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A VELOCITY MODEL PERPENDICULAR TO THE ACAPULCO TRENCH BASED ON RESMAC DATA

F. F. CASTREJON V.*
A. A. PORRES L.*
F. A. NAVA P.**

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RESUMEN

La interpretación de las fases sísmicas observadas en registros de la Red Mexicana de Apertura Sísmica Continental (RESMAC), por medio de las diferencias en tiempos de travesía y rastreo de rayos, se utilizó para probar dos modelos de velocidad bidimensionales de uso corriente para la región de la Trinchera de Acapulco (sur de México). Como se encontró que los modelos eran inadecuados para explicar las observaciones, hubo que desarrollar un nuevo modelo "MEXD". El modelo MEXD presenta una corteza continental de 40 km de grosor, representada por capas horizontales, paralelas, de velocidad constante, y una capa de 24 km de grosor sumergiéndose con un ángulo de 13° en dirección N20°E, que representa la corteza oceánica subducida.

ABSTRACT

The interpretation of seismic phases observed in records from the Mexican Continental Aperture Seismic Network (RESMAC), by means of differences in travel times and ray tracing, was used to test two currently used bidimensional velocity models for the Acapulco Trench (southern México) region. The models were found to be inadequate to explain the observations; hence, a new model "MEXD" was developed. The MEXD model features a 40 km thick continental crust represented by horizontal, parallel, constant velocity layers, and a 24 km thick layer dipping with an angle of 13° in the N20°E direction, that represents the subducted oceanic crust.

* *IIMAS, UNAM, Apdo. Postal 20-726, 0100 México, D. F., MEXICO.*

** *Instituto de Geofísica, UNAM, Ciudad Universitaria, 04310, México, D. F., MEXICO.*

INTRODUCTION

Most of the large destructive earthquakes in Mexico occur along the segment of the Middle America Trench known as the Acapulco Trench (Fig. 1) and are related to the subduction of the Cocos Plate under the Northamerican Plate in this region (*e.g.* Dewey and Bird, 1970; Núñez, 1983). Thus, the correct evaluation of seismic risk and identification of seismic gaps and/or quiescent zones in this area, which depend largely on the correct location of the earthquakes that occur in this region, are important for all of southern and central Mexico. However, the flat horizontally layered velocity models used routinely for earthquake location in this region (*e.g.* *RESMAC Bull.*, 1984; *SSN Bull.*,1984; Lermo, 1984) are inadequate to represent a structure that prominently includes a dipping feature corresponding to the subducted plate. This problem is particularly bad for small and medium earthquakes that occur along the coast and offshore, for which the azimuthal coverage by regional stations is extremely inhomogeneous and the number of observations is small.

It is also necessary to consider a dipping layer in order to explain features of observed phases corresponding to the so-called plate waves (Lomnitz, 1982; Nava *et al.*, 1984). A step in this direction was taken by Toledo and Nava (1983) and Nava *et al.* (1984) who modified two currently used flat-layered velocity models by introducing a dipping region, in order to qualitatively explain some plate wave features.

A logical next step was to decide which of the above mentioned models, and other models currently used by Mexican seismological groups, modified in the same way, represent more adequately the observed arrival times. To do this, we based our study on data from the Mexican Continental Aperture Seismic Network (RESMAC), because the digital format of the RESMAC records simplifies data handling and makes possible the application of filters and other data processing techniques that facilitate the interpretation.

Some features from models that have been proposed for the region under study and for neighbouring regions are the following. Molnar and Sykes (1969) obtained a dip of 38° for the downgoing Cocos Plate in the region, based on seismicity and focal mechanism studies. Fix (1975) obtained an average model from Arizona, USA to Chiapas, México, based on surface wave studies; this model, featuring 5 layers, and a 43 km thick crust, has been used for the region of Chiapas, (*e.g.* Castro, 1980; Novelo, 1980). Chael and Stewart (1982) obtained a dip of 14° in the N23°E

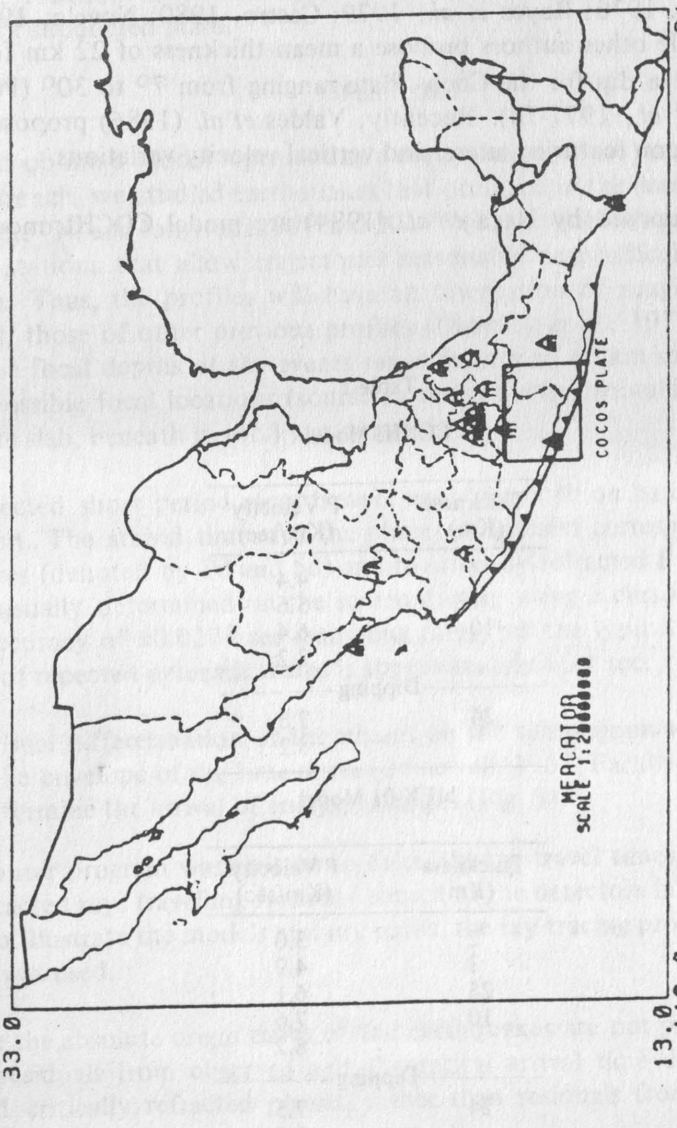

Fig. 1. Station distribution of the Mexican Continental Aperture Seismic Array RESMAC. Area within box is shown in detail in Figure 2.

direction for the subducted Cocos Plate in the region of Petatlán, Gro. A mean continental crust thickness of some 40 km and a subducted plate dip ranging from 7° to 25° have been obtained from seismicity and travel times by several authors (Dewey and Bird, 1970; Reyes *et al.*, 1979; Castro, 1980; Novelo, 1980; Valdés *et al.*, 1982), while other authors propose a mean thickness of 22 km for the continental crust and a dip for the Cocos Plate ranging from 7° to 30° (Ponce *et al.*, 1978; Drowley *et al.*, 1977-78). Recently, Valdés *et al.* (1986) proposed a model for the Oaxaca region featuring lateral and vertical velocity variations.

The models proposed by Nava *et al.* (1984) are model COCHI, modified from

Table 1

COCHI Model

Thickness (Km)	P Velocity (Km/sec)
5	4.4
7	5.6
10	6.4
	8.2
--------Dipping--------	
24	7.5
	8.2

MEX-01 Model

Thickness (Km)	P Velocity (Km/sec)
2	3.0
3	4.9
25	6.1
10	7.6
	8.2
--------Dipping--------	
24	7.5
	8.2

a model used for location of earthquakes in the Acapulco region (Beroza *et al.*, 1985); and model MEX-01, modified from the MEX model, used by RESMAC for routine location. Both models, shown in Table 1, feature a dip of 13° for the 24 km thick subducted plate.

METHOD

In order to obtain a model representing a cross section of the structure perpendicular to the trench, we studied earthquakes that occurred in the area between latitudes 16° and 18.5°N, and longitudes 99° and 101°W (Fig. 2, Table 2) and were recorded at RESMAC stations that allow trajectories reasonably perpendicular to the strike of the trench. Thus, the profiles will have an orientation of roughly N20°E, which agrees with those of other previous profiles (Drowley *et al.*, 1977-78; Valdés *et al.*, 1982). The focal depths of the events range from 4 to 60 km so that the complete range of possible focal locations (source in the upper horizontal layers, in the lower ones, in the slab, beneath it, etc.) was sampled.

The selected short period records were analyzed both on hard paper copies and on a screen. The arrival times for the phases of interest corresponding to direct P and S waves (denoted by Pd and Sd) and to critically refracted P waves (denoted by Pr) were usually determined on the screen display using a cursor. This method allows an accuracy of ±0.0277 sec (sampling rate), but the typical precision obtained by means of repeated determinations is approximately ±0.1 sec.

When visual differentiation of the phases on the seismogram was difficult or ambiguous, the envelope of the time series (Bracewell, 1965; Farnbach, 1975) was used to help determine the arrival of energy packages (Fig. 3).

A computer program was written to calculate the travel times for direct and critically refracted rays travelling from the source to the detectors in a two dimensional model. To illustrate the models and ray paths, the ray tracing program TRAZO (Nava, 1986) was used.

Because the absolute origin times of the earthquakes are not precisely known, we used the residuals from observed and theoretical arrival time differences between direct and critically refracted phases, rather than residuals from individual phase travel times.

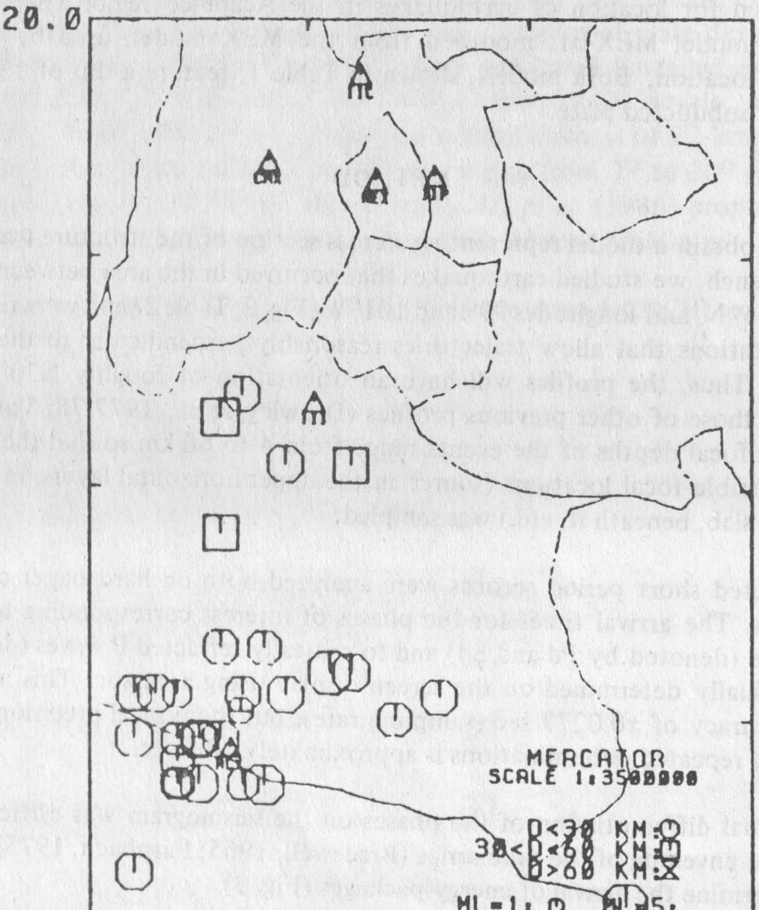

Fig. 2. Epicenters of the studied events.

Table 2

Event	Latitude	Longitude	Date	ML	Depth Km.
17:046	18.1	99.3	12-I-81	4.0	60R*
19:089	17.8	99.9	24-VI-81	3.9	40R
19:109	17.2	99.3	14-VII-81	4.1	30
19:116	17.0	99.8	20-VII-81	2.6	5
21:026	18.1	99.6	4-XI-81	4.1	4
21:060	18.4	99.8	22-XI-81	3.9	30R
23:059	16.9	100.0	7-VI-82	3.8	15
24:082	16.9	100.1	10-VII-82	3.6	10
24:102	17.3	99.7	19-VII-82	4.3	40R
25:001	18.4	101.3	20-VII-82	4.1	10
25:006	17.2	99.4	22-VII-82	4.9	5
25:012	18.3	99.9	24-VII-82	4.3	40R
25:055	16.7	100.0	18-VIII-82	4.4	5
25:062	16.9	100.0	19-VIII-82	4.5	9
25:085	17.3	100.6	11-IX-82	3.5	10
26:003	16.7	99.7	2-X-82	4.6	10
26:020	16.9	100.3	14-X-82	4.2	5
26:072	16.7	100.1	8-XI-82	3.7	10
26:081	16.7	100.1	12-XI-82	3.7	10
27:006	16.3	100.3	29-XI-82	4.1	10
27:015	16.7	99.8	3-XII-82	3.5	20
27:088	17.1	100.1	13-I-83	3.9	10
28:041	16.9	99.9	4-II-83	4.1	16
29:018	16.9	100.1	12-IV-83	3.5	10
29:053	17.1	99.8	6-V-83	4.0	6
30:070	16.9	100.1	25-VII-83	3.7	6
31:029	17.1	100.2	29-VIII-83	4.2	10
31:051	16.8	100.1	-IX-83	3.7	8
31:095	16.6	101.3	13-X-83	4.4	20
32:047	17.0	99.1	14-XI-83	3.7	5
32:068	17.1	98.9	30-XI-83	3.9	15
33:011	17.1	100.3	14-XII-83	3.9	10
33:049	17.3	99.9	7-I-84	3.8	10
33:058	17.1	99.6	11-I-84	4.1	6

* R indicates fixed-depth location.

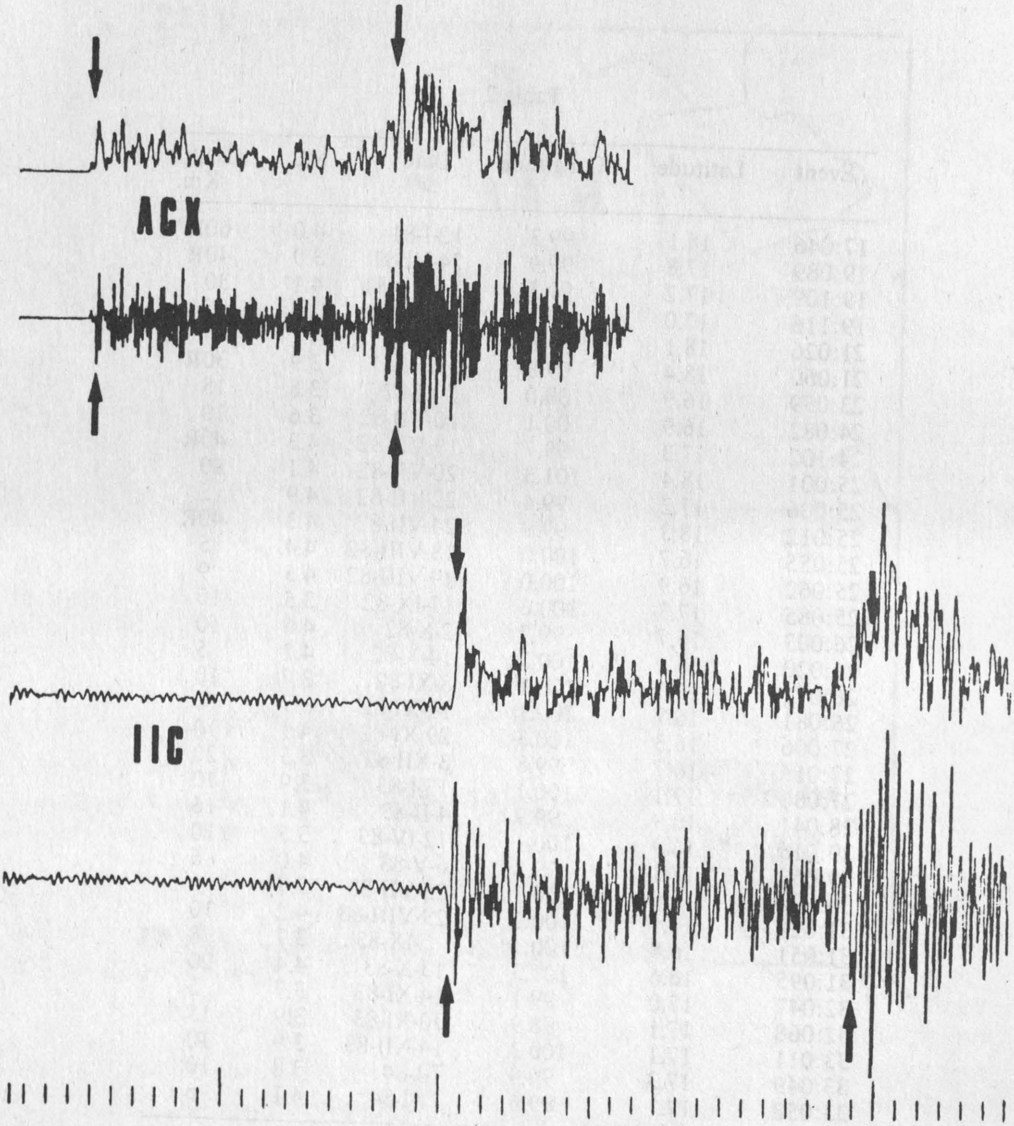

Fig. 3. Example of the use of the seismogram envelope to help in arrival time determination.

Thus, for each station we evaluated the observed differences D1 and D2:

$$D1 = Sd - Pd,$$

$$D2 = Pd - Pr,$$

and the corresponding theoretical differences D3 and D4 assuming $Vp/Vs = \sqrt{3}$. From these differences, we evaluated the difference residuals R1 and R2:

$$R1 = D1 - D3,$$

$$R2 = D2 - D4,$$

which are a measure of the model adequacy, and whose minimization is the basis for model modifications.

DATA INTERPRETATION AND MODEL DETERMINATION

We studied 33 events occurred between January 1981 and March 1984 in the zone mentioned above. The events were selected for clearly identifiable P and S phases. A minimum of 2 and a maximum of 6 records from different stations were studied for each event. Records from ACX station were included whenever possible, because it is the station closest to the epicenters, and hence it showed good arrivals for direct phases which were a good constraint for the source location.

Initially, we tested the MEX-01 and COCHI models to see whether they satisfied the observations. Extremely large time difference residuals, some of them greater than 10 sec, indicated that the models were inappropriate and/or the location was erroneous. Because the reported hypocenters are only approximate, both locations and depths were varied within a range of ±5 km to eliminate the effect of erroneous locations on the residuals. The general effect of this variations was to decrease some of the residuals while considerably increasing the others, indicating that the large values of the residuals were not mainly due to mislocation.

Another indication that the models under consideration are not adequate is that, for a large range of depths (20 - 60 km), arrivals corresponding to rays travelling towards inland stations are observed; while according to the models, they should be trapped at depth in a low velocity wave guide. Also, more refracted phases are observed on the seismograms than the theoretical ones predicted by the models. Some of the "best" possible residuals for models MEX-01 and COCHI are shown in Table 3.

The inadequacy of the examined models pointed out the necessity for a better model to satisfy the observations. Hence, we proceeded to elaborate a new model incorporating the combined favorable characteristics of model MEX-01 (its velocities) and COCHI (its shallow interfaces) according to the following criteria:

a) The number of identifiable critically refracted arrivals defines the minimum number of model interfaces.

b) The amplitude of the refracted waves depends (among other factors) on the velocity contrast between the refracting layer and the layer immediately above it; large amplitudes corresponding to strong contrasts for small angles of incidence ($\theta < 30^{\circ} - 40^{\circ}$) (Grant and West, 1965). This criterion was used only when applicable.

c) Direct ray arrivals are usually the best determined ones, due to the generally large relative amplitude of direct phases. Direct ray theoretical arrival times (referred to some appropriate origin time) should correlate well with the observed arrival times at all stations.

d) The assumption of a dipping layer acting as a partial wave guide is necessary in order to explain early arrivals from earthquakes recorded near the coast.

The procedure was the following:

The wave velocities in a horizontal layer were modified according to the arrival times for the direct rays; then, the layer thicknesses were modified according to the refracted ray arrival times. This process was carried out beginning at the shallow layer, and the hypocentres were shifted (within a 5 km radius sphere) to obtain minimum residuals. A time correction for the elevation of the stations Dt defined by:

$$Dt = -h(Vo^{-2} - Vr^{-2})^{1/2}$$

where h is the elevation, Vo is the velocity of the surface layer, and Vr is the velocity of the refracting layer (Nava and Brune, 1982) was applied to the data. Both the dip and the thickness of the subducted crust were also varied.

Table 3

Event	STAT	MEX-01 Pd-Sd	MEX-01 Pd-Pr	MEX-01 Pd-Pr	COCHI Pd-Sd	COCHI Pd-Pr	COCHI Pd-Pr	MEXD Pd-Sd	MEXD Pd-Pr	MEXD Pd-Pr
25-01	CRX	-0.78	-1.67	–	2.34	0.28		0.21	0.09	
	HP	1.7	1.34	–	3.56	-0.36		0.13	0.25	0.29
26-03	ACX	0.23	–	–	0.02			0.04		
	HI	3.65	–	–	5.65	0.48	2.38	0.06	0.12	-0.02
	HC	0.86	–	–	-0.39	0.98	4.07	0.20	0.12	0.08
	HP	-3.78	–	–	1.86	4.04	0.91	0.47	-0.04	0.03
26-81	ACX	0.17	–	–	0.35	1.37		0.01	–	–
	HI	1.2	–	–	2.3	3.2		0.16	0.04	–
	CRX	3.4	–	–	3.1	4.9		0.27	0.02	–
	HP	4.85	–	–	8.40	0.45		0.22	0.01	–
	HC	2.02	–	–	6.00	1.63		0.52	0.04	
27-06	ACX	-2.30	–	–	2.05			0.04		
	HI	-1.73	–		0.88	0.73		0.15	0.15	
	CRX	-1.92	–	–	1.06	1.56		0.02	0.0	
	HP	0.50	–	–	1.81	1.95		0.29	0.09	–
	HT	1.10	–	–	1.85	1.96		0.22	0.09	
	HC	1.80		–	1.95	1.97		0.30	-0.12	
31-29	ACX	-1.78	–	–	0.69			0.0	–	–
	HI	0.82	–	–	1.60	2.00		0.14	-0.29	0.03
	MEX	1.20	–	–	2.00	2.10		0.05	0.15	0.09
	HP	1.35	–		2.20	2.34		0.01	0.05	-0.39
	HT	1.65	–	–	2.38	2.43		0.18	0.03	-0.06
	HC	1.99	–	–	2.45	2.56		0.48	0.42	0.77
31-51	ACX	-1.39	–	–	-5.15			0.01	0.0	0.12
	CRX	0.24			2.48	0.06		0.01	0.07	0.0
	HI	1.70		–	3.43			0.21	0.39	–
	HP	2.33		–	4.01			0.03	0.18	
19.89	ACX	1.34	–	–	2.23	–		0.3		
	MEX	0.14	–	–	1.14			0.13		
	HP	0.10	–	–	2.12			0.09		
	HC	0.20	–	–	1.12	–		0.31	–	
	CRX	0.08	–	–	3.12			0.04		
17-46	ACX	3.13	–		5.1			0.05	–	–
	HP	0.68	–	–	2.12			0.14	–	–
	HC	1.92	–	–	3.2			0.27	–	

RESULTS AND DISCUSSION

The process outlined above was iterated several times until changes resulted in no further decrease of the mean square value of the residuals. The resulting model MEXD which consists of 5 horizontal and 2 dipping layers, and results in a residual mean square value of 0.185 sec., is shown in Table 4 and Figure 4.

Table 4

MEXD Model

Thickness (Km)	P Velocity (Km/sec)
5	4.0
9	5.8
8	6.25
18	7.1
	8.2
——————Dipping——————	
24	7.5
	8.2

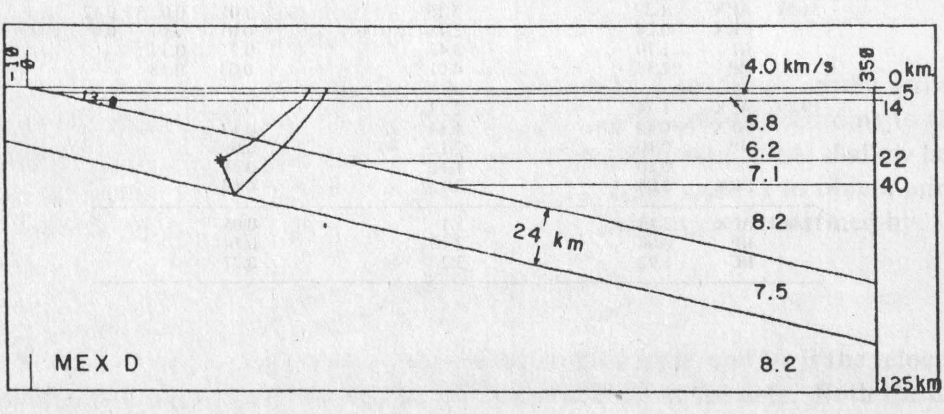

Fig. 4. MEXD model. The origin of the horizontal scale coincides with the trench at the surface.

The resulting thickness of 40 km for the continental crust agrees with the one proposed by other studies in the Pacific coast of Mexico (Reyes *et al.*, 1979; Valdés *et al.*, 1982; Dewey *et al.*, 1970; Castro, 1980). The subducted crust has a dip of 13^{o} in the approximate N20^{o}E direction and a thickness of 24 km which agrees with the tentative values in the COCHI and MEX-01 models.

Model MEXD is appropriate to represent the structure, because:

- The relative times of the refracted phase arrivals identifiable on the RESMAC records correlate with the theoretical ones.

- The model is able to reproduce the observed phases for all source depths, while COCHI and MEX-01 are adequate for some depth ranges only.

- MEXD permits rays critically refracted in the Cocos Plate - Continental Crust Interface, which are observed in records from stations ACX and III.

- The differences in the arrival times of the first arrivals at different stations agree with those obtained from MEXD.

- Features a partial wave guide in the form of a low velocity channel caused by the subducted plate as proposed by Nava *et al.* (1984).

Figures 5 and 6 are examples of how the observed phases on a seismogram are fitted by the MEXD, COCHI, MEX01, SISMEX and Valdés *et al.* (1982) models. They show that use of the MEXD model gives the best fit for this region.

Thus, we conclude that the MEXD model is a reasonably good working model appropriate for the Acapulco Trench region. It will also be useful as a starting model in the interpretation in the near future of deep seismic profiles data already collected in southern México.

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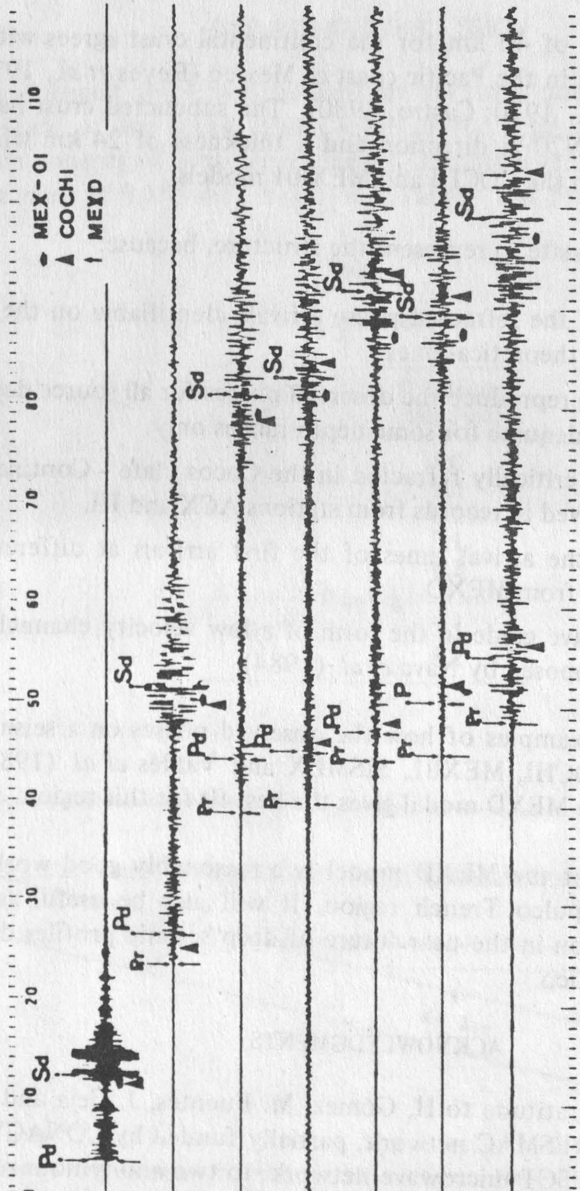

Fig. 5. Example of the better fit to observed arrivals by theoretical times from the MEXD model as compared with those from the MEX-01 and COCHI models.

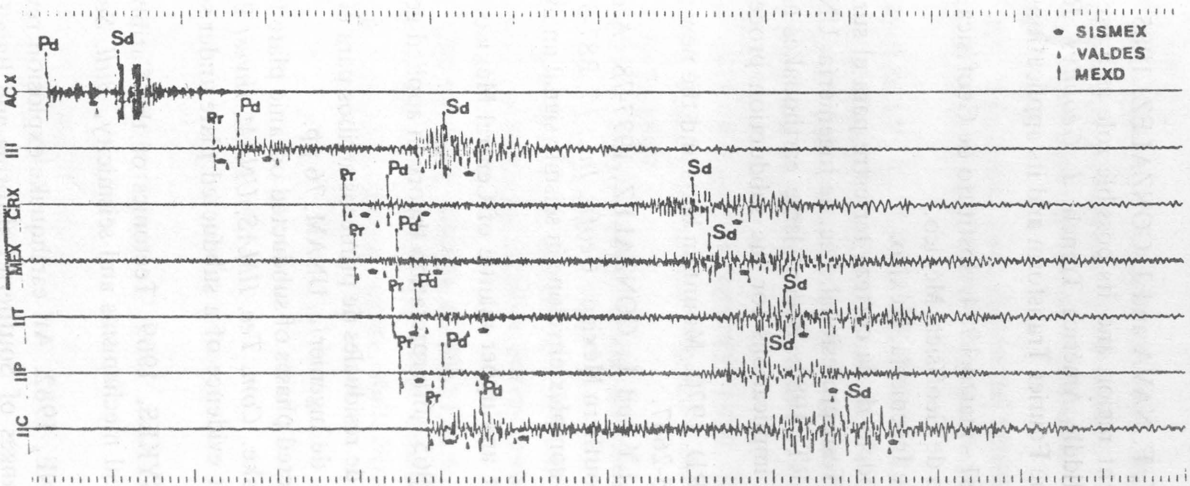

Fig. 6. Comparison between the MEXD model and the SISMEX and Valdés *et al.* (1982) models.

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