A preliminary crustal model of the Oaxaca continental margin and subduction zone from magnetotelluric and gravity measurements

Jorge A. Arzate [1], [2], Mariane Mareschal [1] and Jaime Urrutia-Fucugauchi [2]

1 Génie Minéral, Ecole Polytechnique, Montréal, Québec Province, CANADA.
2 Laboratorio de Paleomagnetismo y Geofísica Nuclear, Instituto de Geofísica, UNAM, México.

RESUMEN

Se presenta un modelo de estructura regional para el margen continental sur de México, en la región de Oaxaca. El modelo se deriva principalmente de datos de catorce sondeos magnetotelúricos (MT) a lo largo de dos transectos, localizados entre Puerto Escondido y Oaxaca (Transecto W) y Puerto Angel y Oaxaca (Transecto E) y datos de gravimetría en un perfil entre Puerto Escondido y Alvarado. El modelado de los datos gravimétricos se realizó empleando diversos métodos como análisis espectral, inversiones de una capa con densidad constante y variando exponencialmente y ajuste de modelos tipo Talwani de polígonos en 2 y 2.5 dimensiones. El modelado de los datos de MT se realizó empleando el algoritmo de Marquardt SVD en una dimensión en las fases y resistividades aparentes promedio obtenidas después de remover el corrimiento o desplazamiento estático. La corrección del desplazamiento estático se realizó refiriendo los datos a un sitio con baja o nula distorsión galvánica. La litosfera oceánica subducente de la Placa de Cocos se representa por una capa conductora, que presenta un bajo ángulo de buzamiento. En varios sondeos del transecto W se observa una capa relativamente conductora y de espesor variable, la cual se empleó como elemento adicional para invertir los sondeos MT. Esta capa o horizonte de baja resistividad, en el orden de 10 a 90 ohm-m presenta una inclinación regional de unos 20 a 25 grados hacia el continente. La profundidad de esta capa es de unos 10 km en los sondeos cercanos a la costa y de unos 33 km en el interior. Las variaciones en la geometría de esta capa, que en algunos segmentos es horizontal o con una inclinación hacia el océano sugiere la ocurrencia de un conductor bi-dimensional, lo que es apoyado por las relativamente altas magnitudes de los vectores de inducción, que consistentemente se orientan hacia el SW. La corteza muestra un engrosamiento en la porción central de los dos perfiles MT. Los modelos de gravimetría presentan una geometría para la interfase corteza/manto que sigue muy cercanamente a los datos de MT, con una profundidad entre unos 8 y 10 km mayor. El ángulo de subducción estimado del modelo gravimétrico es de 13 grados. La topografía del Moho muestra una buena correlación con rasgos estructurales mayores en la superficie.

PALABRAS CLAVE: Magnetotelúrico, gravimetría, litosfera, zona de subducción de Mesoamérica, Estados de Oaxaca y Veracruz, sur de México.

ABSTRACT

A preliminary model of the conducting layer associated with the continental margin and the Cocos Plate subduction zone along two transects normal to the southern Mexico continental margin is presented. The transects are located approximately from Oaxaca City to Puerto Escondido (W-transect), and to Puerto Angel (E-transect). The study is based on fourteen magnetotelluric (MT) soundings and on regional gravity measurements. Modelling of gravity data includes spectral analysis, 2 and 2.5-D Talwani-type models and several inversion schemes with constant and exponentially variable density contrasts. One dimensional inversion of MT data using a Marquardt SVD algorithm was performed on the rotationally invariant determinant average apparent resistivities and phases after static shift was removed with reference to a site apparently devoid of galvanic distortion. A conductive layer of varying thickness was correlated with a seismic reflecting horizon under various MT sites of the western profile. These correlated soundings were used to constrain the inversion results of the remaining MT sites. We assume that the top of the electrically conductive horizon corresponds to the top of the Phanerozoic lower continental crust, which has an approximate dipping angle of 20° to 25° and is characterized by conductivities from 10 to 90 ohm-m. Although this boundary is in general plunging towards the continent there are several sites in both transects at which it flattens and even reverses its trend. This may be an artefact of the 1-D inversion in zones where the data are 2 or 3-D. This is supported by relatively high induction vectors consistently pointing SW at these sites. The crust thickens towards the central portion of both MT transects, beneath the Sierra Madre del Sur. There is a good correspondence with gravity models derived from spectral analysis and estimates of the crust/mantle boundary. There is however an apparent depth difference (8 to 10 km) between the MT- and gravity-derived crust/mantle boundary. The dip of the subducting plate estimated from the gravity model is shallow, about 13 degrees. The topography of the Moho shows a correlation with major structural features at the surface.

KEY WORDS: Magnetotellurics, gravity, lithosphere, Middle America, subduction zone, Oaxaca and Veracruz States, southern Mexico.

INTRODUCTION

Gravity and electromagnetic (EM) geophysical techniques, and particularly the magnetotelluric (MT) method, have been successfully used in the past for lithospheric studies in continental margins (e.g. Kurtz *et al.*, 1986; EMSLAB Group, 1988; Wannamaker *et al.* 1989). The widely reported anomalously low electrical resistivities

associated with the presence of fluids in relatively young subducting zones at the interface of the continental lower crust and the subducting oceanic lithosphere may help study similar tectonic phenomena in other parts of the world. The present MT and gravity survey is part of a multi-disciplinary international scientific effort (GEOLIMEX) to study the subduction zone in southeastern Mexico. The results reported in this paper are of preliminary nature and may contribute to interpretations of other groups working in the area.

It has been suggested that the observed electrical high conductivity and reflectivity properties of the lower crust are due to the presence of water (*e.g.* Gough, 1986). We assume that fluids caught in the subduction tectonic zone and transported along the lower crust are responsible for the anomalous electrical conductivity observed in our MT transects. These fluids would be released and get trapped under an inpermeable zone which is thought to occur at the 400°C isotherm.

We present a model of the continental lithosphere which has not yet been corrected for galvanic distortion observed at several sites, but that may be a good first approximation to the structure of the continental lithosphere in central and southern Oaxaca. There is a good correlation with the results of the gravity models derived from spectral analysis and estimates of the crust/mantle interface. The apparent depth difference between the inferred crust/mantle boundary from MT and gravity may be probably due to poor static shift corrections.

MAGNETOTELLURIC SURVEY

A total of fourteen MT measurements were carried out mainly south of Oaxaca City along two profiles (Figure 1) which cross three different suspected terrane boundaries. The location of sites according to the main geological provinces was as follows: site 6 is located in the Sierra de Juarez, north of Oaxaca City; sites 1, 2, 3, 4, 7 and 8 are distributed in the Oaxaca Valley; sites 5, 9, 10 and 11 were located in the Sierra Madre del Sur, and sites 12, 13 and 14 are located in the Xolapa terrane along the Pacific margin.

The data acquisition was in the frequency interval between 384 and 5 x 10-4 Hz (or 2000 sec). A remote reference unit about 0.5 to 1 km apart from the site location was used. The horizontal components of the magnetic field were recorded in the remote site so that local inhomogeneities at the site location or any cultural noise could be monitored and accounted for.

Generally speaking, the telluric and magnetic signal to noise ratios were very good. As a result good quality data was recorded. The location of the MT soundings was done according to the availability of relatively noise-free sites which were tested for AC components prior to a definite measurement. Thus some of the sites have to be located in topographically accidented remote areas which resulted in near surface distorted field curves. The observed electrical

resistivities in most of the MT sites is in general less than 50 ohm-m for the surface layer. This has the advantage of reducing the static shift problem, however, it also limits the investigation depth.

MAGNETOTELLURIC MODEL

The apparent resistivities and phases were calculated and plotted in pseudo-sections for both North-South (NS) and East-West (EW) azimuths. The NS apparent resistivities and corresponding phases are shown in Figure 2 for both transects. Although the electrical structure in the apparent resistivity pseudo-section is obscured by the presence of static shift at several sites, the high phase values in the lower part of the phase sections reveal a gently dipping conducting layer in both profiles.

In order to be able to correct for static shift, the rotation of the impedance tensor individual components as a function of period (Chakridi, 1991) was performed, and departure from a 1-D earth was observed at each site. Site 2 had diagonal elements close to zero and off-diagonal elements nearly equal and independent of the rotation angle at high frequencies (Figure 3), thus it was used as the reference site to correct the rest of the curves for static shift.

The rotationally invariant determinant average apparent resistivity and phase were computed for the corrected sites and a 1-D Marquardt inversion was performed on them. This is an approximation which allows to model all electrical responses as due to vertical effects with no lateral contribution. It is a very useful approach as a first step in the analysis to define the general electrical model of a region. The inversion process was constrained for sites 4, 5 and 13 using seismic reflection results (Figure 4) from Couch and Burbach (1985). These sites were selected because they were within 100 km of the seismic line. The other soundings were modeled relatively to these three sites. Figure 5 shows the electric structure for the Oaxaca-Puerto Escondido and the Oaxaca-Puerto Angel profiles (also referred to as the west and east profiles) obtained by assuming 1-D structure under each site i. e. with no side effects.

A conductive layer is observed for both profiles, whose upper boundary is located at depths ranging between 10 km for the sites closest to the Pacific Ocean, to 33 km for those farther inland. It seems gently dipping, although there are sites where the trend appears to reverse as can be observed at sites 3, 1 and 2, and 9, 8 and 7 in the respective transects. Although not well constrained, the lower boundary suggests a thickening of the layer in the middle of both profiles. Specific details need to be modeled with a 2- or even 3-D algorithm after distortion effects have been removed. As expected, the dip of the subducting slab is shallow. This is consistent with earthquake epicenter locations and with the rapid convergence between the Cocos and North American plates. A fast plate convergence results in a small component of gravitational sinking which translates into a smaller angle of subduction as well as in a wider spacing and depression of the isotherms (*e. g.* Cross and Pilger, 1982).
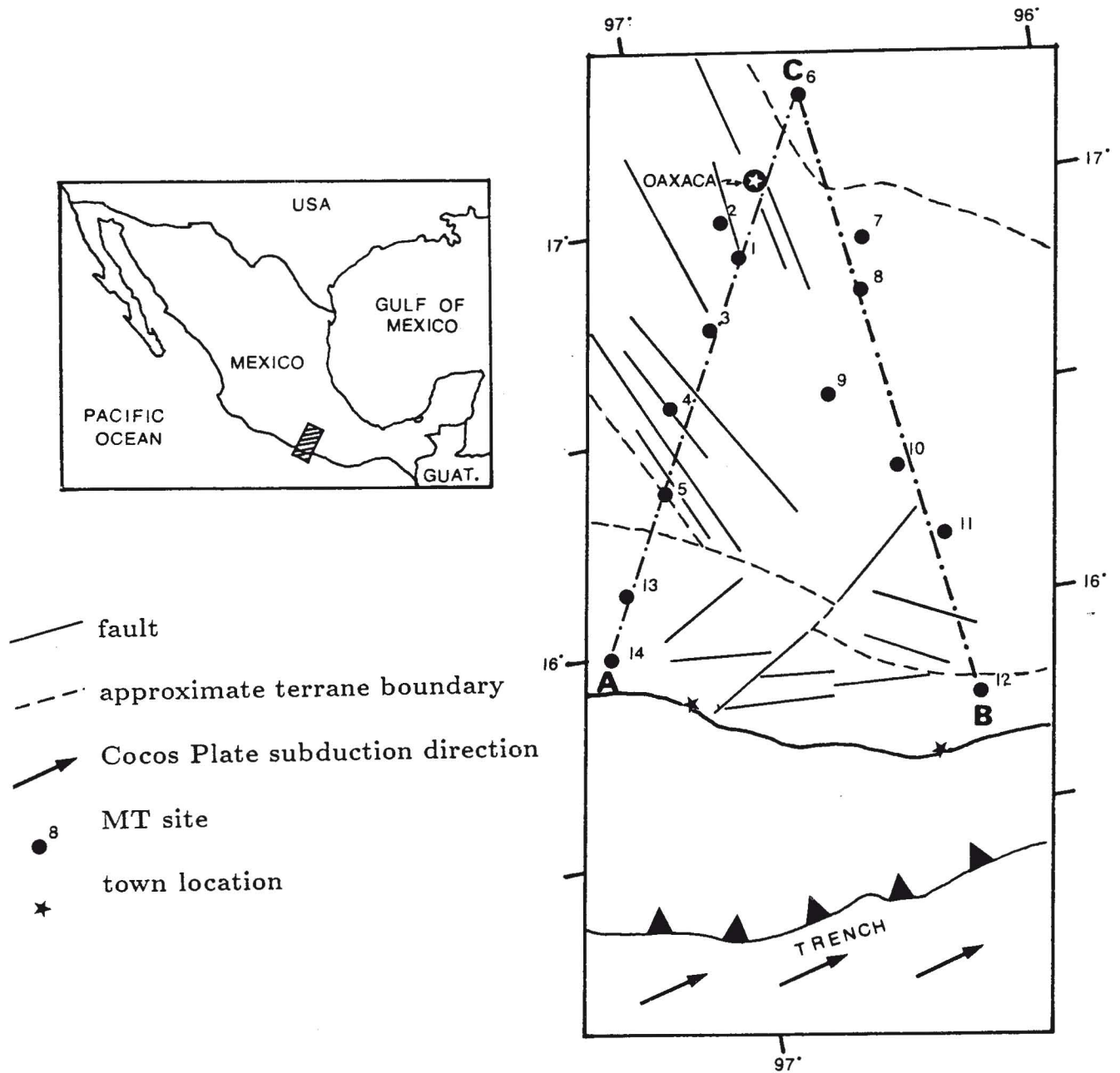
Fig. 1. Location map of the surveyed area. Dashed rectangle in the upper left frame is the enlarged map shown to the right. The MT projection western and eastern transects are indicated by the lines CA and CB respectively.

A two dimensional feature striking NW-SE is suggested by plotting the induction arrows at earth site location (Figure 6). The pointing direction at sites 2, 1, 3, 9, 10 and 11 at different periods remains practically the same and is consistent with the orientation of the major fault system. The approximate azimuth of the suspected conductor is around N45 W.

GRAVITY MODELLING

The Bouguer and Free-Air gravity anomaly data along the geotransect examined by Ortega-Gutiérrez (1990) have been analyzed to provide constraints on the deep crustal

structure. The transect extends from the Pacific Ocean close to the Middle America trench to the Gulf of Mexico, across an assemblage of terranes with varying metamorphic and crystalline basements, ages and tectonic characteristics. The gravity anomaly was digitized at equal spacings for a total of 88 points (Figure 7). The gravity is characterized by a positive anomaly (maximum of 50 mgals) close to the coastline and above the Xolapa complex, which is represented by metamorphic and intrusive rocks. More to the northeast the gravity shows increasingly negative values and a broad regional negative anomaly (up to a minimum value of -180 mgals) over the Grenvillian Oaxaca complex. The profile crosses the Sierra Madre del Sur and the fault

443

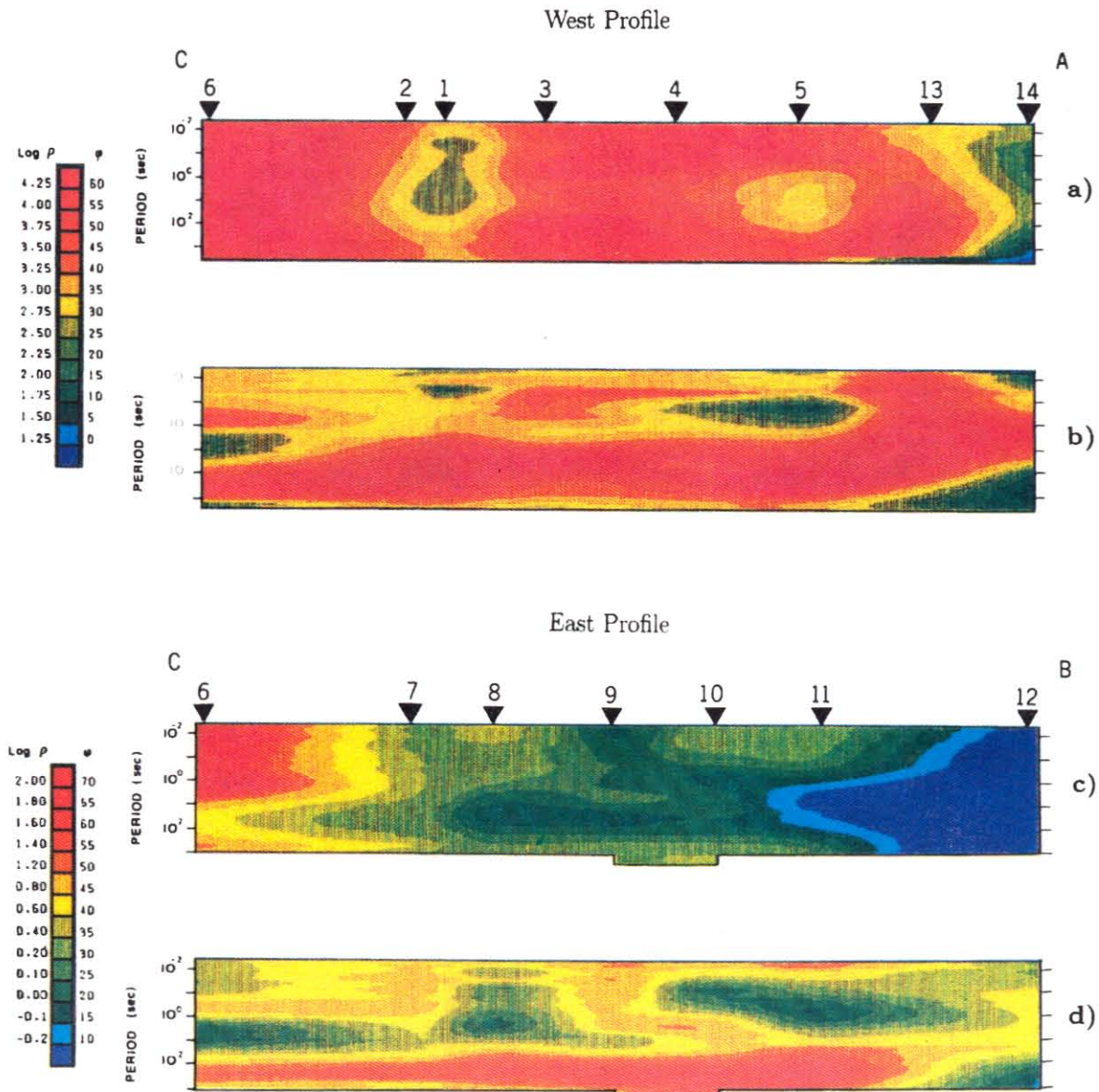E-polarization MT pseudosections

West Profile

East Profile

Fig. 2. NS apparent resistivity and phase pseudosections for the western (CA) and eastern (CB) MT transects. Letters (a and (c refer to the apparent resistivity while (b and (d to the phase angle for profiles CA and CB respectively. Strong static shift effect is observed in both profiles for the apparent resistivity sections which obscures the underneath electric structure. Phase pseudosections, which are not affected by static shift, suggest a conducting elongated structure at long periods.

zone and mylonitic unit of Juchatengo (characterized by a change in the gradient). Minimum values coincide with a wide mylonitic zone to the north of Oaxaca City. The gravity anomaly changes again towards positive values across the Sierra de Juárez, with a positive anomaly over the Gulf coastal plain (in the order of -40 mgals). Then,

the gravity anomaly rises uniformly over the coastal plain and Gulf of Mexico (Figure 7).

A first analysis of the gravity anomaly without previous assumptions on the geometry and density contrast of the subsurface units was completed. Spectral analysis
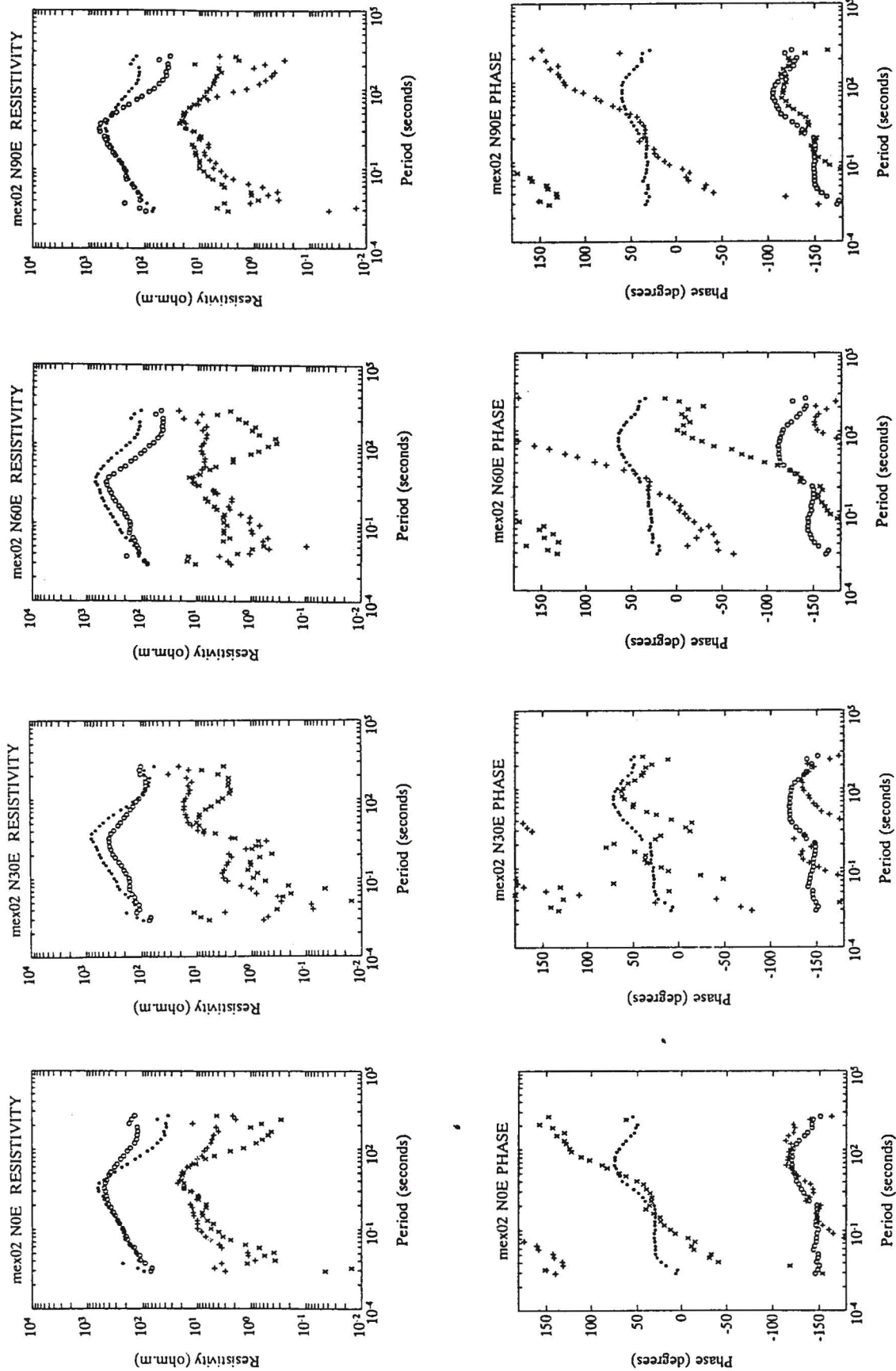
Fig. 3. The resistivities (upper set of figures) and phases for *Site 2* computed from each of the impedance tensor elements Z_{xx}, Z_{xz}, Z_{yx}, and Z_{yy} are shown here at different rotation angles: a) 0°, b) 30°, c) 60° and d) 90°. Curves with the "o" and "*" symbols were computed using the off-diagonal elements of the tensor, i.e. Z_{xy} and Z_{yx} respectively while curves with the symbols "+" and "x" were computed using the diagonal elements Z_{xx} and Z_{yy} respectively. ρ_{xy} and ρ_{yx} are not significantly affected with the rotation of the impedance tensor neither are ϕ_{xy} and ϕ_{yx} curves. Scatter in the ρ_{xx} and ρ_{yy} as well as for ϕ_{xy} and ϕ_{yx} curves is due to the near-zero values of Z_{xx} and Z_{yy}. This *Site 2* shows quasi 1-D characteristics specially at the higher frequencies and therefore it was used to correct for static-shift of the western profile.
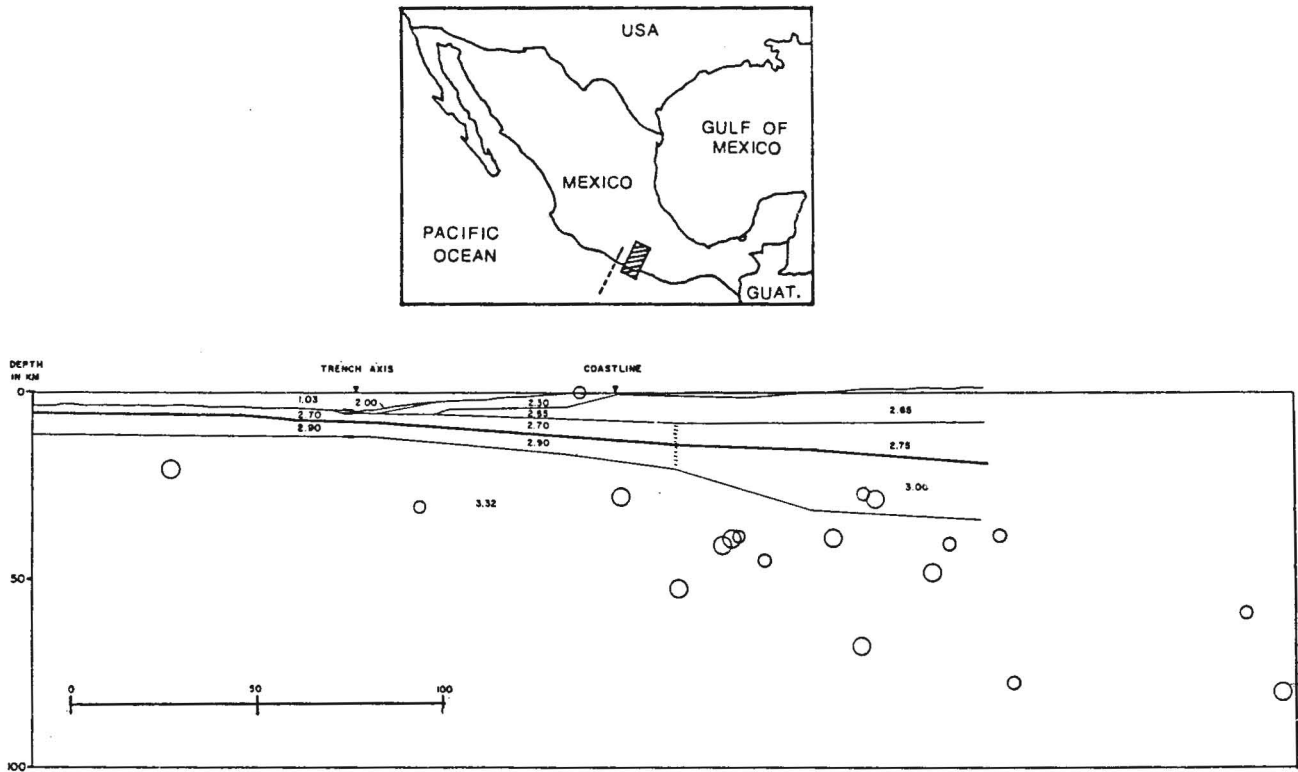
445

Fig. 4. Seismic cross section (after Couch and Burbach, 1985) used to constrain the MT inversion. Its approximate location is indicated by a dashed line in the upper left figure, were the shaded rectangle refers to the surveyed area. Open circles in the section represent epicenter locations. The larger circles represent magnitudes greater than 5.5 while the smaller represent magnitudes between 5.0 and 5.5. The numbers are densities in gm/cm^3.

(Spector and Grant, 1970) was used to provide a statistical estimation of the top depth of assemblages of bodies (Bhattacharyya and Leu, 1975, 1977). Results for the profile in terms of the logarithmic plot of the smoothed amplitude spectrum as a function of wave number yield the following interfaces: 44, 28, 18 and 15 km (Figure 8). The deepest interface may correspond to the crust/mantle boundary.

Further analysis of the topography of the crust/mantle boundary was completed with an iterative algorithm that modifies the lower boundary geometry of single layer model until a fit to the observed gravity anomaly is obtained. Several models with different density constrasts and average depths to the interface were tested. Figure 9 shows a model with a density contrast of 0.7 gr/cc and an initial average depth of 30 km. The fit shown is after the 20th iteration. The interface shows smooth variations approximately between the average depths estimated from the spectral analysis. The interface shallows at the Pacific Ocean and Gulf of Mexico margins (Figure 9). A similar analysis with a polygonal body that allows the density to increase with depth from 2.6 gr/cc to 3.3 gr/cc gives essentially the same results with high frequency fluctuations superimposed.

Polygonal Talwani-type models have been constructed using the geologic sections of Ortega-Gutiérrez (1990).

The resolution of details of crustal structure is not satisfactory.

Couch and Woodcock (1981) and Valdés *et al.* (1986) presented gravity models for profiles located to the west of the profile here analyzed. The interfaces of 15 and 44 km from our spectral analysis correspond to interfaces interpreted by Valdés *et al.* (1986) for the Pinotepa- Alchichica profile. The Moho is estimated at 45 ± 4 km depth, and the lower crust (characterized by seismic velocities of 6.85-7.0 km/sec and densities around 3.089 gr/cc) is interpreted in terms of high-grade metamorphic and mafic intrusive rocks (Valdés *et al.*, 1986).The model used by Couch and Burbach (1985) lies further west, close to Acapulco, and includes a crust composed of 3 layers with densities of 2.65, 2.75 and 3.00 gr/cc (Figure 4). This seismic and gravity section was used to constraint the MT inversion. ·

The average dip of the subducting plate estimated from the gravity model is shallow, some 13 degrees (Figure 9). This agrees well with the seismic interpretations for the region. The Moho in the gravity model shows a topography that correlates well with major structural features at the surface, i. e. the Sierra Madre del Sur, the Juchatengo mylonitic zone, the Oaxaca Grenvillian complex, the Oaxaca/Juárez mylonitic zone, the Sierra de Juárez and the Juárez/Maya contact zone. The gravity model assumes that
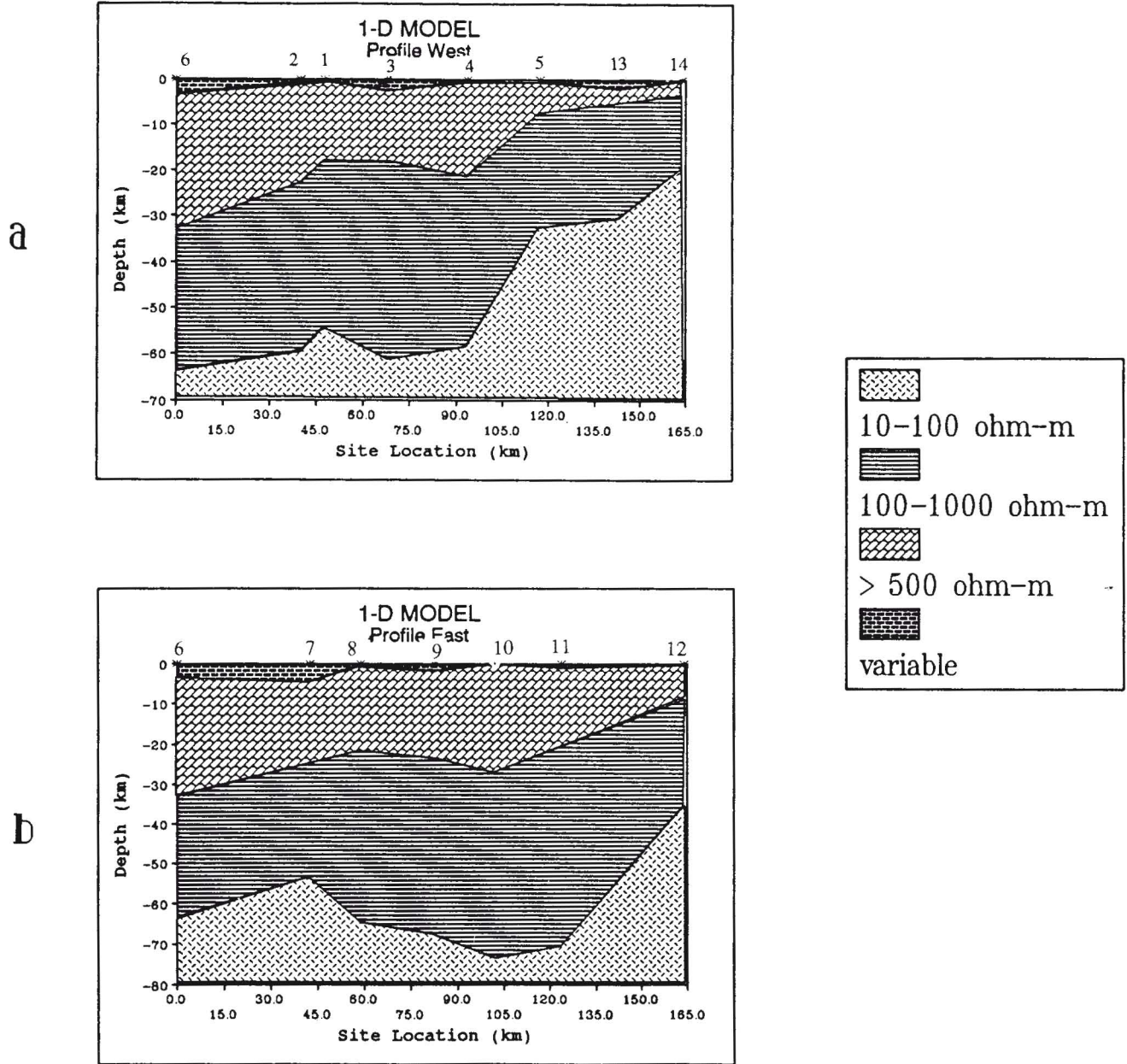
Fig. 5. Electrical sections obtained from the simultaneous resistivity and phase inversion of the MT sites. Both the west (a) and east (b) profiles suggest a gently dipping lower crust of varying thickness. There is some indication of the thickening of the layer at sites located in the middle of both profiles. Site location is indicated by asteriscs.

the gravity anomaly signal is entirely due to deep sources. If part of the anomaly is explained in terms of shallow density variations then the Moho topography does not require such large amplitude variations. Further modelling of the gravity anomaly is required to evaluate the contributions of shallow crustal features.

DISCUSSION

The geophysical geotransect across the continent from the Pacific Ocean to the Gulf of Mexico provides an opportunity to investigate the structure and tectonics of the active Pacific margin with the Cocos plate subduction zone and the passive margin of the Gulf of Mexico. It traverses a complex collage of terranes and major structural features represented by fault and deformation zones and wide mylonitic units, characterized by a complex tectonic history (Ortega-Gutiérrez, 1990; Urrutia-Fucugauchi, 1984; Ratschbacher *et al..* 1991). The central region is characterized by an anorthositic body and a sequence of ortho-and para-gneisses and charnockites of the Grenvillian Oaxaca complex (*e.g.* Ortega-Gutiérrez, 1990). The terrane along the Pacific margin is characterized by metamorphic rocks and intrusives of the Xolapa Complex. The boundary between these two units in the region of Juchatengo is re-
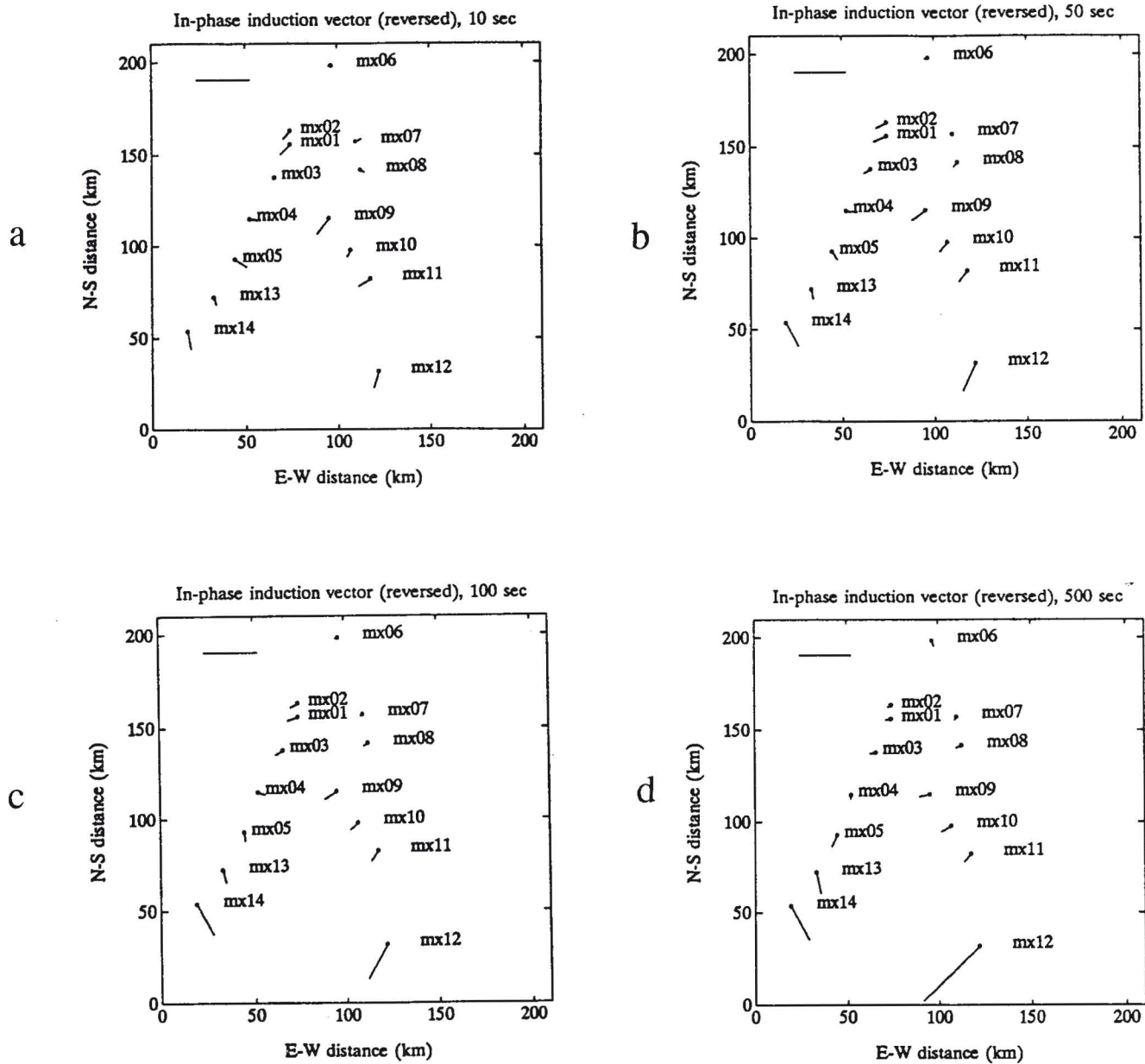
Fig. 6. Induction vector plots at different periods. (a) 10 sec, (b) 50 sec, (c) 100 sec, and (d) 500 sec. The arrows at sites 1, 2, 9, 10, 11 and 12 point systematically SW at all periods, which suggest the presence of an elongated conducting structure striking NE. The sites closest to the ocean (12 and 14) seems to be affected by the current channeling along the ocean edge. The bar in the upper left shows a unity inducting vector. Sites number are have the prefix "mex0".

presented by a deformation zone that includes mylonites, ultramylonites and cataclastites (*e.g.* Ratschbacher *et al.*, 1991). To the north, the transect crosses another wide mylonitic zone at the boundary with the Juárez terrane. The basement along the Gulf coastal plain may belong to the Maya terrane. There have been several studies on the structure and characteristics of the crust and mantle beneath the region (*e.g.* Shor and Fisher, 1961; Ross and Fisher, 1965; Couch and Woodcock, 1981; Moore *et al.*, 1982; Lomnitz, 1982; Nava *et al.*, 1985, 1988; Valdés *et al.*, 1986).

The use of different deep investigation geophysical methods may provide further constraints on the subsurface structure and characteristics of the continental lithosphere and the plate subduction process. The results from the present magnetotelluric and gravity study are summarized in a simplified way in Figure 10. The estimated crust/mantle boundaries from MT and gravity show a similar geometry. The gravity interface lies however some 8-10 km deeper than the MT estimate. This difference may be due to distinct physical properties associated with a small amount of fluids, grain size variation, porosity and fracturing in the

OAXACA GEOTRANSECT
BOUGUER GRAVITY ANOMALY
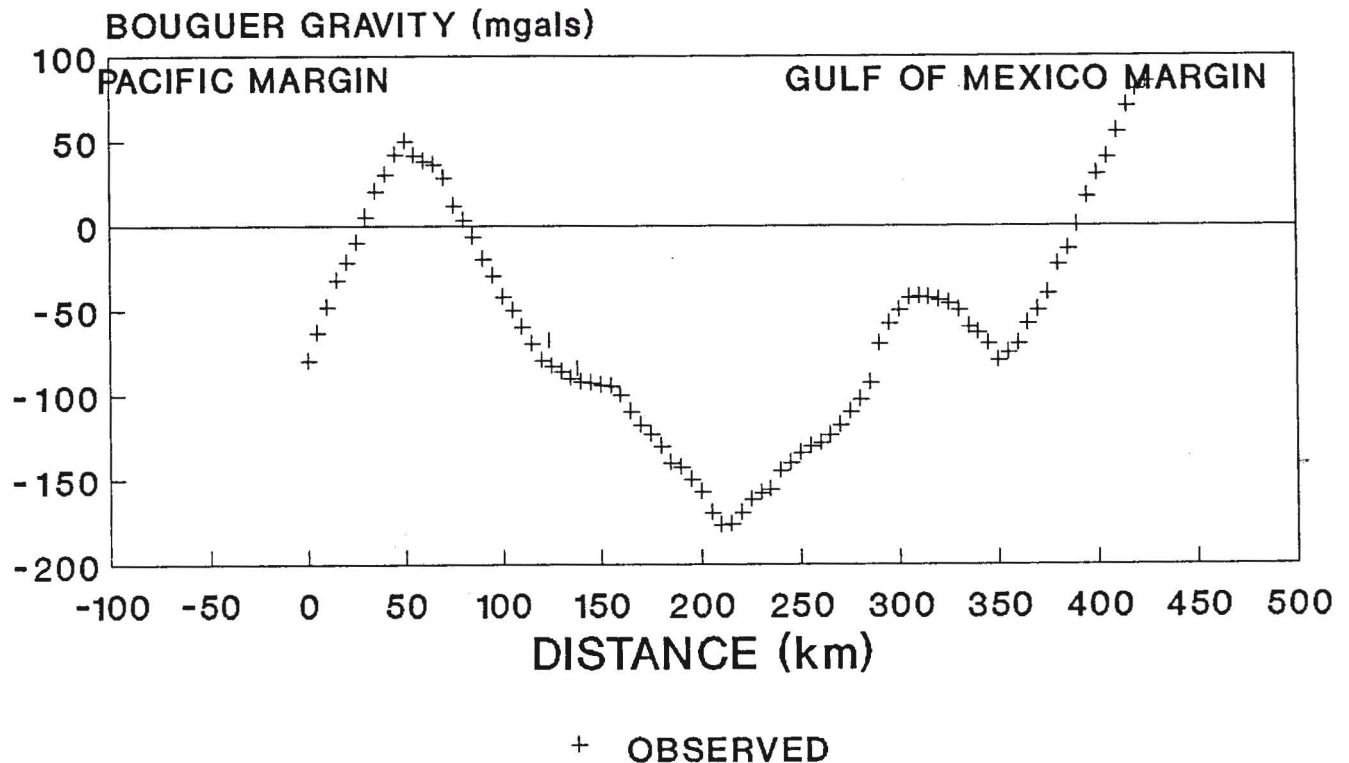
PUERTO ESCONDIDO - LOS TUXTLAS

Fig. 7. Bouguer gravity anomaly (in mgals) for the transect between Puerto Escondido in the Pacific margin and Los Tuxtlas in the Gulf of Mexico coast. See Ortega-Gutiérrez (1990) for details of the transect. The Bouguer data is complemented by Free-Air anomaly data for the sea portions.

lower crust; but it is more likely due to poor static shift corrections.

If low electrical resistivity and high a seismic reflectivity seismic reflectivity at crustal depths have a common origin, as suggested by various authors (e.g. Hyndman and Sheare, 1989), then the depth to the Precambrian or Phanerozoic lower continental crust can be assessed from MT measurements. A depth profile for a data set distributed along two profiles suggests depths ranging from 10 to about 30 km, the shallower end being located closer to the sea (Figure 10). The resistivities found after the static shift removal were in ther range between 10 to 90 ohm-m which is in agreement with other lower crust conductivity measurements (*i. e.* Shankland and Ander, 1983; Shankland, 1989). The average dip of the subducting slab is shallow, less than 25°, in average some 12° towards the continent (coinciding with the estimations of Couch and Woodcock, 1981 and Valdés *et al*,

1986). The down dip trend reverses slightly coinciding with the aparent thickening of the crust at these places. If this geometry is related to the subducting plate, it may be either the effect of a poor static shift correction or a real feature related to the fast convergence rate between the North American and Cocos plates, yet to be confirmed by ongoing improved 2-D modeling.

The 1-D approach allowed us to visualize the main tectonic features and to correct for static shift. The determinant average apparent resistivity (or ρ effective) tends to suppress the effect of any 2-D structures. Because of averaging, details in the two perpendicular polarizations of the field curves (which emphasize the presence of good conductors) are neglected and consequently some information is lost. The next modelling step should include a two dimensional model of the lithosphere to take into account the effects caused by the presence of a two-dimensional
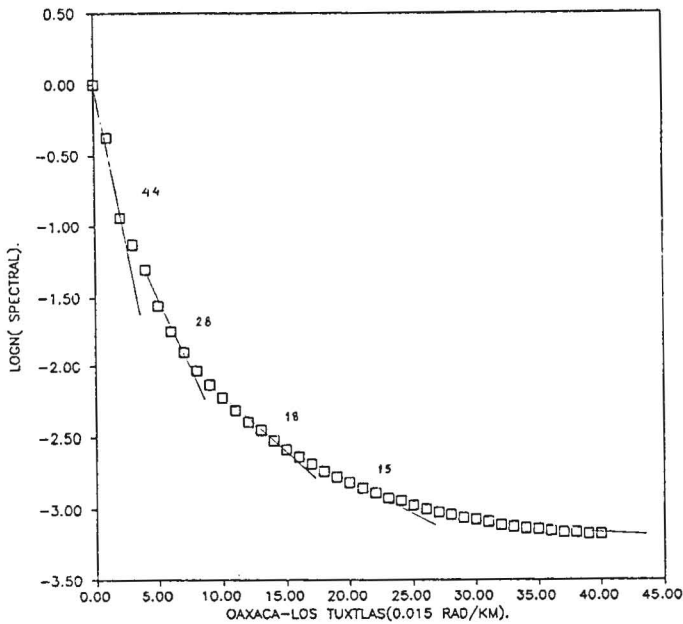
449

Fig. 8. Semi-logarithmic plot of the smoothed amplitude spectrum as a function of wave number. Estimates of depths to interfaces are: 44, 28, 18 and 15 km.

conductor suggested by the induction direction and magnitude arrows as well as other field distortion indicators.

OAXACA GEOTRANSECT
BOUGUER GRAVITY ANOMALY

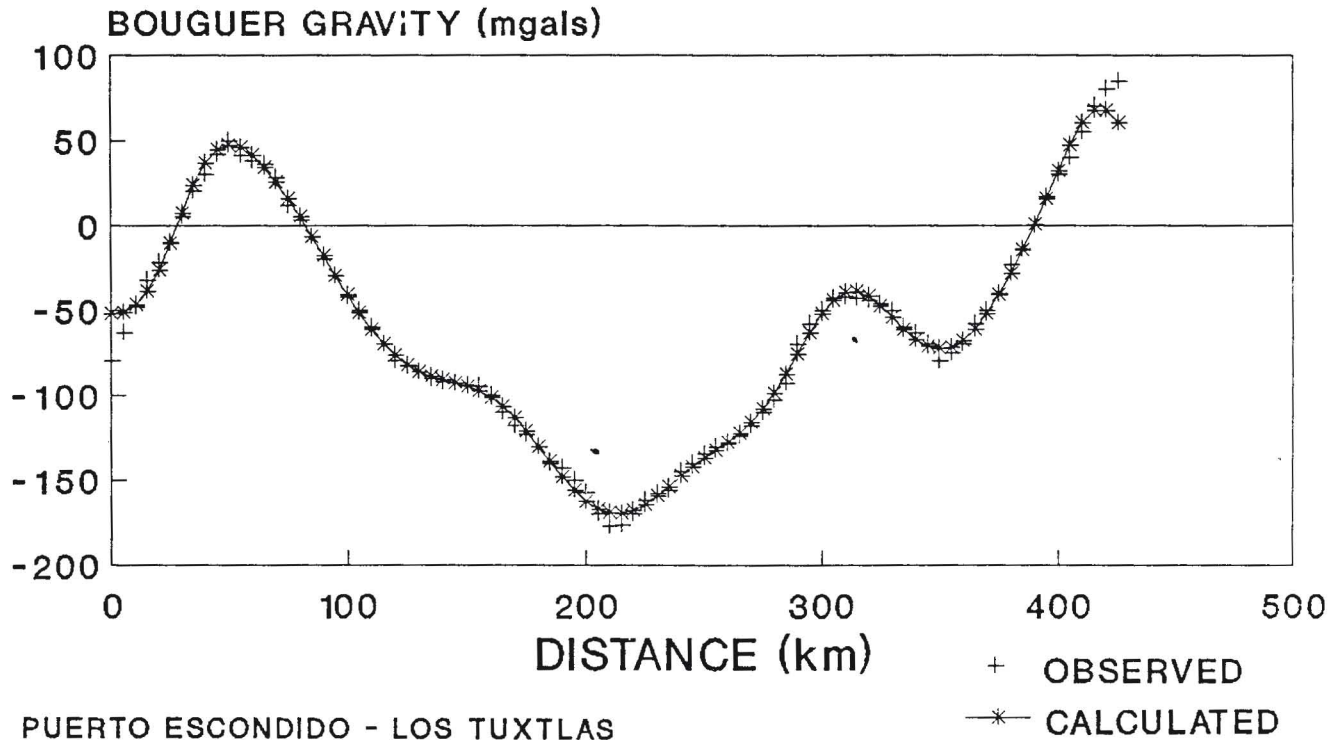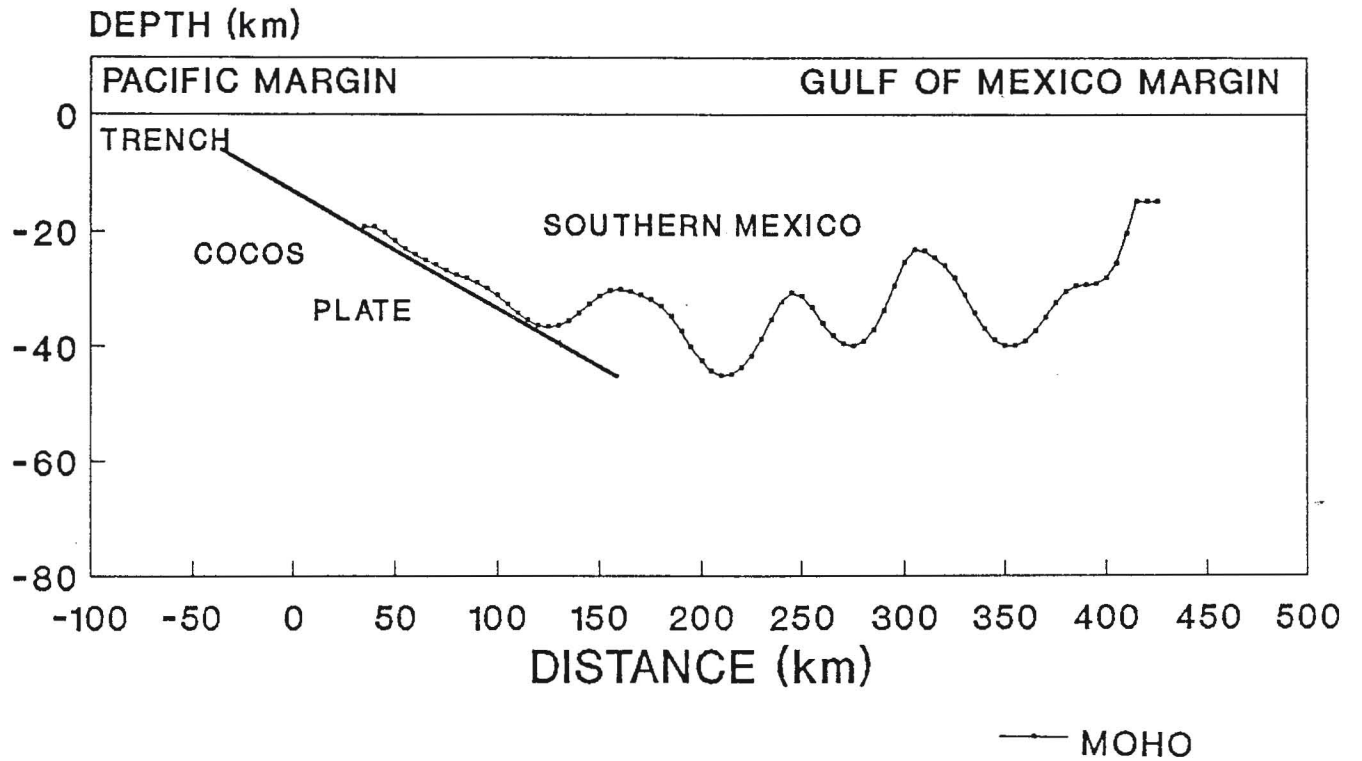

PUERTO ESCONDIDO - LOS TUXTLAS

Fig. 9a. Comparison between the observed and calculated gravity anomalies, corresponding to the model shown in Fig. 9b.

OAXACA GEOTRANSECT
BOUGUER GRAVITY ANOMALY

PUERTO ESCONDIDO - LOS TUXTLAS

Fig. 9b.Gravity interpretation of the crust/mantle interface along the Puerto Escondido-Los Tuxtlas transect. Approximate location of the top of the subducting Cocos plate is indicated by the thick line. The dip of subduction is about 13°. The regions where the Moho shallows correlate with major features and terrane boundaries.
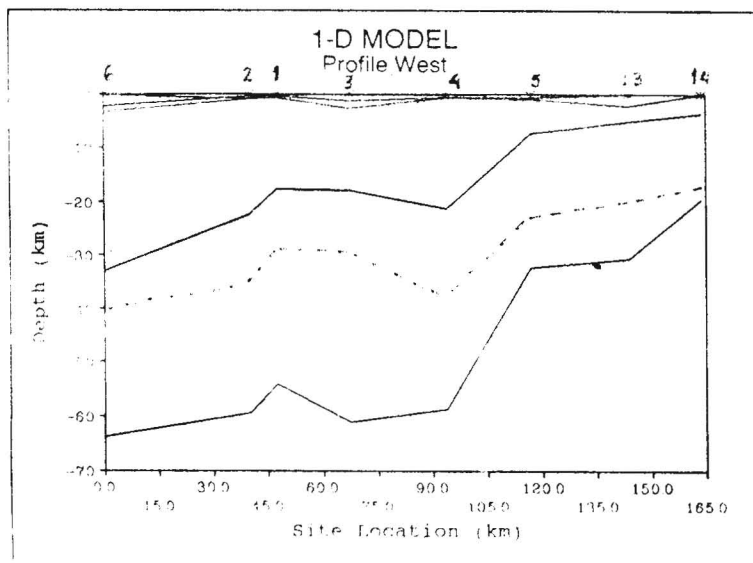

Fig. 10. Comparison between the crustal models derived from MT (continuous lines) and gravity (discontinuous lines) for the western profile. Note the similarites in the geometry and the depth difference between the models.

451

BIBLIOGRAPHY

CHAKRIDI, R., M. CHOUTEAU and M. MARESCHAL, 1992. A simple technique for analysing and partly removing galvanic distortion from the magnetotelluric impedance tensor: Application to Abitibi and Kapuskasing data (Canada), *Geophys. J. Int., 108*, 917-929.

COUCH, R. W. and G. V. BURBACH, 1985. Cross section, Southern Mexico, Guatemala and Costa Rica margin, *In:* J. W. Ladd and R. T. Buffler (Eds), Middle America Trench off western Central America, Atlas 7, Ocean Margin Drilling Program, Regional Atlas Series: Marine Science International, Woods Hole, MA, Sheet 13.

COUCH, R. and S. WOODCOCK, 1981. Gravity and structure of the continental margins of southwestern Mexico and northwestern Guatemala. *J. Geophys. Res., 86*, 1829-1840.

CROSS, T. A. and R. H. PILGER, 1982. Controls of subduction geometry, location of magmatic arcs, and tectonics of arc and back-arc regions., *Geol. Soc. Am. Bull. 93*, 545-562.

EMSLAB group, The, 1988, The EMSLAB Electromagnetic sounding experiment, *EOS (Trans. A. Geophys. Union), 69*, 7, 89.

GOUGH, D. I., 1986. Magnetoteluric evidence for subduction of seafloor sediments, *Nature, 321*, 566.

HYNDMAN, R. D. and P. M. SHEARER, 1989. Water in the lower continental crust: modelling magnetotelluric and seismic reflection results, *Geophys. J. Int., 98*, 343-365.

KURTS, R. D., J. M. DeLAURIE and J. C. GUPTA, 1986. A Magnetotelluric sounding across Vancouver Island sees the subducting Juan de Fuca Plate, *Nature, 312*, 596-599.

LOMNITZ, C. 1982. Direct evidence of a subducted plate under southern Mexico. *Nature, 269*, 235-238.

MOORE, J. C., J. S. WATKINS, T. H. SHIPLEY, K. C. McMILLEN, S. B. BACHMAN and N. LUNDBERG, 1982. Geology and tectonic evolution of a juvenile accretionary terrane along a truncated convergent margin: Synthesis of results from the Leg 66 of the Deep Sea Drilling Project, southern Mexico. *Geol. Soc. Am. Bull., 93*, 847-861.

NAVA, F. A., V. R. TOLEDO and C. LOMNITZ, 1985. Plate waves and the 1980 Huajapan de León, Mexico earthquake. *Tectonophysics, 112*, 463-492.

NAVA, F.A. *et al.*, 1988. Structure of the Middle America trench in Oaxaca, Mexico. *Tectonophysics, 154*, 241-251.

ORTEGA-GUTIERREZ, F., 1990. Ocean-Continent Transect H3. *Geol. Soc. Am.* Chart, Scale 1: 1500,000.

RATSCHBACHER, L., U. RILLER, M. MESCHEDE, U. HERRMANN and W. FRISCH., 1991. Second look at suspect terranes in southern Mexico. *Geology, 19*, 1233-1236.

ROSS, D. and G. SHOR, 1965. Reflection profiles across the Middle America Trench. *J. Geophys. Res., 70*, 5551-5572.

SHANKLAND T. J. and M. E. ANDER, 1983. Electrical conductivity temperatures and fluids in the lower crust, *J. Geophys. Res., 88*, 9475-9484.

SHANKLAND, T. J., 1989. A case of two conductors, *Nature, 340*, 102.

SHOR, G. G., JR. and R. L. FISHER, 1961. Middle America Trench: Seismic refraction studies. *Geol. Soc. Am. Bull., 72*, 721-730.

TALWANI, M., J. L. WORZEL, and M. LANDISMAN, 1959. Rapid gravity computations for two-dimensional bodies with application to the Mendocino submarine fracture zone. *J. Geophys. Res., 64*, 49-59.

URRUTIA-FUCUGAUCHI, J., 1984. On the tectonic evolution of Mexico: paleomagnetic constraints. *In:* Plate Reconstruction from Paleozoic Paleomagnetism, AGU. *Geodynamics Series, 12*, 29-47.

VALDES, C. M., W. D. MOONEY, S. K. SINGH, R. P. MEYER, C. LOMNITZ, J. H. LUETGERT, C. E. HELSLEY, B. T. R. LEWIS and M. MENA., 1986. Crustal structure of Oaxaca, Mexico, from seismic refraction measurements. *Bull. Seismol. Soc. Am., 76*, 547-563.

WANNAMAKER *et al.* 1989. Resistivity cross section through the Juan de Fuca subduction system and its tectonic implications, *J. Geophys. Res., 94, 14*, 127-14, 144.

Jorge A. Arzate[1,2], Mariane Mareschal[1] and Jaime Urrutia-Fucugauchi.[2]

1 Génie Minéral, Ecole Polytechnique, C.P. 6079, Succ. A., Montréal, Quebec Province, H3C #A7 CANADA.

2 Laboratorio de Paleomagnetismo y Geofísica Nuclear, Instituto de Geofísica, Universidad Nacional Autónoma de México., Del. Coyoacán, 04510, México, D.F.. México.