References and Notes

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2. E. N. Skomal, *IEEE Trans. Electromagn. Compat.* **11**, 66 (May 1969).
3. ——, *ibid.*, p. 76.
4. A heavy rain occurred on 7 September after a dry period of some weeks. The rain had no discernible effect on subsequent records. The midday temperature on 6 December was around 10°F.
5. Surface brightness temperature is defined by the relation $P = KTB$, in which P is the power radiated in frequency band B by a unit area of surface at absolute temperature T, and K is Boltzmann's constant. If the radiating source is much larger than the antenna beam, the antenna can be thought of as being enclosed in a "black cavity" at temperature T.

29 January 1973; revised 13 March 1973 ■

Aftershocks and Intensity of the Managua Earthquake of 23 December 1972

Abstract. *Two portable seismic stations and a fixed array of five seismometers were used to record aftershocks in the vicinity of Managua, Nicaragua, after the earthquake of 23 December 1972. Approximately 3000 aftershocks were recorded during a 20-day period in January 1973. Left lateral motion along at least two faults, both trending N40°E, is inferred from the seismic data. This is in good agreement with dislocations mapped at the surface in Managua. The data suggest that the shallow earthquakes of the Managua region are a consequence of north-south compressional stresses and east-west tensional stresses. This is consistent with regional plate movements deduced in other investigations.*

In the aftermath of the earthquake that struck Managua on 23 December 1972 at 06h:31m:36s G.M.T., the government of Nicaragua is faced with an extremely difficult question: Should they rebuild the capital city where it stands or establish a new city?

At the invitation of General Anastasio Somoza, head of the National Emergency Committee of Nicaragua, we went to Managua to make seismic measurements, survey the pattern of the destruction caused by the earthquake, and supply as much information as possible on the distribution of earthquake activity within Nicaragua. To appreciate the magnitude of the problem, it must be remembered that 400,000 people lived in Managua—20 percent of the total population of Nicaragua. It was the seat of government and the major industrial center of the country. Today, central Managua lies in nearly complete ruin. Between 4,000 and 6,000 people died, and 20,000 were injured. Fifty-seven thousand structures were lost or severely damaged, leaving between 200,000 and 250,000 people homeless.

The people of Managua had a warning. On the evening of 22 December two small earthquakes were felt at about 9:30 p.m. and 10:15 p.m. local time (6 hours behind G.M.T.). But small earthquakes are frequent occurrences in the vicinity of Managua, and no one could foresee the disastrous earthquake that was to occur at about 31 minutes after midnight.

Managua is situated near the western edge of a long, narrow depression—the Nicaragua Trough—that runs through much of Central America (Fig. 1). A belt of youthful volcanoes runs along the depression. This feature is interpreted as a graben in which the block that forms the floor of the trough has moved downward relative to the blocks on either side (*1*). There is some evidence that the bounding block to the west has tilted downward toward the Pacific, raising the western wall of the trough (*1*). The volcanoes of Nicaragua are noted for the explosive character of their eruptions. It is estimated that outpourings of ash from these volcanoes over the past 200 years have been sufficient to cover the entire region of the seismic belt to an average depth of 1 m (*2*). In fact, most of the ash falls to the west of the volcanic belt owing to the prevailing easterly winds. Thus, over long periods of time, the danger of widespread destruction in western Nicaragua may be as great from volcanism as it is from earthquakes.

Sixty-eight earthquakes, large enough to be located by the World-Wide Standard Seismograph Network (WWSSN) (generally magnitude 4 and larger), have occurred in Nicaragua in the past 11½ years, as shown in Fig. 1. This number includes the coastal zone arbitrarily taken as extending 15 km from shore along the western border of Nicaragua. Many earthquakes, too small to be located by the WWSSN, have undoubtedly occurred in this region during the interval plotted. Many others occurred seaward of the 15-km limit. But neither the small earthquakes, nor those that occur farther seaward, are likely to be hazardous to land areas in Nicaragua.

As shown in Fig. 1, the earthquakes of Nicaragua are confined almost entirely to a belt lying along the western border of the country. Ninety percent

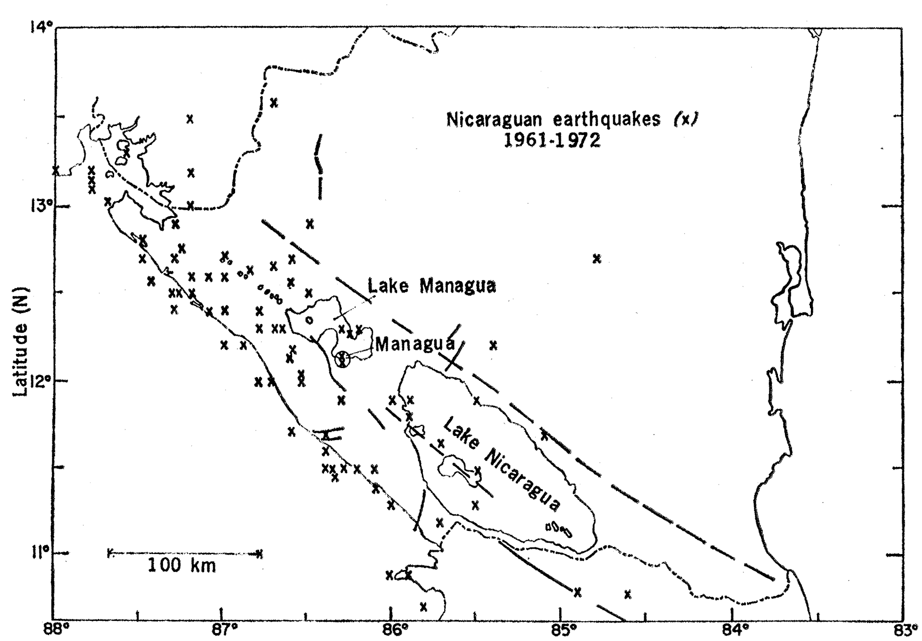


Fig. 1. Earthquake epicenters (crosses) located in Nicaragua by the World-Wide Standard Seismograph Network between 1 January 1961 and 31 August 1972. The edges of the Nicaragua Trough (dashed lines) are as given by McBirney and Williams (*1*).

of the earthquakes plotted fall within 70 km of the coastline. The largest of these was the Managua earthquake of 23 December 1972, with a magnitude (M_L) of 6.2. In general, the earthquakes of the region are intermediate to small in size. Ten of the located earthquakes occurred near Managua (within 35 km) during the 11½-year period considered here. The eastern region of Nicaragua is essentially aseismic.

Using the criteria given by the modified Mercalli intensity scale (*3*), we have determined the intensity distribution of the earthquake of 23 December to be as shown in Fig. 2. From this distribution, the earthquake must have been centered beneath the southern end of Lake Managua, close to the shoreline of central Managua, at shallow depth (a few tens of kilometers or less). An intensity of IX is assigned to central Managua out of a maximum of XII.

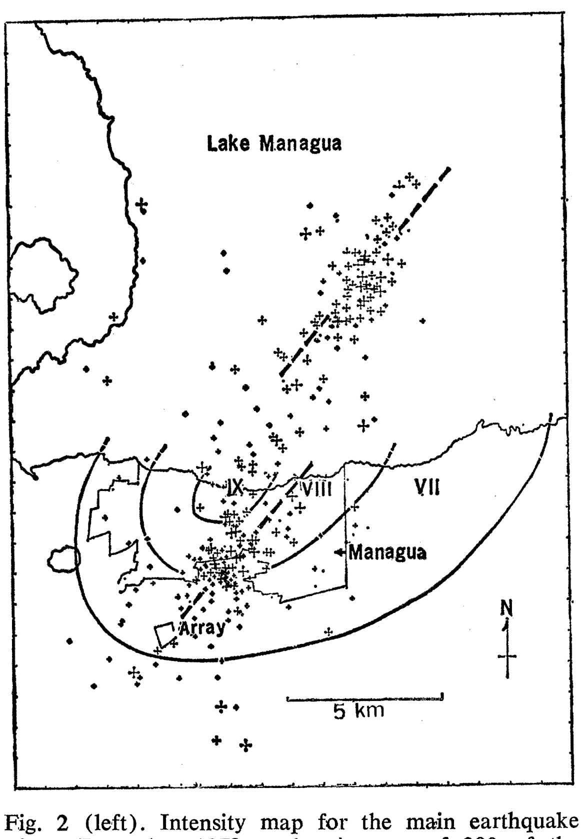
Damage to structures in a particular area varied greatly depending on the type of construction. In general, the severe damage suffered in Managua was a result of the fact that structures there are poorly designed for resistance to earthquake vibrations; this is particularly true of the widely used type of construction called taquezal (a combination of wood and adobe).

Two portable seismograph stations and a fixed array of five seismometers were used in our study. The portable stations were moved at daily intervals to measure aftershock activity over the region from Managua southward 30 km to Masaya. Recordings with these two stations between 10 and 30 January 1973 were made at a total of 30 different sites including 8 sites near the summit and flanks of the Santiago and Masaya volcano complex.

The fixed array was installed on the property of the Nejapa Country Club, 5 km south of downtown Managua, on 16 January 1973. The five seismometers of the array were connected by cables to amplifiers and a magnetic tape recorder located near the center of the array. The maximum separation between seismometers was 890 m. Accurate timing was provided by a stable clock synchronized with WWV radio time transmissions. Continuous recordings were made from the seismic array over a period of 9 days.

Two explosions were detonated in Lake Managua at ranges of 0.5 km (75 kg of dynamite) and 4 km (110 kg) from the shoreline of Managua. Seismic signals from these explosions were recorded by both the portable stations and the seismic array at ranges up to 9.4 km. These measurements have been used to determine the local structure and the velocities of seismic waves in the material underlying Managua.

Managua is located on a thick deposit of alluvium and deeply weathered volcanic ash that has accumulated in the Nicaragua Trough. The age of the trough is uncertain, but McBirney and Williams (*1*) estimated that subsidence



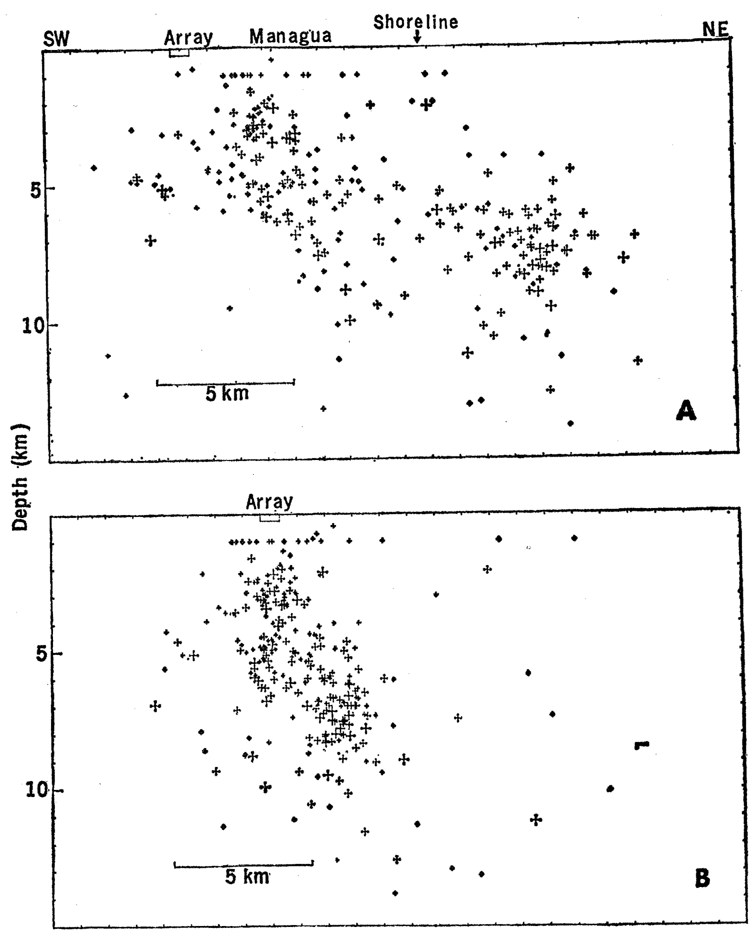


Fig. 2 (left). Intensity map for the main earthquake of 23 December 1972, and epicenters of 300 of the aftershocks located by data from a five-station seismic array. The relative accuracy of the location of each aftershock is proportional to the size of the plus sign marking its position. At least two linear trends in the aftershock activity are suggested, as indicated by the dashed lines. These coincide closely with fault lines mapped at the surface. Left lateral motion along the inferred faults (northwestern side moving in a southwesterly direction relative to the southeastern side) is inferred from the radiation pattern of the seismic waves from the aftershocks and from the observations of surface displacements. Fig. 3 (rght). Focuses of aftershocks (pulses) projected onto (A) a vertical plane oriented northeast-southwest through the center of the array and (B) a vertical plane perpendicular to the dashed lines of Fig. 2. The corresponding epicenters are shown in Fig. 2.

and infilling of the trough occurred during the past 1 million years (Quaternary). Using the seismic signals detected from the two explosions in Lake Managua, we determined the thickness of the trough infilling to be about 1.4 km beneath Managua. The compressional wave and shear wave velocities in this material are 2.6 and 1.3 km/sec, respectively. The compressional wave velocity in the underlying Tertiary volcanic rock that presumably forms the floor of the trough is about 3.6 km/sec. The difference in elevation between the present trough floor and the top of the western wall reaches nearly 1 km near Managua. Thus, we can say that the relative vertical movement along the western edge of the graben has been about 2.4 km.

The number of aftershocks detected during the 20-day period covered by this report (10 to 29 January 1973) varied between 50 and 200 per day. The magnitudes of these earthquakes ranged between 0.0 and 3.0. Approximately ten aftershocks large enough to be felt in Managua occurred during this period. Using the velocity model derived from the two explosions described above, we have located 300 aftershocks to date. As shown in Fig. 2, two clusters can be distinguished within the distribution of aftershock epicenters. After the Managua earthquake a series of seven to ten parallel fault lines trending northeast-southwest through the city could be mapped (*4*). There is evidence of left lateral motion at several points along the faults (the northwestern side moved in a southwesterly direction relative to the southeastern side). The southern cluster coincides closely with the principal fault mapped in the area, indicated by a dashed line in Fig. 2. The trend of the fault is N40°E.

The directions of the fault movements responsible for the aftershocks can be deduced from the directions of the first motions of the recorded seismic waves. The solution is not unique, since only compressional waves were used. Of the two possible solutions, one is in good agreement with the surface observations (predominantly left lateral movement along faults trending approximately N40°E). As shown in Fig. 3, the aftershocks are concentrated at depths of between 2 and 8 km, with a few as deep as 14 km and as shallow as 1 km. The planes of the active zones are essentially vertical. Thus, we conclude that the aftershock clusters define two steeply dipping faults, or systems of faults, each about 10 km in length and 10 to 15 km in vertical extent, along which left lateral movement was taking place at the time of our fieldwork. The northern fault system is approximately in line with a fault that cuts through to the southeast along which movement occurred during the devastating earthquake of 1931. If the two faults are part of the same system, the actual length of that system may be much greater than 10 km, with current activity restricted to the segment defined by the aftershocks.

A system of crustal stresses compatible with the inferred directions of faulting is north-south compression and east-west tension. We obtained the same stress distribution from an analysis of aftershocks following an earthquake that occurred in Costa Rica, 235 km southeast of Managua, on 14 April 1973 (*5*). This suggests that the same stress system may persist over a region including most of Nicaragua and Costa Rica.

This stress system may be explained as a consequence of differential movements between two plates: the Cocos plate on the western side of Nicaragua and the Caribbean plate on the eastern side. According to the hypothesis of Molnar and Sykes (*6*), the Caribbean plate is presently moving eastward, "dragging" eastern Nicaragua with it, while the Cocos plate is moving in a northerly direction, plunging beneath the western edge of the Central American Arc.

The agreement between the source mechanism of the Managua earthquake and inferred plate movements implies that the large-scale tectonic processes that formed the Nicaragua Trough are still active. Thus, we must assume that the probability of future earthquakes in the Managua region is high. If a reconstructed city is to survive where the ruins of Managua now stand, it must be built to withstand earthquakes of at least moderate intensity.

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Platinum-Like Behavior of Tungsten Carbide in Surface Catalysis

Abstract. *Tungsten carbide catalyzes the formation of water from hydrogen and oxygen at room temperature, the reduction of tungsten trioxide by hydrogen in the presence of water, and the isomerization of 2,2-dimethylpropane to 2-methylbutane. This catalytic behavior, which is typical of platinum, is not exhibited at all by tungsten. The surface electronic properties of the latter are therefore modified by carbon in such a way that they resemble those of platinum.*

There are several indications in the literature (*1–3*) that addition of carbon to nonnoble metals (such as Mo and W) confers to them some of the catalytic properties typical of the noble metals (such as Pt and Pd). For example, a study of the reaction of 1,1,3-trimethylcyclopentane in the presence of metal films (Fe, Co, Ni, W, Rh, Pt, and Pd) showed that only platinum rearranged the reactant to appreciable amounts of xylene (*1*). However on tungsten, while no xylene was observed initially among the reactions products, it was found after an induction period at the higher temperature studied (*1*).

The possibility that formation of a transition metal carbide is responsible for the observed change of behavior of tungsten is further suggested by a report that an increase with time in the rate of ethane hydrogenolysis over a molybdenum catalyst can be ascribed to the formation of carbide, as detected