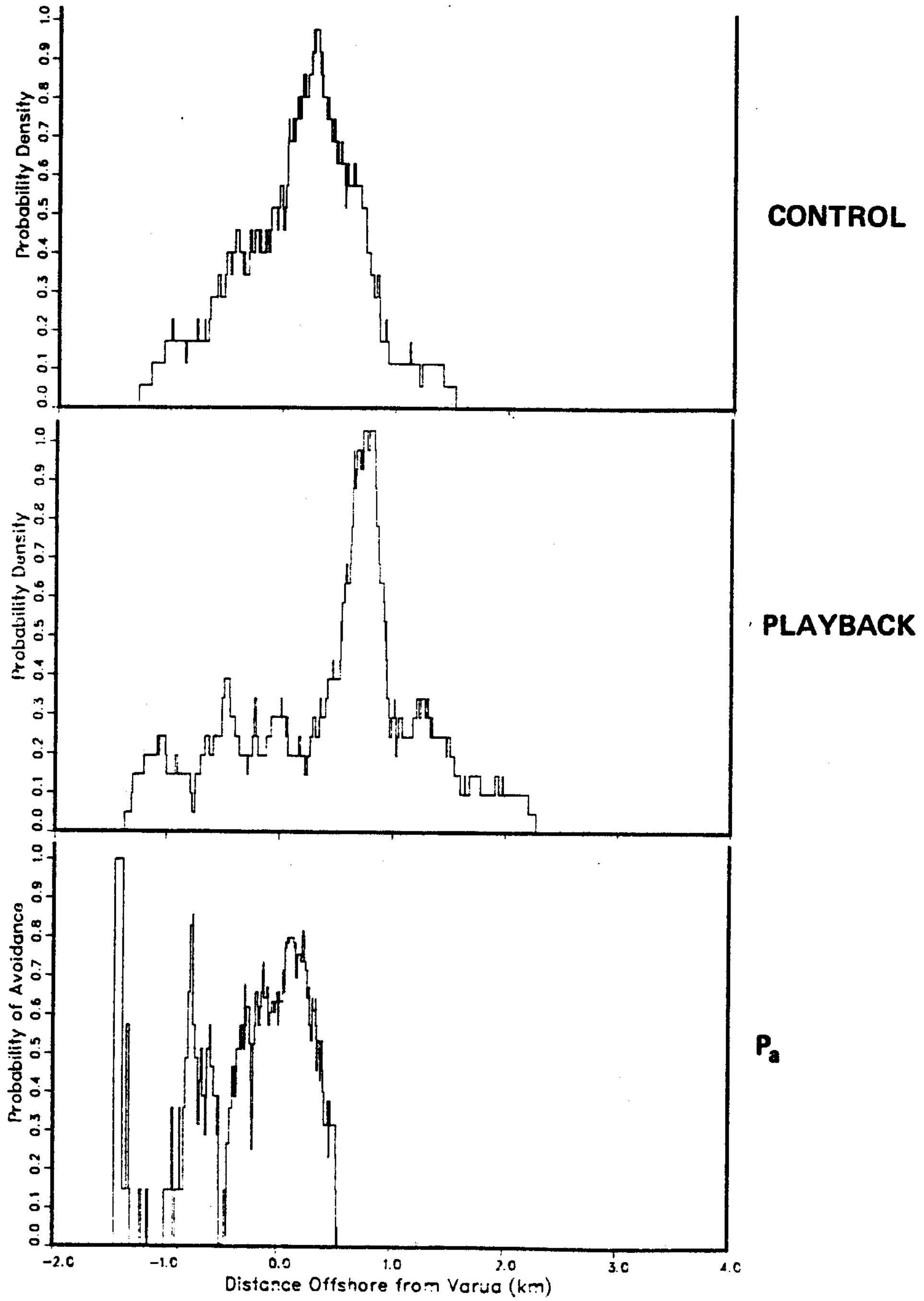


FIG. 8.7. DRILLING PLATFORM AVOIDANCE ANALYSIS.

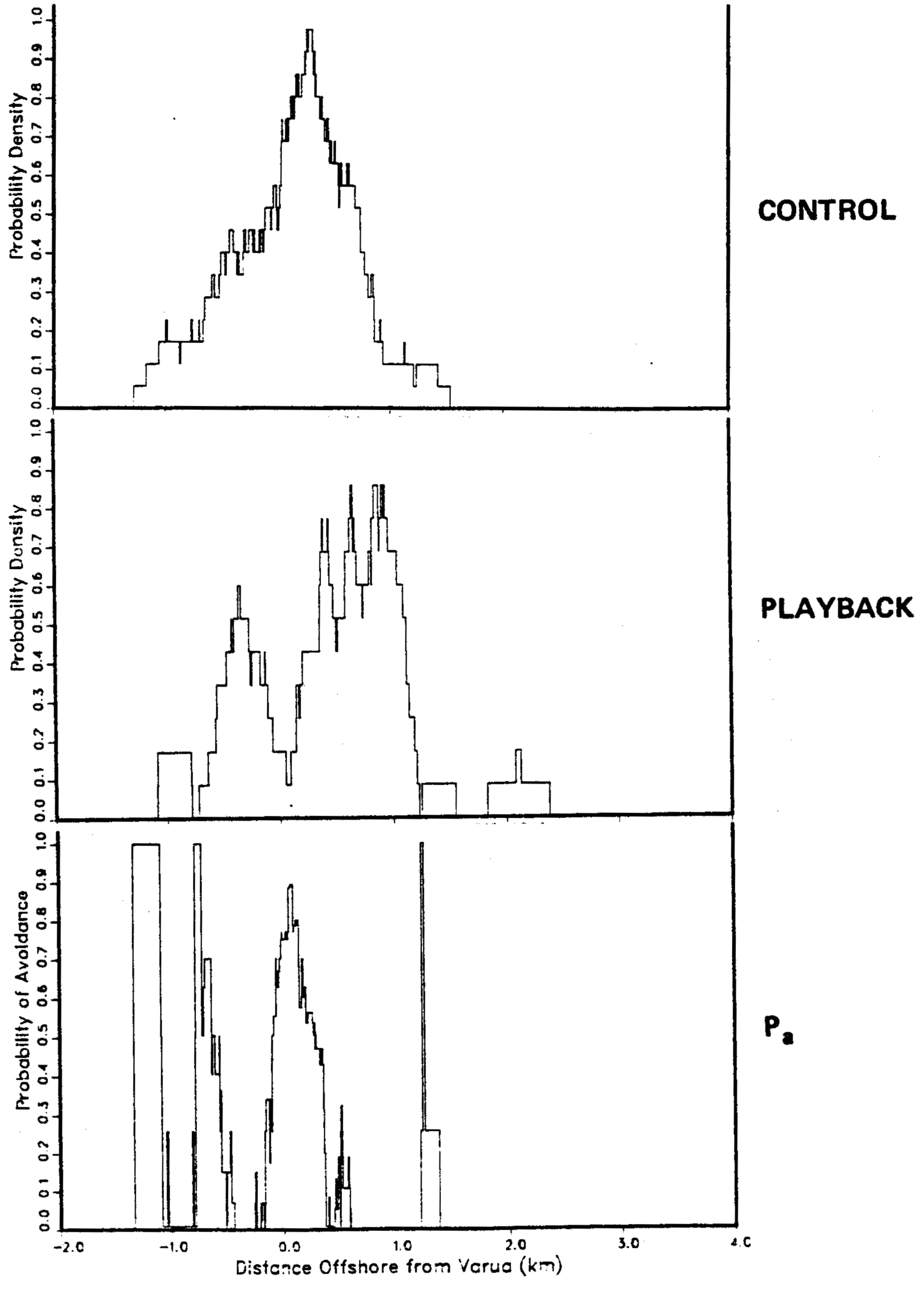


FIG. 8.8. PRODUCTION PLATFORM AVOIDANCE ANALYSIS.

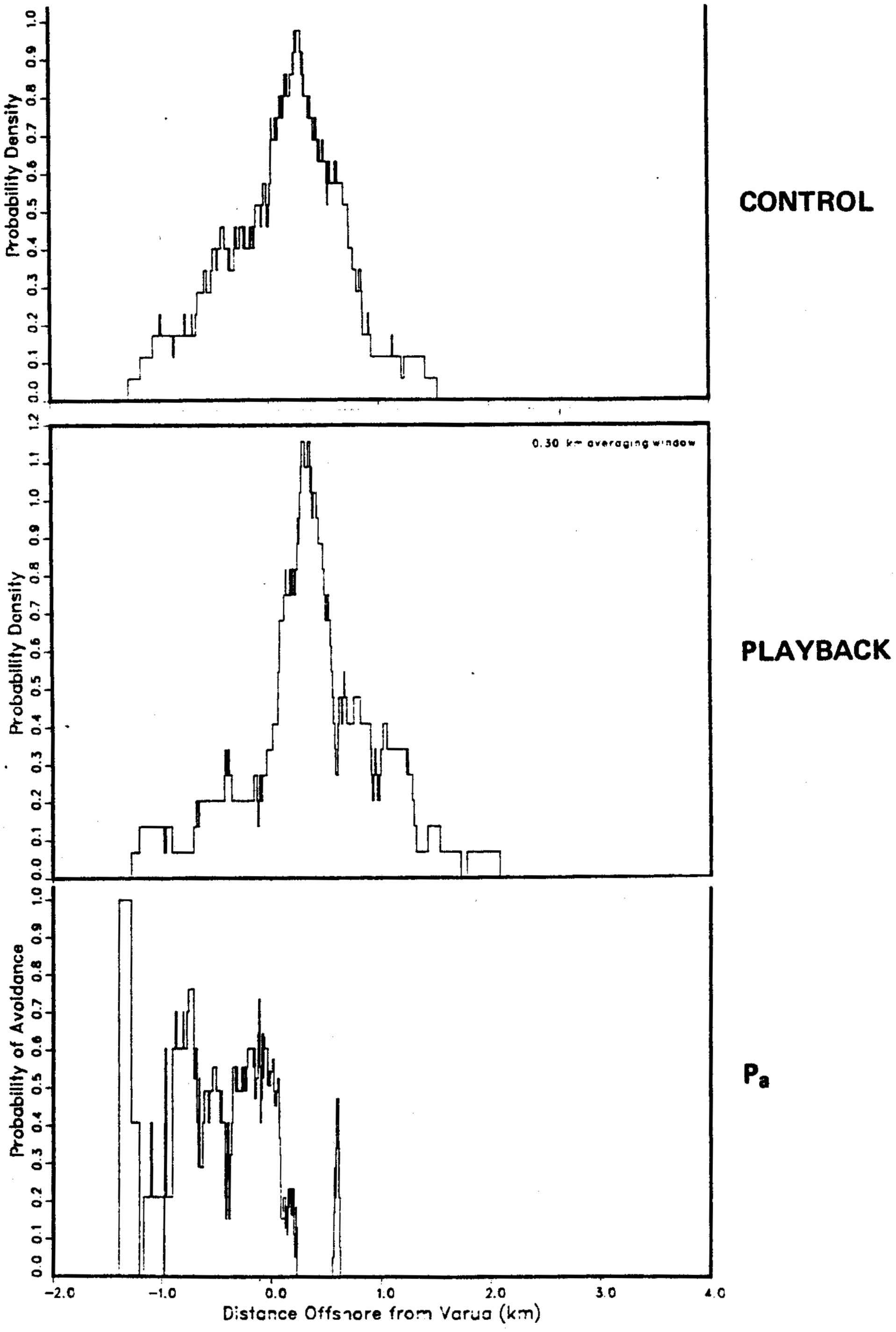


FIG. 8.9. HELICOPTER AVOIDANCE ANALYSIS.

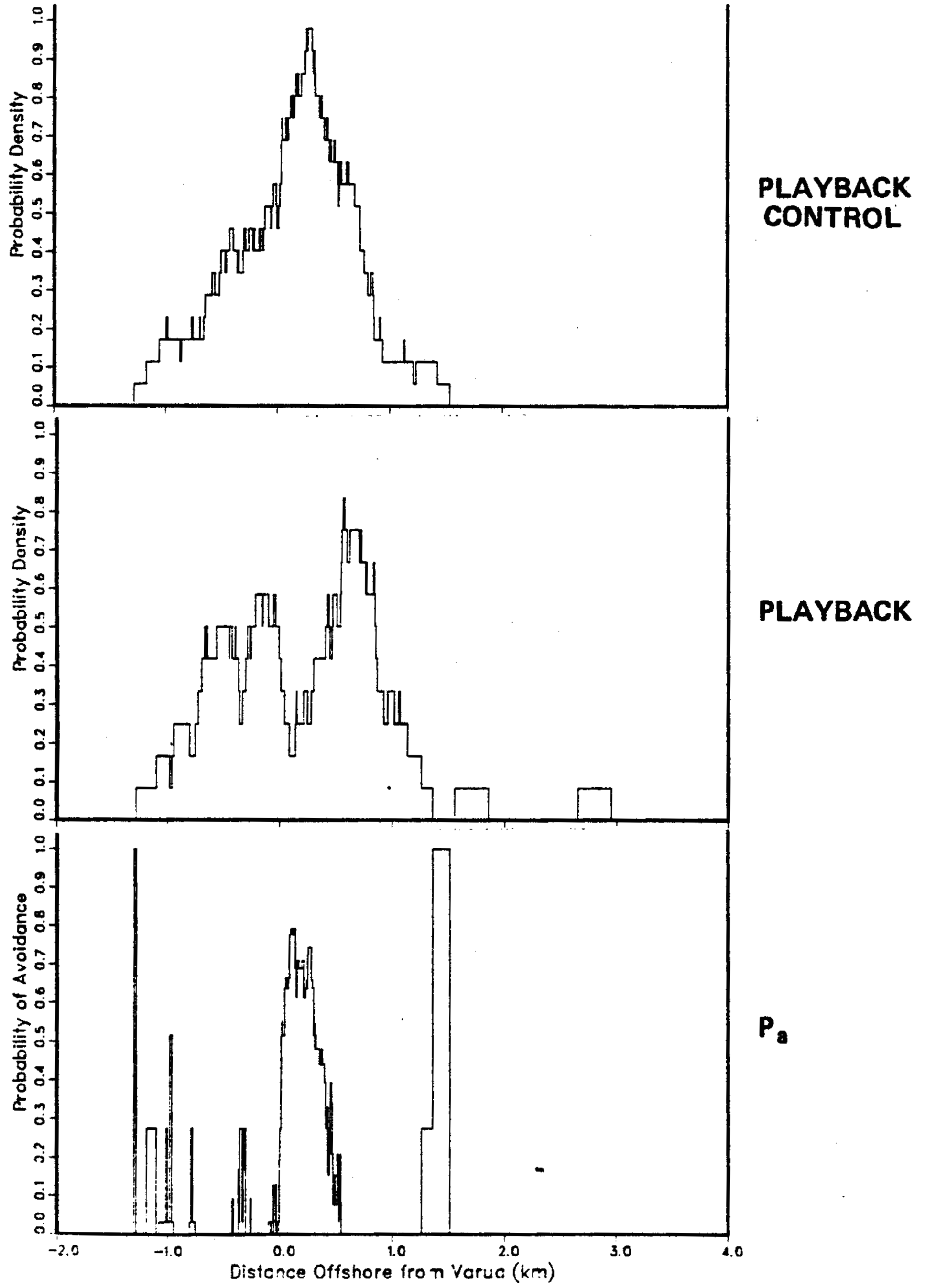


FIG. 8.10. SEMISUBMERSIBLE RIG AVOIDANCE ANALYSIS.

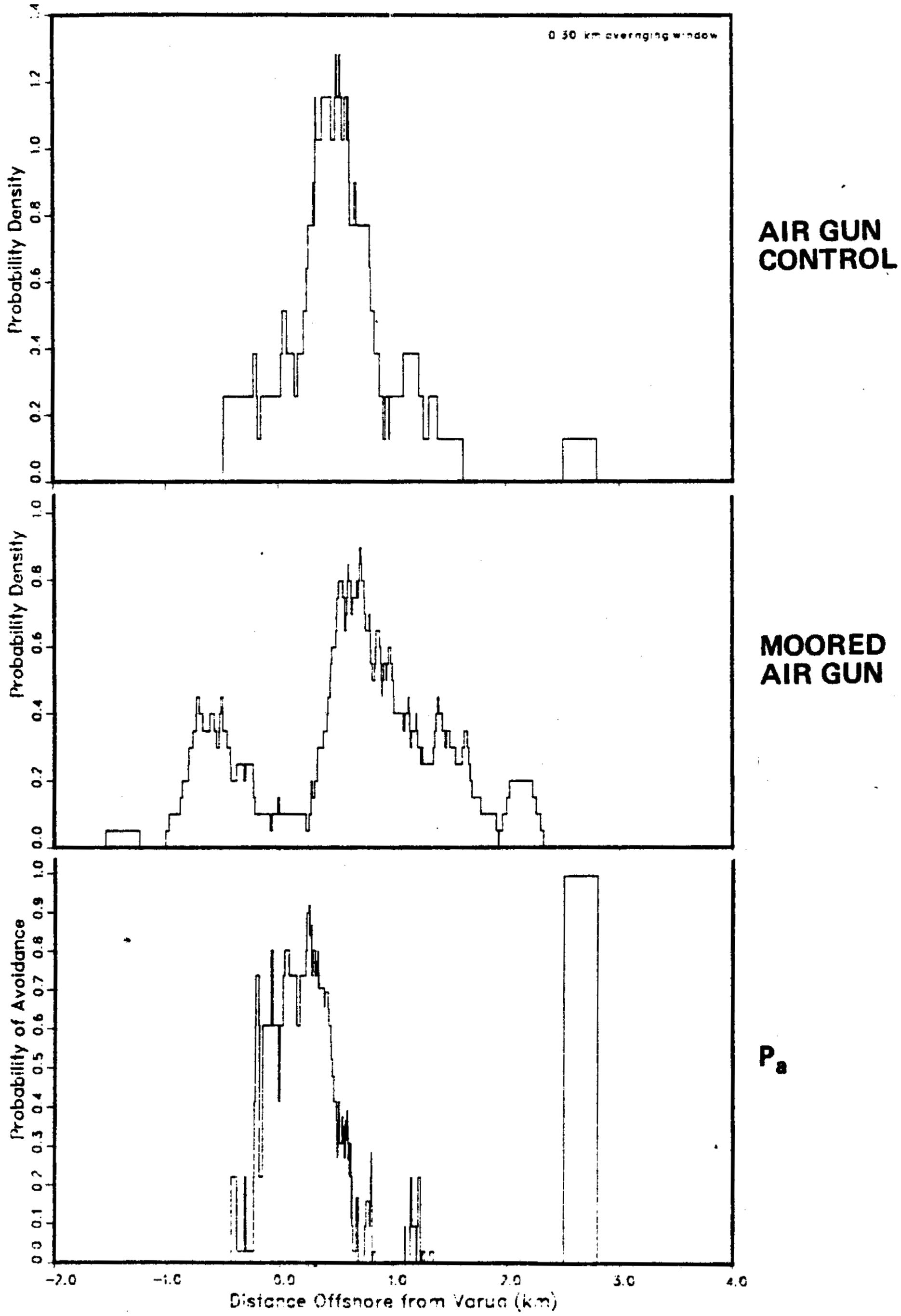


FIG. 8.11. MOORED AIR GUN AVOIDANCE ANALYSIS.

comparison. Note that some of the density values exceed 1. This is an artifact of the windowing approximation and results from not using a normalized y coordinate system. We wished to retain an absolute y coordinate reference to permit comparison of density plots obtained from distributions with an unequal number of samples. The y distance values on the plots can be considered to be normalized to 1 km rather than to the distance of the last observed track.

The probability of avoidance plots shown in the figures are obtained by computer implementation of Eq. (8) using the data shown in the control and test track density plots. No editing of the density plots was performed prior to the processing. As a result, the small sample difference regions in the tails of the density plots show up as large avoidance regions because of the normalization process. The significance of the avoidance density plot values can be judged by the length of their vertical increments. If a large number of samples were present in the original distributions, the vertical increments in the density plot are small; hence a small sample size produces a large vertical increment, consequently, even a low density of whales at a given y value in the control distribution will produce a large avoidance value if it was not matched or there were no whales at that y value during the experimental conditions. In interpreting the results of the probability of avoidance analysis, the central regions near the source thus are the principle regions of interest.

As a test of the sensitivity of the procedure, the track density for the control period with the VARUA present (with no playback) was compared with the track density for the combined control days with no boat present. The probability of avoidance density was calculated and the results are shown in Fig. 8.12. The central region of the avoidance density plot shows that some avoidance of the VARUA on 18 January was occurring. The prob-

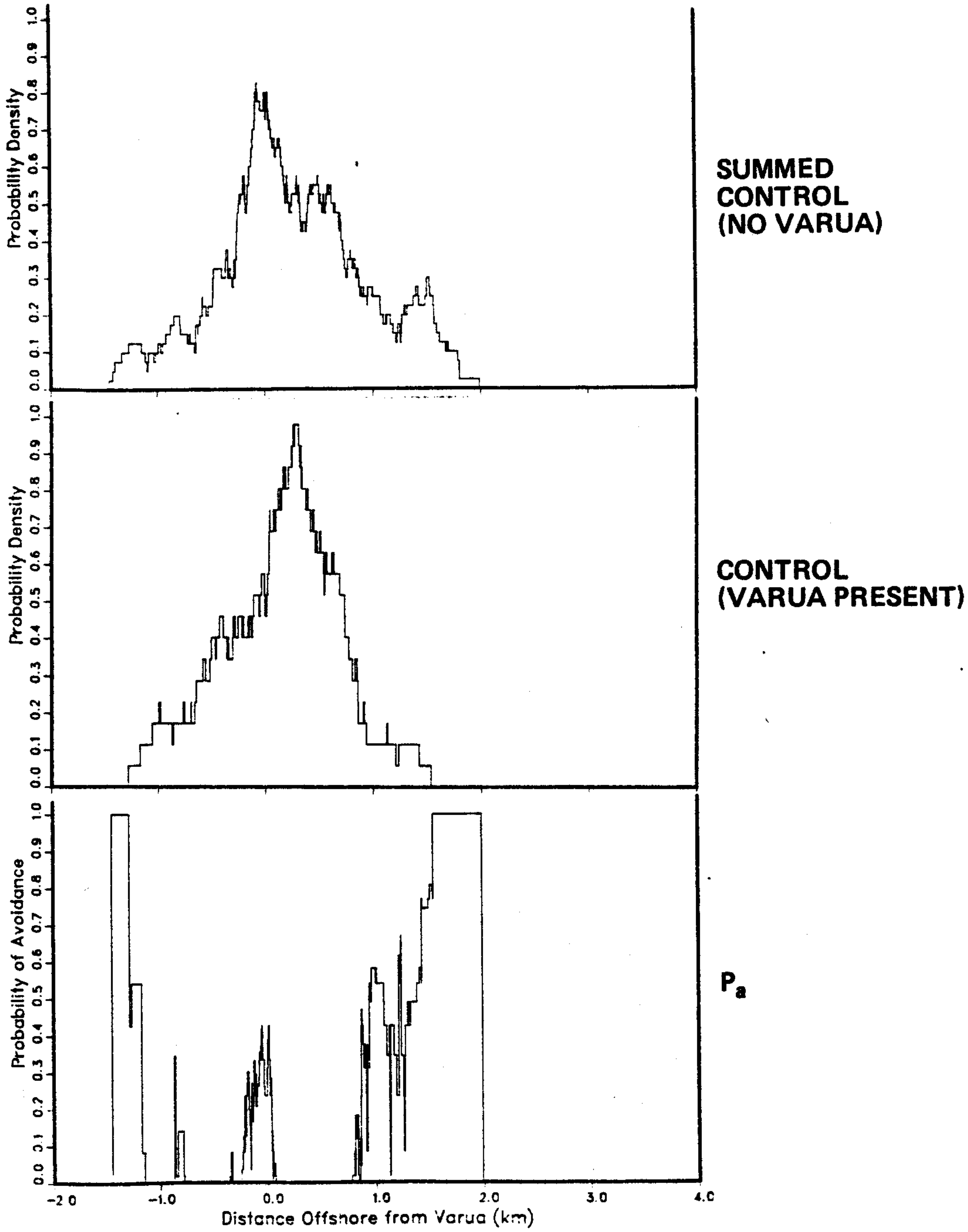


FIG. 8.12. COMPARISON OF CONTROL PERIODS.

ability values are considerably lower than those observed in the previous figures for acoustic stimuli, however. Note that the control used for the previous avoidance probabilities was the period with VARUA present so that this VARUA effect was considered in the calculations.

8.2.2 Determination of acoustic response characteristics

The probability of avoidance plots can be used directly to relate avoidance distances to specific sources and to sound level values. This can be done by recognizing that the y values shown in the plots can be converted to equivalent sound exposure levels by using Eq. (7) from Sec. 5. The mean value of the stimuli source levels can be obtained from Table 3.1 for the playback tests. For the air gun tests, Eq. (6) can be used directly to obtain the equivalent pulse pressure level from range values.

By using the relationships just described, the probability of avoidance plots shown in Figs. 8.6 through 8.11 can be converted to plots showing probability of avoidance versus sound exposure level. This "acoustic response characteristic" has the advantage of not being site-specific and, hence, is more generally applicable than plots which relate sound exposure level to range in a given test area. If the probability of avoidance plots were symmetrically centered on the source location, conversion of range values to sound exposure values would involve only an application of the sound propagation equations cited. However, as can be seen in the figures, the avoidance curves are generally neither symmetric nor centered on the source location. This asymmetry is mostly a result of the fact that whales under normal conditions were not distributed uniformly or symmetrically relative to the migratory path, and they tended to avoid the playback source area by diverting to seaward. As a result, the analysis required a method of utilizing both sides of the avoidance probability curve relative to the source position in determining an average sound level for a given probability level.

The procedure that was employed involved the following steps:

- Shift the avoidance density distribution to be centered on the source (this involved a shift of less than 1 window-width, 300 m, for all stimuli)
- Weight the range values in both tails of the distribution in accordance with their sample density and calculate the average avoidance range for a given probability level.
- Calculate the sound exposure value for the average range using the effective source level for the stimulus.

The results of this procedure were plotted for each stimulus and are shown in Fig. 8.13.

Examination of Fig. 8.13 shows that for the playback stimuli, the drillship sound produces an avoidance reaction at the lowest level (110 dB re 1μ Pa). The production platform does not seem to produce an avoidance reaction until a level of about 119 dB is reached. The other playback sounds produce reactions midway between the drillship and production platform. However, all of the playback stimuli seem to produce nearly complete avoidance at sound exposure levels of 130 dB and higher. Resolution of the avoidance distances for levels greater than 130 dB was limited by the analysis window width (see the playback sound contour plot in Fig. 8.1).

In contrast with the playback stimuli avoidance levels, the air gun does not seem to produce significant avoidance until effective peak pressure levels of 164 dB are reached. Nearly complete avoidance occurs at levels of 180 dB. The difference in

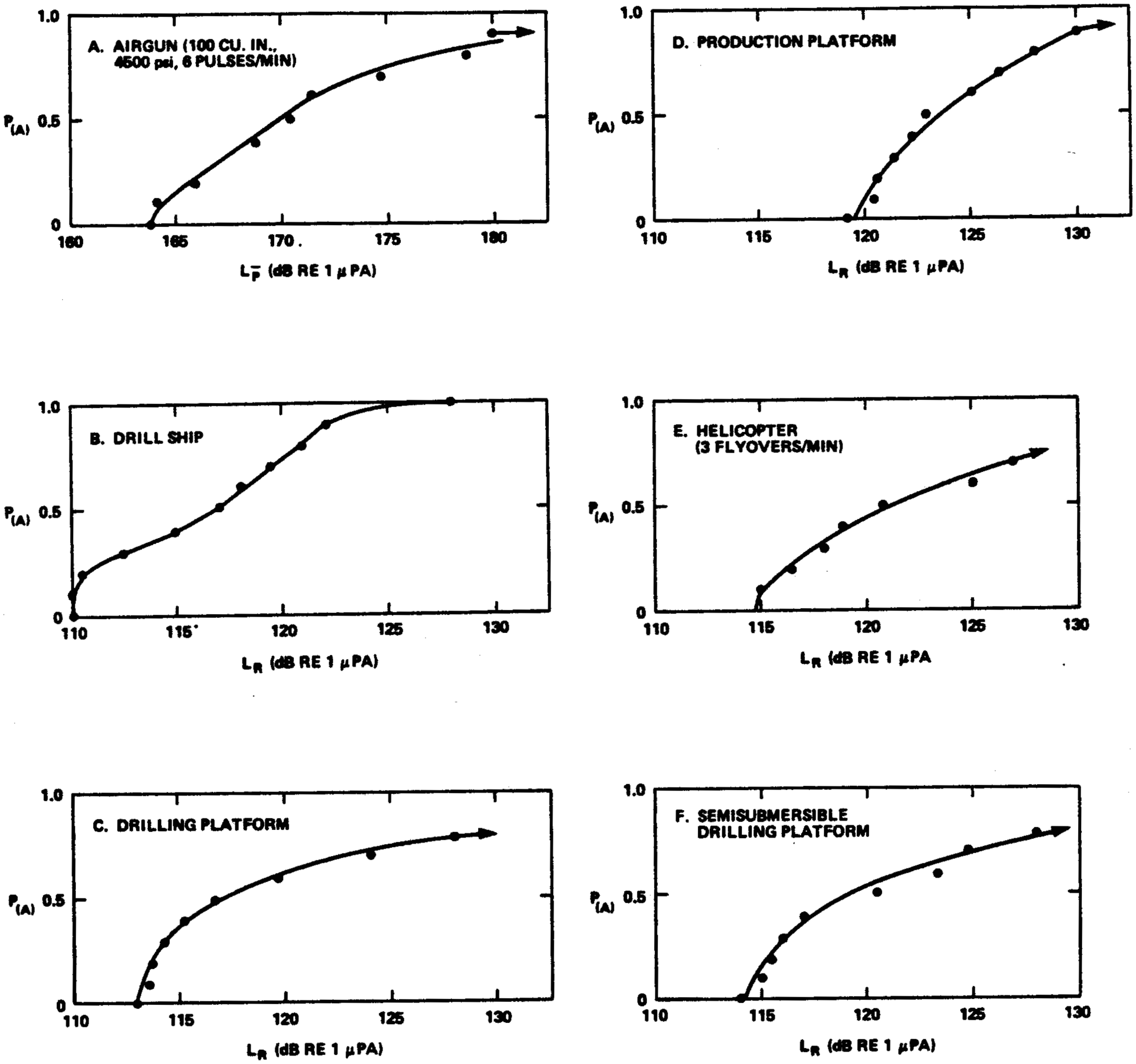


FIG. 8.13. PROBABILITY OF AVOIDANCE CHARACTERISTICS FOR PLAYBACK AND AIR GUN STIMULI.

avoidance level between the continuous sound of the playback tests (with the exception of the helicopter) and the impulsive sound (6 pulses/min.) of the air gun thus ranged from 50 to 55 dB. This is similar to the difference in sound levels reported for tests of equivalent noisiness with human subjects when comparing continuous and impulsive noise (Fidell, et al., 1970).

8.3 Application of Acoustic Response Characteristics

The acoustic response characteristics relate avoidance behavior to sound exposure levels. In this application, the data for deriving the characteristics were obtained using specific types of sounds and observing the swimming behavior of migrating gray whales. Thus, application of these characteristics to predict avoidance reaction in other areas must be limited to the same species and similar circumstances.

8.3.1 Industrial noise sources

The range at which a given probability of avoidance will occur for a planned operation site can be estimated if the effective source level is known and the sound transmission loss (TL) for the area in question is either known, or can be measured or estimated. The maximum sound exposure level for the selected avoidance criterion is obtained from the characteristic for the playback stimulus which most closely matches the spectrum of the planned source. A sound level contour can then be drawn showing the expected avoidance zone for this criterion.

8.3.2 Air gun and seismic array sources

Site-related TL characteristics are also required for estimating the probable avoidance distance for air gun operation in other areas. Figure 8.12 shows that an effective pulse pressure level of 170 dB will produce a 0.5 probability of avoidance. The

0.5 probability level is used rather than the customary 0.95 level since the 0.95 level is not adequately defined by the available data. Since seismic array operations are of more interest than single air gun sources, an estimate of the range for .5 probability of avoidance of a 4,000 cu. in. air gun array will be made using data from Report 5366.

Several complicating factors prevent direct scaling of seismic array and single air gun pressure versus range data. These factors can be understood by comparing the propagation models for the two types of sources. The effective pulse pressure level for a 4000 cu. in. array operating in the test area was found to have the following propagation model

$$L_p = 190 + (DI) - 5 \log(d_s) - 25 \log(R) - 440\left(R/(d_s+d_r)\right) + 6 \text{ (dB re } 1\mu\text{Pa)} \qquad (9)$$

where DI is a horizontal directivity factor resulting from the length of the array relative to the dominant wavelength of the signal, R is the distance from the source (km), and d_s, d_r are the source and receiver depths, repectively, in meters. For completeness, the propagation model for the single air gun, given previously as Eq. (6), is repeated here

$$L_p = 168 - 5 \log(d_s) - 15 \log(R) - 440\left(R/(d_s+d_r)\right) + 6 \text{ (dB re } 1\mu\text{Pa)} \qquad (10)$$

Note that, in addition to the directivity of the array, the acoustic spreading loss terms are different, with a 25 log(R) slope for the array as compared to the more usual 15 log(R) slope for the single air gun. In shallow water where these sources are most often operated, the bottom loss term, which has a linear range dependence, is also very important. Thus, the pulse pressure outputs of these sources cannot be related by a simple range ratio.

A scaling relationship between the array and single air gun can be derived by setting the two above equations equal to each other if range scaling is required for equivalent pressure levels. If pressure scaling is required, the equations can be used independently to obtain required range equivalents for given operating depths and desired peak pressures. The relationship between single air gun and array pulse pressures is illustrated in Table 8.1 which was developed using the above propagation relationships for the test area together with the airgun avoidance data from Fig. 8.13.

The range values shown in Table 8.1 should not be used for other areas without first examining the known or estimated TL characteristics for the areas in question. If there is a good degree of similarity with the TL values obtained for the study area off the California coast, then the range values of Table 8.1 could serve to provide general estimates for the new area. Where TL differences are expected or known to exist, the propagation equations should be modified accordingly, preferably by using measured data.

TABLE 8.1. EFFECTIVE PEAK PRESSURE VERSUS RANGE RELATIONSHIPS BETWEEN AIR GUN AND SEISMIC ARRAY SOURCES IN THE TEST AREA.

		Predicted Range (d_r = 50 m)			
		d_s = 50 m		d_s = 200 m	
P_a	L_p dB//1 μPa	Air Gun (m)	Array* (km)	Air Gun (m)	Array* (km)
0.1	164	750	2.8	650	3.6
0.5	170	400	2.1	300	2.5
0.9	180	100	1.2	70	1.2

Air Gun - 100 cu. in., 4500 psi, 6 pulses/min.

Array - 4000 cu. in., 2000 psi, 4 pulses/min.

*The predicted range values for the array are based on the assumption that the probability of avoidance sound exposure values for the array are approximately equal to those of the air gun.

9. CONCLUSIONS AND RECOMMENDATIONS

9.1 Conclusions

The following conclusions summarize the results of the behavioral observations and acoustic measurements for the January 1984 field tests and the subsequent data analysis. The conclusions generally agree with those stated in Report 5366 covering the previous field work. Any differences which have been found are generally minor and are usually the result of obtaining a larger data base.

9.1.1 Behavioral responses of gray whales during southbound migration

In order to assess the possible responses of migrating gray whales to industrial and air gun sounds, the track deflection program developed for last years' study was used. The measures for assessing responses were:

Track deflection (D_y) - the distance inshore or offshore of the sound source (VARUA or Cheyenne Arrow).

Speed - Cumulative speed of a whale group for a particular interval.

Course bearing - The course of the whale group for a particular interval.

VARUA bearing - the angle between the course of the whale group and the bearing to the sound source.

Probability density functions which measure the percentage of tracks crossing a segment of a grid line were developed from the track deflection cumulative frequency data on the D_y score. These probability density functions illustrated the effects of the sound playbacks in km of displacement of the whales from their normal migratory swimming patterns.

A measure of the probability of avoidance was developed by comparing the densities of whale tracks under control and experimental conditions. The results of this analysis are presented in Sec. 9.1.2.

The results of comparing all playbacks pooled together compared to a pooled control condition strongly indicate that whales avoided the area of the playback source and there was some indication that they slow down both before and after passing the source. The results of the track deflection program for each acoustic exposure are presented in Table 9.1. This table shows that each stimulus except for semi-submersible evoked statistically significant responses.

9.1.2 Acoustic measurements

Playback Source

The playback tests again demonstrated that gray whales have low-frequency hearing thresholds which are below the prevailing ambient noise levels in the test area. This was initially observed using orca vocalization playback stimuli during the January, 1983 field tests. It was confirmed again during the January, 1984 tests when small changes in course bearing were observed at a range of 3 km in response to industrial noise playbacks. The signal levels of the playback stimuli at this range approached 0 dB in the loudest 1/3 octave band of the signal. The result of these course changes, as the whales approached the sound source, was an increase in the distance between the whales and the source at the closest point of approach. This behavior was defined as avoidance behavior.

TABLE 9.1. SUMMARY OF RESPONSES OF GRAY WHALES TO SIX CATEGORIES OF ACOUSTIC EXPOSURE USED IN THE JANUARY 1984 SOUTHBOUND MIGRATION FIELD SEASON.

	Acoustic Exposure					
Statistical Measure	**Production Platform**	**Drilling Platform**	**Drillship**	**Semi-submersible**	**Helicopter**	**Moored Air Gun**
Track Deflection (D_y)	deflect away at +1.0 km to -0.5 km and at -2.0 km	deflect away at +1.0 km to -2.0 km	deflect away at +2.0 km to -2.0 km	NS	deflection at -1.0 km to -2.0 km	deflect away at +3.0 km to +1.0 km and at 0.0 km
Speed	slow down at at +2.0 km to 0.5 km and at -1.0 km to -3 km	one case of slow down and at +3.0 km to +2.0 km	speed up at +0.5 to 0.0 km slow down and 0.0 km to -1.0 km	NS	NS	slow down at 0.0 km to -0.5 km
Compass Bearing	NS	NS	One case of deflection at +2.0 to +1.0 km	NS	deflection at +3.0 to +1.0 km	deflect away at +2.0 km to 0.0 km
VARUA Bearing	deflect away at 1.0 km to 0.5 km	deflect away at + 3.0 km to -1.0 km	deflect away at +2.0 km to -2.0 km	one case of deflec- at -2.0 km to -3.0 km	deflect away at +3.0 km to +2.0 km, at +0.5 km to 0.0 km and at -0.5 km to -2.0 km	deflect away at 1.0 km to 0.0 km

An analysis procedure was developed which permitted determination of the probability of avoidance of the region near the playback source. This measure showed that avoidance behavior began at sound exposure levels of around 110 dB (re 1 μPa) for the overall signal and was greater than 80% for regions with signal levels higher than 130 dB. Some variation among the various playback stimuli was observed with the drillship producing the greatest avoidance and the production platform the lowest, for levels between 110 and 125 dB. However, for levels between 125 and 130 dB the reactions to all playback stimuli were comparable.

The results obtained using the probability of avoidance analysis demonstrated greater sensitivity to small track distribution changes than the Kolmogorov-Smirnov test procedure. This is particularly true for track distribution changes which primarily affect the variance of the distribution without producing much change in the mean. For the semisubmersible rig playback and, to some degree, for the air gun experiment, the whale tracks diverged both inshore and offshore of the source area rather than the overall distribution of tracks deflecting seaward as was the case for most of the playback experiments. Thus, for the semi-submersible playback, the Kolmogorov-Smirnov tests did not show significant differences between the control and experimental conditions, but the avoidance analysis did show a considerable change in the track density near the source when compared to the control condition track density in the same area.

Air Gun Source

The probability of avoidance analysis for the air gun source showed that the threshold of avoidance behavior occurred for effective peak pressure levels around 164 dB. This was somewhat higher than the level of 160 dB which was observed to produce changes in the migration behavior of mother-calf pairs during the April-May 1983 field test. Effective peak pressure levels of 180 dB (re 1μPa) were observed to produce nearly complete avoidance of the area.

Effective Range of Operating Sources

A summary of the results of the probability of avoidance analysis is given in Table 9.2(a) for the playback stimuli and the air gun. An estimate of the effective range of the original petroleum industry sources was made by assuming that they were operating in the test area. This was necessary because TL characteristics for the original source locations were not available (except for the drillship). The TL characteristic shown in Fig. 5.11 was used for ranges greater than 100 m with the assumption that the source was at the VARUA position. For ranges less than 100 m a 20 log (R) characteristic was assumed. With these assumptions, Table 9.2(b) was developed which shows the effective range of the sources for a 0.5 probability of avoidance. Note that the effective range of most of the noise sources is less than 100 m if the very low frequency components of their signals produce avoidance reactions comparable to the playback spectrum at the same exposure level.

In making this estimate of effective range, we have considered that the hearing sensitivity of gray whales for low frequency noise components below 40 Hz is comparable to their hearing sensitivity in the playback range above 40 Hz. The low frequency sound exposure levels producing a 0.5 avoidance probability for each source were thus considered to be equal to the values determined using the playback data for that source. The effective range values estimated for the low frequency components should thus be conservative since it is probable that the low frequency hearing threshold of whales actually becomes

TABLE 9.2(a). COMPARISON OF PROBABILITY OF AVOIDANCE LEVELS FOR THE TEST STIMULI.

Stimulus Level, dB re 1μ Pa

P_a	Drillship	Drilling Platform	Production Platform	Helicopter	Semi-submersible	Avg. Playback	Air Gun (Seismic Array)
0.1	110	114	120	115	115	115	164
0.5	117	117	123	120	120	119	170
0.9	122	>128	>129	>127	>128	>127	>180

TABLE 9.2(b) EFFECTIVE RANGE IN TEST AREA FOR $P_a = 0.5$

	Drillship	Drilling Platform	Production Platform	Helicopter	Semi-submersible	Air Gun	Seismic Array^5
Sound Level at 100 m	136$^{(1)}$	89 (109)^2	109 (118)	103$^{(3)}$ (118)	101 (111)	180	212 (dB re 1μPa)
Sound Level for P_a=0.5	117	117	123	120	120	170	170 (dB re 1μPa)
Required TL Change	19	-28 (-8)	-14 (-5)	-17 (-2)	-19 (-9)	10	42 (dB re 1 m)
Est. Range for P_a=0.5	1.1 km	4 m (40 m)	20 m (56 m)	14 m$^{(4)}$ (79 m)	11 m (35 m)	400 m	2.5 km

Notes:

(1) Estimated sound level at 100 m for broadband or summed tonal components of original source included with good fidelity in playback (from Table 3.1).

(2) Estimated sound level at 100 m of loudest low frequency tonal components of original source not reproduced adequately by playback (from Table 3.1).

(3) These levels are estimated for a direct flyover at an altitude of 100 m.

(4) These values are altitude predictions for producing 120 dB in the water at a point just below the surface for a direct flyover.

(5) Data from Report No. 5366, array orientation-broadside.

(6) Referred to transmission loss at 100 m.

less sensitive at low frequencies as an adaptation to the characteristic of low frequency ambient noise in the ocean which increases in level as frequency decreases.

The values of 1.1 km for the drillship and 2.5 km for the seismic array for a 0.5 probability of avoidance show that these sources are much more important from the standpoint of potential migration behavior impact than are the drilling platform, production platform, semisubmersible rig, and helicopter sources which have only short range effects for the examples tested.

9.2 Recommendations

9.2.1 Acoustic studies

The procedure developed for obtaining the approximate probability density plots from the track frequency distributions needs to be refined to minimize the effects of the discrete increments in the distribution, particularly for distributions with smaller sample sizes. A smoothing window function such as a Gaussian or Hanning window may be better than the rectangular window used in the present analysis.

The usefulness of the probability of avoidance characteristic should be tested by additional studies in other areas to determine if the predicted avoidance behavior is observed at the sound exposure levels determined in this study. Further study should be made of gray whales engaged in non-migratory activities such as feeding, to determine if sound avoidance levels change under different social context.

The problem with working with high cost sources such as air gun support vessels and seismic array vessels is that the desire to maximize the amount of time spent collecting test data comes at the expense of obtaining adequate control data. It is difficult to have the source remain inactive while control data are obtained. While we did better in this regard during the January, 1984, season than during the previous test periods, more control data would have been useful to improve the confidence levels of the statistical analysis.

9.2.2 Mitigating acoustic source impact

Platforms, Drillships, and Helicopters

The behavioral observations for the playback stimuli suggest that only the loudest industrial noise sources evoke avoidance behavior from migrating gray whales at ranges greater than 100 m. The effective decoupling of elevated platforms from the water surface probably is very useful in reducing the amount of acoustic energy radiated into the water from this type of source. Helicopters are a very localized noise source because of the limited area through which they radiate sound into the water. Thus, flight paths directed to minimize overflight of whales will also minimize the observed disturbing quality of helicopter noise. The loudest oil and gas industry sources, excluding seismic exploration sources, are probably drillships, dredges, tankers, and their icebreaking counterparts which are now being used in the arctic. Mitigation of noise from these sources is difficult. It can be achieved by design considerations in new construction, by modification of existing vessels, or by scheduling operations to have a minimal impact on periods of whale avoidance. Since all of these alternatives are expensive, it is important to establish the noise levels at which significant behavioral changes occur in the impacted species so that irrelevant noise reduction efforts can be avoided.

Seismic Sources

The directionality of the seismic array can be utilized to reduce sound levels near shore by directing survey tracks primarily normal to the shoreline, if the data overlap requirements of the survey permit this type of grid pattern. Surveys in shallow water (less than 100 m) are benefited by high bottom reflection loss if nonducted propagation conditions exist. Seasonal changes in propagation conditions should be studied to determine if there is a maximum TL period.

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APPENDIX A

OFFSHORE SEISMIC SURVEY HISTORY IN CALIFORNIA AND THE MIGRATION OF GRAY WHALES

Paul R. Miles

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A.1 INTRODUCTION

It has been established for many years that the California stock of the gray whale, Eschrichtius robustus, migrates annually along a coastal corridor between the breeding grounds in the lagoons of the Baja peninsula of Mexico to their feeding grounds in the Bering and Chukchi Seas near Alaska. Questions regarding the impact of increasing industrial activities on the gray whale, including oil and gas exploration and development operations along the continental shelf require answers since such activities often coincide with the presence of this endangered species either during migration, breeding, or feeding. As has been stated previously in this report and in the companion report, BBN No. 5366*, the overall objective of the BBN research effort is to investigate the behavioral response of migrating gray whales to acoustic stimuli associated with oil and gas exploration and development. Included in the present contract is a requirement to develop a history of offshore seismic surveying activities along the California coast and to determine the degree of coincidence of such activities with the presence of migrating gray whales.

The approach taken in the performance of this brief study has utilized the literature survey contained in BBN 5366, gleaning details from selected references in that survey and to distribute a questionnaire regarding offshore-California seismic survey operations to 53 companies and organizations. The history of survey operations has been developed using the available literature and questionnaire responses. Discussions and review of the files of the California State Lands Commission with regard

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*Malme, C.I., P.R. Miles, C.W. Clark, P. Tyack, and J.E. Bird, BBN Report 5366, "Investigations of the Potential Effects of Underwater Noise from Petroleum Industry Activities on Migrating Gray Whale Behavior," November 1983.

to marine seismic survey activities also provided important data to this study. The questionnaires were distributed by the International Association for Geophysical Contractors (IAGC) for BBN and responses have been catalogued by code number only, so as to protect any proprietary information which could be associated with a given company. Further, the Minerals Management Service has been consulted and findings were reviewed regarding geophysical survey activities in California waters. A detailed summary of the gray whale migration characteristics along the California coast also has been compiled, updating earlier published information by Pike (1962) and others for comparison with the seismic survey history to determine the potential for coincidence of survey operations with migrating gray whales.

It must be stated at the outset that this seismic survey history must be considered to be an overview and should not be used as a complete or exhaustive itemization of survey activities since the commencement of major offshore subbottom profiling work during the 1940's. Necessarily, the extent of this history has been dictated in large part by the detail and number of responses to the questionnaire.

The following pages include the results of the development of a seismic survey history and a review of the types of seismic techniques used (Section A2), an update of the characteristics of the gray whale migration along the California coast (Section A3) and a comparison of the two reviews to determine the extent of coincidence between migrating whales and seismic survey activities in a conclusions section (Section A.4). A list of selected references is provided at the back of this Appendix.

A.2 SEISMIC SURVEY HISTORY

A.2.1 Background

Seismic exploration requires the use of high energy sources of sound or vibration to generate seismic waves in the earth's crust for the purpose of defining geologic structure. Multiple point firing of seismic sources and reception of refracted and reflected signals permits the definition of structural differences in the sub-surface geology through the use of appropriate signal processing. The ultimate purpose of such work is to locate geologic structures which are associated typically with the presence of oil or gas. Given the location of such structures, an organization may then decide to drill to the potential source. Early seismic work was done on land only and then started to be performed in marsh areas along the coast, particularly the Gulf coast, and then into the shallow waters of the continental margins. This expansion of seismic exploration into the marine environment commenced in the mid-1940s with the use of chemical explosives, primarily dynamite and TNT. Most of the oil and gas industry work was performed close to shore where reserves could be tapped with relative ease from land-based and near-shore drilling equipment. Academic institutions also performed surveys in both shallow and deep water, with the primary objective of developing an understanding of the geology and structure of the continental margins. Location of petro-fuel deposits was not a major interest of these groups (e.g., Lamont Geological Observatory, Scripps Institution of Oceanography, and Woods Hole Oceanographic Institution).

The almost exclusive use of explosives for geophysical exploration continued until the mid-1960's (Espey, 1977) concentrating on refraction survey techniques requiring a two ship operation. With this technique, one ship would fire a series of explosive charges while opening the distance from a second vessel having a hydrophone system for measuring arriving seismic signals which are refracted within the geologic structure. If a charge is fired at a deep depth to maximize energy coupling efficiency, a phenomenon termed bubble pulse oscillation causes a train of several high level pulses of sound. These multiple pulses cause a confused or "noisey" return signal from the geological structure.* The exploration industry solved the bubble pulse problem by firing the charges at a shallow depth where the initial bubble was vented to the atmosphere. This technique, however, required the use of larger explosive charges since the venting signficantly reduced the energy coupling efficiency. About 30 times as much explosive was needed to achieve the same useful seismic energy of a deep charge according to Mayne (1972) and Kramer, et al. (1968). Charge sizes ranged from 1- to 200-300 lbs of dynamite or similar chemical explosive, with most common sizes ranging from 30 to 50 lbs, depending on the application and desired depth of penetration of seismic energy.

The problems of handling, supply in remote areas and, to a large extent, concern regarding damage to fish and other marine life resulted in the development of new "non-dynamite" seismic energy sources commencing in the mid-1960 period. These sources tended to be relatively small in size and could be operated in arrays and fired with appropriate time control to achieve downward beamforming of the acoustic energy. With these new developments in seismic energy sources which could be fired repeatedly

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*The explosion causes a large rapidly expanding gas bubble to occur within the water volume. The momentum of that expansion carries the bubble volume beyond the point defining a balance between hydrostatic pressure and the released energy from the explosion. The hydrostatic pressure then causes the bubble to compress rapidly until the stored energy from the compression causes the bubble to rebound. This bubble oscillation can occur several times causing a high level pulse of sound with each rebound.

for long periods of time, the survey techniques evolved into using seismic reflection almost exclusively, permitting both source and receiver to be operated from a single vessel. Significant savings in operating costs resulted.

The non-dynamite sources include:

- air gun; compressed air discharge into a piston assembly
- sparker; electric discharge of a capacitor bank across electrodes
- boomer; electric discharge of a capacitor bank across two metallic plates
- gas sleeve exploder; ignition of a gas mixture (usually propane and oxygen) in a plastic sleeve
- water gun; high pressure water to solenoid-triggered piston
- Vaporchoc*; high pressure steam ejection through jets into the water
- Flexichoc*; impulsive exposure of an evacuated chamber to hydrostatic pressure
- Flexotir*; small charges (1/8-lb) of explosive contained in a perforated sphere
- Vibroseis*; continuously-driven piston with variable frequency waveform
- Aquapulse*; gas exploder.

In all of these new sources, various methods have been developed to either suppress or nearly eliminate the bubble pulse phenome-

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*Trademarks of: Compagnie Generale de Geophysique (Vaporchoc), Institute Francais du Petrole (Flexichoc and Flexotir), Continental Oil Co. (Vibroseis) and Western Geophysical Co. (Aquapulse).

non without the need to vent to the atmosphere.

In summary, dynamite and other explosives were used almost exclusively in marine seismic exploration work from the beginning in about 1945 until the mid-1960's. "Non-dynamite" sources now are used in 99% of the marine exploration surveys (Espey, 1977). These statements apply to all survey work done along the continental margins of the United States, including California, as well as throughout the world. Air guns and sparker systems have been used most extensively in the late 1970's and 1980's.

A.2.2 Typical underwater sound levels from sources

A comparison of typical peak-to-peak pressures calculated to occur at a distance of 1-meter from the source for various seismic exploration devices, with corresponding peak source levels (sound pressure level at 1-meter) is given in Table A.1. The standard exploration industry unit for peak-to-peak pressure generated by a device is bar-meters or the number of atmospheres (14.7 psi = 1 atmosphere or 1 bar) measured at a distance of 1 meter. Acoustic sound pressure level at 1 meter (source level) is computed from the peak-to-peak pressure according to the following algorithm,

$$L_s = 100 + 20 \log \left(\frac{P_{pp}}{2} \times 10^6\right)$$

where P_{pp} is the peak-to-peak pressure in bars. Energy sources in the table have been arranged in order of estimated source level. Levels for the non-dynamite sources apply to energy measured in a low frequency band, usually 0 to 125 Hz. The

TABLE A-1. SEISMIC ENERGY SOURCE CHARACTERISTICS.

	Size	Approx. Peak-to-Peak Pressure (bar-m)	Est. Source Level dB//µPa @ 1 m	Reference
Explosive Sources				
TNT (and 60% dynamite)	1#	448	267*	Arons (1954)
	30#	1416	277*	Arons (1954)
Black Powder	1#	40	246	Urick (1967)
Non-explosive Sources				
Air Gun Array	40, 100 in.^{3} guns (2000 psi)	63	250	Malme, et al. (1983)
Water Gun Array	18, 80 in.^{3} guns	36	245	Richardson, et al. (1983)
Vaporchoc II	2 kg steam (8 jets, 60 Bar)	32	244	Richardson, et al. (1983)
Air Gun	2000 in.^{3} (1 ea.)	18	239	Bolt Inc.
Flexichoc Array	16 elements	10	234	Richardson, et al. (1983)
Vaporchoc I	2 kg steam (1 jet, 60 Bar)	8	232	Richardson, et al. (1983)
Air Gun	100 in.^{3} (1 ea.)	4	226	Bolt Inc.
Air Gun	100 in.^{3}	2.5	222	Malme, et al. (1983)
Water Gun	80 in.^{3} (1 ea)	2.2	221	Seismic Sys., Inc.
Sparker	30 k-joule	2.2	221	Richardson, et al. (1983)
Gas Exploder	Single sleeve	1.4	217	Richardson, et al. (1983)
Water Gun	57 in.^{3}	1.4	217	Hydroshock, Inc.
Mini-Boomer (Acoustipulse)	500 joules	0.8	212	BBN/McLelland

*Arons predicted level at 100 m range, corrected to 1 meter according to spherical spreading (20 log R).

Ranking by "Energy Ratio"**		Energy Ratio	
	Dynamite (60%)	0.37	Kramer, et al. (1968)
	2000 psi Air Gun Array	0.36	
	Aquapulse Gas Exploder	0.092	
	Sparker (18 kj)	0.016	
	Boomer (1 kj)	0.011	
	Sparker (1 kj)	0.006	

$$**\text{Energy Ratio} = \frac{\text{Potential Energy of Bubble}}{\text{Intrinsic Energy of Source}}$$

levels for explosives are typical broadband levels, but most energy is concentrated in the low frequency portion of the spectrum.

Reviewing the table clearly demonstrates that the use of TNT or 60% dynamite develops significantly higher peak-to-peak pressures than the non-dynamite sources. Recall that since dynamite has to be vented at the surface in order to avoid the bubble pulse problem, 30 times more explosive is required to achieve the same seismic efficiency as a non-vented charge at depth. The non-explosive (non-dynamite) sources clearly exhibit lower peak-to-peak pressures than the TNT or dynamite sources, although the 40 unit array of air guns exhibits about 4 dB higher sound pressure level than a 1# charge of black powder. It is very important to note, however, that the purpose of arraying sound sources is to obtain directivity so as to direct energy downward toward the ocean bottom. In so doing, downward and beam-aspect levels are generally about the same (the levels for arrayed sources in the table are for beam aspect). The radiation pattern has a double cardiod pattern exhibiting nulls in sound level directly ahead (bow) and directly aft (stern) of the towed direction for the array. Nulls of 20 dB or more can usually be expected, representing a 10:1 reduction of peak sound pressure from a seismic energy source. Typical firing rates of these "non-dynamite sources vary from one pulse every 3 to 15 seconds, depending on the system and geologic application.

Also included in Table A.1 is a ranking of a few seismic energy sources based on "Energy Ratio" as presented by Kramer et al. (1968). Energy Ratio in this example is the ratio of the potential energy of the gaseous bubble caused by the source to the intrinsic energy of the source. This ranking was developed by Kramer and his associates both theoretically and experimentally, assuming each device is fired at the same depth. The energy priorities are very similar to the rankings in the main part of the table, based on peak pressure and sound pressure level. In their ranking and associated graphical comparisons, TNT and 60% dynamite follow the same energy ratio curve.

The important conclusion to be drawn from this brief summary of seismic energy sources is that through the development of non-dynamite devices, and improved signal processing techniques, the marine seismic exploration industry has been able to improve the quality of data while significantly reducing the amount of seismic energy required. Potential impact on marine life has been reduced accordingly.

The recent report by Bolt Beranek and Newman Inc., Malme, et al. (1983), demonstrated that a 40 unit array of 100 in.^{3} air guns caused some statistically detectable changes in normal behavior of migrating gray whales (mother/calf pairs) when exposed to beam-aspect sound levels at a distance of about 2.7 miles (5 kilometers). A single 100 in^3 air gun elicited similar response from a distance of about 0.6 miles (1 kilometer). At bow or stern aspect, array-produced sound levels could be expected to approach that of the single air gun.

A.2.3 Marine seismic exploration in California

The development of a precise history of seismic surveying in California waters, both within the 3 mile territorial limit of state waters and offshore in the outer continental shelf regions, is dictated by the degree of response from industry, government, and university sources. This survey was performed in a short period of time and few organizations maintain a running summary of all offshore exploration work which is in a form that lends itself to general publication. Much of the data are considered to be proprietary because of the highly competitive nature of the business. The International Association of Geophysical Contractors

(IAGC) agreed to serve as a clearing house of tabular summaries of survey work performed. A total of 53 oil companies, marine geophysical survey companies including a few universities and government organizations were asked by the IAGC to complete a form that asked for the following information:

- survey number,
- survey period,
- approximate geographic coordinates,
- survey system or energy source used,
- firing rate,
- number and size of vessels used.

Each organization was assured that company names would be removed from all data submitted and that only a code number would be assigned to facilitate discussion. Of the 53 organizations solicited, 12 responded, 9 of which provided data summaries. The California State Lands Commission (CSLC) had been performing a similar historical summary for other reasons and they offered to allow us to use their summaries, given approval from the originating organization. Those approvals were obtained and doing so increased the number of responding organizations with data to 21. Finally, the U.S. Geophysical Data Center in Boulder, Colorado, offered to scan their extensive geophysical data files and to summarize seismic surveys for offshore California areas. They provided data from four university or university-related groups, three government agencies and the U.S. Navy, increasing the total number of marine seismic survey organizations to 29, representing a respectable percentage of all organizations that have done work in California. Discussing the response with various people gives us confidence that probably about 80% of the survey work done at least since 1970 has been covered. In fact, there may be some duplication, since some of the respondants are marine geophysical survey organizations which develop seismic survey files on "spec" and offer those data to the oil and gas industry as a whole for their use. Therefore, some of the oil and gas industry responses may duplicate some of the survey industry responses. The percentage of the data in that category could not be resolved.

The following figures (A.1 through A.32) provide a general overall summary of the responses to our inquiries through the IAGC and the CSLC. Because of the highly variable nature of the detail in the responses, it has been necessary to provide data which represent a general summary of the seismic survey history in the region. Precise locations of survey areas were usually not provided and instead general locations were given such as "Santa Barbara Channel" or "Santa Maria Basin." While seismic energy sources used were usually specified, their precise definition, such as array size or peak-to-peak pressure per pulse usually was not given. In addition to noting the type of system used, we have also indicated in a general sense whether the survey work was performed during probable presence of migrating gray whales, during periods when migrating gray whales are not present and those surveys for which no survey period was given.

Reviewing the years during which survey work was performed (noted in the legend of each figure), it becomes apparent that very few responses provided data for periods before 1970. Most of the data apply to work performed after 1975. Approximately 50% of the surveys were performed during times when there is a probable presence of migrating gray whales. While migration patterns are discussed in detail in the following section, one can expect the presence of either southbound or northbound whales at almost any time in California waters between mid-December

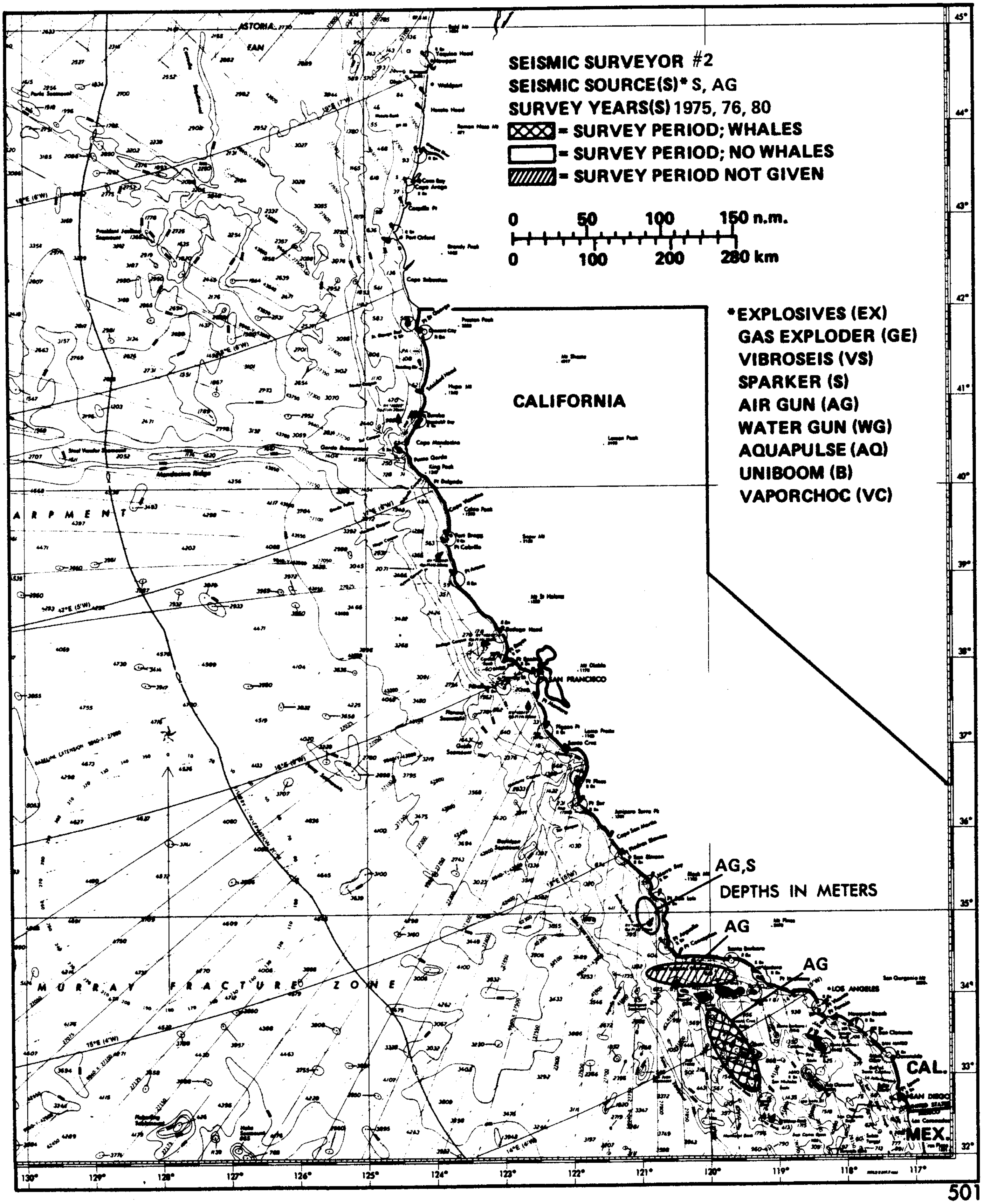

FIG. A.1. SEISMIC SURVEY ACTIVITIES OF ORGANIZATION #2.

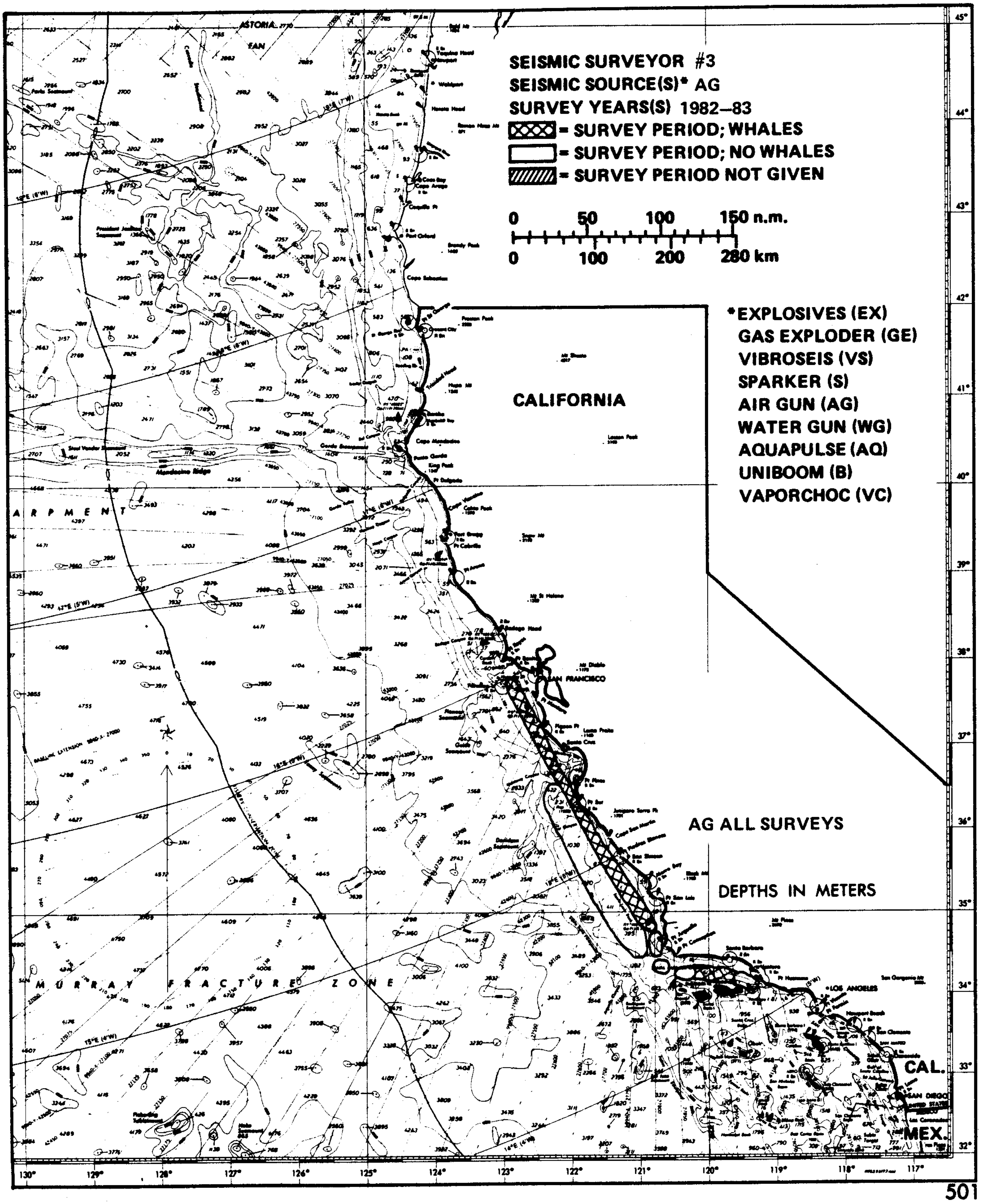

FIG. A.2. SEISMIC SURVEY ACTIVITIES OF ORGANIZATION #3.

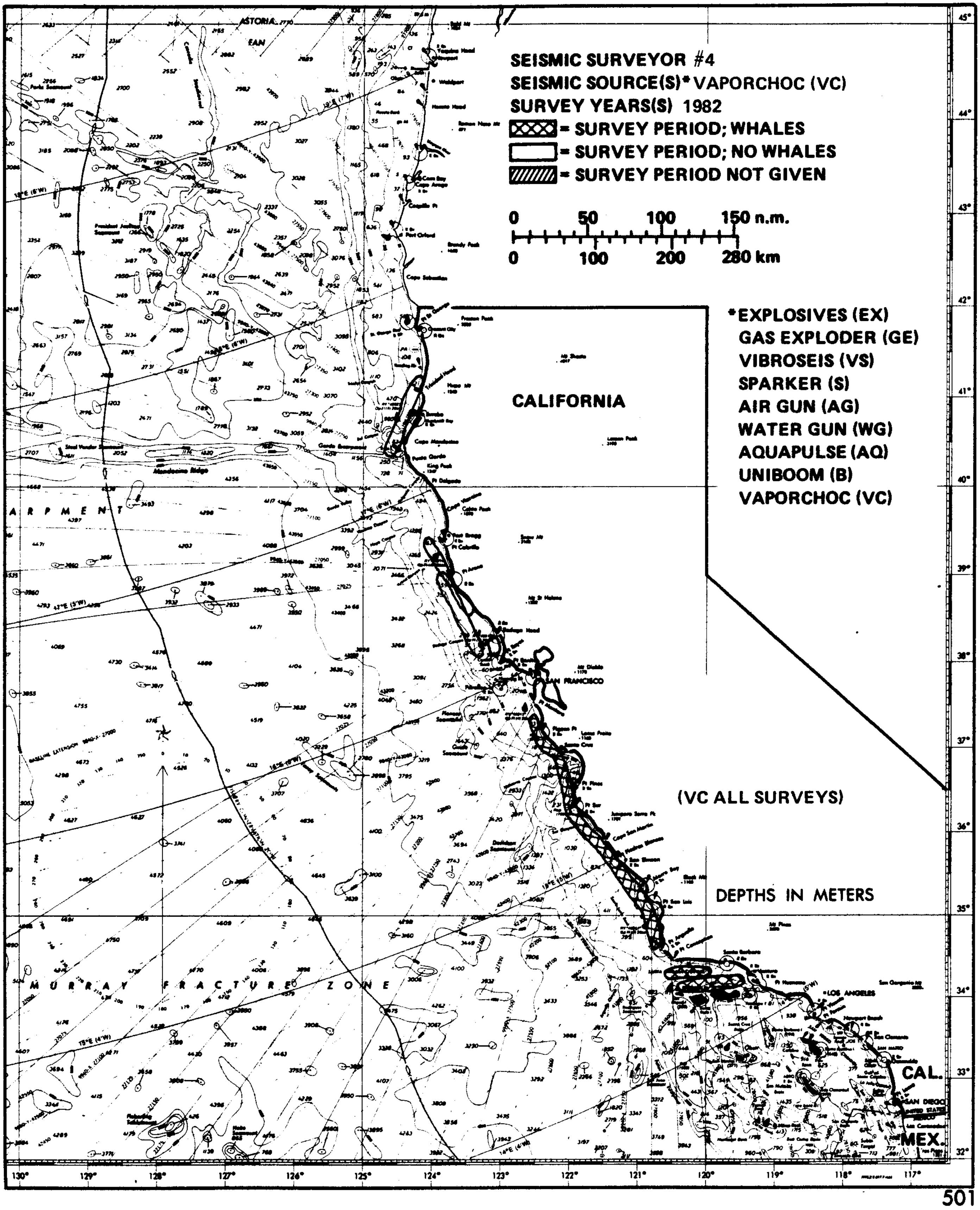

FIG. A.3. SEISMIC SURVEY ACTIVITIES OF ORGANIZATION #4.

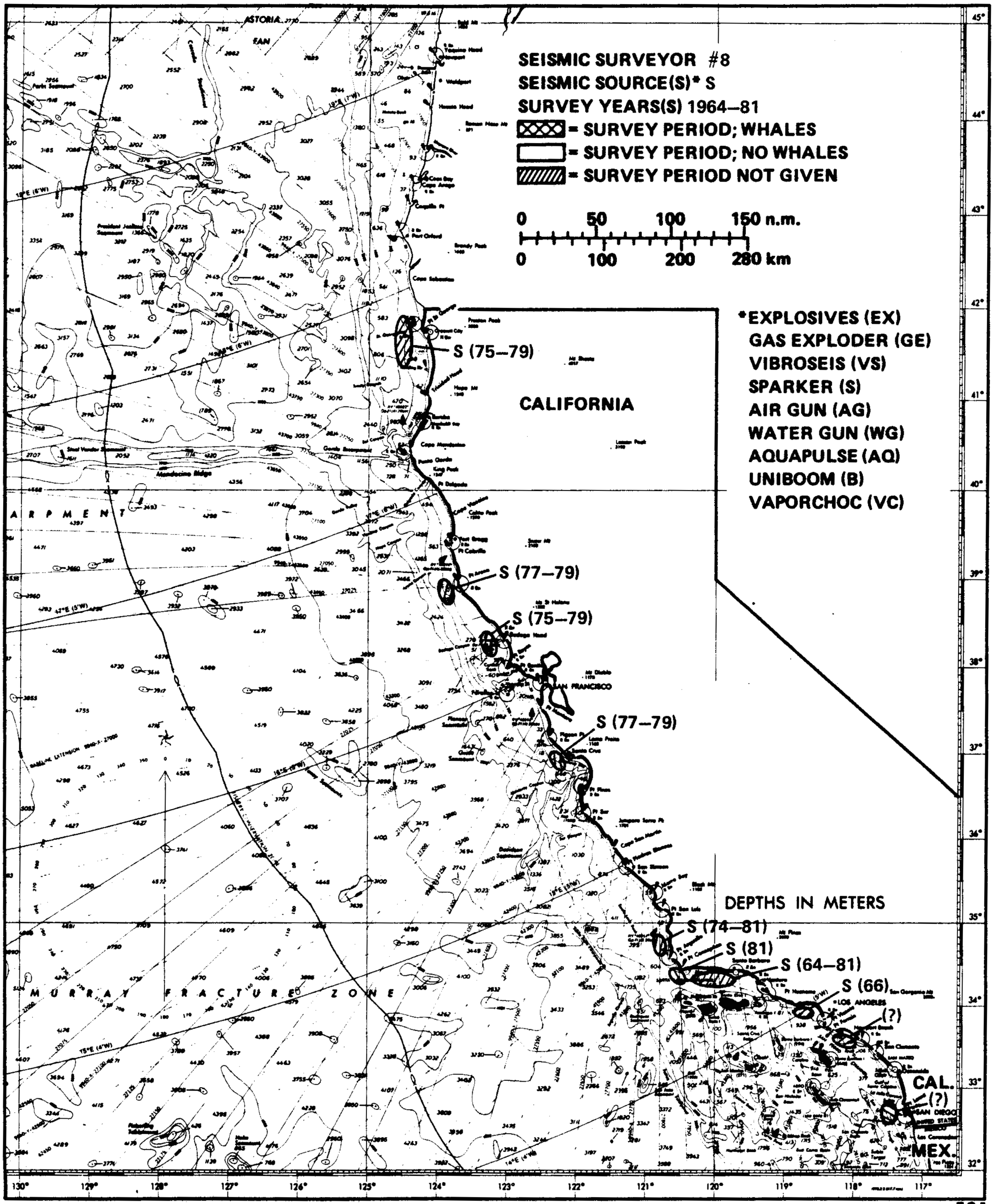

FIG. A.4. SEISMIC SURVEY ACTIVITIES OF ORGANIZATION #8.

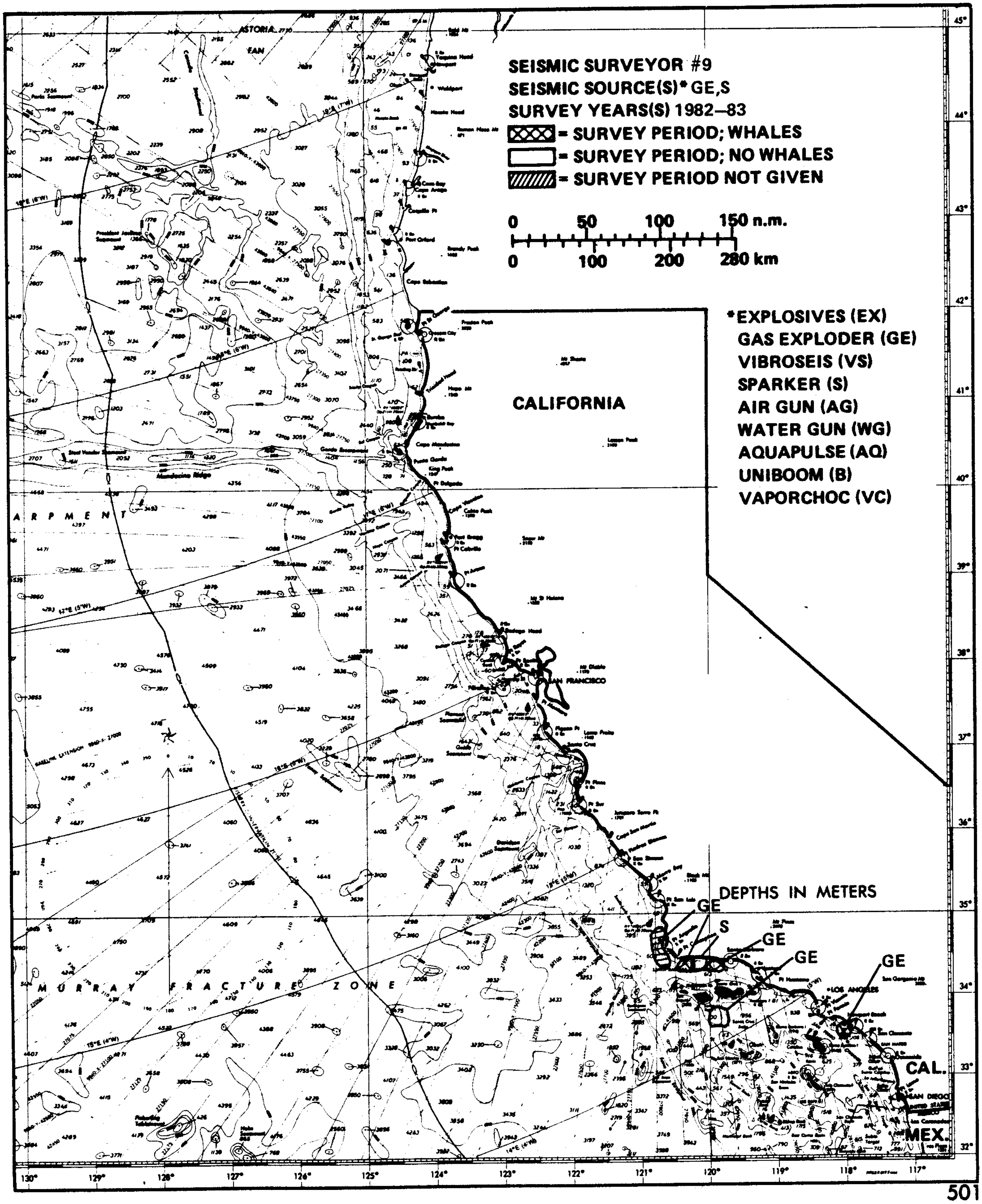

FIG. A.5. SEISMIC SURVEY ACTIVITIES OF ORGANIZATION #9.

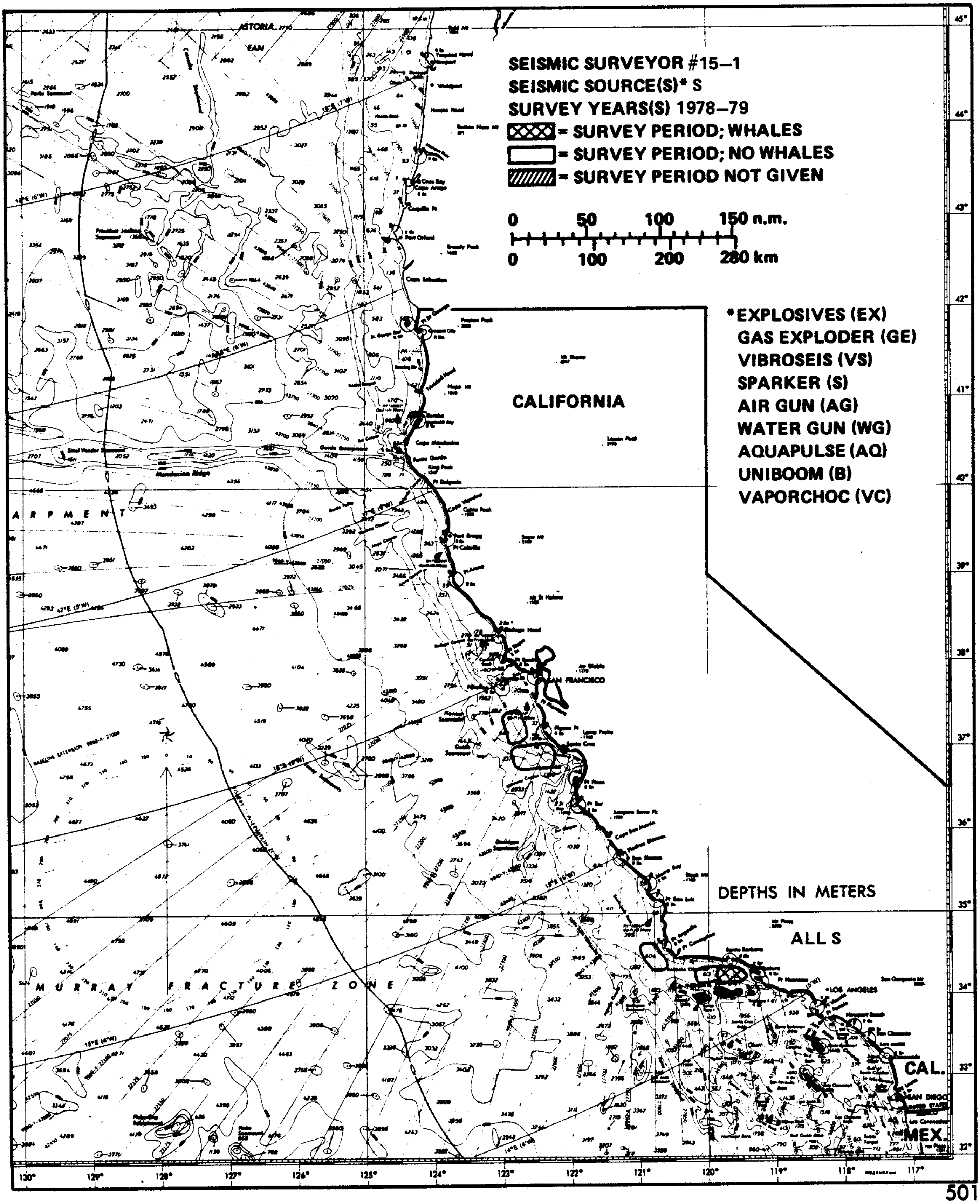

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FIG. A.6. SEISMIC SURVEY ACTIVITIES OF ORGANIZATION #15, CHART #1.

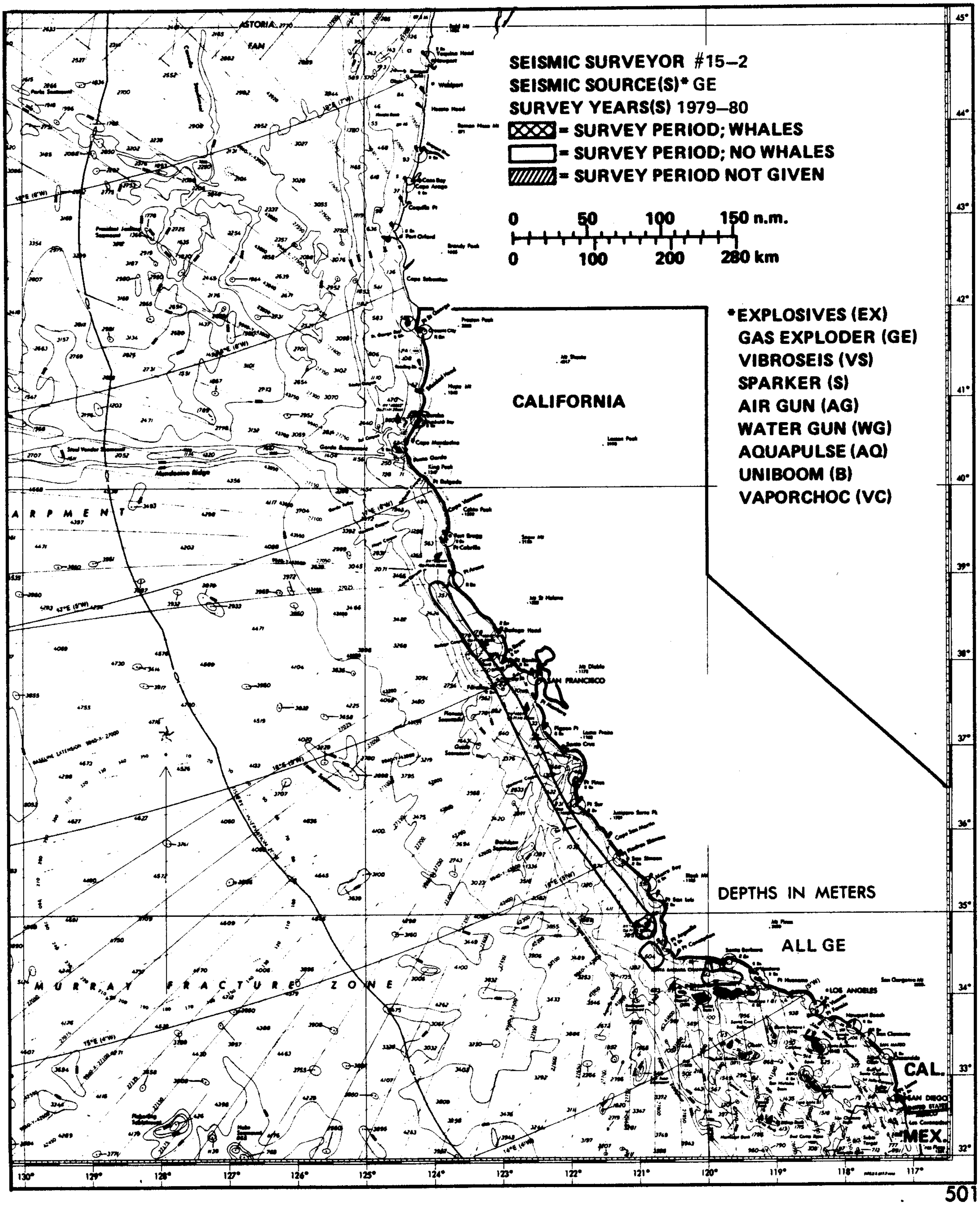

FIG. A.7. SEISMIC SURVEY ACTIVITIES OF ORGANIZATION #15, CHART #2.

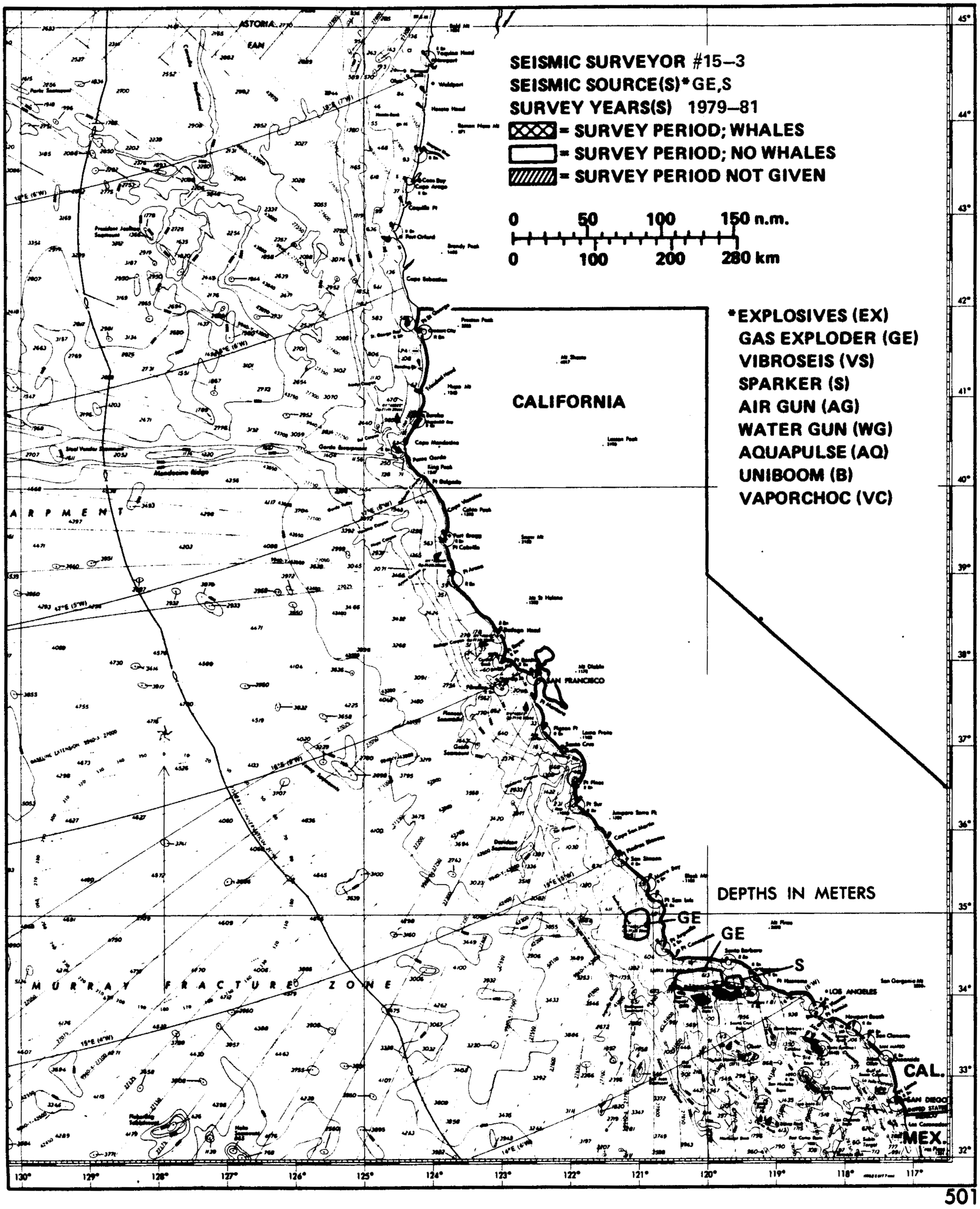

FIG. A.8. SEISMIC SURVEY ACTIVITIES OF ORGANIZATION #15, CHART #3.

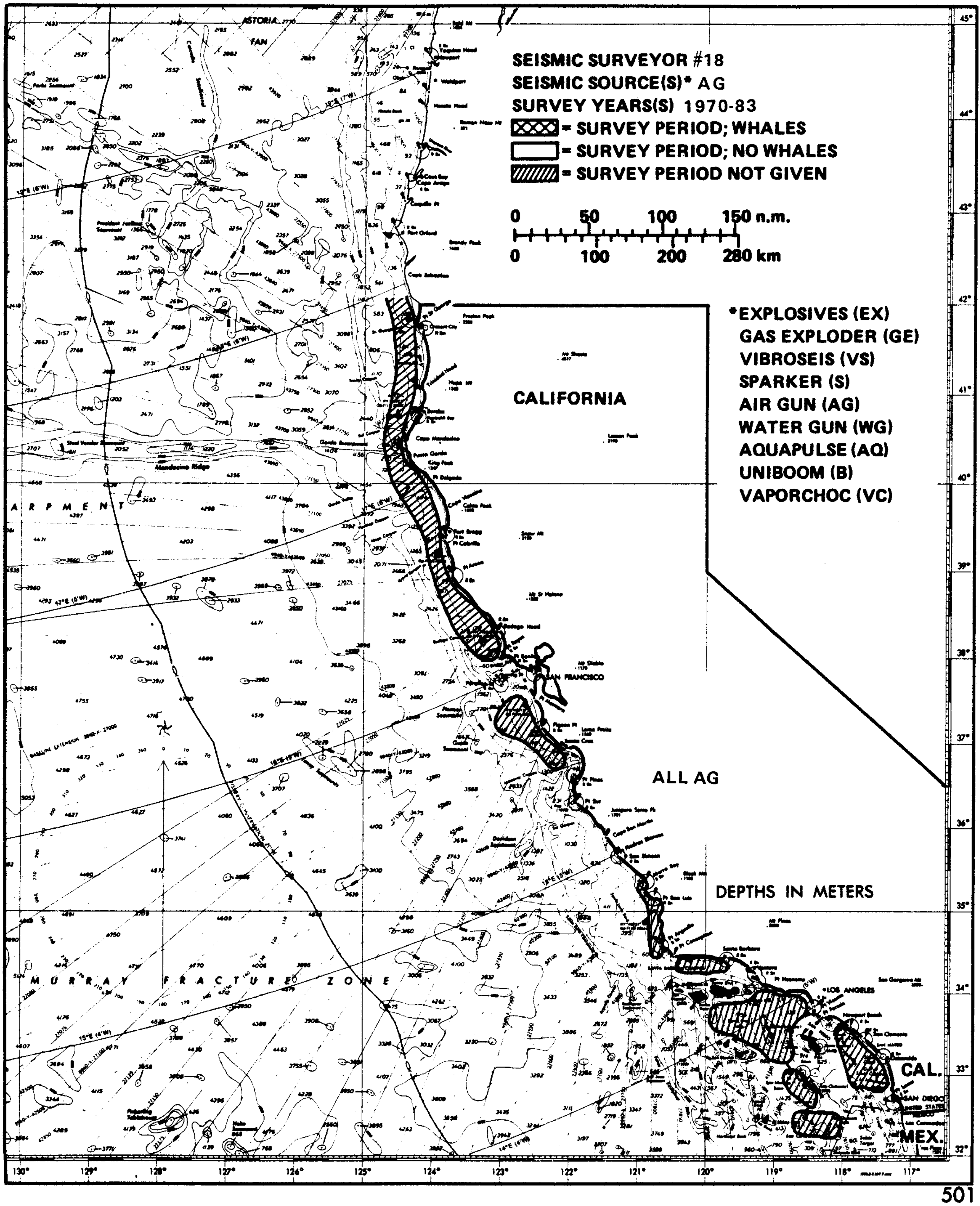

FIG. A.9. SEISMIC SURVEY ACTIVITIES OF ORGANIZATION #18.

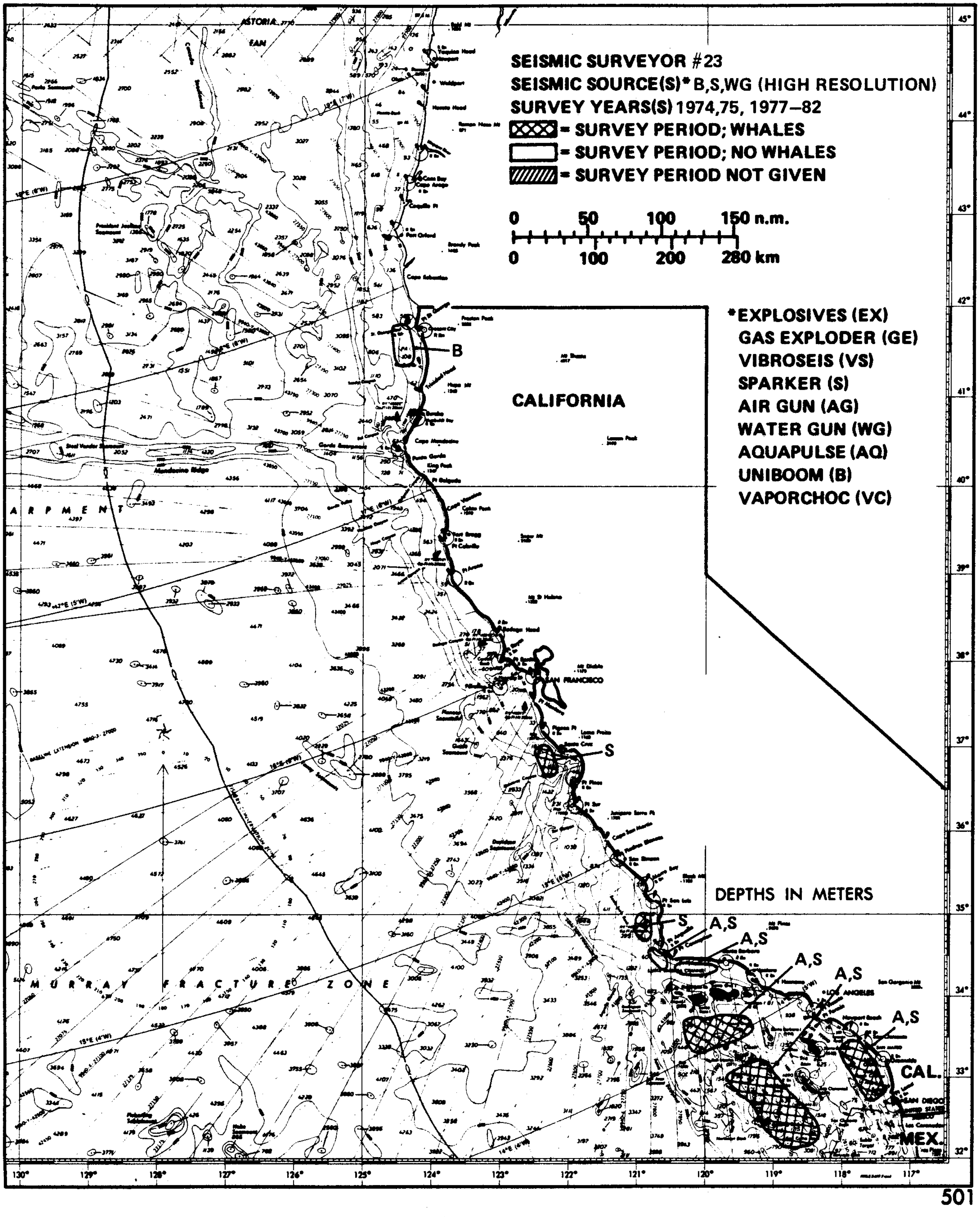

FIG. A.10. SEISMIC SURVEY ACTIVITIES OF ORGANIZATION #23.

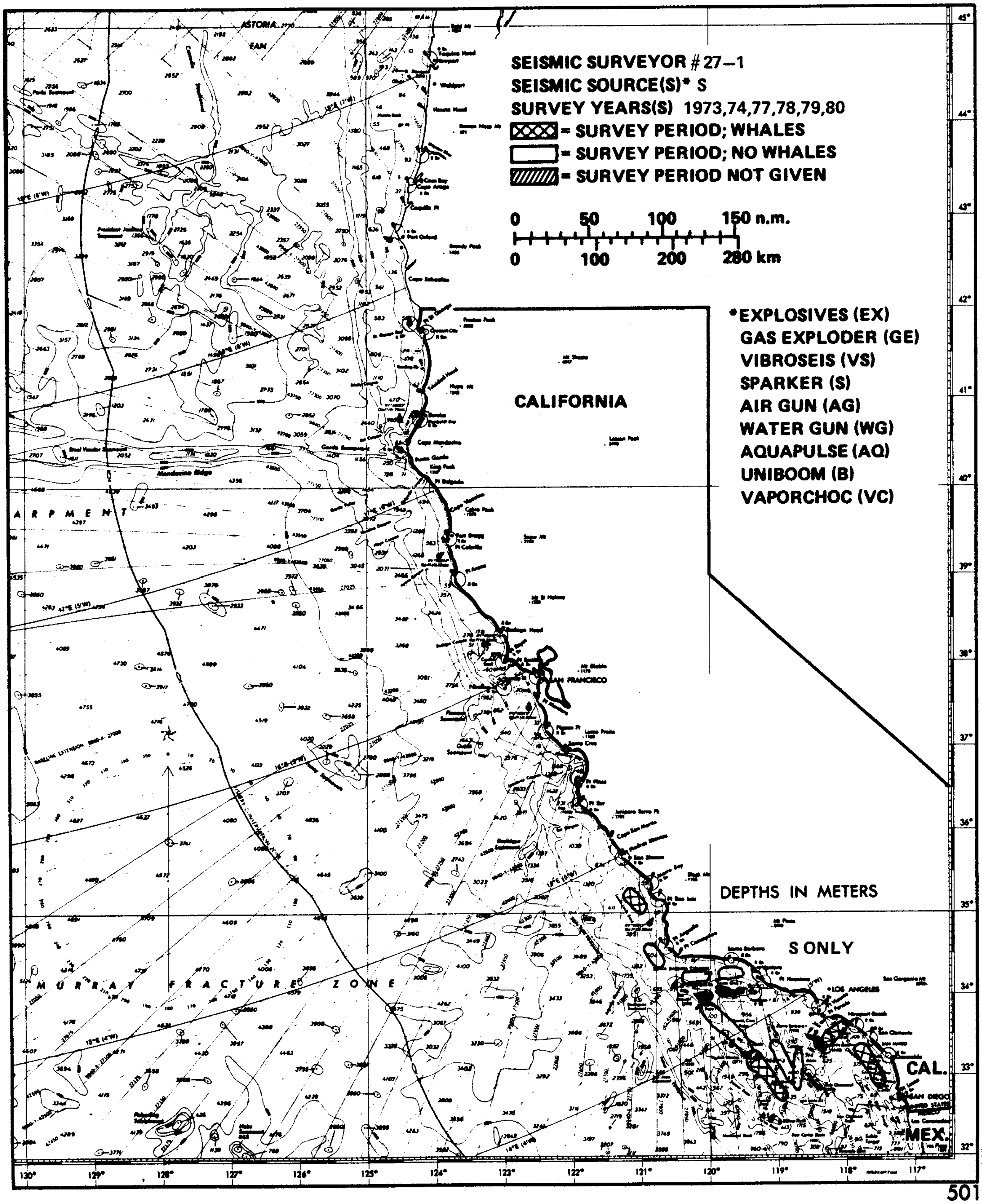

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FIG. A.11. SEISMIC SURVEY ACTIVITIES OF ORGANIZATION #27, CHART #1.

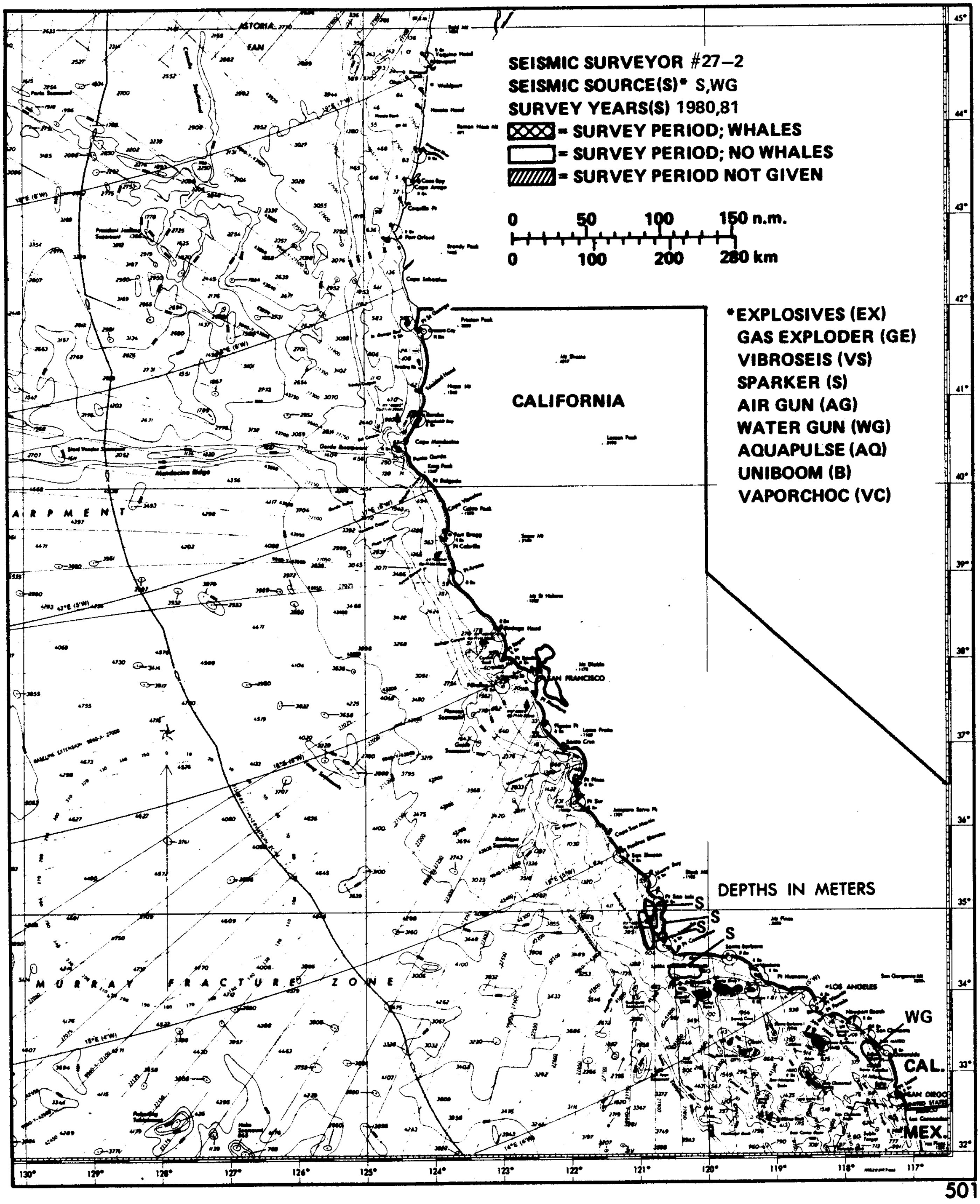

FIG. A.12. SEISMIC SURVEY ACTIVITIES OF ORGANIZATION #27, CHART #2.

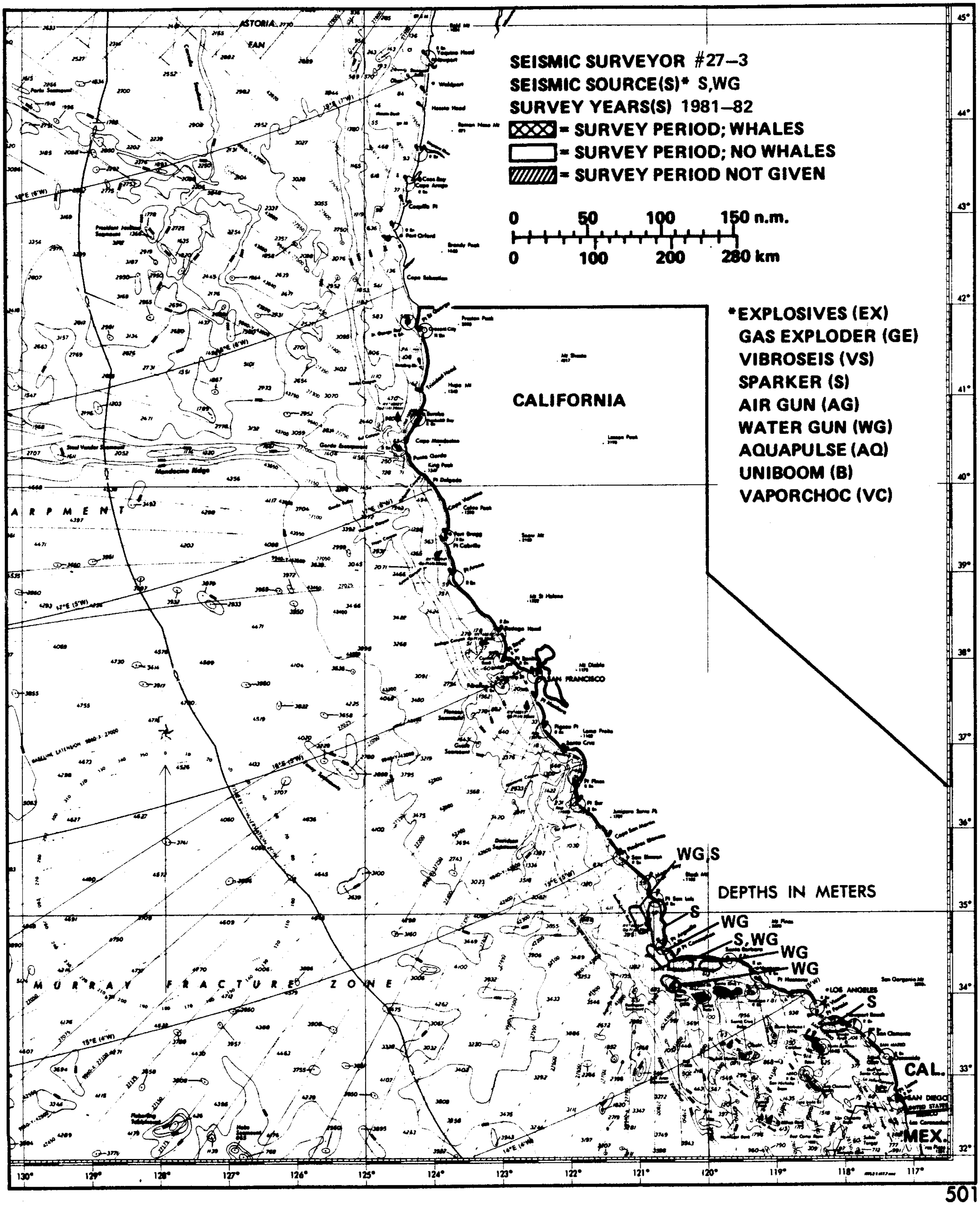

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FIG. A.13. SEISMIC SURVEY ACTIVITIES OF ORGANIZATION #27, CHART #3.

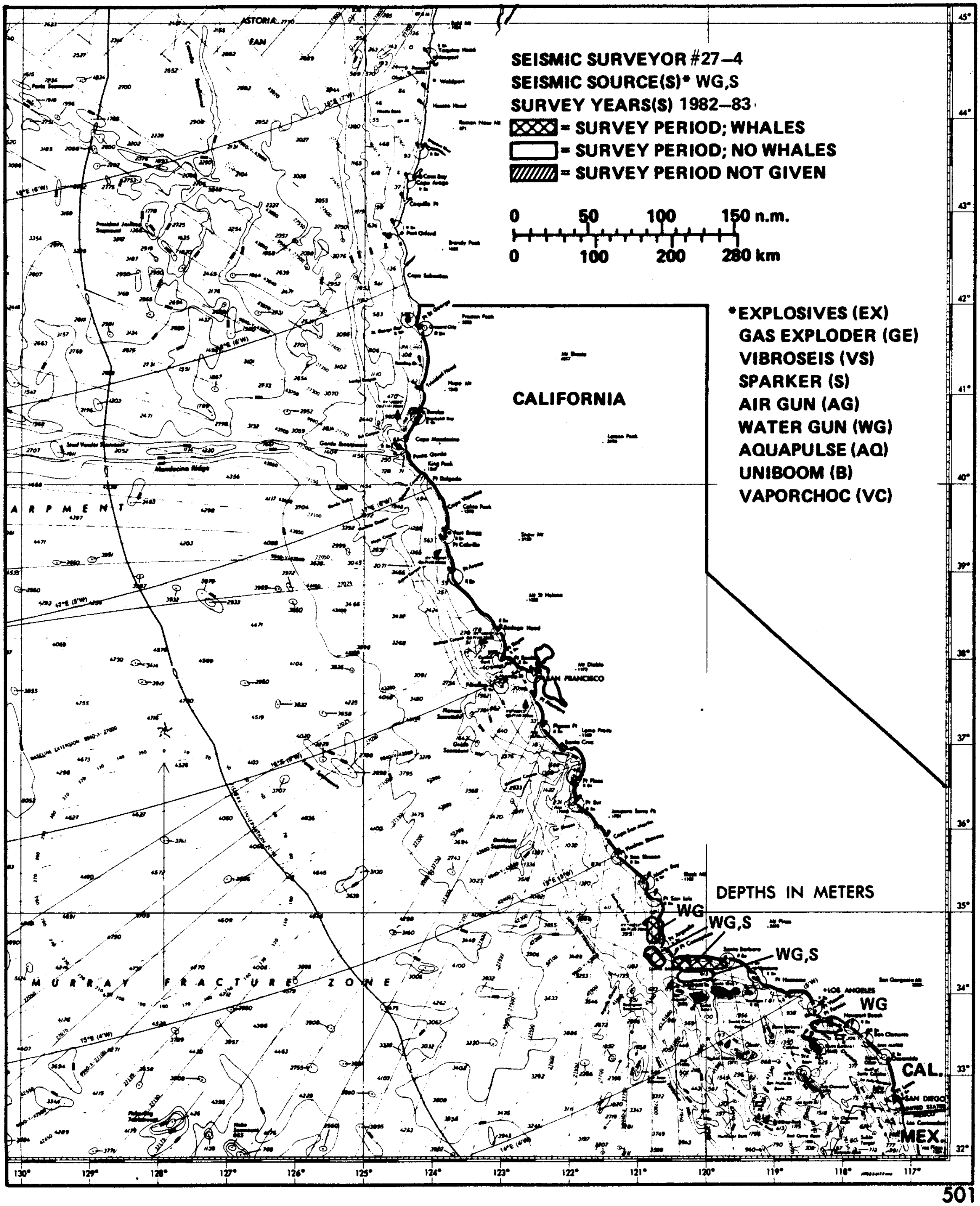

FIG. A.14. SEISMIC SURVEY ACTIVITIES OF ORGANIZATION #27, CHART #4.

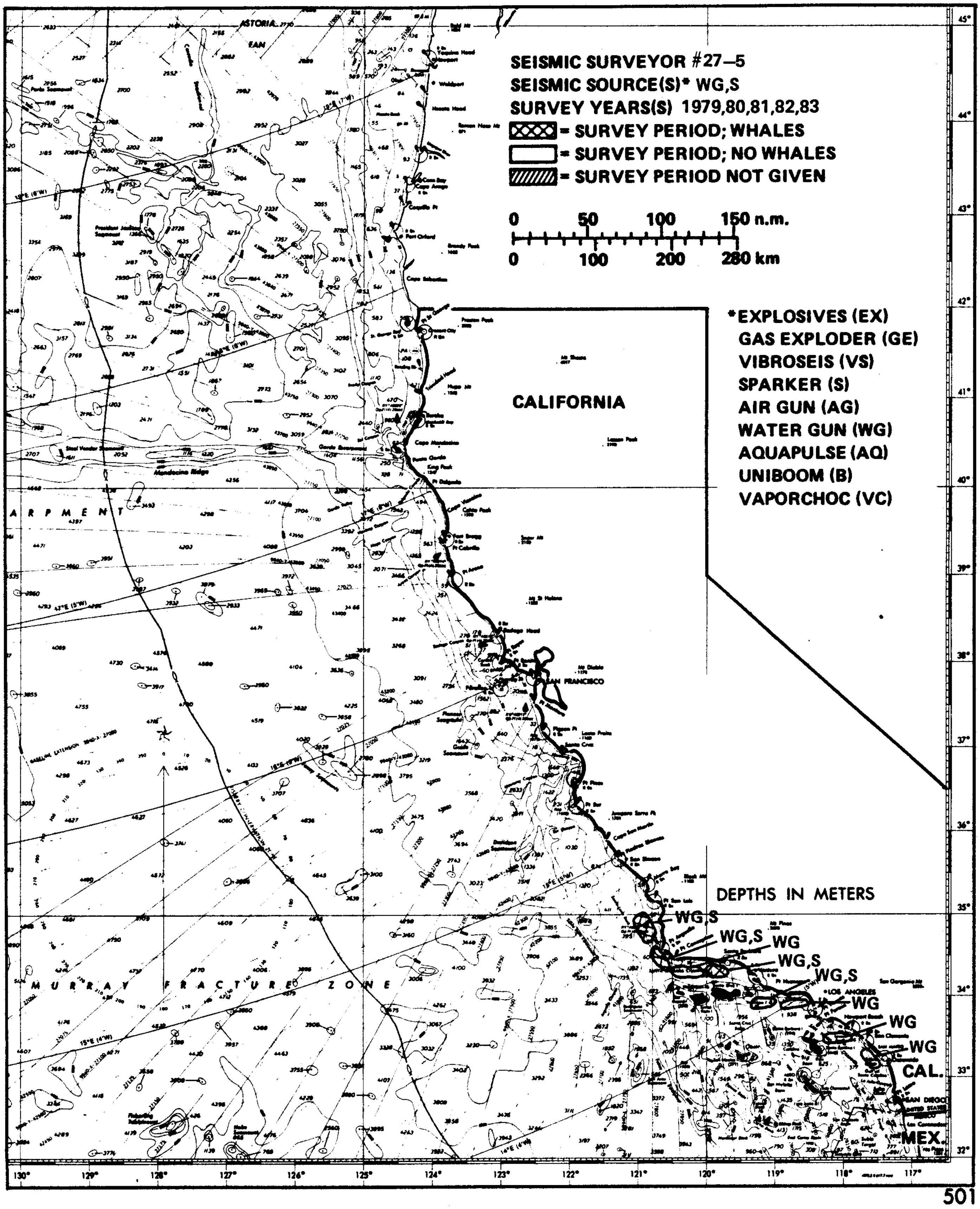

FIG. A.15. SEISMIC SURVEY ACTIVITIES OF ORGANIZATION #27, CHART #5.

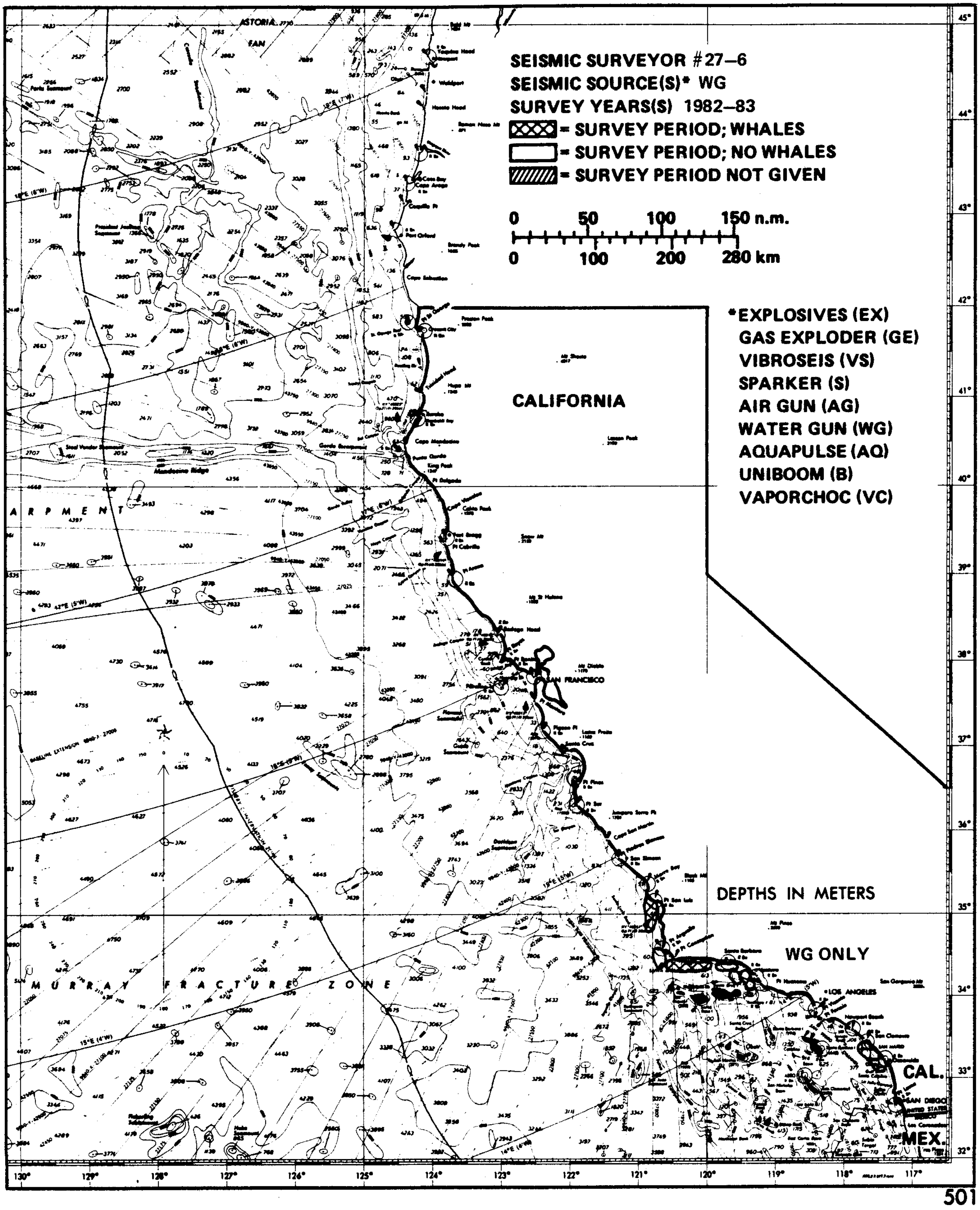

FIG. A.16. SEISMIC SURVEY ACTIVITIES OF ORGANIZATION #27, CHART #6.

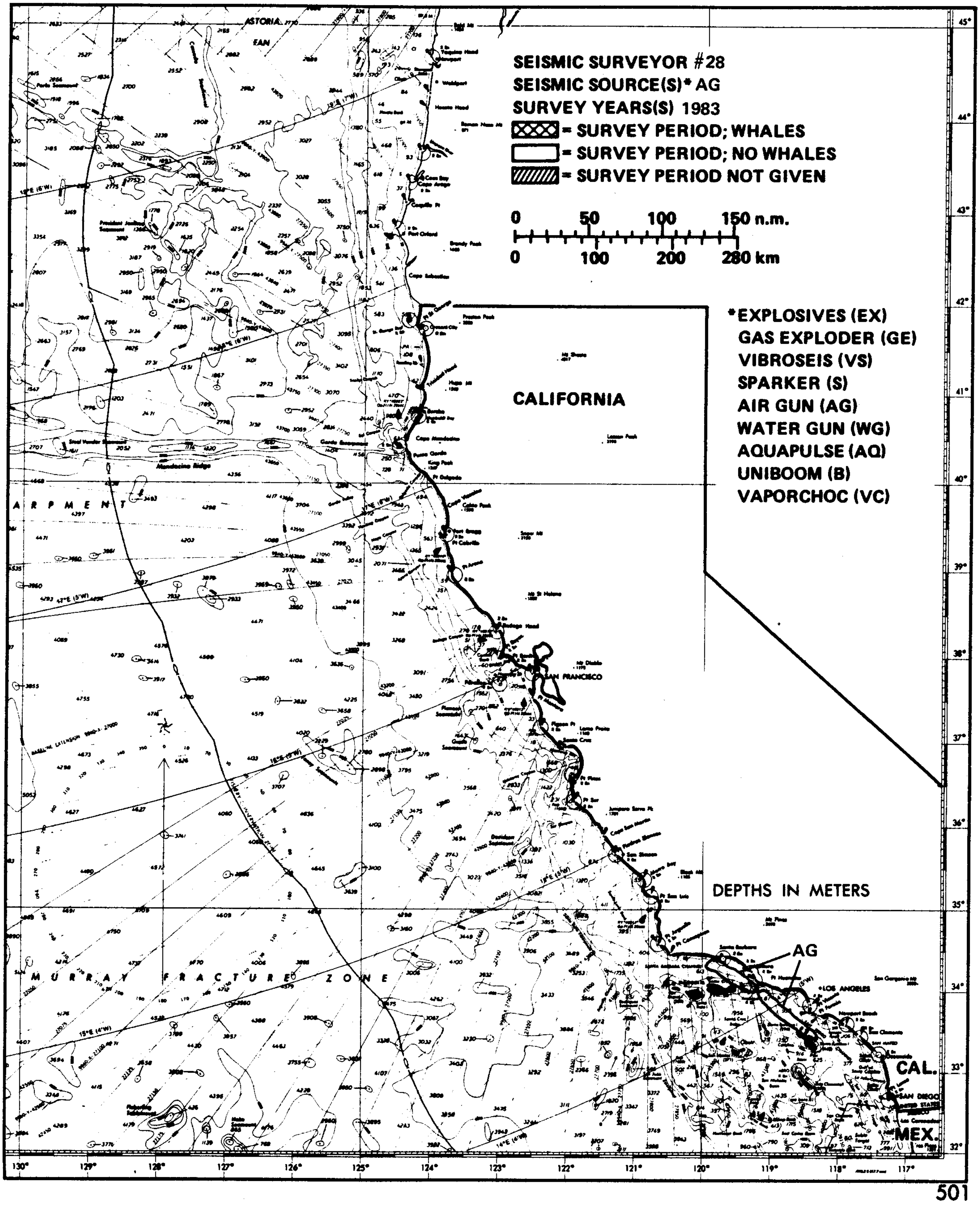

FIG. A.17. SEISMIC SURVEY ACTIVITIES OF ORGANIZATION #28.

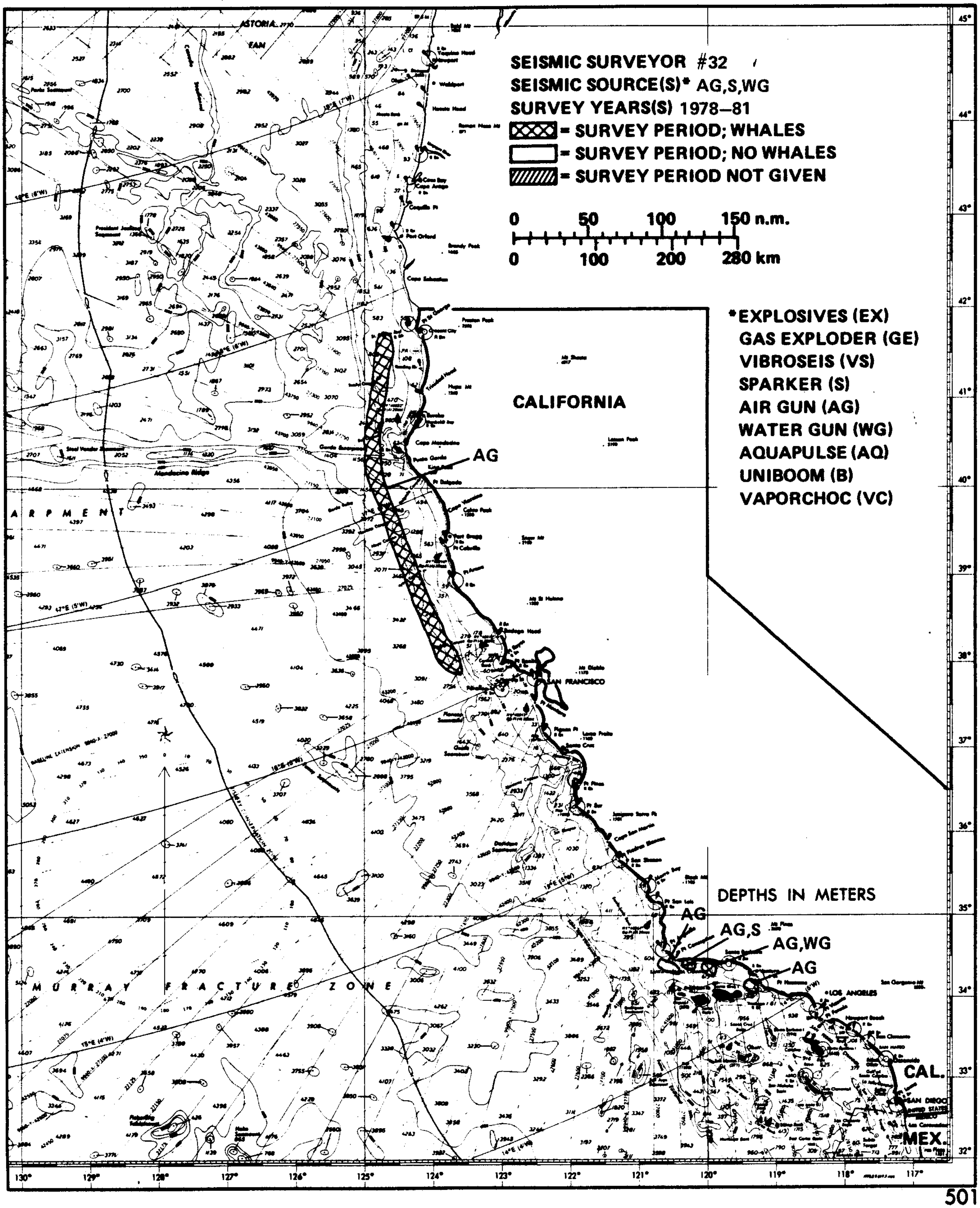

FIG. A.18. SEISMIC SURVEY ACTIVITIES OF ORGANIZATION #32.

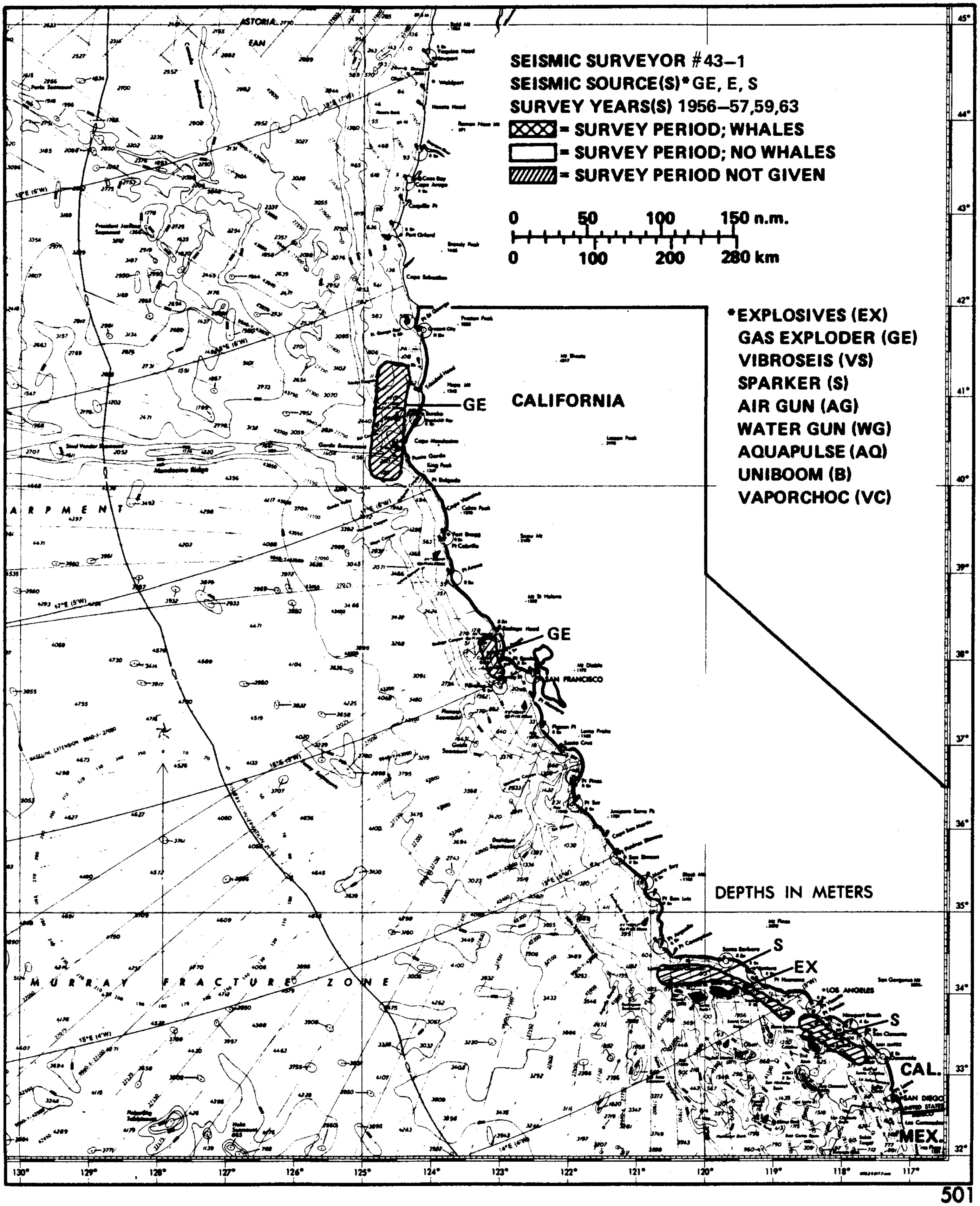

FIG. A.19. SEISMIC SURVEY ACTIVITIES OF ORGANIZATION #43, CHART #1.

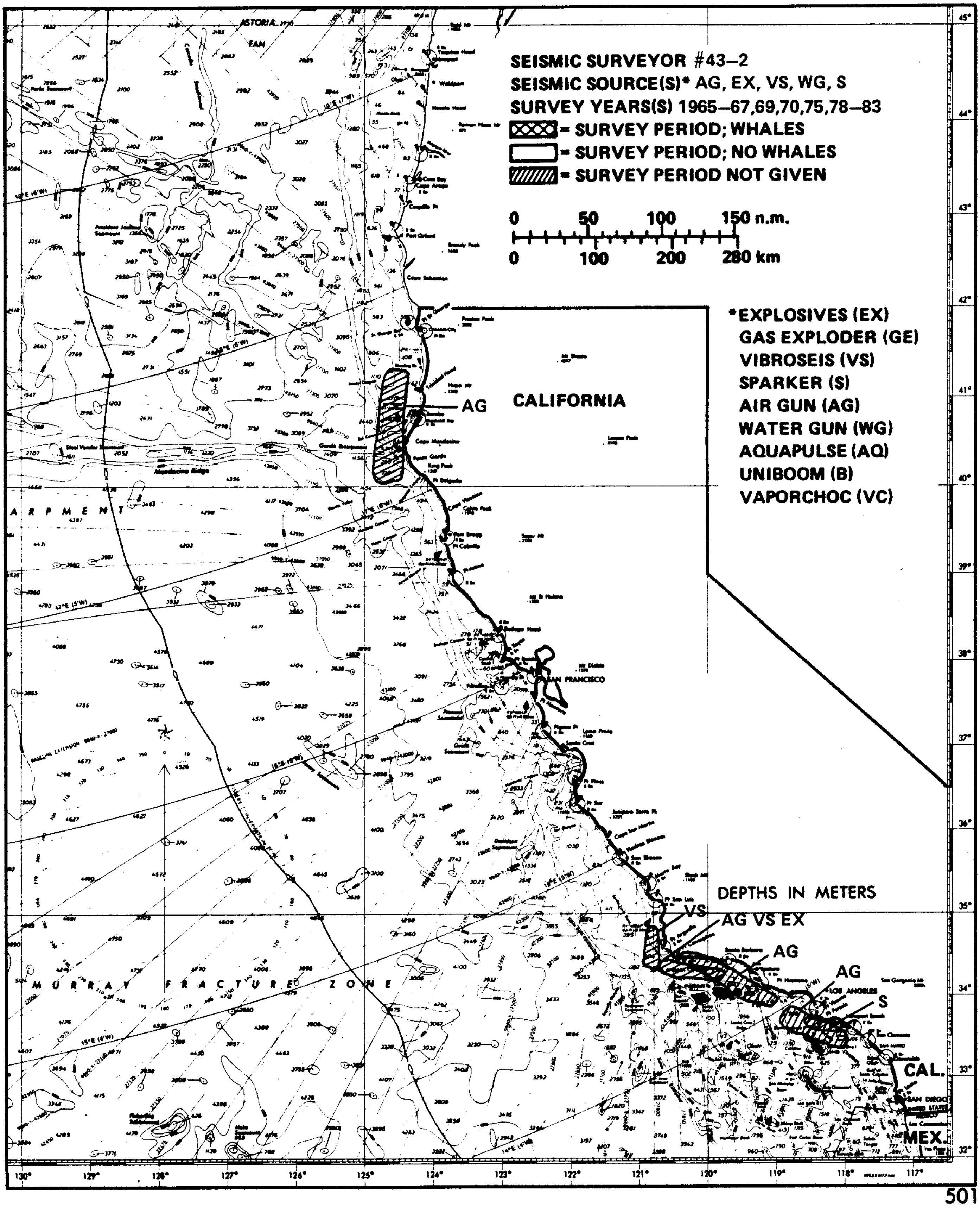

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FIG. A.20. SEISMIC SURVEY ACTIVITIES OF ORGANIZATION #43, CHART #2.

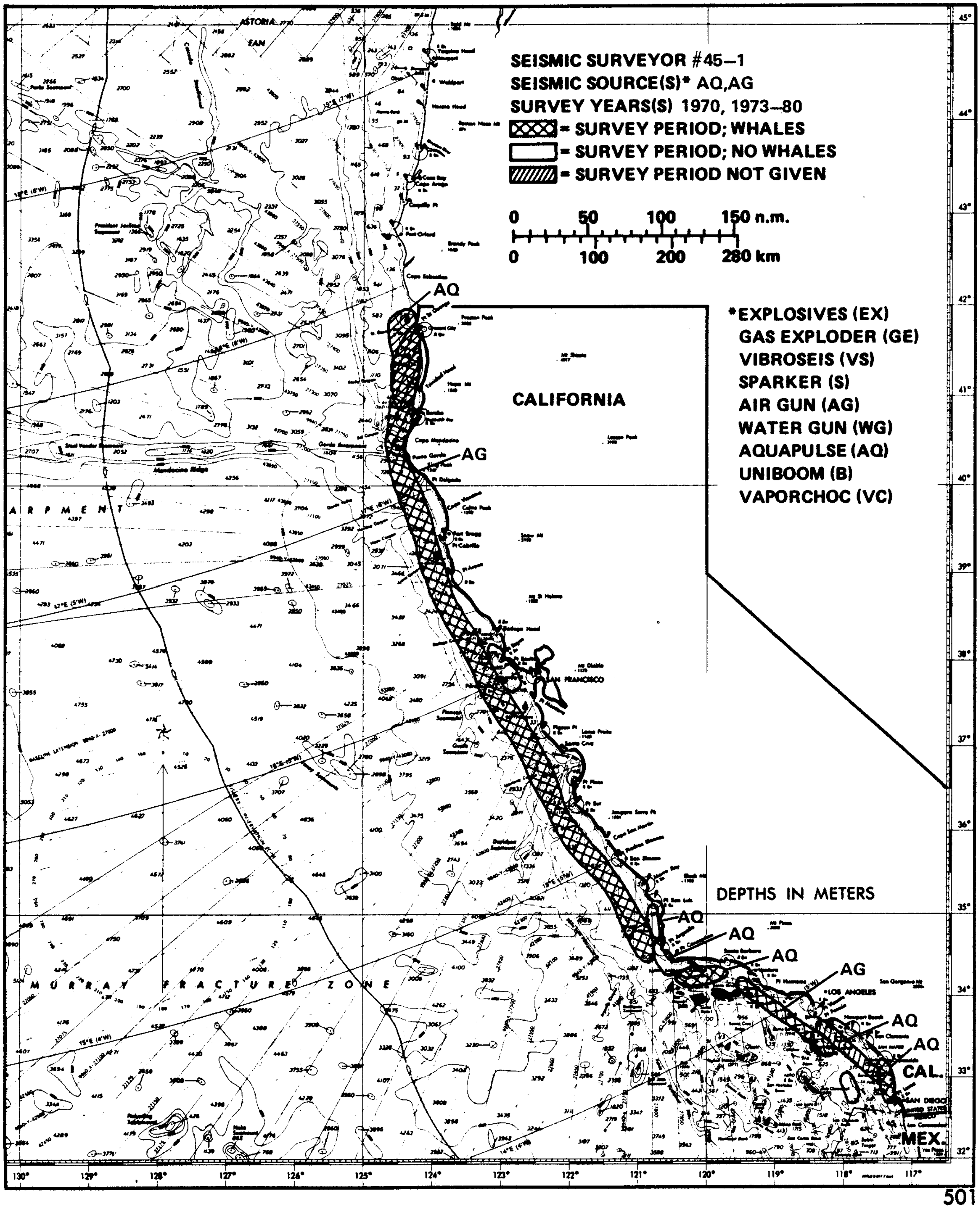

FIG. A.21. SEISMIC SURVEY ACTIVITIES OF ORGANIZATION #45, CHART #1.

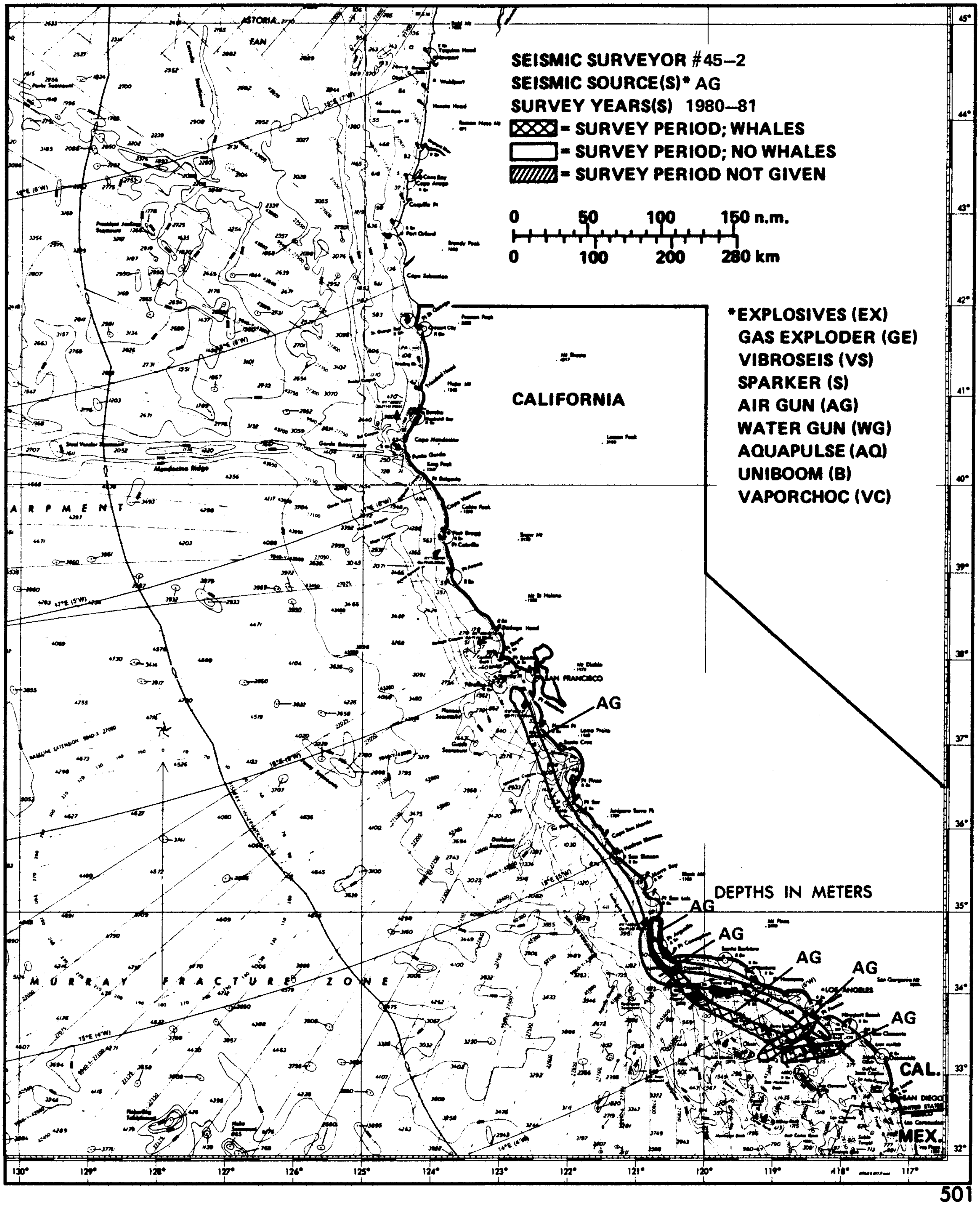

FIG. A.22. SEISMIC SURVEY ACTIVITIES OF ORGANIZATION #45, CHART #2.

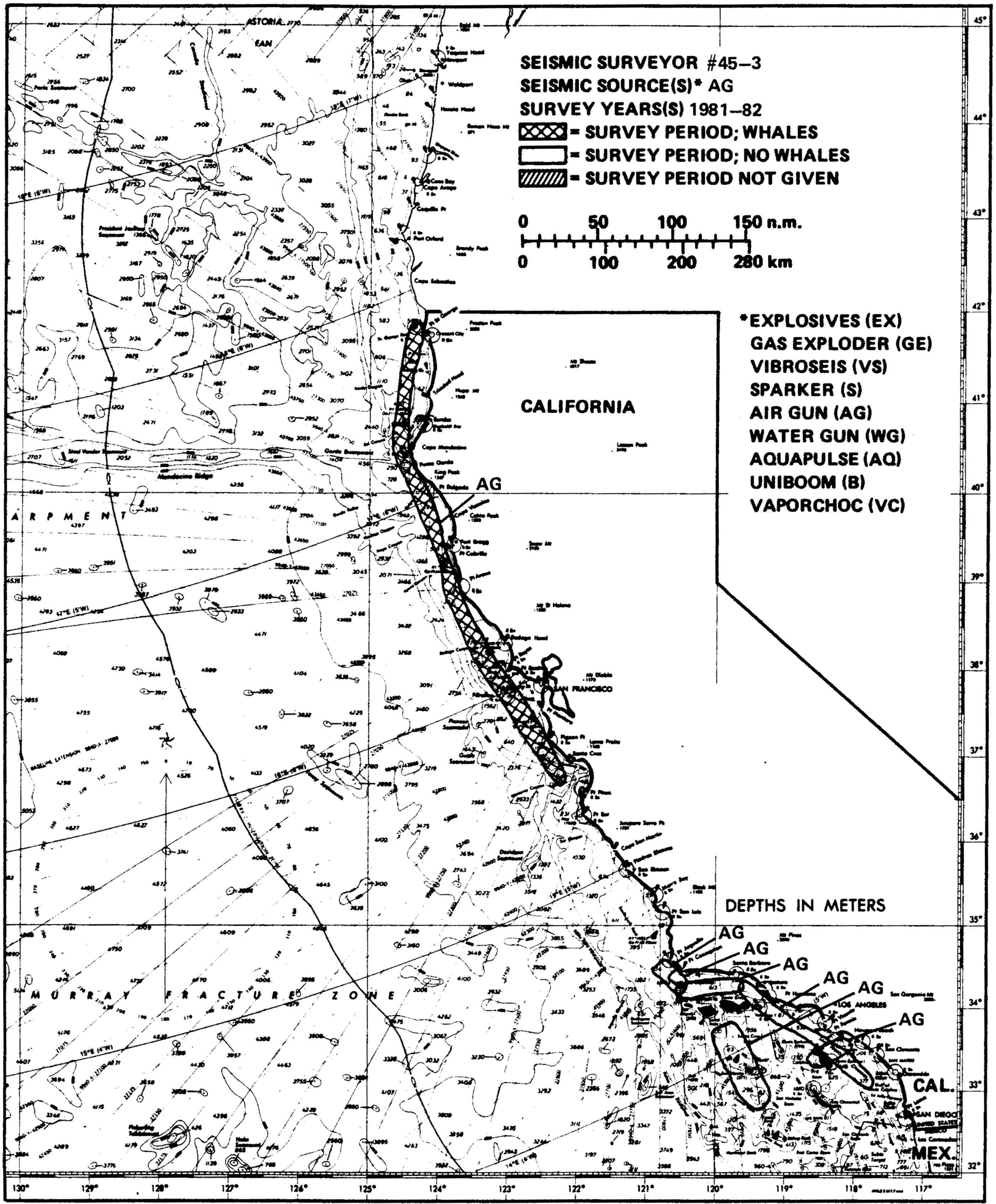

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FIG. A.23. SEISMIC SURVEY ACTIVITIES OF ORGANIZATION #45, CHART #3.

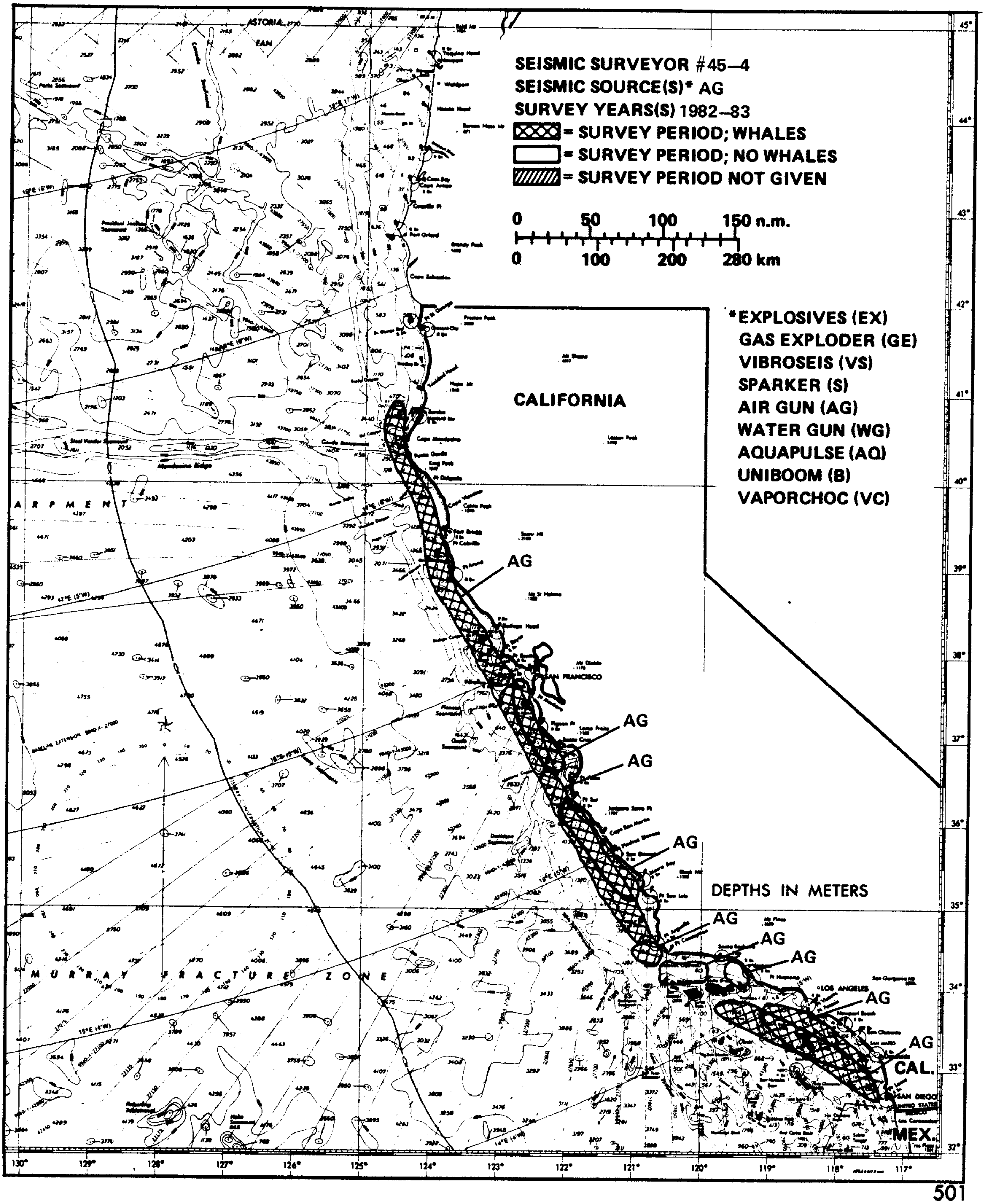

FIG. A.24. SEISMIC SURVEY ACTIVITIES OF ORGANIZATION #45, CHART #4.

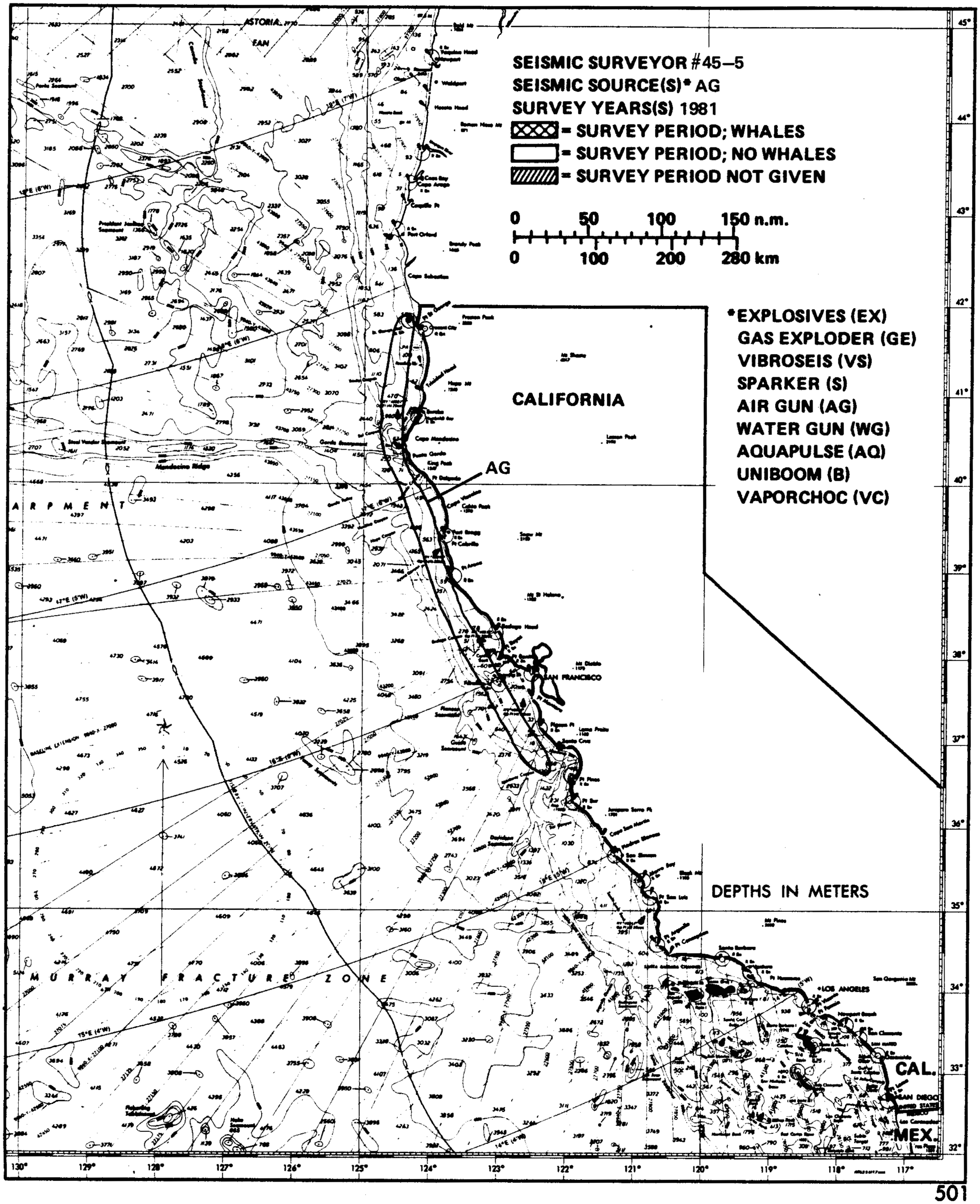

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FIG. A.25. SEISMIC SURVEY ACTIVITIES OF ORGANIZATION #45, CHART #5.

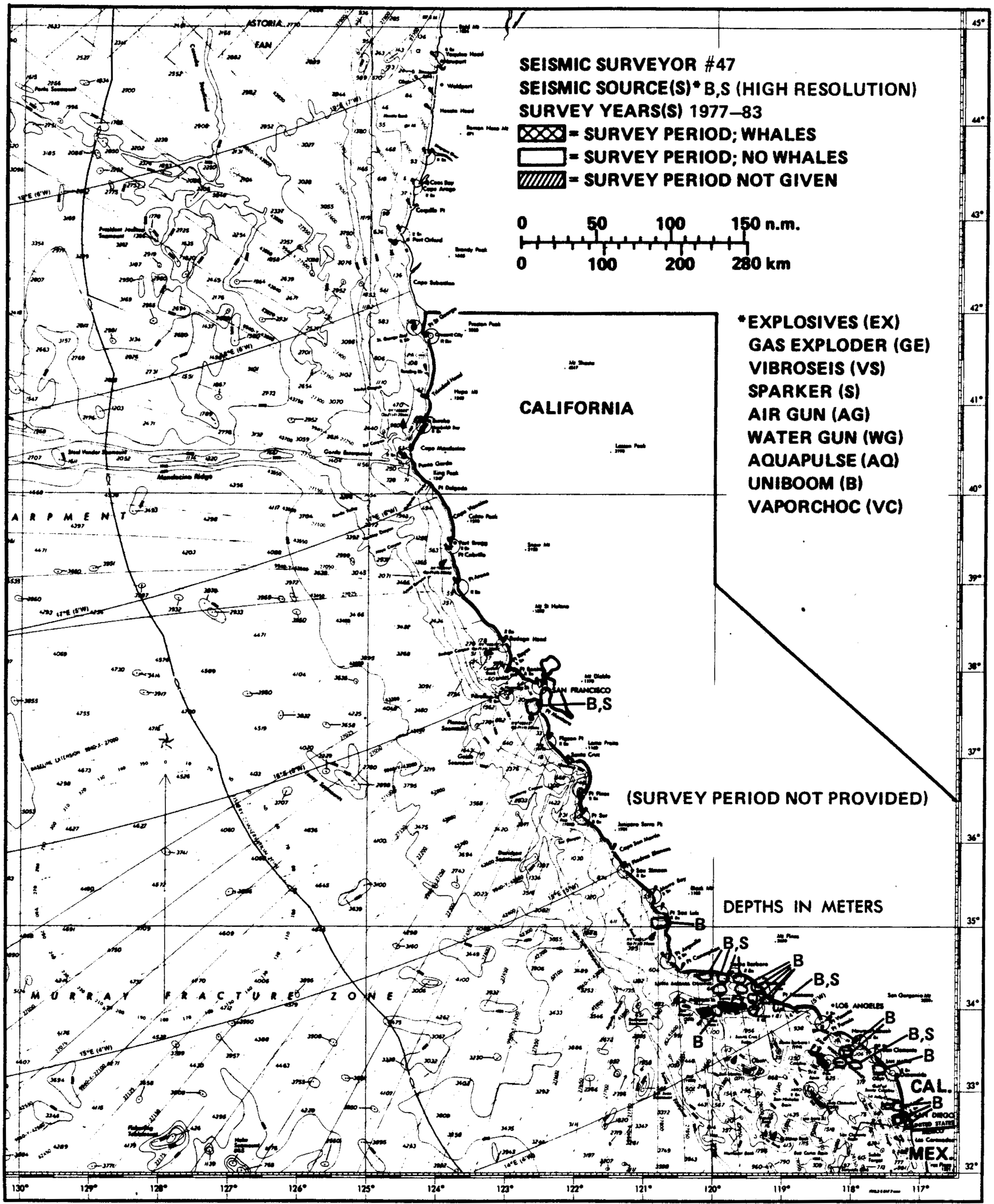

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FIG. A.26. SEISMIC SURVEY ACTIVITIES OF ORGANIZATION #47.

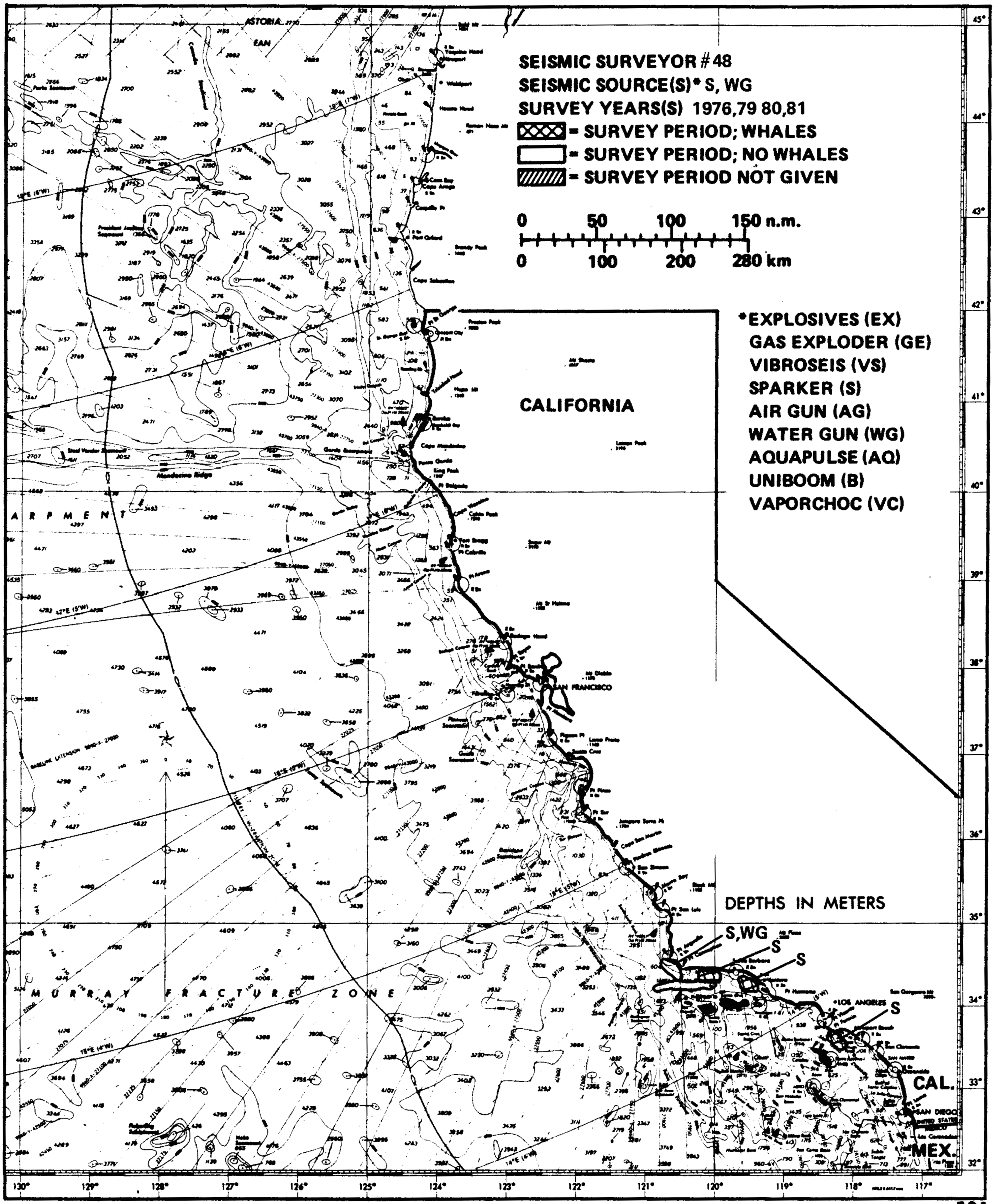

FIG. A.27. SEISMIC SURVEY ACTIVITIES OF ORGANIZATION #48.

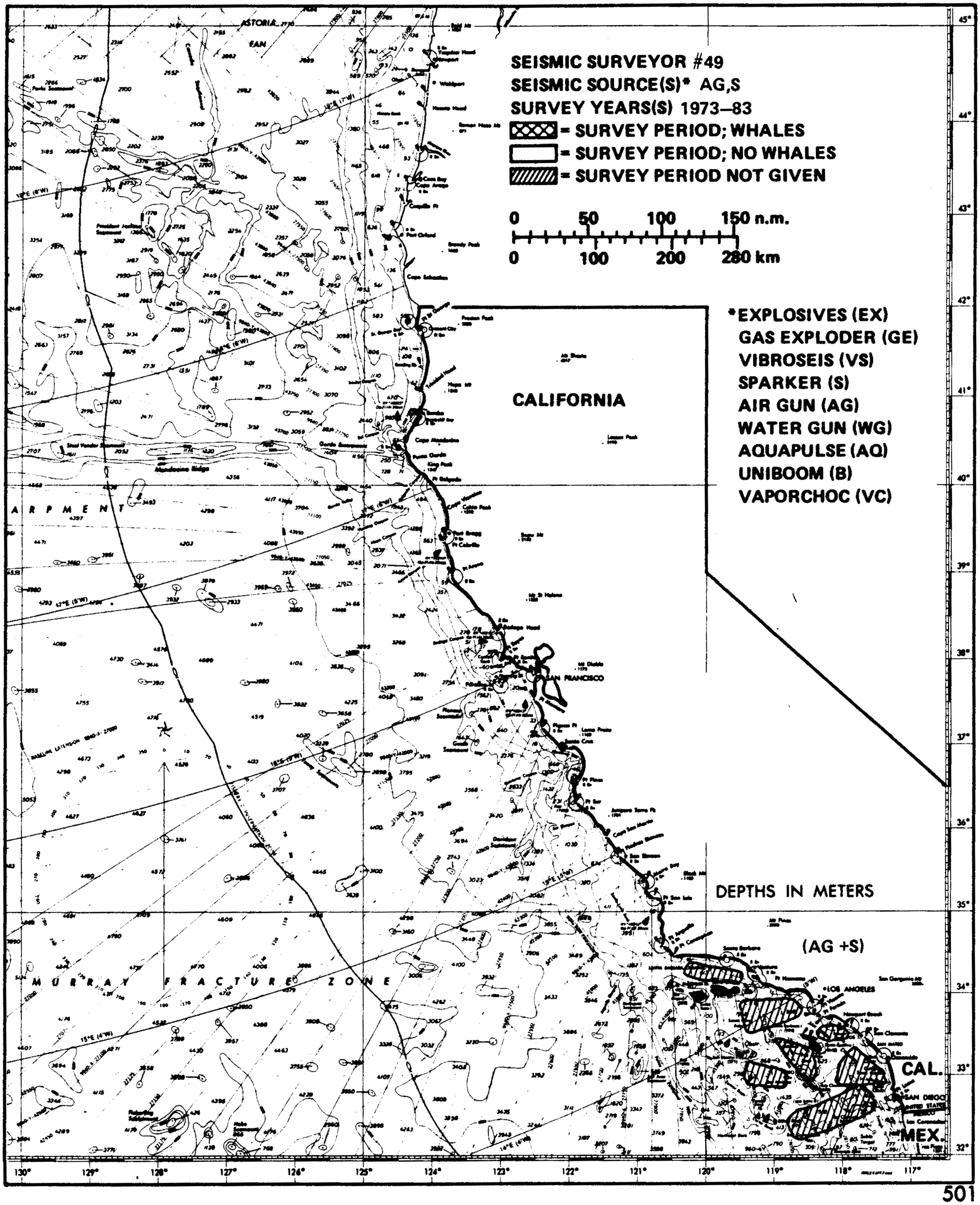

FIG. A.28. SEISMIC SURVEY ACTIVITIES OF ORGANIZATION #49.

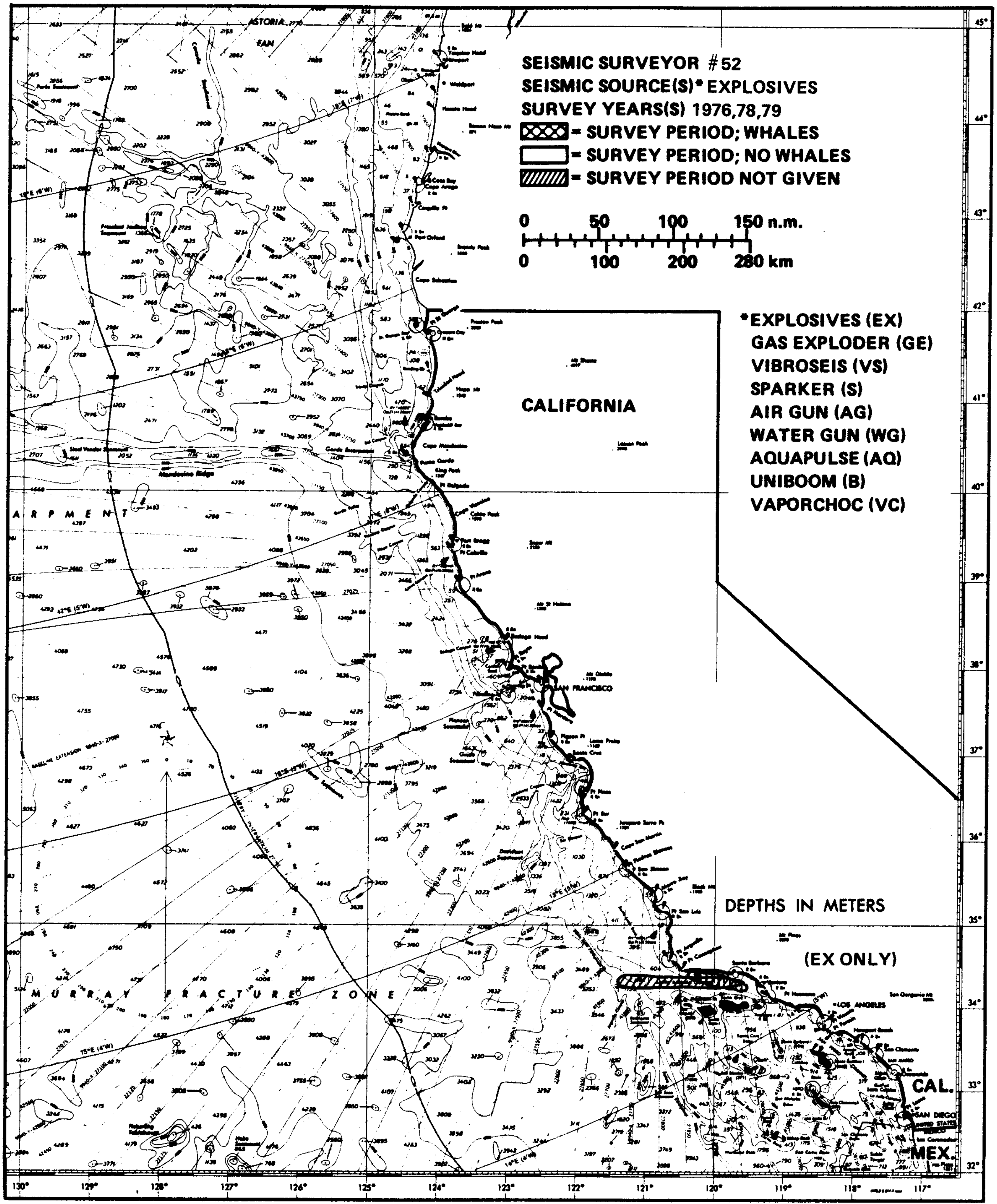

FIG. A.29. SEISMIC SURVEY ACTIVITIES OF ORGANIZATION #52.

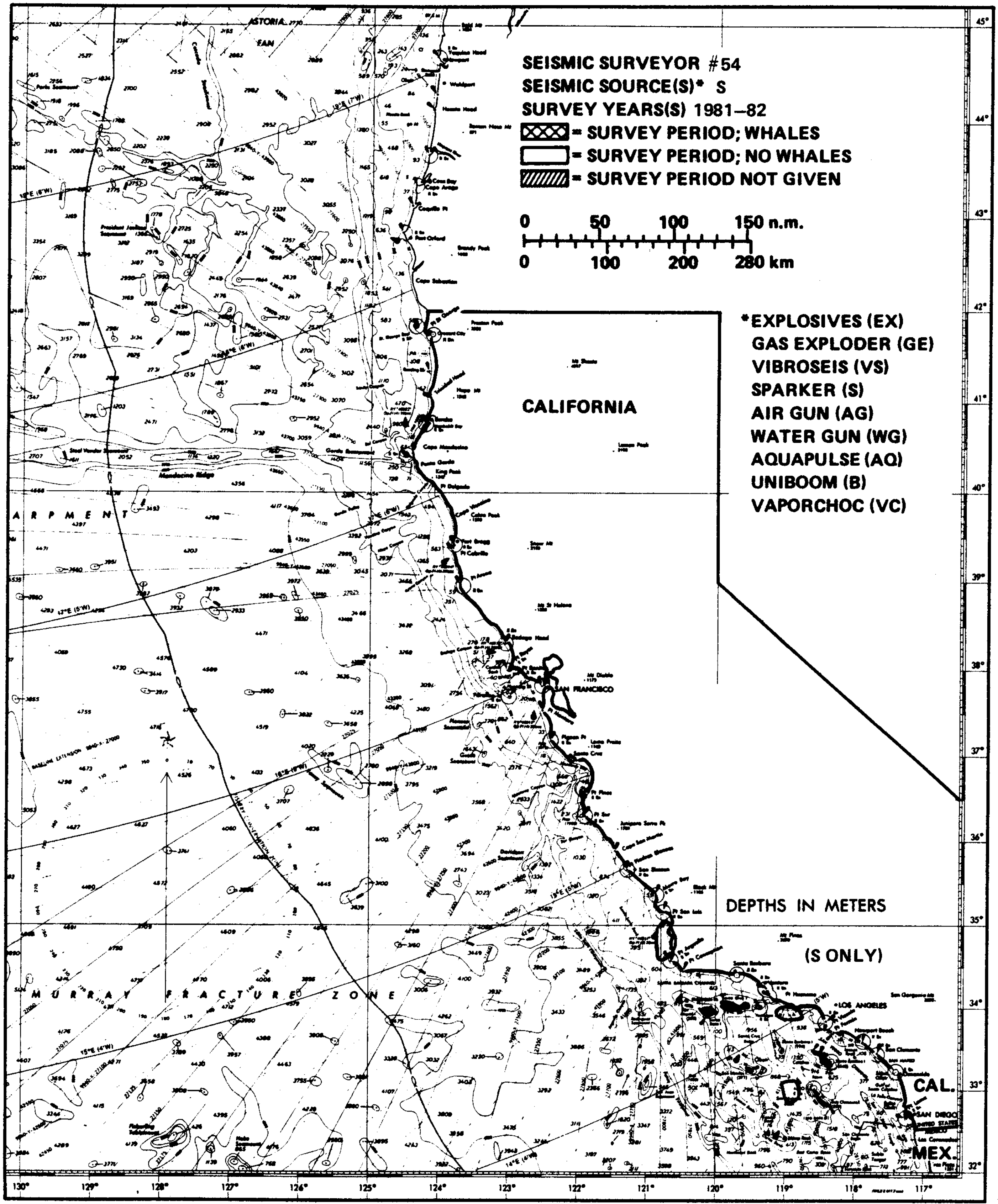

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FIG. A.30. SEISMIC SURVEY ACTIVITIES OF ORGANIZATION #54.

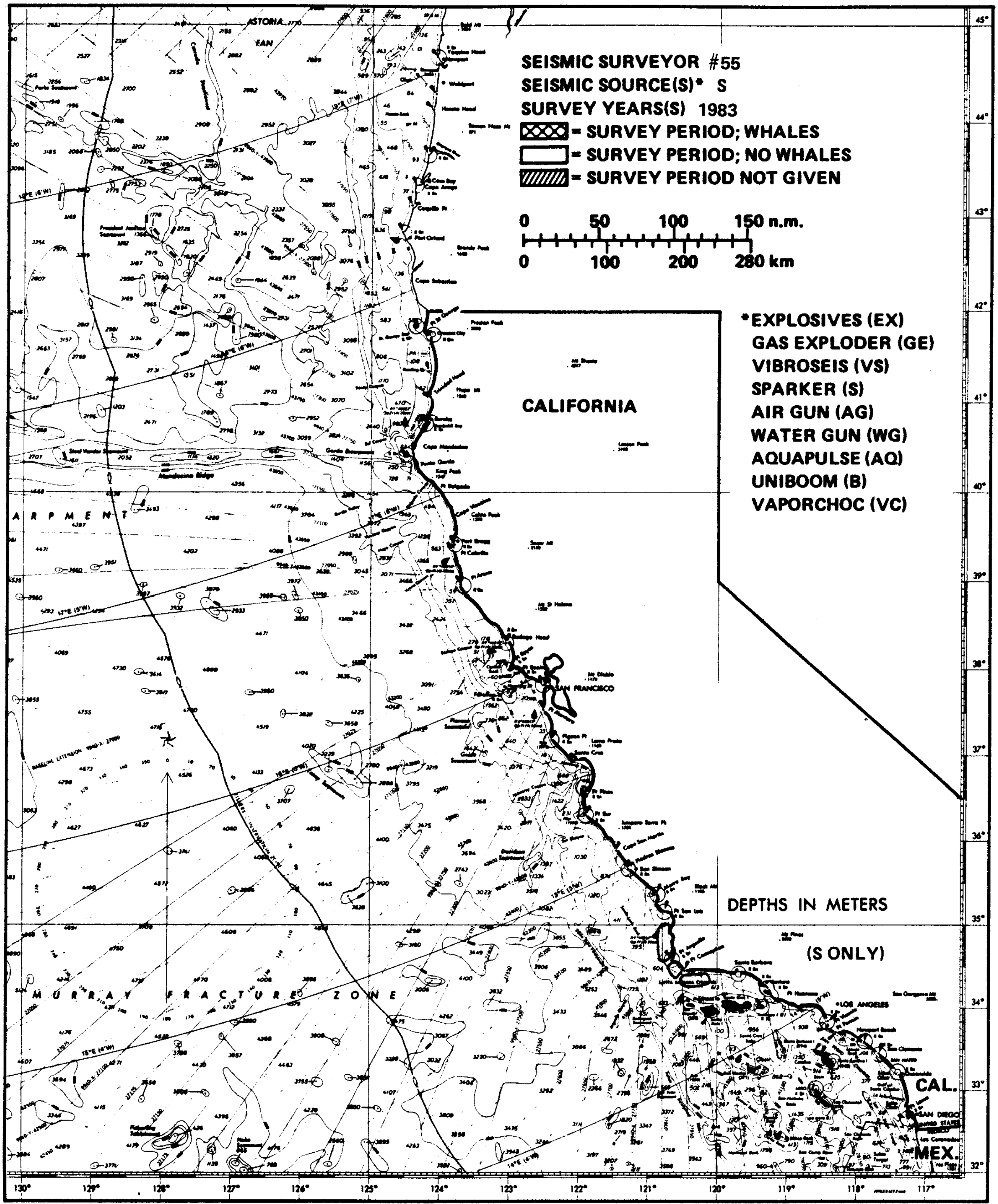

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FIG. A.31. SEISMIC SURVEY ACTIVITIES OF ORGANIZATION #55.

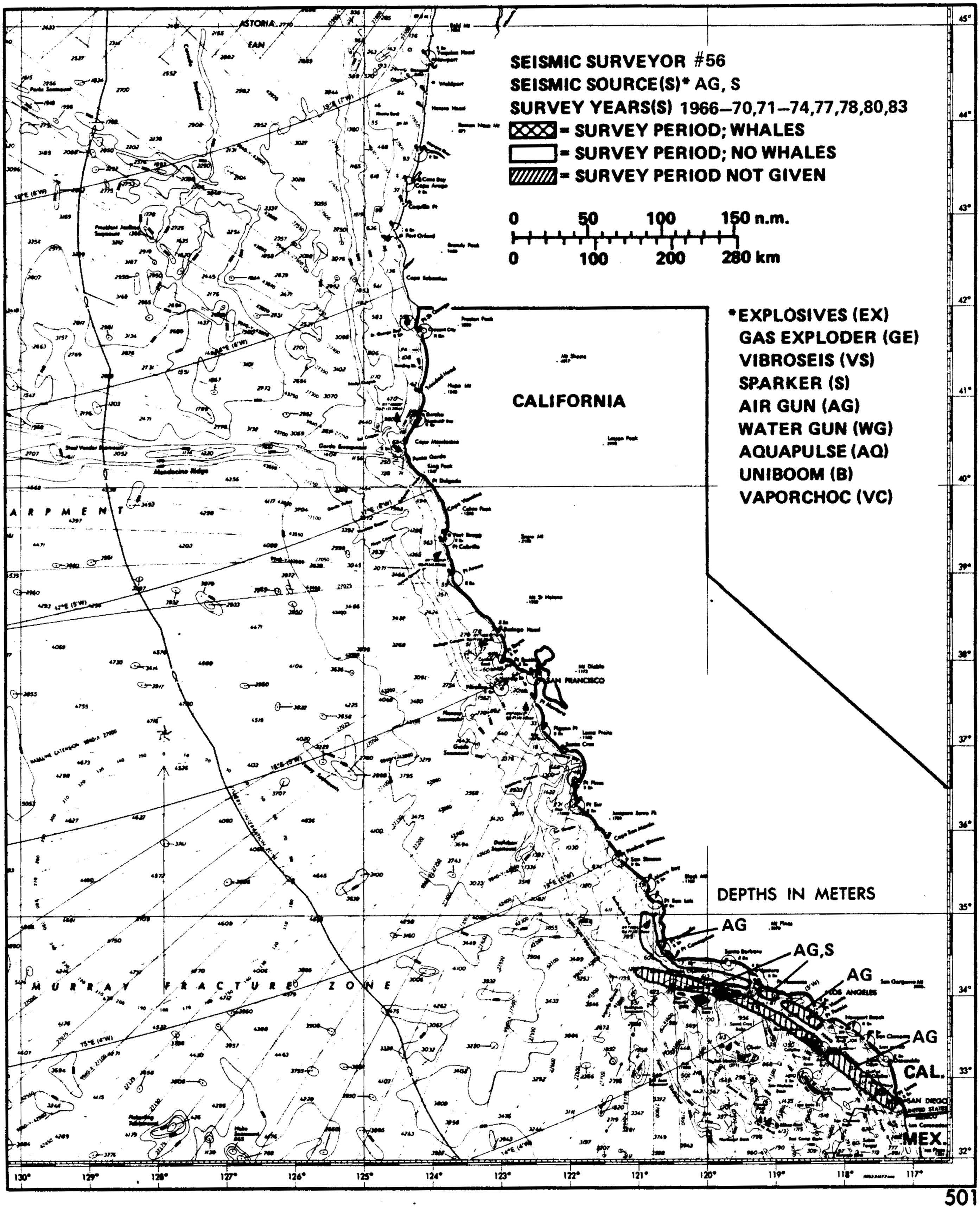

FIG. A.32. SEISMIC SURVEY ACTIVITIES OF ORGANIZATION #56.

until the third week in the following May, encompassing a 5 to 5 1/2 month period. A large part of the seismic survey work has been performed in Southern California waters, with emphasis on the Santa Barbara Channel, Channel Islands, southern basins, and the Santa Maria Basin (north of Point Conception to about Morro Bay). It is difficult to develop numbers regarding distance of the surveys to potential migrating gray whales without precise data regarding the actual locations and dates of the survey work. Nevertheless, if we accept the general nature of these figures, it is probable that only a small percentage of the actual surveys were performed within distances where behavioral responses could be expected (based on the published results of the BBN measurements, Malme, et al. (1983)). That is, it appears that since non-dynamite sources now represent about 99% of the seismic systems used (since the mid- to late-1960's), the survey work would probably have to be within 3 miles of migrating gray whales to cause behavioral response. The degree of response is discussed below. The question regarding long-term impact cannot be answered at this time.

Figures A.33 through A.40 provide computer plots of surveys performed by Lamont, NOAA, U.S. Geological Survey, Oregon State University, University of Hawaii, U.S. Navy, Scripps, and Minerals Management Service. These data were provided by the National Geophysical Data Center.

Most of the responses to the IAGC and CSLC inquiries included general information regarding the number of line miles surveyed. Table A.2 tabulates those data, demonstrating that the 21 respondents submitting data accumulated a total of 371,325 line miles during the period 1964-1983 along the California coast. (In the survey industry, it is standard to itemize length of surveys in statute miles rather than nautical miles.) The file review performed for this study by the National Geophysical

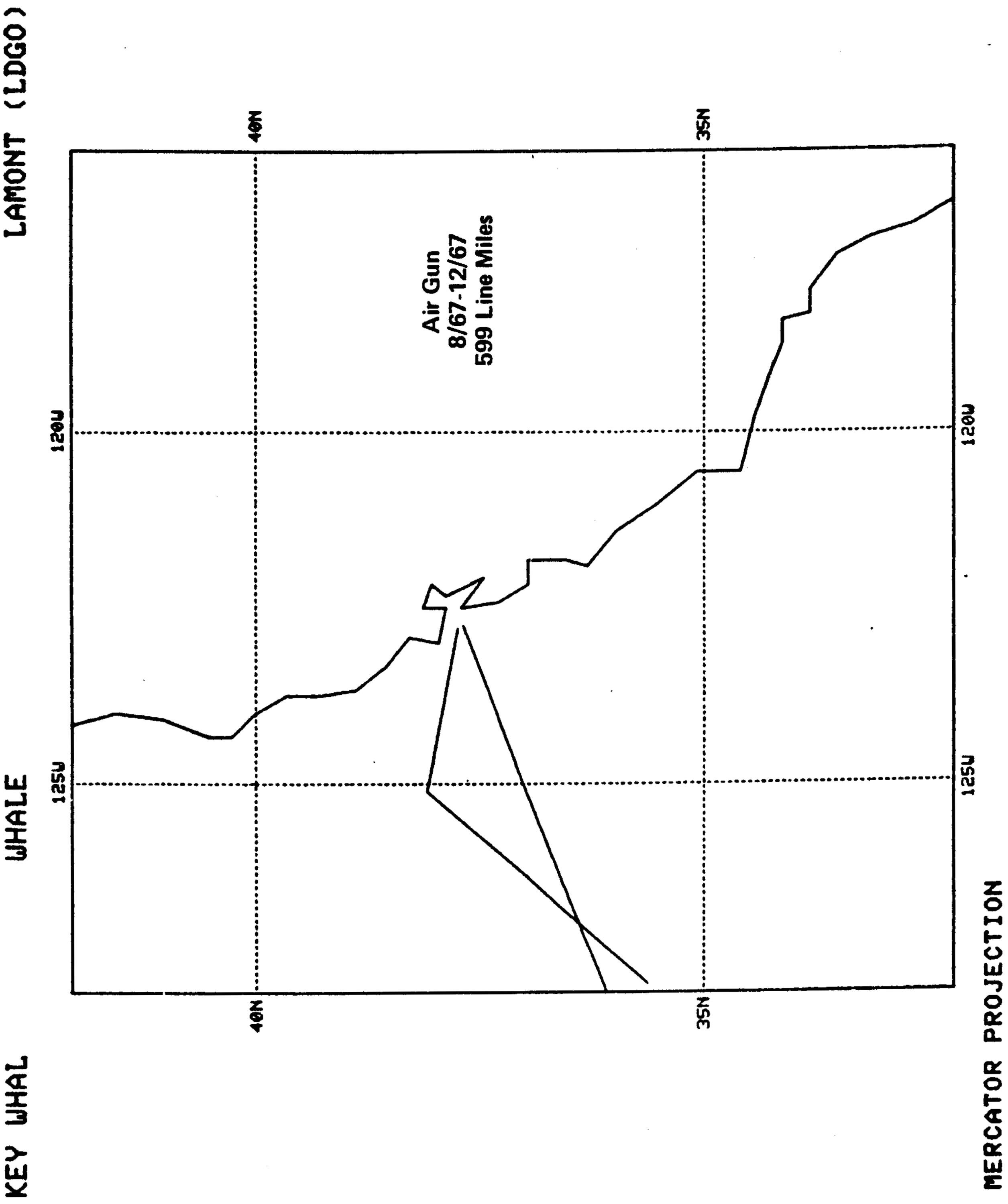

FIG. A.33. LAMONT SEISMIC SURVEY ACTIVITY VIA NGDC.

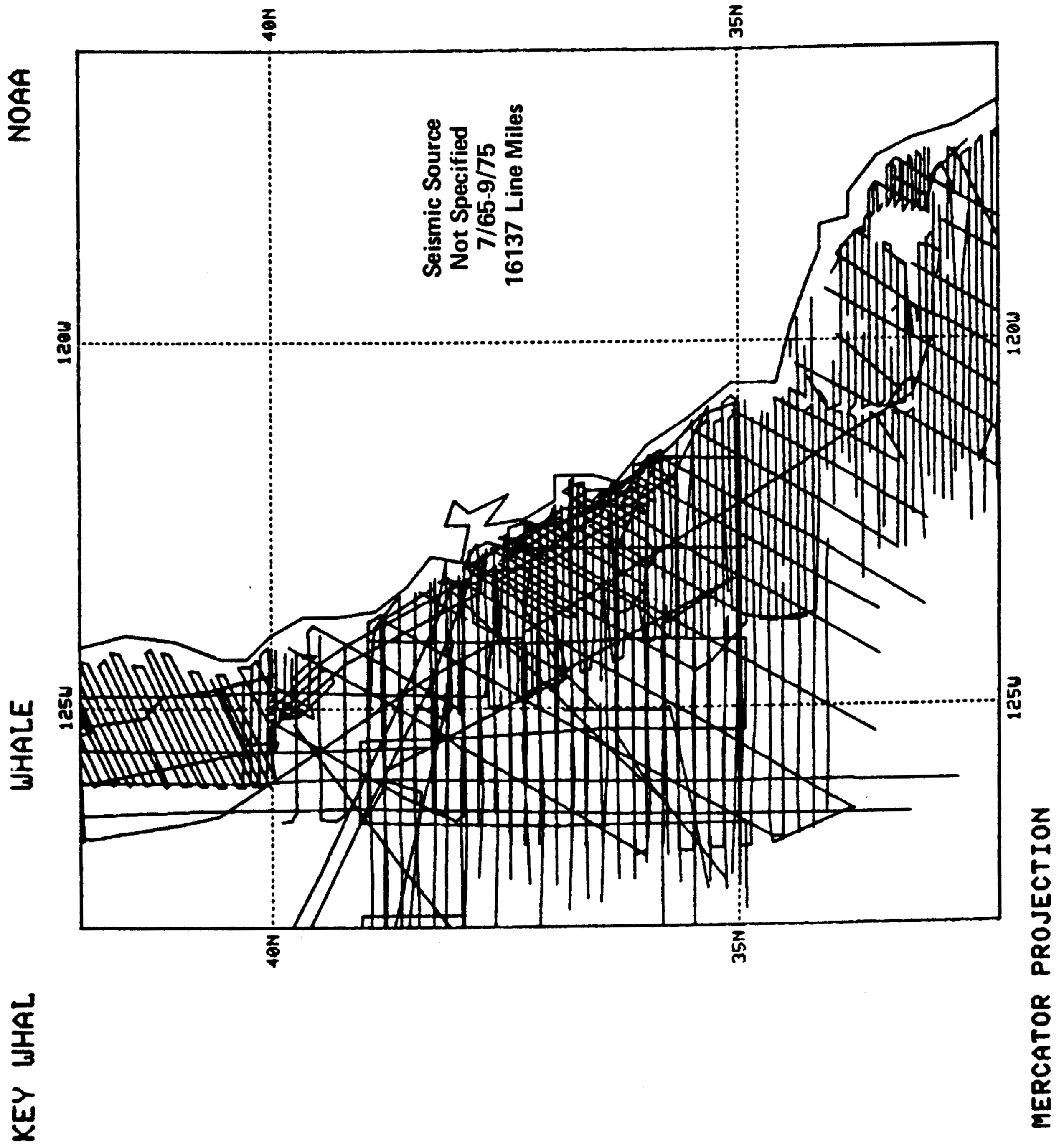

FIG. A.34. NOAA SEISMIC SURVEY ACTIVITY VIA NGDC.

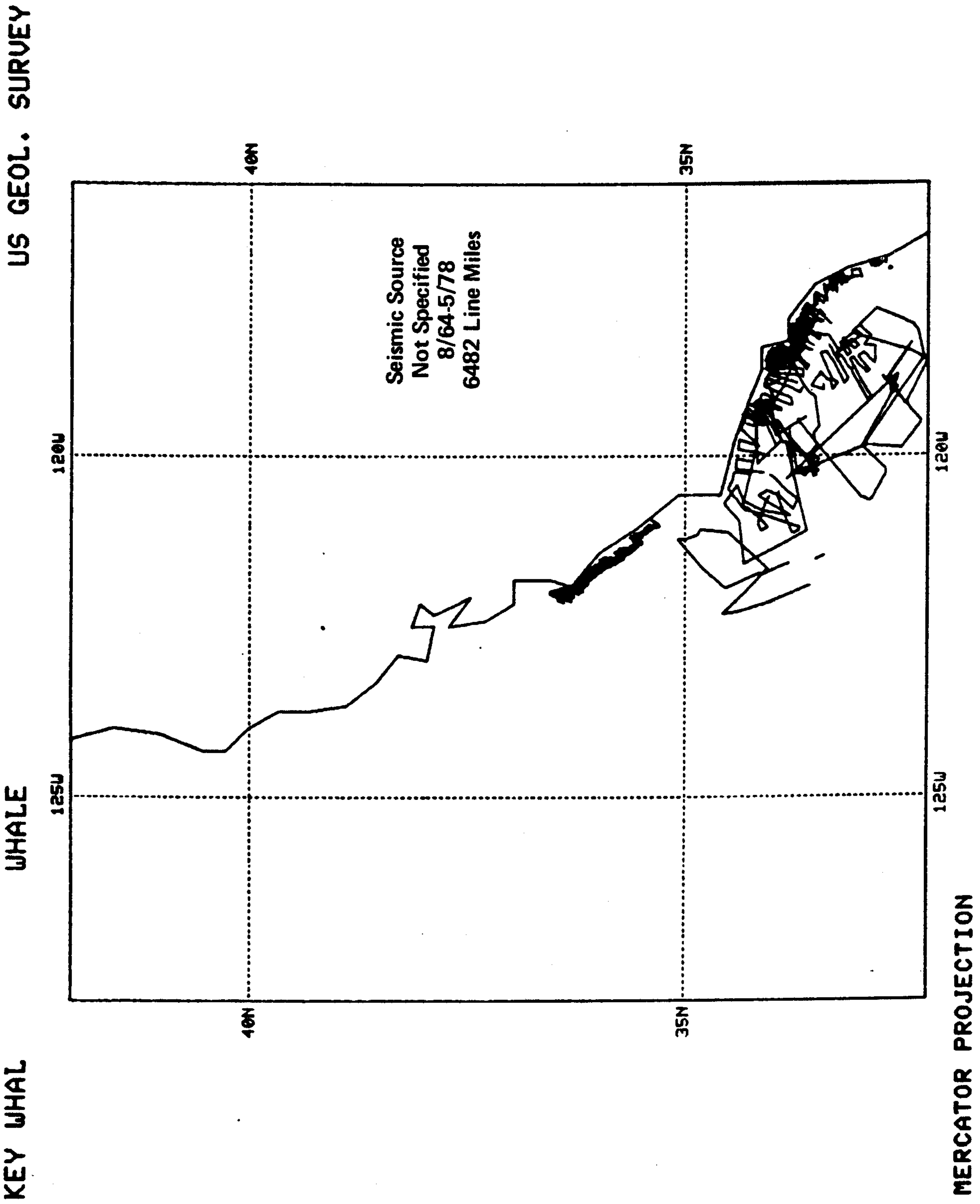

FIG. A.35. USGS SEISMIC SURVEY ACTIVITY VIA NGDC.

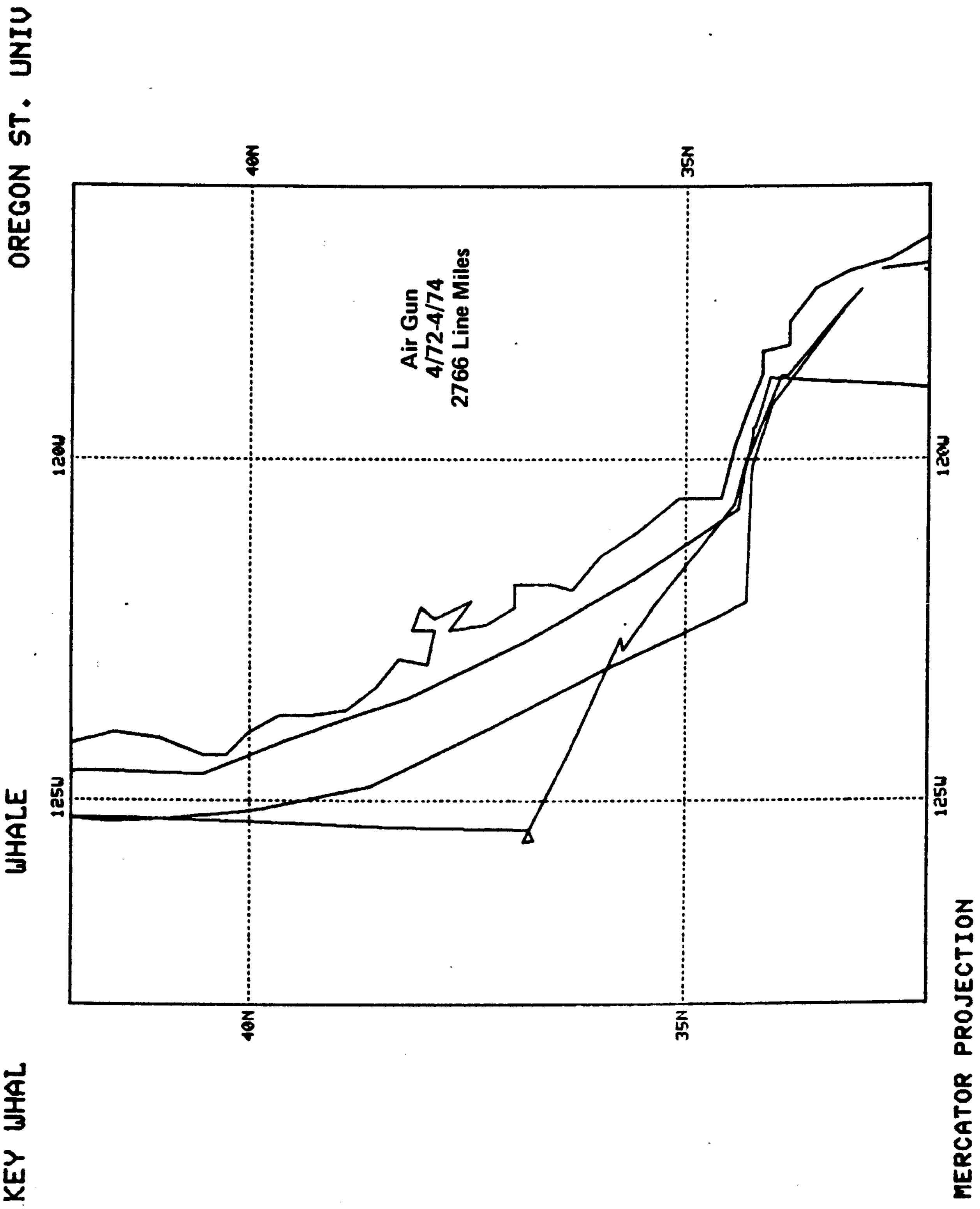

FIG. A.36. OREGON STATE UNIVERSITY SEISMIC SURVEY ACTIVITY VIA NGDC.

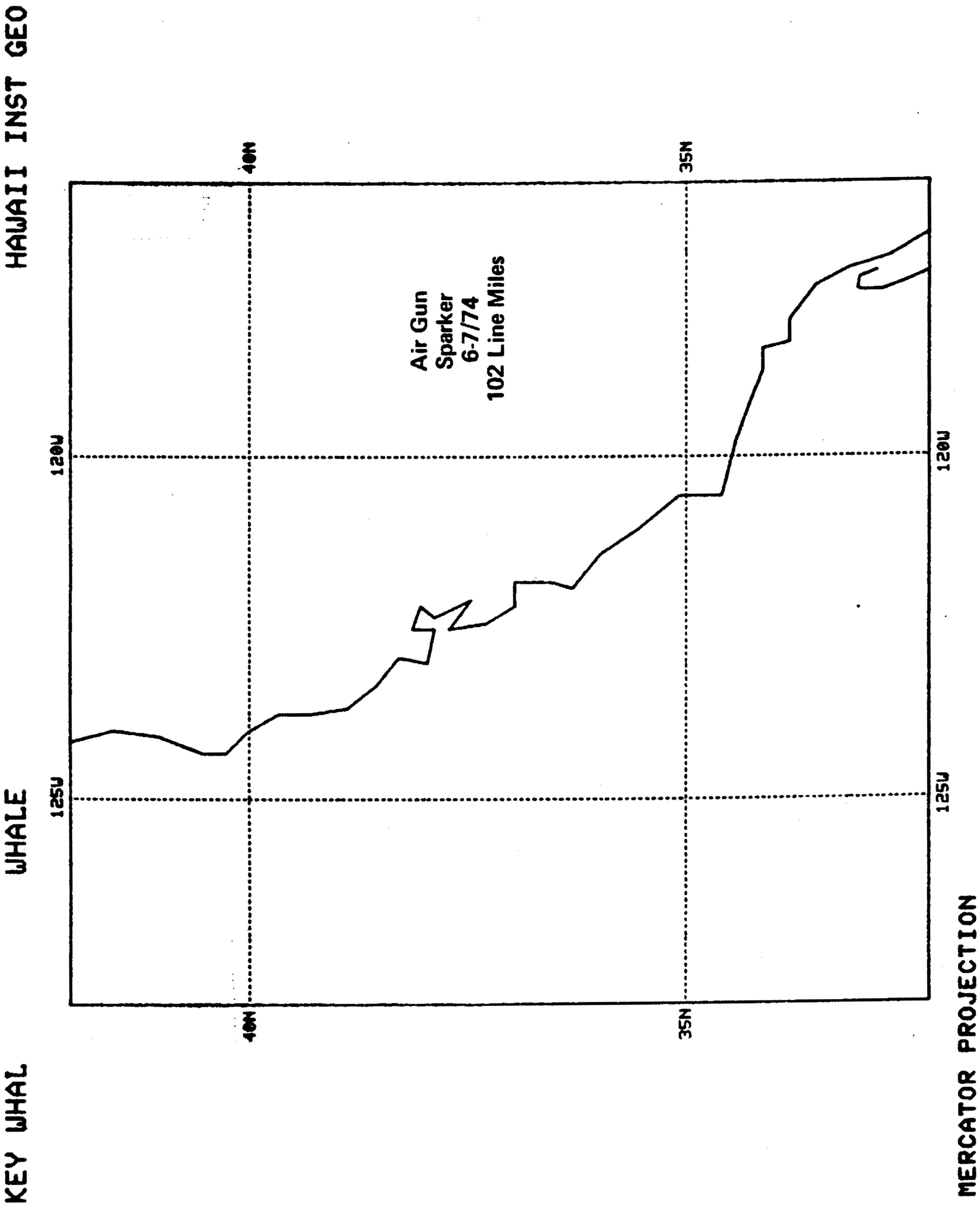

FIG. A.37. UNIVERSITY OF HAWAII SEISMIC SURVEY ACTIVITY VIA NGDC.

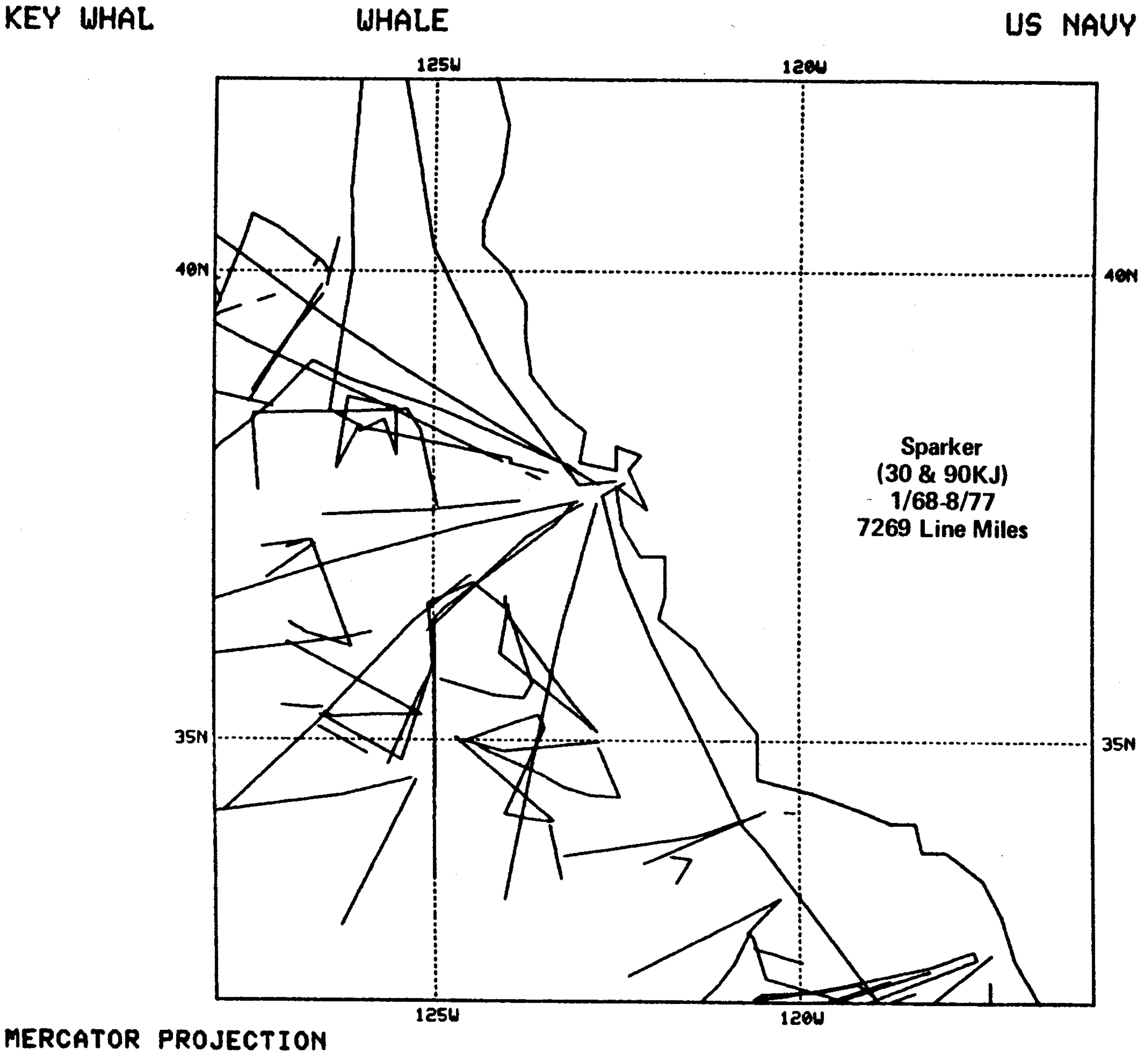

FIG. A.38. U.S. NAVY SEISMIC SURVEY ACTIVITY VIA NGDC.

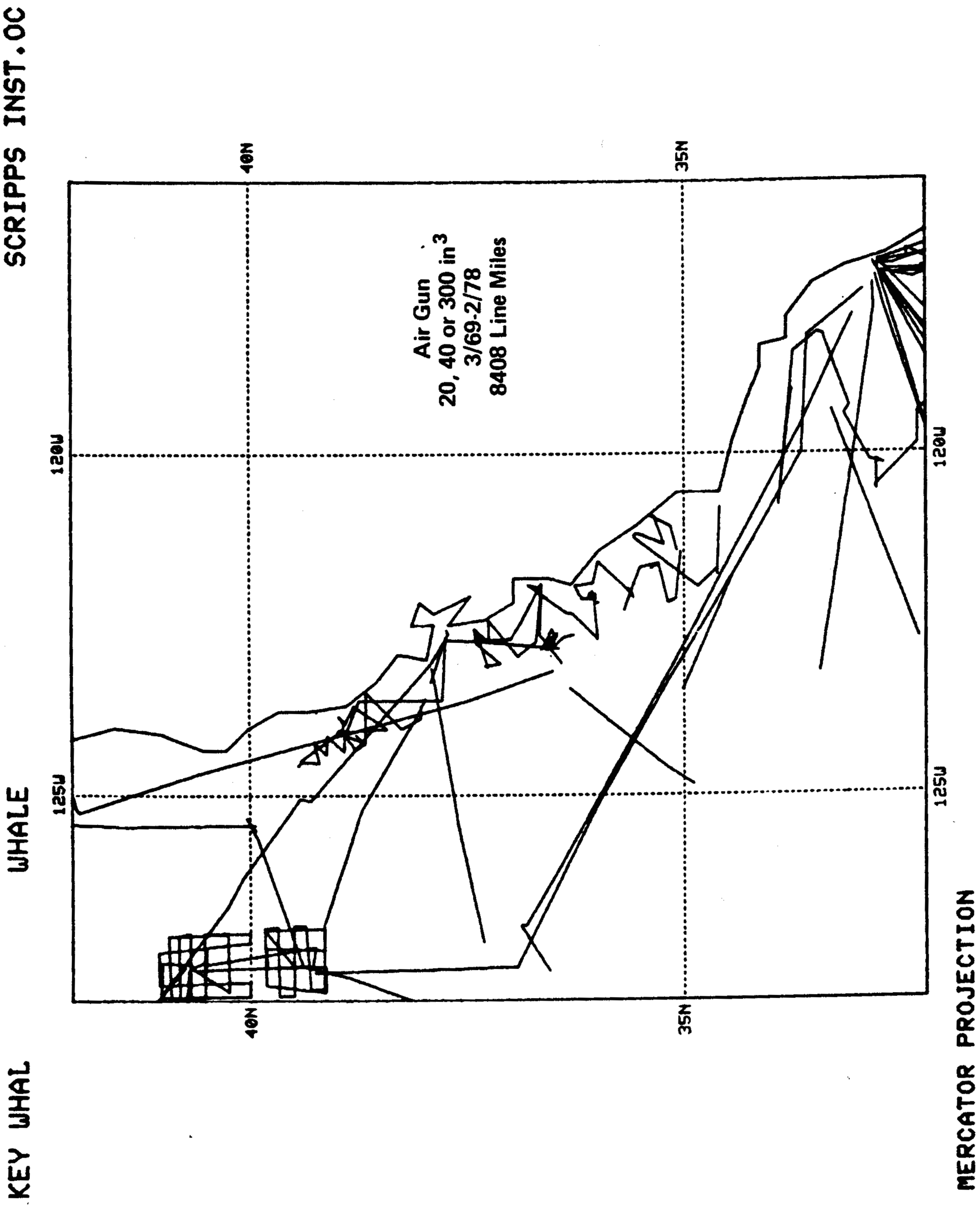

FIG. A.39. SCRIPPS SEISMIC SURVEY ACTIVITY VIA NGDC.

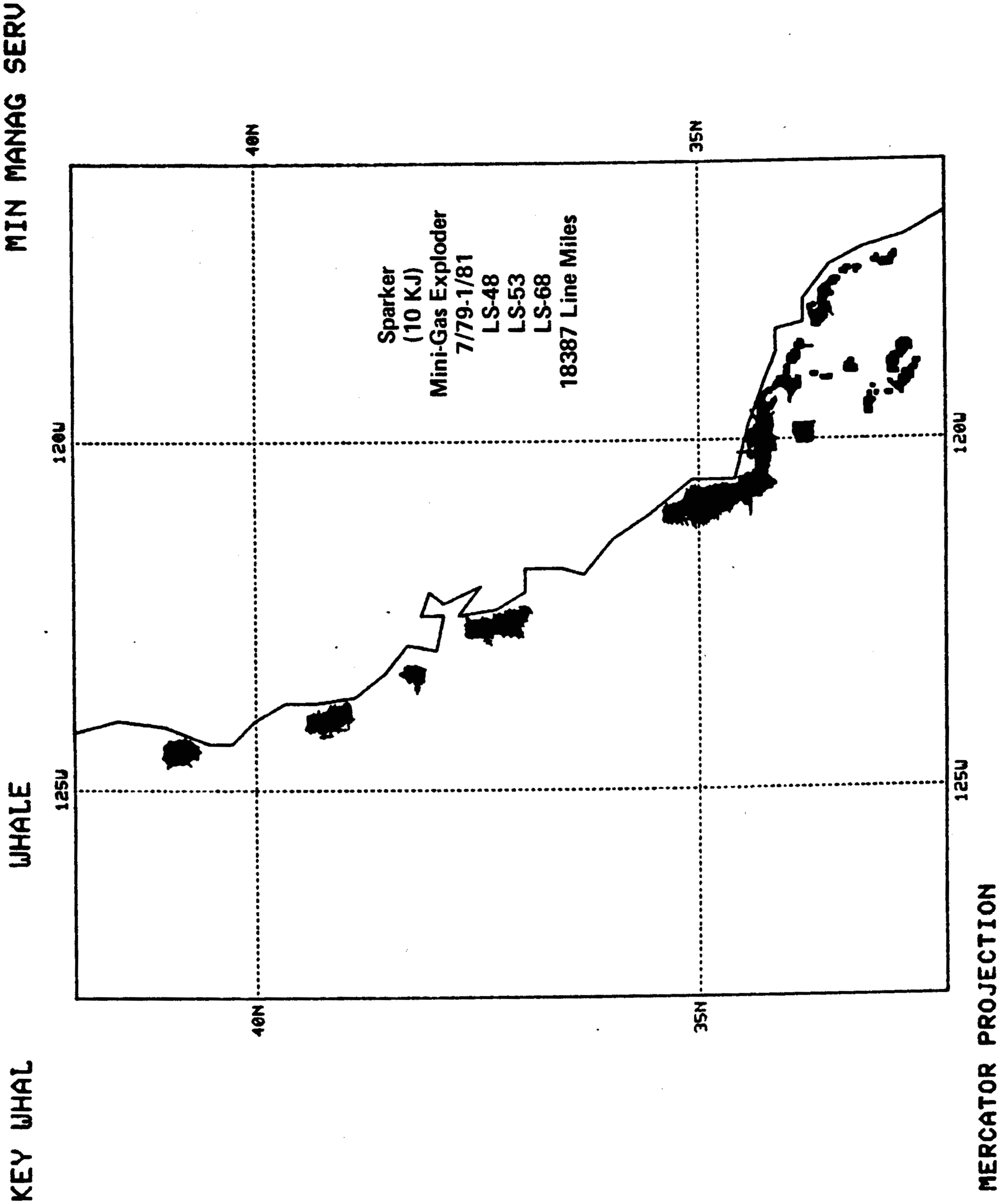

FIG. A.40. MMS SEISMIC SURVEY ACTIVITY VIA NGDC.

TABLE A.2. SUMMARY OF SEISMIC SURVEY LINE MILES.

Seismic Surveyor	Line Miles (Statute)		Years
IAGC and CSLC:			
2	Unknown		1975, 76, 80
3	12,250		1982, 83
4	25,972		1982
8	42,053		1964-81
9	1,100		1982-83
11	46,517*		1974-83
15-1	6,000	45,600	1978-79
-2	24,950		1979-80
-3	14,650		1979-81
18	32,440		?
23	10,916		1974-82
27-1	6,335	21,200	1973,74,77,78-80
-2	3,746		1980-81
-3	2,678		1981-82
-4	1,767		1982-83
-5	3,920		1979,80,82,83
-6	2,754		1982-83
28	2,300		1983
32	Unknown		-
43	Unknown		-
45-1	39,060	111,660	1970,73-80
-2	7,080		1980-81
-3	13,140		1981-82
-4	47,160		1982-83
-5	5,220		1981-82
47	2,971		1977-83
48	1,320		1976-81
49	8,120		1973-83
52	?		1976-79
54	2,300		1981-82
55	650		1983
56	3,956		1966-83
	371,325		

*No plot; data submitted did not include locations of surveys.

TABLE A.2. (Cont.) SUMMARY OF SEISMIC SURVEY LINE MILES.

Seismic Surveyor	Line Miles (Statute)		Years
National Geophysical Data Center:			
Lamont	599		1967
NOAA	16,137		1965-75
USGS	6,482		1964-78
Oregon St. Univ.	2,766		1972-74
U.S. Navy	7,269		1968-77
Scripps Inst. Oceanog.	8,408		1969-78
U. Hawaii	102		1974
MMS Land Sale 48	5,551	18,387	1977-78 (Oct.-Feb)
MMS Land Sale 53	8,115		1979-80 (July-June)
MMS Land Sale 68	4,721		1980-81 (Oct.-Jan.)
	60,150		

FINAL TOTAL 431,475 Line Miles

Data Center shows an additional 60,150 line miles for 1964-1981. There is a good chance, which cannot be confirmed, that the 18,387 line miles in the NGDC data for Minerals Management Service are redundant with some of the survey summary data provided by industry for this study. Nevertheless, a total of 429,175 line miles of survey work (not considering possible redundant entries) along the coast of California was performed during the 1964 to 1983 period. Unfortunately, because of the general nature of the line mile summaries provided, we cannot itemize line miles by individual year or by shorter periods. Work prior to 1964, for the most part, was done with explosives. Probably over 90% of the work summarized here was performed with "non-dynamite" seismic survey techniques. Considering the responses to this study from the industry and other organizations and general discussions with several organizations, we feel that this summary represents about 80% of all survey work performed during the period noted. The remaining 20% may offset the amount of redundancy in the data. Therefore, it appears that about 430,000 line miles of seismic survey work has been performed in California since the mid-1960's.

Table A.3 provides a summary of line miles of marine geophysical surveys as published in Geophysics, the journal of the Society of Exploration Geophysicists (SEG) as prepared by the SEG for the California State Lands Commission. While this compilation is probably not complete (in fact, it apparently includes surveys in West Coast regions other than California), it does emphasize the variable nature of seismic survey activity. The sharp null of activity from 1970 to 1972 was due to the oil embargo problems of that period.* Other fluctuations cannot be

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*Two of the respondants to the BBN survey did do work in that null period, however. They reported a total of 2,820 line miles in 1970 and 2,000 miles in 1971.

TABLE A-3. OFFSHORE PETROLEUM SEISMIC ACTIVITY.
(Prepared by Society of Exploration Geophysists.)

Year	Area	Crew Months	Approx. Line Miles*
1960	Pacific Coast	4	3,084**
1961	Pacific Coast	34	26,214**
1962	Pacific Coast	53	40,863**
1963	Pacific Coast	39	30,069**
1964	Pacific Coast	45	34,695**
1965	West Coast	49	37,779**
1966	California	26	20,046**
1967	California	34	26,214**
1968	California	10	7,710**
1969	California	19	14,649**
1970	California	5	3,855**
1971	California	0	0
1972	California	3	2,313**
1973	California	27	20,817**
1974	California	58.2	44,872**
1975	California	31.0	25,548
1976	California	28.9	18,209
1977	West Coast	20.7	15,173
1978	West Coast	38.8	29,806
1979	West Coast	28.3	26,500
1980	West Coast	57.5	39,843
1981	West Coast	33.4	21,024
1982	West Coast	53.0	50,716
		TOTAL EST.	539,999

*Line miles = statute miles covered by survey.

**Crew months were provided by SEG; we have assumed an average of 771 line miles/crew months to compute line miles. This average was obtained from the years 1975-1982 for which both line miles and crew months were provided.

explained at this time, although many such variations are directly due to such factors as political climate, size, and conditions of active reserves and predictions of energy use rate by the country as a whole.

The SEG compilation includes 184,233 line miles for "California," 134,925 line miles for "Pacific Coast," and 220,841 line miles for "West Coast." The responses to the survey under this project for California waters, summarized in the previous figures, represent 369,025 line miles plus an additional 60,150 line miles from the Geophysical Data Center contributions. The period covered by these responses is 1960 to 1983 with a small contribution (2,174 miles) in early 1984. If the SEG summary is reasonably accurate, there must be California data included in either or both of the "West Coast" and "Pacific Coast" categories.

Concluding statements regarding this seismic survey history are discussed in Sec. A.4.

A.3 GRAY WHALE MIGRATION

Of the two known stocks of the gray whale, one inhabits and migrates in the northwestern Pacific coastal regions and the other is located in the eastern Pacific migrating annually along the west coast of North America. These two stocks have been designated the Korean and California stocks, respectively, by Rice and Wolman (1971) in their detailed monograph concerning the life history and ecology of the gray whale. Fortunately for this study, it is the California stock which has received the most attention by researchers both in the past and increasingly so in recent years. The Rice and Wolman monograph provides an excellent summary of the coastal migration and population estimates of the California stock as well as reviewing briefly the limited information available on the Korean stock. In 1962, Pike published an extensive summary of the migraton habits of the gray whale, citing observations by many researchers, from the feeding grounds all along the Pacific coast of North America to the breeding lagoons in Mexico. Both publications serve as standard references for those concerned with gray whale research.

In the first phase of this present research effort by Bolt Beranek and Newman and its team of whale behavioral scientists studying the behavioral response of migrating gray whales to acoustic stimuli, James Bird published an extensive literature review in BBN Report No. 5366 (Malme, et al., 1983). Approximately 150 publications were reviewed and reported findings regarding migration, population dynamics, and behavior associated with industrial activity were summarized.

With regard to the migratory characteristics of the gray whale, particularly along the coast of California, we will supplement here the earlier findings of Pike (1962) and Rice and Wolman (1971) with the more recent findings of such researchers as Poole (In Press), Reilly (1981), Braham (In Press), and Herzing and Mate (In Press), among others. Figure A.41 presents the general geographic features of the southern portion of the gray whale migratory range, highlighting particular observation regions which have been used in recent years by various researchers. Several of these regions will be referred to in the following discussion.

Generally, the recent research supports the earlier findings regarding near-coast migratory corridors and the fact that southbound whales exhibit swimming speeds which average twice that of northbound migrants (4 to 5 kts vs 2 to 3 kts). It has now become clear that at least along the California and Oregon coasts instead of the single broad moving pulse shown by southbound animals, the northbound migration is divided into two phases. The first phase (Phase A) is made up primarily of adult and immature animals travelling singly and in small groups followed approximately 1.5-2 months later by a second phase (Phase B) or wave of mother/calf pairs. Southbound migrants generally travel from 2 to 5 km offshore and, in a few limited cases, as distant as 200 km from shore while the northbound whales are closer to shore and frequently are observed in or near the surf-zone, depending on which phase is passing an observation site. The Phase A migration tends to track 1 to 3 km from shore and Phase B, the mother/calf pairs, usually is seen near the surf zone. Detailed summaries of migration timing, swimming rates, migration corridors, and population dynamics particularly along the California coast, are presented below. No attempt will be made to repeat the details of statistical analyses by others, although a general review of their findings are included where appropriate.

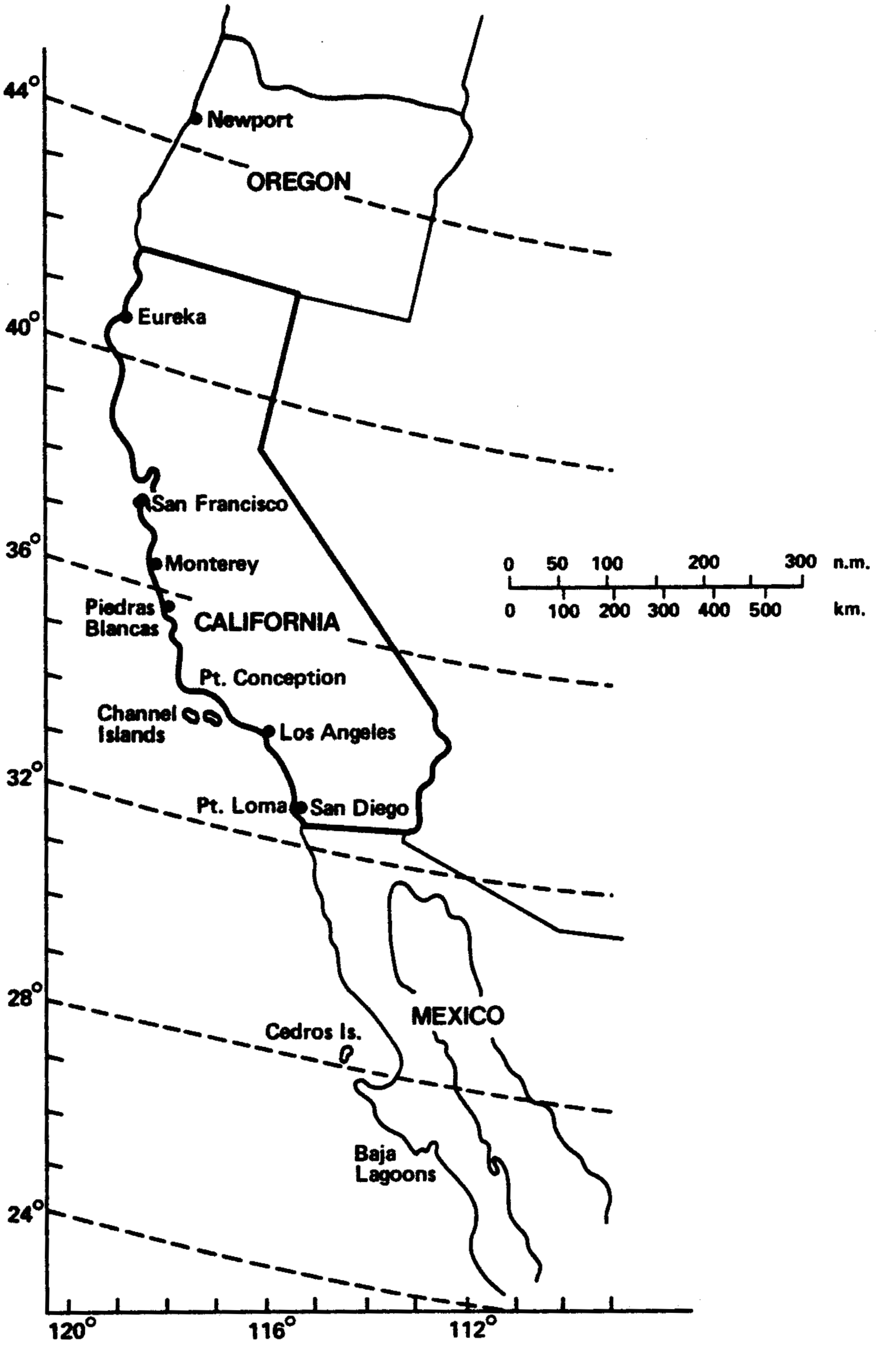

FIG. A.41. SOUTHERN RANGE OF GRAY WHALE MIGRATION.

A.3.1 Migration Timing

Since Pike (1962) is commonly used as a source for estimating migration timing between the northern feeding grounds and the southern breeding lagoons, it is helpful to superimpose recent data on his cyclic migration plot. Figure A.42 provides those data. Approximate peak arrival times of the migrating gray whale population are plotted with the Pike summary using his format. The distance axis is referenced to Cedros Island in Mexico which is located at the north end of the breeding lagoons region of the Baja peninsula. Typical geographic locations used for gray whale observation are noted. The references used for the data points given in the figure are noted by the number next to each closed circle. It is immediately apparent that the northbound arrival times are offset somewhat from the Pike summary, generally commencing earlier in the year by 2 to 4 weeks than estimated in that reference. The bi-modal or dual phase migration reported by Poole (In Press), Dohl, et al. (1981), and Herzing and Mate (In Press), is demonstrated in the Monterey, Northern California, and Yaquina Head, Oregon, data points with the "singles" arriving early and the mother/calf pairs arriving late. A general 2 to 3 kt trend for swimming speed is obtained by the slope of the migration curve. Southbound migrants adhere very closely to the schedule originally reported by Pike and demonstrate a 4 to 5 kt speed during the more rapid portion of the curve from British Columbia to Point Loma in Southern California. Rice and Wolman (1971) reported, through limited collection and examination of both southbound and northbound whales in the mid-1960 period, that females without calves generally travel earlier than males and adult gray whales migrate earlier than sexually immature animals. It appears that the sampling during northbound migration occurred during Phase A, particularly since mother/calf pairs apparently were not encountered. Their sampling took place

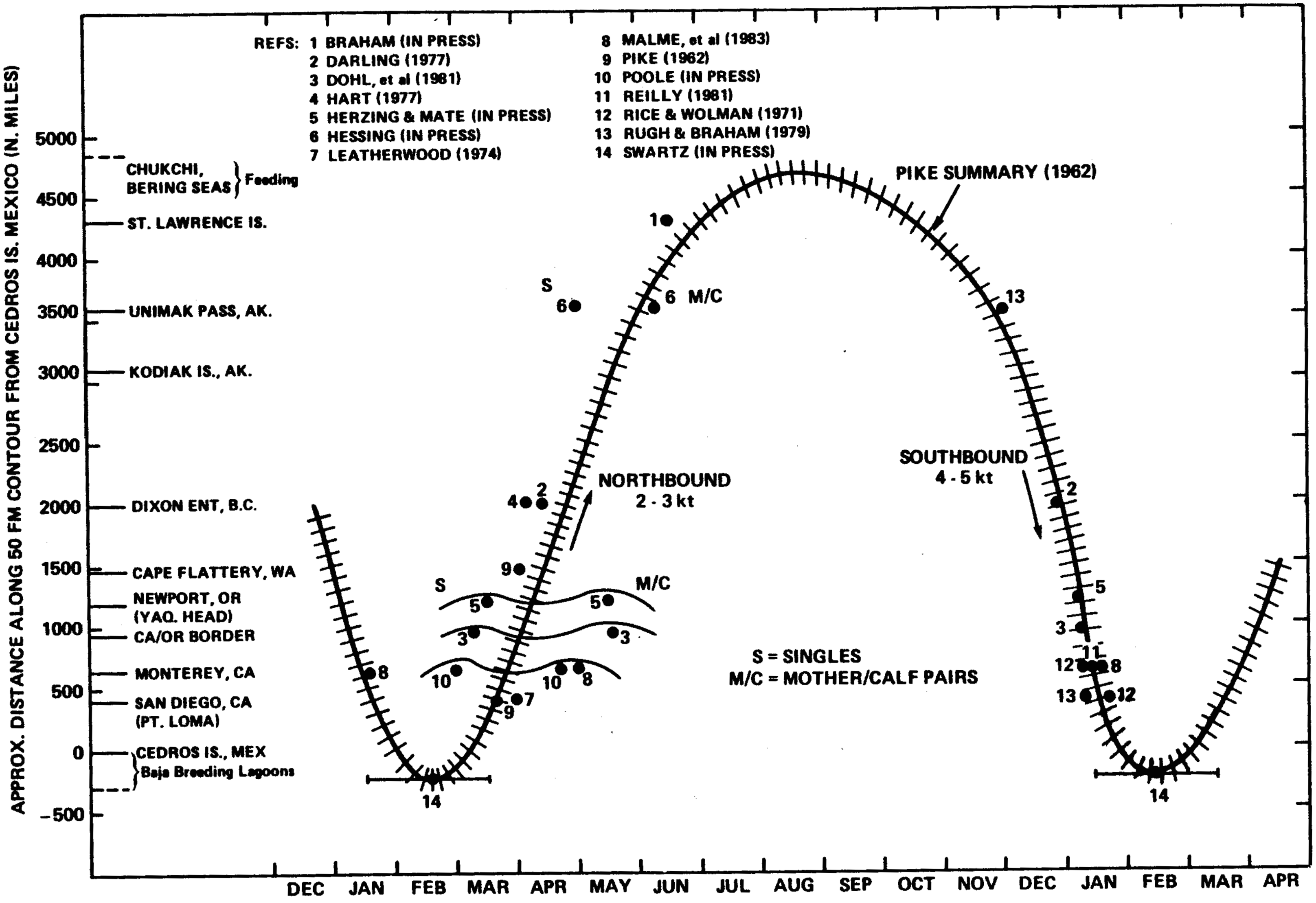

FIG. A.42. CHUKCHI SEA TO BAJA BREEDING LAGOONS GRAY WHALE MIGRATION PATTERN.

near the 38° North latitude region of central California. Nevertheless, Hessing (In Press) reports a bi-modal trend of northbound migrants as far north as Unimak Pass in 1980 when peak numbers of whales were observed during the last week of April and then mother/calf pairs started arriving during the second week of May. Several authors report sitings along the southern coast of Alaska, Canada, and northern United States coasts during the off-migratory season indicating that some small percentage of the population does not travel the full migration route.

It is particularly useful to expand the scale of Fig. A.42 to examine migration timing in the California coastal region. Figure A.43 provides that summary. While it would be helpful to have more data, the trends are clear. In this figure, the source of the data regarding the peak numbers of whales per day passing a given observation point is indicated by the parenthetical number referencing listings in the previous figure. The years refer to when the peak occurred. Mean speed of migration is that which was computed from the table in the next section. The two-phase or bimodal northbound migration is clearly established in this figure and it is conceivable that the mother/calf pairs travel northward more slowly than the "singles" in phase A. It appears, in fact, that the San Diego observations reported by Pike (1962) encompassed both peaks of the northbound migration. Peak dates with a question mark on the Pike data (as well as that for Leatherwood) are provided as a reasonable but unreported estimate of the time of peak passage. During observations by BBN at the peak of the mother/calf migration (Ref. 8), the mean speed was 2.8 kt ± 0.6 kt, although there appeared to be more activity, including milling, apparent feeding, and moving about in kelp beds and the surf, than they observed during southerly migrations. Included in this figure is a qualitative approximation of the distribution of the number of animals passing a given observation point. Here, the peak of each migration pulse applies to

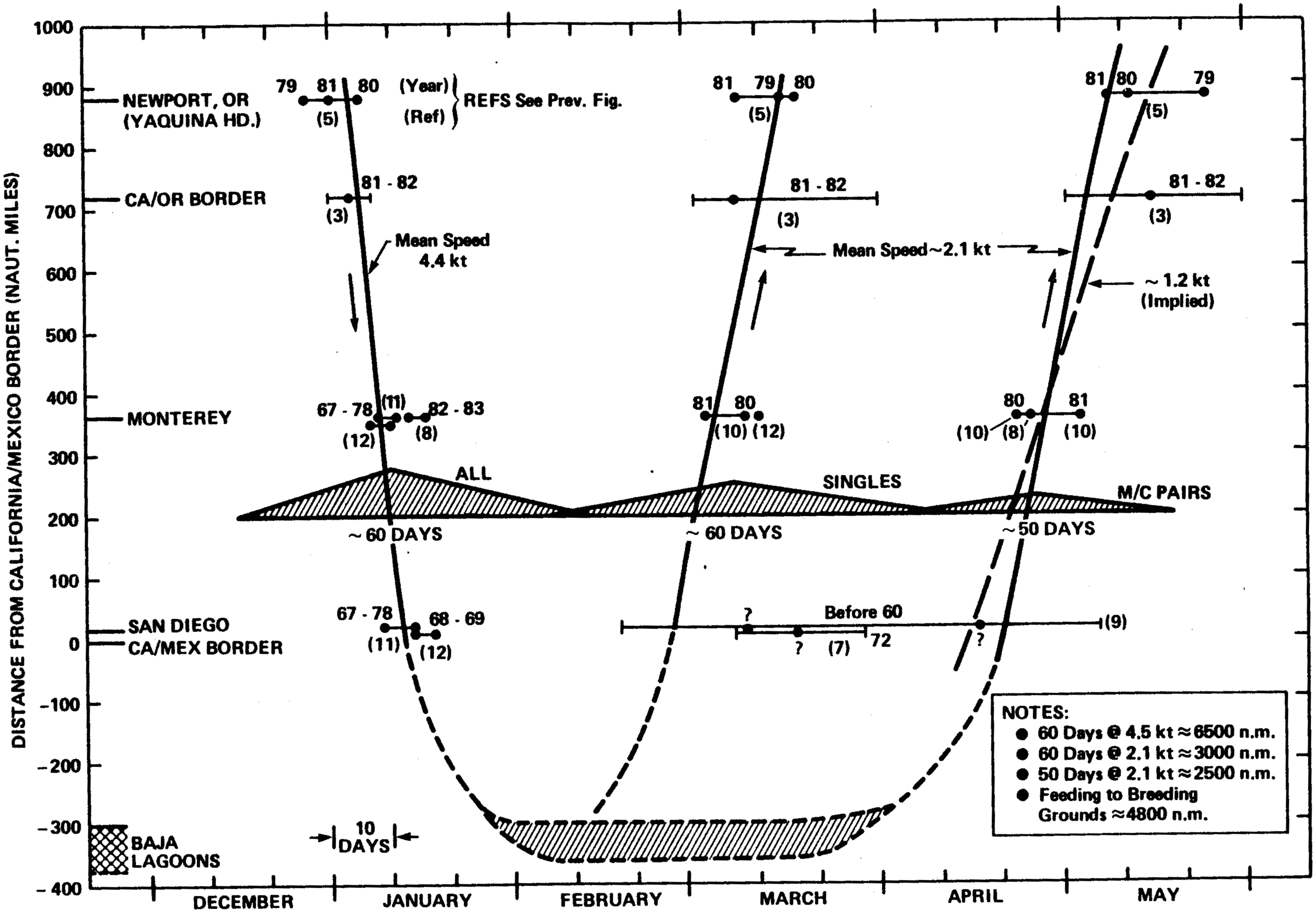

FIG. A.43. GRAY WHALE MIGRATION PATTERN IN CALIFORNIA.

that observed in the Monterey area. These are provided to indicate the time distribution of these pulses and, generally, to indicate that the peak rate of whales during the southbound migration is higher than either of the northward pulses as one might expect since the southerly migrants have been divided into two groups for northward travel. Approximate duration of each pulse is noted and it is also indicated that in some years and locales, particularly from central to southern California, that there is an overlap between trailing southbound migrants and early northbound animals. Similarly, there is often a period of northbound singles travelling in the same period as early northward mother/calf pairs. Some observers, including Rice and Wolman (1971), and Reilly (1981), have observed a skewed character of these time-based distributions. The peaks generally occur a few days before the geometric mean of the time period.

The other dimension of the migration pulses would be awkward to show and we have resorted to generalization with the notes in the table included with the figure. A migration pulse is spread out along the coast in a very significant way. The table probably over-generalizes the effect. Nevertheless, a pulse is clearly many hundreds of miles long and probably is in the order of 3,000 to 4,000 miles. Speed of travel along the migration route varies, usually starting out slowly and then speeding up as the animals progress along the full 4,500 to 5,000 nm track.

All of this points to the fact that there will be gray whales found continuously in California waters from early December until mid-May, every winter and spring. There have been a few reported isolated cases of gray whales which apparently summer-over in areas such as the Farallon Islands near San Francisco. It is not known whether these represent the exception rather than the rule.

A.3.2 Swimming Speed

The following table (Table A.4) summarizes swimming speeds along the migration route reported by various observers. The southbound mean speed was computed by averaging all values except for the Unimak Pass to San Diego speed which appears to be biased by slow start-up of the pulse. One particularly interesting set of data is that reported by Mate and Harvey (In Press) relating to average speeds of a single northbound whale which had been tagged and tracked using a radio telemetry link. The gradual increase in speed as the whale progresses along the migration route, which has been suspected by others, is established in these data. There is little evidence regarding night-time travel rates, although the whale tagging data, as well as distant point-to-point monitoring of peak population arrival times, indicate that swimming rate does not change significantly from day to night.

A.3.3 Migration Corridors

It has been reported by many observers that southbound gray whales use a corridor which is further off-shore (averaging 2 to 5 km from shore) than the northbound migrating whales (Phase A is commonly 1 to 3 km from shore and Phase B from 10 to 200 m). Gray whales are coastal migrants although they apparently venture occasionally into deep or open ocean areas. They generally stay within the 10 to 50 fathom contours and according to Rice (1965) gray whales are not often observed in water deeper than 180 m. During their coastal paths the southbound whales and Phase A of the northbound whales commonly travel from point-to-point to cross bays and avoid bights and harbors. Phase B or the mother/calf pairs during their northward trek commonly work the surf-zone, enter kelp beds and travel through bights and around rocks. The reason for this is unclear although several

TABLE A.4. GRAY WHALE SWIMMING SPEEDS DURING MIGRATION.

Location	Southbound	Northbound	Reference
Cape Flattery, WA	-	1.5 - 2.0 kt	Pike (1962)
CA/Oregon/B.C. Coasts	4 kt	2 kt	Pike (1962)
Yaquina Head, Oregon	-	2.7 kt	Herzing & Mate (In Press)
Yaquina Head to Monterey	3 - 4 kt	-	Herzing & Mate/Reilly*
Monterey	4.05 ± 1.62 kt	2.8 ± 0.6 kt	Malme, et al. (1983)
Monterey	4 - 5 kt	2 - 2.5 kt	Rice & Wolman (1971)
Central CA to Central Oregon	-	1.5 kt	Mate & Harvey (In Press)
Monterey to San Diego	4.7 kt	-	Reilly (1981)
San Diego (Pt. Loma)	4.6 kt	-	Pike (1962)
San Diego	5.5 kt	-	Cummings, et al. (1968)
San Diego	3.9 kt	-	Sumich (1983)
San Diego	4.6 kt	-	Wyrick (1954)
San Diego	-	1.5 kt	Leatherwood (1974)
Unimak Pass to San Diego	2.3 kt	-	Rugh & Braham (1979)
Oregon to Unimak Pass	-	2.05 kt	Mate & Harvey (In Press)
Mean Speed	4.4 kt	2.07 kt	

Single Tagged Gray Whale: [Mate and Harvey (In Press)]

Baja to San Diego	-	0.76 kt
San Diego - Coos Bay, Oregon	-	1.8 kt
Oregon Coast	-	2.2 kt
Oregon - Unimak Pass, AK	-	2.85 kt

*Derived from peaks reported by Herzing and Mate (In Press) for Oregon and Reilly (1981) for Monterey.

researchers (e.g., Poole, In Print) consider the need for feeding along the near-shore bottom as a strong possibility. Also, the presence of killer whales, Orcinus orca,, often causes gray whales to enter kelp beds and the surf zone where, it is speculated, it is more difficult for the orcas to acoustically locate and/or communicate effectively. Therefore, it is conceivable that mother/calf pairs stay close to shore for protection as well as for feeding purposes. Dohl, et al. (1982), demonstrates observed migration corridors between Point St. George and the Channel Islands south of Point Conception to consist primarily of a single corridor but near San Francisco and the Channel Islands, several tracks are used. At San Francisco, they are commonly seen to the west in the Farallone Islands, approximately 25 miles from shore and also at about 15 and 10 miles or less from shore. At Point Conception, the corridors again split with some whales travelling west of the Channel Islands, some between the islands and some east of the islands. Between Pt. Conception and San Diego and south into Mexico, some gray whales have been observed as far as 200 km (108 nm) from shore [Rice and Wolman (1971)], where they are crossing the large coastal indentation between Pt. Conception and Pt. Loma. These departures from general in-shore corridors are generally limited to these two main areas in Caifornia. Table A.5 summarizes migration corridor locations reported by various observers.

Historically, Poole (In Press) reviews the trends of the whaling industry and documents the fact that most of the hunting of gray whales occurred in coastal or in-shore regions. The primary sources of information used by Poole, as well as others such as Reilly (1981) were publications by Scammon in 1874 and Townsend in 1887. They indicate that the original northbound migration corridor of gray whales included the kelp zone. However, he goes on to say that later speculation regarding mother/calf pairs indicated the general belief that the whaling

TABLE A.5. MIGRATION CORRIDORS.

SOUTHBOUND MIGRATION

Location	Max. Distance from Shore	% of Census	Reference
Newport, Oregon (Yaquina Head)	3.2 to 4.8 km (1.7 to 2.6 nm)	68%	Herzing & Mate (In Press)
No. California (along coast)	1.8 km (1 nm)	-	Dohl, et al. (1981)
(San Francisco)	46 km (25 nm)	-	Dohl, et al. (1981)
(Channel Is.)	83 km (45 nm)	-	Dohl, et al. (1981)
Monterey (Yankee Pt.)	1.5 km (0.8 nm)	73%	Rice & Wolman (1971)
Monterey	1.9 km (1.0 nm)	95%	Rice & Wolman (1971)
Monterey	1.6 km (0.9 nm)	94%	Sund & O'Connor (1974)
Monterey (Yankee Pt.)	1.6 km (0.9 nm)	40%	Reilly (1981)
	5 km (2.7 nm)	95%	Reilly (1981)
Monterey (Soberanes Pt.)	1 to 4 km (0.5 to 2 nm)	-	Malme, et al. (1983)
Channel Islands	200 km (108 nm)	-	Rice & Wolman (1971)
San Diego (Pt. Loma)	9.3 km (5 nm)	41%	Rice & Wolman (1971)
	195 km (105 nm)	100%	Rice & Wolman (1971)

NORTHBOUND MIGRATION

Monterey (Piedras Blancas)	10 to 200 m	13%	Phase A	Poole (In Press)
	0.2 to 0.8 km (0.1 to 0.4 nm)	20%		
	0.8 to 3.2 km (0.4 to 1.7 nm)	67%		
	10 to 200 m	96-99%	Phase B	Poole (In Press)
Monterey (Soberanes Pt.)	10 to 500 m		Phase B	Malme et al. (1983)
Pt. Buchon to Pt. Estero	12 km (6.5 nm)		Phase A	Poole (In Press)
(Morro Bay)	10 to 400 m		Phase B	Poole (In Press)
Newport, Oregon (Yaquina Head)	1.6 to 3.2 km (0.9 to 1.7 nm)	50%	Phase A	Herzing & Mate (In Press)
	0 - 0.8 km (0-.4 nm)	97%	Phase B	Herzing & Mate (In Press)

industry had driven this portion of the population to off-shore routes. However, further study by Poole indicates that most of the early qualitative reviews of population during the northward migration referred to time periods before one would expect Phase B to pass. All early reports indicated that Phase A of the northbound animals were found close to shore. Poole concludes that there is a strong possibility that the mother/calf pairs were missed by whalers and other observers for nearly 100 years because of the nearly two month lag in arrival of mother/calf pairs travelling near and in the surf-zone. Reilly (1981) also presents a historical review and demonstrates that the southbound migration also has consistently occurred close to shore. The early reports do not quantify the distance from shore although the whaling fishery was classified as being coastal.

A.3.4 Historical Population Trends

In an attempt to determine the potential impact of seismic surveying on migrating gray whales, a detailed review of research by various observers regarding population growth or decline may not be totally appropriate. Nevertheless, it is useful to provide a general review of some of the findings of research scientists who have performed detailed statistical studies of gray whale population dynamics and then to relate that in a general way to the history of seismic surveying.

Early commercial hunting of gray whales in the late 1800's (primarily from about 1846-1874 with less intense whaling until 1900) obviously depleted the stock to near extinction. Present day aboriginal kills of gray whales in the western Chukchi Sea or Chukotski Peninsula areas by the USSR (reported by the International Whaling Commission in 1979) are causing an annual depletion of about 1.2% or 164 whales based on 1979 stock size estimates (Reilly, et al., 1983). Gray whales became protected by international agreement in 1946 and prior to that they were given general protection in 1937. The USSR and Japan did not sign those agreements.

Reilly (1981) and Reilly, et al. (1980), show that prior to the period of heavy whaling activity in the late 1800's, historical records and qualitative reports indicate that there were about 15,000 gray whales in the California stock. They quote the Scammons report in 1874 as stating that the stock in 1853-56 was "probably not over 30,000." By 1875, they report that by estimates of others, the stock had been depleted to about 4,400 animals and Reilly (1981) quotes Henderson as feeling that the depletion continued resulting in a stock of about 2,000 at the turn of the century. Rice and Wolman (1971) show that data by Gilmore in 1960 indicates that at least in the period of 1952 to 1960 following cessation of major hunting (except for an upsurge in the Soviet fishery), the population of observed whales off Pt. Loma increased by 11% per year. Whether these observations truly represent that level of growth of the whale population (including those animals beyond visual capability) is not clear. They further report analysis of data reported by Hubbs and Hubbs in 1967 which indicates that between 1952 to 1954 the population increased at an unspecified rate on the wintering grounds in the Baja and then stayed constant between 1954 to 1964. Rice and Wolman applied statistical analysis to those data and estimated that the population did grow at a rate of 0.8% per year. Reilly (1981) performed analysis of 10 censuses performed by Gard which indicated an annual overall exponential rate of population increase of 2.86% per year during the 1952 to 1976 period, which includes a 6.64% increase during the 1950's.

Reilly in his Ph.D. thesis (1981) and Reilly et al (1983) performed a very detailed statistical analysis of observation data over a 13-year period (1967 to 1979). The data was based on shore observations near Monterey of the full migration period and an extensive series of aerial overflights perpendicular to shore. From their data, they generated statistically based estimates of total population size for each of the 13 years. Coincidentally, the seismic survey history data acquired under this project includes the same 13-year census period. Table A-6 organizes the seismic survey data in terms of line miles for each of the years between 1964-1983. Most of the data submitted to BBN allowed tabulation of work performed by year, although 5 out of the 29 organizations for which we have data provided only total line miles for a period of a few years. In those cases (their total survey line miles represents 8% of the total from all respondents), we assumed even distribution of survey line miles over the years which they reported. Figure A.44 presents the results of Reilly whale population estimates from 1967-1979 as well as the seismic survey history data. Included with the Reilly data is their estimate of a 2.5% per year net annual growth rate of the gray whale population, based on regression analysis of their data. If one accepts that the 1.2% per year aboriginal harvest of gray whales reported earlier can be applied over the full 13-year period, a total growth rate of about 3.7% of the population is indicated. The cause of the fluctuations in population from year to year is probably related to the visual count which may be due to visibility conditions, stalling or over-wintering of portions of the population in regions other than the observation sites, meteorological effects and oceanographic phenomena. Increased turbidity in the ocean has been suspected of causing gray whales to avoid areas where previous high counts have been obtained and fluctuating food supply could also impact count rates.

TABLE A-6. APPROXIMATE NUMBER OF LINE MILES OF MARINE SEISMIC SURVEY ACTIVITY IN CALIFORNIA.

Year		Line Miles
1964		2,044
65		9,462
66		7,537
67		1,058
68		2,102
69		5,257
70		9,996
71		4,425
72		4,904
73		13,202
74		25,513
75		24,799
76		15,816
77		19,844
78		22,691
79		41,102
80		39,222
81		41,802
82		76,606
83		64,093
	TOTAL	431,475

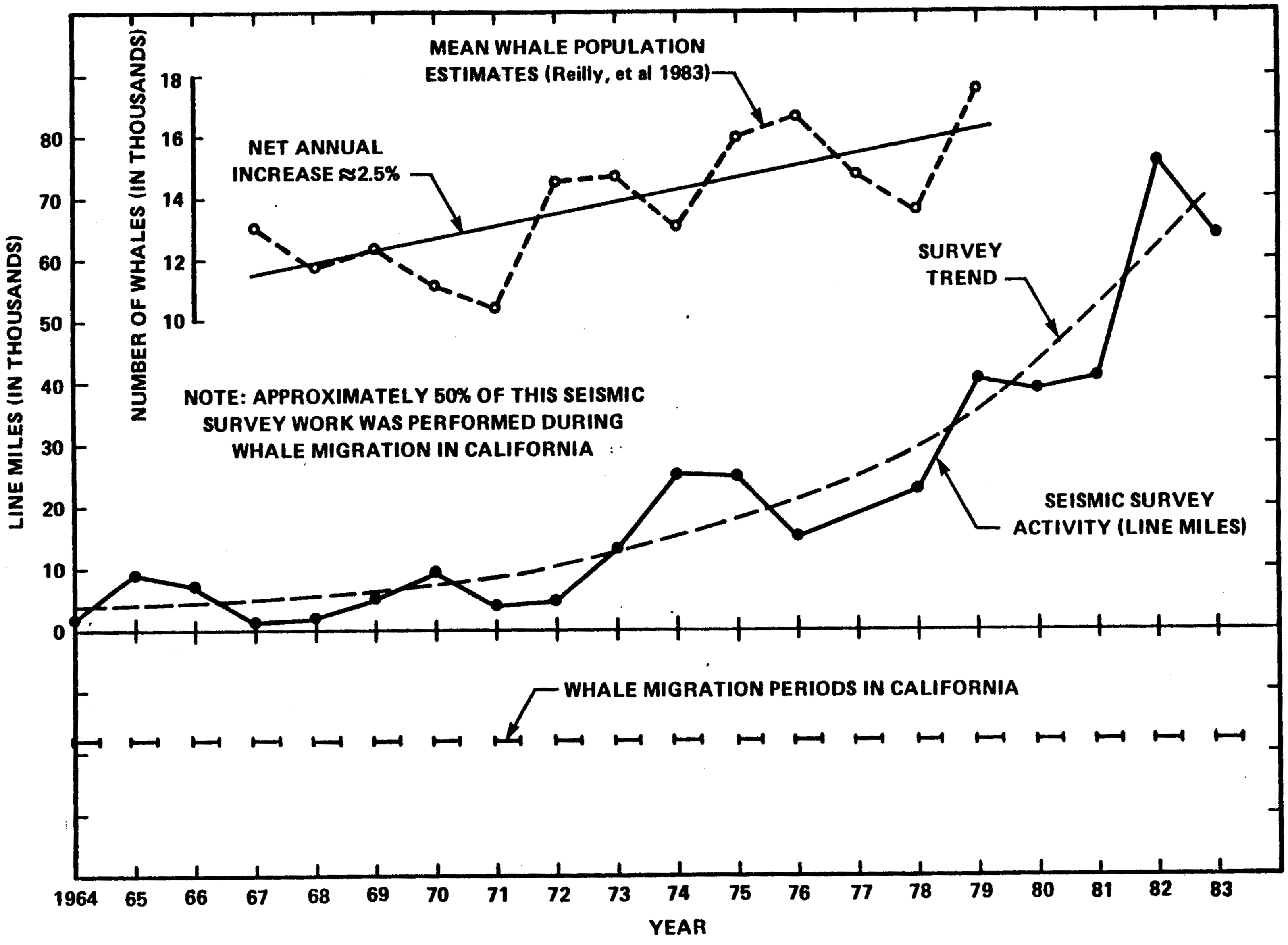

FIG. A.44. MARINE SEISMIC SURVEY ACTIVITY IN CALIFORNIA COMPARED TO THE REILLY ESTIMATE OF GRAY WHALE POPULATION GROWTH.

The seismic survey history data shown in the lower portion of the figure demonstrates an exponential increase in line miles covered by the industry. The gray whale population has increased linearly in approximately the same period. Note that approximately 50% of the survey activity shown in this figure was performed during whale migration in California. Based on these limited data samples and the differing nature of growth rates, one is tempted to conclude that the two variables are unrelated. That is, long term growth of the gray whale population probably is not influenced by seismic survey activity. Depending on where one looks in the fine structure of the two sets of data, one can observe increasing whale population with increasing seismic survey activity (1971-73) as well as increasing whale population with decreasing seismic activity (1974-1976). Nevertheless, the trends imply that seismic survey activity does not impact whale population growth as defined by the Reilly analyses.

Using historical data regarding gray whale population and reported catch rates together with assumptions regarding prehistoric aboriginal kills, Reilly (1981) performed some detailed simulation studies of population history. He coupled that analysis with the 13-year census data, requiring that the population growth curves (trajectories) must pass through the 95% confidence intervals which he established for the beginning and end of his 13 year period. Only one model provided a good match with prior history and his findings for the 1967-1979 period. That model (his Fig. 23 in the above reference) estimates a population level of about 2000 animals in 1900 and a 1980 population of about 15,500 whales, with a maximum equilibrium population level of 24,000. His model also shows a sharp knee in the population growth curve, with the slope becoming significantly less steep starting in about 1958-60. He states that that period relates directly to an upsurge and continuation of the

Soviet gray whale fishery, mentioned previously. Figure A.45 provides a comparison of the 1900-1980 portion of his model and the seismic survey activity during gray whale migration from the mid-1940 period until 1983. We were not able to acquire line mile data for the 1945-1964 period, during which only explosives were used by the new marine seismic survey industry. The dashed portion of the curve represents an extrapolation of seismic survey activity to that earlier period. Again, the exponential nature of the growth in seismic survey activity apparently does not impose itself on the growth rate of the whale population. The sudden change in slope of the Reilly model in about 1959 is due to the imposition of increased aboriginal kills in the Chukchi Sea and Chukotski Peninsula regions of the gray whale summering grounds. It was not until about 1965, when non-explosive devices were introduced, that the rate of seismic exploration began to increase exponentially.

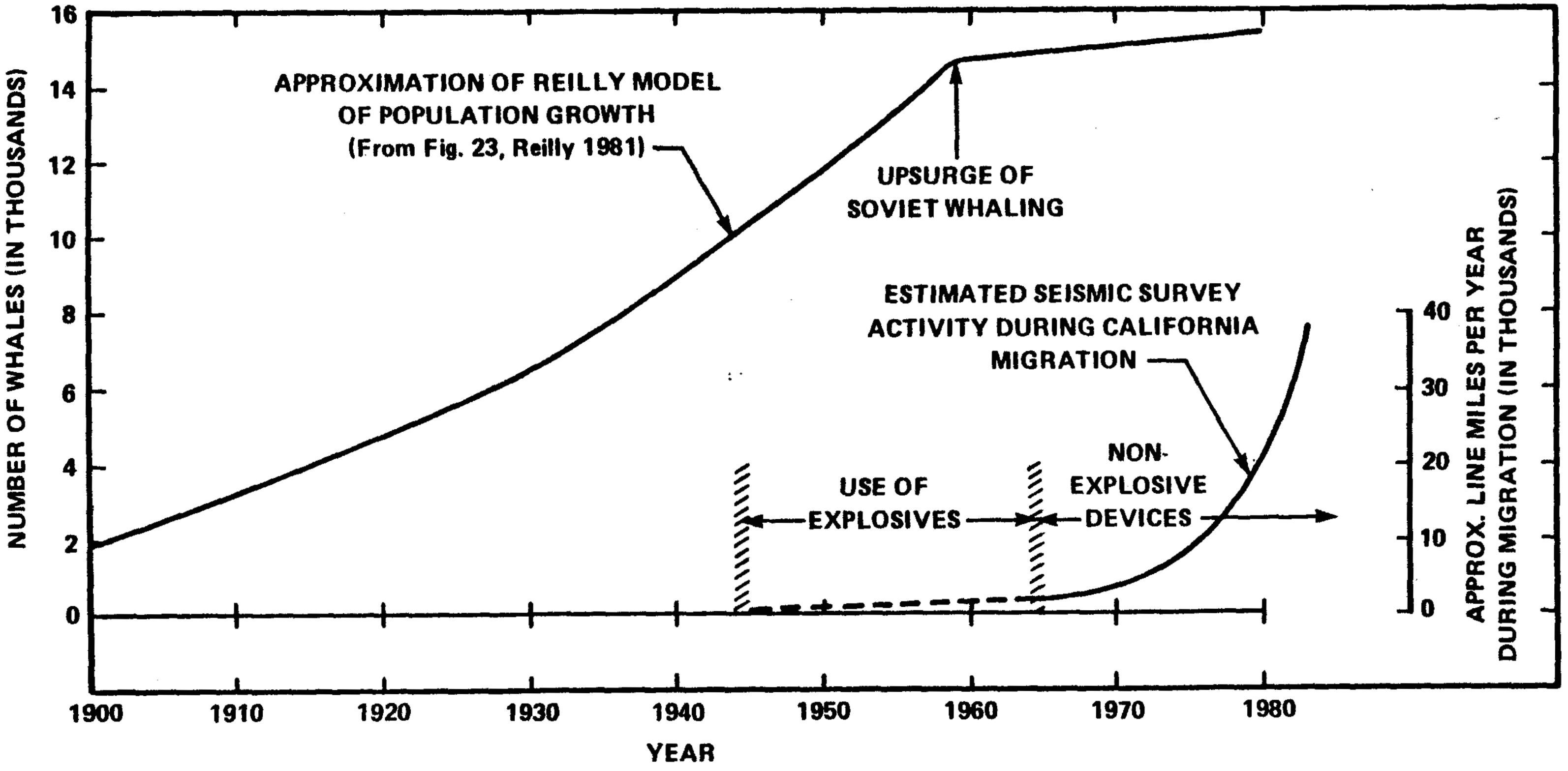

FIG. A.45. COMPARISON OF REILLY MODEL OF GRAY WHALE POPULATION GROWTH WITH ESTIMATED MARINE SEISMIC SURVEY ACTIVITY IN CALIFORNIA DURING MIGRATION.

A.4 CONCLUSIONS

A general review of the offshore seismic exploration history in California has been derived in the previous pages together with an update of the migration characteristics of they gray whale along the California coast. The summary has been possible through compiling results of a questionnaire survey distributed to the oil and exploration industries, discussions with the California State Lands Commission, Minerals Management Service, and the National Geophysical Data Center. A literature review, both regarding marine seismic survey activities and the migration and population dynamics of gray whales provided additional information in support of this study. While a more precise compilation of data (particularly regarding the seismic survey history) would be helpful, the existing accumulation of data probably provides a first order indication of survey activity and a general indication of its degree of possible association with the presence of gray whales. The following more specific comments can be made.

1. The offshore seismic survey industry has gone almost completely (99%) to the use of non-dynamite types of sources such as air guns and sparkers which exhibit significant reductions of energy per pulse when compared to dynamite. Coupling that fact with improved signal processing techniques has permitted the industry to obtain the required data more efficiently and more quickly than in the past.
2. While survey activity is increasing because of demands for locating new oil and gas reserves, much of the work is going further offshore, onto the outer continental shelf. Movement of survey activities into the OCS regions minimizes potential impact on the coastal migrating gray whale. Most censusing work indicates

that over 90% of the population travels within the three nautical mile territorial limit of California (less than 6 km from shore) except when travelling across the mouth of embayments or running from point-to-point. Seismic survey work done within state territorial waters during whale migration could have some effect on gray whales, although BBN tests indicate these are likely to be short-term behavioral responses such as relatively small changes in swimming speed or heading (see Item 6 below).

3. Little specific information could be derived in this study regarding a direct relationship between seismic survey activity and a major perturbation in migration habits primarily because of a lack of precise information from respondents to the questionnaire regarding location and timing of surveys performed. Therefore, no statistical analysis of correlation could be performed. Migration corridors apparently have remained basically the same since records were first kept in the mid 1800's. Very little quantitative and/or statistical information regarding migration corridors is available in the early literature although recent summaries do provide a fairly detailed treatment of early data. The gray whales were then and continue to be coastal migrants. The migration corridors are repeatable from season to season, with some small fluctuations in precise location and in corridor width in local areas. There is no quantitative evidence that the whales either have or are changing their migration corridors to deep ocean areas to avoid seismic survey activity. The southbound migration corridor tends to stay within a band 2 to 5 km from shore except when crossing bays and going from point-to-point. Northbound migration of single and small groups of whales (Phase A) usually stay

within 1 to 3 km from shore corridor with frequent sitings closer than 1 km. The later Phase B of the northbound migrants (mother/calf pairs) travel very close to the surf zone (10 to 200 meters). Approximately 50% of the reported seismic survey activity in California waters was performed during gray whale migration periods.

4. Migration timing past a given point on the coast is predictable within a few days. The migrations consist of waves lasting for approximately 60 days with the peak in population density occuring close to or slightly earlier than the geometric mean. There has been some speculation that fluctuations in the migration timing may be due primarily to natural causes such as storms and food supply. Within California waters, the southbound migration lasts from mid-December until about the third week in February. The northbound migration in California is split into two phases. Phase A, made up of single and groups of immature and adult animals, travels north from early February until mid-April and Phase B, the mother/calf pairs travel from mid-March until the third or fourth week of May. The migration schedule of the mother/calf pairs tends to be less predictable than either phase A or the southbound migrants. There is often some overlap of southbound and northbound Phase A migrants and Phase A/Phase B migrants. Therefore, there is a 5 to 5 1/2 month period from December to the following May during which migrating whales will be present somewhere along the coast of California. Swimming speeds are 4 to 5 kts (7.4 to 9.3 km/hr) southbound and 2 to 3 kts (3.7 to 5.6 km/hr) northbound.

5. While no specific long lasting correlation between perturbations in migration and seismic surveying activities can be determined at this time, it is interesting and useful to note that, at least over the last decade and a half when seismic survey activity was increasing exponentially, the gray whale population has continued to grow at a rate of 2.5% per year.

6. Careful behavioral observation and field measurements of migrating gray whales by BBN (Malme, et al., 1983 and this volume) has demonstrated that some second order changes in course and swimming speed can result from industrial sounds associated with oil and gas development sounds (drill rigs, helicopter, drilling platforms, etc.). For these behavioral changes, the source must be less than 2 km away. Air gun array sounds cause course and speed changes as well as milling behavior when distances between the air gun system and the whales are less than 5 km (2.7 nm) away. A single air gun elicited similar responses at ranges of 1 km or less. The important point here is that while the whales reacted to the sources as noted above, they seemed to habituate to the presence of the intrusion and continued on their prescribed migration path after passing the source. Transient sounds tended to show, occasionally, what could be classified as a short term startle response. Questions regarding long-term physiological influence on individual whales cannot be answered from these test results although preliminary comparisons showed no apparent harmful effects on the overall gray whale population.

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Wyrick, R.F. (1954) "Observations on the Movements of the Pacific Gray Whale, *Eschrichtius glaucus (Cope)*, J. Mammal (35).

APPENDIX B

TRACK PLOTS AND CUMULATIVE FREQUENCY DISTRIBUTION PLOTS

B.1 TRACK PLOTS FOR THE SOUTHBOUND GRAY WHALE MIGRATION IN JANUARY 1984

Track plots are presented for control and experimental conditions during the January playback period (Figs. B.1 through B.9). See Fig. 1.1 for site positions. The plots indicate the paths taken by all groups during each presentation of the stimulus condition listed. Tracks start with the first sighting after the playback started and with the last sighting before the playback ended. The thick curved line near the bottom of the plot shows the location of the coast line. The coordinates of the plot are kilometers north along the x-axis and kilometers west along the y-axis. The origin is centered on the Soberanes observation site. The VARUA is indicated by a triangle in the plots showing playback or airgun experiments, while the Lobos Rocks are indicated by two octagons at approximately 0.5 km north and 0.8 km west. These plots are presented in the following order of playback condition - Control No Boat Present, Control VARUA Present, drillship, drilling platform, production platform, helicopter, semi-submersible, air gun control period, and air gun.

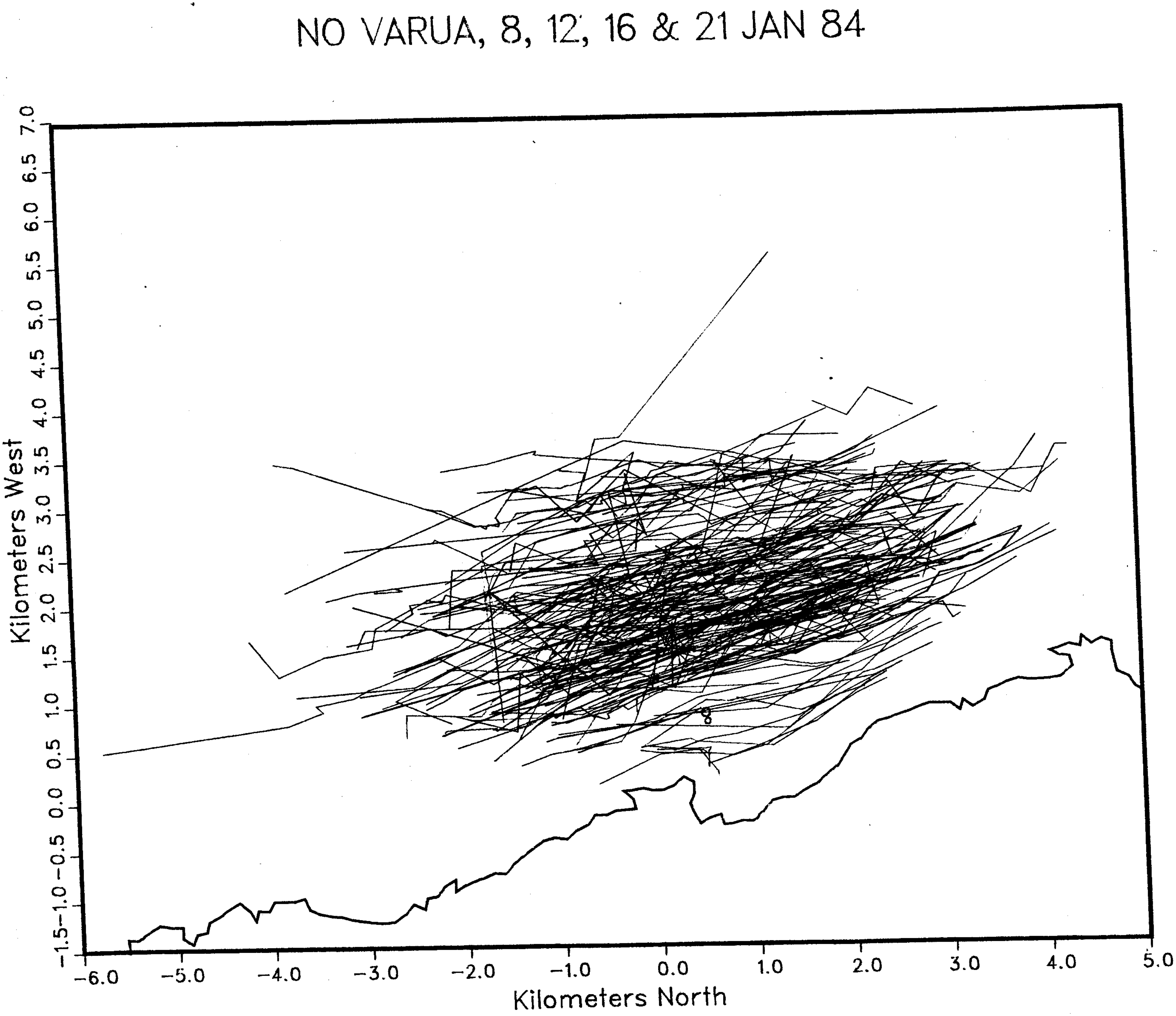

NO VARUA, 8, 12, 16 & 21 JAN 84
Kilometers West
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-6.0
-5.0
-4.0
-3.0
-2.0
-1.0
0.0
1.0
2.0
3.0
4.0
5.0
Kilometers North

FIG. B.1.

VARUA PRESENT, PLAYBACK CONTROL, 18 JAN 84

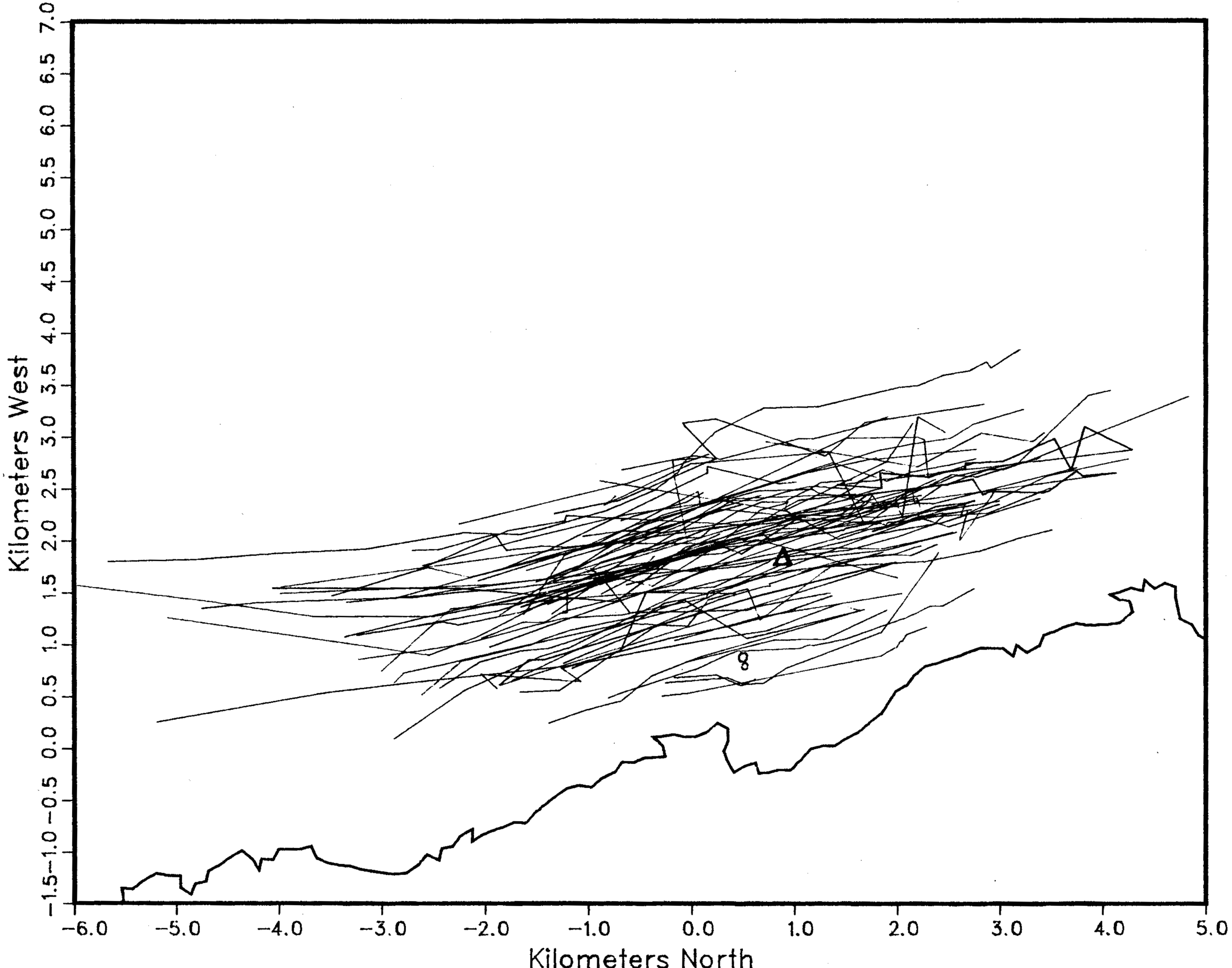


FIG. B.2.

DRILLSHIP, 13, 15, & 19 JAN 84

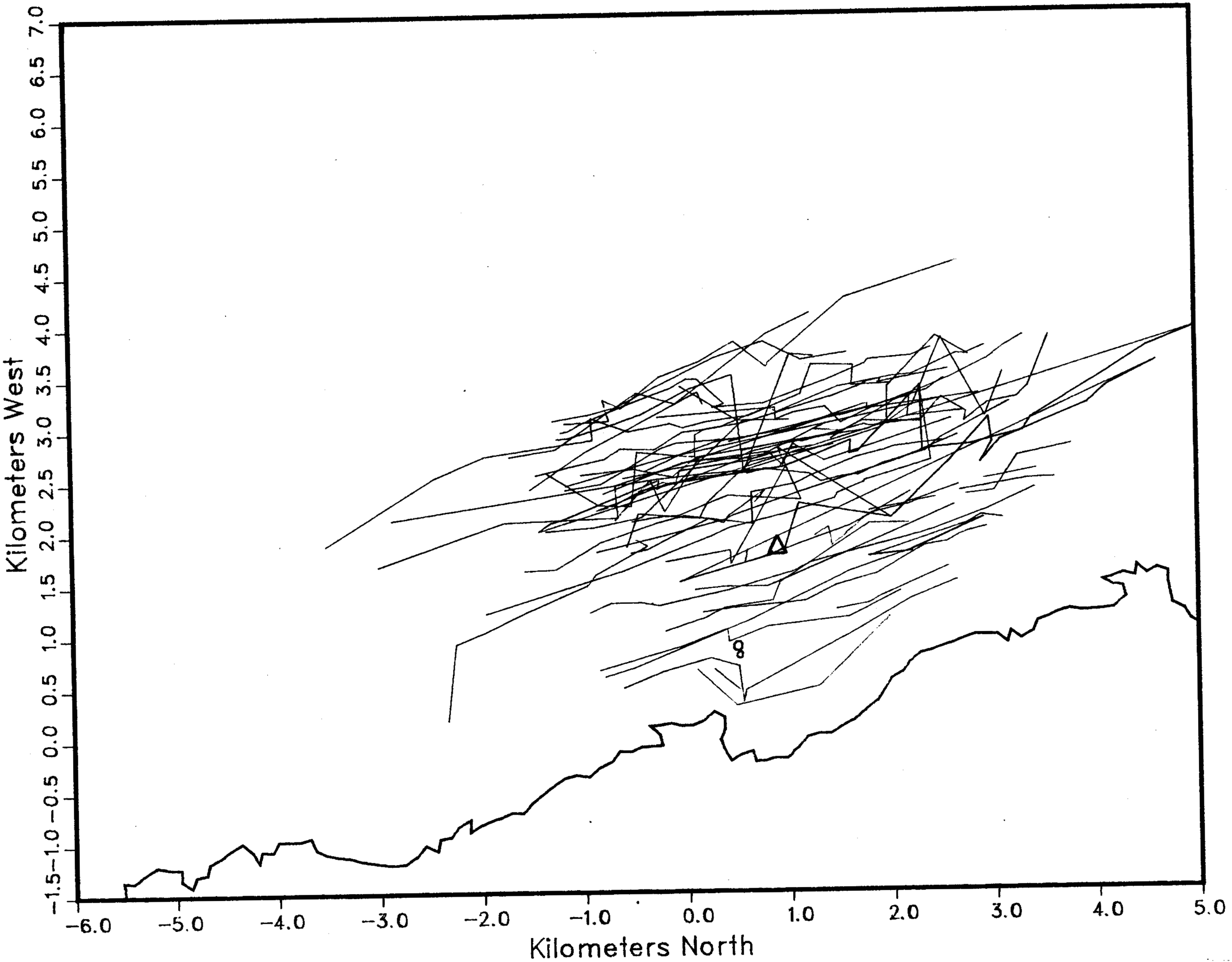
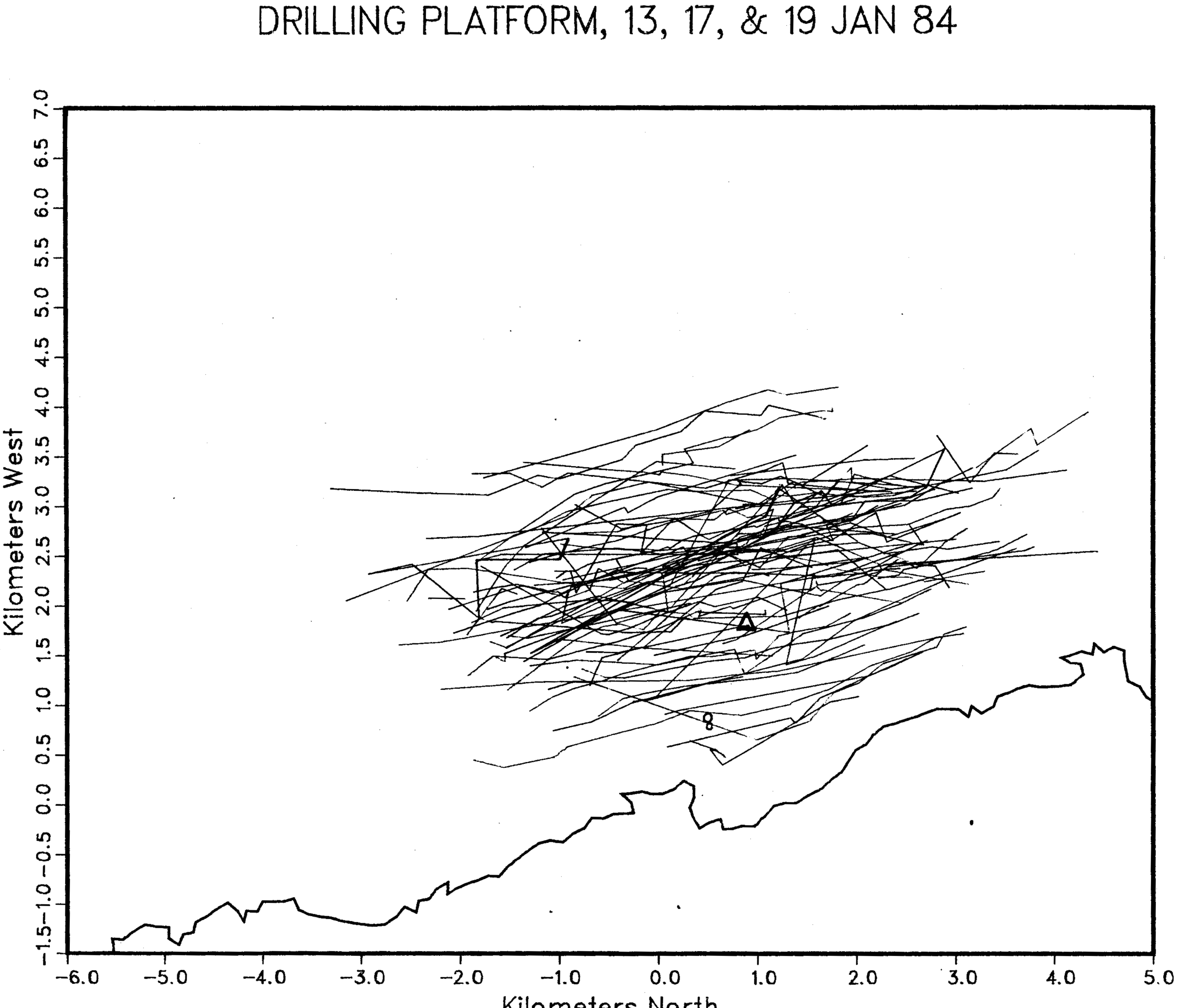


FIG. B.3.



DRILLING PLATFORM, 13, 17, & 19 JAN 84

FIG. B.4.

PRODUCTION PLATFORM, 14, 15, & 20 JAN 84

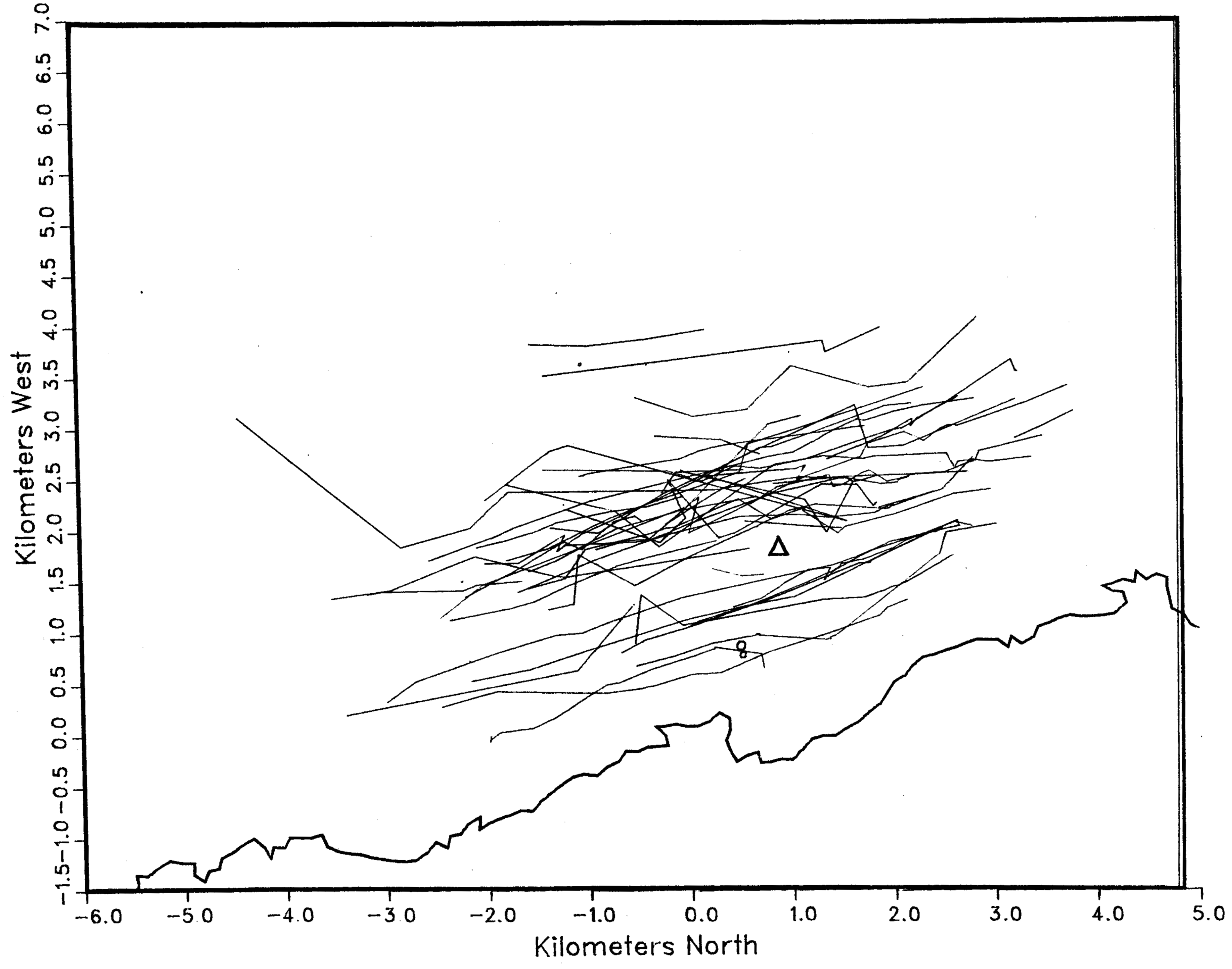


FIG. B.5.

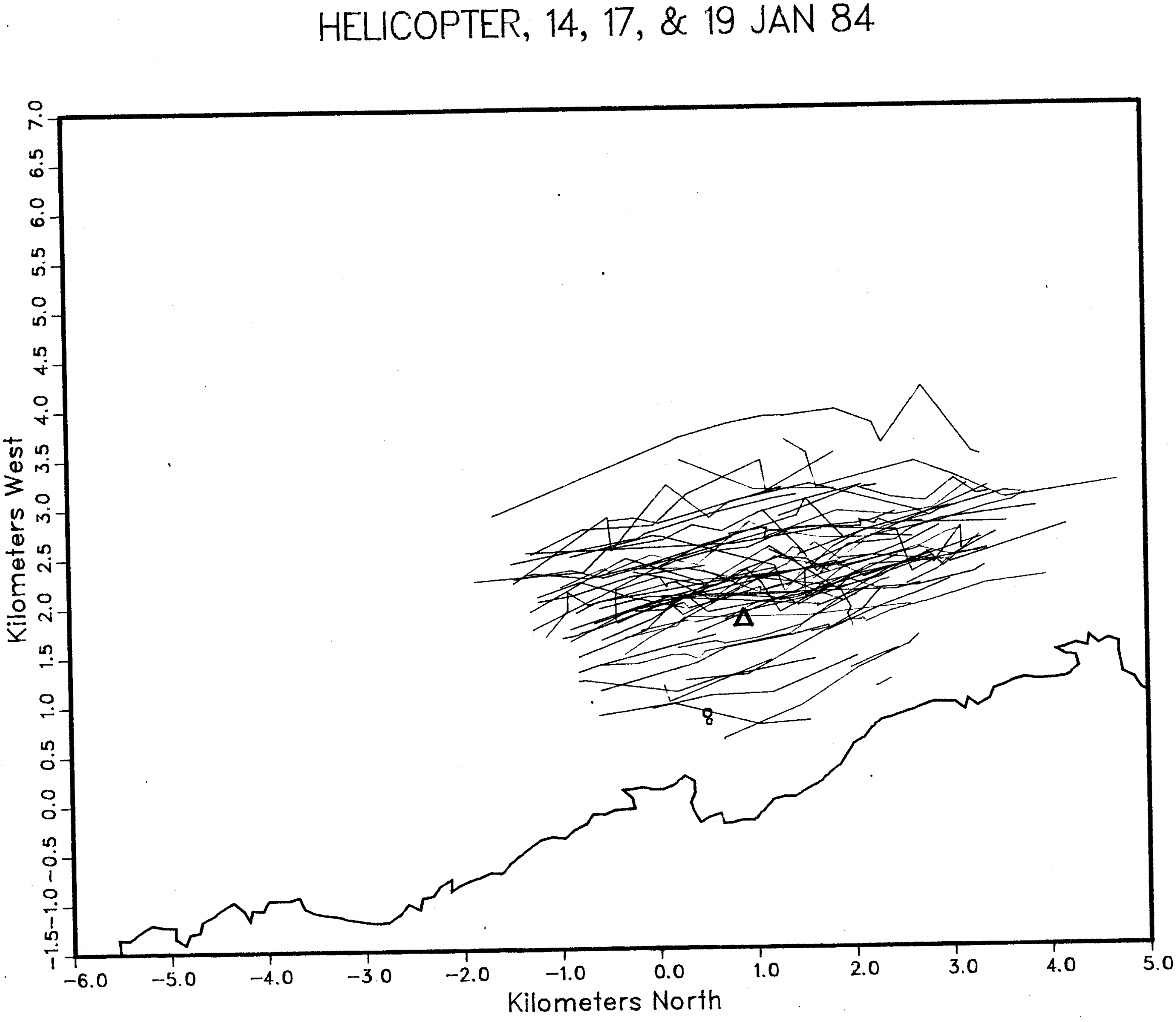

HELICOPTER, 14, 17, & 19 JAN 84
Kilometers West
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
Kilometers North
−6.0
−5.0
−4.0
−3.0
−2.0
−1.0
0.0
1.0
2.0
3.0
4.0
5.0

FIG. B.6.

SEMISUBMERSIBLE, 15, 17, & 20 JAN 84

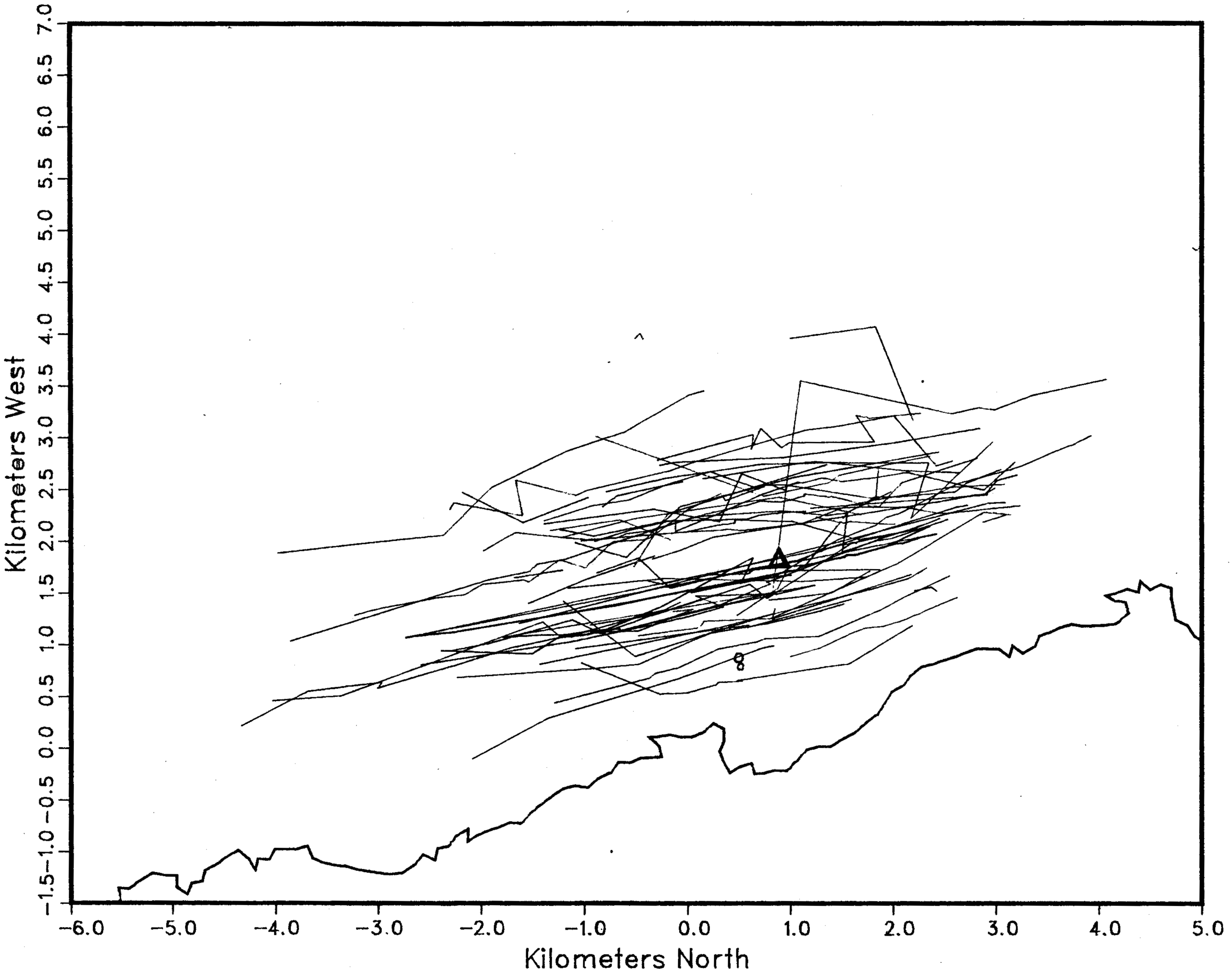


FIG. B.7.

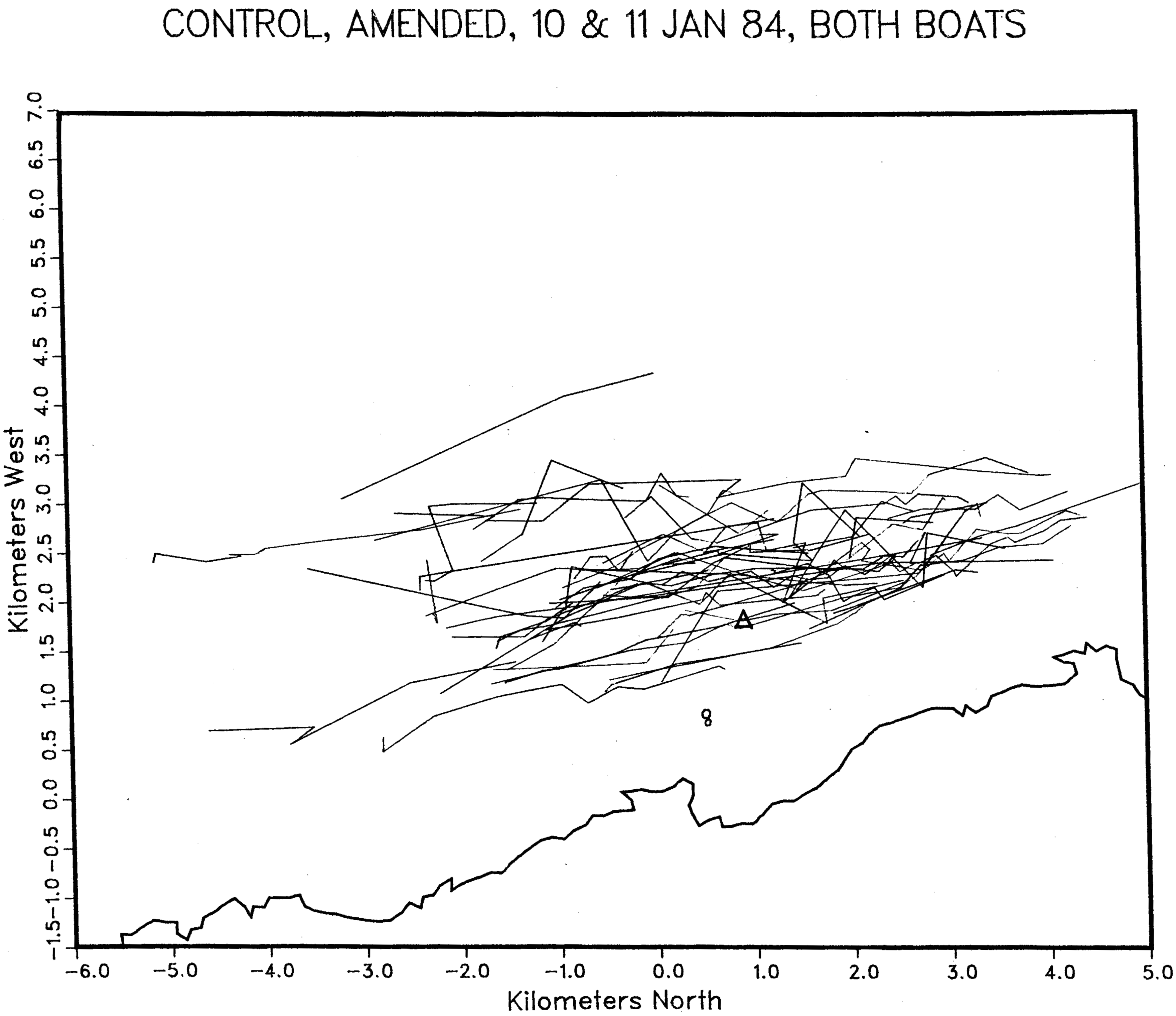

CONTROL, AMENDED, 10 & 11 JAN 84, BOTH BOATS
Kilometers West
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
Kilometers North
-6.0
-5.0
-4.0
-3.0
-2.0
-1.0
0.0
1.0
2.0
3.0
4.0
5.0

FIG. B.8.

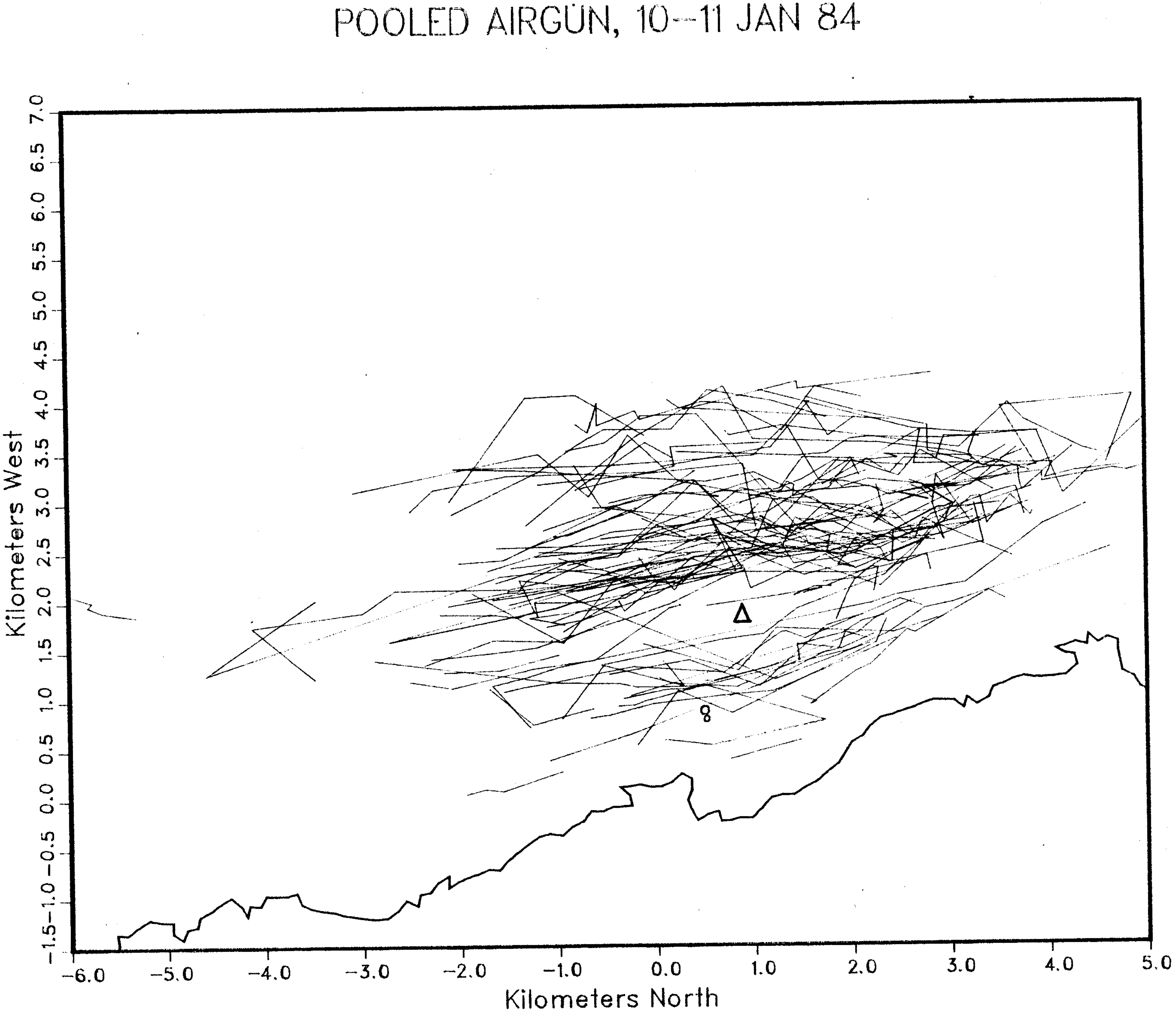
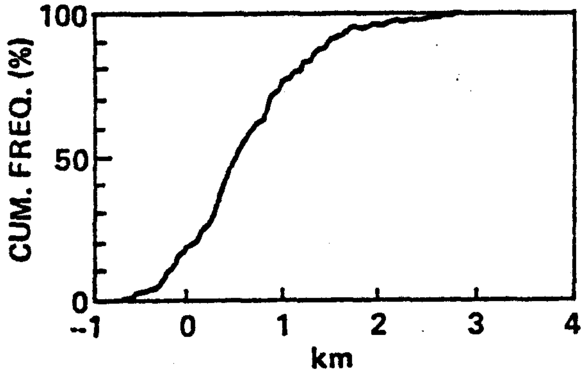

POOLED AIRGUN, 10--11 JAN 84
Kilometers West
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
Kilometers North
-6.0
-5.0
-4.0
-3.0
-2.0
-1.0
0.0
1.0
2.0
3.0
4.0
5.0
Δ
o

FIG. B.9.

B.2 CUMULATIVE TRACK FREQUENCY DISTRIBUTION PLOTS FOR TWO LINEAR TRACK DEFLECTION MEASURES IN JANUARY 1984

Plots are presented of cumulative frequency distributions for two linear track deflection measures, D_y and Speed, for each of the six experimental conditions and for four control conditions (Figs. B.10 through B.20). These plots are presented in the same order as the track plots. On the left edge of each page is listed the measure and the playback condition. Score D_y is labeled "D_y (grid crossings measured from VARUA)". the D_y plots show 11 cumulative track frequency distributions on each page, one for each grid line crossed, starting with 4.0 = 4.0 km North of the VARUA and ending with -4.0 = 4.0 km South of the VARUA (see Fig. 7.1). The speed plots show 10 cumulative frequency distributions on each page, one for each grid interval crossed. An easy way to compare the distributions of these measures between experimental and control conditions is to make transparent photocopies of the control plots. These can then be used as overlays to compare distributions with the Experimental Plots (see Figs. 8.4 and 8.5).

Key for Figs. B.10 through B.21:



Track Deflection Parameter (e.g., D_y, Speed) as Noted in Figure Title.

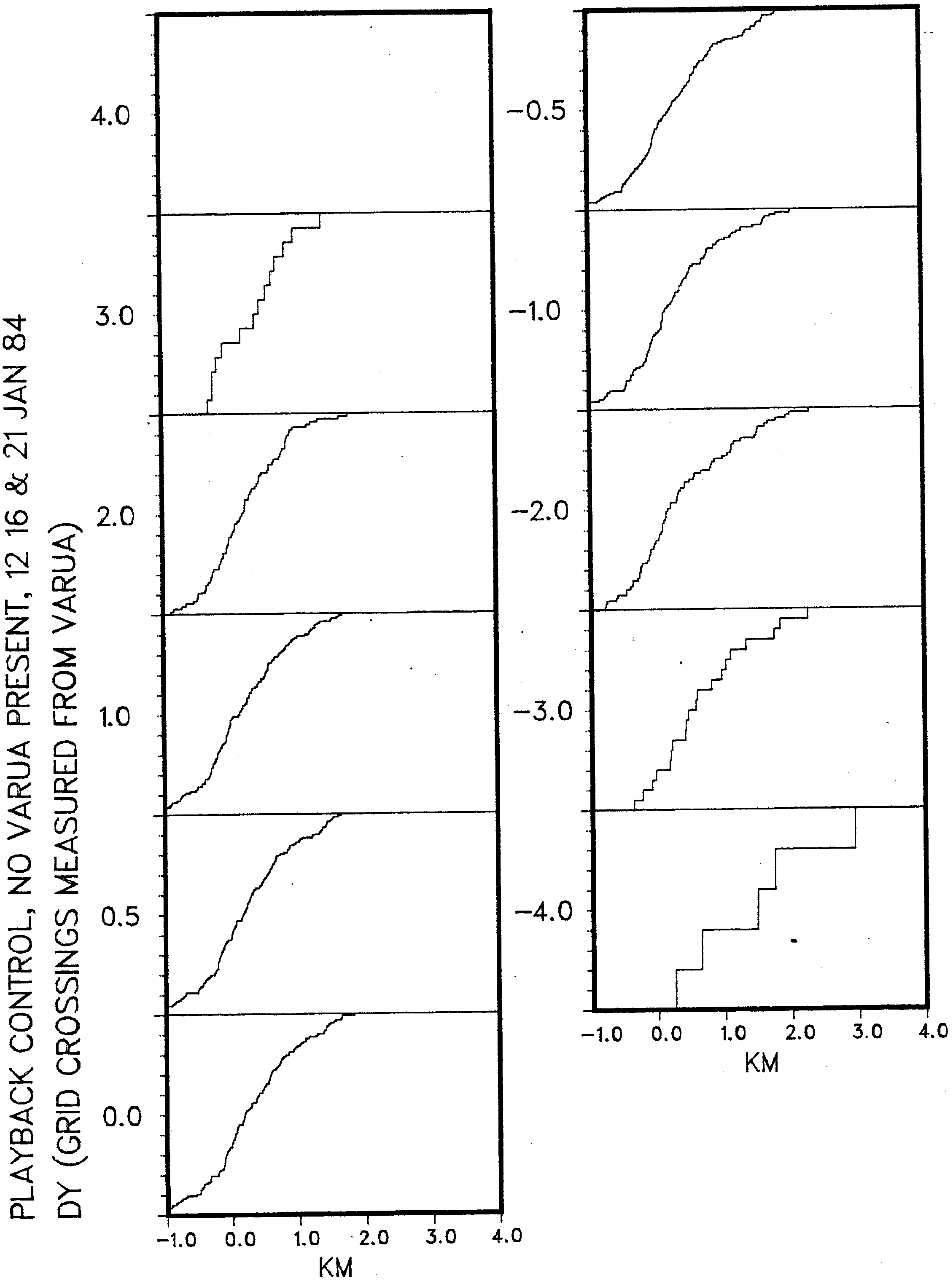
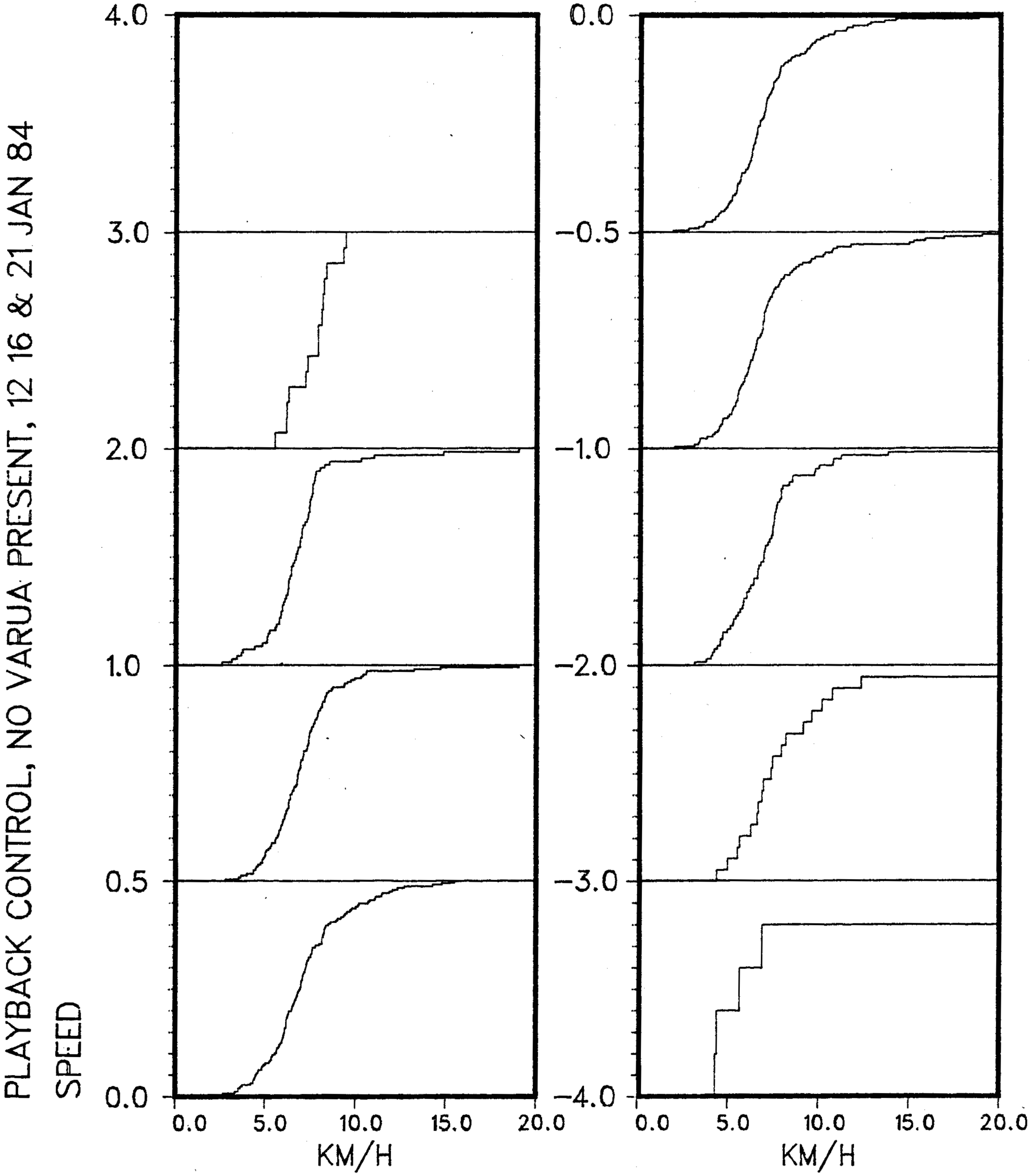

PLAYBACK CONTROL, NO VARUA PRESENT, 12 16 & 21 JAN 84
DY (GRID CROSSINGS MEASURED FROM VARUA)
4.0
3.0
2.0
1.0
0.5
0.0
-0.5
-1.0
-2.0
-3.0
-4.0
-1.0
0.0
1.0
2.0
3.0
4.0
KM

FIG. B.10a.



PLAYBACK CONTROL, NO VARUA PRESENT, 12 16 & 21 JAN 84
SPEED
4.0
3.0
2.0
1.0
0.5
0.0
0.0
-0.5
-1.0
-2.0
-3.0
-4.0
0.0
5.0
10.0
15.0
20.0
KM/H
0.0
5.0
10.0
15.0
20.0
KM/H

FIG. B.10b.

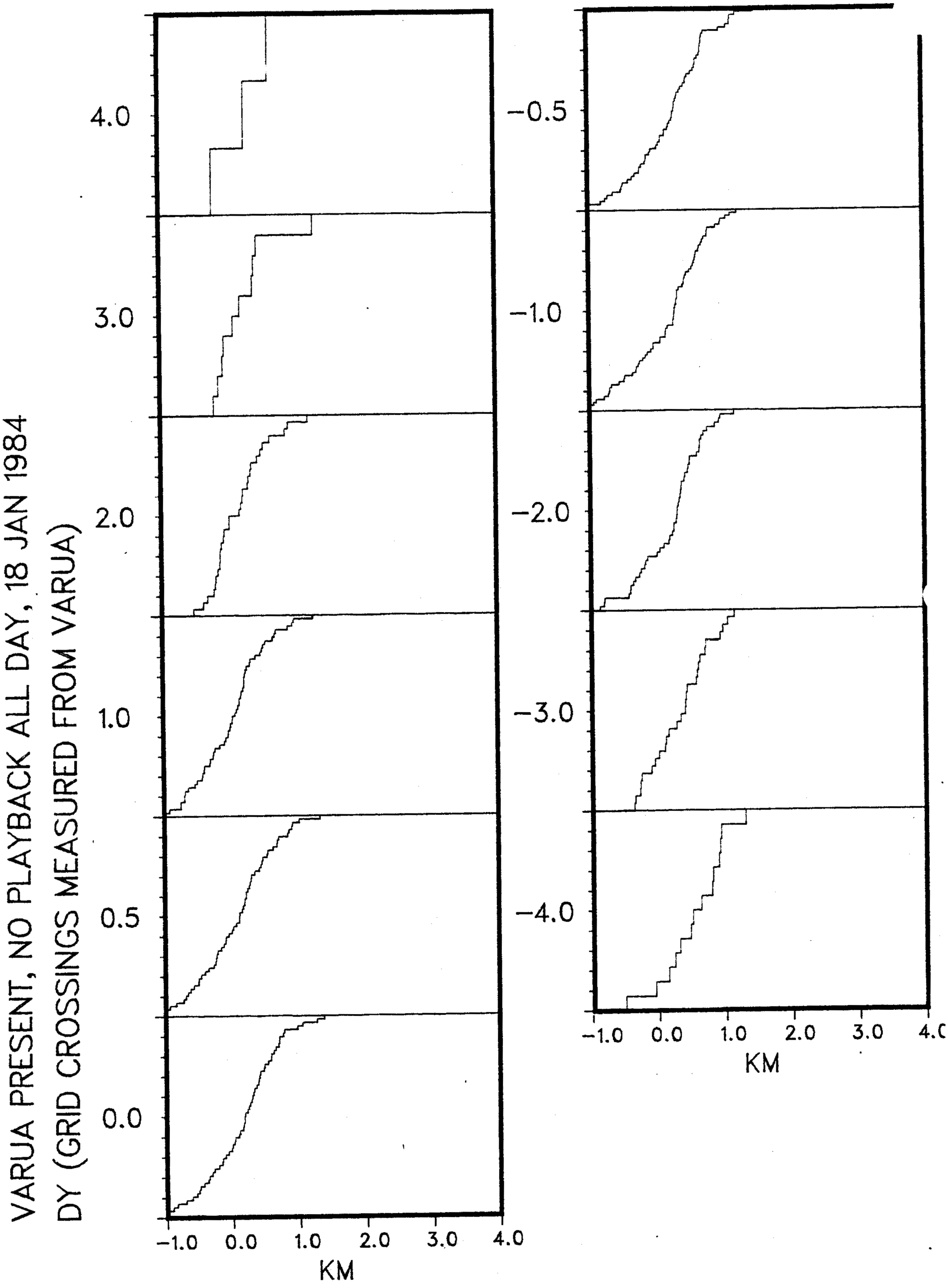

VARUA PRESENT, NO PLAYBACK ALL DAY, 18 JAN 1984
DY (GRID CROSSINGS MEASURED FROM VARUA)
4.0
3.0
2.0
1.0
0.5
0.0
−0.5
−1.0
−2.0
−3.0
−4.0
−1.0
0.0
1.0
2.0
3.0
4.0
KM

FIG. B.11a.

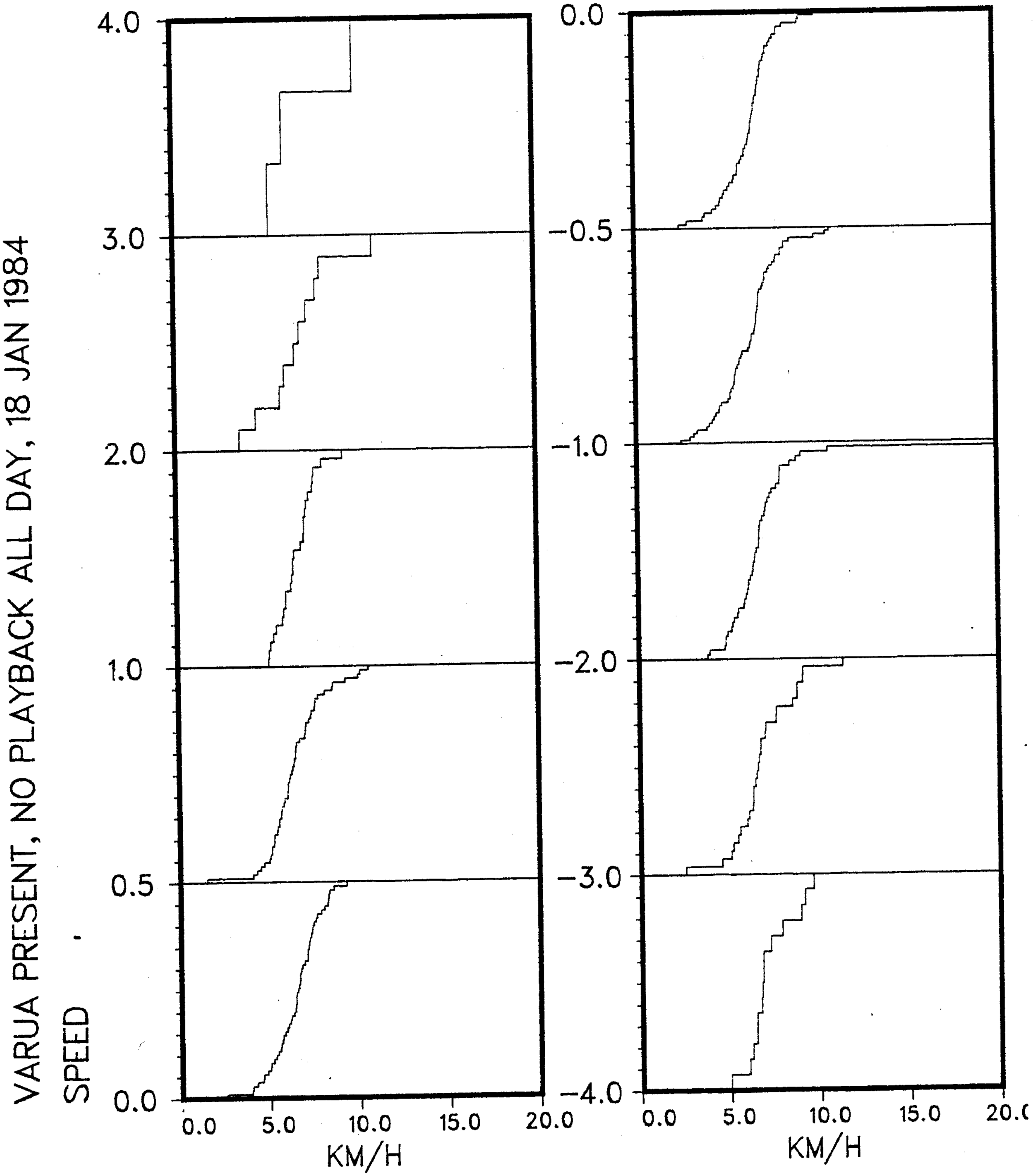

VARUA PRESENT, NO PLAYBACK ALL DAY, 18 JAN 1984
SPEED
4.0
3.0
2.0
1.0
0.5
0.0
0.0
-0.5
-1.0
-2.0
-3.0
-4.0
0.0
5.0
10.0
15.0
20.0
KM/H
0.0
5.0
10.0
15.0
20.0
KM/H

FIG. B.11b.

DRILLSHIP 123

DY (GRID CROSSINGS MEASURED FROM VARUA)

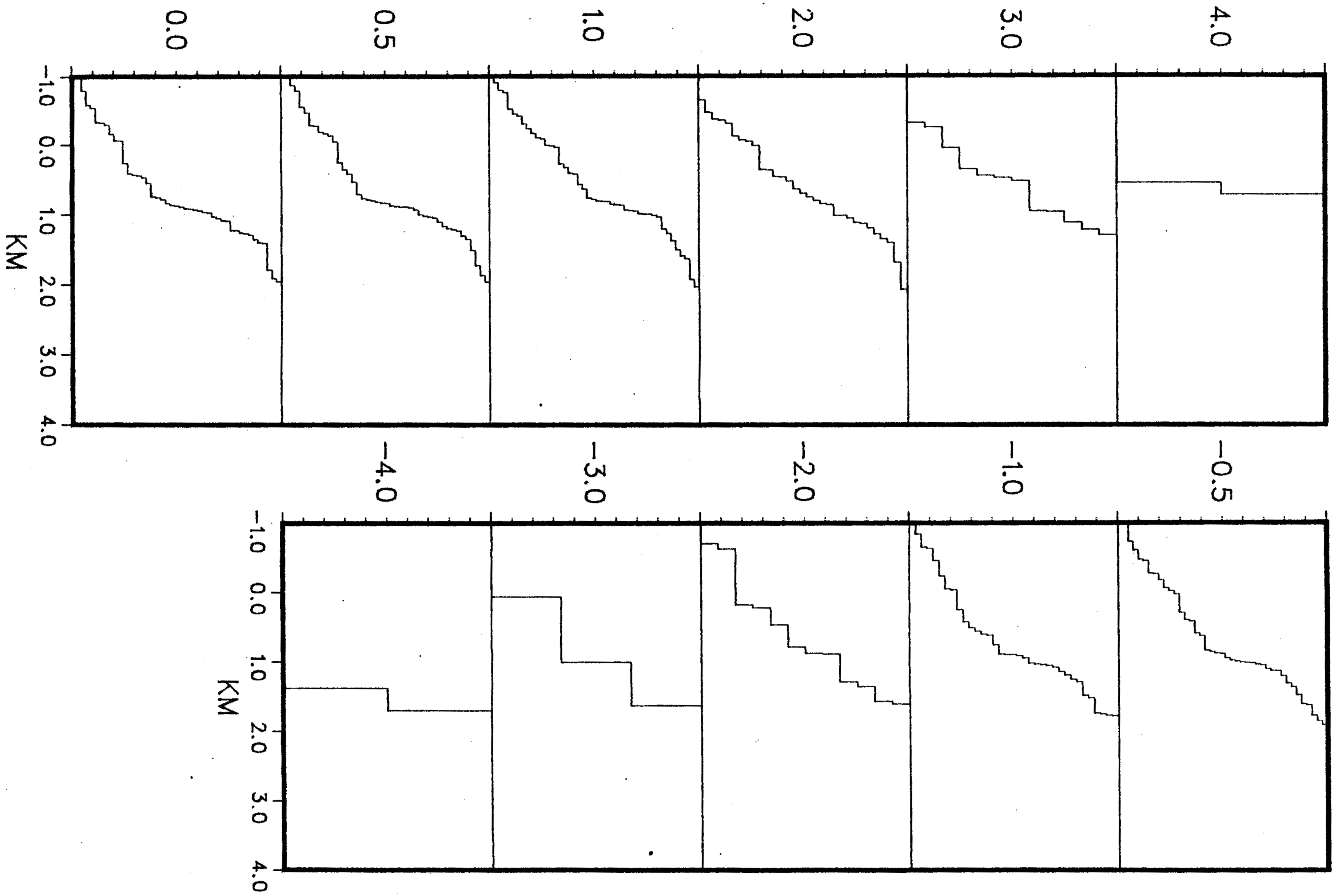


FIG. B.12a.

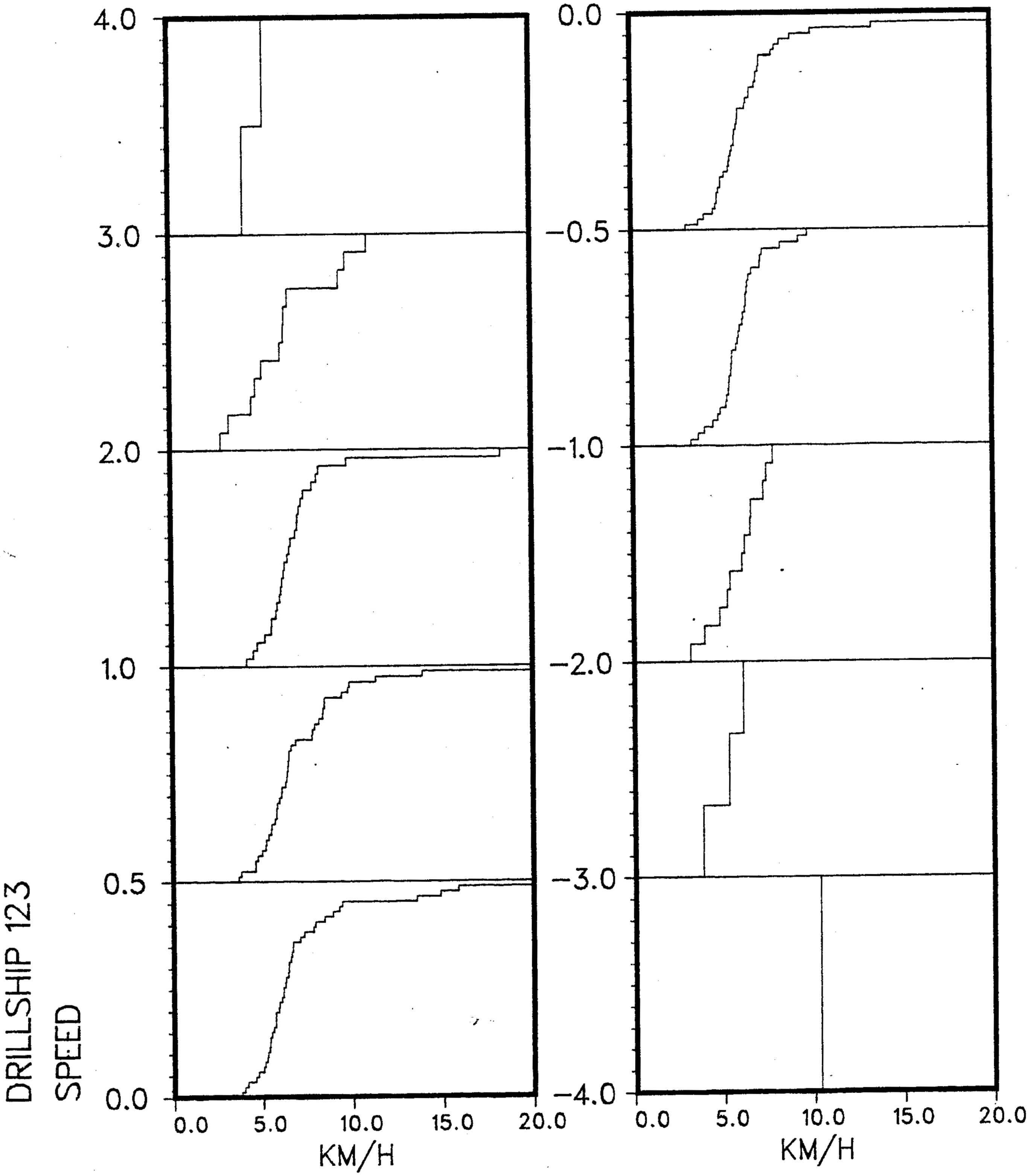

DRILLSHIP 123
SPEED
4.0
3.0
2.0
1.0
0.5
0.0
0.0
-0.5
-1.0
-2.0
-3.0
-4.0
0.0
5.0
10.0
15.0
20.0
KM/H
0.0
5.0
10.0
15.0
20.0
KM/H

FIG. B.12b.

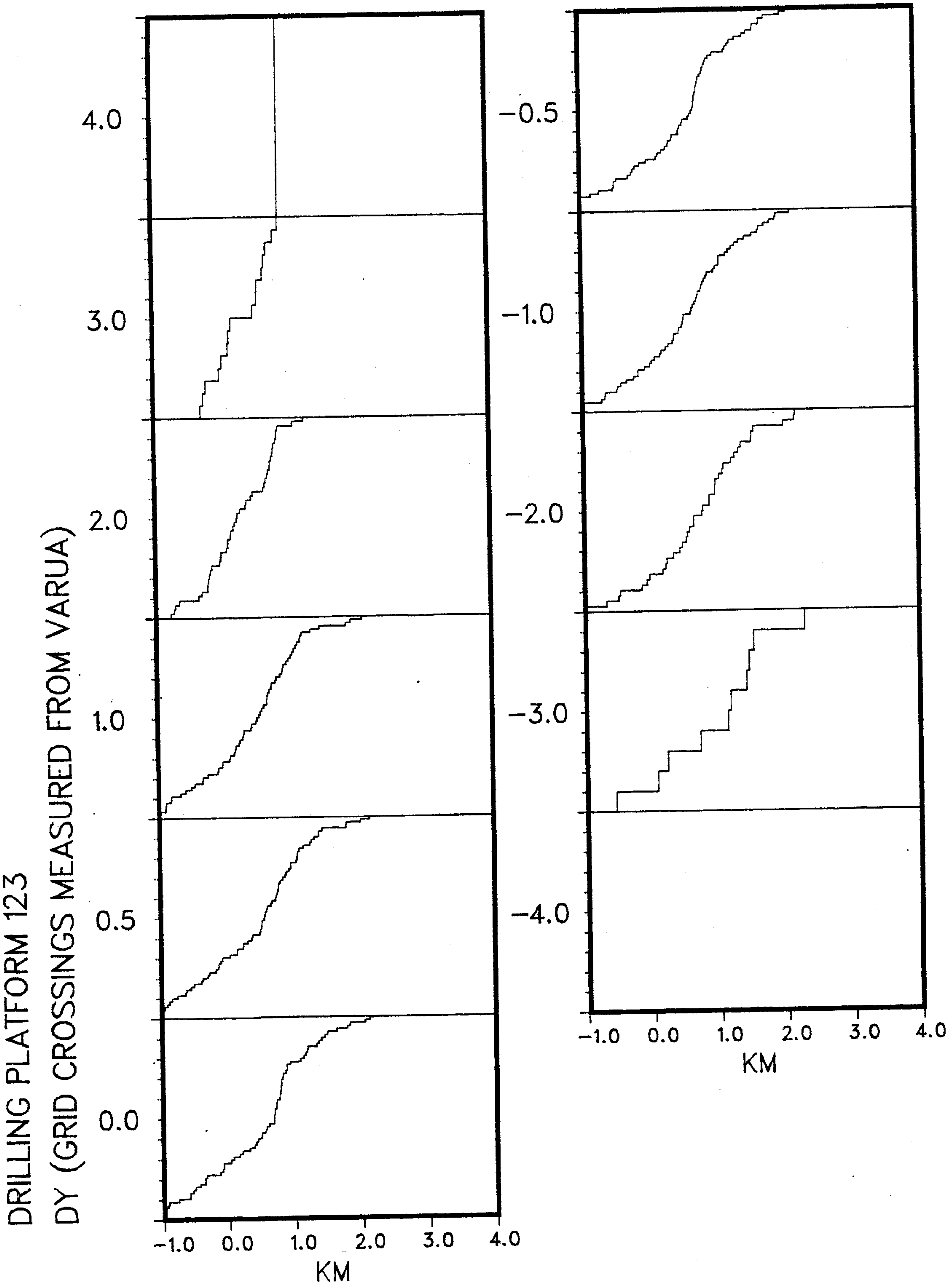

DRILLING PLATFORM 123
DY (GRID CROSSINGS MEASURED FROM VARUA)
4.0
3.0
2.0
1.0
0.5
0.0
-0.5
-1.0
-2.0
-3.0
-4.0
-1.0
0.0
1.0
2.0
3.0
4.0
KM

FIG. B.13a.

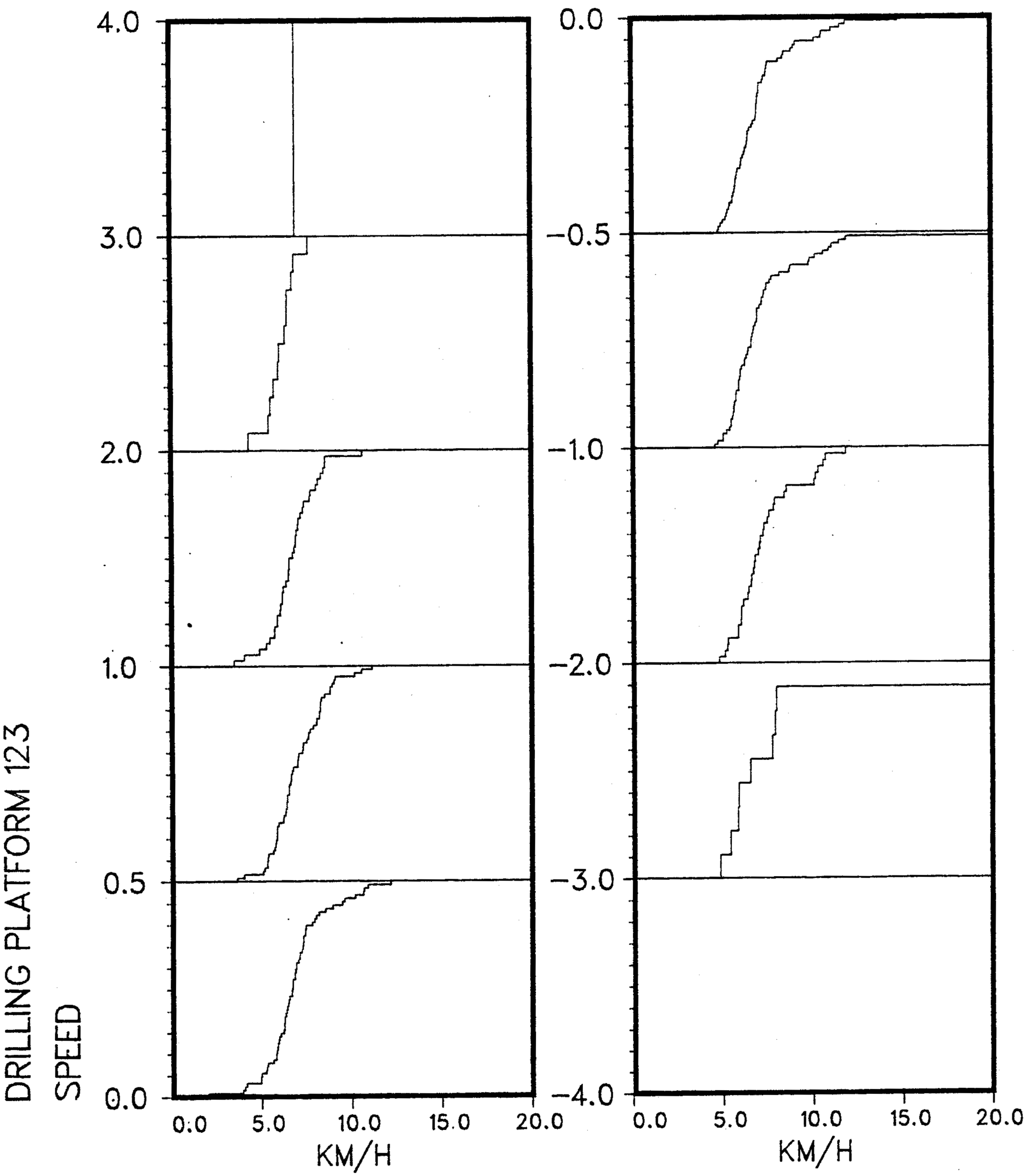

DRILLING PLATFORM 123
SPEED
4.0
3.0
2.0
1.0
0.5
0.0
0.0
5.0
10.0
15.0
20.0
KM/H
0.0
-0.5
-1.0
-2.0
-3.0
-4.0
0.0
5.0
10.0
15.0
20.0
KM/H

FIG. B.13b.

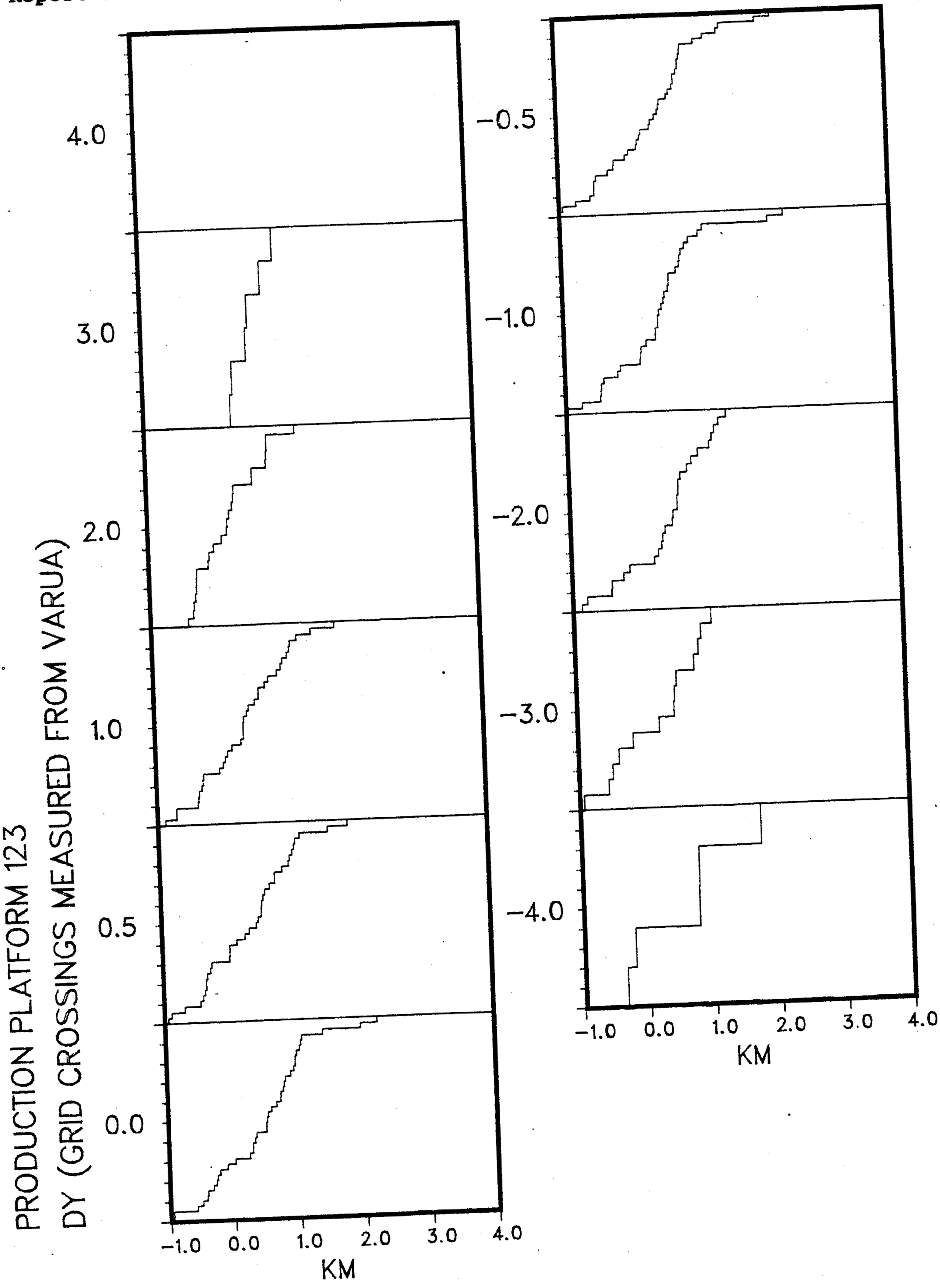

PRODUCTION PLATFORM 123
DY (GRID CROSSINGS MEASURED FROM VARUA)
4.0
3.0
2.0
1.0
0.5
0.0
-0.5
-1.0
-2.0
-3.0
-4.0
-1.0
0.0
1.0
2.0
3.0
4.0
KM

FIG. B.14a.

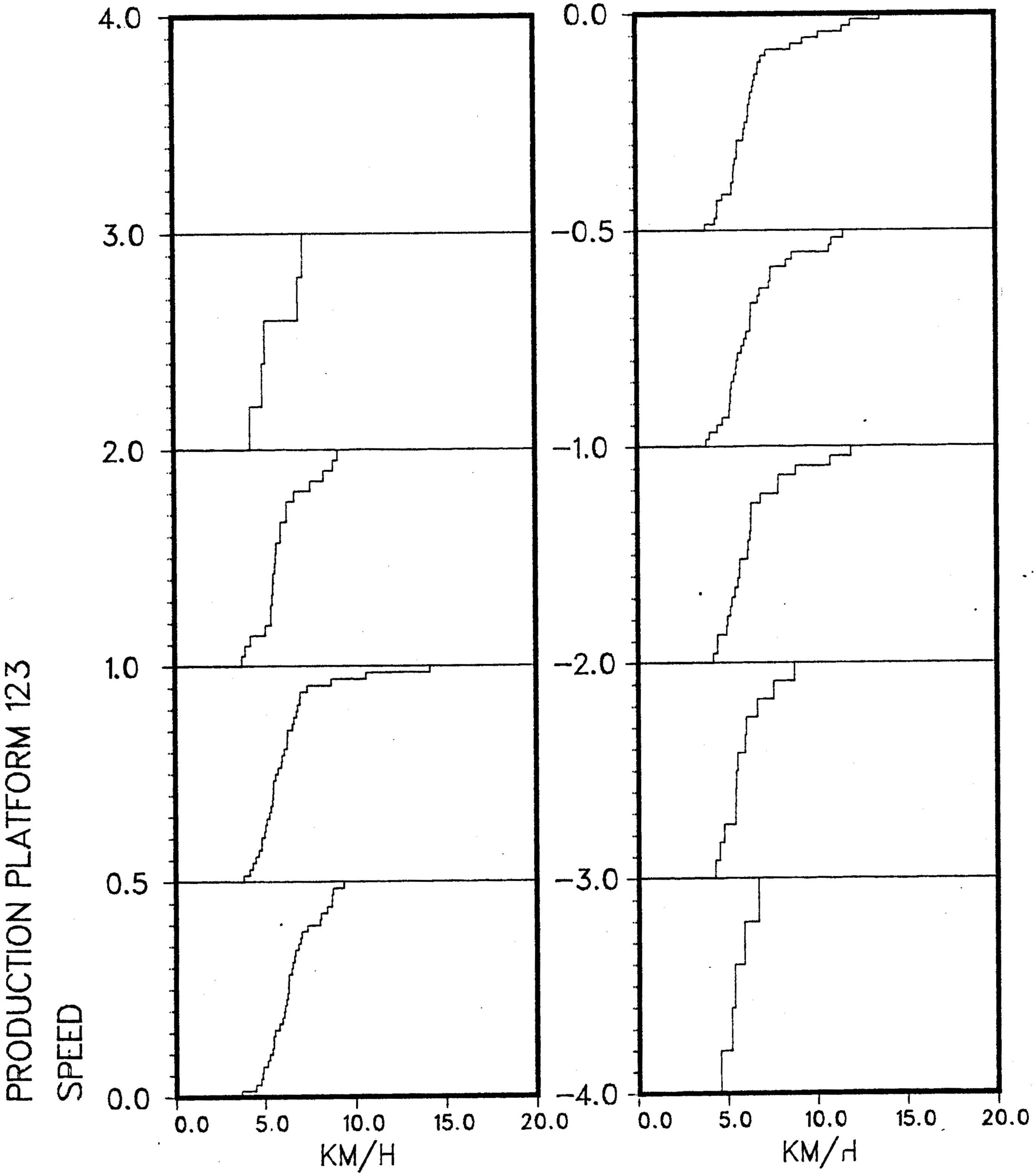

PRODUCTION PLATFORM 123
SPEED
4.0
3.0
2.0
1.0
0.5
0.0
0.0
5.0
10.0
15.0
20.0
KM/H
0.0
-0.5
-1.0
-2.0
-3.0
-4.0
0.0
5.0
10.0
15.0
20.0
KM/H

FIG. B.14b.

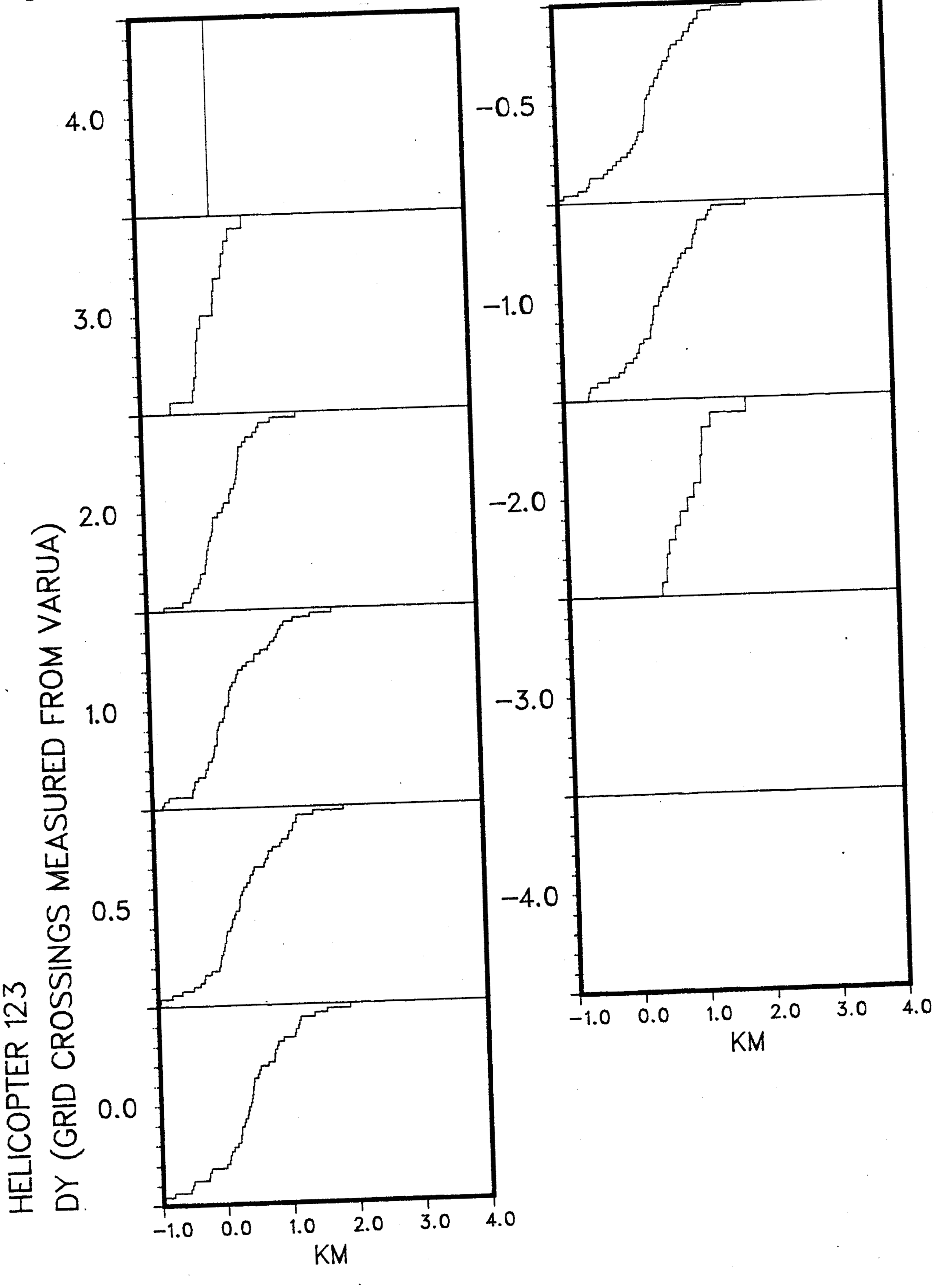

HELICOPTER 123
DY (GRID CROSSINGS MEASURED FROM VARUA)
4.0
3.0
2.0
1.0
0.5
0.0
−0.5
−1.0
−2.0
−3.0
−4.0
−1.0
0.0
1.0
2.0
3.0
4.0
KM

FIG. B.15a.

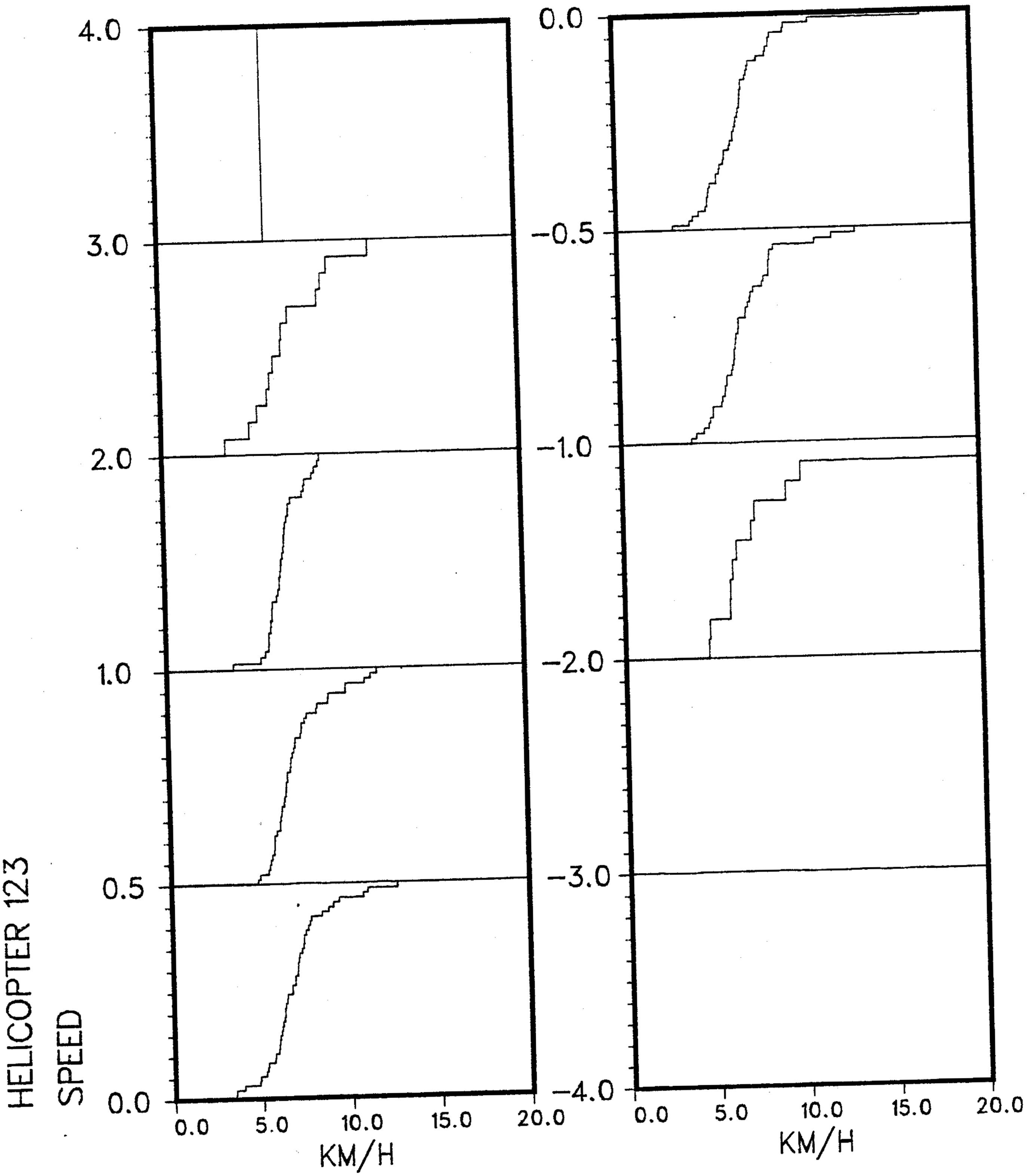
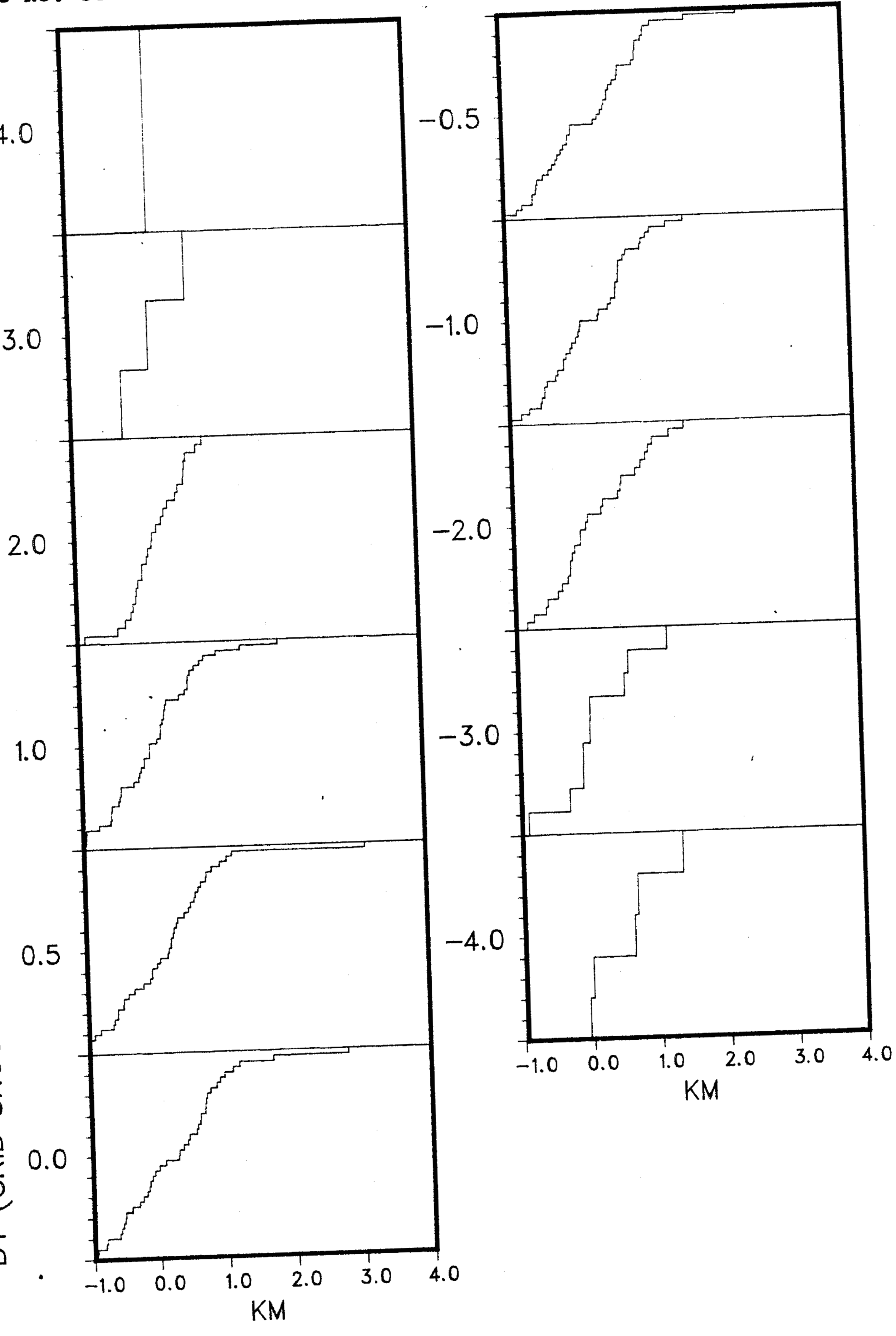

HELICOPTER 123
SPEED
4.0
3.0
2.0
1.0
0.5
0.0
0.0
5.0
10.0
15.0
20.0
KM/H
0.0
-0.5
-1.0
-2.0
-3.0
-4.0
0.0
5.0
10.0
15.0
20.0
KM/H

FIG. B.15b.



POOLED SEMISUBMERSIBLE
DY (GRID CROSSINGS MEASURED FROM VARUA)

FIG. B.16a.

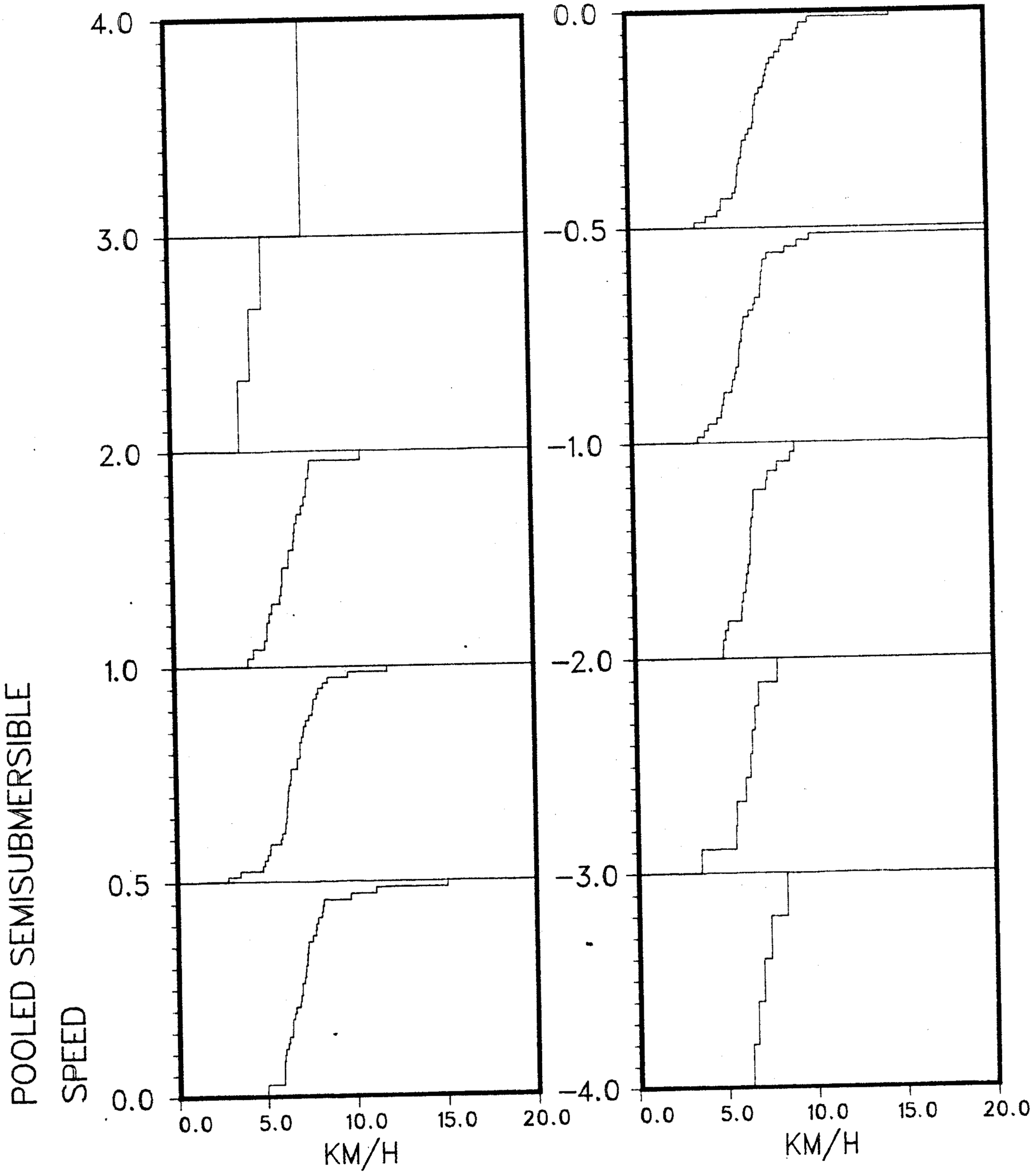

POOLED SEMISUBMERSIBLE
SPEED
4.0
3.0
2.0
1.0
0.5
0.0
0.0
5.0
10.0
15.0
20.0
KM/H
0.0
-0.5
-1.0
-2.0
-3.0
-4.0
0.0
5.0
10.0
15.0
20.0
KM/H

FIG. B.16b.

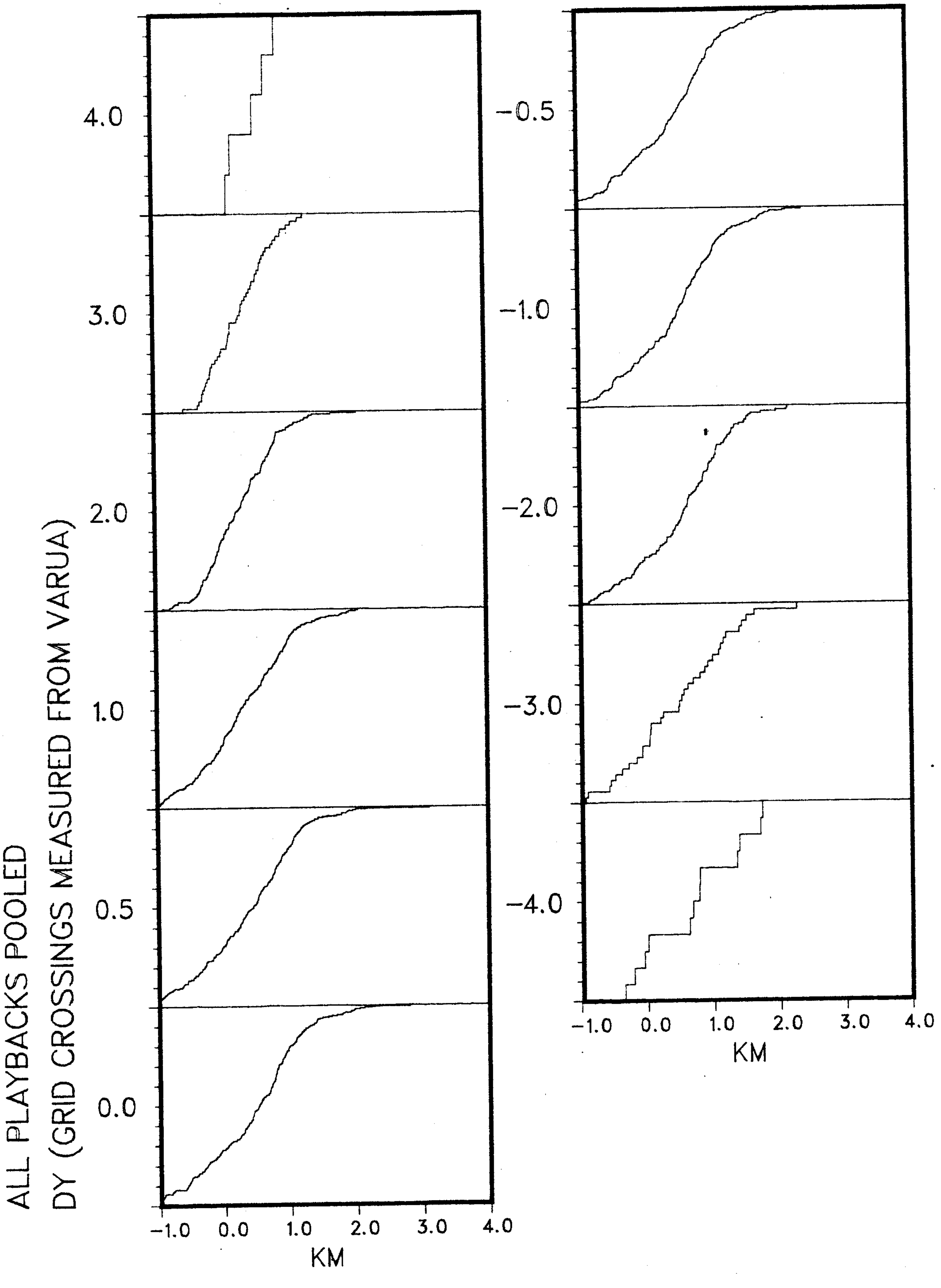

ALL PLAYBACKS POOLED
DY (GRID CROSSINGS MEASURED FROM VARUA)
4.0
3.0
2.0
1.0
0.5
0.0
-0.5
-1.0
-2.0
-3.0
-4.0
-1.0
0.0
1.0
2.0
3.0
4.0
KM

FIG. B.17a.

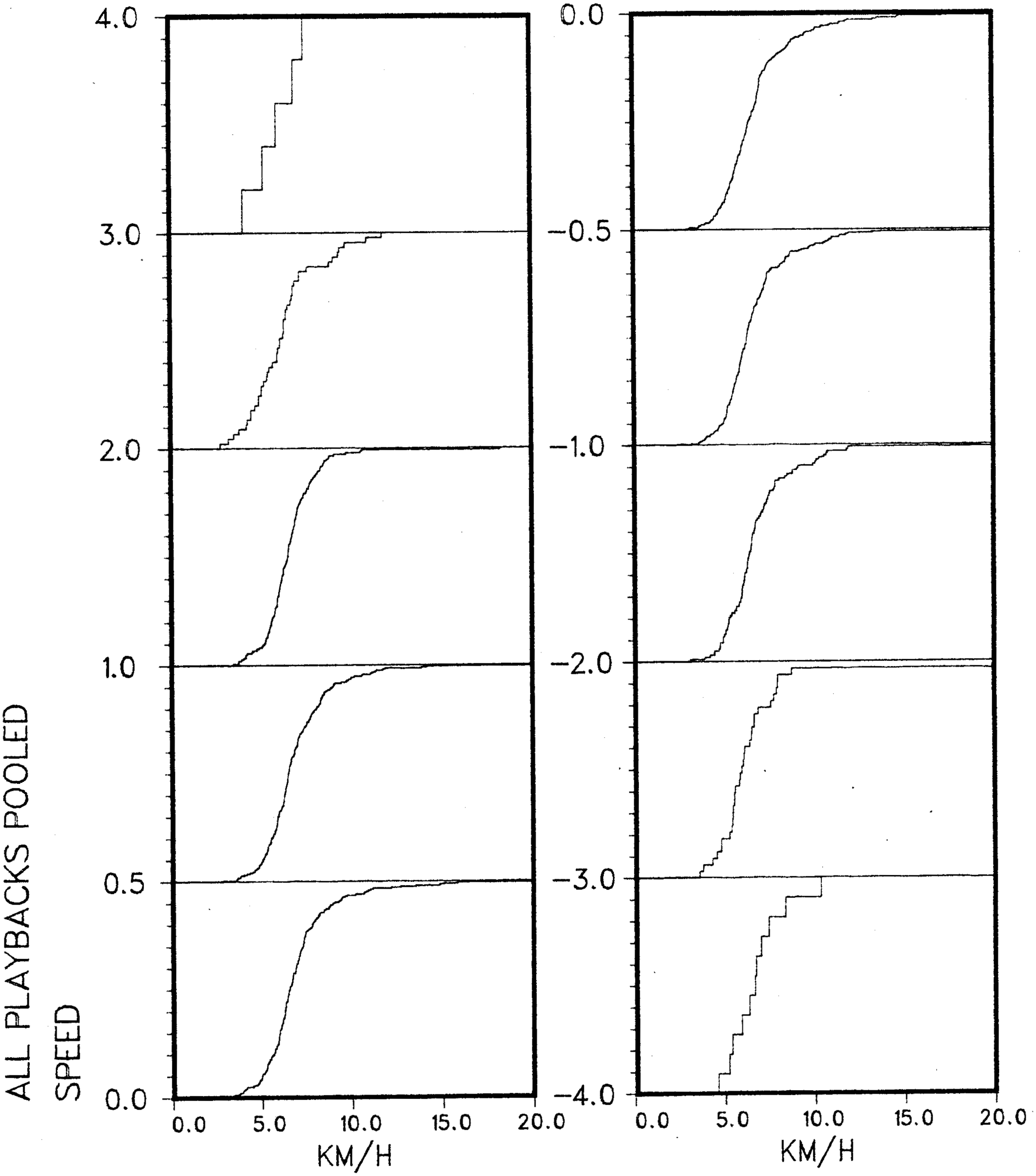
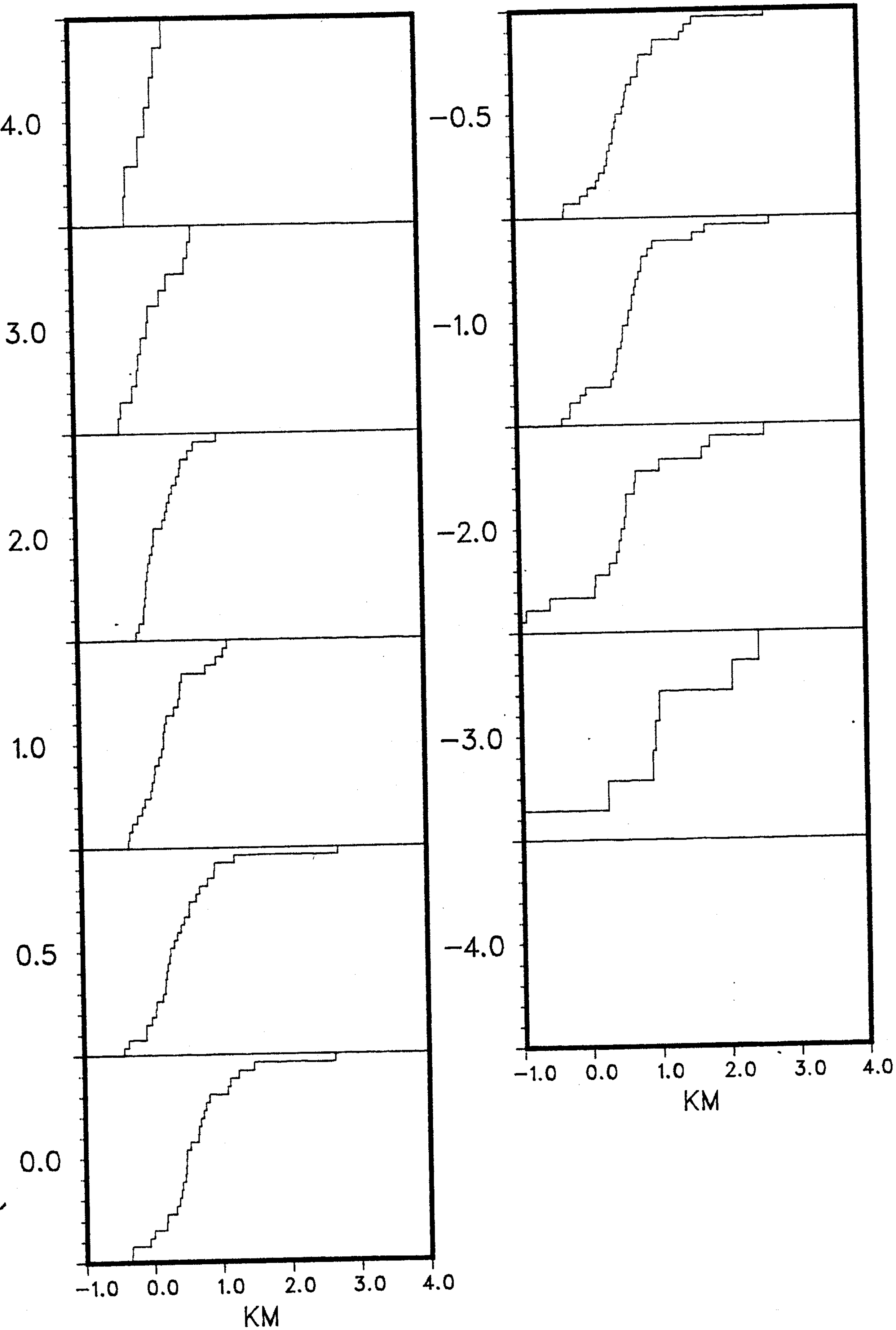

ALL PLAYBACKS POOLED
SPEED
4.0
3.0
2.0
1.0
0.5
0.0
0.0
-0.5
-1.0
-2.0
-3.0
-4.0
0.0
5.0
10.0
15.0
20.0
KM/H
KM/H

FIG. B.17b.



AIR GUN CONTROL, BOTH BOATS PRESENT
DY (GRID CROSSINGS MEASURED FROM VARUA)

FIG. B.18a.

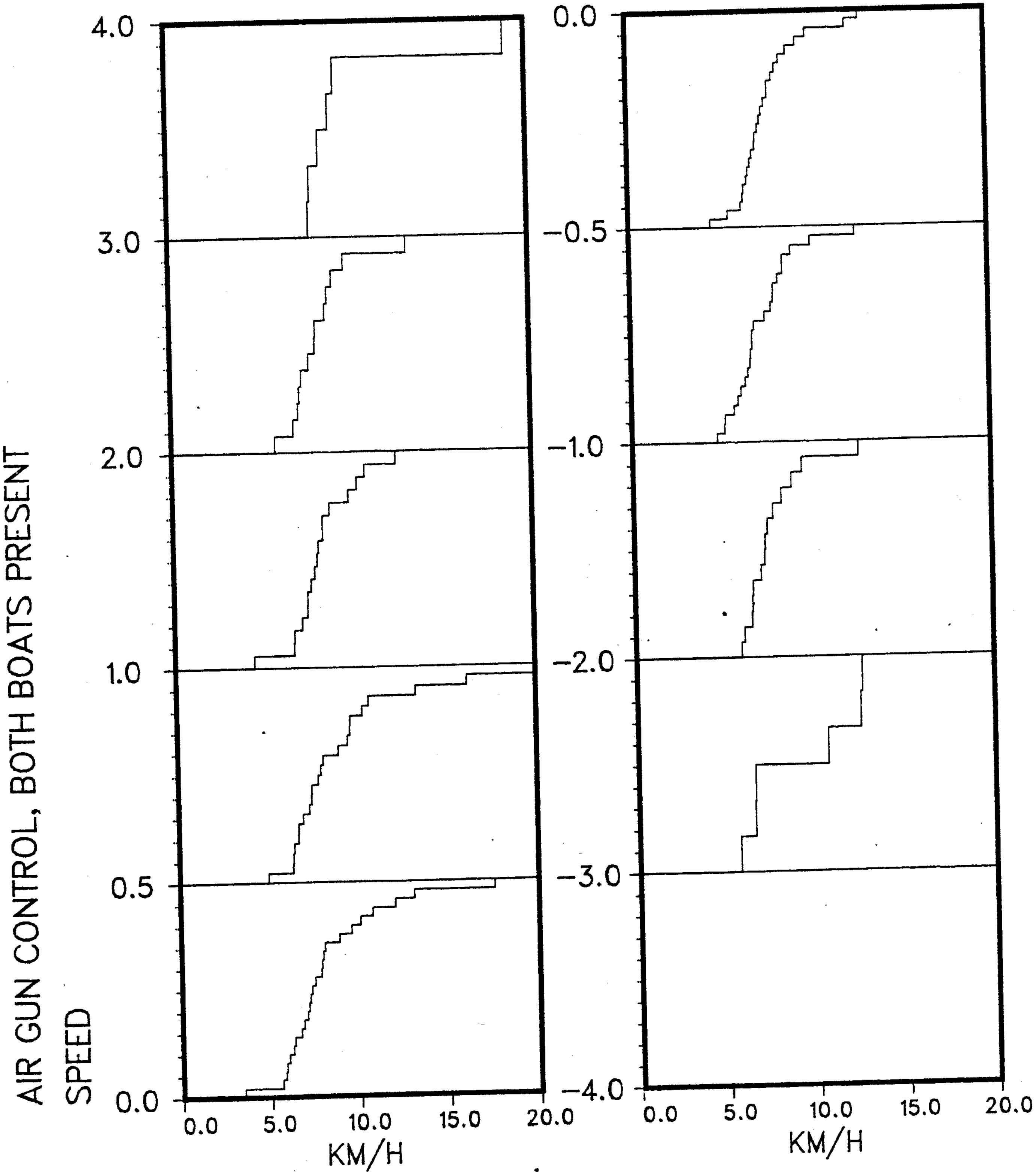

AIR GUN CONTROL, BOTH BOATS PRESENT
SPEED
4.0
3.0
2.0
1.0
0.5
0.0
0.0
-0.5
-1.0
-2.0
-3.0
-4.0
0.0
5.0
10.0
15.0
20.0
KM/H
0.0
5.0
10.0
15.0
20.0
KM/H

FIG. B.18b.

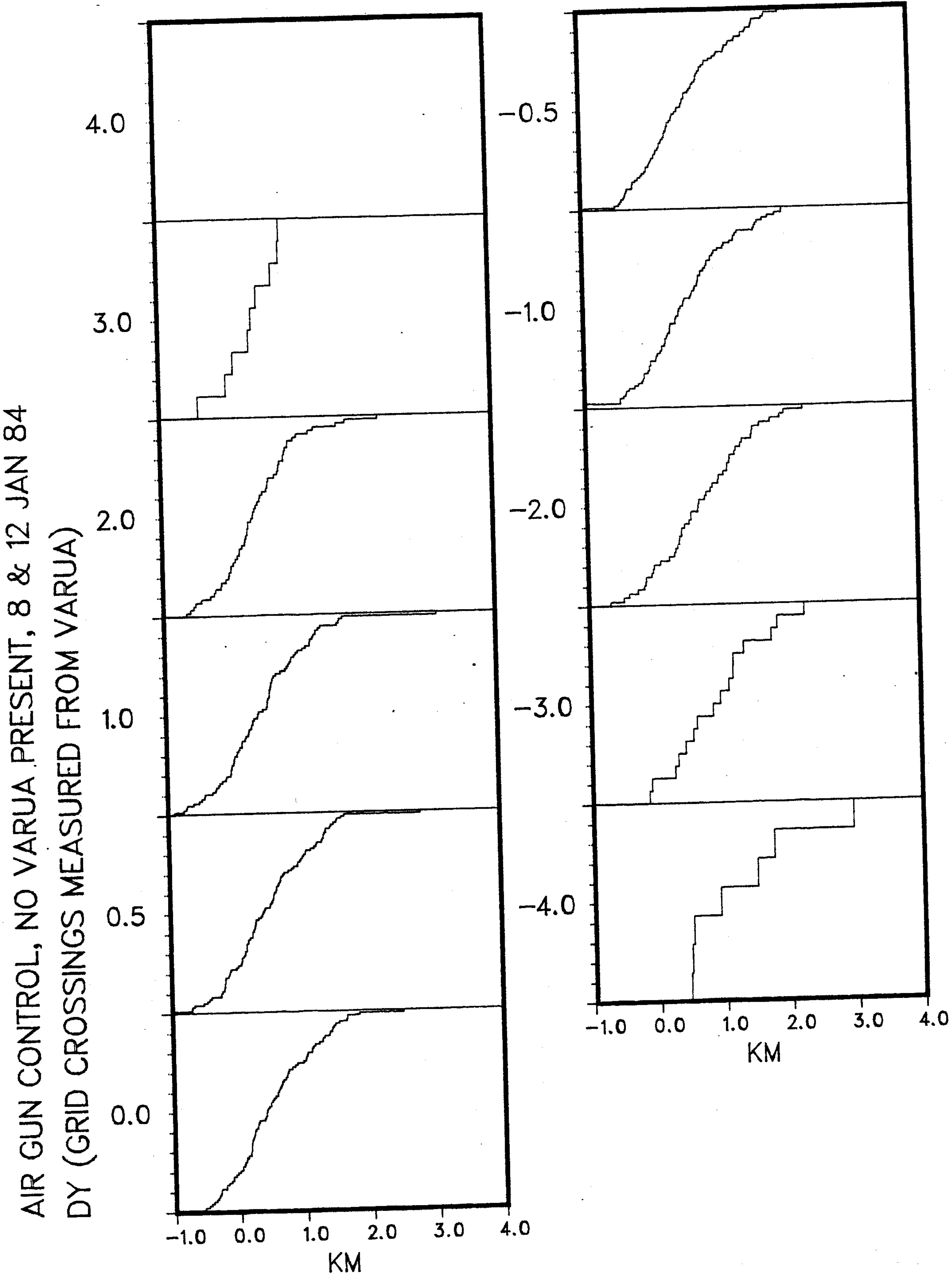

AIR GUN CONTROL, NO VARUA PRESENT, 8 & 12 JAN 84
DY (GRID CROSSINGS MEASURED FROM VARUA)
4.0
3.0
2.0
1.0
0.5
0.0
-0.5
-1.0
-2.0
-3.0
-4.0
-1.0
0.0
1.0
2.0
3.0
4.0
KM

FIG. B.19a.

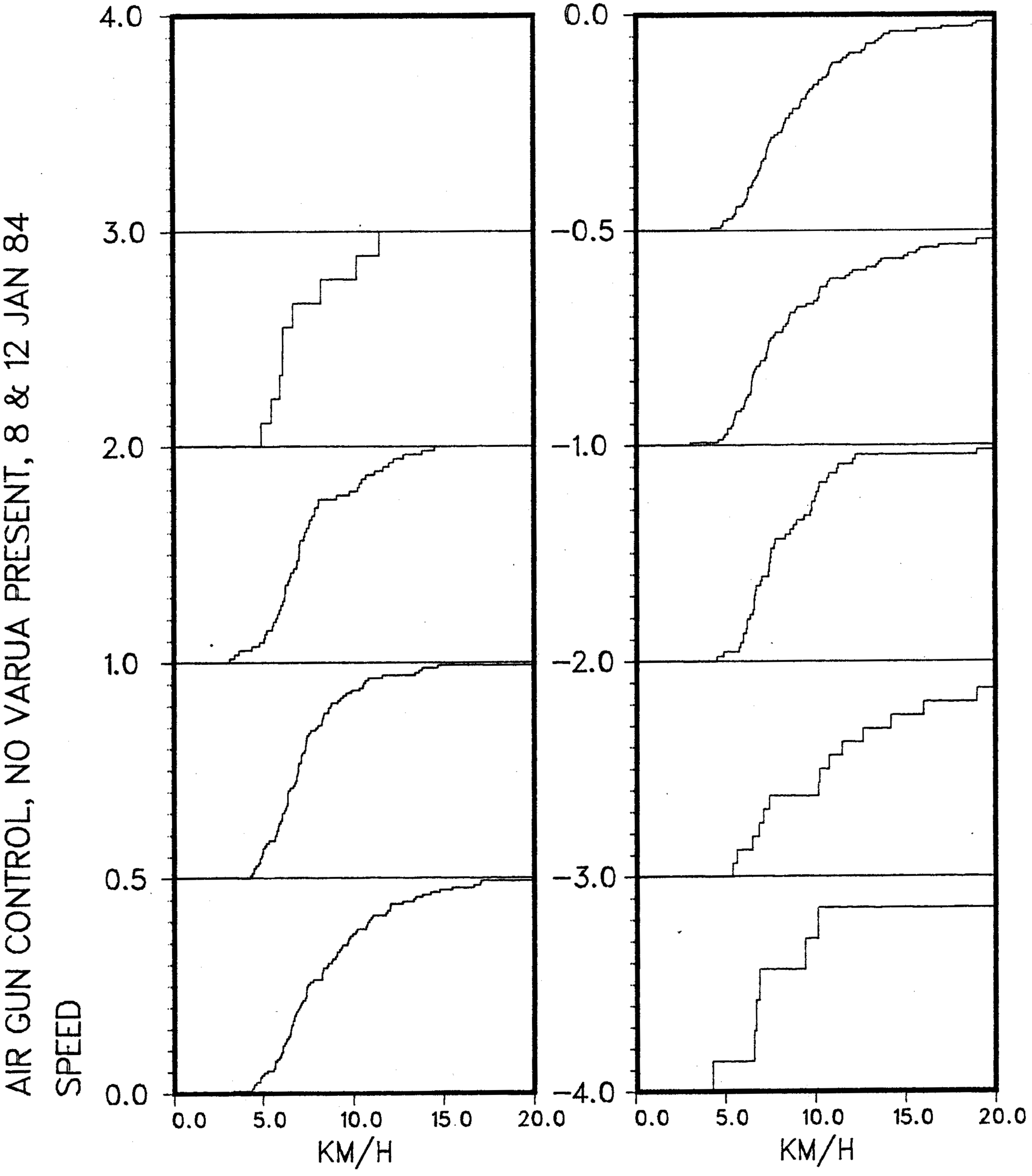

AIR GUN CONTROL, NO VARUA PRESENT, 8 & 12 JAN 84
SPEED
4.0
3.0
2.0
1.0
0.5
0.0
0.0
-0.5
-1.0
-2.0
-3.0
-4.0
0.0
5.0
10.0
15.0
20.0
KM/H
0.0
5.0
10.0
15.0
20.0
KM/H

FIG. B.19b.

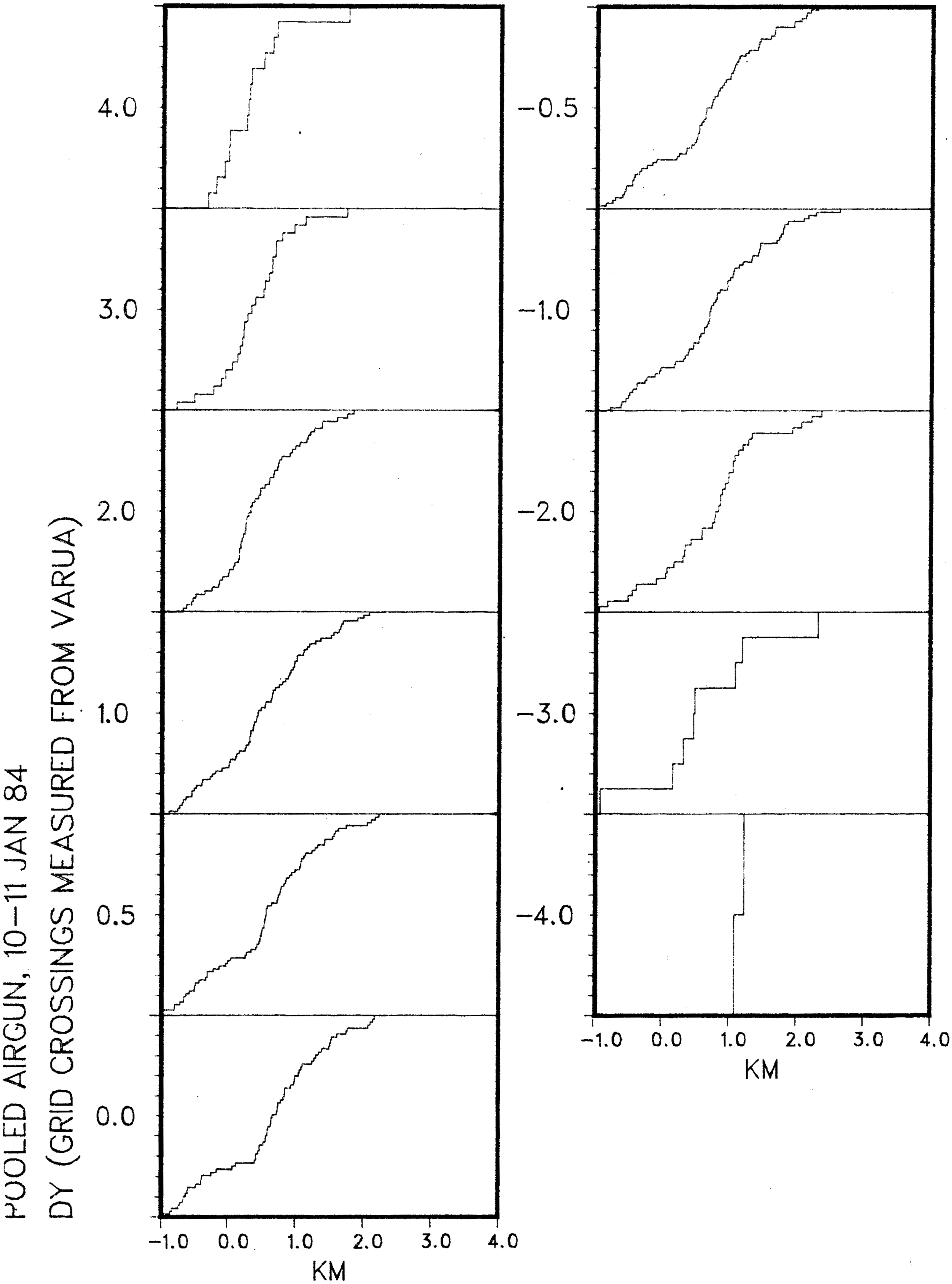

POOLED AIRGUN, 10–11 JAN 84
DY (GRID CROSSINGS MEASURED FROM VARUA)
4.0
3.0
2.0
1.0
0.5
0.0
−0.5
−1.0
−2.0
−3.0
−4.0
−1.0
0.0
1.0
2.0
3.0
4.0
KM
−1.0
0.0
1.0
2.0
3.0
4.0
KM

FIG. B.20a.

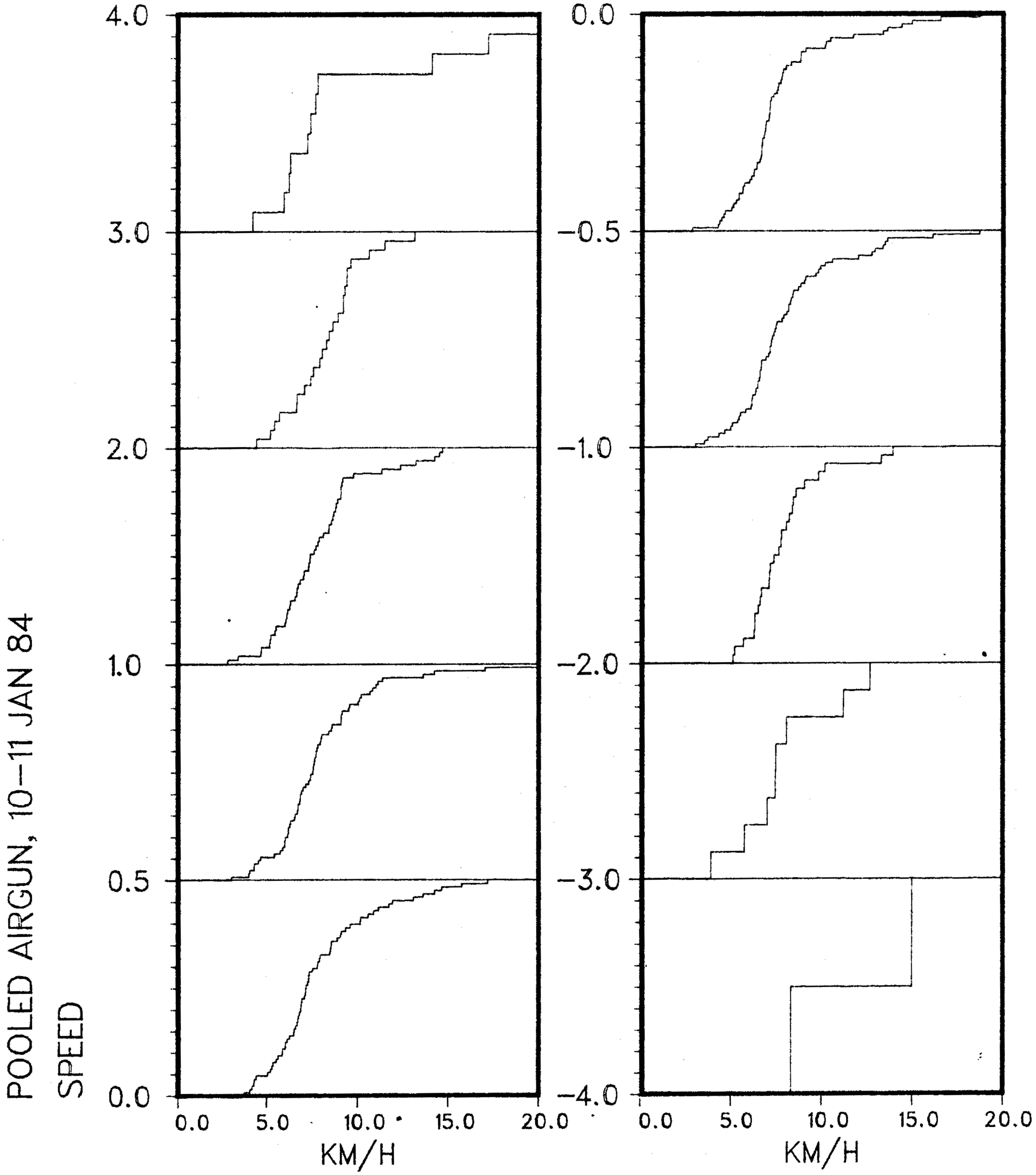

POOLED AIRGUN, 10–11 JAN 84
SPEED
4.0
3.0
2.0
1.0
0.5
0.0
0.0
-0.5
-1.0
-2.0
-3.0
-4.0
0.0
5.0
10.0
15.0
20.0
KM/H
0.0
5.0
10.0
15.0
20.0
KM/H

FIG. B.20b.

APPENDIX C

PLAYBACK STIMULI SPECTRA

APPENDIX C: PLAYBACK STIMULI SPECTRA

This appendix contains a set of 1/3 octave band spectra for each of the playback stimuli used in the study. Spectra for both the original recording dub and the playback are included for comparison. The playback spectra were obtained by analyzing the recorded output of the projector monitor hydrophone located 6 m from the projector system. The projector depth for all playbacks was 12 m. Spectra from analysis of the original recording dub are shown with their relative level adjusted to facilitate comparison with the playback spectra. Note that some of the industrial stimula used were obtained from recordings having considerable fluctuation in level and spectrum content. Thus, it was difficult to obtain an exact match of the machinery operating condition for the dub-playback comparison. Hence, some of the figures presented here show spectra differences which may not be due entirely to system response effects.

The projector system response was considerably improved over that used during the 1983 study. The low frequency response was moved down to 32 Hz from 50 Hz and the 10 dB "crossover notch" at around 1 kHz was removed. As a result, the industrial sounds were more accurately simulated.

The response data for drillship, drilling platform, production platform, helicopter, and semisubmersible rig, are presented in Figs. C.1 through C.5 on the following pages.

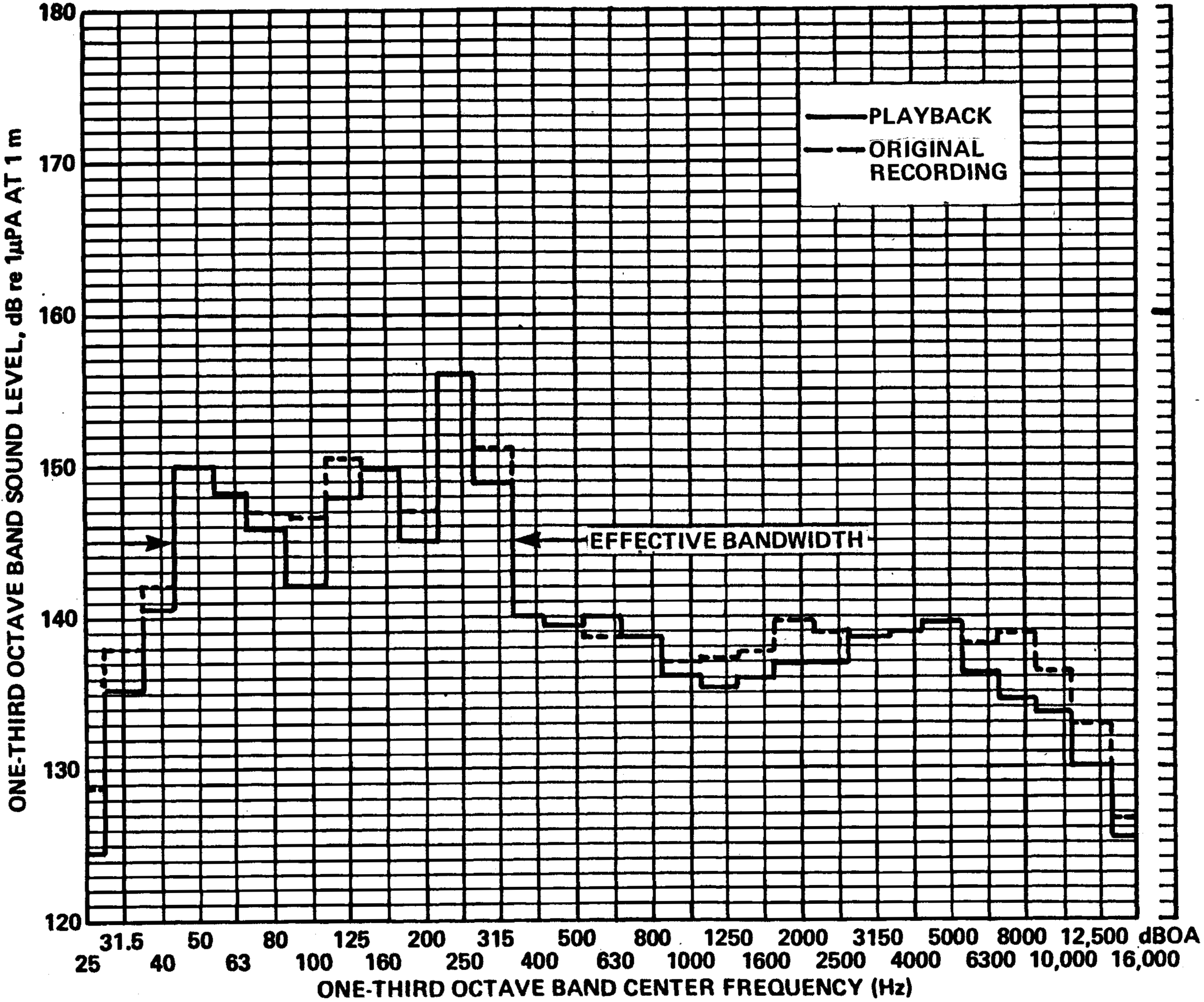


FIG. C.1. DRILLSHIP STIMULUS

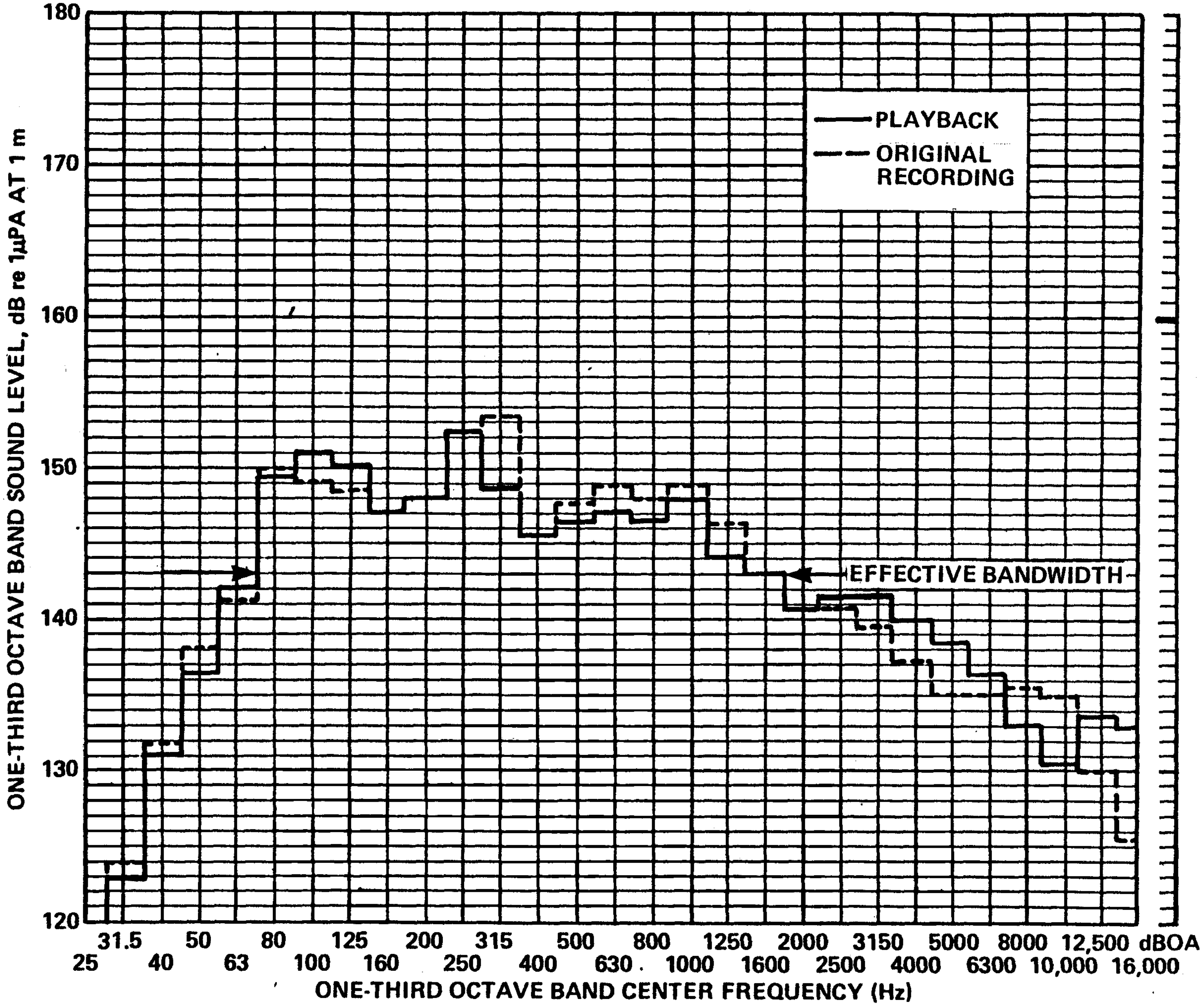


FIG. C.2. DRILLING PLATFORM STIMULUS.

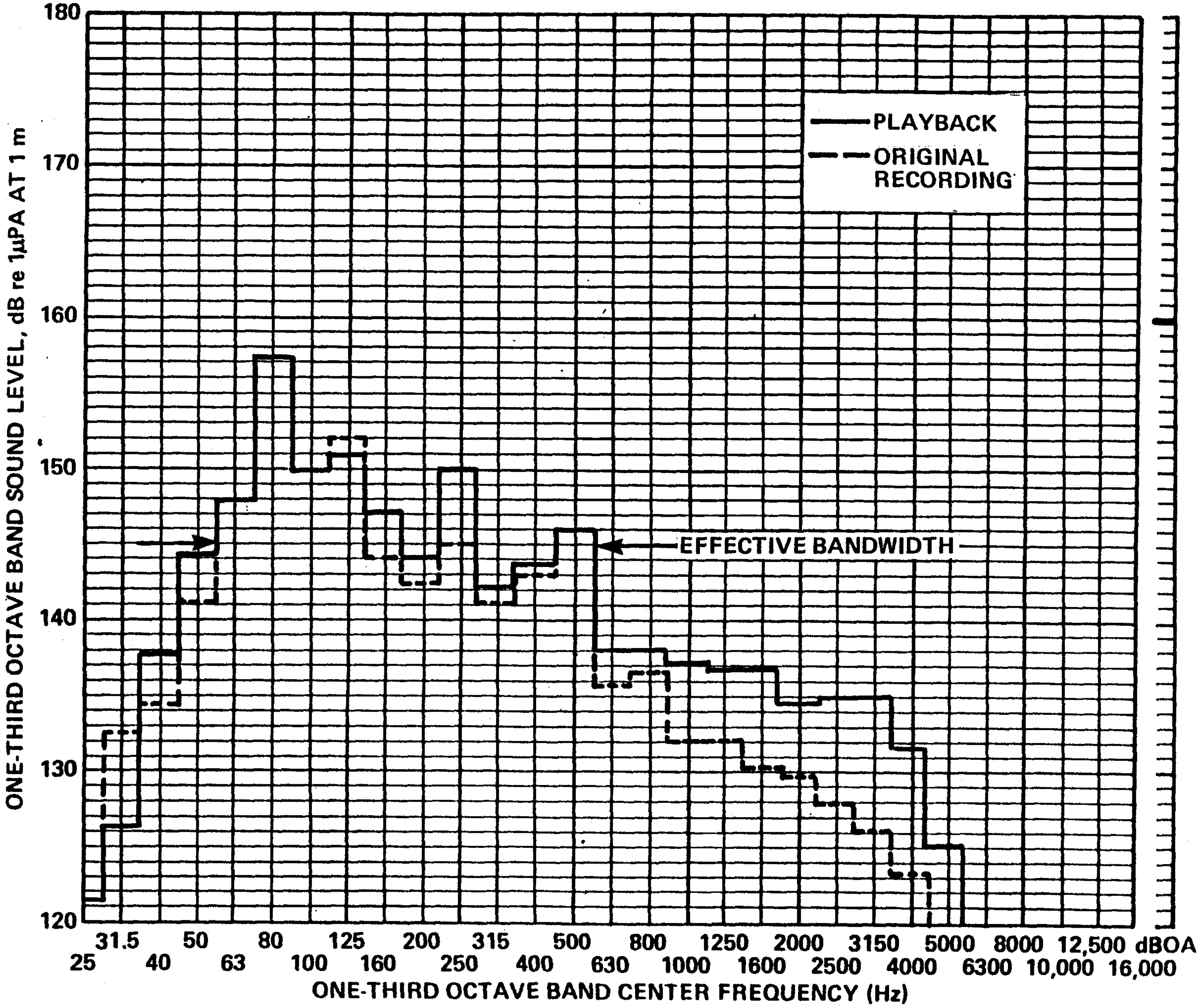


FIG. C.3. PRODUCTION PLATFORM STIMULUS.

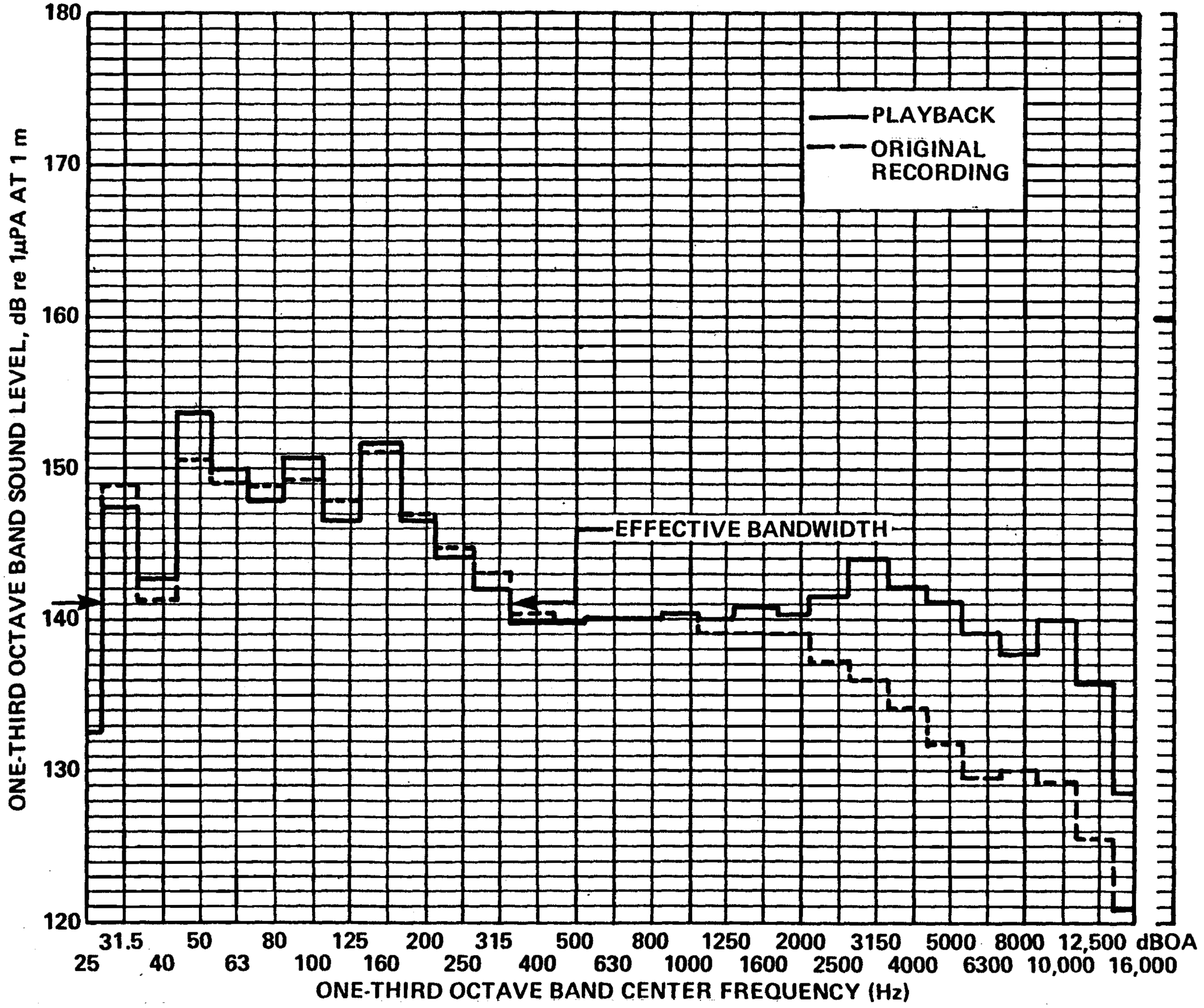


FIG. C.4. HELICOPTER STIMULUS.

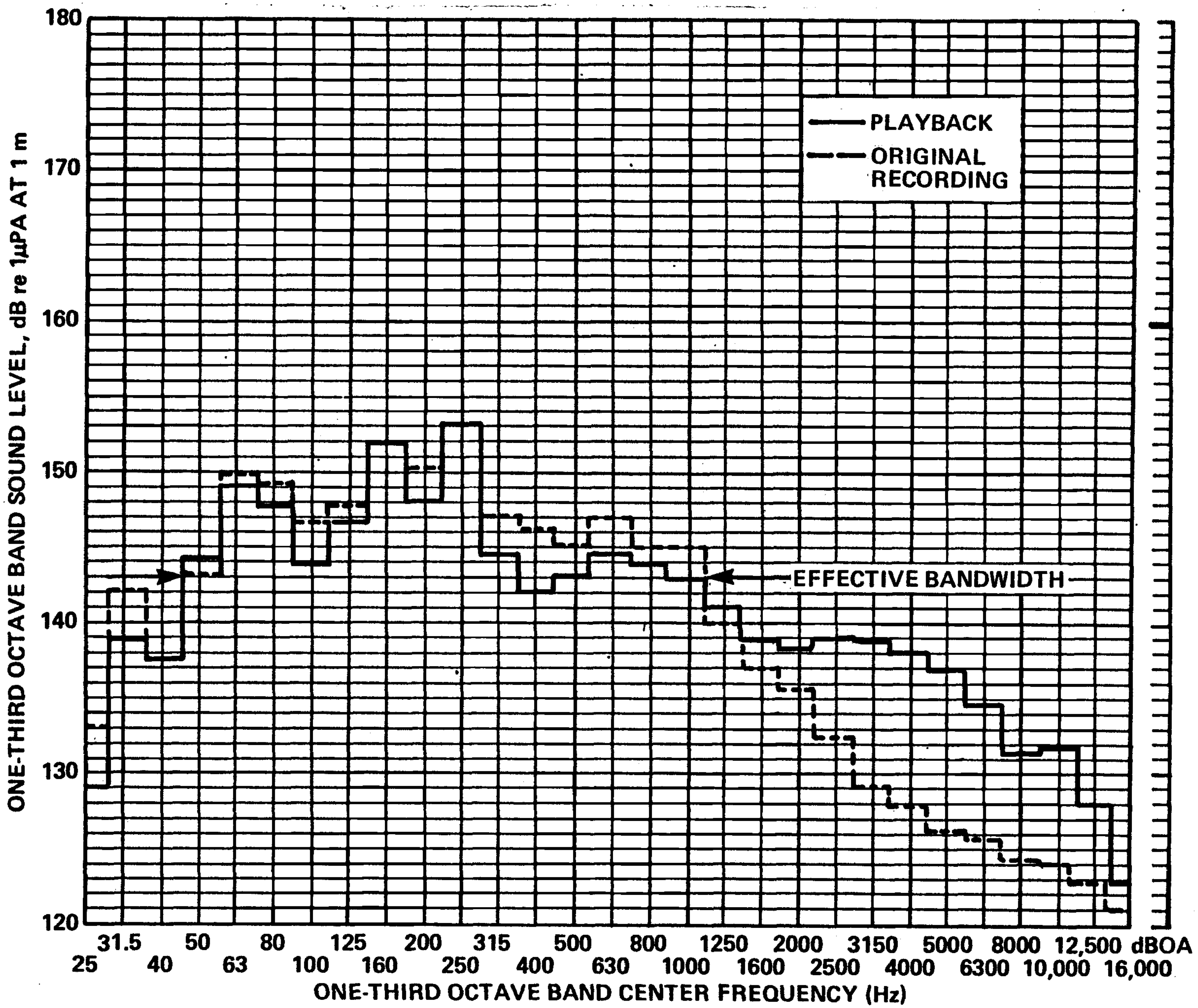


FIG. C.5. SEMISUBMERSIBLE DRILL RIG PLATFORM STIMULUS.

APPENDIX D

EFFECTS OF SOUNDS ASSOCIATED WITH PETROLEUM INDUSTRY ACTIVITIES ON THE BEHAVIOR OF SEA OTTERS IN CALIFORNIA

Marianne L. Riedman

D.1 INTRODUCTION

The purpose of this study was to obtain additional information on the behavior of southern sea otters (Enhydra lutris nereis) exposed to various waterborne acoustic stimuli projected during BBN studies of migratory gray whale (Eschrichtius robustus) behavior. This two-week field study was a continuation of more extensive observations on sea otters made in the winter and spring of 1983 during similar BBN acoustic experiments (Malme, et al, 1983[1]; Reidman, 1984[2]). During the January 1984 southward migration of gray whales, sea otters near Soberanes Point, California, were exposed to controlled underwater seismic exploration sounds generated by an air gun and tape-recorded industrial noise associated with offshore oil and gas operations. Observations were made on the behavior, density, and distribution of sea otters in the immediate vicinity of the sound sources before and during the BBN acoustic experiments. Results of the observations made on sea otters during the 1984 sound projection period are summarized in this report.

D.2 STUDY AREA AND METHODS

The BBN playback of industrial noise and air gun projection of seismic sounds took place near Soberanes Point, located 12 km south of Carmel, California. The Soberanes Point area was also the central site of the previous winter and spring sound projection experiments and behavioral observations on sea otters in

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[1] Malme, C.I., P.R. Miles, C.W. Clark, P. Tyack, and J.E. Bird, 1983. Investigations of potential effects of underwater noise from petroleum industry activities on migrating gray whale behavior. Bolt Beranek and Newman Report No. 5366 to the Minerals Management Service, Alaska.

[2] Riedman, M.L., 1984. Studies of the effects of experimentally produced noise associated with oil and gas exploration and development on sea otters in California. Final report to the Minerals Management Service, Alaska, 51 pp.

1983 (Fig. D.1). Three days of seismic sound experiments using a single air gun on the MV CHEYENNE ARROW were conducted from 9 to 11 January. (The single air gun volume was 100 $in.^3$ at 4500 psi, with a pulse interval of 10 sec.) On 9 January, air gun sounds were produced along a series of transects paralleling the shoreline at approximate distances of 13 km, 5 km, and 1.6 km from shore. On 10-11 January, the CHEYENNE ARROW was moored near Lobos Rocks approximately 1.5 km from shore.

Five different types of tape-recorded industrial sounds which are generated during offshore oil and gas operations were projected underwater near Soberanes Point for six days (January 13 through 15, 17, 19, 20). The sound projection system was suspended from the RV VARUA, which was located north of Soberanes Point approximately 1.8 km from shore. Details regarding the timing of sound projection periods, sound source locations and acoustic characteristics of the industrial and air gun sounds are provided in the Experimental Procedure section in the body of this report. Industrial and seismic sounds were projected at intervals between 0830 and 1700 hrs.

While the overall sound projection experimental conditions were similar to those which took place in 1983, there were a few minor differences with respect to the potential degree of exposure experienced by the sea otters near Soberanes Point. For example, during the playback of industrial sound in 1984, the VARUA was positioned further offshore by about .3 to .8 kilometers, and therefore, the sound source was more distant from sea otter-inhabited areas during the 1984 experiments. Similarly, during the single air gun experiments, the CHEYENNE ARROW did not approach the sea otters as closely as did the single air gun vessel of 1983, which was up to twice as close to otters engaged in various activities during some of the 1983 acoustic experiments.

In addition, although weather and sea conditions were variable during the 1984 sound projection period, the overall weather was relatively mild and visibility was adequate in comparison to the stormy weather and rough seas characterizing part of the 1983 field season. Sea conditions in 1984 varied from very calm to moderately rough with high swells. Ambient noise levels in otter-inhabited areas would be expected to be lower during days when the seas were calm and surf was low.

Data on sea otters were collected over a 14-day period, from 7 to 20 January. Observations were made from shore using Trinovid Leitz 10-40x binoculars and a 50-80x Questar spotting scope. A minimum of one census of the 2.7 km Soberanes Point area (Fig. D.2), where the sound source was centrally located, was made each day during the sound projection period (9 to 20 January), so that any changes in distribution or movements out of the sound projection area could be noted. During the two days prior to the initiation of the acoustic experiments, two counts of the Soberanes Point area were made, and one census was taken of a 12 km area from Rocky Point to Yankee Point (Fig. D.1) in order to collect baseline information on the abundance and distribution of otters within the sound projection vicinity, assess the most suitable observation sites and determine the proportion of otters located within the 2.7 km Soberanes Point area. Another 12 km census was made on 18 January, a control day when no playback took place, to determine if any changes in density or distribution of sea otters had occurred. Because weather and sea conditions, as well as the location of kelp beds, can influence the distribution of sea otters, these natural environmental variables were monitored closely throughout the study period.

With the exception of 18 January, observations on otters were conducted on a "double-blind" basis in which the timing and type of sound being projected were unknown to the shore-based observers. Radio contact, however, was continuously available with the shore-based gray whale observers and the BBN research team controlling the acoustic experiments on board the VARUA.

During the sound projection period, sea otters within the Soberanes Point area were closely monitored for any unusual or alarm behaviors, or obvious movements away from the sound source. In particular, observations were focused on foraging sea otters that were closest to the VARUA or CHEYENNE ARROW, since diving animals were presumably more susceptible to the effects of waterborne noise than otters at the surface. Feeding otters were followed throughout the duration of their foraging bout or as long as they were within view. The number of successful vs unsuccessful dives (in which the otter did or did not obtain prey) were recorded. Because the sound source vessels were situated about 1.5 to 1.8 km offshore, efforts were directed towards monitoring sea otters that were foraging furthest offshore and closest to the sound source.

D.3 RESULTS AND DISCUSSION

Abundance and Distribution of Sea Otters

The density of sea otters observed in the Soberanes Point area was relatively high throughout the sound projection period. There was no movement of otters away from the sound source or out of the Soberanes Point vicinity. The number of independent sea otters varied over the study period, ranging from 15 to 38 ($\overline{X}$ = 25), although numbers were most often counted in the high twenties (Table 1). Each day, between two to four dependent pups were observed. Two of the four pups were relatively large (older than three months of age) and two were small (less than three months). The abundance of independent otters and dependent pups was similar to that observed in January of 1983.

On 8 January, a 12 km census taken from Yankee Point to Rocky Point showed that there were 65 independent otters and six pups in this area. After 10 days of air gun and playback experiments, on 18 January, another census of the same area was taken with similar results of 61 independent and eight pups. On average, half of the total number of sea otters within the 12 km census area were found in the 2.7 km Soberanes Point area.

The density and distribution of sea otters within the Soberanes Point region often fluctuated from day to day. These fluctuations, however, were apparently related to changes in weather and sea conditions, time of day, and the relatively small size of the census area, rather than to the projection of seismic or industrial sounds. Similar results were obtained during the 1983 study. In general, on days when sea conditions were rough, fewer otters were seen in the Soberanes Point area. Conversely, on calm days the highest counts of otters were recorded.

"Otter" Cove (referred to as "Lobos" Cove in the 1983 report) was often used as a rafting spot for large numbers of otters; up to 30 independent otters and three pups were observed in a large raft in this cove. The proportion of otters rafting in "Otter" Cove and "Jade" Cove (Fig. D.2) at Soberanes Point varied in relation to wind direction and intensity and swell size. When a particular cove or rafting spot was exposed to high wind and rough seas, there were few or no otters rafted in the area. During days when sea conditions were rough, the comparatively low number of otters recorded in the Soberanes Point area may have reflected movements to sheltered coves outside of the census area, such as Yankee Point Cove or Kasler Point Cove. Because the Soberanes Point census area was relatively small, fluctuations in density were apt to be more pronounced than in a larger area, since otters could easily move outside the census boundaries to feed or seek sheltered rafting sites.

Behavioral Observations

Sea Otters in the Soberanes Point area did not exhibit any behaviors which could be considered unusual or indicative of disturbance or alarm throughout the sound projection period. Of interest is one alarm reaction exhibited by several animals rafted in Otter Cove and apparently initiated by airborne noise. While observing a group of 18 rafted otters at a distance of about 150 meters, I turned on my radio at a loud volume. Several of the resting otters immediately appeared startled as they looked towards me and dove beneath the surface, swimming to a new rafting location. The loud radio noise evidently called attention to my presence, which caused the otters to leave the area.

Foraging Observations

Observations made near Soberanes Point during the projection of seismic and industrial noise indicated that no disturbances or changes in the typical foraging pattern of sea otters took place. While an effort was made to observe otters that were feeding close to the sound source, the CHEYENNE ARROW and VARUA were situated 1.5 and 1.8 km from shore, respectively, and otters do not normally forage this far offshore. Therefore, all of the foraging observations were made on otters no closer than 900 m from the sound sources, and most of the observations were made on otters feeding 1.3 to 1.6 km from the sound source vessels in water approximately 5 to 17 m in depth.

On 11 January, the last day of the air gun experiments, two otters were observed foraging about 600 m offshore near Lobos Rocks and approximately 900 m from the CHEYENNE ARROW. Although the air gun was operating at the time, these animals fed for 50 minutes and 85 minutes in this area before gradually moving northeast. The duration of feeding dives usually ranged from one to 2 1/2 minutes, and otters obtained food in most of the dives, although it was difficult to see the type of prey they were eating.

On 17 January, an otter was seen foraging directly inshore of the VARUA by 1.2 km during playback of drilling platform sounds (1122-1318), which was the minimum distance to the VARUA an otter was seen feeding. The otter continued feeding for approximately one hour, diving for periods of up to 2 minutes, 45 seconds, and obtaining prey on most of the dives.

Throughout the three-day seismic experiments, when the air gun was operating, observations were made on a total of 16 otters engaged in foraging activity. On average, 80% of the feeding dives were successful (N = 368 dives). Dive times averaged 84 seconds. During the six-day period of industrial sound playback, when sounds were being projected, observations were made on a total of 26 otters engaged in foraging bouts. On average, 78% of their foraging dives were successful (N = 607), and the mean duration of all dives was 79 seconds.

The overall proportion of successful and unsuccessful feeding dives at Soberanes Point was close to that observed in our 1983 study, and similar to the proportion of successful dives previously reported in California. Previous studies in California have shown that an average of 73% to 75% of all feeding dives were successful (Loughlin 1979[3]; Estes, Jameson, and Johnson, 1980[4]). The average duration of feeding dives were

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[3] Loughlin, T.R., 1979. Radio telemetric determination of the 24-hour feeding activities of sea otters, Enhydra lutris, pp. 717-724. In: A Handbook on Biotelemetry and Radio Tracking (C.J. Amlaner, Jr. and D.W. Macdonald, Eds.). Pergamon Press, Oxford.

[4] Estes, J.A., R.J. Jameson, and A.M. Johnson, 1980. Food selection and some foraging tactics of sea otters, pp. 606-641. In: Worldwide Furbearer Conference Proceedings (J.A. Chapman and D. Pursley, Eds.). Frostburg, Maryland.

also within the range of average reported dive times, which range from 52 to 90 seconds (Estes 1980[5]). The average dive time at Soberanes Point represents the high end of this scale and may reflect the fact that an effort was made to observe sea otters that were diving in deeper water closer to the sound sources.

D.4 CONCLUSIONS AND SUMMARY

During the January 1984 southward migration of gray whales, seismic exploration sounds produced by a single air gun and tape-recorded industrial noise associated with offshore oil and gas operations were projected underwater near Soberanes Point, California. Results from this two-week study support those reported in a previous study on sea otters at Soberanes Point conducted in the winter and spring of 1983 during similar BBN acoustic experiments. Although the basic experimental procedures were similar to those of the 1983 study, during the 1984 acoustic experiments the sound sources were positioned further offshore and away from otter-inhabited areas by several hundred meters. In addition, the weather and sea conditions were generally calmer in 1984.

The behavior, density, and distribution of sea otters in the vicinity of the sound projection sources were not affected by the playback of industrial noise or air gun production of seismic sounds. The foraging behaviors of otters that were feeding distances of 900 meters to 1.6 kilometers from the sound sources continued normally and undisturbed during the sound projection periods. Sea otters do not usually forage as far offshore as the sound source vessels were located, and no animals were observed feeding closer than 900 meters to the single air gun vessel CHEYENNE ARROW or 1.2 km to the industrial sound projection

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[5] Estes, J.A., 1980. <u>Enhydra lutris</u>. Mammalian Species No. 133, pp. 1-8, 3 figs.

vessel VARUA. During periods of sound projection, foraging otters were able to capture prey successfully on an average of 78% to 80% of the time, and remained underwater during feeding dives that lasted an average of 79 to 84 sec.

No movements of sea otters away from the sound sources and out of the Soberanes Point area occurred during any of the acoustic experiments. The density of sea otters was relatively high in the 2.7 km Soberanes Point area and ranged from 15 to 38 independent otters and two to four pups. Daily fluctuations in the abundance and distribution of otters in the Soberanes Point area were associated with the small size of this census area, weather and sea conditions and the degree of shelter provided by a particular rafting site.

Acknowledgements

I am grateful to Bob Brownell, Chris Clark, Jim Estes, Chuck Malme, Paul Miles, and Peter Tyack for providing field assistance and equipment.

TABLE D.1. DENSITIES OF SEA OTTERS WITHIN THE A) 2.7 km SOBERANES POINT CENSUS AREA, AND B) THE 12 km CENSUS AREA FROM ROCKY POINT TO YANKEE POINT DURING JANUARY 1984. SINGLE AIR GUN EXPERIMENTS WERE CONDUCTED FROM 9 TO 11 JANUARY; INDUSTRIAL SOUNDS WERE PROJECTED JANUARY 13 THROUGH 15, 17, 19, 20.

Date	Independent Otters	Large Pups	Small Pups	Total Pups
		a. Soberanes Point		
7 Jan.*	15	2	-	2
8 Jan.*	36	2	1	3
9 Jan.	22	2	-	2
10 Jan.	16	1	1	2
11 Jan.	17	2	1	3
12 Jan.*	25	2	1	3
13 Jan.	28	2	1	3
14 Jan.	38	2	2	4
15 Jan.	36	2	2	4
16 Jan.*	16	1	1	2
17 Jan.	30	2	1	3
18 Jan.**	26	2	1	3
19 Jan.	23	2	1	3
20 Jan.	28	2	1	3
		b. Rocky Point to Yankee Point		
8 Jan.*	65	4	2	6
18 Jan.**	61	5	3	8

*Sound source vessels not present.

**Sound source vessel VARUA moored; no playback.

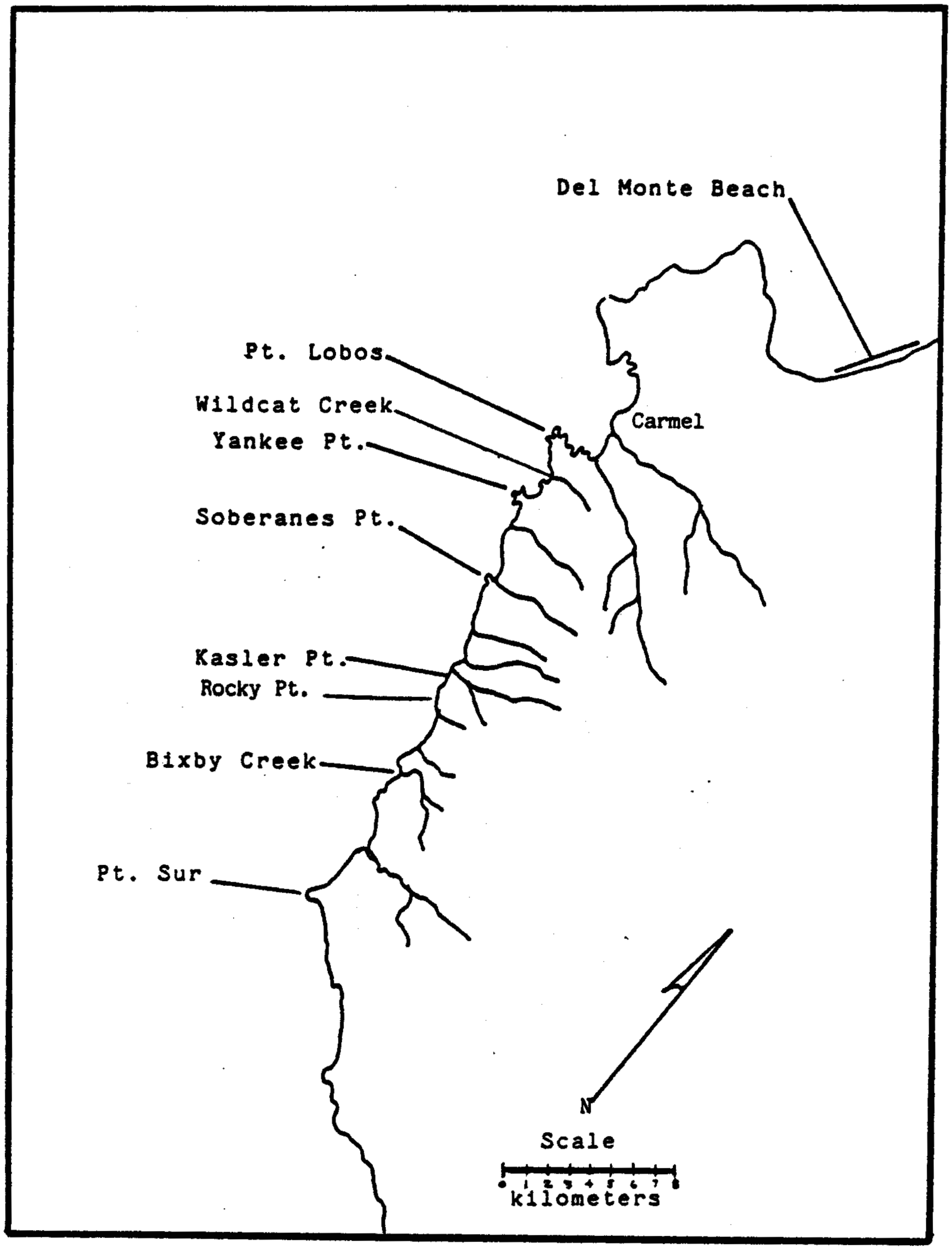

FIG. D.1. STUDY AREAS.

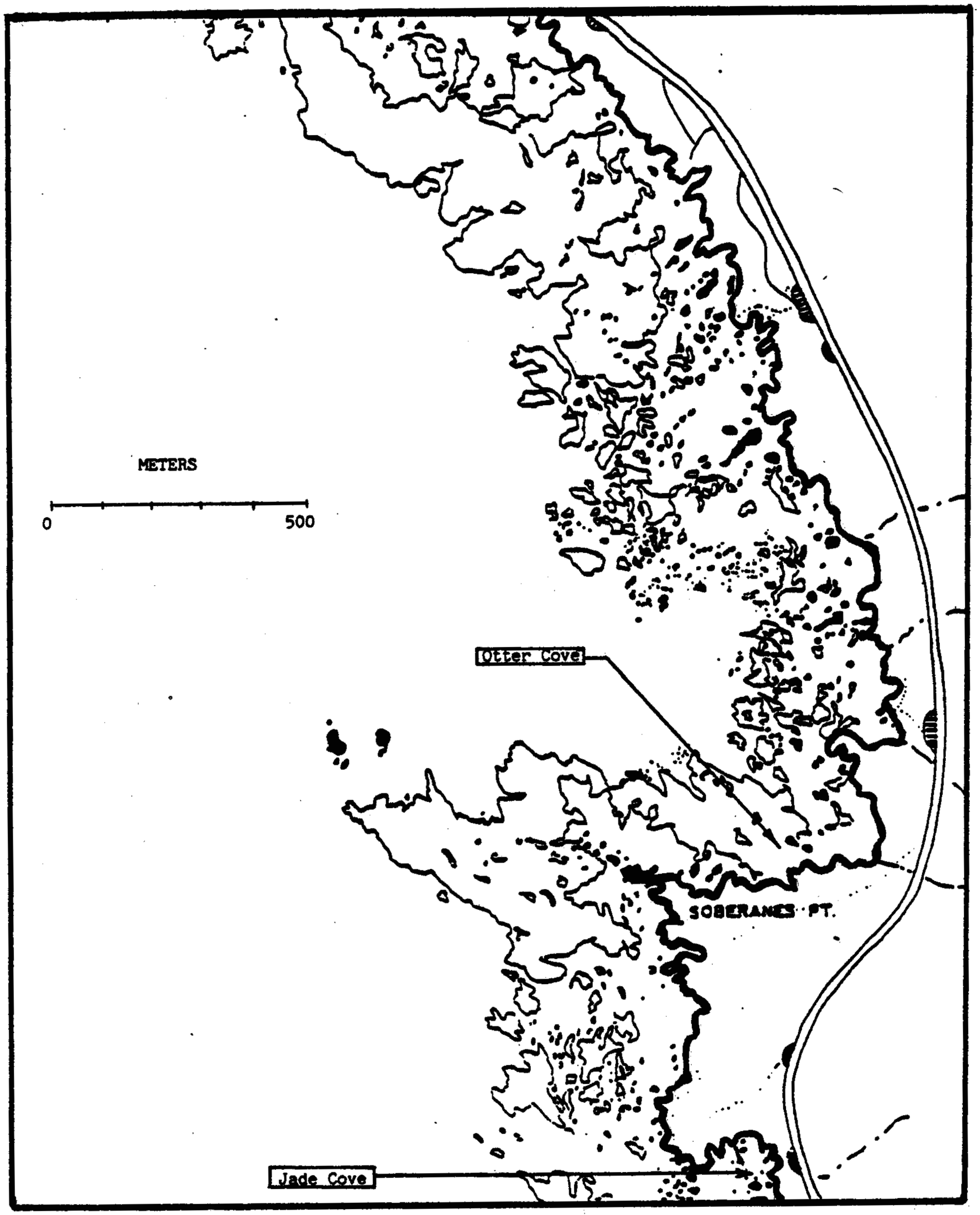

FIG. D.2. SOBERANES POINT SEA OTTER OBSERVATION REGION.

APPENDIX E

THEODOLITE TRACKING SYSTEM ERROR ANALYSIS

E.1 Theodolite Tracking System Error Analysis

The use of two transit stations during this project for tracking whale groups allows an empirical measurement of range errors in the transit technique. The measurement of horizontal angles for azimuth determination is little affected by refraction and is more precise than is required for reasonable accuracy of location. The measurement of vertical angles for range determination is, however, much more critical and is affected by refraction, curvature of the earth, tide, ocean waves, and swells. The distance from the transit station to a whale equals the altitude of the transit above sea level (corrected for tide) times the tangent of the vertical bearing angle (corrected for tide) times the tangent of the vertical bearing angle (corrected for curvature of the earth). The precision of range data is thus directly proportional to the altitude of the transit station for a given level of angular resolution of vertical bearings. As shown in the following calculations, the elevations of Soberanes and North sites, 75.7 and 63.4 m respectively, were high enough to allow range estimates at 5 km (the maximum range of our observations), to within ± 16 m for Soberanes site and ± 20 m for North site, given the ± 10 second precision of our vertical angle measurements (calculations ignore the trivial effect of earth's curvature for simplicity).

These calculations ignore possible sources of error due to refraction and ocean waves, however. In order to estimate these errors, a program was written to search through the January transit sighting data for simultaneous sightings of the same group of whales or boat. The program then calculates an azimuthal position (x_{az}, y_{az}) by triangulating from the horizontal angles of the two stations. The range error of each station is calculated as the distance between the azimuthal position and the position calculated for each station using both vertical and horizontal angles.

CALCULATION OF RANGE RESOLUTION

Soberanes Site

Altitude = 75.7 m range = 5000 m

$\tan\alpha = \arctan(66.05) = 89.1326^\circ = 89^\circ\ 07'\ 57.4''$

for error of +10" $\alpha = 89^\circ\ 08'\ 07.4'' = 89.1354^\circ$

$\tan\alpha = 66.262$

range = 75.7 x 66.262 = 5016.1 m

for error of -10" $\alpha = 89^\circ\ 07'\ 47.4'' = 89.1298''$

$\tan\alpha = 65.839$

range = 75.7 x 65.839 = 4984.037

North Site

Altitude = 63.4 m range = 5000 m

$\tan\alpha$ = range/alt = 78.9

$\alpha = \arctan(78.9) = 89.274^\circ = 89^\circ\ 16'\ 24.7''$

for error of +10" $\alpha = 89^\circ\ 16'\ 34.7'' = 89.2763''$

$\tan\alpha = 79.167$

range = 63.4 x 79.167 = 5019.2

for error of -10" $\alpha = 89^\circ\ 16'\ 14.7'' = 89.2708^\circ$

$\tan\alpha = 78.564$

range = 63.4 x 78.564 = 4980.95

Since groups of whales often were spread over 20 to 50 m (up to 100 m) this analysis does not test the limits of precision for the transit analysis, but rather yields an indication of the resolution of observations of whale groups.

This error analysis program was run for all of the January data files and yielded 325 pairs of sightings. Of these 325 pairs, 10 yielded apparent errors of >1.0 km and these are listed in Table E.1. Cases one through eight involved simultaneous endings of tankers much farther offshore than our typical five km maximum range of whales. These error figures show that the additional height of soberanes station produced lower errors at great range than at North station. Case 10 has a large error in data from one station but very small error in data from the other. This probably represents a case of error in the logging of vertical angle at one station (rate for this error = 1 error/325 pairs of sightings * 2 stations per pair) = .0015. Case 9 has a very large error that arose when the two stations called two different boats of groups of whales by the same name through a misunderstanding (error rate = 1/325 * 2 = .0015).

Figures E.1 and E.2 show the distribution of the error in sightings from Soberanes Site and North Site, respectively, as a function of range from the site to the whale. Both figures show approximately 30 points with errors of >100 m and these points appear not to scale strongly with range. Some of these may arise from errors in measuring or in copying down the vertical bearings erroneously from the theodolite, while others may come from measurements of widespread groups.

TABLE E.1. LIST OF ALL CASES OF APPARENT ERRORS OF > 1.0 km FROM ERROR ANALYSIS OF ALL JANUARY DATA FILES (OUT OF 325 PAIR SIGHTINGS).

	Soberanes		North	
Case	Error (km)	Range (km)	Error (km)	Range (km)
1	1.496	16.057	3.734	16.226
2	1.460	13.224	1.25	14.562
3	4.920	19.69	4.984	18.662
4	0.928	13.671	1.106	14.564
5	-0.109	13.009	3.153	13.038
6	-0.542	11.701	3.365	12.364
7	-1.206	12.729	-10.406	13.210
8	0.747	13.953	1.283	15.228
9	-40.959	38.210	-42.013	39.819
10	1.067	2.773	0.003	2.388

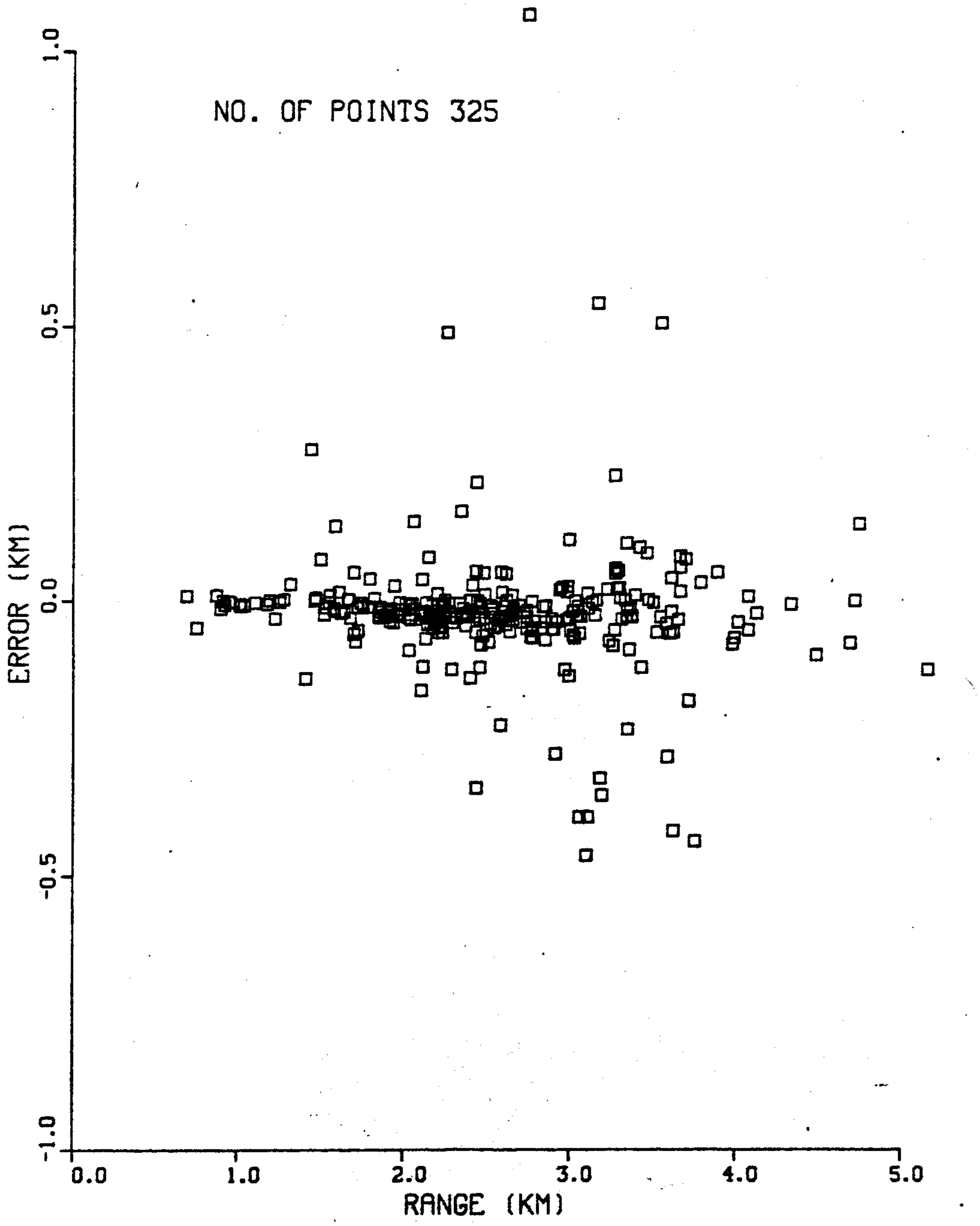

FIG. E.1. ERRORS IN RANGE FROM VERTICAL BEARINGS AT SOBERANES SITE IN 1984 AS A FUNCTION OF RANGE.

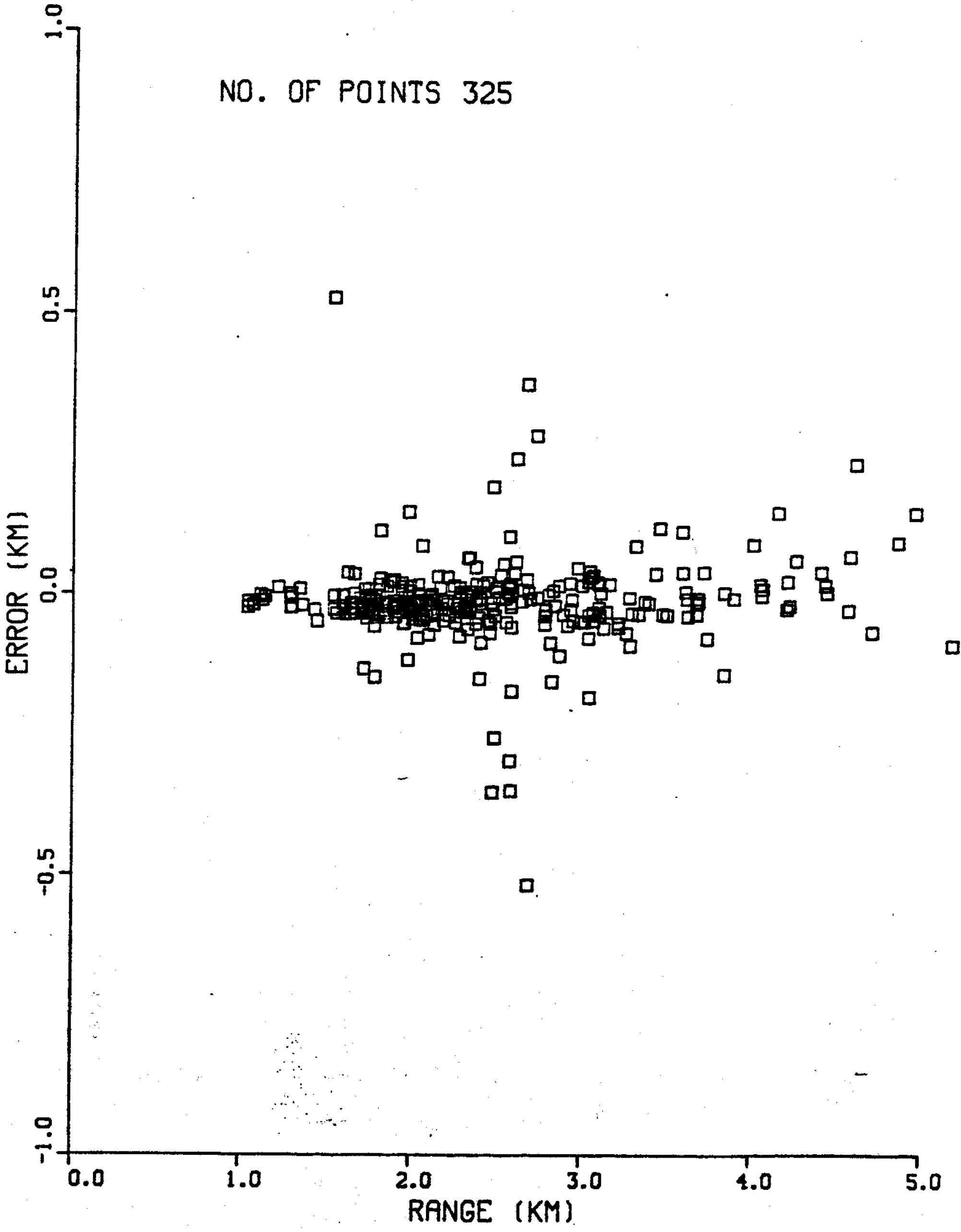

FIG. E.2. ERRORS IN RANGE FROM VERTICAL BEARINGS AT NORTH SITE IN 1984 AS A FUNCTION OF RANGE.

The bulk of points fall in a clear line of error less than ± 50 m out to a range of 4.0 km, and this appears to be a good working estimate of the precision of our technique.

This analysis also confirms the accuracy of the altitudes we used for the two transit sites. If measured our altitudes were too high or too low, there would be a systematic bias in error increasing further offshore or inshore as a function of range depending on whether the measured altitude was too high or too low, respectively. The absence of this bias shows our measurements of height above sea level and connection for tide were accurate.