# COORDINATED OCEAN B0TTOM SEISMOGRAPH MEASUREMENTS
# IN THE KODIAK SHELF AREA

by

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## Introduction

Many special working groups and panels have pointed out the need for measurements of sea floor accelerations caused by potentially damaging earthquakes in offshore zones of oil and gas potential. The Alaska continental shelf is currently the most important example of such a zone within U. S. Territory. There is also a need for recording microearthquakes to increase the data set available for earthquake risk assessment and to delineate active faults that may transect zones of economic interest.

A low-cost seismic station for recording earthquakes on the sea floor has been developed at the University of Texas, Marine Science Institute, and has been used extensively over the past four years.

A system for recording strong-motions of the sea floor caused by earthquakes has also been developed and field tested as part of a collaborative effort between Exxon Production Research Company (EPR), the University of Texas-Marine Science Institute (UT-MSI), and the National Oceanic and Atmospheric Administration (NOAA). Operational systems can be constructed at relatively low-cost (less than $10,000 per station), can operate on the sea floor for one year or more with minor modification, and can be deployed and retrieved from relatively small vessels. A recoverable preload system designed to imbed a set of vertical spikes attached to the base of the frame that serves as a pier for the ocean bottom station, has also been developed. Theoretical and experimental studies show that the ocean bottom station is capable of recording ground accelerations of up to about 1 g, in the 0.1 Hz to 10 Hz frequency band, with good fidelity (Steinmetz et al., 1979).

Field operations using a combination of microearthquake and strong-motion seismograph stations during the first year of the present program (1979-1980), and initial results, are described in the following sections of this report.

## History of Program to Date

The design and testing of various types of ocean bottom seismic (OBS) stations has been a principal activity of the University of Texas-Marine Science Institute since its beginning in 1972. In 1978, the Exxon Production Research Company (EPR) awarded a contract to MSI to begin development of a 3-axis digital system capable of recording strong-motions of the sea floor. Members of the EPR research staff undertook the task of investigating techniques for obtaining adequate ground coupling in marine sediments.

Three prototype stations were installed off Kodiak, Alaska in the fall of 1978. These were successfully recalled by acoustic command after about 1 month of operation. Five additional strong-motion stations were constructed during the spring of 1979 with the financial support of Exxon. During the following June (1979), under the sponsorship of the NOAA/OCSEAP program, all of the 8 strong-motion OBS stations, and 11 high-gain (microearthquake) OBS stations were deployed off Kodiak Island from the NOAA ship DISCOVERER at locations shown in Figure 1. Three additional strong-motion stations, modified for land use, were installed on neighboring islands in close proximity to the offshore network. The stations of the high-gain network were recovered in August of 1979. Several of the strong-

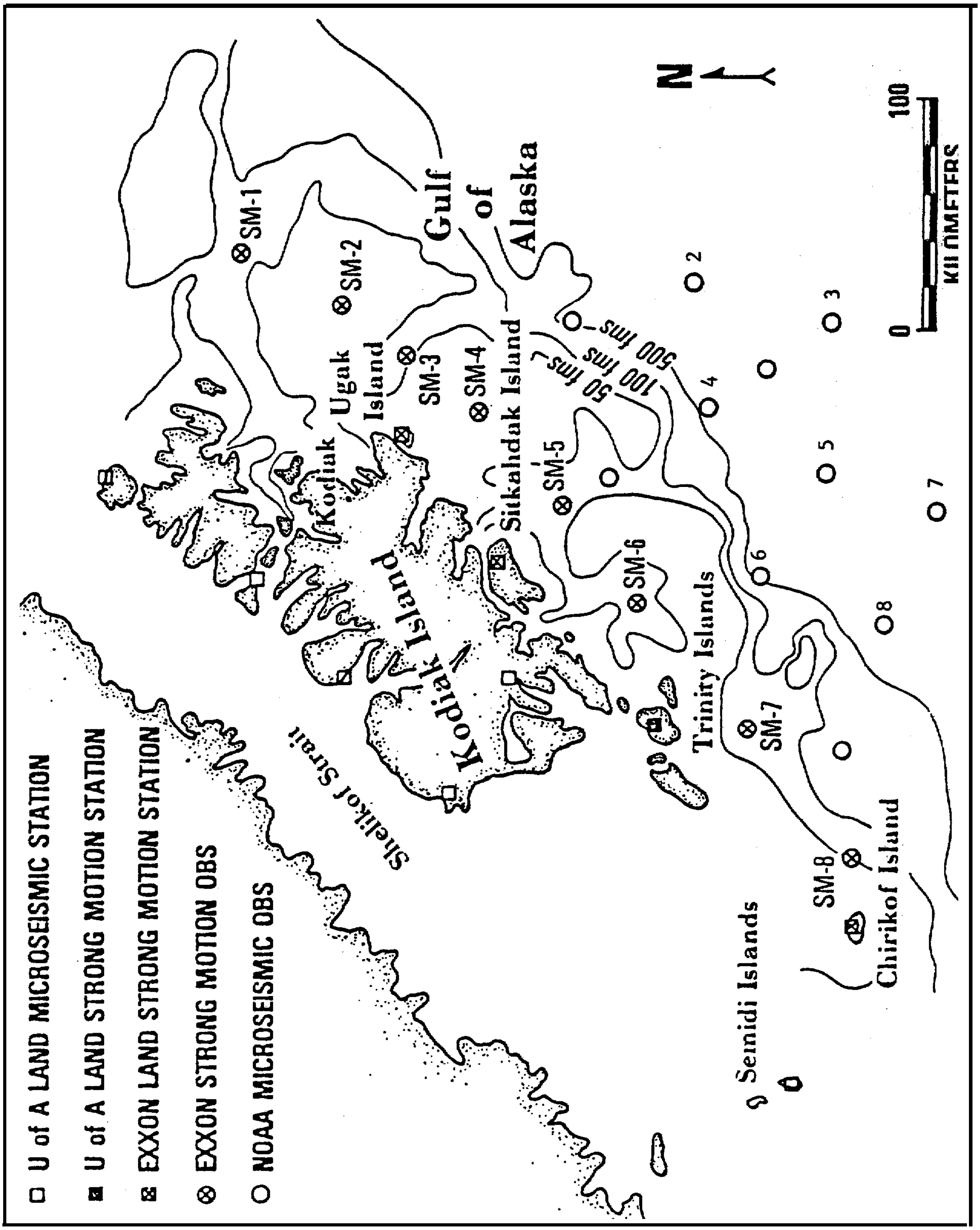



Figure 1

Figure 1. Map showing locations of ocean bottom seismic stations installed in June, 1979. Strong-motion and high-gain stations of the University of Alaska network on Kodiak and adjacent islands are also shown. Repeat installation of high-gain stations at sites marked 1-8 is proposed for the summer program of 1980.

motion stations were recovered and redeployed during cruises in August and October, 1979. In the October exercise, 4 strong-motion stations were left on bottom to be recovered the following spring. These were recovered in March of 1980. Thus, 12 successful recoveries of strong-motion station have been achieved out of 15 attempts. Of the three losses, 2 were sustained at sites with hard" clay sediments. Damage to the stations on impact is suspected as the cause of their failure to return to the surface. Two premature releases have occurred, and this may account for the disappearance of the third station.

Despite these losses, we now feel that enough progress has been made toward understanding and eliminating design defects, that we can enter the program planned for 1980-81 with a high level of confidence.

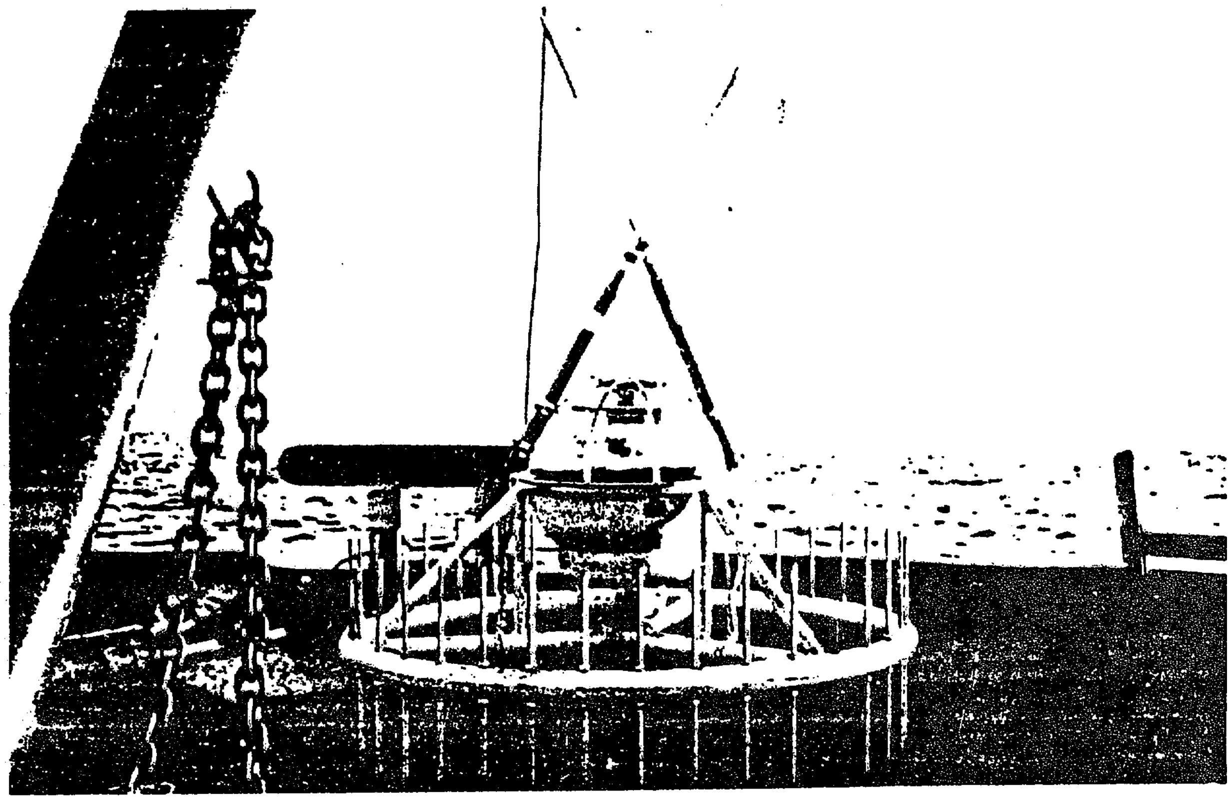
## Brief Description of Instrumentation

The UT/Exxon strong-motion OBS is described in recent papers by Steinmetz et al. (1979, 1980). The high-gain station used in refraction studies and normal earthquake recording has been described by Latham et al. (1978).

We wish to emphasize at this point that the primary goals of the design effort for the strong-motion OBS stations were threefold: (1) to keep system cost low enough that deployment of extensive networks of stations would be feasible; (2) to minimize power drain to the point that operational life times of one year or more could be achieved on internal battery supplies; and (3) to keep size and weight to levels that would permit the use of small vessels in the deployment and retrieval operations. The first goal is paramount. It is evident that the probability of acquiring useful strong-motion data will increase with the number of stations deployed. Also, since the radiation pattern from an earthquake fccus is not uniform, measurements over a range of distances and azimuths are needed to properly define the spatial distribution of ground accelerations related to a given earthquake.

An ocean bottom seismometer station, in sea floor configuration, is shown in Figure 2. The complete system ready for deployment, including the preload system described below, is shown in Figure 3. The primary system elements are shown schematically in Figure 4.

The circular, spiked frame is 1.2 m in diameter and the complete station without preload, weighs 81.6 kg in air. The electronic subsystems, tape recorder, battery pack, and triaxial geophone accelerometers, are contained in a single, spherical pressure vessel made of a high strength glass capable of withstanding pressures of 700 $kg/cm^2$ (10,000 psi). The sphere is 43 cm in diameter and has a net positive buoyancy of 6.8 kg. The bottom hemisphere of the pressure vessel fits snugly into a molded plastic cap. Two small radio beacons, used in recovery, are mounted externally on the sphere. The geophones are mounted in the bottom of the sphere. The pressure vessel, with its plastic bottom cap, recovery radios, and internal components are retrievable and redeployable and are referred to as the return capsule. When deployed, the return capsule is firmly attached to the circular steel frame footing by a spring-loaded loop of stainless steel wire, as shown schematically in Figure 4. This wire is electrolytically dissolved on acoustic command (or clock timer) releasing the return capsule which then ascends to the ocean surface from its own positive buoyancy. The new mechanical link provides enough tension between the instrument package and support frame that 1.0 g of ground acceleration in both the vertical and horizontal directions can be experienced without relative movement between the frame and package.



STRONG MOTION OCEAN BOTTOM SEISMOMETER

Figure 2. A strong-motion seismic station as it would appear on the sea floor.

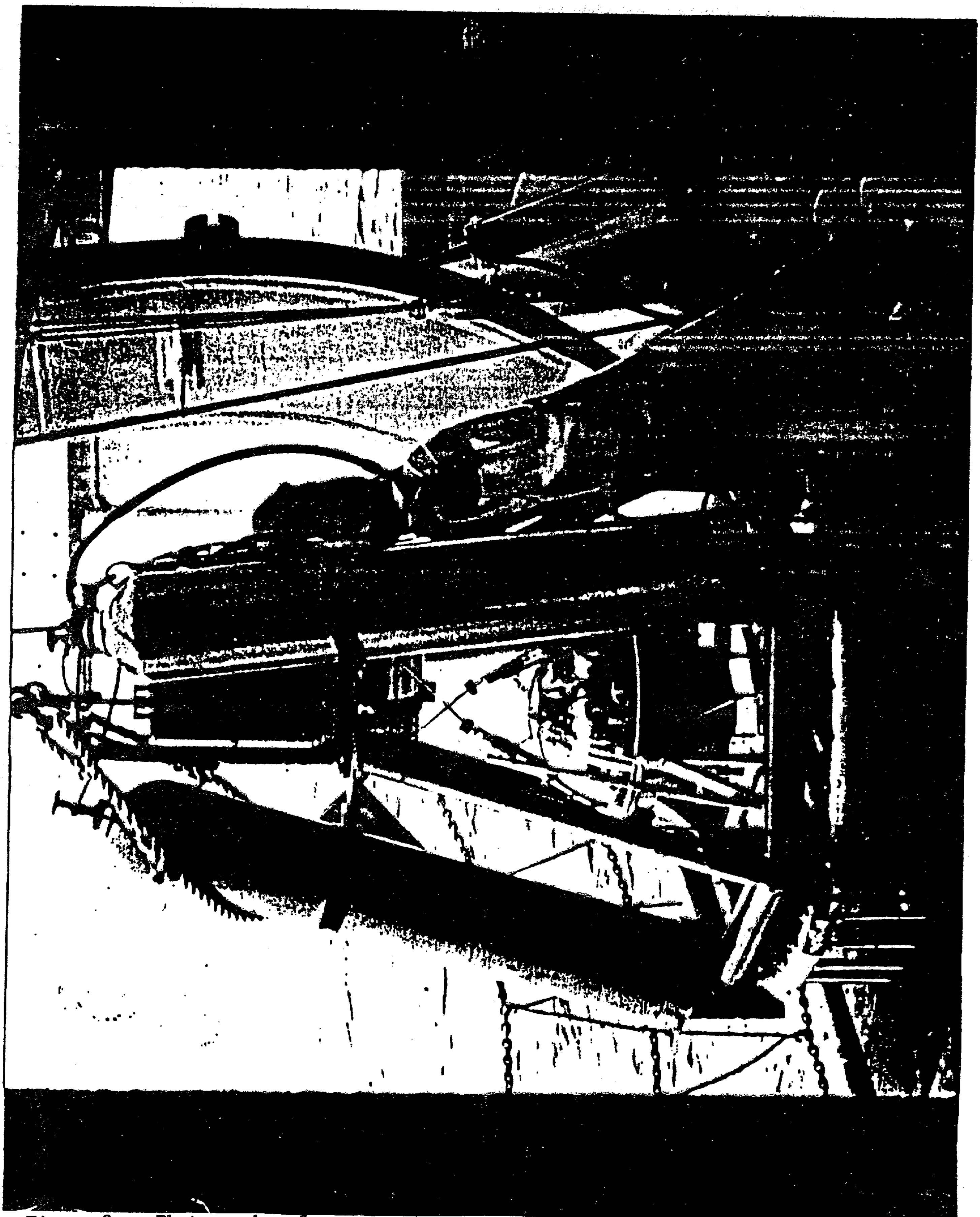


Figure 3. Photograph of a strong-motion seismic station, with preload system, prepared for launch.

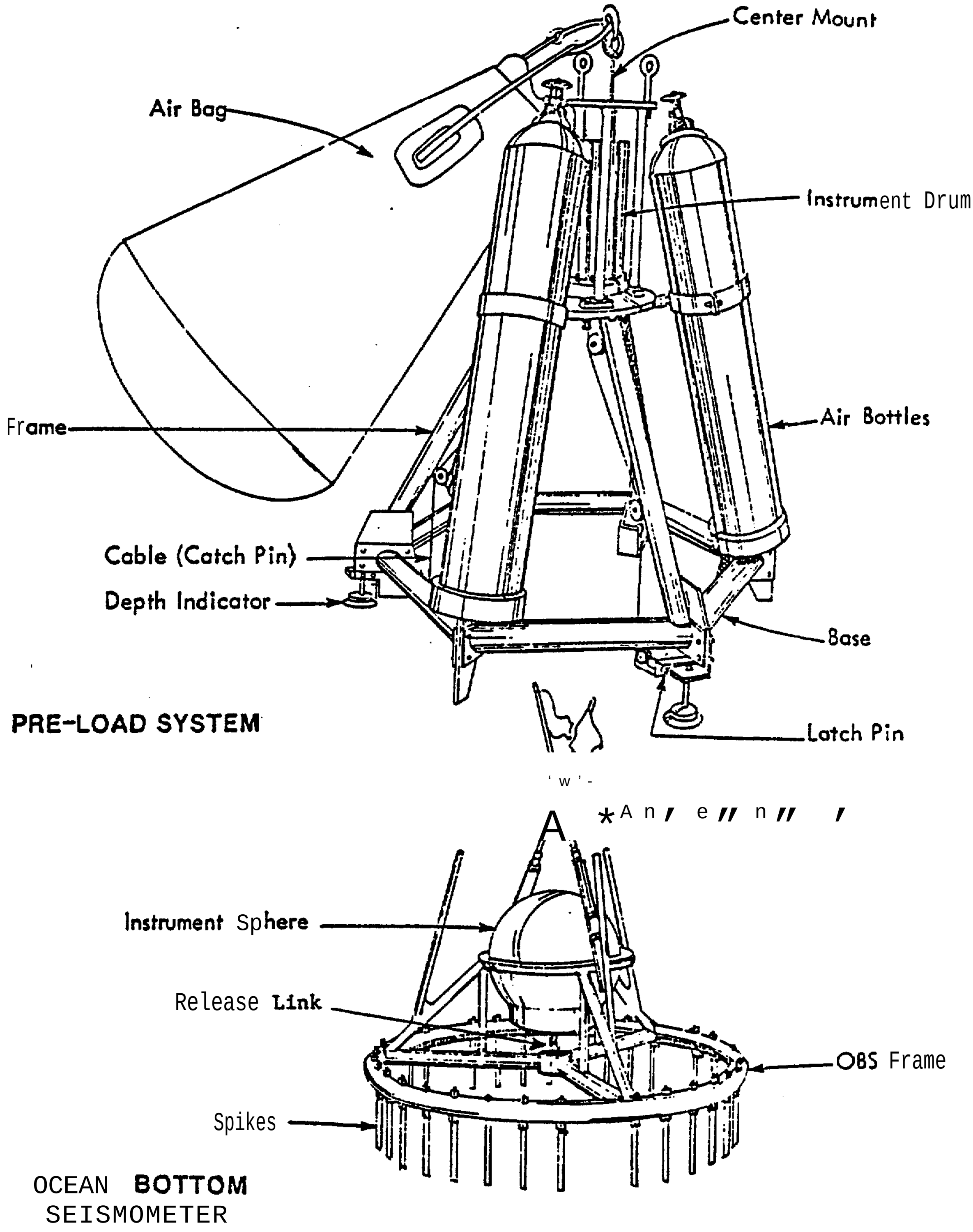



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PLATE 1

Figure 4. Sketch of the major elements of the strong-motion ocean bottom seismography system.

Up to 33 adjustable spikes are affixed to the base ring to penetrate the sea floor. A large 680 kg tripod device; used as a preload, fits over the sphere with its base locking into the base of the steel footing. This is used to increase the terminal free fall velocity and mass of the system to achieve full penetration and seating of the footing into the sea floor. The preload is decoupled and retrieved after sensor deployment to avoid the undesirable dynamic effects of the additional preload mass. Following bottom impact, a timer initiates release of gas into the air bag shown in Figure 4. High pressure air displaces water within the bag, increasing buoyancy. When sufficient lift is achieved, the preload frame is decoupled and floats to the surface. A gyrocompass, attached to the preload frame, records the azimuthal orientation of the horizontal component sensors. A more detailed discussion of this device is given by Steinmetz et al. (1980).

The electronics subsystem of the SM-OBS consists of gain-ranging sensor amplifiers, shaping filters to give geophone outputs flat to ground acceleration, analog-to-digital converter, and two microprocessors with memory to perform the functions of event detection, data transfer to magnetic tape in digital format, and tape recorder control. The recording system is "triggered" on when the signal amplitude from any of the three geophones exceeds a preset acceleration threshold (usually $10^{-3}$ g). First data recorded corresponds to data entered into memory 5 sec before the trigger instant. This ensures preservation of the onset of the signal that produced the trigger. Data will continue to be recorded until the acceleration threshold is not exceeded in any 5-see time-window. A crystal controlled clock provides time words incorporated into the header of each recorded data block. Date/time groups are entered into memory and compared with clock time to initiate such functions as system turnon, activation of the transponder for possible recall by acoustic command, and release of the return capsule at the preset clock release time. A second, less accurate clock, operating on an independent battery supply, is also set to the desired release time as a backup to the master clock. The overall system dynamic range is 96 db.

Every effort has been made to minimize system power drain. At present, a station can operate on the sea floor for about 6 months using 22 D-size lithium cells mounted within the pressure vessel. By screening components for low power consumption and increasing the number of cells in the battery pack, we expect to obtain a useful lifetime of one year.

A major concern in making strong-motion measurements offshore is the dynamic behavior of the soil-instrument system. Because ocean bottom soils near the mudline can be very soft, achievement of adequate ground coupling for strong-motion measurements is a significant design problem. An extensive experimental and analytical study of this problem (see Steinmetz et al., 1979) was conducted to insure that the fidelity of the measurements were acceptable at accelerations of up to 1.0 g over the frequency range of 0.1 Hz to 10 Hz. Based on this study, it was concluded that the present system responds accurately in very soft, cohesive soils with shear strengths on the order of 490 to 975 $kg/m^2$ (100 to 200 psf). Having shown this, the accuracy of the system in stiffer soils is assured if adequate penetration of the base spikes can be achieved. The study did point out, however, that it is necessary to insure that the footing is well seated so that the base ring maintains full contact with the soil. This led to the decision to develop a means for preloading the footing to insure adequate seating; without adding permanently to the system mass .

Brief Summary of Results to Date

The initial 6-week period of operation of the high-gain OBS network (June-August, 1979, 11 stations) was one of unusual quiescence off Kodiak. Also, faulty tape recorder operation resulted in partial loss of data from 5 of the high-gain stations. Nevertheless, sixty earthquakes were recorded by two or more OBS stations. A typical seismogram from a local earthquake recorded by one of the high-gain OBS stations is shown in Figure 5. Arrival times for all earthquake phases identified in the OBS records were transmitted to Dr. Hans Pulpan for comparison with readings from the University of Alaska land station network. Thus far, it has been possible to locate 89 earthquakes using data from the combined onshore-offshore network. The preliminary epicenter locations for these earthquakes are shown in Figure 6. The focal depths range from less than 10 km to about 200 km. Much of the activity during the period of the 1979 experiment was located beneath the Lower Cook Inlet. The hypocenters of the detected events are concentrated along the inclined (Benioff) zone associated with the subduction of the Pacific plate beneath western Alaska.

Since we plan to repeat the microearthquakes experiment off Kodiak during the summer of 1980, we defer further comment on the seismicity of the region until the much larger data set that we anticipate, can be assembled. We point out, however, that the location accuracy, particularly depth estimates, for the earthquakes that occurred between Kodiak and the trench axis during the 1979 experiment is much greater than would have been possible without the OBS network.

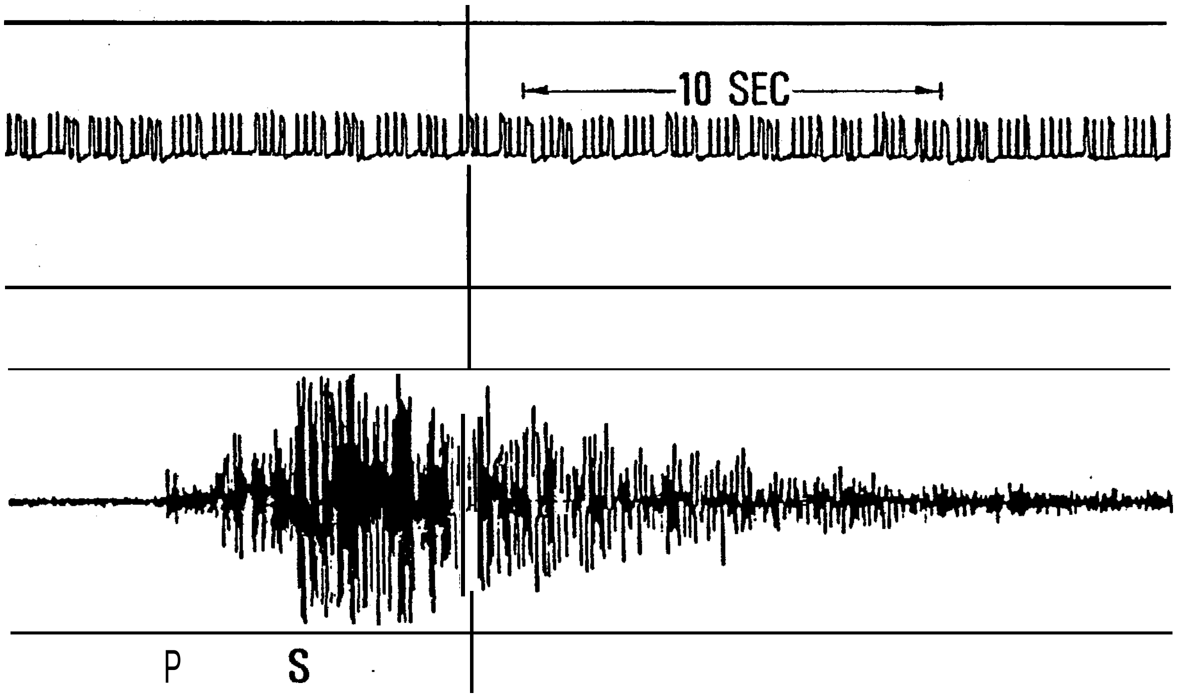


Figure 5. Typical earthquake recorded from high-gain OBS #5 off Kodiak. Identified arrivals are the **compressional** wave (P) and the shear wave (S).

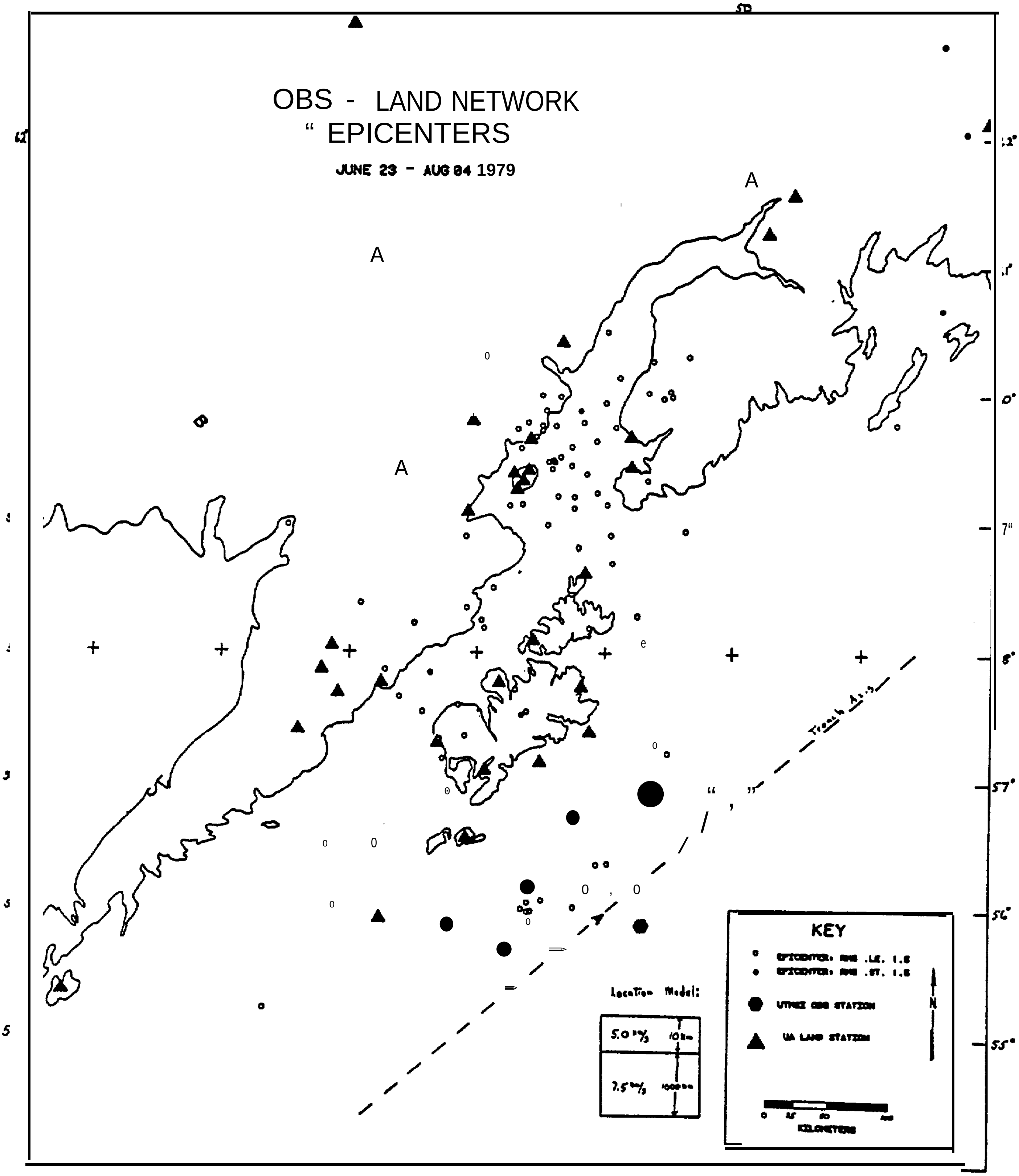


Figure 6. Locations of epicenters of earthquakes recorded by the combined land and ocean bottom seismic network during the summer of 1979.

Concerning the strong-motion portion of the program, no earthquakes large enough to produce meaningful strong-motion data have occurred in the Kodiak zone since monitoring operations were begun under this program.

An important new research opportunity may emerge from the data set obtained from the high-gain OBS stations off Kodiak during 1979. For years we have been puzzled as to the origin of a set of distinctive seismic signals that have been recorded in every OBS experiment in widely ranging locations. These were much more numerous in the Kodiak experiment than had previously been encountered. The Kodiak experiment was the first one in which we deployed the ocean bottom stations over a large range of water depths. A plot of the daily rate of occurrence of these events, versus station depth, is shown in Figure 7. It is evident that the rate of occurrence diminishes rapidly with increasing depth until a depth of about 1500 m is reached. Also, the sources are local, i.e., a given event is never recorded at more than one station. Hence, the distribution of sources with depth is as shown in Figure 7. Finally, these same signals are recorded in zones of no known seismic activity, e.g., the Gulf of Mexico. Taken together, these facts are almost indisputable evidence that the strange events are of biological origin. If so, the important point of Figure 7, is that the activity does not diminish to zero at abyssal depths, but remains at a fairly high level (14 to 35 events per day). By adding a bottom camera capable of imaging the OBS station at the time of each trigger, we may have discovered a new method of surveying benthic sea life.

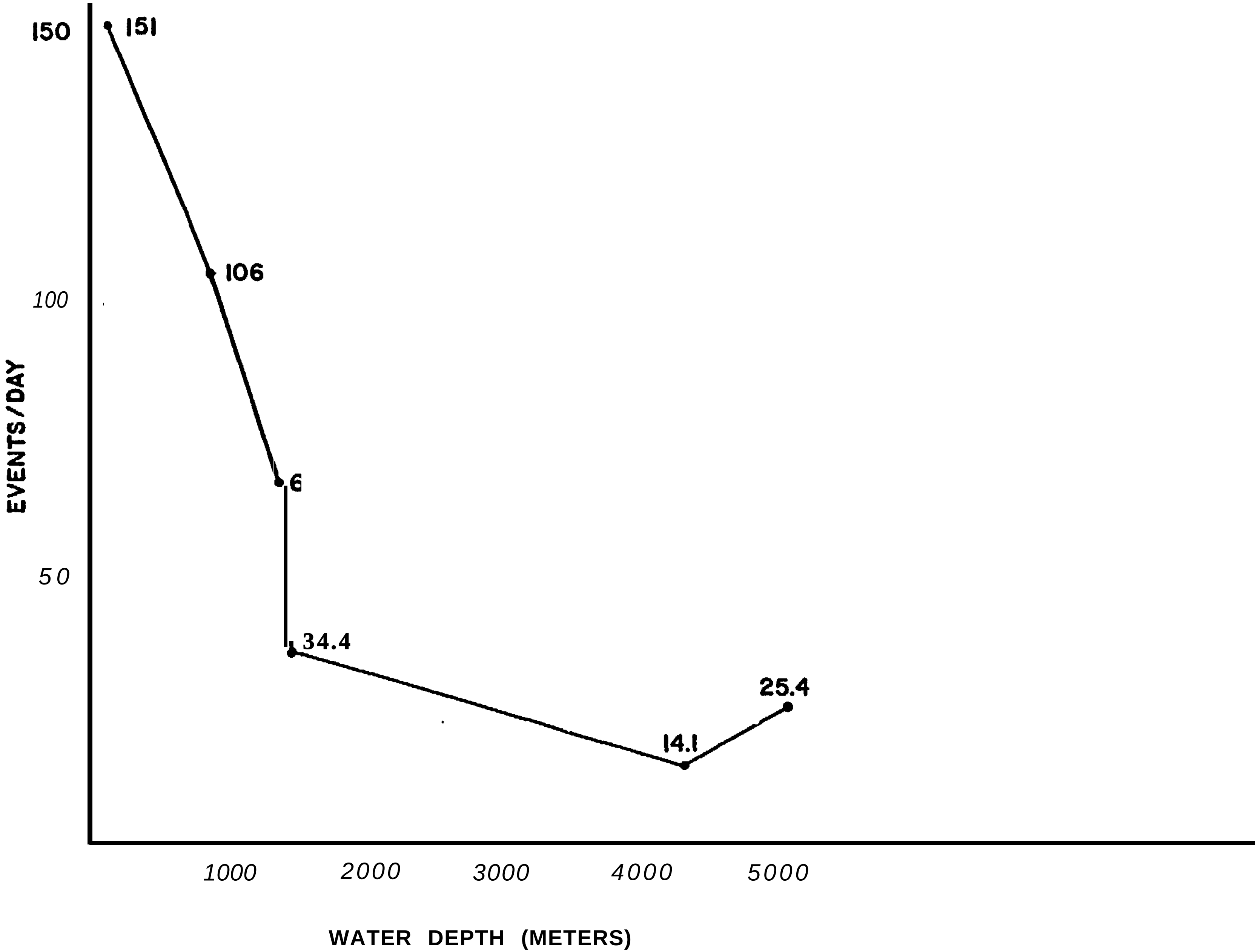


Figure 7. Number of events believed to be of biological origin detected by various high-gain OBS stations versus station depth.

Field Operations and Construction Plans

1. Strong-motion measurements. Industry support has been obtained for the construction of 12 additional strong-motion stations over the next two years. Briefly, our present plan for field operations and construction is the following:

(a) Deploy the four existing stations-in the Kodiak shelf zone in June, 1980.

(b) Construct six additional stations. Deploy these new stations plus the balance of the present stations, at the approximate locations shown in Figure 8, in September, 1980. Recover these stations in June, 1981.

(c) Construct six additional stations. Deploy these new stations plus the balance of the previously constructed stations at the earlier sites, and install at least 1 station at a new site in Norton Sound, in June-July, 1981. Recover and redeploy all stations in June-July, 1982.

The selection of sites for installation of strong-motion stations proposed here is based upon a combination of factors including: (1) regional seismicity, (2) the locations of sedimentary basins of possible interest to the oil industry, and (3) the need to obtain data that will permit testing and refinement of the earthquake risk assessments derived in the Offshore Alaska Seismic Exposure Study (OASES).

Obviously, the probability of obtaining strong-motion data is highest within the belts of highest seismicity. However, site specific data, i.e measurements obtained on the specific sediment types to be encountered in future production operations, is also required. Finally, we prefer a combination of sites that will record signals from earthquake sources that follow raypaths that traverse the major structural elements of the offshore Alaska provinces.

As shown in Figure 8, the seismically active belt of greatest concern extends along the Aleutian Trench, past Kodiak Island, and into interior Alaska along a N-S trend. A weaker trend extends in an E-W direction into Norton Sound. Two "gaps" in seismic activity have been identified within the major seismic belt: one in the northern Gulf of Alaska and one centered on the Shumagin Islands. The term seismic gap has taken on a variety of meanings in recent scientific literature. Here, we mean the region bordered by major rupture zones (as defined by aftershocks) of earlier earthquakes. Presumably, these gaps are the most likely candidates for future large earthquakes: although, this point is not well established.

During the first year of the program, we propose to concentrate the strong-motion stations along the OCS regions of the western Gulf of Alaska and Aleutian Islands, with several stations located behind the Island Arc in the Bristol and St. George Basins of the Bering Sea. A suggested distribution is shown in Figure 9. A total of ten stations is indicated in the network. This assumes that we have 4 stations remaining after recovery in October, 1980 of the network now operating off Kodiak, and that six additional stations can be constructed during the summer of 1980. Note that we have included stations in the vicinity of the Shumagin Gap.

In the second and following years of the program, we propose to extend the network northward with at least one station operating in Norton Sound. The stations of the proposed network span a large segment of the 'Aleutian seismic belt. In the event of a large earthquake within this belt, the raypaths of recorded signals will traverse the major structural

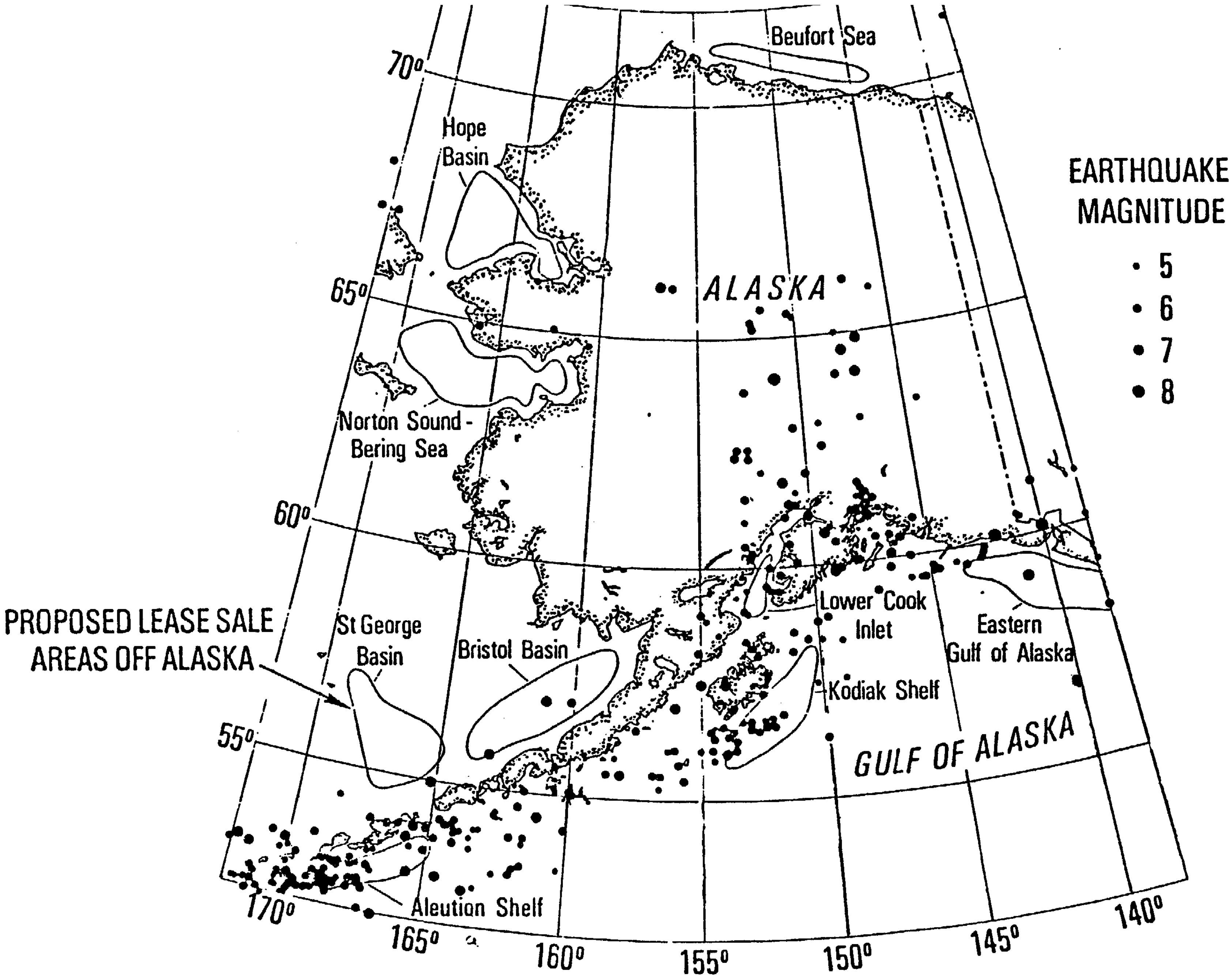


Figure 9. Map showing recommended distribution of an initial 10-station network of strong-motion OBS stations. One or two additional stations would be placed in Norton Sound during the second and

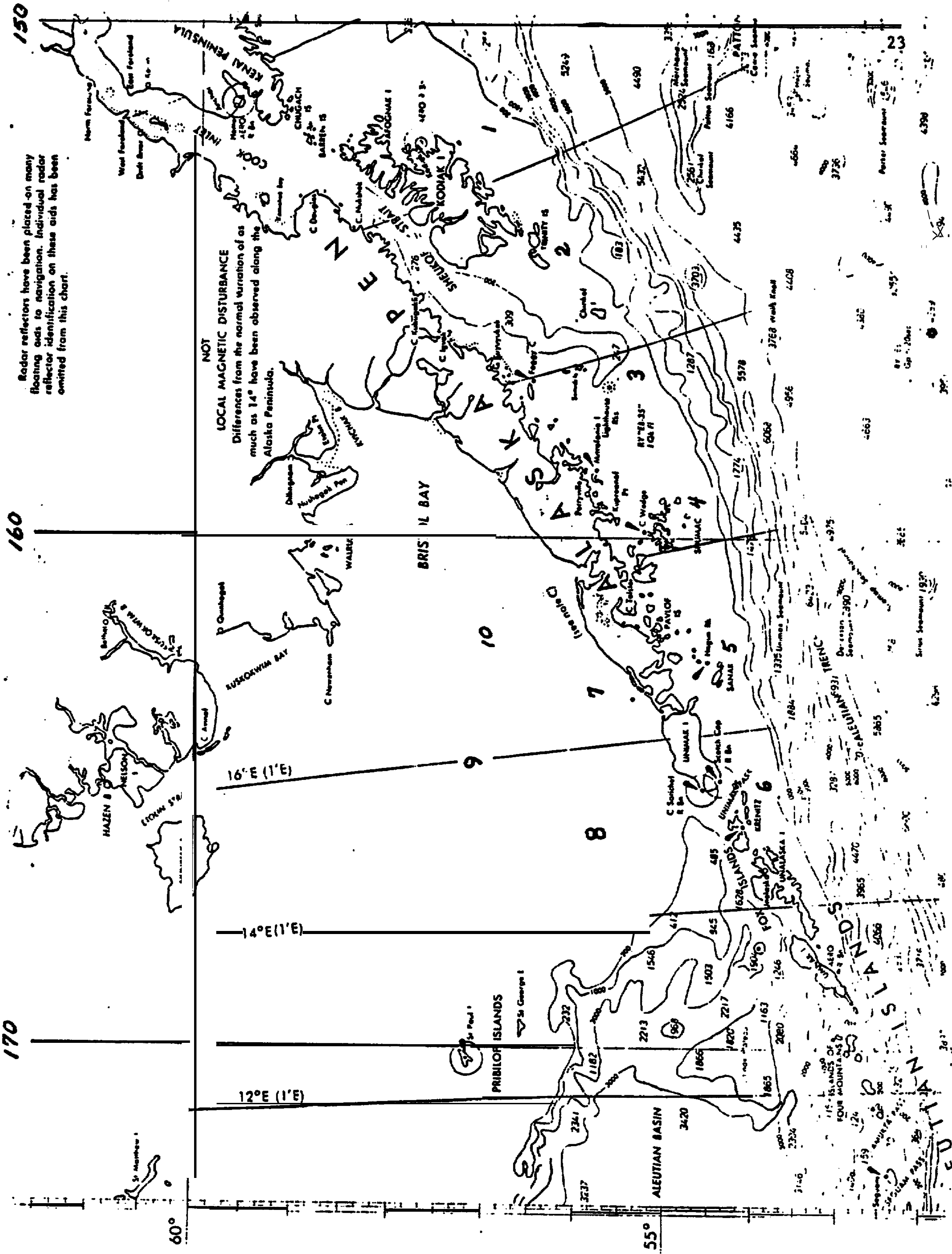


Figure 8. Map showing the distribution of earthquakes of magnitude greater than 5 that have occurred in the Alaska zone during the past decade. Major sedimentary basins of the region are also indicated.

elements of the region: (1) forearc shelf, (2) island ridge, and (3) backarc basin. These data will contribute importantly to the refinement of model parameters, particularly attenuation, assumed in the OASES study. In addition, they will provide the first records of the actual waveforms of sea bottom accelerations.

We wish to point out that site surveys" (precision depth profile and sonobuoy refraction lines) and sediment cores will be needed to properly interpret any strong-motion data eventually obtained. We propose that such surveys be deferred until useful strong-motion data are obtained at a given site.

2. Microearthquake measurements. Owing to the limited success of the microearthquake measurements program in 1979, we plan to return to the Kodiak zone during the summer of 1980 with 8 of our high-gain OBS stations to repeat the experiment. Suggested station locations are numbered 1-8 in Figure 1. Three additional high-gain stations will be constructed during 1980 to increase the total number available to thirteen.

Improvements in station design are proposed in two areas: (1) Improve tape recorder reliability by installing new drive motors, and eliminating the optical end of tape sensor which has failed to operate properly in many cases; and (2) increase the reliability of the acoustic recall system so that it can serve as the primary recovery method.

3. Construction of six strong-motion stations for use on land. six additional strong-motion stations for use on land will be constructed in 1980. These will be installed and operated by personnel of the University of Alaska as part of their existing network of radio-telemetering seismic stations.

Data Processing and Analysis Plans

1. Microearthquake (high gain OBS) data analysis. A series of tasks will be accomplished jointly with the University of Alaska. (a) First we will generate a list of readings of times of first arrivals for all events recorded on OBS playouts. (b) These data will be used by the University of Alaska in their standard quarterly bulletin calculations. The University of Alaska presently has the capability of producing a seismological bulletin with earthquake origin times, locations, depths, magnitudes and statistical parameters about one month after receipt of data. Their existing system will be able to absorb the additional station locations and additional arrival time readings without serious impact. A subset of well-recorded earthquakes from the final bulletin list will be selected for (c) focal mechanism studies, and (d) crust-mantle structural analyses. Secondary phases and frequency content will be analyzed. It seems likely that progress can be made in identifying tectonic units characterized by particular seismic velocities, in elastic absorption, and focal mechanism patterns. These problems will be of interest to both groups, and copies of original data on these events will be exchanged. (e) The same data will also be of use in more detailed studies of wave propagation characteristics over the joint network. Surface wave data will be studied by normal mode methods, and a comprehensive effort will be made to understand the details of generation and propagation of waves in these well-recorded events. In particular, short period surface waves generated by moderate to large earthquakes in the region will provide waveforms which can be interpreted in terms of rigidity profiles for the upper sedimentary layers of the continental shelf. These results will ultimately be useful to platform design engineers.

Seismic bulletins will be distributed as at present by the University of Alaska.

2. Strong-motion data analysis. Strong-motion data will be reformatted to produce computer compatible 9-track data tapes. These, along with analog playouts and supporting documentation (locations, calibrations, available information on sub-bottom structure, and source parameters) will be distributed to NOAA and the industrial sponsors.

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