

23. AIR GUN-OCEAN BOTTOM SEISMOGRAPH SEISMIC STRUCTURE ACROSS THE JAPAN TRENCH AREA¹

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ABSTRACT

A number of controlled-source seismic refraction studies using an ocean bottom seismograph (OBS) array have been made in the Japan Trench area recently. This report focuses on results from air-gun data of two experiments. The first carried out in 1981, had a 250 km-long profile along the 3000-m depth contour on the landward side of the trench. The second experiment, conducted in 1982, had a 300-km-long profile along the inner lower trench slope and also included two profiles perpendicular to the trench axis.

General features previously discovered were more firmly established by the nature of bottom measurements and the close spacing of the shots. Continental-type upper crust exists as near as 40 km landward of the trench, and a thick sedimentary, low-velocity prism underlies the inner lower trench slope.

The depths of the subducting Moho boundary are a few kilometers shallower than previously thought and dip more gently from beneath the trench axis to the continental slope break.

It is difficult to substantiate Layer 2 subduction because of its thickness and probable gradual transition to Layer 3.

INTRODUCTION

To understand the subduction geometry and the consequences of the subducting ocean crust, the lateral heterogeneity of structure down to at least 50 km beneath the eastern edge of northern Honshu, Japan, and to ~20 km on the ocean side of the Japan Trench must be investigated. Although a number of studies have been made in the area using various methods (Ludwig et al., 1966; Murauchi and Ludwig, 1980; Nagumo et al., 1980; Nasu et al., 1980; Suyehiro et al., 1981; Suyehiro, Inatani, et al., 1984; Tamano et al., 1981), the minimum required depth range has not yet been clarified nor has the coverage in space been sufficient to follow the rapid lateral change in structure. Recently OBSs (ocean bottom seismographs) have become compact and reliable instruments for data retrieval (Yamada et al., 1981). The advantage of an OBS as a signal receiver compared to other conventional instruments has been demonstrated by many researchers (e.g., Avedik and Renard, 1973; Whitmarsh and Lilwall, 1983). Thus far, a number of OBS experiments have attempted to reveal the structure down to the uppermost mantle using dynamite and/or an air gun as controlled sound sources (Asano et al., 1981; Kanazawa et al., 1983; Suyehiro et al., 1985; Suyehiro, Kanazawa, et al., 1984). The profiles in these experiments were designed to be much longer than in previous ones. The spatially dense air-gun coverage was used to map a detailed crustal structure, whereas explosion

data clarified the deeper structure outlined by the air-gun data.

This paper summarizes the results obtained so far in the area with emphasis on air gun-OBS data. A final structure model, incorporating explosion data, will be presented elsewhere.

PREVIOUS RESULTS

Ludwig and others (1966) showed, for the first time, laterally varying features in the structure across the Japan Trench. In addition, they showed that the continental structure persists seaward to within ~50 km west of the trench axis and that normal ocean crust lies eastward of the trench.

Multichannel results indicate the variability in sediment thickness and a notably thick accumulation on the continental side of the trench axis. Also, seismic reflection profiles depict at least two reflectors that can be traced across the trench; these reflectors are horizons marking the subducting ocean crust. The interval velocity between the two reflectors, the latter interpreted as the Moho boundary, is estimated to be about 6.5 km/s, from which the Layer 2 subduction cannot be substantiated (Matsuzawa et al., 1980).

Murauchi and Ludwig (1980) compiled the available seismic data and produced a vertical section across the Japan Trench. The main features shown include the continental crust, which extends to within 30 km of the trench axis in some profiles; a 7-km/s layer that exists beneath the continental slope; an implication of a three-dimensional structure, meaning that structure changes along the strike of the trench axis; and so little sediment accumulated in the sedimentary prism that an accretionary mechanism of slope evolution is unlikely.

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The above model section included the results of Asano and others (1981), who used OBSs as receivers and dynamite explosions as source along a profile extending ~300 km along the 1500-m depth contour, the first study of its kind in the area. This experiment, in contrast to other profiles (which were short but had denser shot spacing), revealed much deeper structure, probably down to ~25 km, the mantle of the subducting plate.

AIR-GUN DATA COLLECTION AND ANALYSIS

The OBS analog data consist of vertical and horizontal sensor outputs, digitized at 10-ms sampling rate with compensations for wobble and flutter. Considering the accuracy of OBS clocks, total time accuracy of a few tens of ms is achieved.

Distances are first calculated from direct water wave traveltimes and checked against LORAN-C plus NNSS readings. A linear relation between the two distances permits estimation of average water wavespeed. Final distances are obtained using this water wavespeed and the traveltimes.

Interpretations are made from the many record sections of each profile, which are produced with different gain or reduction wavespeed for better phase identification and then trace-stacked.

OCEAN DISCOVERER AND LEG 87 EXPERIMENTS

As previously stated, one must resolve structures to at least Moho depth of the subducting plate, to understand the subduction tectonics. Experiments such as that of Asano and others (1981) are helpful, but these need more detailed resolution of shallower structures if deeper structures are to be defined with more confidence. To provide such information, two experiments were conducted in 1981 and 1982 in the area east of northern Japan. Hole 584 was drilled in between the profiles of the two experiments.

Results of the 1981 Experiment

In 1981, a seismic refraction experiment was carried out east of the slope break (Suyehiro, Kanazawa, et al., 1984). Four OBSs (numbered 6, 7, 8, and 9) were laid out for a long-range refraction experiment (Fig. 1). An air gun (Bolt type 1500-C, 9 l, 100 kg/cm²) and dynamite shots were used as controlled sources spanning a distance of ~250 km along the 3000-m depth contour. The data discussed in this paper are from Legs I, II, and IV of the *Ocean Discoverer* cruise.

By use of a dense shot coverage, the experiment was designed to resolve structure down to ~30 km depth. The explosion data are now under analysis, and preliminary results from air-gun data are presented in the following paragraphs.

The air-gun signals could be observed up to a range of 50 km. Arrivals from the top sediment layer were not clear, but arrivals with apparent wavespeeds of 4.8 and 6.0 km/s were seen distinctly. On the southern side of OBS 6, an apparent wavespeed of 6.0 km/s persisted to a distance of 50 km. Later arrivals clearly seen in the horizontal component data agree with those from the vertical component data, assuming P to S conversion at the basement.

A two-dimensional ray tracing was performed to fit all the data from the three legs, producing a model of the mean structure. Beneath the sedimentary layers with wavespeeds of 1.9 and 4.8 km/s and thicknesses of 1.5

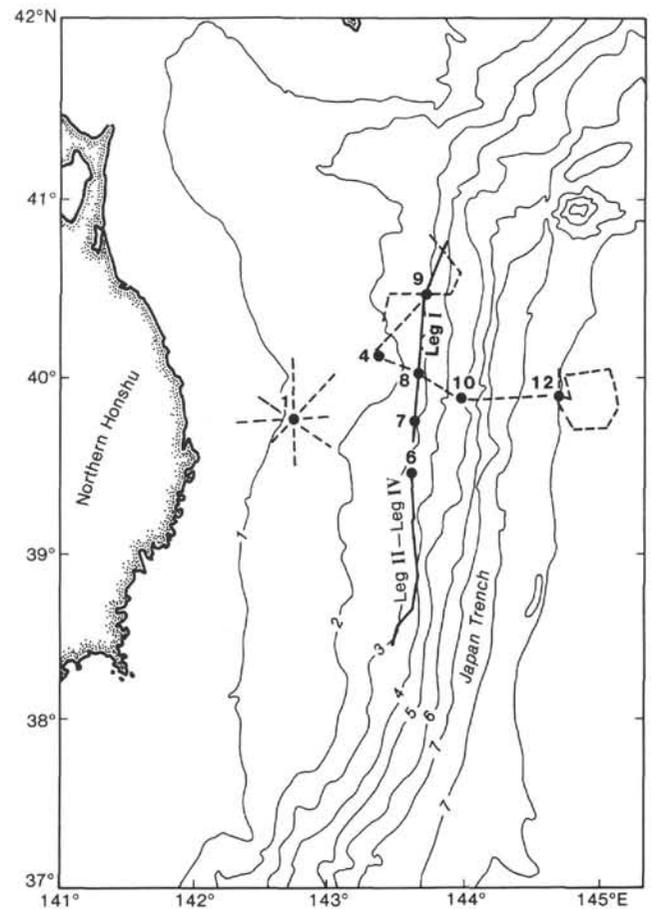


Figure 1. Map of region east of northern Honshu, Japan. Layout of 1981 seismic refraction experiment is shown. OBSs are shown by circles. Air-gun profile results shown by solid lines are discussed in this chapter. Dashed lines are air-gun profiles not treated in this chapter.

and 3.2 km, respectively, lies a layer with P wavespeed of 6.0 km/s, representative of the upper crust beneath the Japanese island arc. Air-gun data alone cannot delimit the thickness of this layer nor the lowermost crustal wavespeed, but the predominance of a 6.0-km/s layer is likely.

The data from OBS 7 suggest a PmP reflection, which would bring the Moho to about 18 km depth. Existence of a 6.7-km/s layer alters this position of the Moho little. This value will be more firmly defined by the results from dynamite explosions.

Results of the 1982 Experiment

This experiment was also planned to reveal the structure down to a few tens of kilometers, using the same general method as that of the 1981 experiment. Two profiles were shot along the 4500-m isodepth line corresponding to the inner trench slope (Fig. 2). A slightly different signal frequency was used to increase the signal-to-noise ratio and the accuracy of the data (Suyehiro et al., 1985). Among the five OBSs, the recovered data from the southernmost (S15) exhibited a large noise level and were not used in the analysis.

Synthesis of these data reveals thick, low-wavespeed sediment (2.0–3.0 km/s) overlying a 6.3-km/s layer. Ar-

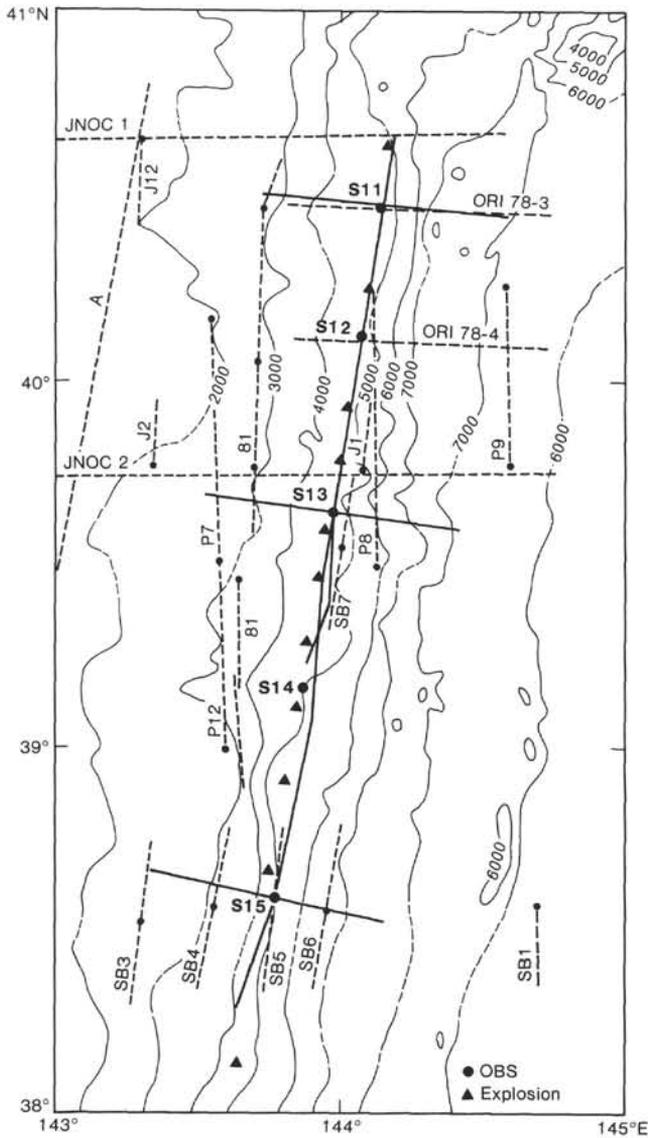


Figure 2. Map of 1982 seismic refraction experiment. Its layout shown by solid lines (S11-S15), broken lines indicate other seismic studies carried out in the region. P7, P8, P9, and P12 are two-ship refractions (Ludwig et al., 1966; Murauchi and Ludwig, 1980). JNOC 1, JNOC 2 and ORI 78-3, ORI 78-4 are multichannel reflection lines (Matsuzawa et al., 1980; Nasu et al., 1980; Tamano et al., 1981). J1, J2, and J12 are sonobuoy measurements and OBS refractions (Nagumo et al., 1980; Murauchi and Ludwig, 1980). SB1, SB3, SB4, SB5, SB6, and SB7 are sonobuoy measurements (Murauchi et al., 1979). A is a long-range explosion-OBS refraction experiment (Asano et al., 1981). Layout of 1981 experiment is the same as shown in Fig. 1.

rivals with apparent wavespeeds of 3 km/s can be traced to a distance of ~20-30 km, well beyond the crossing distance with the 6.3-km/s phase. Neither the layers with 4-5-km/s apparent wavespeed, that is, consolidated sediment, nor the ocean Layer 2 were found. The apparent lack of Layer 2, however, may not be real (see Discussion section).

Another feature is a change in north-south direction manifested by the change in the Moho depth, which gradually becomes shallower southward. Larger ampli-

tudes were observed for arrivals interpreted to be PmP phase on the southern sides of profiles at each OBS.

Japan Trench Model

A structural model across the Japan Trench that incorporates the results from our 1981 and 1982 experiments reveals markedly different structures along the 4500-m and 3000-m isobaths (Fig. 3). The Moho boundary was substantiated and estimated to be at 15 km by PmP observations as well as Pn arrivals from dynamite shots. The three sediment layers drawn for our 1982 model are somewhat arbitrary distinctions (Fig. 3). A gradual increase in wavespeed also explains the data and is probably more realistic.

East-west profiles S11 and S13 (Fig. 2) of the 1982 experiment show that the region with thick sediment seems to be narrow (Fig. 3). Although an unambiguous interpretation is difficult to make for these profiles, the presence of a layer with Layer 2-type wavespeed seaward and just beneath the north-south profile can ex-

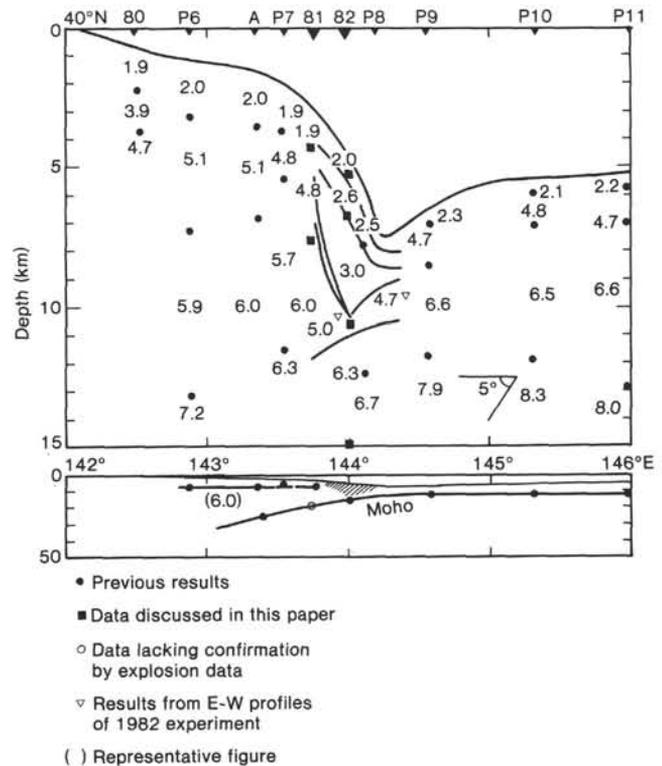


Figure 3. Vertical cross section across the Japan Trench at about 40°N showing P wavespeed structure. Upper figure has a vertical exaggeration of 17:1, whereas the lower figure is 1:1. Results from air-gun data of 1981 and 1982 experiments (denoted 81 and 82, respectively) are given. Two-dimensional ray tracing was performed to obtain these models. Lower crust beneath 3000 m water depth is not resolved. Moho depth is constrained by PmP observation and varies little with lower crustal wavespeed change. Solid curves are drawn from results of 1982 east-west profiles. Wavespeeds with triangles are from these profiles. Results of the same area from other workers are also incorporated. Identifications are the same as given in Figure 2. Wavespeeds marked 80 are taken from Suyehiro et al. (1981). Bottom figure shows Moho depths, low-wavespeed prism (hatched area), and presence of material with continental upper crustal wavespeed.

plain the data. Subduction of Layer 3 (6.3 km/s) at less than 5° landward dip to ~3000 m water depth is inferred from the data.

DISCUSSION

The air gun-OBS data are very useful for resolving structure in the depth range starting beneath the top unconsolidated sedimentary layer (which is best described by reflection data) and continuing down to the lower crust. Provided that the Moho depth is shallower than ~20 km, there is a good chance of observing PmP phase to define its depth.

The apparent lack of arrivals from Layer 2 beneath the sedimentary prism at the lower inner trench slope is in agreement with another set of OBS-air gun refraction data (Nagumo et al., 1980). Various later phases that are important in uniquely constraining detailed structure were observed but none seemed to be related to arrivals from Layer 2.

Although the boundary between Layers 2 and 3 may not be a first order discontinuity (Spudich and Orcutt, 1980), two types of layers with representative wavespeeds of 4.7 and 6.5 km/s have been identified in the western Pacific (Ludwig et al., 1966; Nishizawa et al., 1984). With an OBS, <5-km range is available to detect arrivals from Layer 2 as first arrivals seaward of the trench for profiles P9, P10, and P11 of Ludwig and others (1966). Their interpretation relies mostly on later arrivals from surface observation. Preliminary results from OBS observations by Nishizawa and others (1984) show the existence of Layer 2, which seems to be of transitional character.

Calculations indicate that it is much more difficult to detect Layer 2 beneath the inner lower trench slope if the thickness of Layer 2 is less than 2 km (i.e., identification is possible from later arrivals). Its transitional nature would further complicate the matter. At this stage of interpretation of our data, we cannot state clearly whether Layer 2 does or does not subduct.

From sonobouy measurements, Murauchi and others (1979) proposed the existence of a layer with a velocity of 5.1-5.2 km/s and interpreted it to be subducting. Such a structure beneath our OBSs would be observable as first arrivals for a short range. These arrivals were not detected. This absence may be due to the difference in latitude of the two experiments, that is, a three-dimensional effect.

Our 1982 east-west profiles show the area with thick sediment overlying a 6.3-km/s layer starts immediately beneath the trench axis and attains a maximum thickness beneath the north-south profile and diminishes at ~40 km landward from the trench axis.

The 1981 profile is located between Profiles P7 and P8 of Ludwig and others (1966). The crust here shows continental structure, which supports the above inference, and is in agreement with the sonobouy measurements at other latitudes.

The Moho depth inferred from the two air gun-OBS experiments requires a more gentle dip from the trench axis to 3000 m water depth than previously suggested (Murauchi and Ludwig, 1980). Hence, a large change in

dip angle occurs nearer to the land (Fig. 3). Because the Moho depth of the subducting plate becomes as deep as 50 km at the eastern edge of Honshu Island, an experiment near land, employing a powerful source, is required to delineate that structure; this is an area where data are lacking. So far, short-range air gun-OBS experiments made in this area could reveal the upper crust only (Suyehiro et al., 1981; Suyehiro, Inatani, et al., 1984).

SUMMARY

OBSs can retrieve information of seismic structure more accurately with higher signal-to-noise ratio than conventional methods. In a region such as the vicinity of the Japan Trench where the structure shows marked complexity, ocean bottom instruments afford better resolution.

The plate subduction geometry was not well known in the region because previous investigations could not penetrate to sufficient depths to reveal structure down to ocean Moho subduction. Dense and long-distance coverage using air guns and explosives as controlled sources is required for such purpose. We have carried out two such experiments in the region.

The following results were obtained from the air-gun data. Beneath a 3000-m-thick water layer and a 1.5-km-thick uppermost sediment layer, lies a 4.8-km/s layer of ~3 km thickness. The crust below has a wavespeed of 6.0 km/s, indicative of continental upper crusts. Arrivals with apparent wavespeeds of 6.0 km/s can be traced to a distance of ~50 km N-S (i.e., parallel to axis), suggesting predominance of the layer in the upper crust.

The vicinity of the inner lower trench slope is characterized by a thick (5-6 km), low-wavespeed (2-3 km/s), sedimentary layer overlying a 6.3-km/s layer down to about 15 km, where the Moho boundary is found. It is inferred that either Layer 2 is lacking or extremely difficult to identify because of the gradual change to Layer 3 and the thinness of Layer 2.

Models from profiles crossing the trench axis, which satisfy the above structure, suggest a gently dipping (<5°) ocean crust and the existence of a narrow, low-wavespeed, sedimentary prism.

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