GEOFISICA

INTERNACIONAL

REVISTA DE LA UNION GEOFISICA MEXICANA, AUSPICIADA POR EL INSTITUTO DE GEOFISICA DE LA UNIVERSIDAD NACIONAL AUTONOMA DE MEXICO

Vol. 14 México, D. F., 1 de enero de 1974 Núm. 1

EARTHQUAKE RISK IN MANAGUA: A CRITICAL VIEW

C. LOMNITZ*

RESUMEN

Se presenta una interpretación crítica del sismo de Managua de 1972. La falla de Tiscapa, de 16 km de longitud y desplazamiento transcurrente, controla el riesgo sísmico local en Managua. El desplazamiento del basamento ocurrió en un plano vertical único que atraviesa el Lago Tiscapa con rumbo N 32° E; no existe prueba de fallamiento múltiple. Las fracturas superficiales complejas pueden explicarse en base a esfuerzos acumulados en los sedimentos, debidos en parte a la presencia del cráter de Tiscapa que obstaculiza el movimiento de la falla. Faltan antecedentes históricos precisos en cuanto a terremotos destructivos en la falla de Tiscapa, con la excepción del sismo de 1931 ($M = 5.8$). Toda la región se encuentra intensamente fracturada con fallas activas en el Holoceno; parece dudoso que existan sitios alternativos que presenten menos riesgo geológico que el que ocupa Managua en la actualidad.

A continuación se presenta un cálculo para el riesgo sísmico máximo en Managua; se estima que el daño actualizado para un futuro indefinido alcanzaría a 3.33×10^9 córdobas. La inversión necesaria para la protección sísmica de las construcciones no excedería un 30% de dicha cantidad. De ahí que la adopción inmediata de medidas apropiadas para el control del riesgo sísmico, mediante la planificación urbana y los reglamentos de construcciones, parece representar una buena estrategia inicial, no solamente en Nicaragua, sino en toda la región sísmica comprendida entre la costa del Océano Pacífico y la Fosa Media de América Central.

ABSTRACT

A critical interpretation of the 1972 Managua earthquake is proposed. Tiscapa Fault, a 16-km long strike-slip fault, controls the local earthquake hazard in Managua. Faulting in the basement occurred along a single vertical plane striking N 32° E through Lake Tiscapa; there is no proof of multiple faulting. The complex surface fracture patterns may be accounted for by strain release in the sediments, partly as a result of Tiscapa Crater acting as a cylindrical

* *Instituto de Geofísica, UNAM.*

obstacle astride the fault. There is no clear historical precedent for destructive earthquakes on the Tiscapa Fault, except for the 1931 earthquake ($M = 5.8$). The entire region is intensely fractured by faults having Holocene displacements, and it has yet to be shown that there are acceptable sites that are geologically safer than that of present-day Managua.

An upper-bound computation of seismic risk in Managua leads to an actualized estimate of 3.33×10^9 cordobas for damage over an indefinite time period. The investment required for earthquake-resistant construction will reach at most 30% of this amount. An immediate adoption of adequate measures of earthquake risk control, through urban planning and building regulations, represents a sound first-level strategy not only for Nicaragua but also for the entire seismic region including the Pacific seaboard and the Median Trough of Central America.

INTRODUCTION

This paper is a critical assessment of earthquake risk in the urban area of Managua. The evaluation of earthquake risk in specific areas has not yet reached the stage of an exact science (Lomnitz, 1974). Our present results may be summarized as follows: (a) the available geological and geophysical evidence bears out the conclusion of repeated surface faulting on the Tiscapa Fault, though not necessarily on its branch faults; (b) the historical evidence does not substantiate the hypothesis that major events occur on the Tiscapa Fault as often as every 50 years or less; (c) the local pattern of surface breaks observed in 1972 may be attributed in part to release of surface strains due to shaking, and in part to shear stress patterns generated in surface soils by Tiscapa Crater: in either case, they do not necessarily reflect the pattern of basement faulting; (d) much of Nicaragua is intensely fractured by faults that may be similar to the Tiscapa Fault, and it has yet to be shown that there are acceptable sites that are geologically safer than that of present-day Managua.

A quantitative upper-bound evaluation of earthquake risk in Managua is appended. The method for deriving the estimated actualized loss is used here for the first time. Results show that the maximum investment in lateral-force building provisions (which have to be observed in any case, no matter where the city is rebuilt) represents less than 30% of an estimate of the actualized seismic damage to be expected in Managua.

The evidence

On 23 December 1972 a shallow-depth earthquake of surface-wave magnitude 6.1 occurred on the Tiscapa Fault, which crosses the urban area of Managua, Nicaragua. The fault had been previously mapped by Kuang and Williams (1971). The pattern of aftershock activity showed that (a) the extent of tectonic displacement along the Tiscapa Fault was about 16 km; (b) the fault plane was vertical to a depth of at least 10 km and showed left-lateral strike-slip motion along a practically rectilinear trend striking N 32°E (Fig. 1). This trend forms an angle of about 75° with the coastline.

The total visible extent of the Tiscapa Fault (based on geologic evidence) is of the same order as the 1972 fault break. This is not a long fault. It features a small cinder cone, called Lake Tiscapa, and it presents a vertical Holocene offset of the order of 10 meters (Fig. 2), showing that the fault has a vertical throw toward the southeast.

An earlier destructive earthquake occurred on 31 March 1931. A comparative study of Tacubaya seismograms yields a surface-wave magnitude of 5.8 for this earthquake. Surface cracks, dubiously attributed to faulting, were observed; the linear pattern of lurching and damage (2 km by 100 meters) strongly suggested the presence of a parallel branch fault located to the northwest of the Tiscapa Fault.

Other small branch faults were proposed by various authors (Brown et al, 1973; Fiedler, 1973; Ambraseys, 1973; Mooser, 1973) on the evidence of linear patterns of surface fractures. Some authors have explicitly inferred that these branch faults were activated during the 1972 earthquake. This is a groundless assumption, since no aftershock activity can be traced to any but the Tiscapa Fault (Brown et al, 1973). It is also significant that no substantial Holocene offsets are connected with any of these branch faults (Fig. 2). Hence, we may assume that the observed surface fractures were caused by the release of acumulated strains in the sediments, as in the Borrego Mountain earthquake (Allen and Nordquist, 1972), rather than by multiple faulting in the basement.

Bonilla (1971) has correctly pointed out that branch faults are quite generally observed in North American earthquakes, at distances of up to 6-12 km from the main fault. The branch faults of the Tiscapa system are presumably of this kind, though they appear rather less prominent than those of the San Andreas or Hayward systems. Yet Brown et al, (1973) maintain in contradiction to Bonilla (1971), that "in most urban areas crossed by active faults, the fault breaks are simple", and therefore "the hazard from active faults is as great, if not greater, at Managua than at any other large city for which data are available".

This discrepancy may serve to highlight the latitude of interpretative reasoning which is still common in earthquake risk estimations. If one is willing to grant the Tiscapa Fault a unique status among strike-slip faults, one is no longer forced to agree that the risk of surface faulting ought to be ranked much higher for those North American cities where longer faults, capable of generating earthquakes a thousand times more energetic than the 1972 Managua earthquake, traverse the urban area.

Let us review the historical evidence concerning local earthquakes in Managua. The single previous instance of *major* seismic damage (minor events, such as the earthquake of magnitude 4.6 in 1968, being difficult to keep track of) was the 1931 earthquake. Available documents indicate that this earthquake was quite destructive; yet the degree of destruction nowhere exceeded the 1972 levels of damage, even within the 100-meter wide strip along the presumptive branch fault. There are no observable Holocene displacements in this zone. If there had been local faulting in 1931, why should the levels of damage have been comparable in both instances? On the other hand, if the cracking observed in 1931 was *not* due to tectonic faulting, why insist on making a distinction between earthquakes on the Tiscapa Fault and on each of its branch faults? In either case, the practical significance of the branch faults as separate entities of earthquake risk is much diminished, particularly when one remembers that the 1931 branch fault is only 1 km away from the Tiscapa Fault.

The fractures in the sediments represent a significant local hazard to structures built across them; hence branch faults are important because they influence the strain patterns in the sediments. But for purposes of overall risk estimation we may adopt the view expressed by Ambraseys (1973) and Ward et al, (1974), who recognize the Tiscapa Fault as the controlling active structure in the Managua area.

Let us now discuss the frequency of occurrence of earthquakes on the Tiscapa Fault. Saint-Amand (1973) proposes that events of the magnitude of the 1972 disaster could occur up to 3-4 times per century, while Brown et al (1973) suggest, also without specific evidence, that a repetition of the 1972 earthquake "can reasonably be expected within the next 50 years". A detailed search of the seismic history of Nicaragua (Leeds, 1973) fails to provide new examples of damaging local shocks on the Tiscapa Fault, though such events could hardly have escaped notice at least since Managua became the capital of the country. Earlier seismic damage in Managua, in 1844, 1858, and 1881, was minor and should not be confused with the characteristic features observed in the 1931 and 1972 events. In conclusion, earlier earthquakes were either connected with local faulting elsewhere in Nicaragua, or with large coastal events such as the earthquake of 29 April 1898 (magnitude 7.9), which likewise caused minor damage in Managua. An objective analysis of seismic history shows, if anything, that Managua is not necessarily the most unfavorable location in Nicaragua from the standpoint of geologic risk.

The preceding conclusion tends to be borne out by the intense fracture pattern displayed on ERTS imagery (Fig. 3). Many of these fractures exhibit Holocene displacements which are more impressive than the Tiscapa Fault: this is a highly fractured, highly seismic region. Yet demographic, climatic and economic constraints determine the location of the capital as well as of other major population centers in this very region, rather than on the less seismic Atlantic coastal plain. The choice of an alternate site for the capital city might be an extremely difficult one to make, as witnessed by the fact that no alternate sites have yet been suggested.

Precedents for city relocation after destructive earthquakes are available in Central America. Of 6 recorded instances between 1538 and the present, none has achieved its purpose of protecting the population against geological risks. In the two most recent attempts (Cartago and San Salvador), the relocation efforts were subsequently abandoned for lack of public support.

It is worth pointing out that methods are available for locating potential earthquake fractures across an urban area. An unpublished report (Govt. of Mexico, 1973) makes use of trenching and other subsurface methods, in order to formulate new urbanization patterns which may help minimize geological risks in the reconstruction of Managua.

Origin of fracture patterns in Managua

For an area as small as Managua, the information on surface geology is relatively complete. In particular, the pattern of fractures in the sediments has been exhaustively documented (see, e.g. Brown et al, 1973; and Ambraseys, 1973).

It is not in the nature of strike-slip faulting to exhibit such complicated fracture patterns on a small scale; rather, we may assume that the main basement fault follows approximately the straight line defined by the aftershock locations (Fig. 4). Besides, this rectilinear trace can be detected visually on aerial photographs taken after the earthquake, though it is not closely matched by the fracture pattern on the ground. The discrepancy between the trace of the Tiscapa Fault in the basement and at the surface appears to be due to a perturbation of the strain pattern in the sediments. A probable origin of this perturbation is shown in Fig. 5, which represents a comparative study of shear failures in soils due to a cylindrical obstacle astride a left-lateral fault.

The broad pattern of soil deformation in this case does not depend on scaling factors (Duncan and Lefebvre, 1973). The purpose of Fig. 5 is to illustrate the possibility that a stress perturbation due to Tiscapa Crater may account for the following features of the observed fracture pattern: (a) the fractures are discontinuous, complex, and imperfectly aligned with the basement fault trace as determined from aftershock activity; (b) the duplications and bifurcations are found primarily within two quadrants, i.e. in the NE and SW quadrants; (c) evidence of passive earth pressure may be found at 45° to the direction of fault motion, for instance near the SE rim of the crater; (d) there are characteristic deflections of the trends of fractures near the intersection of the fault with the crater rim, e.g. near the U.S. Embassy and opposite, near the Military Hospital.

It is suggested that the Tiscapa Crater acts as a shallow cylindrical obstacle within the upper sedimentary layer, which resists shearing deformation transmitted from the basement by either side of the fault. This is the first time that deflection of a fault trace by a volcanic crater has been reported. It presently becomes easier to understand certain inconsistencies in earlier interpretations, such as the apparent reversal of strike-slip motion on surface fractures near Stations 18, 19, 20, 50 and 56 (Brown et al, 1973).

Earthquake risk in Managua

The analysis which follows is not intended as a definitive estimate, but rather as an upper-bound calculation of earthquake risk in Managua. Its main purpose is to inject a certain quantitative element into the discussion. Upper-bound estimates may be useful where major policy decisions (such as the possible relocation of a large city) may be involved.

Thus, let us assume that critical events on the Tiscapa Fault occur every T years on the average, and that each critical event produces an economic loss similar to the 1972 earthquake. Let us take T = 33.3 years, i.e. three critical events per century.

This interval is large enough so that we may assume approximate statistical independence between successive events (Lomnitz, 1974). In this case the sum of the actualized losses for an indefinite time period may be shown to converge to a finite value (Hasofer, 1973):

$$L = pC/\gamma T$$

conversion were admissible it could not responsibly be made applicable to Managua in the present uncertain state of the art of seismic risk estimation. The aim of this paper is confined to showing that the timely adoption of engineering measures of control of earthquake risk represents a definite economic advantage in countries of high overall seismicity such as Nicaragua.

CONCLUSION

The lesson of Managua may be summarized as follows: (a) field observations, even in areas as small and as thoroughly researched as Managua, may admit of more than one interpretation in terms of earthquake risk; (b) alternative strategies of earthquake control should be discussed as broadly and explicitly as possible.

In a disaster of the magnitude of the 1972 earthquake, any predictive statement concerning the evaluation of relative geological risks is likely to carry policy implications. Some of these implications may be quite radical, such as the eventual resettlement of large populations, or the decision to delay reconstruction indefinitely. Earth scientists must be aware of such implications and must be prepared to formulate sensible suggestions for alternate strategies, including possible alternate sites, or recommendations for urban planning at the time of reconstruction.

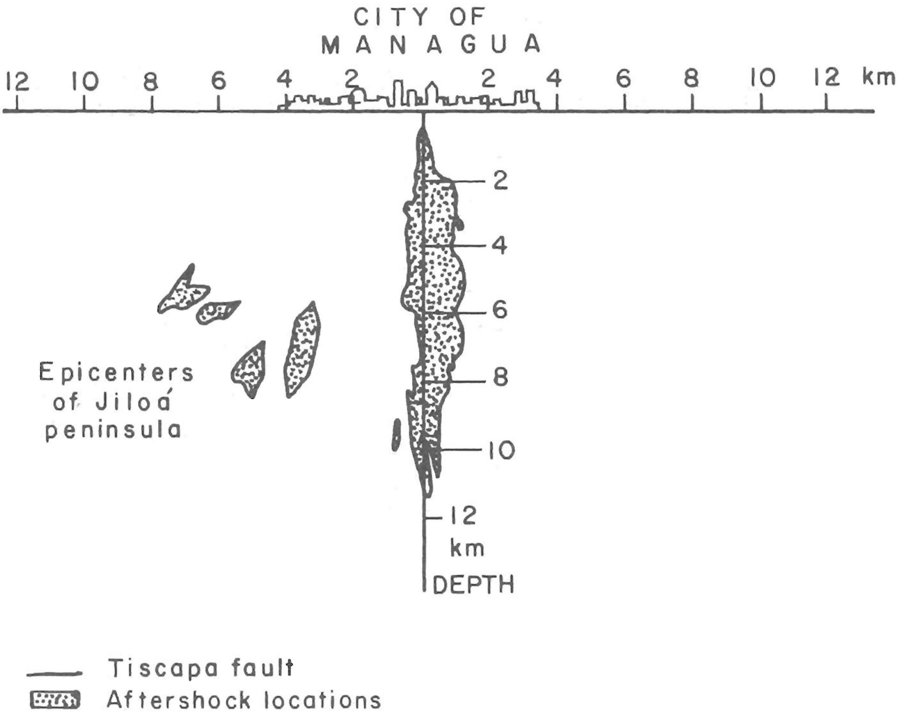

Figure 1. Vertical and horizontal projections of aftershock distribution, adapted from Brown et al (1973). The stippled areas correspond to areas where at least two confidence ellipses overlap, showing that the activity was concentrated along a vertical plane trending N 32°E through Lake Tiscapa.

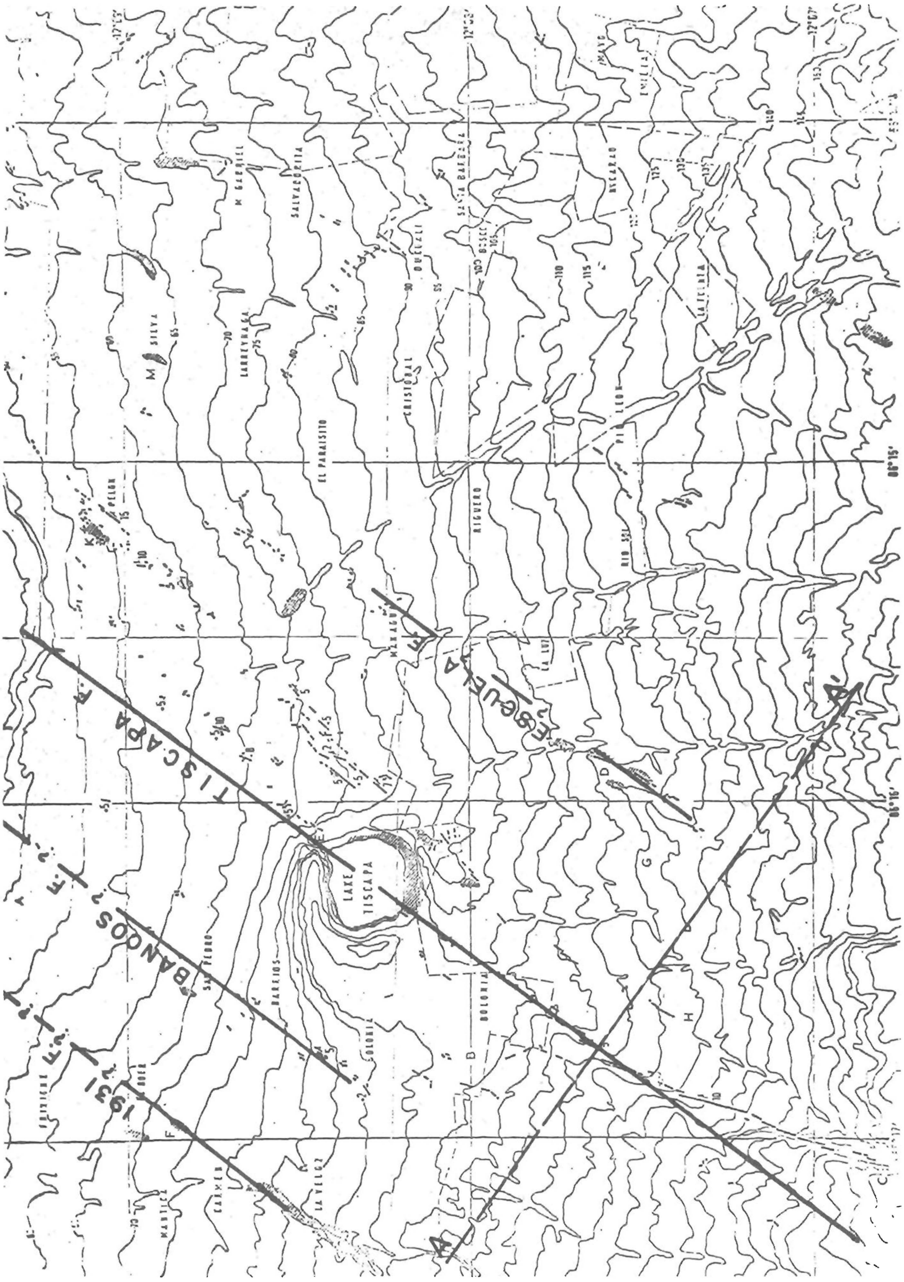

Figure 4. Fracture pattern of the 1972 earthquake, according to Ambraseys (1973). The *heavy* lines represent approximate basement fault traces, inferred by the present writer on the basis of aftershock locations (Tiscapa Fault), and lineations on aerial photographs.

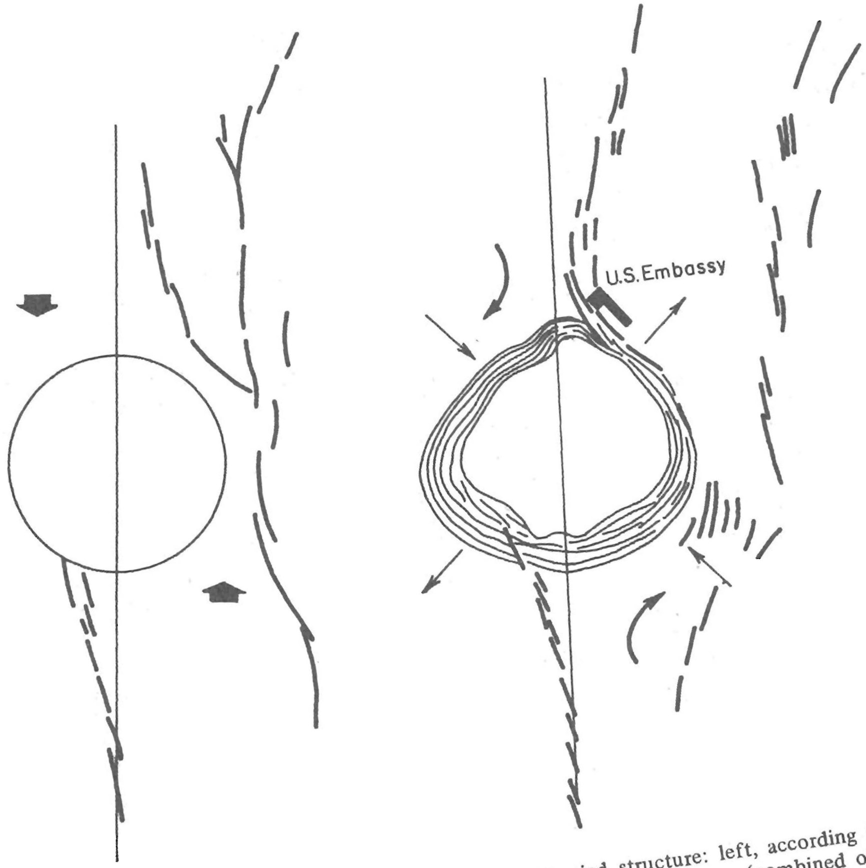

Figure 5. Diversion of a fault by a cylindrical buried structure: left, according to Duncan and Lefebvre (1973); right, schematic fracture patterns in Managua (combined observations by various authors).

ACKNOWLEDGMENT

I thank Professor Emilio Rosenblueth for his criticism of the paper, and for calling my attention to the work of J. M. Duncan and G. Lefebvre. Discussion by A. M. Hasofer and J. N. Brune is gratefully acknowledged.

BIBLIOGRAPHY

ALLEN, C. R., and A. R. NORDQUIST, 1972. Foreshock, main shock and larger aftershocks of the Borrego Mountain Earthquake, *U. S. Geol. Survey Prof. Paper 787,* 91 pp.

AMBRASEYS, N. N., 1973. The earthquake of Managua, Nicaragua, 1972, *Nature,* 244: 427-428.

BONILLA, M. G., 1971. Geology and hydrology applied to engineering and the public welfare, *U. S. Geol. Survey Prof. Paper 750-A:* 168-169.

BROWN, R. D., P. L. WARD and G. PLAFKER, 1973. Geologic and seismologic aspects of the Managua, Nicaragua, earthquakes of December 23, 1972, *U. S. Geol. Survey Prof. Paper 838,* 34 pp.

CRUMLISH, J. D., and G. F. WIRTH, 1967. *A Preliminary study of engineering seismology benefits,* ESSA, Dept. of Commerce, 46 pp.

DUNCAN, J. M., and G. LEFEBVRE, 1973. Earth pressures on structures due to fault movement, *Proc. Am. Soc. Civ. Eng.,* J. Soil Mechs. Found. Div., 99: 1153-1163.

ESTEVA, L., 1973. Riesgo sísmico, *Rept. Estudios Técnicos, Managua, Secr. Obras Públicas,* México, 22 pp.

FIEDLER, F., 1973. Some aspects of the 1972 Managua earthquake, Conf. Science and Man in the Americas (oral presentation), June 1973.

Government of Mexico, *Managua,* 3 vols. (Secr. Obras Públicas, México, 1973).

HASOFER, A. M., 1973. Design for infrequent overloads, preprint, Inst. Ingeniería, UNAM 4 pp.

KUANG, J., and R. L. WILLIAMS, 1971. Mapa Geológico de Managua, 1:50 000, *Catastro e Inventario de Recursos Naturales, Nicaragua, Sheet 2952 III.*

LEEDS, D. J., 1973. Destructive earthquakes in Nicaragua, *in* Managua, Nicaragua Earthquake of December 23, 1972, *Earthq. Eng. Res. Inst. Conf. Proc.,* 1: 26-51.

LOMNITZ, C., 1974. *Global tectonics and Earthquake Risk,* Elsevier, Amsterdam, 322 pp.

MOOSER, F., 1973. Informe Geológico del macrosismo del 23 de diciembre de 1972, *Rept. Estudios Técnicos, Managua,* Secr. Obras Públicas, México, 61 p.+ 7 p.

RINKER, J. N., 1973. Image showing fracture pattern analysis, from ERTS-1 image by NASA (1972), courtesy of U. S. Geol. Surv., EROS Data Center.

SAINT-AMAND, P., 1973. The seismicity and geologic structure of the Managua, Nicaragua area, *in* Managua, Nicaragua Earthquake of December 23, 1972, *Earthq. Eng. Res. Inst. Conf. Proc.*, 1: 8-25.

WARD, P. L., J. GIBBS, D. HARLOW and A. ABURTO, 1974. Aftershocks of the Managua, Nicaragua earthquake and the tectonic significance of the Tiscapa Fault, *Bull. Seis. Soc. Am.* 64: 1017-1029.