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Detection and Location of Earthquakes in the Central Aleutian Subduction Zone Using Island and Ocean Bottom Seismograph Stations

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A network of eight University of Texas ocean bottom seismographs (OBS) operated for 6 weeks in 1978 about 50 km offshore of Adak Island, Alaska, and nearby islands. In 1979 a similar network of nine instruments was deployed for 7 weeks farther offshore within and up to 100 km seaward of the Aleutian trench. For shallow earthquakes on the outer trench slope, for shallow earthquakes in the thrust zone, and for intermediate-depth events we have analyzed the OBS and island-based network data and evaluated the island network's capabilities for earthquake detection and location and for focal mechanism determination. Our three major conclusions are presented. The first concerns shallow earthquakes on the outer trench slope. In 1979 about 30 earthquakes occurred within the Aleutian trench and up to 60 km seaward of the trench axis. The island network located none of these events and detected *P* phases for only three of them. Ray tracing shows that the islands lie in a geometric shadow zone for events on the outer trench slope. The best located events are shallower than 20 km and exhibit first motions consistent with normal faulting. Several authors have suggested that these events are caused by bending of the oceanic lithosphere at the outer rise prior to subduction. If so, then the event locations reported here show that the bending stresses exceed the strength of lithosphere only in a narrow zone extending about 10 km landward and 60 km seaward of the trench axis. The second conclusion concerns shallow earthquakes in the thrust zone. Epicenters determined by island stations alone are virtually identical to epicenters determined using data from both island and OBS stations. The locations are similar whether they are determined using flat-layered velocity models or a more realistic model and a ray-tracing scheme. Nearly all the earthquakes detected by the OBS network are also recorded by island stations. Three composite focal mechanism solutions that use data from both island and OBS stations have *P* axes parallel to the direction of plate convergence. The thrust zone events are separated from events on the outer trench slope by a gap in seismicity about 50 km wide situated on the inner trench slope. The third conclusion concerns earthquakes deeper than 70 km. Epicenters determined using island network stations alone lie 10 to 80 km south of those determined using OBS and island stations, with the differences between epicenters depending both on event depth and on the velocity model used. Ray tracing with a realistic velocity model shows that for events at 200-km depth locations are about 80 km north of locations determined from island data alone. These results do not support the observed increase in the dip of the Benioff zone beneath 100-km depth that is suggested by locations determined from island network data alone using a flat-layered velocity model.

INTRODUCTION

Estimating earthquake locations in island arcs is complicated by several factors. Both local and teleseismic locations are affected by the heterogeneity of the lithosphere and mantle near island arcs. The seismic velocity is higher in subducted lithosphere than in the surrounding mantle [e.g., *Mitronovas and Isacks,* 1971; *Suyehiro and Sacks,* 1979; *Huppert and Frohlich,* 1981], while the velocity in the mantle above the subducted lithosphere is somewhat lower [e.g., *Ishida,* 1970; *Frohlich and Barazangi,* 1980] than the earth's 'average' velocity as represented by the model of *Herrin et al.* [1968]. Attenuation of seismic waves is also highly variable, depending on whether they travel within or above the subducted lithosphere [e.g., *Barazangi and Isacks,* 1971; *Grow and Qamar,* 1973; *Barazangi et al.,* 1975]. Near the earth's surface, sediment thickness and rock type differ considerably between the volcanic islands, the inner trench slope, the trench, the outer trench walls, and the outer rise [e.g., *Grow,* 1973].

In addition, placing seismic stations only on the islands produces a linear station geometry with poor ability to resolve certain location variables. For example, in an arc that extends mostly east to west such as the Aleutians, an island network may have poor depth control for shallow events and poor north-south control for deeper events.

In the central Aleutians, differences in the shape and orientation of the Benioff zone have been reported by investigators using teleseismic and local data. For example, *Barazangi and Isacks* [1979] found that the dip of the Benioff zone determined from a local island network [e.g., *Engdahl and Scholz,* 1977] was steeper than that determined from teleseismic locations. Local station network locations also show an abrupt kink or change in dip of the Benioff zone at about 100-km depth [*Engdahl,* 1977] which is not evident in teleseismic locations [*Barazangi and Isacks,* 1979]. As has been suggested by *Davies and House* [1979], we shall show that this feature is an artifact caused by the large seismic velocity contrast between the subducted lithosphere and the material above it.

Several studies using seismic ray-tracing methods [e.g., *Davies and Julian,* 1972; *Jacob,* 1972; *Engdahl et al.,* 1977; *Fujita et al.,* 1981] have confirmed that both teleseismic and

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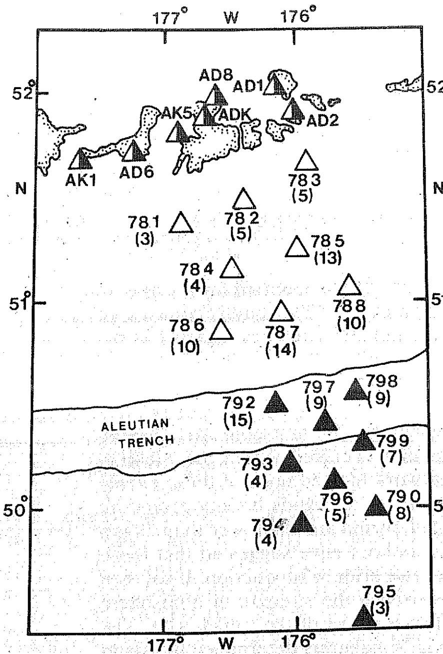

Fig. 1. Locations of seismic stations during the 1978 and 1979 experiments. Next to the station locations are the station name and, for the OBS stations (in parentheses), the number of events per day recorded by the station. Key: half-solid triangle, island station; open triangle, 1978 OBS station; solid triangle, 1979 OBS station. The contour lines delineating the Aleutian trench are at 3500-fathoms depth.

local locations are strongly influenced by the large velocity variations in the subducted region and also that refraction can produce 'shadow zones' near island arcs, where arrivals are weak or absent. These studies also show that subducting lithosphere can significantly affect the takeoff angles of earthquake rays and thus cause systematic bias in determined earthquake focal mechanisms.

This paper discusses a different method for improving the location of events, namely, the deployment of ocean bottom seismographs (OBS) seaward of the island stations. Numerous modeling studies have shown that reliable epicenters generally can be found for earthquakes within the boundaries of a local network [e.g., *Peters,* 1973; *Buland,* 1976]. Since OBS instruments can be deployed in any desired station geometry, much more accurate locations can be obtained with them than with an island network alone. In addition, OBS networks may detect events which the land network cannot because of their small magnitude or because of their location in a 'shadow zone.'

The OBS and island networks provide an especially favorable station geometry for locating events near the trench and in the zone of underthrusting landward of the trench. For this reason, the epicenters reported in this paper are probably located more accurately than any events near deep ocean trenches elsewhere in the world. A preliminary analysis of the central Aleutian OBS experiments described in this paper has been reported in an earlier publication [*Frohlich et al.,* 1980]. Also, *S-P* intervals from these OBS stations have been analyzed in a previous publication [*Chen et al.,* 1982] focusing on activity above and landward of the underthrusting zone, in or near the so-called 'accretionary prism.'

Another objective of this study is to augment available information on the focal mechanisms of earthquakes near Adak. While focal mechanism solutions have been determined teleseismically for a number of larger earthquakes in the central Aleutians [*Stauder,* 1968], the island network gives coverage of only a limited part of the focal sphere, so that the determination of focal mechanisms for smaller earthquakes recorded only by the island network is very difficult. In the present study we report composite focal mechanisms which include data from OBS stations and for which we have used ray tracing to evaluate systematic bias caused by island arc structure.

EXPERIMENTAL METHODS

Description of Field Program

The field program included two separate deployments of OBS instruments. In 1978, nine OBS units were deployed by the NOAA ship *Rainier* to begin operation on June 21, and eight units were recovered successfully by the NOAA ship *Discoverer* early in August (Figure 1 and Table 1). In 1979, eleven OBS units were deployed by the *Discoverer* to begin operating on April 29. Although all eleven units were recovered successfully by the *Discoverer* on June 14, only nine units produced usable data (Figure 1 and Table 1). The OBS unit at site 79-2 in Table 1 operated in and was recovered from a depth of 7112 m below sea level. No University of Texas OBS had previously been operated at this great a depth. The OBS units used in these experiments are similar to those described in detail by *Latham et al.* [1978].

The OBS clocks are compared to WWV before deployment and after recovery, and the clock drift is generally less than about 10 s per month. Because the ocean bottom is at very nearly a constant temperature over the course of a typical experiment, phase arrival times are calculated assuming a constant drift rate. The calculated times are considered to be accurate to better than 0.1 s.

Although the OBS units contained only one vertical component seismometer (seismometer frequency f_0 = 4.5 Hz for the 1978 study, and f_0 = 8.0 Hz for the 1979 study), each of the island stations has both an east-west and a vertical component seismometer. For this reason the *S* wave arrival times reported for the island stations are more reliable than those for the OBS stations. The Adak island station network normally includes fourteen stations; however, during the 1978 and 1979 OBS experiments, only seven stations were operational. These were ADK, AD1, AD2, AD6, AK1, AK5, and AD8. Peak magnifications of over 500,000 are obtained for these stations at a frequency of 10 Hz, and the data are telemetered to Adak Observatory and recorded there on Develocorder film.

Data Processing

For processing the OBS data, the analog information recorded on the cassette tapes is converted to digital form and then transcribed on paper records by an electrostatic plotter. *P* phases, *S* phases, and other unidentified arrivals are picked from the paper records and graded with respect to quality. Arrival times for *P* phases rating a quality Q = 1 are accurate to better than 0.1 s, whereas arrival times for Q = 4 phases may be uncertain by more than 1.0 s. When possible, the first motions are also picked and graded. Our experience indicates that while phases graded Q = 1, Q = 2, and Q = 3 provide useful information for locating events, only first motion data with a rating of Q = 1 produce consistent focal mechanisms.