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A Seismic Refraction Study of the Crustal Structure in the Active Seismic Zone East of Taiwan

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An array of 10 Hawaii Institute of Geophysics (HIG) ocean bottom seismometers (OBSs) was emplaced off the east coast of Taiwan for a cooperative study conducted by scientists from HIG and institutions in Taiwan. As part of this experiment, three overlapping seismic refraction profiles were shot across the array parallel to the coast of Taiwan. The results of the ray trace modeling of these data indicate that the crust off southern and central Taiwan is about 8 km thick in this area and can be modeled by several layers with velocities and thicknesses that lie within the range associated with "normal" oceanic crust. Near 23.5°N a downwarping and thickening of the crustal layers occurs in the model. This downwarped trough of low-velocity materials may represent the sediment-filled axis of the Ryukyu Trench. If this is true, it indicates a more southerly trench position in this area than that previously published by other investigators. To the north of this downwarping, the bottom shoals rapidly, and the velocity structure undergoes a transition that may indicate a change to arc or continental type crust.

INTRODUCTION

During June and July 1985 an array of 10 Hawaii Institute of Geophysics (HIG) ocean bottom seismometers (OBSs) was emplaced off the east coast of Taiwan (Figure 1). This experiment was part of a cooperative study conducted by scientists from HIG, the Institute of Earth Sciences, Academia Sinica, and the Institute of Oceanography, National Taiwan University (NTU), for the purpose of improving the monitoring accuracy of the Taiwan Telemetered Seismic Network (TTSN) by placing OBSs to the east of the island, where better azimuthal coverage is needed to obtain more accurate hypocenter locations. The OBSs were deployed from the R/V *Ocean Researcher I*, operated by NTU, and were recovered after a period of 33 days. The analog data cassettes were returned to HIG and processed into digital form for further study. The data collected by the OBS and TTSN arrays are being used to investigate the tectonic setting of the region east of Taiwan through seismicity and source mechanism studies [*Hsu et al.*, 1987].

Several lines of the controlled source refraction shots were conducted to specific OBSs. In this paper these refraction data are modeled using a ray trace algorithm to obtain the crustal velocity beneath the OBS array. The velocity structure obtained is then used in an attempt to resolve several questions about the nature of the plate boundaries in the tectonically complex area near Taiwan.

TECTONIC SETTING

The tectonic setting of Taiwan is an unusual one in the island arc systems of the western Pacific (Figure 2). The island of Taiwan formed as a result of the collision of the Philippine arc with the edge of the Eurasian plate beginning approximately 4 m.y. before present in the early Pliocene [*Karig*, 1973; *Wu*, 1978; *Letouzey and Kimura*, 1985]. Prior to this collision, eastward subduction of the oceanic crust of the South China Sea occurred beneath the northern Luzon arc. The collision resulted in compression, thickening, and uplift of the sediments of the Asiatic continental shelf to form the western part of Taiwan. The volcanic arc itself was then accreted to this wedge of sediments forming the eastern Coastal Range of Taiwan.

The young orogenic belt of Taiwan consists of folded and faulted metamorphic basement rocks of Mesozoic age overlain by metamorphic and sedimentary rocks of Tertiary age. These formations occur in long, narrow, NNE trending belts. Nearly the entire section consists of a stack of folded, imbricate thrust sheets (Figure 3).

The Longitudinal Valley is a 150-km-long, NNE trending feature that separates the uplifted sedimentary sequences on the west from the volcanic arc sequence of the eastern Coastal Range. The floor of the valley has a width of 5 to 7 km and is about 200 m above sea level. To the east side the Coastal Range reaches a height of about 1600 m, while to the west the Central Range reaches nearly 4000 m within 35 km of the valley. The Longitudinal Valley is believed to be the contact or suture zone between the sedimentary sequence of the continental margin and the volcanics of the Luzon arc [*Juan*, 1975; *Lin and Tsai*, 1981; *Biq*, 1981; *Ho*,1986].

To the south of Taiwan, eastward subduction of the South China Sea plate beneath the Philippines is occurring along the Manila Trench [*Taylor and Hayes*, 1983]. The seismic evidence indicates that westward subduction is currently developing to the east of Luzon along the Philippine Trench and East Luzon Trough [*Karig*, 1973; *Seno and Kurita*, 1978; *Lin and Tsai*, 1981; *Lewis and Hayes*, 1983]. *Bowin et al.* [1978] have suggested that the east dipping subduc-

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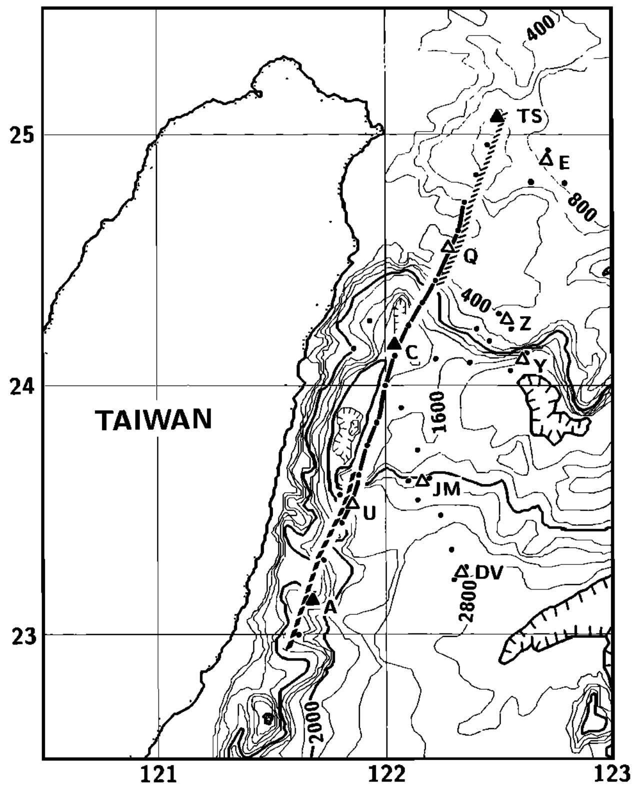

Fig. 1. Bathymetric map of the study area. The OBS locations are shown as triangles. The solid triangles are OBSs used in this study. Contour interval, 200 fathoms (365 m).

tion along the Manila Trench has been "sealing" southward from Taiwan as the more easily subducted crust of the South China Sea is consumed and the thicker crust of the continental shelf reaches the trench.

The Luzon volcanic arc extends from Luzon Island to Taiwan. Recent volcanic activity is confined to Luzon and the small islands between Luzon and Taiwan such as Batan and the Babuyan Islands. No active volcanoes are known in the Coastal Range of Taiwan where volcanism occurred during the late Miocene and Pliocene. This supports the hypothesis that collision, and the resulting cessation of volcanism, began in the northern arc in the Miocene and progressed southward to Luzon where volcanic activity continues today [*Ernst et al.*, 1985].

The distribution of historical seismicity shows a gradual change as one moves north from Luzon toward Taiwan (Figure 4). The distribution of epicenters in central Luzon defines a shallow (< 200 km) east dipping Wadati-Benioff zone associated with subduction along the Manila Trench [*Seno and Kurita*, 1978; *Wu*, 1978; *Lin and Tsai*, 1981; *Hamburger et al.*, 1983]. Moving further north, the western seismicity becomes shallower and more diffuse, and an eastwardly dipping slab can no longer be defined.

The data also show a concentration of shallow events on the east side of Luzon that have thrust mechanisms. Although a subducting slab is not well defined by the seismicity, it is thought that subduction is beginning along the East Luzon Trough [*Fitch*, 1972; *Wu*, 1978; *Seno and Kurita*, 1978; *Cardwell et al.*, 1980; *Lin and Tsai*, 1981]. *Lewis and Hayes* [1983] collected several multichannel reflection profiles off eastern Luzon that clearly delineate the subducting plate and the deformation of the associated subduction complex. No compressive deformation was observed north of 18°N, where the eastern concentration of seismicity becomes more diffuse.

In the region between Luzon and Taiwan the seismicity is spread across a broad, shallow zone and includes both strike-slip and thrust events. *Seno and Kurita* [1978] proposed a model in which compression in this area is accommodated by left-lateral shear along NW–SE trending faults. However, *Karig* [1973] proposed that the arcuate NNE–SSW trending bathymetric troughs which cut the North Luzon Trough and the Luzon Arc represent the traces of active left-lateral faults. Karig's hypothesis is supported by *Lewis and Hayes* [1983], who interpret the bathymetry and seismicity to indicate that faulting is occurring along curvilinear north to northeast trending fault traces. *Mrozowski et al.* [1982] found that the basement structural fabric in the west Philippine basin is predominantly oriented NE–SW. This further supports the choice of the NE trending nodal plane as the fault plane for the focal mechanisms in this area.

Beneath Taiwan the seismicity forms a shallow, diffuse zone concentrated along the eastern margin of the island [*Wu*, 1978; *Tsai et al.*, 1977; *Lin and Tsai*, 1981; *Lee*, 1983]. Off northeastern Taiwan the foci deepen to the north and merge into the events associated with the Ryukyu arc [*Katsumata and Sykes*, 1969; *Tsai et al.*, 1977]. Focal mechanism studies of the events beneath Taiwan indicate that the island is predominantly undergoing east-west compression with some left-lateral shear occurring along NNE trending faults [*Wu*, 1970, 1978; *Lin and Tsai*, 1981].

The earthquake data suggest that the convergence of the Eurasian and Philippine Sea plates is being accommodated in Taiwan by thrusting and left-lateral strike slip centered in the Longitudinal Valley area [*Hsu*, 1962; *Wu*, 1970; *Seno and Kurita*, 1978; *Lee*, 1983]. One explanation for the tectonic complexity of the Taiwan area is that a broad zone of deformation, rather than a discrete plate boundary, has formed in Taiwan. Subduction and collision may be occurring in a belt over 100 km wide. This type of deformation zone may represent an early phase in the process of arc reversal [*Ho*, 1986].

To the northeast of Taiwan, northwestward subduction of the Philippine Sea plate is occurring beneath the Eurasian plate along the Ryukyu Trench. Convergence between the Philippine Sea plate and the Eurasian plate is occurring in a NNW direction at a rate of 7 cm/yr [*Seno*, 1977]. The Ryukyu arc is constructed on the Asiatic continental margin and is bounded by the active Okinawa Trough back arc basin in the north and the Ryukyu Trench subduction zone in the south. The timing of the evolution of Taiwan and the opening of the southern Okinawa Trough suggest that rifting was the result of clockwise rotation and extension of the Eurasian plate caused by the collision of the Luzon arc with the continental margin [*Letouzey and Kimura*, 1985].

Recent volcanic activity along the Ryukyu arc occurs at a distance of between 160 and 250 km from the trench and is located 80 to 120 km above the Wadati-Benioff zone [*Letouzey and Kimura*, 1985]. Most of the recently active volcanoes of the arc are located in Kyushu and the northern

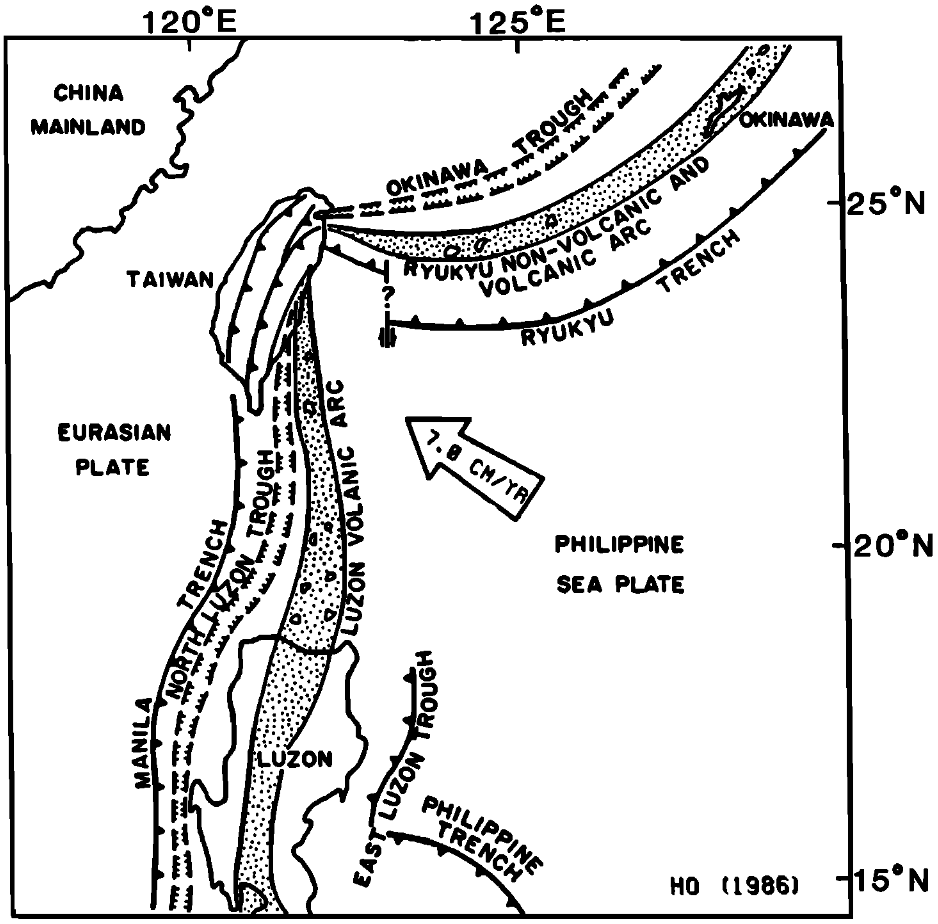

Fig. 2. The plate tectonic setting of Taiwan [*Ho*, 1986]. The Philippine Sea plate is moving northwestward and subducting beneath the Ryukyu arc in the north and the Philippines in the west. The collision of the Luzon arc with the continental shelf is causing a complex collision zone to form around Taiwan.

part of the arc. In fact, only one Pleistocene arc volcanic center is located between Okinawa and Taiwan.

Data Collection and Reduction

Because of severe weather conditions, the controlled source seismic refraction portion of the experiment was severely curtailed. Thirty-nine explosive shots, from 5 to 250 kg each, were fired for location of OBSs and as refraction sources. In addition, a single line of airgun shots was run across five of the OBSs, parallel to the east coast of Taiwan, and perpendicular to the bottom structure as indicated by the bathymetry (Figure 1).

Each OBS continuously recorded four channels of data on analog tape cassettes: hydrophone, time code, 4.5 Hz horizontal geophone, and 4.5 Hz vertical geophone [*Sutton et al.*, 1977; *Byrne et al.*, 1983]. Of the five OBSs located along the airgun line: OBS U suffered a deployment problem and recorded only poor quality geophone data (no hydrophone data) during the refraction experiment, and OBS Q, located at a very shallow depth, suffered from extreme ocean current noise. As a result, only OBS TS, OBS C, and OBS A returned refraction data that were considered good enough for this study.

After retrieval of the instruments the data were adjusted for any tape skew errors incurred in the recording process and digitized onto computer tape. A correction was subsequently made for any drift of the OBS and ship clocks from the WWV standard. Navigation during the experiment was based on trisponder stations, transit satellite fixes, and radar fixes to Taiwan shore stations. Navigational accuracy was variable during the experiment, but the average navigational error is estimated to be less than 0.3 km. Relative shot and receiver locations were determined by a generalized inversion of direct water wave travel times using a method that is similar to an earthquake location algorithm but in which both the source and receiver locations are determined [*Sinton*, 1982]. The shot line records for each OBS were then demultiplexed, and each of the sensor channels was plotted in record section format.

For each of the three OBSs studied, the signal-to-noise ratio was much better for the hydrophone than for either of the two geophones, therefore the hydrophone data were chosen for analysis. The poor quality of the geophone data is probably due to the fact that all of the instruments were deployed in an area of relatively thick (200–1000 m) sediments [*Lu et al.*, 1977]. This may have resulted in poor coupling between the geophones and the bottom, causing reverberation effects that show up as ringing on the geophone records. This occurred in spite of the fact that HIG OBSs are thought to be among the best coupled instruments available [*Sutton et al.*, 1977].

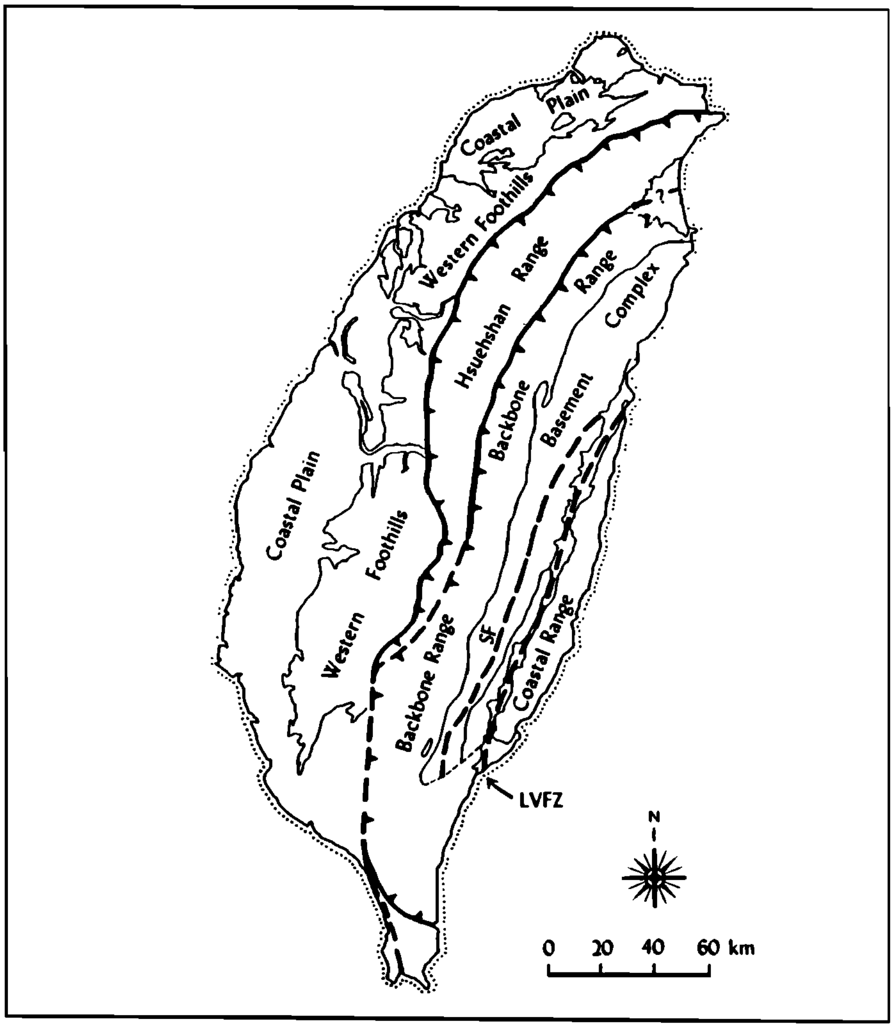

Fig. 3. Tectonic/morphologic belts of Taiwan. The arc materials of the Coastal range are separated from the folded and faulted sedimentary rocks to the west by the Longitudinal Valley fault zone (LVFZ) [*Ernst et al., 1985*].

DATA ANALYSIS

The three OBS-shot line combinations chosen for analysis are shown in Figure 1. The most southerly receiver, OBS A (at a depth of 2240 m), was located in an area of relatively smooth bottom. The central receiver, OBS C (at a depth of 3130 m), was located at the base of a major change in slope to the north. OBS TS (at a depth of 1300 m), the most northerly receiver, was located in the Okinawa Trough near the shelf of the East China Sea. Each shot line consists of closely spaced (200–500 m) airgun shots and a few widely spaced explosive shots. The airgun used in this experiment was small (60 in^3 (983 cm^3)); as a consequence, clear first arrivals can only be seen to a very limited range (about 20 km) in the record sections. The larger explosive shots are used to extend the useful ranges of the profiles to more than 50 km in most cases.

The hydrophone record sections were plotted using a reducing velocity of 1.51 km/s (average water column velocity) to check relative navigation. Water wave travel times were measured and the shot-to-receiver distances were corrected. The corrected record sections were then filtered using a six-pole Butterworth filter with a 4 to 14 Hz bandpass and replotted using a reducing velocity of 8.0 km/s (Figures 5a, 6a, 7a). Unfortunately, due to technical problems during the cruise, no bathymetric or reflection seismic data were collected along the shot lines. This severely limits the detail possible in the analysis and interpretation of the record sections, since it was not possible to make any detailed topographic or sediment thickness corrections to the record sections. Bathymetric corrections from published bathymetry are included in the ray trace modeling discussed later.

As a first approximation to the structure, the record sections were interpreted by fitting straight-line segments to the first arrivals. Initial velocity-depth models consisting of constant velocity layers were then calculated for each shot line. Shot lines A and TS are single-ended lines, and as such, no determination of layer dip is possible by the above method. Shotline C, however, is a split-spread line and shows a marked asymmetry between the two sides of the profile, indicating that significant layer dip is to be expected.

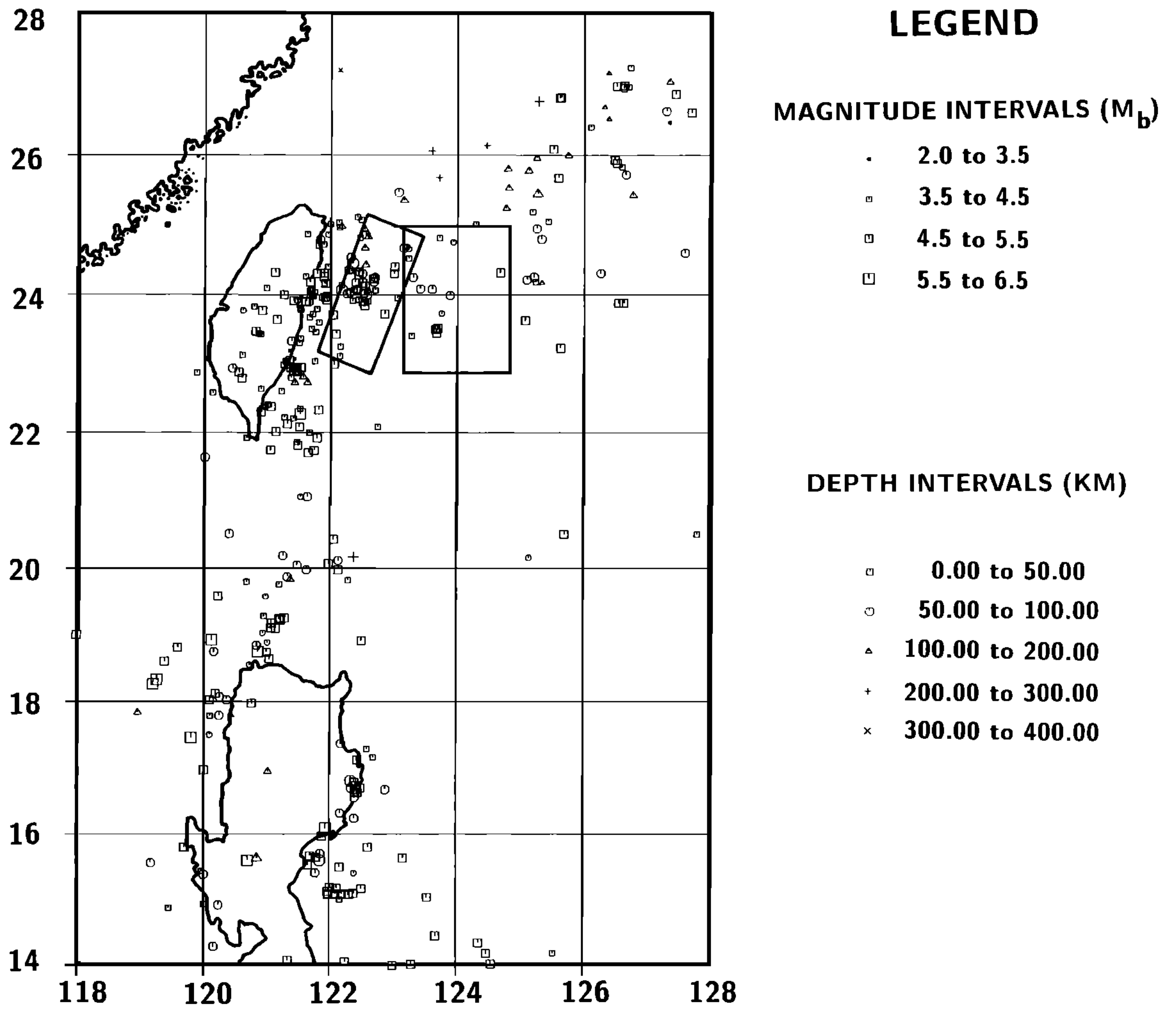

Fig. 4. The distribution of seismicity (WWSSN data, 1960 – 1982) along the western margin of the Philippine Sea Plate. The boxes outlined to the east of Taiwan are the locations of vertical sections to be discussed later in this paper.

The simple velocity-depth models obtained for each shotline were used as the basis for further analysis. A model was prepared that included the local bottom topography (based on published bathymetry [*Scripps Institution of Oceanography*, 1978]) and the average velocity-depth function from the line C data. A two-dimensional ray trace program written by *Sinton* [1982], using an algorithm of *Gebrande* [1976], was used to propagate rays through the models. By incorporating the sea bottom relief in the models we effectively included large-scale topographic corrections in the analysis.

The initial model consisted of horizontal, constant velocity layers. A slight vertical velocity gradient was introduced into each layer in the model to produce refracted rays in the ray trace. This model was then perturbed through several generations. The travel times from each model were matched to the hydrophone data through a trial-and-error process in which the short-range data (shallow layers) were matched first and the farthest range data (deepest layers) were matched last. During the course of this modeling it was determined that a low-velocity sediment layer, not evident on the record sections as a first arrival, would have to be included in the model in order to fit the arrivals for the shallowest crustal layer. The velocity for this sediment layer was chosen to be 2.0 km/s on the basis of the sonobuoy work of *Leyden et al.* [1973]. The resulting thickness of this layer, as determined by modeling for each shot line, agrees quite well with the sediment isopach map of *Lu et al.* [1977].

RESULTS

The final velocity-depth model obtained in this study is shown in Figure 8. As expected, significant layer dip was required in the final model to properly match the travel time data of the record sections. The final model consists of the following layers:

1. The shallowest layer is a sediment layer with a velocity (assumed) of 2.0 km/s. The thickness of this layer varies from 1.5 km at the north end of the model (on the continental shelf) to 0.2 km in the deep water at the south end of the line. The thinning of this layer is probably a result of increasing distance from the sediment source area.

2. The second layer in the model was not seen in the OBS A or OBS TS data and was therefore modeled as a

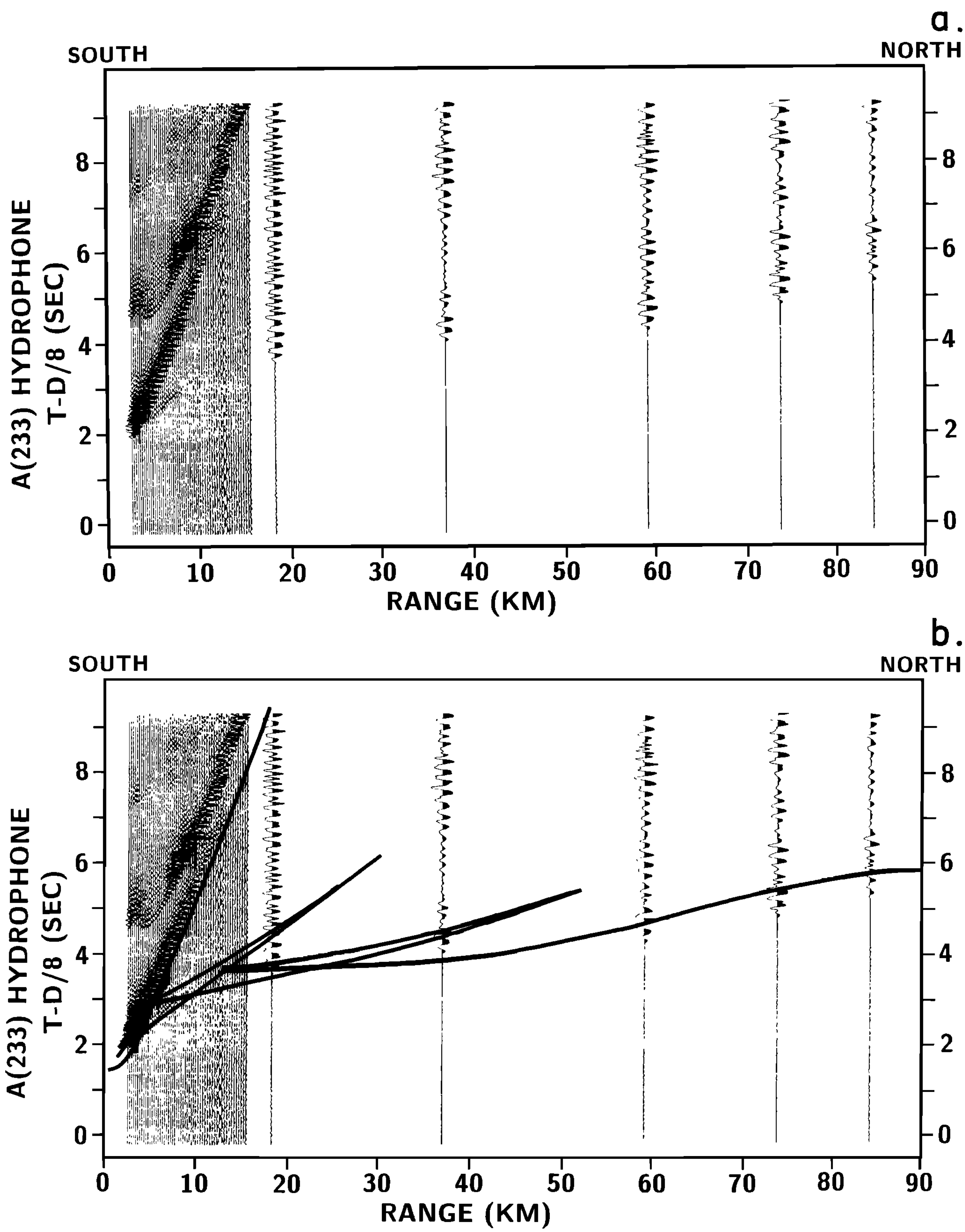

Fig. 5. (*a*) Record section for OBS A. The data have been filtered (4 to 14 Hz) and are plotted with a reducing velocity of 8.0 km/s. Trace amplitudes are individually scaled to the maximum amplitude measured for each trace. (*b*) Comparison of the travel time plot from the ray trace modeling with the record section for OBS A. The travel time plot is in good agreement with the data out to about 35 km.

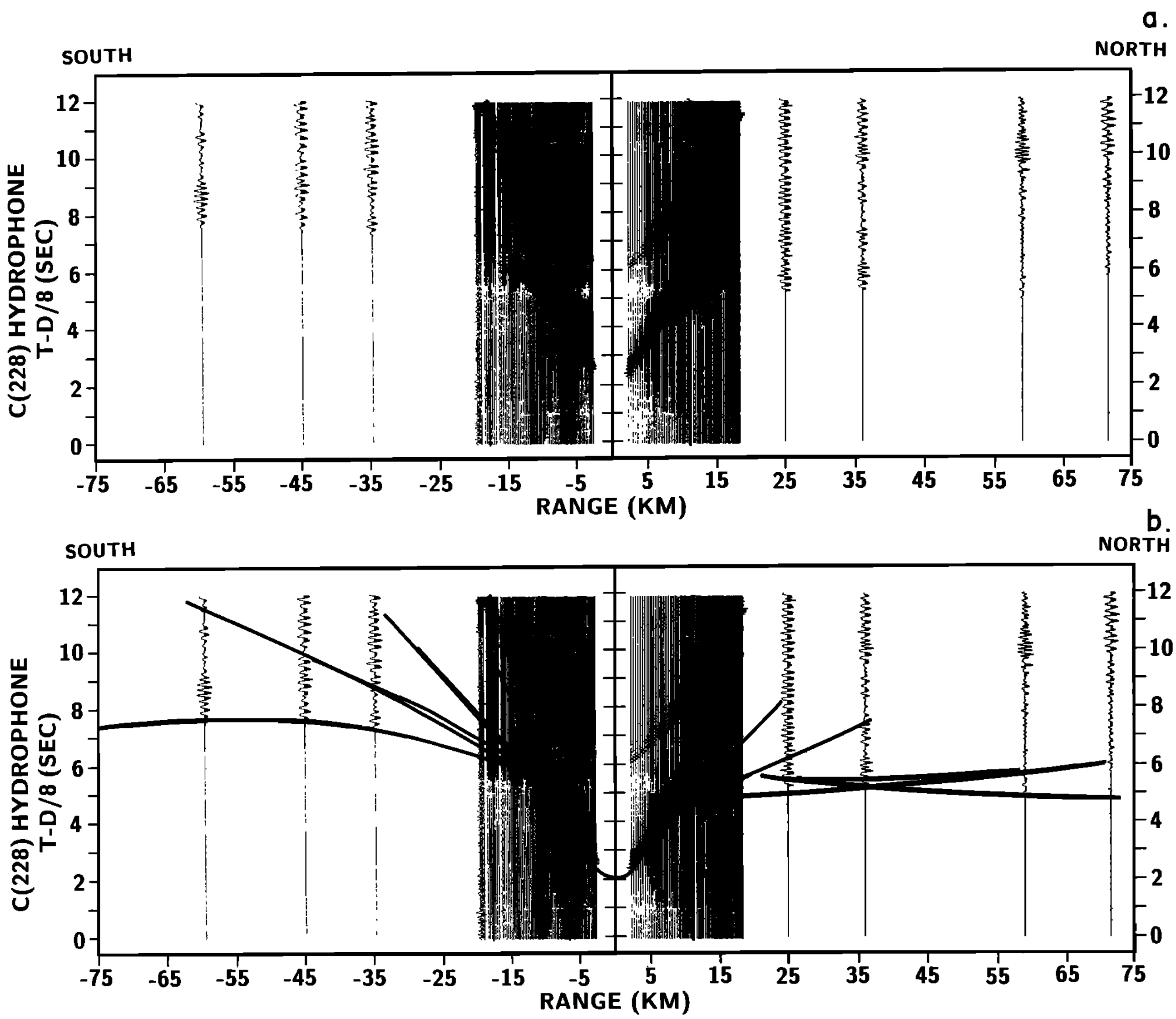

Fig. 6. (*a*) Record section for OBS C. The data have been filtered (4 to 14 Hz) and are plotted with a reducing velocity of 8.0 km/s. Trace amplitudes are individually scaled to the maximum amplitude measured for each trace. The obvious asymmetry indicates that significant layer dip is present. (*b*) Comparison of the travel time plot from the ray trace modeling with the record section for OBS C. The travel time curves match the actual arrivals to within 0.1 s except for the northernmost shot.

wedge of material which pinches out both to the north and south of OBS C. This layer has a velocity of 2.55 km/s and a maximum thickness of 3 km. It may represent a layer of sediments derived from the rapid uplift of nearby Taiwan or sediments accreted by subduction along the Ryukyu Trench.

3. The third layer consists of material with a velocity of 3.85 km/s and has an average thickness of 2.0–2.5 km. This layer probably represents the pillow basalts of the upper oceanic crust itself and has a velocity consistent with oceanic layer 2A [*Houtz and Ewing*, 1976; *Clague and Straley*, 1977; *Christensen and Salisbury*, 1975].

4. The fourth layer in the model is composed of a thick (6–7 km) layer with a velocity gradient of 6.0–6.5 km/s. This velocity is at the high end of the range usually attributed to oceanic layer 2B and is at the same time lower than expected for layer 3 [*Clague and Straley*, 1977].

The fourth layer in the model exhibits the effects of the decrease in resolution with depth for these data. The energy returned from this layer falls in the range where the airgun arrivals die out and we are forced to rely on the sparse explosive shots. As a result, the model may not be a good representation of the actual velocity structure at these depths and this layer may represent an averaging or "blending" of the actual velocity structure. Further evidence of the poor resolution at this depth is the fact that arrivals from material with a mantle velocity (8.1 km/s) can only be seen on the northern half of the OBS C record section.

Because this model was based on the velocities obtained from the central receiver, OBS C, there are some problems in the modeling of the other data. Figures 5b, 6b, and 7b show the comparisons of the travel time curves from the ray trace model with the actual record sections.

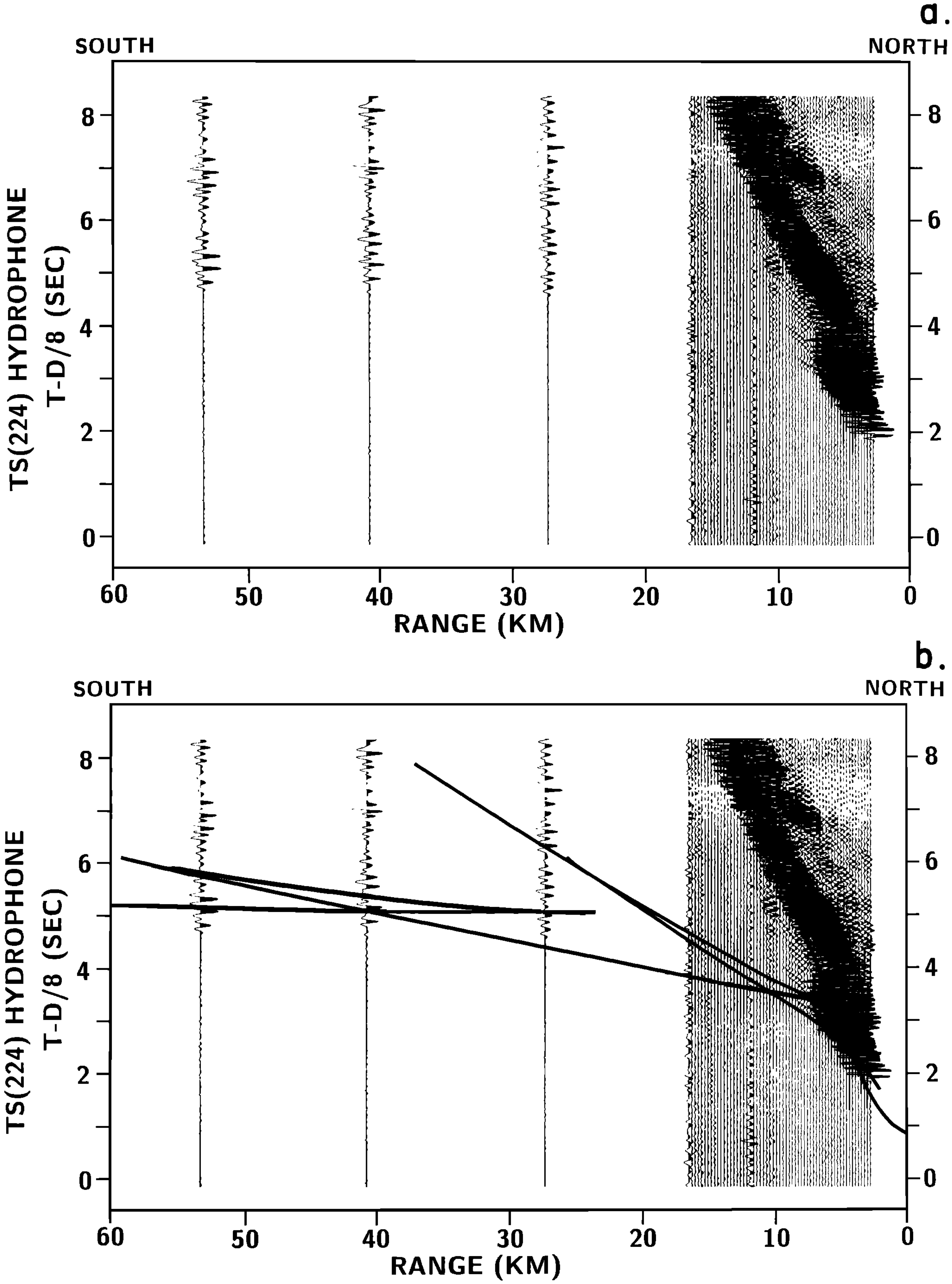

Fig. 7. (*a*) Record section for OBS TS. The data have been filtered (4 to 14 Hz) and are plotted with a reducing velocity of 8.0 km/s. Trace amplitudes are individually scaled to the maximum amplitude measured for each trace. (*b*) Comparison of the travel time plot from the ray trace modeling with the record section for OBS TS. The poor fit of the travel time plot to the data for this OBS is discussed in the text.

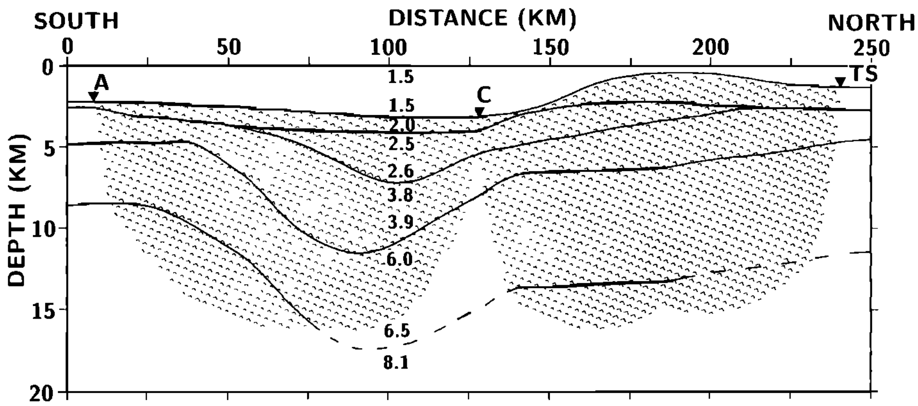

Fig. 8. The final velocity-depth model obtained by the ray trace modeling. The model is characterized by an area of downwarping and crustal thickening to the south of OBS C. The patterned region shows the areas in the model that are constrained by the ray traces. Vertical Exaggeration, 5 X.

The travel time curves match the OBS C record section to within 0.1 s in most places, with the exception of the northernmost explosive shot (Figure 6b). The travel time plot is in good agreement with the OBS A data out to about 35 km (Figure 5b). Beyond this point the ray trace arrivals are consistently late. A better match to arrivals beyond 35 km might be possible with further perturbations to the model and/or an increase in the velocity of the 6.0 to 6.5 km/s layer. However, we believe that the quality of the data does not merit further modeling.

For the same reasons, no further modeling was attempted for the OBS TS data, even though the model matches the data very poorly (Figure 7b). OBS TS is located on the shelf of the East China Sea. The poor match of the model with the data is probably the result of lateral changes in velocity and crustal thickness associated with the transition from oceanic-type, through arc-type, to continental-type crustal material. In fact, the data indicate that a better match could be obtained by increasing the depth and velocity of the 6.0 to 6.5 km/s layer in the model.

As the discussion above indicates, the model is not well constrained beneath OBS A or OBS TS. The structure beneath those receivers should therefore be considered with caution. The model is much better constrained in the vicinity of OBS C. There is, however, a certain amount of ambiguity present in the model, since slightly different velocities, combined with different layer dips and depths, could also be made to fit the arrivals. Velocity changes of up to 0.05 km/s at the top of the model and up to 0.30 km/s for the deepest layer (without changing the interface depths) or depth changes on the order of 0.07 km for the shallowest interfaces to 0.75 km at depth (while holding the velocities constant) would not appreciably alter the travel time curves. Although the absolute accuracy of the velocities and depths in the final model are questionable, the overall structure shown in the model is necessary to adequately match the first arrivals.

DISCUSSION

Wu [1970, 1978] concluded that the Ryukyu arc is displaced to the north about 100–120 km east of Taiwan by a right-lateral trench-to-trench transform fault (Figure 2). This transform was defined by a few right-lateral, strike-slip focal mechanisms that appeared to define a northerly striking fault plane near 123°E. The northerly offset segment of the subduction zone was then thought to connect to the plate boundary in Taiwan (the Longitudinal Valley) near 24°N. This offset of the Ryukyu arc has been generally accepted [*Chai*, 1972; *Karig*, 1973; *Juan*, 1975; *Seno and Kurita*, 1978; *Lin and Tsai*, 1981, *Juan et al.*, 1983], probably because of the overall lack of data from the area.

The Ryukyu Trench, which is well defined along the northeastern part of the arc, becomes broader and shallower as it approaches Taiwan and cannot be easily defined west of 123°E. This may be a result of the more oblique angle of subduction in this area as well as the increased sedimentation from Taiwan. It is also unlikely to be a coincidence that this is also the area where a submarine ridge, the Gagua Ridge, enters the trench from the south. Although *Bowin et al.* [1978] state that the Gagua Ridge is an extinct spreading center, *Mrozowski et al.* [1982] believe that the Gagua Ridge is an upfaulted sliver of oceanic crust, perhaps similar to the ridges found bordering some fracture zones.

Regardless of its origin, the collision of the Gagua Ridge with the Ryukyu Trench appears to have a significant effect on the nature of subduction in this area. It is possible that the right-lateral strike-slip focal mechanisms used by *Wu* [1970, 1978] to define the offset of the trench are in some way related to the collision of the Gagua Ridge with the inner slope of the Ryukyu Trench near 123°E.

The free air gravity map of *Bowin et al.* [1978] shows no apparent offset of the arc and seems to indicate that the trench extends up to the continental margin of eastern Taiwan. *Ho* [1986] cites this gravity data as well as personal communications with French scientists as evidence that the Ryukyu Trench may extend directly to the east coast of Taiwan. This hypothesis of a continuous trench is supported by *Suppe* [1981, 1984] who developed a simple kinematic plate tectonic model for the arc-continent collision near Taiwan. He determined that a continuous Ryukyu Trench was necessary if the back arc spreading of the Okinawa Trough was to be accounted for by his model.

Very little seismic refraction work has been done in the area near Taiwan. However, a few refraction studies have been conducted to the north and east in the Okinawa Trough, the Ryukyu arc, and the western Philippine Sea [*Murauchi et al.*, 1968; *Ludwig et al.*, 1973; *Leyden et al.*, 1973]. There is a close similarity between the crustal velocity structure determined in our study and the above mentioned profiles across the arc to the northeast. Our profile exhibits

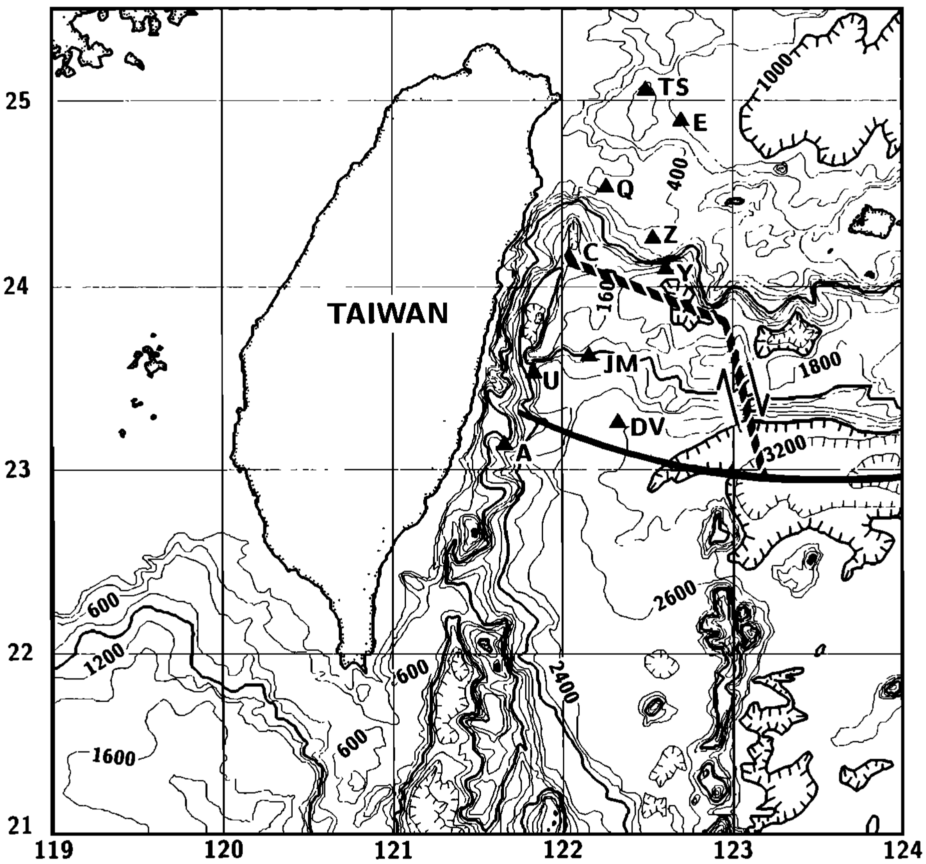

Fig. 9. Map showing the location of the Ryukyu trench based on the results of this study (solid line) and the northward offset of the trench (hachured line) favored by *Wu* [1970, 1978]. Contour interval, 200 fathoms (365 m).

nearly the same crustal velocities and thicknesses found in these profiles. Our profile also shows the downwarping and crustal thickening typical of the trench area to the northeast. We believe that these data provide further evidence for the continuous nature of the Ryukyu arc in this area. Figure 9 shows the location we would pick for the trench on the basis of our profile. The trench axis is chosen to be immediately seaward of the thickened low-velocity layers on the profile. This is in agreement with the trench location on the profiles to the north and east where the trench is well defined.

Figure 10 shows hypocenters ($M_b > 4.8$) located by the WWSSN network during the period (1964–1982) projected onto a plane parallel to the line of our refraction profile. The crustal velocity structure and trench axis location of our study are shown along with the trench axis of *Wu* [1970, 1978]. The filled circles in the figure are events projected onto a profile parallel to our refraction line. The open circles are events projected onto a profile to the east of the transform proposed by *Wu* [1970, 1978]. (See Figure 4 for the profile locations.) The hypocenter locations appear to define a subducting slab which is in better agreement with the more southerly trench axis location than with the more northerly (transformed) position. If the subduction zone is offset as suggested by *Wu* (1970, 1978), we would expect to see an offset of the hypocenters on each side of the transform. No significant offset is observed, thus further supporting the conclusion that the transform does not exist (or is very short) and that the trench is continuous in this area.

Hypocenters (with $M_b > 2.0$) located by the Taiwan Telemetered Seismic Network (TTSN), during the period 1974-1976, were projected onto a plane nearly coincident with the line of our refraction profile by *Tsai et al.* [1977]. This profile seems to indicate that the northerly trench position of *Wu* [1970, 1978] is more consistent with the seismicity. However, the hypocenters located by TTSN may be significantly in error because of the poor azimuthal coverage for events in this area. The profile also includes a large number of shallow events from the eastern part of Taiwan that may be unrelated to subduction.

CONCLUSIONS

The results of this study show that off southern and central Taiwan the crust is about 8 km thick and can be modeled by several layers with velocities and thicknesses that lie within the range associated with "normal" oceanic crust. Near 23.5°N a downwarping and thickening of the low-velocity layers occurs. Immediately to the north of this downwarping, the bottom shoals rapidly onto the continental shelf of the Asian mainland. We believe that this thickened trough of low-velocity materials may represent the sediment-filled axis of the Ryukyu Trench. If this is true, it indicates a more southerly trench position in this area than had been previously thought.

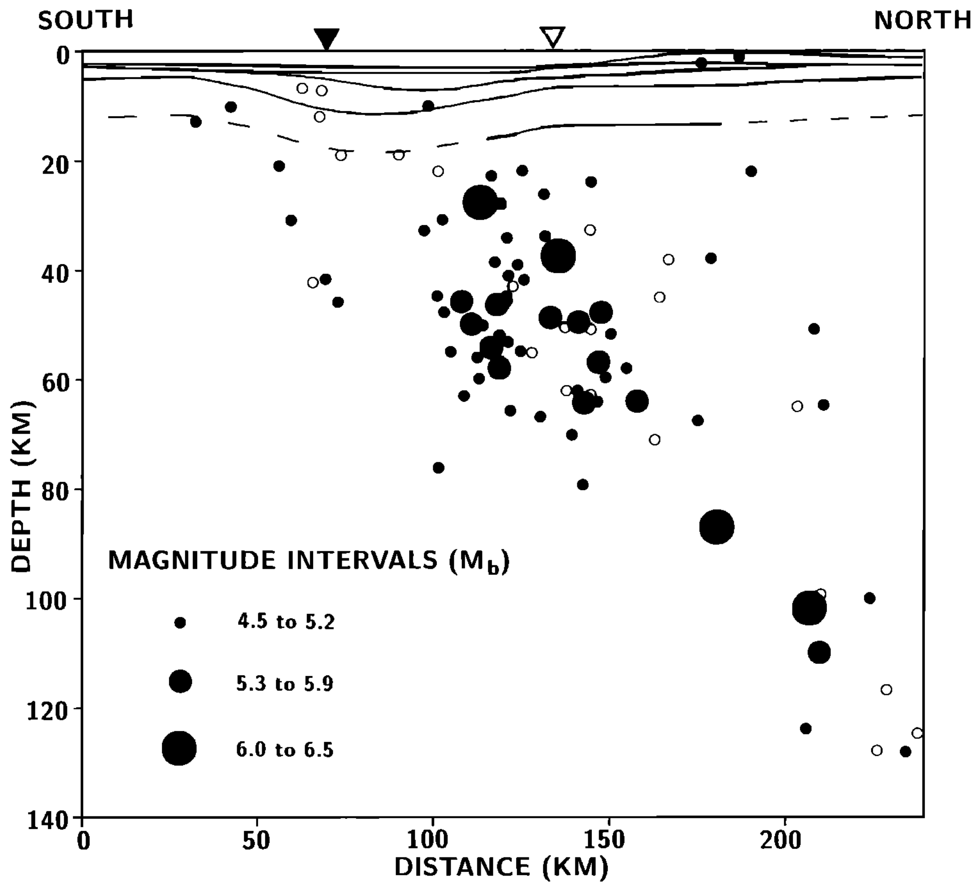

Fig. 10. Hypocenters located by the WWSSN network during the period 1960–1982 projected onto planes perpendicular to the Ryukyu Trench. Profile locations are shown on Figure 4. The open circles are events from the eastern profile while the solid circles represent events to the west of the questionable offset. The open triangle marks the trench location of *Wu* [1970, 1978]. The solid triangle is the trench location of this study.

A southerly trench position is supported by the gravity data of *Bowin et al.* [1978], which indicate that the Ryukyu Trench is continuous near Taiwan and not offset to the north by a transform as hypothesized by *Wu* [1970, 1978]. Seismicity profiles perpendicular to the arc, using data from both WWSSN and TTSN, were examined in an attempt to shed more light on this problem. The WWSSN profiles seem to indicate the presence of a subducting slab that is consistent with a more southerly trench position. No significant offset is observed between profiles on either side of the postulated transform, which also indicates that the transform does not exist.

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