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Preliminary crustal structure of the coast of Guerrero, Mexico, using the minimum apparent velocity of refracted waves

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RESUMEN

Se muestra la estructura de velocidades sísmicas en la costa de Guerrero, México, determinada a partir de las velocidades aparentes mínimas de ondas refractadas. Los datos utilizados en el análisis fueron registrados por la Red Telemétrica de Guerrero, instalada a fines de 1987 para monitorear la actividad de la brecha de Guerrero. Los sismos fueron seleccionados con base en la calidad de su localización y para asegurar un muestreo homogéneo de la estructura de velocidad en la zona. Los resultados muestran que en la zona de subducción la corteza está compuesta de cuatro capas con las siguientes velocidades y espesores: V_1=5.8, V_2=6.5, V_3=7.1 y V_4=7.4 km/s; h_1=10, h_2=8.4 y h_3=5.0 km. No se observaron refracciones provenientes de la discontinuidad de Mohorovicic, a pesar de que se incluyeron eventos alejados del centro de la red. Esto sugiere que en la región la corteza continental inferior descansa directamente sobre la placa de Cocos. Un mapeo detallado de la zona de contacto interplaca indica que ésta se encuentra aproximadamente a la misma profundidad que el espesor total de la corteza continental.

PALABRAS CLAVE: Guerrero, subducción, corteza, estructura de velocidad.

ABSTRACT

The seismic velocity structure beneath the coast of Guerrero, Mexico was determined using the minimum apparent velocities of refracted waves. The data used in the analysis is a selection of local earthquakes recorded by the Guerrero Seismic Network installed at the end of 1987 to monitor the seismicity of this seismic gap. The earthquakes were selected on the basis of the quality of their hypocentral location and to insure a homogeneous and complete sampling of the velocity structure of the study area. The results show that the crust in this subduction zone is composed of four layers with the following velocities and thicknesses: V_1=5.8, V_2=6.5, V_3=7.1 and V_4=7.4 km/s; h_1=10, h_2=8.4 and h_3=5.0 km. No raypaths refracted from the Moho discontinuity were observed, although we included events far from the center of the network. The absence of a mantle refraction in this area may be interpreted as evidence that the lower crust of the overriding continental plate lies directly on top of the upper crust of the subducting Cocos plate without any intervening mantle layer. Detailed mapping of the megathrust seismic zone indicates that the approximate depth of the deepest crustal layer of the upper plate is similar to that of the interplate seismogenic contact.

KEY WORDS: Guerrero, subduction, crust, velocity structure.

INTRODUCTION

The crustal structure is poorly known in Mexico. This is particularly true along the Pacific coast where the Cocos plate subducts beneath North America. In this region, some velocity models have been determined from refraction experiments (e.g. Nuñez-Cornú, 1988), and others come from the analysis of hypocentral residuals of aftershocks located after the 1979 Petatlan earthquake (Valdés *et al.*, 1982; 1986).

In September of 1987, a nine-station, locally telemetered seismic network was installed along the coast of Guerrero in southern Mexico as part of a cooperative project between the Instituto de Geofísica, UNAM and the Institut de Physique du Globe in Strasbourg, France (Solís, 1987; Suárez *et al.*, 1990). The network monitors the seismicity of the Guerrero seismic gap (Figure 1). This is one of the most clearly defined seismic gaps in the circum-Pacific belt (Kelleher, 1973; McNally and Minster, 1981; Singh *et al.*, 1981) where no major earthquakes have occurred at least since 1908. Nishenko and Singh (1987) suggested that this region is one of the segments of the Mexican subduction zone with the longest interseismic time intervals.

In this paper, digital data from the Guerrero network are used to invert for the velocity structure using the method suggested by Matumoto (1977). This method offers a first approximation to the velocity structure of the crust using the principle of Minimum Apparent Velocity (MAV). The method assumes the refraction of seismic waves in a laterally homogeneous medium. Yoshii and Asano (1972) suggested this assumption is valid in most subduction zones for distances up to 200 km. Compared to other methods of tomographic inversion, that of Matumoto (1977) is rather simple and unsophisticated. Our objective here is to use it as a first approximation which serves as a starting model for future work using more precise techniques.

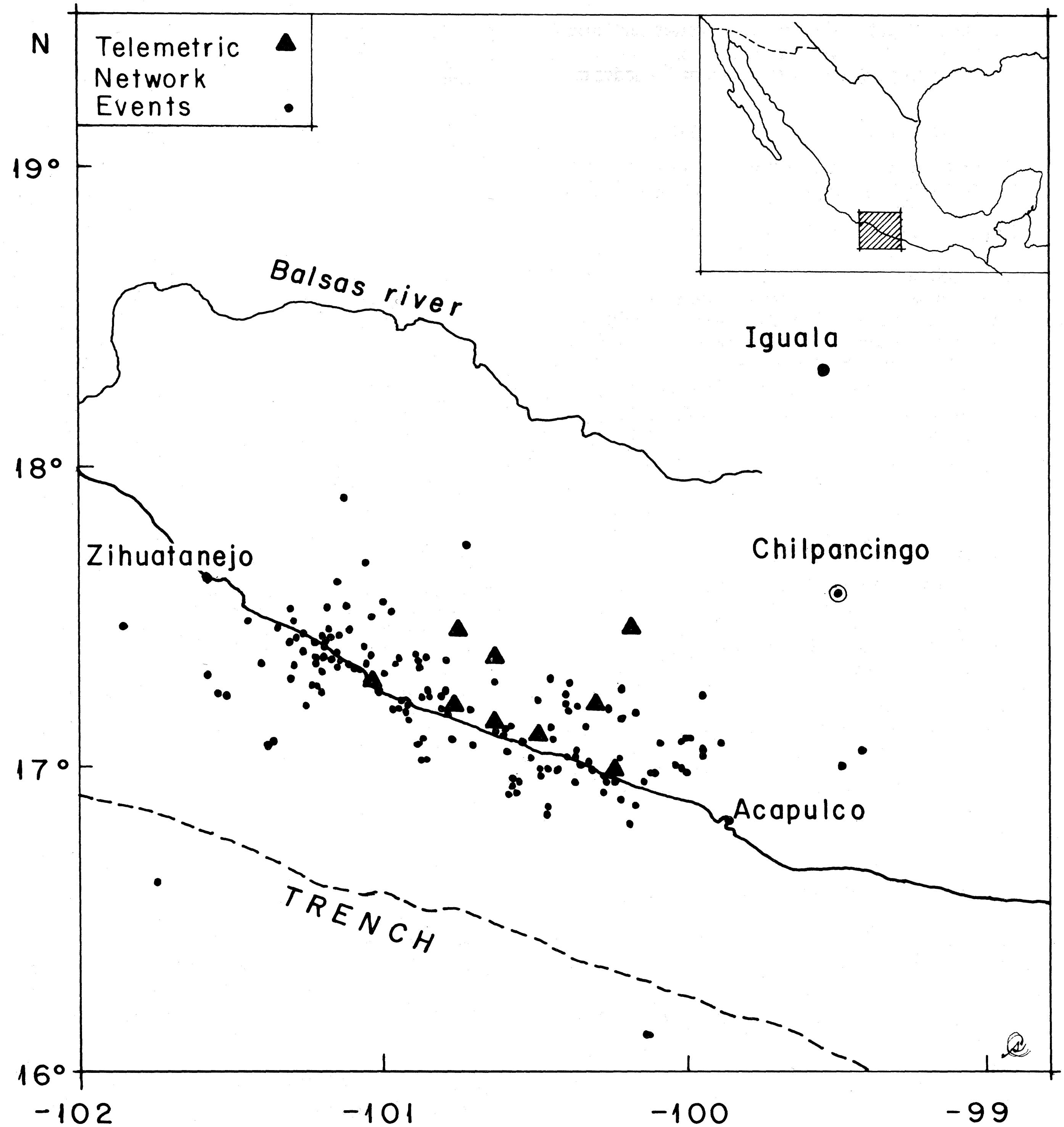

Fig.1. Location of the seismic stations of the Guerrero Network (solid triangles) and the family of earthquakes selected for this study (crosses).

One purpose was to obtain an adequate velocity structure for the routine location of earthquakes recorded by the network. Besides, it was of interest to have a better understanding of this region where the subduction geometry is complex. After an initial dip at a shallow angle, the subducted Cocos plate becomes almost horizontal at a depth of about 40 km (Suárez *et al.*, 1990). This horizontal slab underplating the continent can be clearly followed inland for a distance of about 200 km from the coast. These results suggest an anomalously thin continental lithosphere in southern Mexico with a thickness of less than about 45 to 50 km; about half of what is expected in a continental environment. Clearly, the velocity structure and crustal thickness of this thin lithosphere is of fundamental interest for understanding the tectonic evolution of this active margin.

DESCRIPTION OF THE METHOD

The method of minimum apparent velocity (MAV) is based on the refraction of seismic waves produced by well-located earthquakes on layers that are assumed to be horizontal and laterally homogeneous. It was first applied by Matumoto *et al.* (1977) in Costa Rica, and later by Pardo *et al.* (1985) in Central Chile. Based on the geometry of the Mexican subduction zone, the absence of drastic velocity changes along the strike of the coast is probably a safe assumption. Furthermore, the earthquakes used in the analysis sample a narrow portion of the upper plate along the coast. Thus, in the case of Guerrero, the one- dimensional model used here may be considered a first approximation to the velocity structure of the upper plate near the coast.

Consider a stratified medium composed of layers with a compressional seismic wave velocity V_i and thickness H_i (Figure 2). The point F is the source of the seismic waves, and $\theta_{i,i+1}$ is the angle of incidence at the base of layer i refracted on layer i+1. The apparent velocity VA of a seismic wave front is defined as:

$$VA = \Delta d / \Delta t$$

where Δd is the difference in epicentral distances and Δt is the difference in arrival times between a pair of seismic stations.

Arrivals between F and the critical distance represent waves travelling directly to the surface at velocity V_1. At distances greater than the critical distance, the first arrivals are head waves refracted from layers 2, 3, and 4 travelling with apparent velocities V_2, V_3, and V_4 (Figure 2). In the MAV method, critical distances and the associated apparent velocities are identified, and the thickness, H_i, and seismic velocity, V_i, of each layer are calculated.

A diagram is constructed to obtain the critical distances as well as the apparent velocities (Figure 2, top). This figure plots the measured apparent velocity against the mean epicentral distance for pairs of stations. Figure 2 (bottom) shows the corresponding rays for a shallow earthquake located at point F. As the MAV method uses only the minimum apparent velocity of critically-refracted waves to invert for the velocity structure, the choice of shallow earthquakes is crucial for the success of the method.

For an apparent velocity VA_i (i=1,2,...n+1) and a critical distance d_i (i=1,2,...n) obtained from the diagram of minimum apparent velocity, the travel time for a wave refracted at layer n is given by (Matumoto *et al.*, 1977):

$$t_n = d/V_n + \sum 2 H_i \cos \theta_{i,n} / V_i$$

where d is the epicentral distance ($d_{n-1} < d < d_n$), H_i is the thickness of the i-th layer, and $\theta_{i,n}$ is the angle of incidence at layer i of a wavefront critically refracted from layer n.

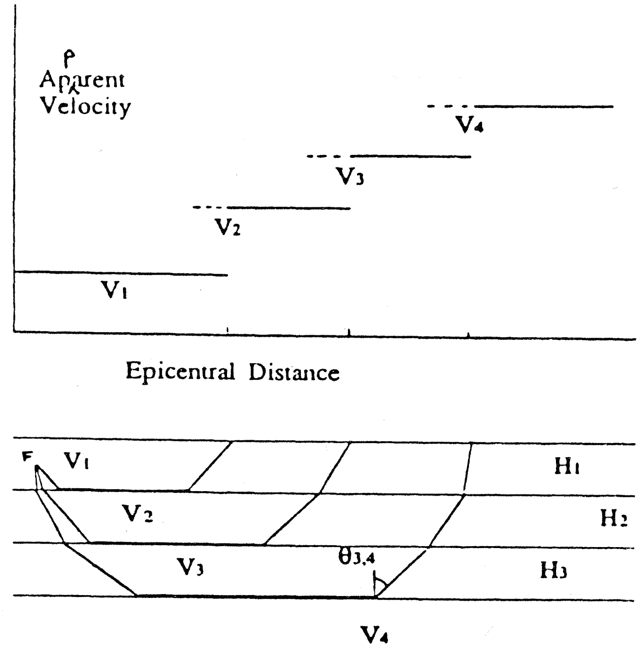

Fig. 2. Relationship between a hypothetical crustal model and its resulting minimum apparent velocity plot. Raypaths produced by a source point F are critically refracted at layers of thickness H_i with seismic velocities V_i. These critically refracted waves are recorded at different epicentral distances with a corresponding minimum apparent velocity.

The thickness H_i (i=1,2,...n) of the layers may be estimated by (Matumoto *et al.*, 1977):

$$H_n = \frac{V_n}{\cos\theta_{n,n+1}} \left[\frac{dn\,(V_{n+1} - V_n)}{2 V_{n+1} V_n} + \sum_{i+1}^{n-1} \frac{H_i}{V_i} \left(\cos\theta_{i,n} - \cos\theta_{i,n+1}\right) \right]$$

The resolution of the method depends on the spacing between the seismic stations. The greater the spread of distances between stations, the better is the possibility of sampling signals refracted from any given layer within the region of interest.

DATA SELECTION AND ANALYSIS

The earthquakes used in this study were recorded by the Guerrero Network (Figure 1 and Table 1), during the period between September 1987 and March 1988. Some events located in June 1988 were also utilized.

From 351 earthquakes recorded during this period, about 68% were within the epicentral distance range necessary to estimate minimum apparent velocities. An effort was made to include shallow events falling outside the network to improve control of the velocity structure. The events were located with the program HYPO71 (Lee and Lahr, 1978).

Table 1

Guerrero Telemetric Network

Station	Lat(°N)	Lon(°W)
Potrero Grande (PGO)	17° 22.51'	100° 37.28'
San Jerónimo (SJR)	17° 8.28'	100° 28.44'
Papanoa (PAP)	17° 18.03'	101° 2.27'
Florida (FLO)	17° 13.53'	100° 23.32'
Nuxco (NUX)	17° 12.65'	100° 45.28'
Puerto de Gallo (PDG)	17° 28.32'	100° 10.82'
Tetitlán (TET)	17° 9.70'	100° 37.83'
Puerto del Edén (PDE)	17° 27.79'	100° 44.46'
El Papayo (PPO)	17° 1.20'	100° 14.40'

The selection of events also included two basic criteria: 1) Events were selected when the epicentral distances of pairs of stations (Δ_1 and Δ_2), met the following criteria: $\Delta_1 < 0.66\ \Delta_2$, and 2) the difference in azimuth between each station pair and the epicenter was less than 30°. All events meeting these criteria were processed and plotted on a minimum apparent velocity plot (Figure 3).

RESULTS OF THE ANALYSIS AND DISCUSSION

The minimum apparent velocity plot of the selected dataset shows four reasonably clear horizons of refracted wavefronts (Figure 3). The dashed lines represent epicentral distance ranges for which data was unavailable. There were no shallow-depth earthquakes that would allow sampling of the upper part of the crust at short epicentral distances. Thus the upper five kilometers of the velocity model could not be defined with the information available (dotted line in Figure 4).

The resulting velocity model is composed of four layers (Table 2 and Figure 4). This model differs from that determined by Valdés *et al.* (1982) in the Petatlan region. Our model shows slightly higher velocities at shallow depth. Also, Valdés *et al.* (1982) proposed a top layer 18 km thick with a P wave velocity of 5.9 km/s, whereas our model subdivides this upper layer into a finer structure consisting of two layers (Figure 4).

Although earthquakes located far from the center of the seismic network were included, no refractions from the Moho were observed. The absence of a mantle refraction (V>7.9 km/s) may be due merely to the absence of seismic rays in our database sampling the deepest part of the crust.

Table 2

Crustal Structure for the Guerrero Gap

Velocity (km/sec)	Depth (km)
5.8	0.0
6.5	10.0
7.1	18.4
7.4	23.4

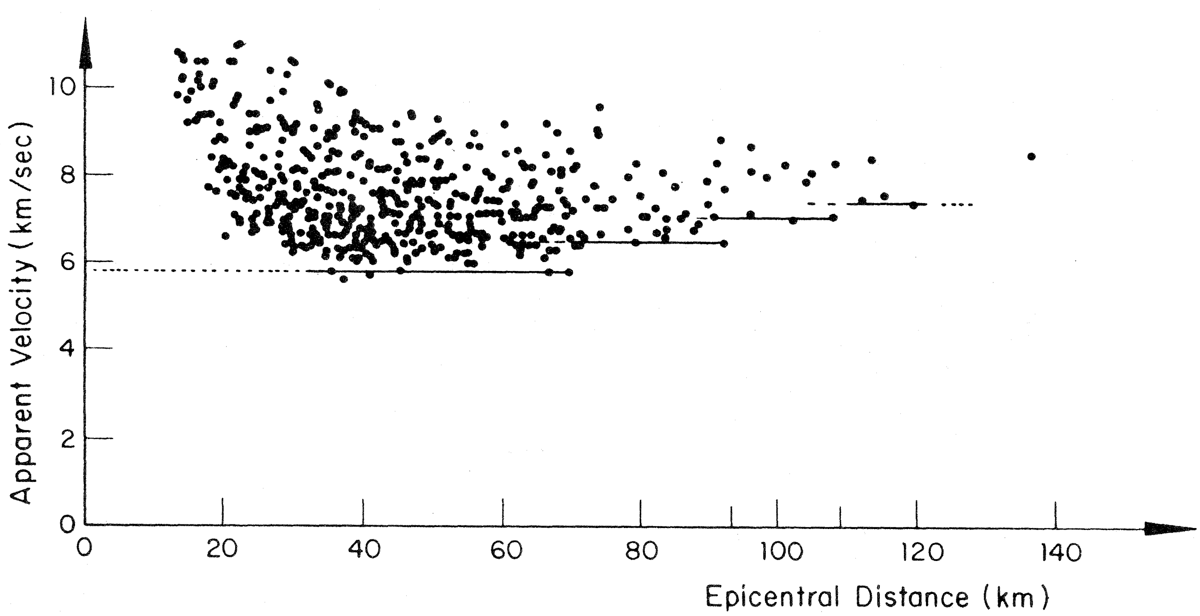

Fig.3. Resulting minimum apparent velocity plot. Dots represent observed apparent velocity arrivals as a function of epicentral distance. Four distinct layers are identified (solid lines). The dashed lines represent epicentral distances where no sampling of arrival times was available.

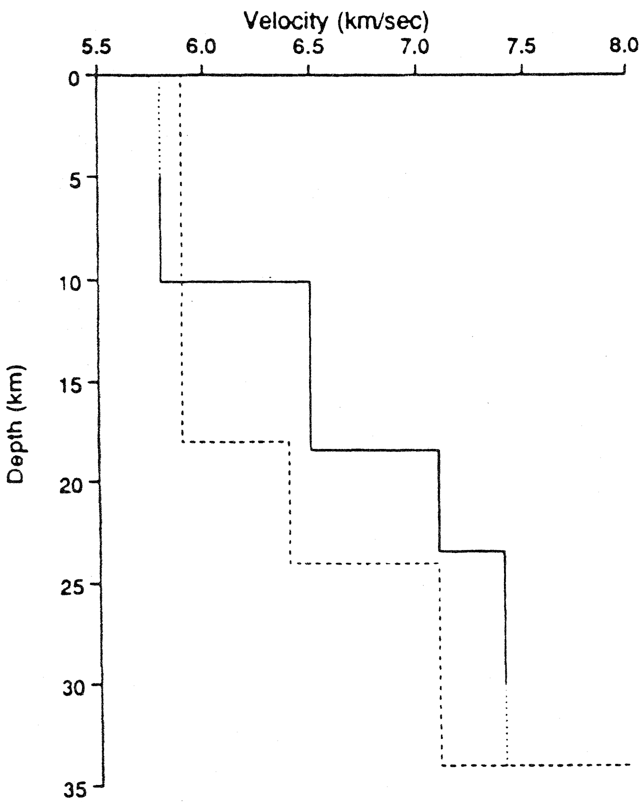

Fig. 4. Seismic velocity structure of the coast of Guerrero as a function of depth resulting from this study (solid line) compared with the results of Valdés *et al.* (1982) (dashed line). The dotted line in the resulting velocity profile indicates depths for which no sampling of refracted waves was available (see Figure 3).

On the other hand, it is possible that the mantle layer may be absent here in the upper North American plate. The deepest interface we encountered was at 23.4 km with a seismic velocity of 7.4 km/s.

This depth of 23.4 km agrees with the thickness of the upper plate determined from seismicity data in this region and corresponds approximately to the interplate seismogenic contact near the coastline (Suárez *et al*, 1990) (Figure 5). Thus it is likely that this value reflects the crustal thickness of the upper plate along the coast. If this were the case, the lower crust of this thin continental plate would lie directly on the Cocos plate without any intervening mantle layer. The deepest layer encountered, with a velocity of 7.4 km/s, may represent the top of the subducted Cocos plate. Because the method uses refracted waves at the interfaces, it is not possible to detect the presence of a low velocity layer in the upper part of the Cocos plate reflecting the upper crust of the subducted slab.

Perhaps, part of the crust of the downgoing slab and of the mantle of the upper plate were tectonically eroded by the subduction process, so that in the forearc the crust of the continental plate rests directly on the subducted slab. Such erosion of the forearc in a subduction zone has been reported in Peru and Japan (Von Huene and Lallemand, 1990; Von Huene and Culotta, 1989). Detailed marine seismic profiles are needed to understand in more detail the geometry and structure of the subduction zone in Guerrero.

SUMMARY

Application of the method of minimum apparent velocity in the Guerrero seismic gap in southern Mexico, leads to a crustal model composed of four layers. The velocity

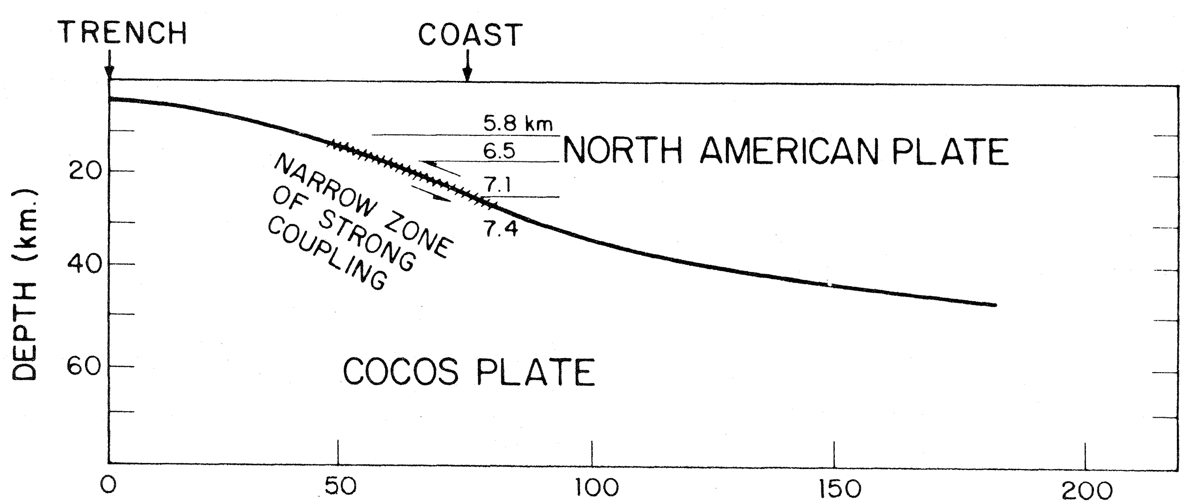

Fig. 5. Geometry of the subducted slab beneath the coast of central Guerrero. The depth and velocity of the layers obtained in the study are shown in the figure. Notice that near the coastline the depth of the deepest layer sampled corresponds approximately to the interplate contact (hatched line), suggesting the forearc of the overriding plate is devoid of mantle and the lower crust of the North American plate rests directly on the Cocos plate.

structure is more detailed than that proposed by Valdés *et al.* (1982) for the Petatlan region, approximately 150 km to the northwest of our study area. The upper crust appears to be composed of two distinct layers. No refracted wavefronts were observed from the Moho discontinuity. The deepest refraction observed comes from a layer starting at a depth of 23.4 km with a P wave velocity of 7.2 km/s. A comparison of the results obtained here with the geometry of the subduction zone interpreted from the microseismic data suggest that a thin crust of about 23.4 km rests directly on top of the Cocos plate without the presence of mantle material.

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