SUBDUCTION OF THE COCOS PLATE AND DEEP ACTIVE FRACTURE ZONES OF MEXICO

VÁCLAV HANUŠ *
and JIŘI VANĚK *

RESUMEN

La morfología y los parámetros de la zona de Wadati-Benioff fueron identificados a base de la distribución de los focos de terremotos en la región de México. La existencia de la zona intermediaria asísmica, que está claramente relacionada con la cadena de los volcanes andesíticos activos centroamericanos, fue verificada en aquellas partes de la zona de subducción, las cuales alcanzaron las condiciones necesarias para la fusión parcial de la placa hundida. Las diferencias en la profundidad de la zona de subducción de la placa de Cocos fueron correlacionadas con el efecto de frenaje de la zona fracturada de Orozco y de la cresta submarina de Tehuantepec. Cinco profundas zonas de fracturas sísmicamente activas, genéticamente relacionadas con el proceso de subducción, fueron identificadas en la placa continental. Estas zonas pueden jugar el papel de posibles canales de alimentación para los volcanes activos del eje volcánico transmexicano.

ABSTRACT

The morphology and parameters of the Wadati-Benioff zone were established on the basis of the distribution of earthquake foci in the region of Mexico. The existence of an intermediate aseismic gap related clearly to the Central America belt of active andesitic volcanoes was confirmed in those parts of the subduction zone where the conditions necessary for partial melting of the downgoing slab were reached. The non-uniform rate of subduction of the Cocos plate could be correlated with the hampering effect of the Orozco fracture zone and Tehuantepec Ridge. Five deep seismically active fracture zones, genetically connected with the process of subduction, were identified in the continental plate as possible feeding channels for active volcanoes of the Transmexican volcanic belt.

* *Profesores visitantes, Instituto de Geofísica UNAM, México; on leave from Geological Institute and Geophysical Institute, Czechoslovak Academy of Sciences, Prague.*

1. INTRODUCTION

The tectonic and volcanic pattern of the region of Mexico seems to be substantially influenced by active subduction of the Cocos plate beneath the North American continent. The proximity of the East Pacific Rise with the Middle America trench and the complicated bathymetry of the Cocos plate appear to be the main factors governing the process of subduction and determining the morphology of the Wadati-Benioff zone in this region.

The present paper deals with the study of the geometry of distribution of earthquake foci between the parallels 15°-20°N in relation to the occurrence of active volcanism and main structural features of the subducting Cocos plate. Special attention was paid to the detailed structure of the Wadati-Benioff zone, to the possible existence of an intermediate aseismic gap in the downgoing slab, and to the distribution of earthquake foci in the adjacent continental wedge. A similar study for the region of Central America will be published in a separate paper.

2. DATA AND METHOD

Since the comprehensive study of Molnar and Sykes (1969) on the tectonics and seismicity of the Caribbean and Middle America regions, an extensive body of new reliable seismological data has accumulated.

For the construction of the Wadati-Benioff zone in the region of Mexico the ISC data (Regional Catalogue of Earthquakes) for the twelve years' period 1964-75 were used. In some areas with low seismicity the data of Molnar and Sykes (1969) from 1950-63 were also included. Altogether 2590 earthquakes were used in the present study.

The region investigated was divided into a system of sections M5-M37 approximately perpendicular to the axis of the Middle America trench (see Fig. 1, where the system of sections M38-M53 in Central America is also given). The area considered in the present paper is roughly limited by 11°-21°N and 90°-110°W.

The general picture of the seismicity was obtained by constructing a figure of the Wadati type (Wadati 1935) plotting the epicenters of shallow, intermediate and deep earthquakes on a suitable geographic map. This map of epicenters also helped us to construct the appropriate scheme of sections with reasonable density of earthquake foci (Fig. 1). The map is not published in the present paper because it does not give a picture differing, in principle, from the results of Molnar and Sykes (1969). Then the graphs giving the depth distribution of earthquake foci in dependence on the distance from the trench axis were constructed for every section considering the magnitude of earthquakes.

3. VERTICAL SECTIONS ACROSS THE TRENCH AND MORPHOLOGY OF THE WADATI-BENIOFF ZONE

The depth distribution of earthquake foci relative to the distance from the Middle America trench axis is given in 33 graphs shown in Figs. 2-34. For easier understanding of the spatial correlation of different phenomena with the morphology of the Wadati-Benioff zone, the position of the axis of the Middle America trench (arrows) and active volcanoes (full triangles) is also given; the Wadati-Benioff zone is denoted by full-line contours and fracture zones in the continental wedge by a hatch pattern.

The position of main structural elements is shown in Fig. 1. The large-scale geomorphological and tectonic units of the ocean floor were obtained on the basis of the bathymetric chart of the North Pacific (Chase *et al.*, 1970) and active volcanoes were taken from Mooser *et al.* (1958).

The general picture shown by the sequence of the vertical sections confirms the existence of a well-defined Wadati-Benioff zone beginning in the vicinity of the Middle America trench (see Figs. 2-34). The subduction zone starts in the section M8, while the seismic activity shown in the sections M5-M7 belongs to the Rivera fracture zone and to the northernmost part of the East Pacific Rise (section M5). The seismicity of the Rivera fracture zone can be also observed southwest of the Wadati-Benioff zone in the sections M8-M11. The dip of the Wadati-Benioff zone varies between 26° and 43° with the prevailing value of 38°-40° to the northeast, its depth, manifested by the deepest earthquakes in individual sections, changes along the trench between 80 and 245 km (sections M9 and M34, 36). The thickness of the Wadati-Benioff zone, measured perpendicularly to the direction of subduction, varies between 55 and 90 km with the prevailing value of 70 km in the northern part and 90 km in the southern part (starting with M28).

In sections M10-M12 and M23-M27 the thickness of the Wadati-Benioff zone increases up to 160 km. The detailed distribution of earthquakes gives an impression that hte Wadati-Benioff zone is composed of two slabs, denoted as A and B in this paper; slab A has the usual position in relation to the trench, whereas slab B is shifted westwards beginning 100-150 km in front of the trench axis. This structure, called double-slab structure, seems to be a new phenomenon in plate tectonics.

The intermediate aseismic gap, found previously in the Wadati-Benioff zone of Andean South America (Hanuš and Vaněk, 1976, 1978a) and in the Tonga-Kermadec island are (Hanuš and Vaněk, 1978 b, c), can be clearly identified in the southern part of Mexico (see sections M28-M37) and in the whole region of Central America (Hanuš and Vaněk, in preparation). The gap is again closely related to the occurrence of andesitic volcanism. However, only two volcanoes of the Central American volcanic belt (Tacana and Tajumulco in section M 37) are situated in the region investigated in the present paper. It seems that in sections M12-M18 the intermediate aseismic gap occurs in the initial stage of development (see also Fig. 35). The active volcanoes Colima, Paricutín and Jorullo can be spatially coordinated to this gap. However, its lower limit is only poorly defined by scarce intermediate shocks indicating the upper boundary of the solid lower part of the slab.

Beginning at section M13 practically through the whole system of sections (excepting sections M20, 25, 27, 29) isolated intermediate and deep earthquakes occur southwest of the active Wadati-Benioff zone lying in an approximately parallel strip below the present zone of subduction. In analogy with our interpretation of deep Andean shocks (Hanuš and Vaněk, 1978a) and a part of deep Tonga and Kermadec shocks (Hanuš and Vaněk, 1978 b, c) these earthquakes seem to manifest the existence of a paleoslab belonging to the foregoing cycle of subduction. However, the seismicity connected with the assumed paleosubduction is relatively weak, the maximum depth of earthquakes being about 500 km (see sections M24 and M32).

Similarly as in Andean South America (Hanuš and Vaněk, 1978a) an increased seismicity can be observed in the continental plate northeast of the Wadati-Beniof zone (see M13-M37) This seismicity appears to be connected with a system of inclined fracture zones, which are genetically related to the process of subduction; this problem will be discussed in paragraph 5.

4. VERTICAL SECTION ALONG THE TRENCH AND COCOS PLATE STRUCTURE

The sequence of the vertical sections in Figs. 2-34 indicates that the depth of penetration of the active subducted plate varies along the Middle America trench. It was shown in our previous papers on Andean South America (Hanuš and Vaněk, 1978a) and on the Tonga-Kermadec region (Hanuš and Vaněk, 1978 b, c) that such a lateral variability was very probably caused by the hampering effect of main structural units of the subducting oceanic plate. In order to correlate the depth of penetration of the Middle American subduction zone with the physiography of the Cocos plate, a vertical section of the Wadati-Benioff zone along the Middle America trench was constructed in Figs. 35 and 36. In the latter section all the earthquake foci belonging to the recently subducted zone are plotted, allowing us to contour the position of the intermediate aseismic gap and the lower limit of the Wadati-Benioff zone. The position of active andesitic volcanoes is also indicated.

The scheme of main structural elements of the Cocos plate is given in Fig. 1. The following units characterized by elevations of the ocean floor and tectonic fractures can be distinguished from northwest to southeast in the region investigated: Rivera fracture zone, East Pacific rise, Orozco fracture zone, Oaxaca zone of elevations and Tehuantepec

Ridge. The position of the above units is also indicated in Figs. 35 and 36.

The depth of the lower limit of the Wadati-Benioff zone gradually increases along the Middle America trench from northwest to southeast, showing local oscillations with an amplitude of about 50 km. Contrary to the well-defined zones of elevations separated by large oceanic plains on the surface of the Nazca and Pacific plates, the northwestern part of the Cocos plate is characterized by a dense, almost continuous sequence of submarine elevations and fracture zones. Therefore the variations of the lower limit of the Wadati-Benioff zone are not so expressive as, e.g., in Andean South America or the Tonga island arc (Hanuš and Vaněk, 1978 a, b). The hampering effect of the system of the ocean floor elevations seems to be one of the reasons that the lower limit of the Middle American Wadati-Benioff zone northwest of the Tehuantepec Ridge submerges only to shallower depths, varying between 70 and 150 km, and the depth of penetration substantially increases to 250 km southeast of the Tehuantepec Ridge in the region of the Guatemala basin. Nevertheless, the local effect of the Orozco fracture zone and that of the Tehuantepec Ridge can be observed in the shape of the lower limit of the subduction zone (see sections M18-M20 in Fig. 35 and M30, M31 in Fig. 36).

In the areas where the East Pacific rise and the Oaxaca zone of elevations disappear under the American continent (sections M10-M12 and M23-M27) the double-slab structure of the Wadati-Benioff zone can be observed. It is very difficult to explain this phenomenon due to a poor knowledge of the deep structure of both the subducting oceanic plate and the adjacent continental regions. According to our experience the double-slab structure can be caused by three different phenomena: (a) the subducting oceanic plate in this part is thicker than usual; (b) the subduction of A was stopped by some obstacle (in the continental plate ?) and new subduction of B started; (c) B is a deep fracture zone running parallely to the trench in front of A. In a recent paper Dean and Drake (1978) found several strike-slip focal mechanisms for earthquakes pertaining to B, which may favour explanation (c); however, further study is needed to clarify the details of the double-slab structure.

In Figs. 35 and 36 the foci of earthquakes coordinated to slab A and the corresponding contour are given; the lower limit of B is shown by a dashed line. The morphology of B for both areas is presented in Fig. 37.

A clearly pronounced aseismic gap begins in the section M28 and continues to Central America. The first active volcanoes associated with this gap are Tacana and Tajumulco. It is not clear why the part of the well-defined aseismic gap northwest of them is not accompanied by any andesitic volcanism.

In the northern part of the subduction zone the only region where the downgoing slab seems to reach the state conditions necessary for partial melting is situated between sections M12 and M18. It appears that in the Transmexican volcanic belt Colima, Paricutín and Jorullo are the only active volcanoes that can be directly connected with the subduction zone.

5. DEEP FRACTURING OF THE CONTINENTAL WEDGE INDUCED BY SUBDUCTION

A detailed analysis of the position of earthquake foci occurring in the continental wedge northeast of the Wadati-Benioff zone reveals that they are not distributed randomly showing a tendency to accumulate in well-separated zones, which dip to southwest and run parallely to the Middle America trench. These zones can be interpreted as a system of deep seismically active fractures induced in the continental plate by the process of subduction.

In the region of Mexico, five fracture zones of this type could be delineated. Going in the direction from southwest to northeast we attached the following names to the individual fracture zones: Churumuco-Ometepec F.Z. (ZX), la Huacana-Escuintla F.Z. (ZO), Los Azufres-Río Salado F.Z. (Z1). Tzindejeh - El Chichonal F.Z. (Z2), Tecolutla-Chiltepec F.Z. (Z3). The names are based on surface manifestations of hydrothermal activity related to the above fracture zones

(González and Molina, 1977). Their position on the surface as given by the associated shallowest earthquakes is shown in Fig. 38. The coordination of individual foci to respective fracture zones (ZO-Z3) is also indicated by hatching in Figs. 2-34.

In the following a detailed description of individual fracture zones is given.

a) Churumuco-Ometepec fracture zone (ZX)

This fracture zone is characterized by very shallow seismic activity. It can be traced from 19°7N, 104°7W to 16°7N, 98°0W (see Fig. 39) running through the states of Jalisco, Colima, Michoacán and Guerrero. The length of the active part of the fracture zone is about 830 km, its average width on the surface being less than 25 km. The dip of this fracture zone could not be determined because the depths of foci did not exceed the conventional value of 33 km.

b) La Huacana-Escuintla fracture zone (Z0)

All the earthquakes associated with this fracture zone are shallow excepting two intermediate shocks in the northernmost and southernmost part. Therefore the dip of the zone Z0 could not be safely determined from transverse sections showing, however, a tendency of a dipping to southwest. The fracture zone starts at 19°7N, 103°4W and can be traced to 11°9N, 85°1W. It goes through the states of Jalisco, Michoacán, Guerrero, Oaxaca, Chiapas to Guatemala, El Salvador, Honduras and Nicaragua. The length of its active part is about 2250 km. The linear course of this fracture zone is interrupted in the region of the Tehuantepec Ridge between 92° and 96°W showing a wedge-like bend to the north with apex near 94°W. The width of the fracture zone on the surface in the northern part is between 80 and 100 km, in the area of the Tehuantepec Ridge between 30 and 50 km, and in the southern part it is between 80 and 90 km (see Fig. 40 A). The distribution of earthquake foci along the fracture zone is shown in the longitudinal section given in Fig. 40 B. The active volcanoes Colima, Paricutín and Jorullo of the Transmexican volcanic belt are situated in the northernmost area of this fracture zone.

c) Los Azufres-Río Salado fracture zone (Z1)

Earthquake foci associated with this fracture zone are distributed from the surface to the depth of 200 km. The fracture zone can be traced from 20°0N, 101°0W to 15°1N, 88°7W, ending at an intersection with the Motagua fracture zone. It runs through the states of Michoacán, Estado de México, Distrito Federal, Puebla, Oaxaca, Veracruz and Chiapas to Guatemala. The length of the active part of the Los Azufres-Río Salado fracture zone is about 1470 km and its width on the surface varies between 20 and 60 km (Fig. 41 A). The dip changes along the strike of the fracture zone in a considerable range: it is 45° to southwest between 0 and 220 km from its beginning, 55° between 220 and 390 km, increases to its maximum value of 60° between 390 and 670 km with a gradual decrease to 52° between 670 and 890 km, 40° between 890 and 1280 km and 35° in the southernmost part between 1280 and 1470 km (see transverse sections in Fig. 41 B). The shape of the lower limit of the fracture zone is shown in Fig. 41 C. Its depth reaches the maximum value of 200 km in the northern part, decreases considerably in the area of the Tehuantepec Ridge and increases again to 85 km in the southern part of the fracture zone. The active volcanoes San Andrés, Xitli and Popocatépetl are associated with this fracture zone, the volcano of Ceboruco being situated in a distance of about 300 km in its prolongation to the northwest.

d) Tzindejeh - El Chichonal fracture zone (Z2)

The fracture zone is characterized by shallow and intermediate seismic activity the maximum focal depth reaching 180 km. It starts at 20°7N, 99°2W and ends at 15°7N, 89°5W with an intersection of the Motagua fracture zone, passing the states of Hidalgo, Puebla, Veracruz, Tabasco and Chiapas to Guatemala. The length of the active part of the fracture zone is about 1220 km and its width on the surface varies between

40 and 55 km (Fig. 42 A). The dip in the northern part is about 35°, in the central part about 55° and in the southern part about 50° to southwest (see transverse sections in Fig. 42 B). The longitudinal section in Fig. 42 C shows a considerable variation of the lower limit of the fracture zone between 60 and 180 km. The active volcanoes Orizaba, San Martín, El Chichón and the middle Quaternary volcano Cofre de Perote are spatially related to this fracture zone.

e) *Tecolutla - Chiltepec fracture zone (Z3)*

Both shallow and intermediate earthquakes determine the course of this fracture zone. The deepest shock belonging to this zone has the focal depth of 170 km. The fracture zone stretches from 20°.1N, 96°.5W to 15°.3N, 87°.4W ending, similarly as zones Z1 and Z2, by an intersection with the Motagua fracture zone. It runs through the Gulf of Mexico, the states of Tabasco and Chiapas to Guatemala. The length of its active part is about 1140 km, the width varying between 35 and 45 km (Fig. 43 A). The dip does not change significantly, being about 55° in the northern part and about 50° to southwest in the southern part (see transverse sections in Fig. 43 B). The shape of the fracture zone is shown in the longitudinal section given in Fig. 43 C. No active volcanism is connected with this fracture zone in the continental region. However, a northwest-trending belt of submarine volcanoes, found in the Gulf of Mexico (Moore and Del Castillo, 1974) may be related to the Tecolutla-Chiltepec fracture zone.

Our interpretation of earthquakes occurring in the continental wedge as a manifestation of deep fracture zones is supported by the available focal mechanism solutions (Molnar and Sykes, 1969; Jiménez, 1977). Normal fault solutions are given by Molnar and Sykes for their events 146,147 and 148, which can be coordinated to the fracture zone Z0. Normal fault solutions are also given by Jiménez for his events 1 and 2, belonging to the fracture zone Z1, and for events 3, 4, 5 and 7, located at the fracture zone Z2. For the same event (numbered as 137 in Molnar and Sykes, 1969, and as 6 in Jiménez, 1977) an inverse fault solution was obtained in both papers. The latter event occurred in the area of the fracture zone Z3.

On the basis of the above scarse evidence any definite conclusions on the tectonic behaviour of the continental wedge would be premature, a greater number of reliable mechanism solutions being necessary. However, it seems that the continental wedge as a whole goes up along the Tecolutla-Chiltepec fracture zone, which is the last subduction-induced deep fracture zone in this region, whereas the blocks limited by fracture zones located nearer to the trench show a tendency of subsidence.

It is interesting that all the active volcanoes of the so called Transmexican volcanic belt occur exactly in the area of the above fracture zones, which seem to play the role of their principal feeding channels (see Figs. 40-42). This interpretation can explain the peculiar geometry of distribution of active Mexican volcanoes (see Mooser, 1972). A detailed discussion of this striking phenomenon will be published in a separate paper (Hanuš, Mooser and Vaněk, in preparation).

In the region of the Tehuantepec isthmus the linear course of fracture zone Z0 is strongly deformed and that of the zone Z1 partially deformed (see Figs. 38, 40, 41). Moreover, a system of transverse seismically active fractures can be delineated in this area. Both phenomena are undoubtedly connected with the hampering effect of the subducting Tehuantepec Ridge and will be treated separately in a special paper.

6. CONCLUSIONS

The main results of the investigation into the geometry of distribution of earthquake foci in Mexico can be summarized in the following five points:

1. The subduction of the Cocos plate beneath the American continent was verified by the existence of a clearly defined Wadati-Benioff zone with the following parameters: prevailing dip of 38°-40° to the northeast, prevailing thickness of 70 km in the northern and 90 km

in the southern part, depth of penetration varying along the trench between 80 and 245 km.

2. The intermediate aseismic gap, connected with the Central American belt of active andesitic volcanoes, was clearly identified in the southern part of Mexico; in the northern part of the subduction zone the aseismic gap may exist only in the initial stage of development.
3. A correlation between the depth range of the Wadati-Benioff zone and the major structural units of the Cocos plate implicates a non-uniform rate of subduction along the Middle America trench due to the hampering effect of major ocean floor topographic features (Orozco fracture zone, Tehuantepec Ridge).
4. In two areas of the subduction zone double-slab structure was found; this structure seems to be a new phemenon in plate tectonics.
5. Five deep seismically active fracture zones induced in the continental plate by the process of subduction were found. These zones may play the role of principal feeding channels of active volcanoes of the Transmexican volcanic belt, thus explaining the peculiar geometry of their distribution.

ACKNOWLEDGEMENTS

The present work was carried out during the authors' stay in Instituto de Geofísica de la Universidad Nacional Autónoma de México, in the framework of the scientific co-operation programme between the Consejo Nacional de Ciencia y Tecnología and the Czechoslovak Academy of Sciences. We are indebted to F. Mooser for support and stimulating discussions on the problems of the Transmexican volcanic belt. We are grateful to Z. Jiménez J. and L. Ponce, for providing us with unpublished seismological data and J. Mammerickx for making bathymetric charts available to us. We wish to thank Z. I. Marín, J. Pazderová and V. Valderrama, for technical assistence.

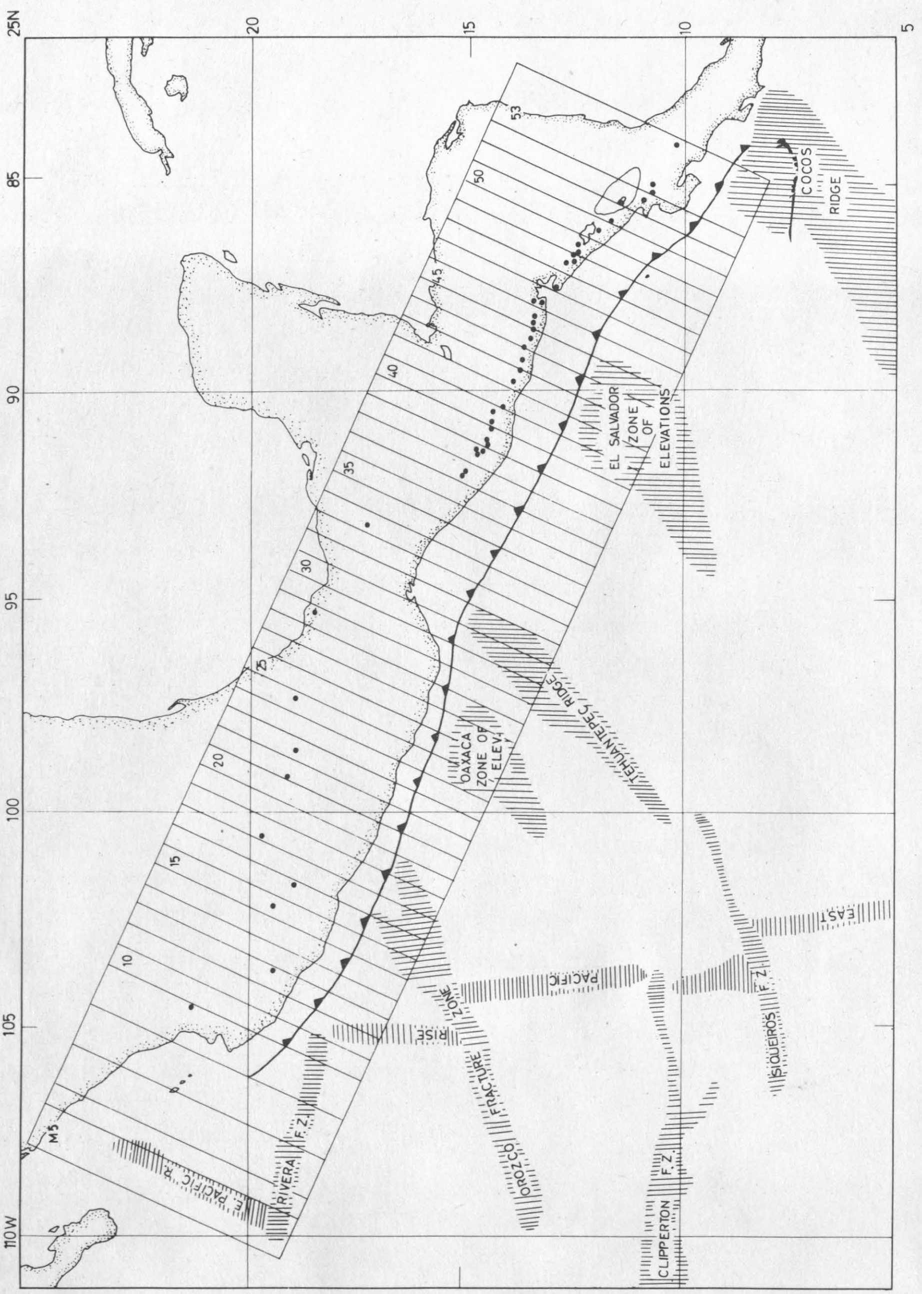

Fig. 1. Main structural elements and scheme of sections used for the study of the Wadati-Benioff zone in Middle America; the axis of the Middle America trench is denoted by a line with saw-teeth pointing in the direction of subduction, active volcanoes by full circles.

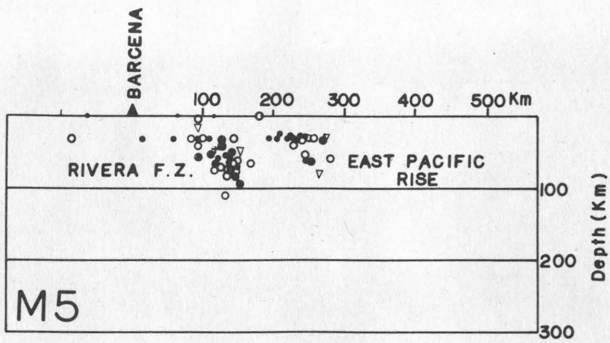

Fig. 2. Vertical section M5 giving the distribution of earthquakes foci in dependence on the distance from the point 19°.2N; 110°.8W; symbols for ISC magnitudes: •≦ 4.0,o4.1-4.5,o4.6-5.0,▽ 5.1-6.0, ▽≧ 6.1; foci from Molnar and Sykes (1969) are denoted by crosses, active volcanoes by full triangles.

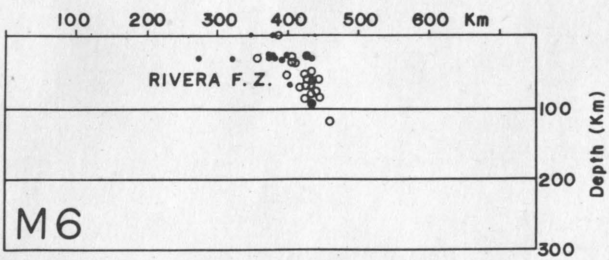

Fig. 3. Vertical section M6, distance measured from the point 15°.8N; 110°.6W.

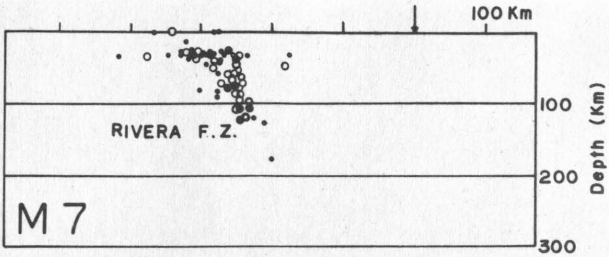

Fig. 4. Vertical section M7, position of the trench axis is denoted by arrow, distance measured from the trench.

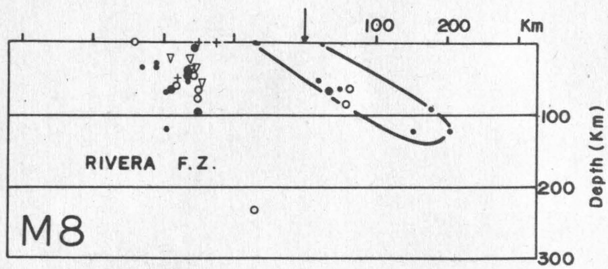

Fig. 5. Vertical section M8, Wadati-Benioff zone is denoted by full-line contour.

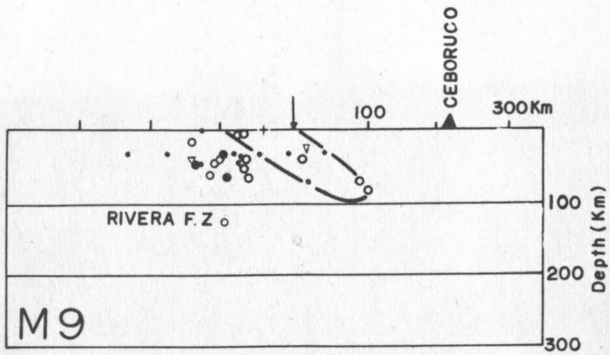

Fig. 6. Vertical section M9.

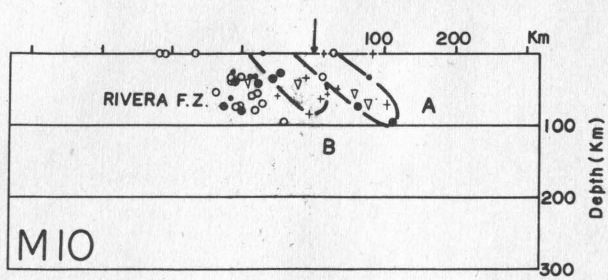

Fig. 7. Vertical section M10, double-slab structure denoted by A and B.

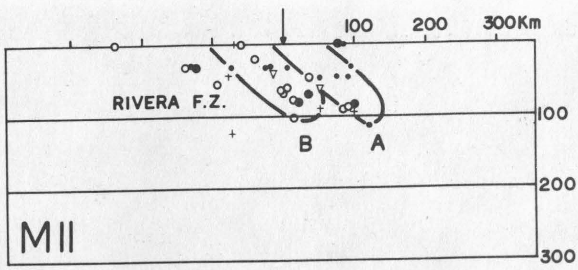

Fig. 8. Vertical section M11.

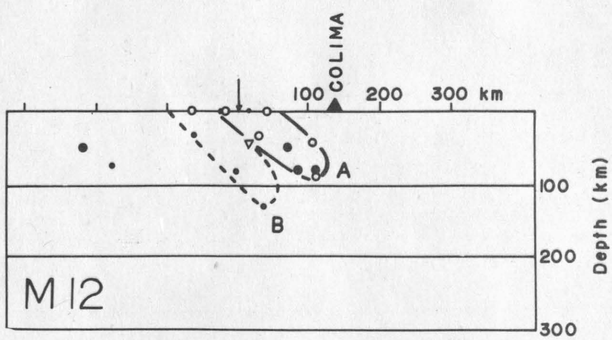

Fig. 9. Vertical section M12.

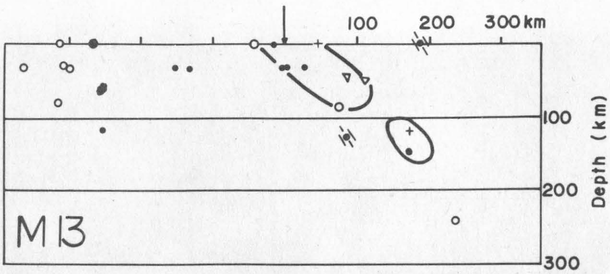

Fig. 10. Vertical section M13, fracture zone ZO denoted by NW-SE hatching, foci in the left part belong to the East Pacific rise.

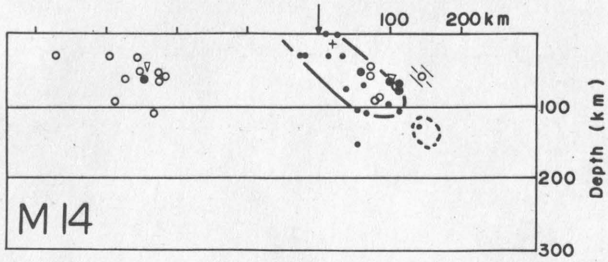

Fig. 11. Vertical section M14, foci in the left part belong to the East Pacific rise.

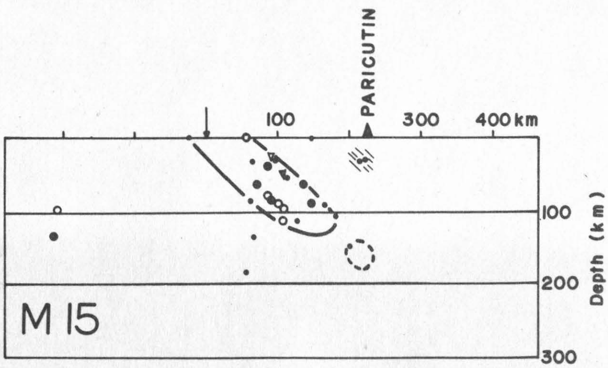

Fig. 12. Vertical section M15, foci in the left part belong to the East Pacific rise.

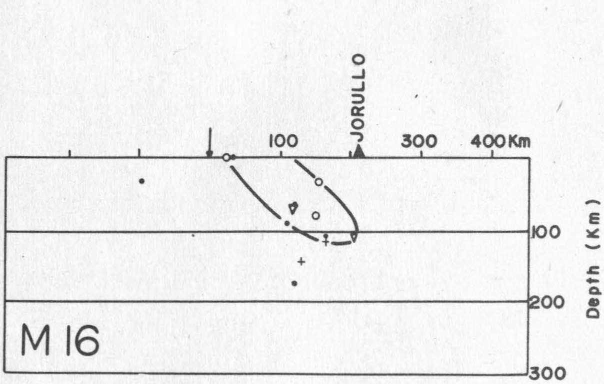

Fig. 13. Vertical section M16.

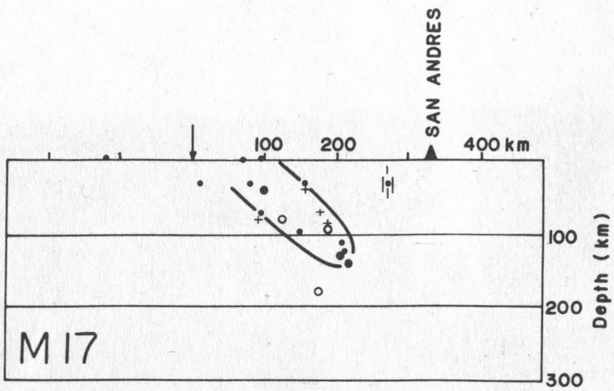

Fig. 14. Vertical section M17, fracture zone Z1 denoted by vertical hatching.

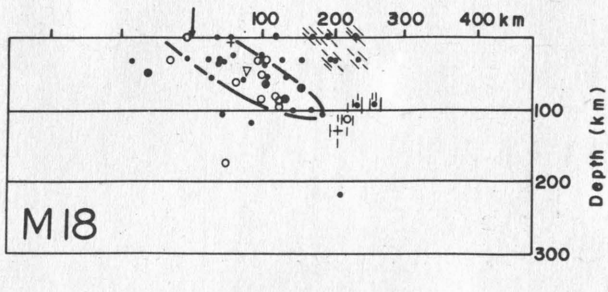

Fig. 15. Vertical section M18.

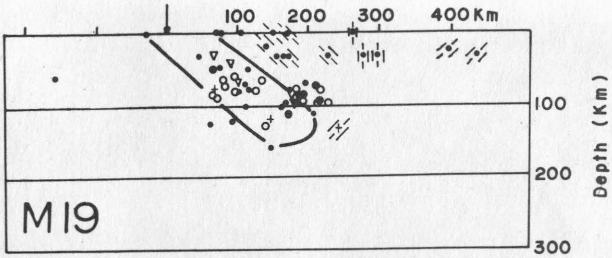

Fig. 16. Vertical section M19, fracture zone Z2 denoted by NE-SW hatching.

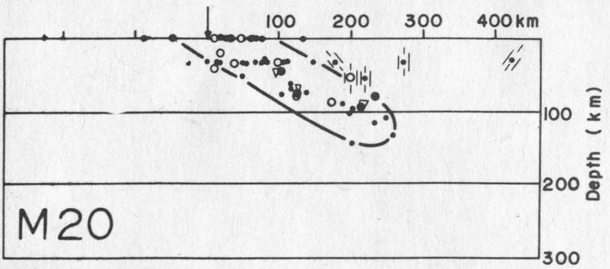

Fig. 17. Vertical section M20.

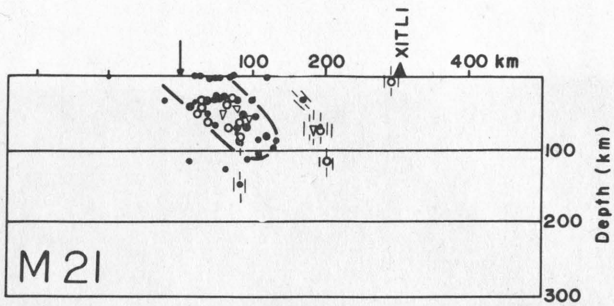

Fig. 18. Vertical section M21.

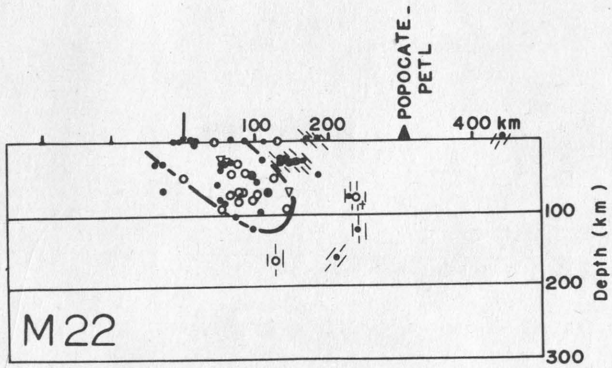

Fig. 19. Vertical section M22.

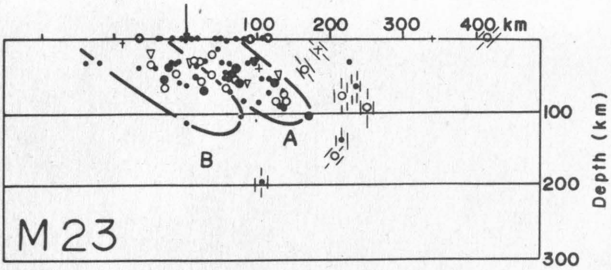

Fig. 20. Vertical section M23, double-slab structure denoted by A and B.

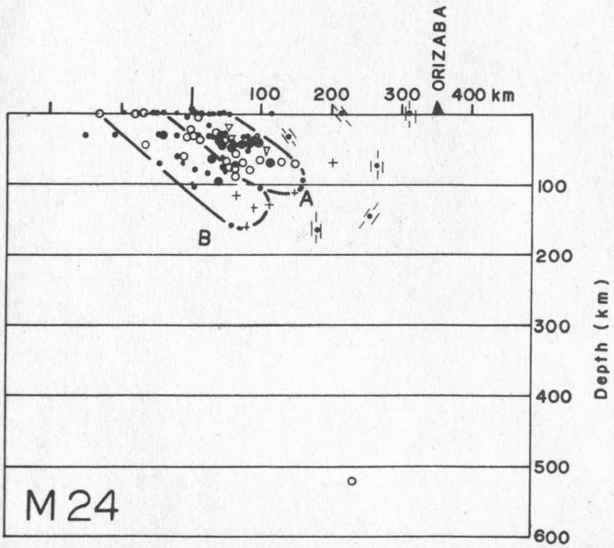

Fig. 21. Vertical section M24.

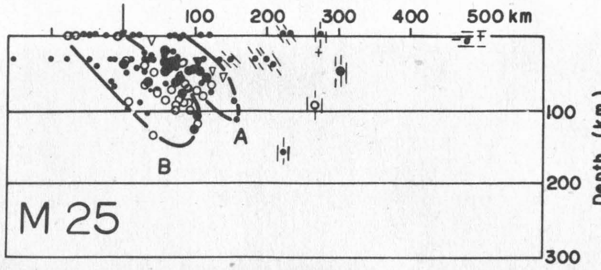

Fig. 22. Vertical section M25, fracture zone Z3 denoted by horizontal hatching.

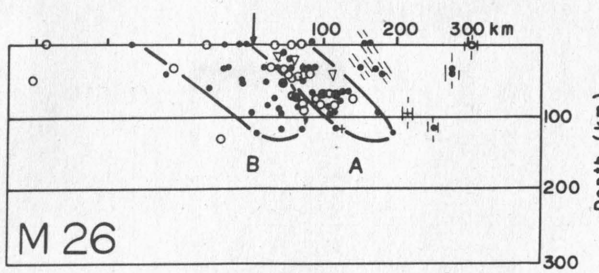

Fig. 23. Vertical section M26.

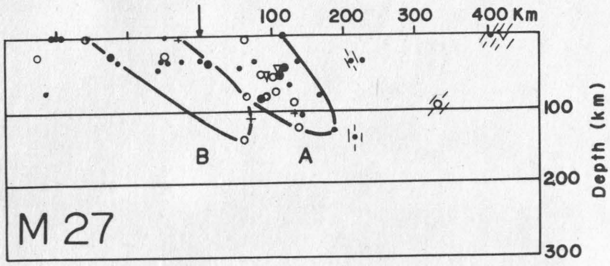

Fig. 24. Vertical section M27.

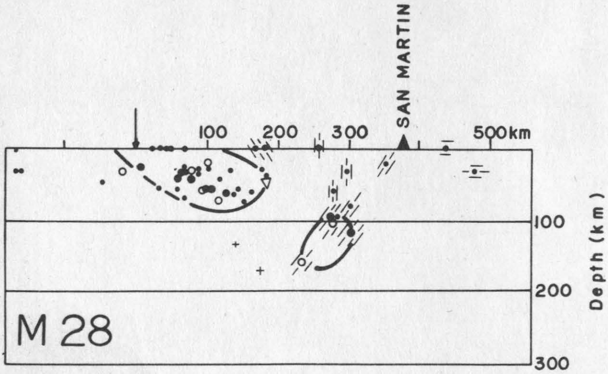

Fig. 25. Vertical section M28.

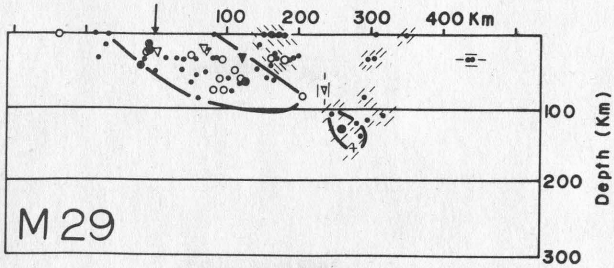

Fig. 26. Vertical section M29.

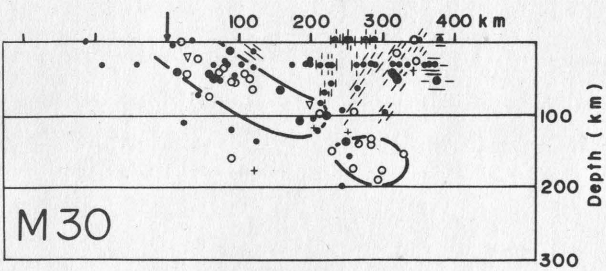

Fig. 27. Vertical section M30.

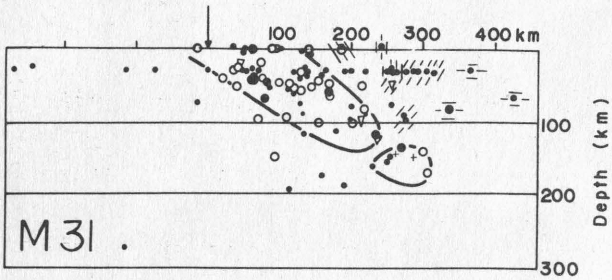

Fig. 28. Vertical section M31.

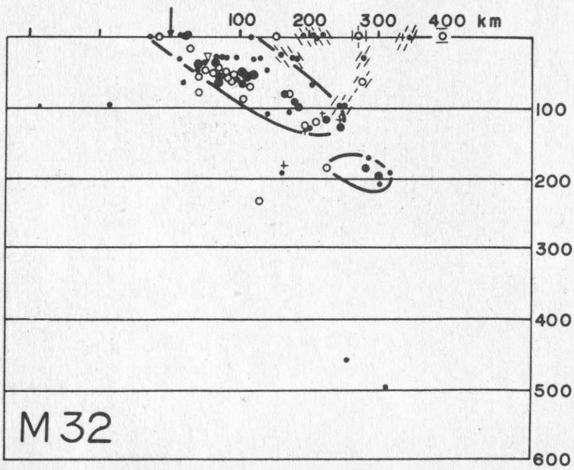

Fig. 29. Vertical section M32.

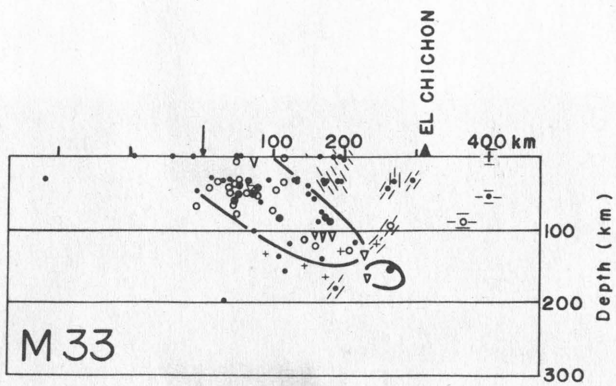

Fig. 30. Vertical section M33.

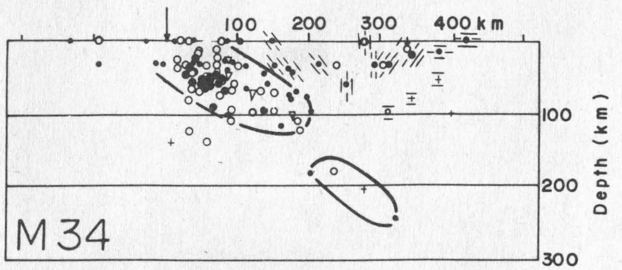

Fig. 31. Vertical section M34.

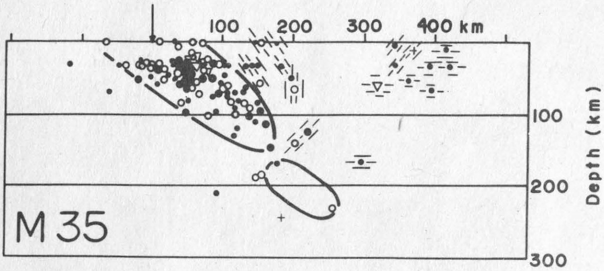

Fig. 32. Vertical section M35.

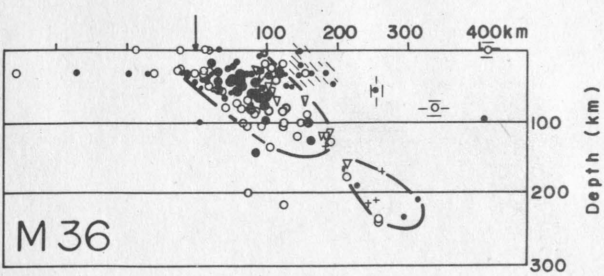

Fig. 33. Vertical section M36.

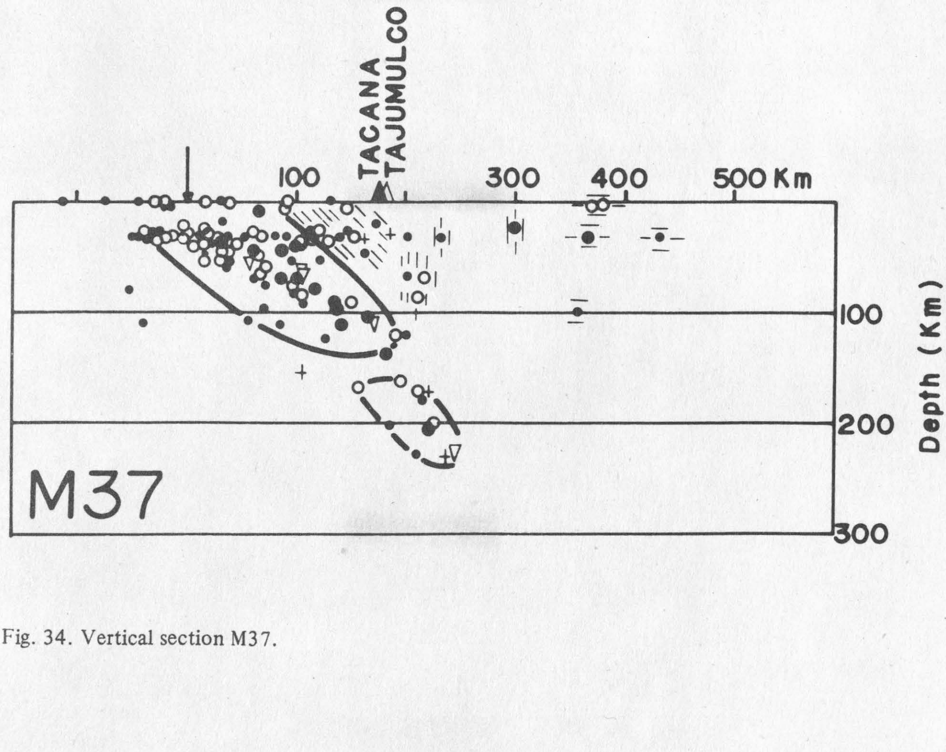

Fig. 34. Vertical section M37.

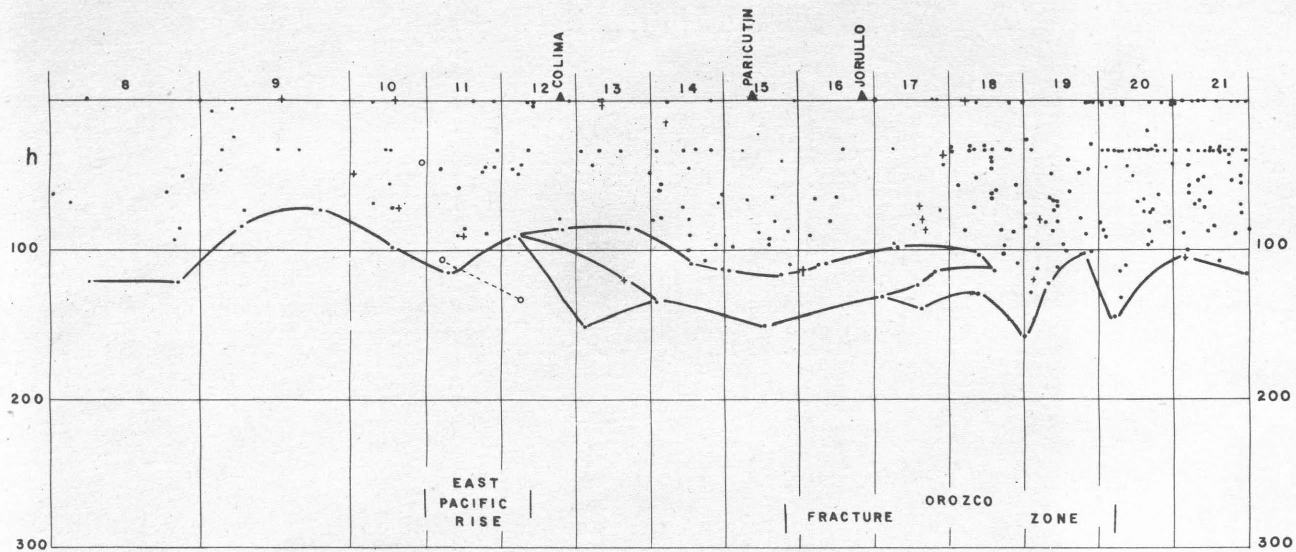

Fig. 35. Detailed morphology of the Wadati-Benioff zone in the northern part of the Mexican subduction zone (sections M8-M21). Earthquake foci, denoted by dots (ISC data) and crosses (Molnar and Sykes, 1969), and position of active volcanoes, denoted by full triangles, are projected into a vertical plane approximately parallel to the axis of the Middle America trench; lower limit of B in double-slab structure is given by a dashed line; depth h in km.

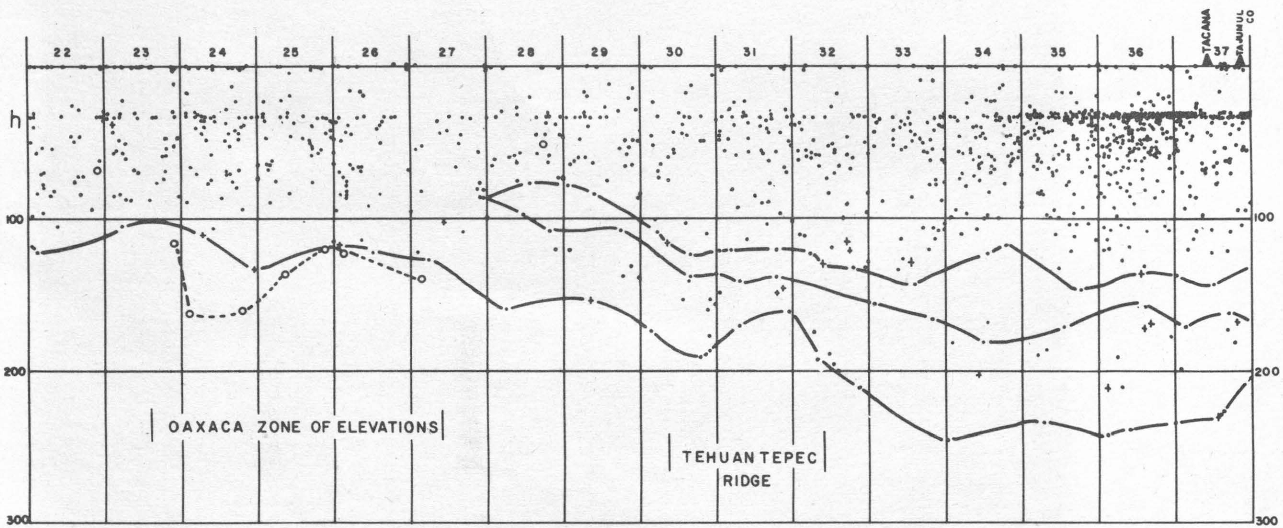

Fig. 36. Detailed morphology of the Wadati-Benioff zone in the southern part of the Mexican subduction zone (sections M22-M37). Earthquake foci are denoted by dots (ISC data) and crosses (Molnar and Sykes, 1969), position of active volcanoes by full triangles, and lower limit of B in double-slab structure by a dashed line; depth h in km.

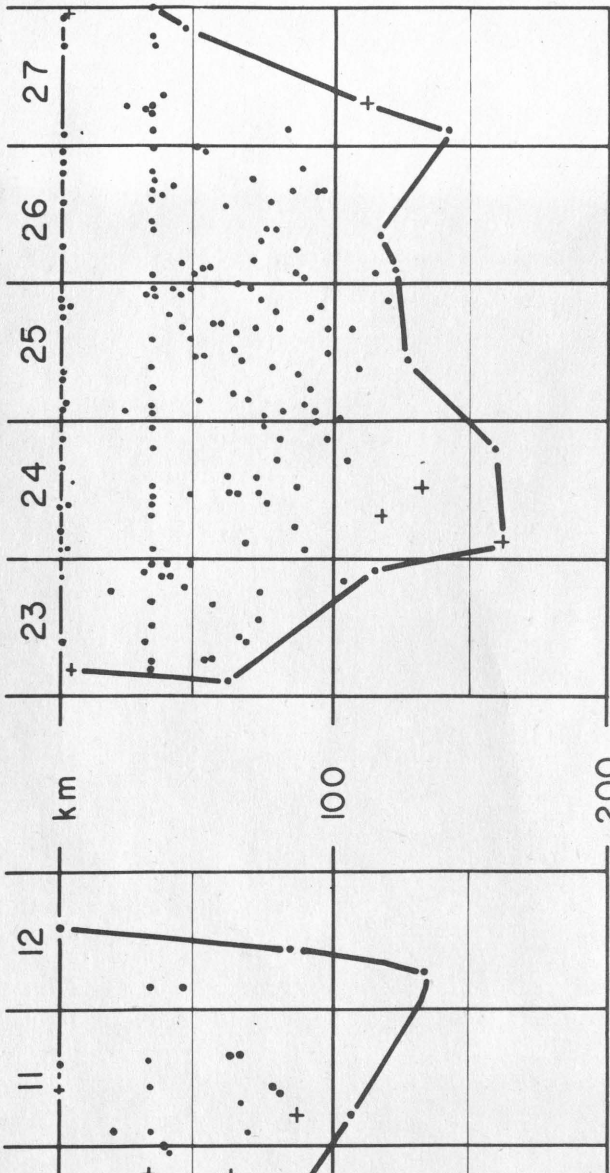

Fig. 37. Detailed morphology of zone B in double-slab structures M10-M12 and M23-M27. Earthquake foci are denoted by dots (ISC data) and crosses (Molnar and Sykes, 1969).

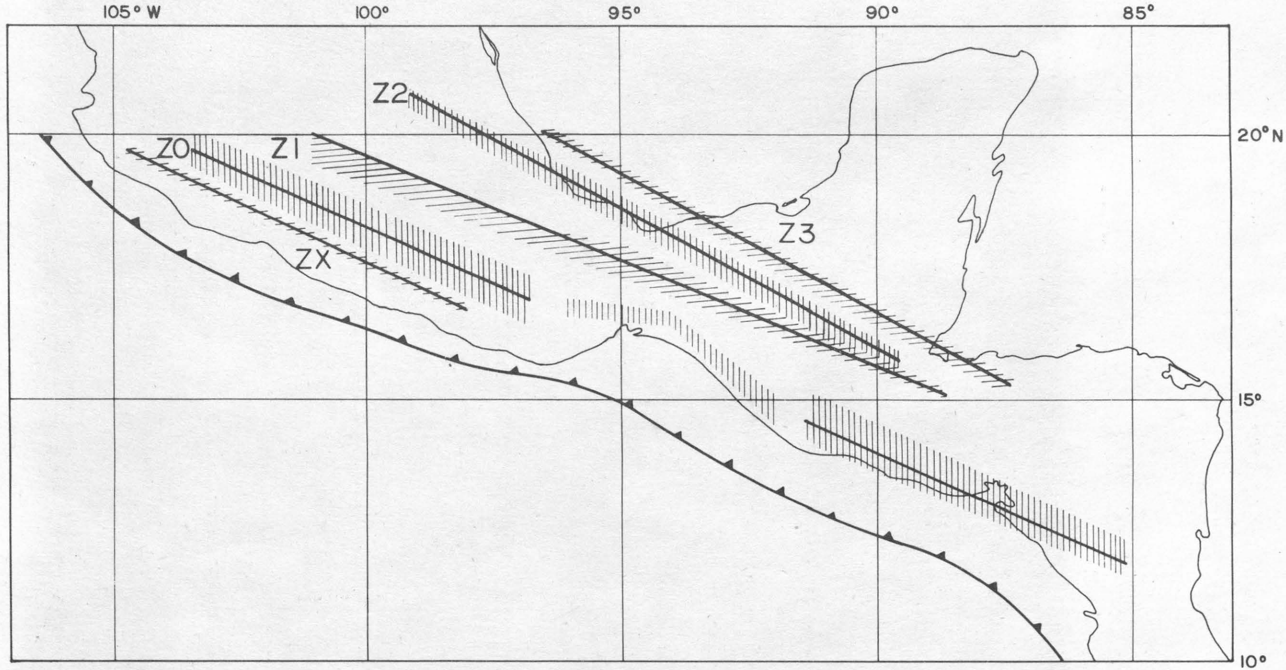

Fig. 38. Position of the fracture zones induced by subduction; ZX: Churumuco-Ometepec F.Z., Z0: la Huacana-Escuintla F.Z., Z1: Los Azufres-Río Salado F.Z., Z2: Tzindejeh-El Chichonal F.Z., Z3: Tecolutla-Chiltepec F.Z. Axis of the Middle America Trench denoted by a line with saw-teeth.

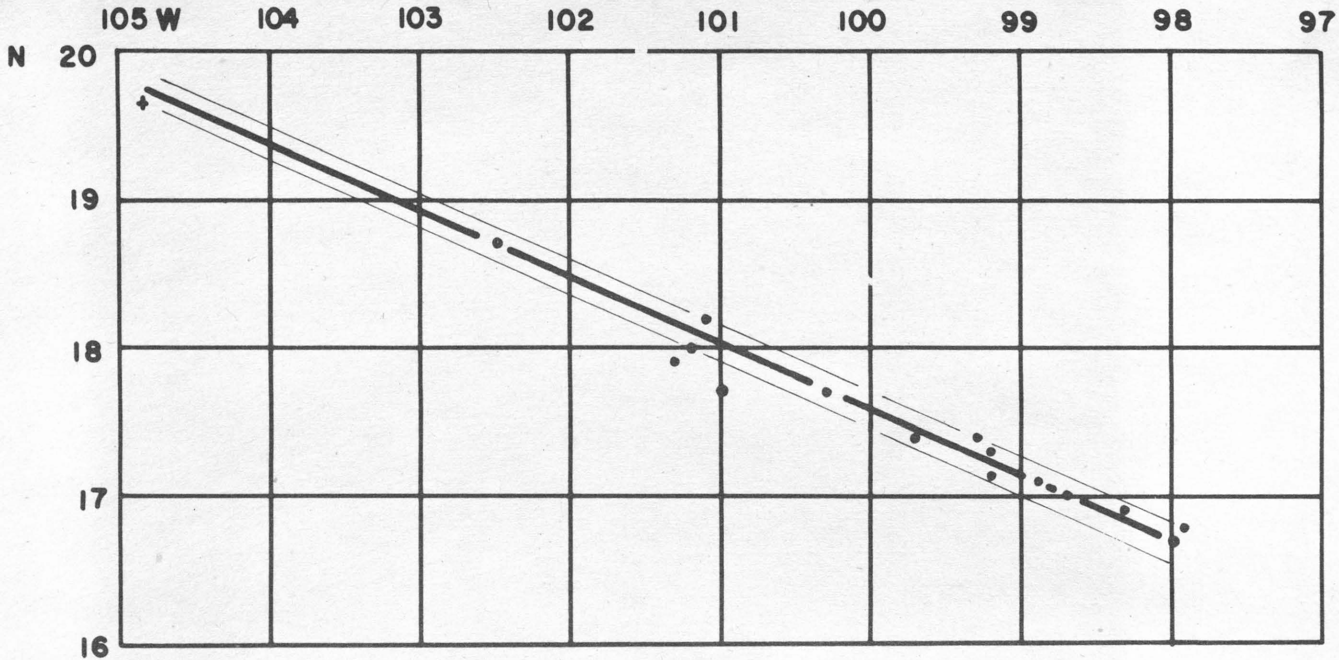

Fig. 39. Position of the Churumuco-Ometepec fracture zone ZX with associated earthquakes.

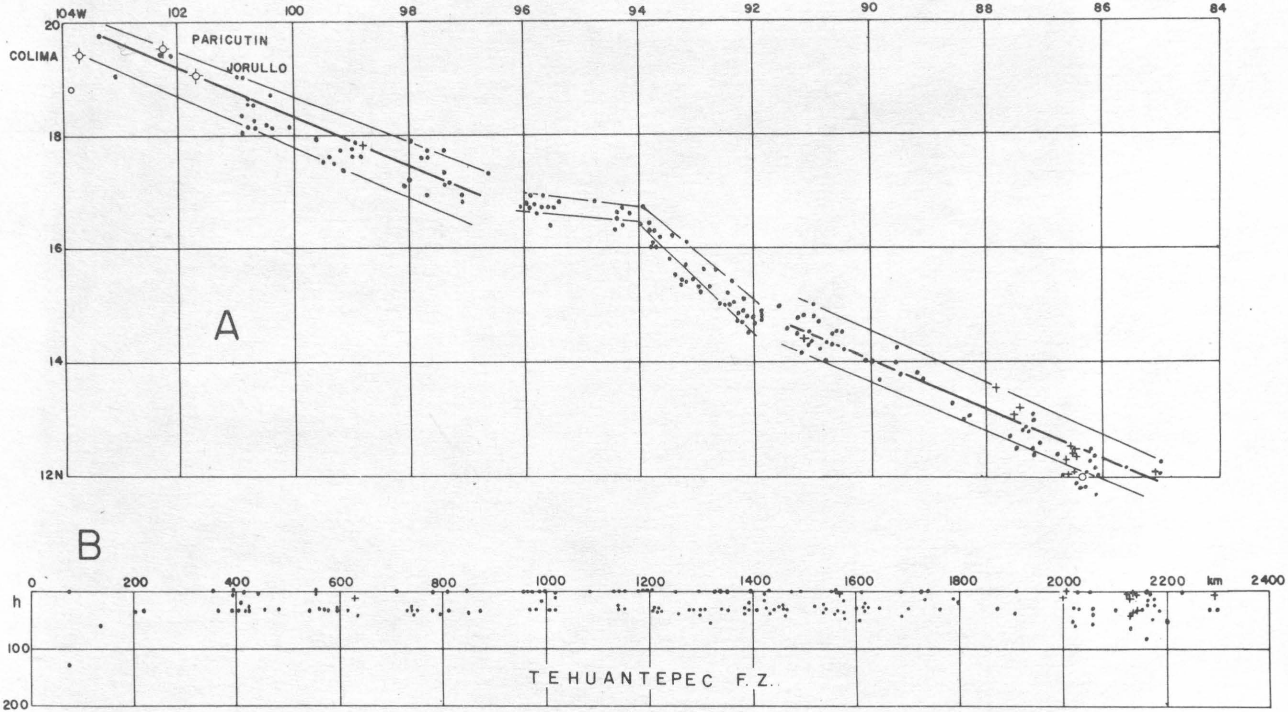

Fig. 40. Position of the La Huacana-Escuintla fracture zone Z0 with associated earthquakes (A) and vertical section along the fracture zone (B): shallow shocks denoted by dots, intermediate shocks by open circles, data from Molnar and Sykes (1969) by crosses; depth in km.

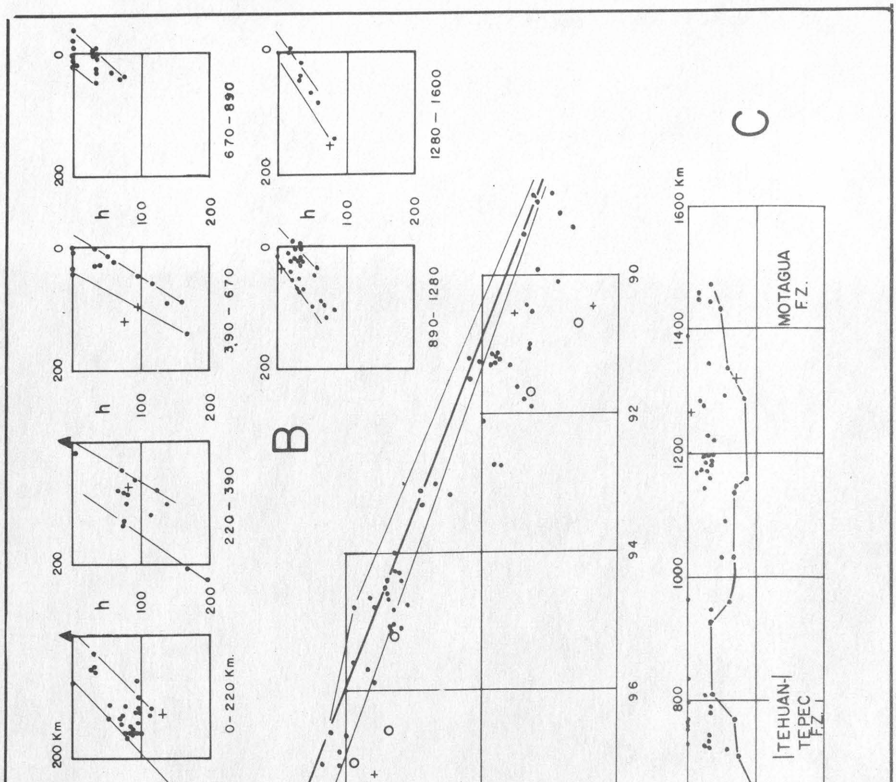

Fig. 41. Position of the Los Azufres-Río Salado fracture zone Z1 with associated earthquakes (A), transverse sections (B) across and longitudinal section (C) along the fracture zone; shocks with focal depth 0-70 km denoted by dots, 70-150 km by open circles, > 150 km by triangles, data from Molnar and Sykes (1969) by crosses; depth h in km.

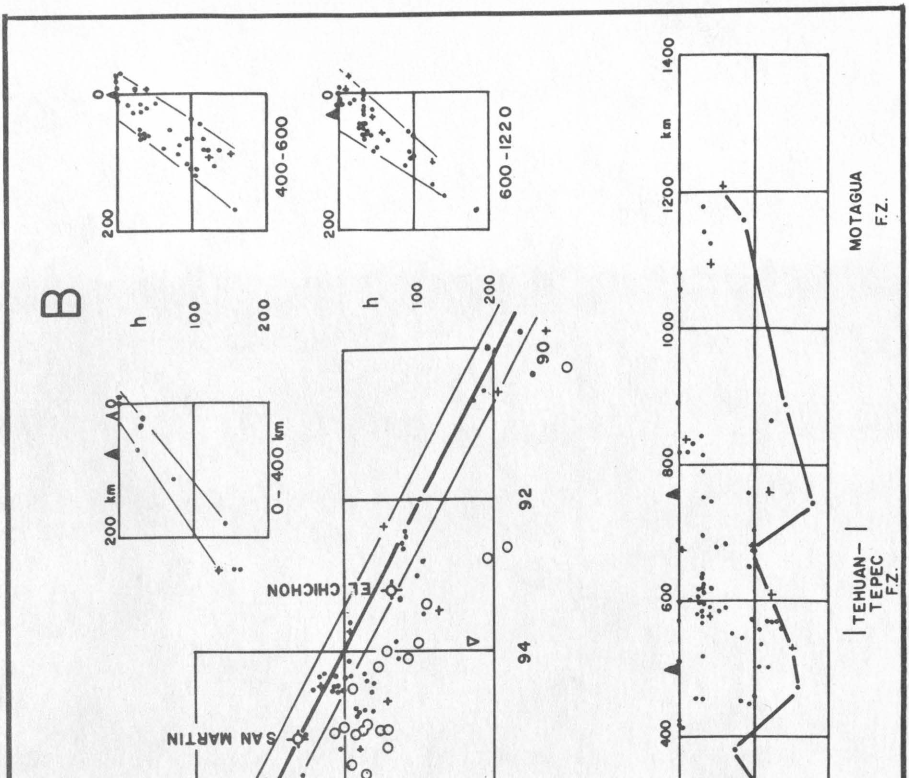

Fig. 42. Position of the Tzindejeh-El Chichonal fracture zone Z2 with associated earthquakes (A), transverse sections (B) across and longitudinal section (C) along the fracture zone; shocks with focal depth 0-70 km denoted by dots, 70-150 km by open circles, > 150 km by triangles, data from Molnar and Sykes (1969) by crosses; depth h in km.

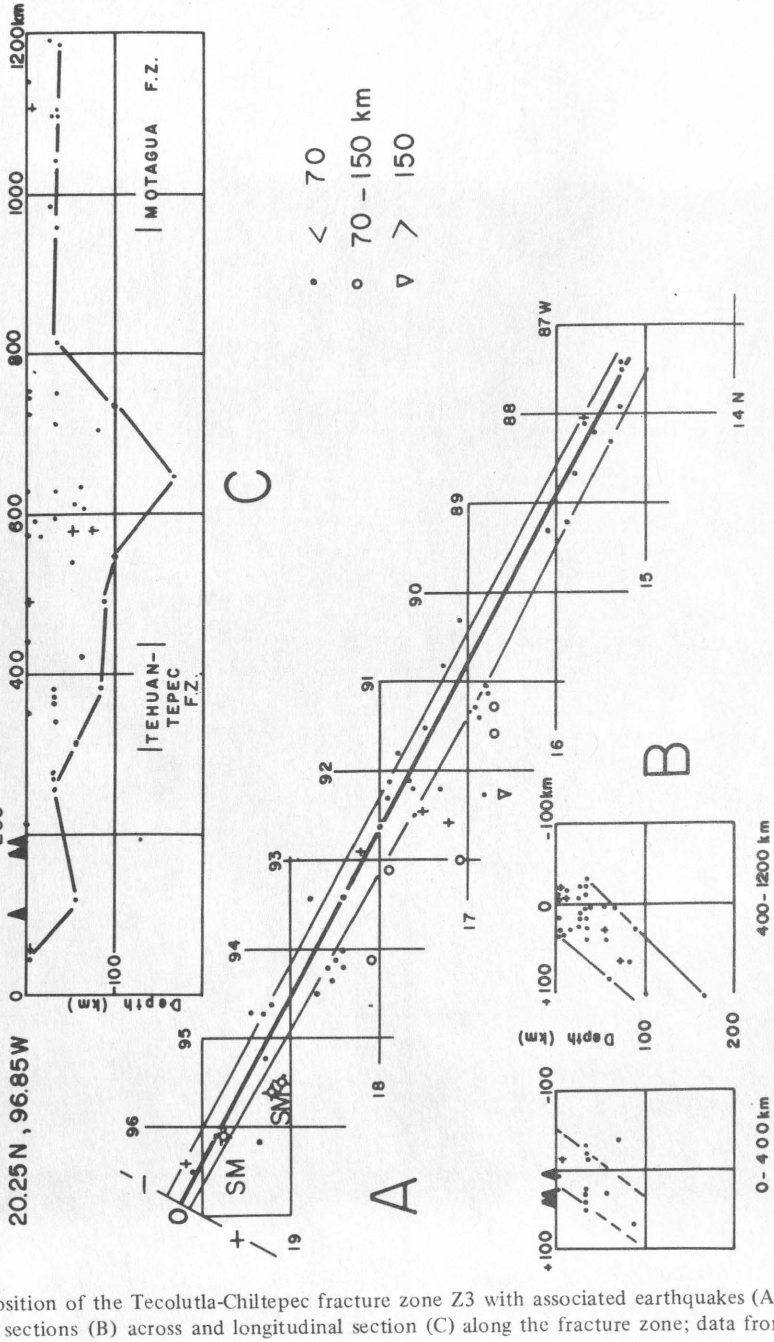

Fig. 43. Position of the Tecolutla-Chiltepec fracture zone Z3 with associated earthquakes (A), transverse sections (B) across and longitudinal section (C) along the fracture zone; data from Molnar and Sykes (1969) are denotea by crosses.

BIBLIOGRAPHY

CHASE, T. E., H. W. MENARD and J. MAMMERICKX, 1970. Bathymetry of the North Pacific, Chart No. 10, Scripps Institution of Oceanography and Institute of Marine Resources, San Diego, USA.

DEAN, B. W. and C. L. DRAKE, 1978. Focal mechanism solutions and tectonics of the Middle America arc. *Journ. Geology*, 86, 111-128.

GONZALES, A. y R. MOLINA, 1977. Manifestaciones termales de la República Mexicana. Comisión Federal de Electricidad, México.

HANUŠ, V. and J. VANĚK, 1976. Intermediate aseismicity of the Andean subduction zone and recent andesitic volcanism. *J. Geophys.*, 42, 219-223.

HANUŠ, V. and J. VANĚK, 1978a. Morphology of the Andean Wadati-Benioff zone, andesitic volcanism and tectonic features of the Nazca plate, *Tectonophysics*, 44, 65-77.

HANUŠ, V. and J. VANĚK, 1978b. Structure of the Wadati-Benioff zone in the Tonga region. *Čas. mineral. geol.* (Prague), 23, 5-23.

HANUŠ, V. and J. VANĚK, 1978c. Geodynamic intepretation of the earthquake distribution in the Kermadec subduction zone. *Studia geoph. et geod.*, 22, 259 - 275.

JIMENEZ J., Z., 1977. Mecanismo focal de siete temblores ($m_b \geqslant 5.5$) ocurridos en la región de Orizaba, México, en el período de 1928 a 1973. Tesis profesional, Facultad de Ciencias, UNAM, México.

MOLNAR, P. and L. R. SYKES, 1969. Tectonics of the Caribbean and Middle America regions from focal mechanism and seismicity. *Geol. Soc. America Bull.*, 80, 1639-1684.

MOORE, G. W. and L. DEL CASTILLO, 1974. Tectonic evolution of the Southern Gulf of Mexico. *Geol. Soc. America Bull.*, 85, 607-618.

MOOSER, F., 1972. The Mexican volcanic belt· structure and tectonics. *Geofís. Intern.*, 12, 55-70.

MOOSER, F., H. MEYER-ALBICH and A. R. McBIRNEY, 1958. Catalogue of the Active Volcanoes of the World, part VI: Central America, *Intern. Volcanol. Assoc.*, Napoli.

REGIONAL CATALOGUE OF EARTHQUAKES, Vol. 1-12, 1964-75. *Intern. Seismol. Centre*, Edinburgh.

WADATI, K., 1935. On the activity of deep-focus earthquakes in the Japan Islands and neighbourhoods. *Geophys. Mag.*, 8, 305-326.