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THE MEXICAN VOLCANIC BELT: STRUCTURE AND TECTONICS

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RESUMEN

El cinturón volcánico mexicano parece ser una antigua sutura cuya reapertura tuvo lugar en el Terciario Medio. Su curso irregular y zigzagueante, con grandes volcanes levantándose en sus esquinas meridionales, hace pensar que en épocas geológicas tempranas la sutura sufrió grandes desplazamientos. La actividad ígnea del cinturón (en su mayoría lavas andesíticas) pudo originarse de la fusión de la Placa de Cocos, posterior a la subducción de la Trinchera de Acapulco. No existe conexión entre la Zona de Fractura Clarion y los grandes volcanes del cinturón, los cuales sólo aparentemente están alineados de Este a Oeste. Probablemente la debilidad cortical por la cual entró el Levantamiento del Pacífico Oriental hendiendo el Golfo de California, originalmente formó, con la sutura del cinturón, una antigua y única zona de debilidad.

ABSTRACT

The Mexican Volcanic Belt appears to be an ancient suture which was reopened in Middle Tertiary times. Its irregular zigzag course with large volcanoes rising on its southern corners suggests that the suture suffered major transcurrent displacements early in geologic history.

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The igneous activity of the belt –mostly andesitic lavas– may be derived from melting of the oceanic Cocos Plate upon suffering subduction in the Acapulco Trench. No connection exists between the Clarion Fracture Zone and the belt's large volcanoes, which only form an apparent east-west alignment. Probably the crustal weakness into which the East Pacific Rise entered upon rifting the Gulf of California originally formed, with the belt's suture, a single ancient zone of weakness.

A. INTRODUCTION

The investigation of the Mexican Volcanic Belt (MVB) has been a part of the Mexican National University's *Instituto de Geofísica* contribution to the International Upper Mantle Project. Reports on the results obtained have been published previously, (Mooser and Maldonado, 1961; Mooser, 1969). The present paper deals with work done between 1969 and 1972.

B. HISTORICAL DEVELOPMENT OF KNOWLEDGE CONCERNING THE MVB

Alexander von Humboldt (1867) introduced the hypothesis that the large Mexican volcanoes stand on a crustal fracture which disects the North American continent along the 19th parallel from the Atlantic to the Pacific Ocean. The Pacific Revillagigedo Islands, 800 km further west, are volcanic structures which that author conceived as belonging to the same giant fracture.

In this way the most simple explanation was established for the trans-Mexican Volcanic Belt (MVB), a 20-70 km-broad structure which extends from Veracruz on the Gulf coast to near Puerto Vallarta in the west (Fig. 1).

As geological investigation progressed, new explanations from the origin and development of the Belt arose. Felix and Lenk (1890) accepted Humboldt's big fracture theory but added to it minor secondary fractures which appear to take off perpendicularly, thus explaining the Popocatepetl-Iztaccihuatl range, among others, which run north-south within the big east-west structure.

The 1950's experienced a revival of Humboldt's fracture hypothesis as a consequence of the discovery of the marine Clarion Fracture Zone, (Menard, 1955). Now the alignment revealed by the large volcanoes appeared to be the continental extension of an oceanic fracture. Subsequently the MVB was visualized as the result of oblique crustal shearing along such "zones of weakness". A step in this direction was taken by Mooser and Maldonado (1961), who considered the whole volcanic zone to be a flock-faulted "geotumor" subsequently subjected to shearing along two alignments: first the Humboldt line in the south and second the Chapala-Acambay line in the north, the former being an extension of the Clarion Fracture zone and the second an extension of the San Andreas fault system prolonged southward into the Gulf of California.

In the same publication, a third alignment –the Balsas line– was inferred on the basis of existing drainage patterns south of the MVB; it is interesting to note that it roughly parallels the Acapulco Trench, a fourth major alignment. These last three alignments are sub-parallel. Their existence may contain the solution to the present difficulty in assembling southern Mexico into the different fittings which attempt to reconstruct pre-drift continental positions.

By the end of the 1950's, the Paricutin area and the Valleys of Mexico and Toluca, located in the central part of the Belt, had been mapped. The great number of cindercones, domes and strato-volcanoes of Upper Cenozoic age thus plotted permitted the recognition of alignments, true and false, in all directions, so that it became any geologist's game to suspect shearings, tensions and compressions of varied types in different localities.

It was then that the author undertook the photogeological mapping of the entire belt, producing maps at scales of 1:40,000 and 1:50,000. This work, concluded by 1968, (Mooser 1969), has shed new light on the structure and origin of this extraordinary trans-continental volcanic alignment. Between 1968 and 1972, several areas were checked in greater detail, especially between Puebla and Veracruz on the eastern end of the belt, (Mooser and Palacios, 1970; Mooser, 1972; Seele and Mooser, 1972), and around Guadalajara (Díaz and Mooser, 1972) and Colima in the western half. At the same time, the structures within the Belt were correlated with tectonic fractures beyond its northern and southern borders, thus establishing criteria for its age. It was also during these last years that attempts were made to interpret the Belt in the light of the new theories on plate tectonics. Thus it was also visualized as a possible extension of the East Pacific Rise (Mooser, Nairn, Noltimier, 1970), a hypothesis which did not hold up under closer investigation; at the present moment this author considers that the trans-Mexican Volcanic Belt is an old zone of crustal weakness which has been reopened since Tertiary times. The lavas produced probably are derived from subduction taking place in the Acapulco Trench.

C. PRESENT STATE OF KNOWLEDGE

1) *New map*

The original surveys have been reduced to a scale of 1:200,000, thus providing a geological map that readily reveals both details and major tectonic alignments. The study of this map shows the MVB to be an irregular structure which follows a zigzag pattern (Fig. 1). Already the map published by Mooser in 1969 (p. 18, Fig. 3) showing the distribution of fractures and Quaternary cones had indicated a sinuous development of the Belt.

2) *General Structure*

As a whole, the MVB may be divided into two parts, with the division drawn by the junction of the north-south running Colima graben and the main east-west structure near Guadalajara. Significantly, this point of weakness is marked by major faults and a large caldera, La Primavera (Fig. 3). From Guadalajara to the Pacific Ocean, the western MVB forms a narrow, quite regular structure which runs to the northwest and merges with the Gulf of California. From Guadalajara to the east, the eastern MVB forms a broad zigzagging band which eventually reaches the Gulf of Mexico on the Atlantic Ocean. The newly-recognized zigzag pattern is the result of prominent crustal breaks or displacements along SW-NE-directed fractures, which may represent deepseated transcurrent faults. Clearly recognizable in the morphology of the eastern MVB are the four major displacements of a left-lateral nature caused by the Malinche line, the Nevado-Pachuca line, the Morelia line and the Tancítaro line. These major lines are paralleled by numerous minor lines, as shown in Fig. 2, for the eastern part of the MVB.

As inferred by discontinued cindercone alignments, the western half of the Belt shows only one minor displacement, also along the NE-directed line, which contrary to the others, is of a right-lateral nature. It is marked by the Laguna del Tesoro explosion caldera.

The prominent set of SW-NE fractures is enhanced by a less significant set of fractures running in an opposite direction, i.e. WNW-ESE. An example of this system is the Hueyotlipan fracture that cuts the large SW-NE Malinche fault and thus produces the weakness for that large volcano to grow north of the city of Puebla (Fig. 3).

In a general way, it appears that the MVB, which forms a large belt structure running across Mexico from WNW to ESE, is crisscrossed by deep-seated fractures and faults that disect it in northeasterly and northwesterly directions. In detail, the MVB consists of sections which run to the SW and sections which run to the NE, both equally 20-30 km broad. Grabens have been developing in the NW-running sections ever since Middle Tertiary time, whereas in the NE-running sections (basins of Mexico City and Oriental) grabens apparently formed principally up to Lower Miocene times.

Superimposed on the above-mentioned fracture grid of the Belt, one also finds other fracture patterns. It seems that the prominent sweepoof horsts and grabens forming the Tarascan Arc (Mooser, 1969) developed from Pliocene time on, probabli as a consequence of the growing plasticity in the lower crust of the MVB. In a similar manner may have been formed the swarn of WE-running faults which extend over a narrow span of some 200 km, controlling the activity of Nevado, Popocatepetl and Malinche Volcanoes; these faults begin in the southern valley of Toluca, continue below the Chichinautzin range south of Mexico City, and extend into the valley of Puebla, creating well-defined blocks in the area of Tlaxcala (Fig. 3).

3) *Positions of Major Volcanoes, Calderas and Mining Centers*

The Humboldt line, marked by the major volcanoes along the Belt can now be defined as non-existent fracture. At the spots on its southern side where the MVB, while following its zigzag pattern, forms corners, there is invariably located a large volcano. These corners, topped by cones (Pico de Orizaba, Popocatepetl, Nevado de Toluca, Tancítaro), coincidentally stand at the 19th parallel, and so does Colima Volcano, which however obeys a completely, different volcanic setting.

It is interesting that the northern corners of the MVB, while not marked by large volcanoes, nevertheless are characterized by important mining centers such as Guanajuato and Pachuca. The large Quarternary calderas olso occur on significant points of the Belt, their presence always revealing major structural weakness: the Humeros Caldera occupies the northern corner of a zigzag in the eastern half of the belt; the already-mentioned Primavera Caldera stands at the intersection of the belt with a structural trend that runs from Colima in the south to the mining center of Zacatecas in the north; the small explosion caldera called Laguna del Tesoro stands at the northern corner of a displacement of the western half of the MVB east of Tepic.

4) *Age of Volcanic Activity in the MVB*

Judging from its eruptive activity, the MVB is of Middle Tertiary age. Its oldest lavas cover folded and eroded Cretaceous marine sediments in the central and eastern parts. Absolute age determinations on early andesites in the northern Valley of Mexico and in the Texcoco Well (Mooser, 1970) yielded maximum ages of 32 and 31 million years. The oldest andesitic lavas belonging to the Chapala formation were shown to be 27 million years old, thus providing that Miocene folding (Fig. 4) ocurred along the Belt west of Michoacan (Díaz and Mooser, 1972).

Within the central and western parts of the MVB, its structure contrasts with the older volcanics covering the areas to the north and south, where volcanic activity generally ceased in the Upper Oligocene and Lower Miocene times. Thus, the slightly folded rhyolitic ashflows along the western Pacific coast, which extend as far east as Queretaro in Central Mexico, are clearly interrupted and overlain by the volcanics of the MVB. Similar volcanics, although not as acid, reappear south of the belt between Puerto Vallarta and the Balsas River, and are also folded. Oligocene volcanics occur also in Taxco area (Fries, 1960).

In a general way, the bulk of the Belt's igneous activity must have developed around Middle Miocene and it has subsisted into recent times.

5) *The MVB and the Cratons to the North and South*

A glance at the geologic map of Mexico (1968) shows the MVB to develop in its general, though irregular, E–W course in such a way that it follows the northern border of a fragmented southern Mexican mass. It is most revealing to observe the different Paleozoic and Precambrian units which seem to fall into five separate blocks. From E to W, one may distinguish the:

1. Block of Chiapas.
2. Block of Oaxaca.
3. Block of Guerrero.
4. Block of Michoacan.
5. Block of Jalisco.

These five blocks are clearly separated by four major geomorphic features:

a) The Isthmus of Tehuantepec.
b) The Morelos Basin.
c) The Balsas River breakthrough to the Pacific.
d) The complex Colima Graben.

At present not enough is known of Mexico's Paleozoic and Precambrian stratigraphy in order to recognize clear structures in these ancient complexes. Nevertheless, it appears that from the Colima graben to the east, the blocks have suffered left-lateral transcurrent displacements, among which the one between the Oaxaca and Chiapas blocks is the most outstanding. From the Colima graben to the west, however, the transcurrent displacements seem to be rightlateral.

One is inclined to suspect a relationship between the fragmentation of the entire southern backbone of Mexico and the zigzag pattern formed by the MVB. For example, the Malinche line, while clearly marked in the Belt by a large volcano, can be followed for considerable distances north and south of the Belt. Its southern extension apparently points into the southern tip of the Morelos Basin, which separates the Oaxaca block from that of Michoacan. Consequently, the Malinche line might reveal a deep crustal displacement projected into and beyond the Belt. In the same manner, the Belt's irregularity on a line drawn between Morelia and Queretaro would be the result of another deep displacement between the blocks of Guerrero and Michoacan projected northward. As to the striking bend produced by the Nevado-Pachuca and the Mina-Atoyac lines, at present no clear expression of these weaknesses has so far been recognized in the southern blocks by this author.

6) *The Age of the Structure*

While Tertiary volcanism along the Belt had clearly outlined its form around Middle Miocene Times, one is led to recognize in its manifestation an older zone of crustal weakness. This zone must have already existed long ago, between a complex and as yet undivided northern craton of Mexico and a fragmented southern craton. The fact that folds affecting the Lower Tertiary volcanics of Nayarit along the Pacific coast, upon extending south move into and then parallel the Belt south of Guadalajara in the Chapala Lake area (Figs. 4, 5), already shows that the MVB constitutes an unstable zone prone to compression. On the other hand, the large fractures which cut the Belt and, upon striking its southern limit produce the giant volcanoes, are features predating the Belt's Tertiary activity; their age might be older than Paleozoic, judging from their projection beyond the limits of the Belt. It is significant that they do not produce displacements in the Lower Tertiary folds of Cretaceous marine sediments, but do apparently displace the Precambrian masses.

Upon assembling the different pieces of evidence, it seems that the belt reflects and ancient suture which suffered transcurrent displacements in pre-Paleozoic times (Mooser, 1972) along the SW-NE-running transcurrent faults. But it was only in Middle Tertiary times that this suture was subjected to tension, and then followed volcanism producing the MVB.

7) *Connections of the MVB with the Gulf of California and the Gulf of Mexico.*

The MVB runs northwestward into the Pacific Ocean and disappears. One is inclined to recognize in the Gulf of California an extension of the suture in which the Belt formed. As is knowm Miocene marine sediments had already been deposited in an original bay between Baja California and present-day mainland Mexico (Gastil et al., 1972; Gastil, personal communication), a fact which suggests a long and narrow crustal weakness for this area also. Thus, when the Eastern Pacific Rise, which struck Mexico's west coast about 30 million years ago, eventually started to tear Baja California from the continent 6 million years ago, Atwater (1970), the rifting significantly followed an ancient weakness which it practically took advantage of. The zigzagging followed by this modern expansion (with lines to the NW and NE) may be a consequence also of an ancient fracture pattern which, further to the SW in the MVB, controls volcanism.

The MVB's visible eastern limits are formed by the Tuxtla volcanic group. This complex of Plio-Pleistocene volcanics following large WNW-ESE-running fractures ends near the harbor of Coatzacoalcos. Judging from the characteristics of the rest of the MVB, it is probable that here the structure strikes against a major SW-NE fault system, which displaces its continuation a considerable distance to the

NE into the Gulf of Mexico. Such an offset is in agreement with the suggested large Isthmianleft-lateral displacement. The originally assumed continuation of the MVB southeastward into Central Chiapas, where there is a large volcanic group, seems doubtful in the light of our present knowledge.

8) *The MVB and Plate Tectonics*

While the Guatemalan volcanic belt parallels the coastline and thus holds and island-arc relation to the spreading Cocos Plate off the Meso-American Trench, no volcanoes line this trench's westward extension on the Mexican coast (Figs. 6, 7). Either subduction in the Acapulco Trench might have begun recently, or it has been occurring at a lower angle, consequently producing magmas further inland, which then only rise under the MVB at a distance of 200 to 300 kilometers from the coastline. The bulk of the magmas produced in the MVB is andesitic (Gunn and Mooser, 1971; Negedank, 1972), a fact that supports their connection with the subduction.

9) *Seismicity*

The Belt's seismicity is generally low; deep-focus earthquakes are not known. However, along its entire extension shallow focus, low energy earthquakes are frequent. Maximum magnitudes of 6 to 6 1/2 R for these are rare; such shocks were registered NW of Guadalajara in 1912; in Acambay also in 1912; near Jalapa in 1920; and north of Coatzacoalcos in 1959. These earthquakes can occur in the graben sections which run NW-SE, paralleling the Belt, or in the deep fault systems which run SW-NE, cutting it. Seismicity seems to decrease abruptly immediately north of the MVB.

There also seems to exist an attenuation of seismic energy transmitted from the Acapulco Trench as this energy spreads northward and hits the Volcanic Belt. It rarely extends beyond the MVB, Figueroa, (1963), probably being absorbed by the increased plasticity of the crust here.

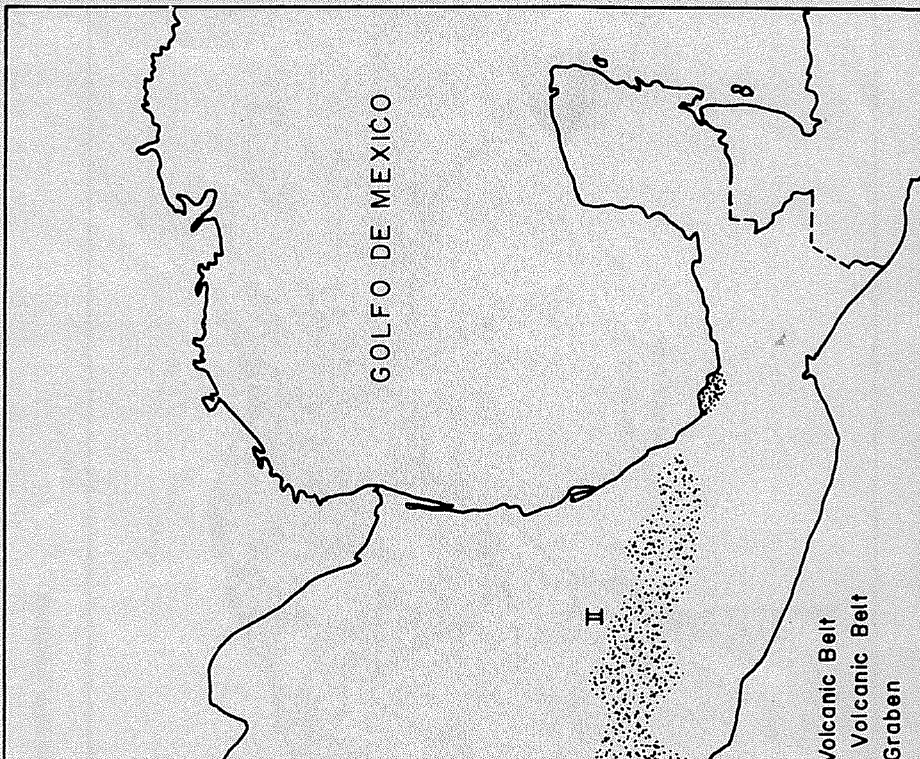

Fig. 1 The mexican volcanic belt.

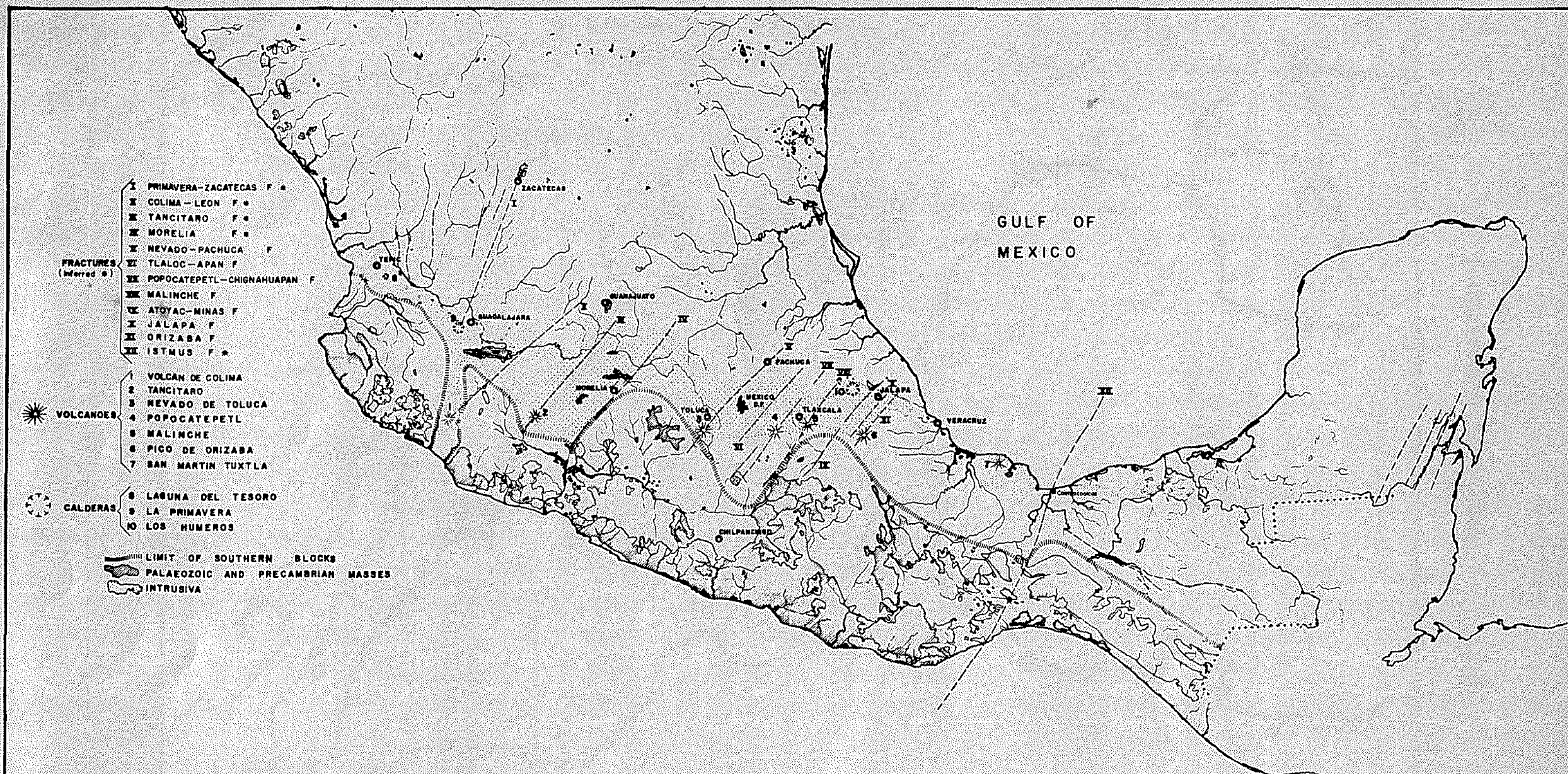

Fig. 2 The Mexican Volcanic Belt and fractures of the large volcanoes.

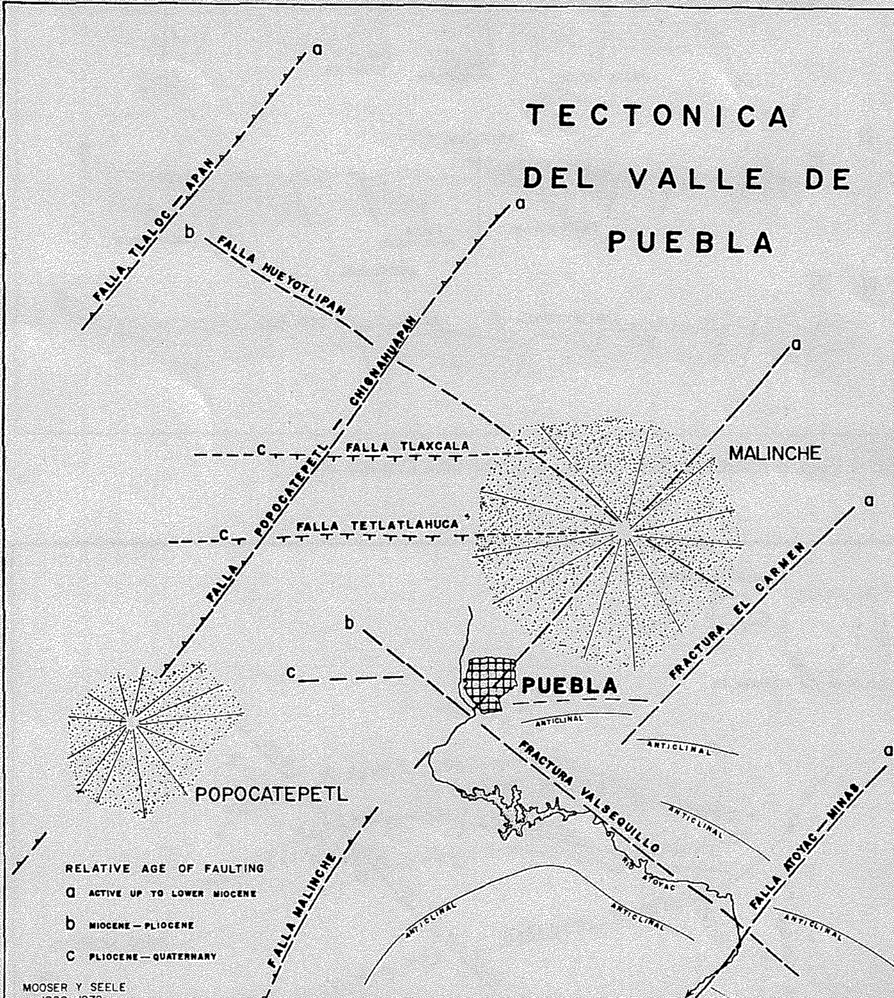

Fig. 3 Tectonic setting for Popocatepetl and Malinche volcanoes.

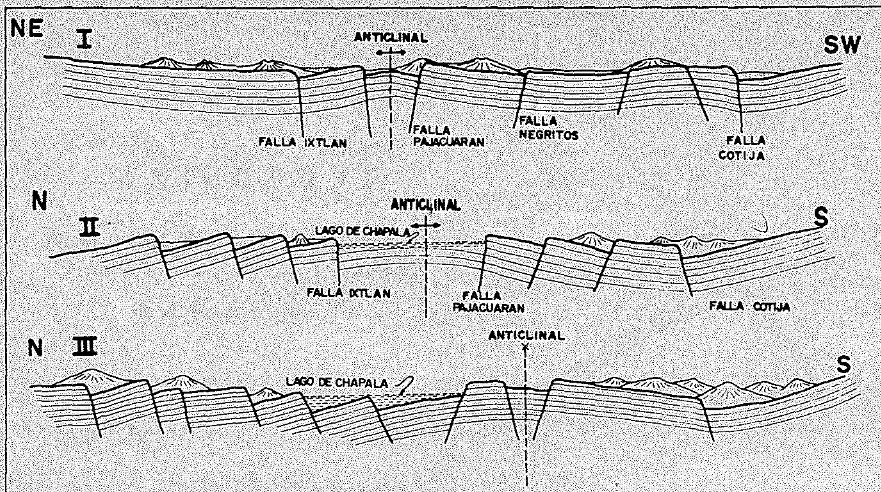

Fig. 4 Folded middle tertiary volcanics in the lake Chapala area.

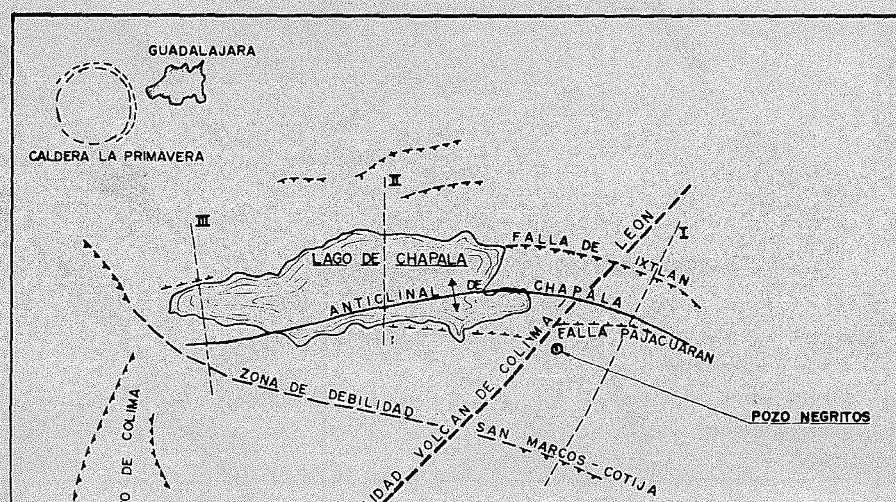

Fig. 5 Tectonic setting of the lake Chapala Area.

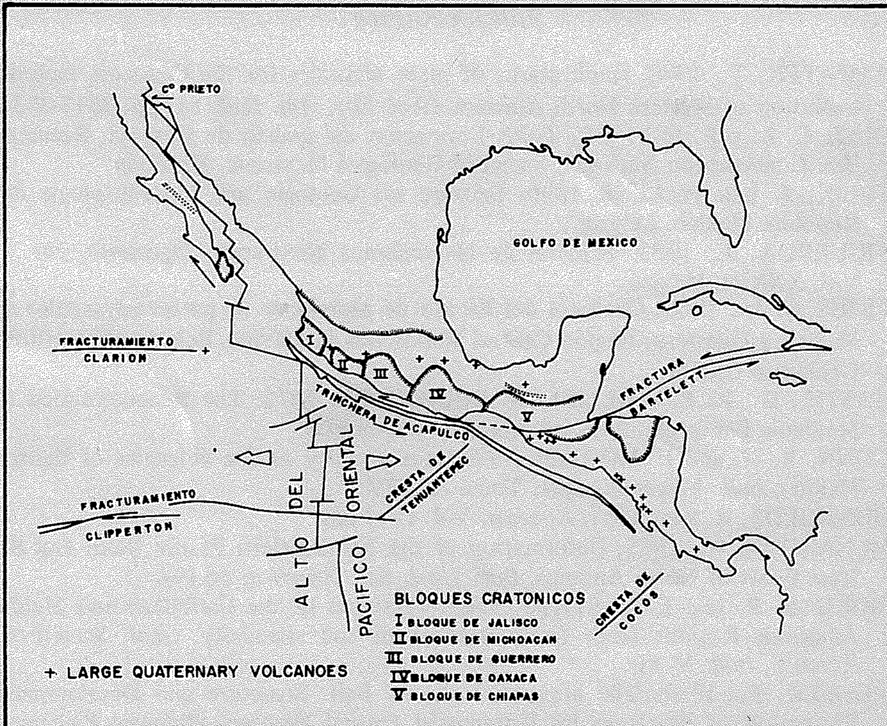

Fig. 6 Structure of southern Mexico and the East Pacific Rise.

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