# *MORPHOSTRUCTURAL ANALYSIS OF OAXACA, MEXICO. APLIED TO SEISMIC STUDIES*

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## RESUMEN

Para investigar la relación entre la sismicidad y la estructura tectónica de la región de Oaxaca, en el sur de México, se usó el análisis morfoestructural: éste se basa en la determinación de los elementos tectónico-estructurales por medio del estudio de las formas y características del relieve. Para determinar las características tectónicas de esta región se utilizaron mapas topográficos, mapas geológicos a la escala de 1:1,000,000 y otros datos geológicos disponibles. Los elementos estructurales principales incluyen domos, bloques tectónicos y lineamientos de diferentes magnitudes. Además se infieren el desarrollo y las relaciones entre estos elementos estructurales. Se diferencian formas activas, inactivas y reactivadas.

Se sugiere una correspondencia entre actividad sísmica y las estructuras tectónicas encontradas para esta región de acuerdo al análisis morfoestructural; se sugiere, además, que los epicentros de los temblores fuertes podrían estar localizados, dentro de la confiabilidad de su determinación, en la intersección de las fallas activas de dirección N65° ± 5°W con las importantes fallas reactivadas de direcciones N-S y E-W. La actividad sísmica precursora y de réplicas asociadas al temblor del 29 de noviembre de 1978 ($M_S = 7.8$) muestran una buena correlación con los detalles de la estructura tectónica de Oaxaca.

La actividad sísmica precursora está probablemente relacionada a la primera estructura de dirección N65° ± 5°W en el continente, después de la trinchera mesoamericana; las réplicas están presumiblemente asociadas a las estructuras continentales con direcciones N-S y E-W, las que reflejarían acomodamientos de bloques a raíz de los desplazamientos típicos de subducción generados por el temblor principal.

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## ABSTRACT

Morphostructural analysis, based on the determination of tectonic structural elements through the study of landforms and characteristics of the relief, was used to investigate the relation between seismicity and the tectonic structure of the Oaxaca region in SW Mexico. Topographic maps, geologic maps on a 1:1,000,000 scale, and other available geologic data were used to identify the tectonic structures of this region. The main structural elements include domes, tectonic blocks and lineaments of different magnitudes. The development of and relations between these structural elements were also inferred. We differentiate active from inactive fault zones and from fault zones that have been reactivated.

We suggest a correspondence between the seismic activity and the tectonic structures found in this region by morphostructural analysis; we also suggest that the epicenters of large earthquakes might be located, within the accuracy of determination, at the intersections of active fault zones N65° ± 5° W and important reactivated fault zones oriented N-S and E-W. The foreshock and aftershock seismic activities associated with the 29 Novembre, 1978, earthquake ($M_S = 7.8$) show a good correlation with the details of the tectonic structure of Oaxaca.

Foreshock activity is probably related to the first (after the Middle Pacific Trench) N65° ± 5° W structure on the mainland; aftershocks are presumably linked to N-S and E-W structures inland, which are related to block accomodations due to subduction movements originated by the mainshock.

## INTRODUCTION

The problem that we consider is the possibility of relating morphostructures with seismicity, and how these data might be used for seismic prognosis and mapping of seismic risk zones.

Our main tool of research was morphostructural analysis. With this method it was possible to determine the tectonic block structure, the main and secondary lineaments, domes, fault zones and other elements that constitute the regional tectonic structure of Oaxaca. The morphostructural method (Anan'ev *et al.*, 1969; Filosofov and Tchernyaev, 1963; Pyotrovskii, 1966,1968; Volchanskaya *et al.*, 1975) allows the differentiation of structures by magnitude, importance and genesis.

The relationship of morphostructures and seismicity have been investigated for the Tien-Shang region in the USSR and for California in the United States (Gerasimov, 1969; Gerasimov and Rantzman, 1973; Gelfand *et al.*, 1973; Gelfand *et al.*, 1976). It was found, for instance, that the epicenters of strong earthquakes with magnitudes higher than six are generally related to the intersections of deep fault zones. It has been proposed that some earthquakes are due to the reactivation of very deep cortical faults, which in some cases, may even reach the upper zones of the mantle (Khain, 1973 a, b; Suvorov, 1968).

## MORPHOSTRUCTURAL METHOD

The morphostructural analysis assumes that the deep tectonic structure of the earth is reflected in the land relief through morfostructures, which represent the principal geomorphological units, created by tectonic movements in combination with erosion and sedimentation processes. These units are, for instance, cordilleras, massifs, plateaus, depressions, domes, and faults. Using the morphostructural analysis, it is possible to find the genesis of the relief forms and their relations to exogenic and endogenic phenomena, which makes this analysis an important method in the exploration for endogenic ore deposits, in tectonic studies, and in other geologic research. The structural elements or geomorphological units are classified in two main groups: linear structures and the area-occupying morphostructures, such as blocks, megablocks, domes, and depressions.

In general, the results of the morphostructural analysis are correlated with geologic, geophysical or geochemical data, depending on the object of the analysis. In this work, we used mainly the correlation of seismic, geologic and morphostructural data. The morphostructural analysis of the Oaxaca region was based on topographic and geologic maps, at a scale of 1: 1,000,000. It is important to point out that this method uses topographic materials at different scales, again depending on the object of the analysis. Satellite photographs are a complementary aid, by only topographic maps allow the quantitative determination of vertical dissection and of covered structures.

## RESULTS AND DISCUSSION

Our preliminary analysis identifies several types of morphostructures in the Oaxaca region (Fig. 1). Linear through-going dislocations of the basament, probable very deep, are clearly observed. These dislocations belong to systems with different orientations: NS, EW denominated Orthogonal System and NW, NE denominated Dyagonal System. Each one of the structures of these systems has its own specific characteristics in the relief i.e., step-like elevations, depressions, dissection zones and others.

The genesis and the dynamics of the development of these structures is probably linked to the tectonic processes of formation of the Gulf of Mexico, the Caribbean depression, and to the tectonics of the Pacific Ocean. The tectonic complexity of Oaxaca could be due to its intermediate position between these three important structural elements.

Oaxaca, as well as the entire region of Mexico to the South of the Volcanic Belt, is characterized by the presence of a megadome with an approximate diameter of 400 km crossed by fault systems with different orientations. One of these systems is radial with its geometrical center in the Mexican Gulf (Fig. 2).

The relative plate velocities given by Minster and Jordan (1978) reach near-peak values in South of Mexico, but gradually diminish to the North. This suggests that the entire systems traversing Mexico could be subject to its greatest deformation in this region. Morphostructural analysis gives strong evidence for this hypothesis; the largest and highest blocks (the highest in all SW Mexico) are located in South Oaxaca; these hanging blocks, elevated and limited by the Orthogonal (N-S and E-W) System, could also have an influence on seismicity due to their instability.

Among the linear structures (Fig. 3), the oldest seems to be the N-S oriented fault system; the movement along these faults presumable began during the genesis of the Gulf of Mexico at the end of the Triassic and the beginning of the Jurassic (Khain *et al.*, 1975).

The characteristics in the relief, morphostructure and geology of the N-S and E-W oriented fault systems seem to indicate that these faults are active or suffered a tectonic reactivation. The faults of these systems have been linked (Khain *et al.*, 1975) to the formation of oceanic trenches under distentional stresses with a tangential velocity that has components along the N-S and E-W oriented fault systems.

Another important structure observed in the Oaxaca region is an active fault system that trends N65° ± 5°W and N30° ± 5°E. The geologic and morphological features of this system are characteristic for high tectonic activity associated to recent subduction processes. A N45° ± 5°W fault system observed in the Oaxaca region is presumably inactive. This system has not been studied in detail, however no relation of this system to seismic phenomena was found.

The morphostructural scheme (Fig. 1) also shows the differences in the elevations of the blocks. The megablocks are related either to depressions or to elevations, and are bounded by lineaments of the Orthogonal System which reflect discontinuities in the vertical tectonic motions. In some places these lineaments are hidden by the sedimentary cover, where they form the so called covered faults. The Orthogonal

N-S and E-W System, probably developed through a long geologic history and comprises the deepest and oldest dislocations, presumable reactivated by neotectonic forces. The largest vertical movements of blocks and megablocks occur along the lineaments of the Orthogonal System.

In the region of Pinotepa Nacional, Guerrero, there is an important fault a N30 ± 5°E trend, that could be a fracture of the Cocos Plate that is reflected on the relief of the Continental North American Plate. In this case, we should expect that earthquakes associated with this fault might represent dislocations with vertical component. We have found to the east subparallel faults that could also limit other megablocks of the lower, subducting, Cocos Plate. The width of these megablocks would be ~ 200 km. There are other East-West oriented fault zones further to the North (~ 17°20') that should be studied as potential seismic zones.

We also compared seismological data with the active lineaments patterns. The seismic activity of magnitude greater than 2.8 which preceeded the 29 November Oaxaca earthquake ($M_S$ = 7.8) (Ponce *et al.*, 1978) appears to be concentrated with the same trend as the Diagonal N65° ± 5°W and N30° ± 5°E, System. The epicenter locations of this activity are quite precise, with location uncertainty less than 5 km (Fig. 3). The mainshock (15°46'N – 96°48'W) is located in the vicinity of the intersection of the N65° ± 5°W and the Orthogonal Systems (N-S, E-W). Large aftershocks of the 29 November Oaxaca earthquake (Ponce *et al.*, 1978; Singh *et al.*, 1980), show concentration along the N-S oriented faults; this may be due to block readjustments along the orthogonal system following the mainshock. It is possible that other large earthquakes may occur near intersections of this type. However the uncertainty in the NEIS-USGS locations may be about 40 to 100 km (Ponce *et al.*, 1978), so more detailed research on epicenter relocation of large earthquakes is needed in order to correlate epicenters with structures.

Based on the morphostructural analysis and the seismic data, the most active faults seem to be those with a N65° ± 5°W and N-S trends. The N65° ± 5°W System could be linked to the subduction processes, while the Orthogonal System could be related to deep and old fracture zones, reactivated by present tectonic forces. As we printed out, the highest blocks of Oaxaca are bounded by the Orthogonal System, so we suggest that these structures could be closely related to the seismotectonic phenomena of this region.

We emphasize that this work is to be considered only as a first effort in the application of morphostructural analysis to seismicity in Mexico. A more detailed and systematic study must be undertaken which should include a joint hypocentral relocation of large and moderate earthquakes. A thorough analysis could be very valuable toward understanding the tectonic structure and mechanism underlying seismicity in this zone and would be useful in building a detailed seismic risk map. It is possible that the foci of large earthquakes may be located at the intersections of linear structures that could be determined by morphostructural analysis in correlation with geophysical and seismic data.

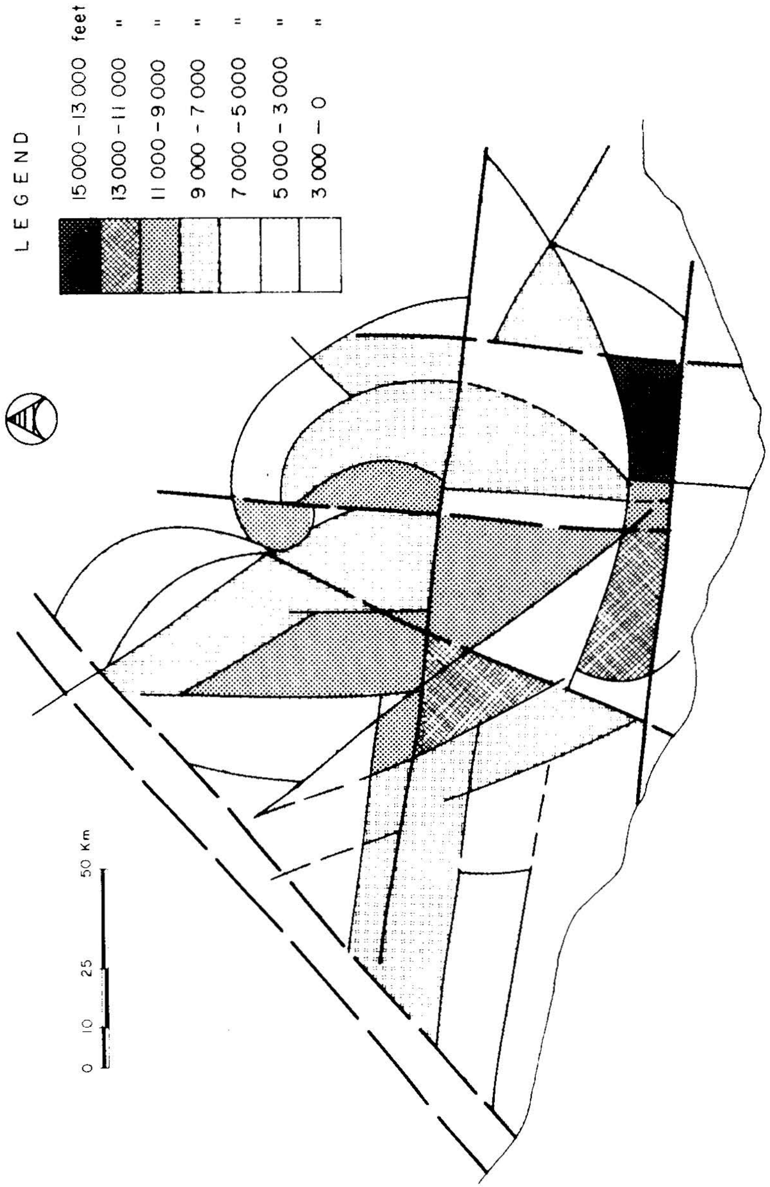
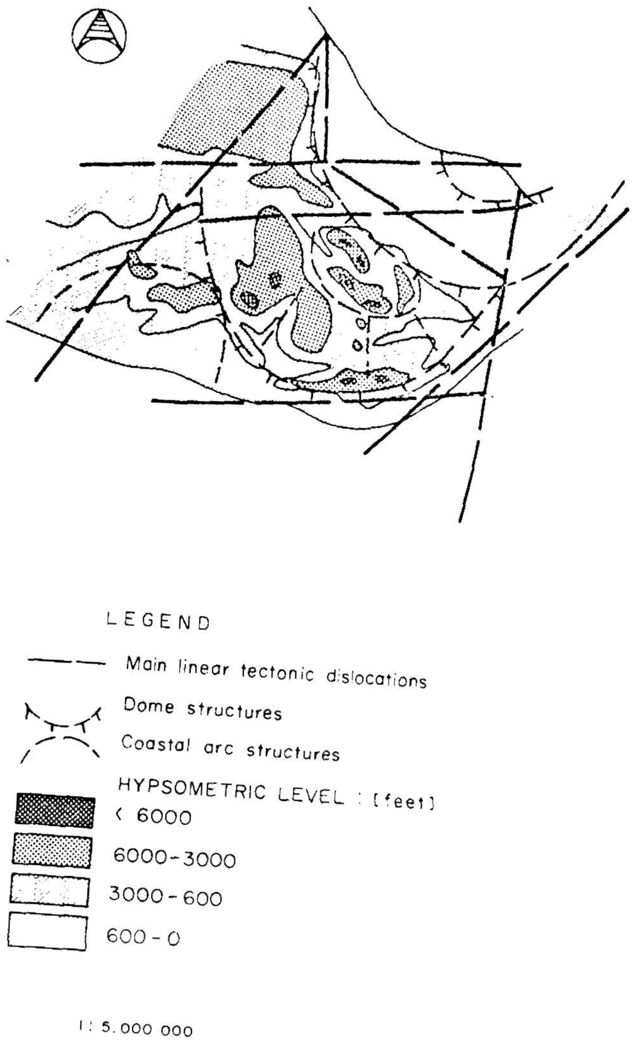



FIG. 1 HYPSOMETRIC LEVELS OF BLOCKS

FIG. 2 SCHEME OF THE MAIN TECTONIC DISLOCATIONS OF OAXACA



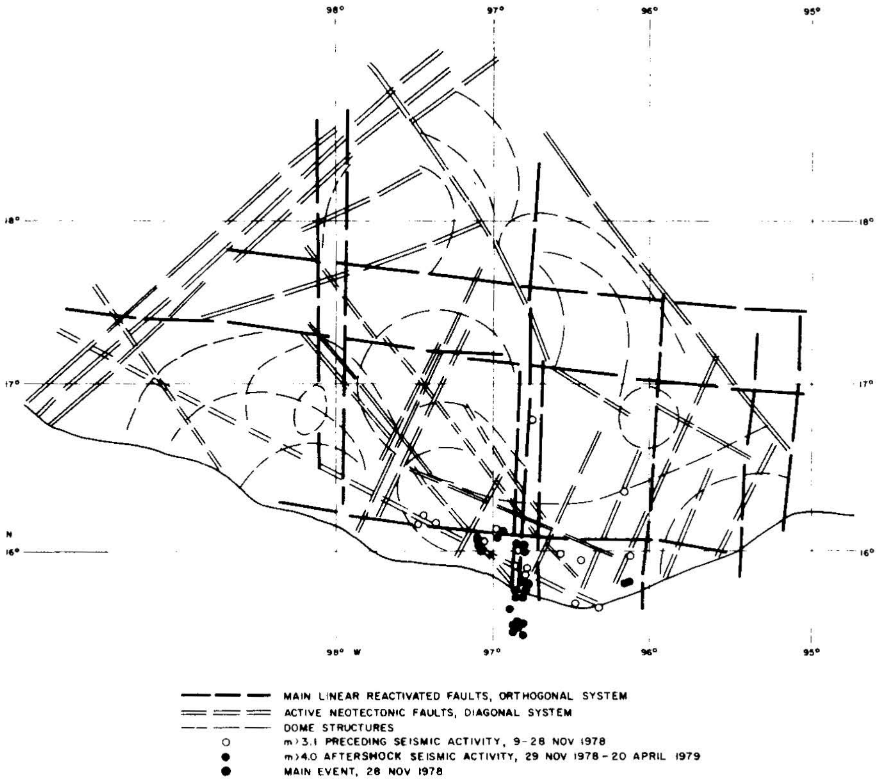



FIG. 3 MAIN FAULT SYSTEMS OF OAXACA, MEXICO

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