induces similar numbers of pyrimidine dimers and endonuclease sites. These results suggest that the endonuclease assay used in this study exclusively detects pyrimidine dimers in DNA damaged by fluorescent light. Thus, the equivalent patterns seen when fluorescent light and ultraviolet light transformation are plotted against numbers of endonuclease sites (Fig. 1) suggest that the pyrimidine dimer is the common causal agent in transformation by these radiations. The experiments were performed at 0° to 4°C to minimize the potential for repair of these dimers during the long exposure times.

The transformation frequencies observed for fluorescent light in the plateau region of the dose-response curve (Fig. 1) are somewhat lower than those observed by Chan and Little (*11*) for germicidal ultraviolet exposure. Although the reason for this lower apparent efficiency of fluorescent light is unclear, the fact that the transformation frequencies were not higher than those observed for ultraviolet light suggests that base damage by fluorescent light (other than pyrimidine dimers) may not be effective in inducing transformation.

The involvement of other DNA photoproducts, however, cannot be ruled out. For example, thymine glycols (monomeric ring-saturated products of the 5,6-dihydroxydihydrothymine type) are a minor DNA photoproduct relative to dimers after irradiation at 254 nm, but become a numerically important product at 313 nm (*23*). The biological importance of glycols is at present unclear, but these lesions might be involved in the fluorescent light effects seen here. Other DNA photoproducts are induced by near ultraviolet and visible light through photodynamic action, a mechanism involving the interaction of light with certain fluorescent, cellular components (*24*). Such damage has been implicated in bacterial mutagenesis (*25, 26*) and could also be a causal agent in transformation by fluorescent light. In addition, DNA strand breaks (*6*) and DNA cross-links (*7*) are induced by fluorescent light. Thus, the involvement of nondimer damage in the transformation we have observed cannot be excluded.

Normal tissue culture conditions should reduce fluorescent light effects. For example, no detectable transformation was observed after 5 hours of exposure through an intervening plastic dish cover (Table 1); presumably the plastic blocked the transmission of a small component of more biologically effective, shorter wavelength in the fluorescent light emission spectrum. The use of gold fluorescent lights would probably also reduce fluorescent light transformation; commercial gold lights, which do not emit wavelengths below 5000 Å, are not mutagenic to mammalian cells (*4*).

Fluorescent light should be regarded as a perturbing but controllable (by glass or plastic filtration) agent in all in vitro survival, mutagenesis, and malignant transformation experiments. The results also suggest that fluorescent light exposure could contribute on a small scale to human skin carcinogenesis.

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The Oaxaca, Mexico, Earthquake of 29 November 1978: A Preliminary Report on Aftershocks

Abstract. *Aftershocks of the 29 November 1978 Oaxaca, Mexico, earthquake (surface-wave magnitude* $M_s = 7.8$*) define a rupture area of about 6000 square kilometers along the boundary of the Cocos sea-plate subduction. This area had not ruptured in a large (*$M_s \geq 7$*), shallow earthquake since the years 1928 and 1931 and had been designated a seismic "gap." The region has also been seismically quiet for small to moderate (*$M \geq 4$*), shallow (depth* $\leq$ *60 kilometers) earthquakes since 1966; this quiet zone became about six times larger in 1973. A major earthquake (*$M_s = 7.5 \pm 0.25$*) was forecast at this location on the basis of the quiescence that began in 1973. The aftershock data indicate that an area approximately equivalent in size to the seismic gap has now broken.*

On 29 November 1978, a large (surface-wave magnitude $M_s = 7.8$) earthquake ruptured the Middle America trench along the coast of Oaxaca, Mexico (Fig. 1). This earthquake attracted particular attention because both its location and size had been forecast by seismologists. The specific time of occurrence, however, was not forecast (*1, 2*).

The seismic potential of this location, first pointed out in 1973, was based on recurrence rates of 50 years or less for large ($M_s \geq 7.0$), shallow (depth $\geq$ 60 km) earthquakes in Mexico and Central America (*1*). Rupture had last occurred in 1928 and 1931, and the area was designated a seismic "gap." The dimensions of the gap were subsequently used to estimate the magnitude ($M_s = 7.5 \pm 0.25$) of a future earthquake (*2*). It was also suggested (*2*) that small to moderate earthquakes ($M \geq 4$) should cease and then resume prior to the main shock in a

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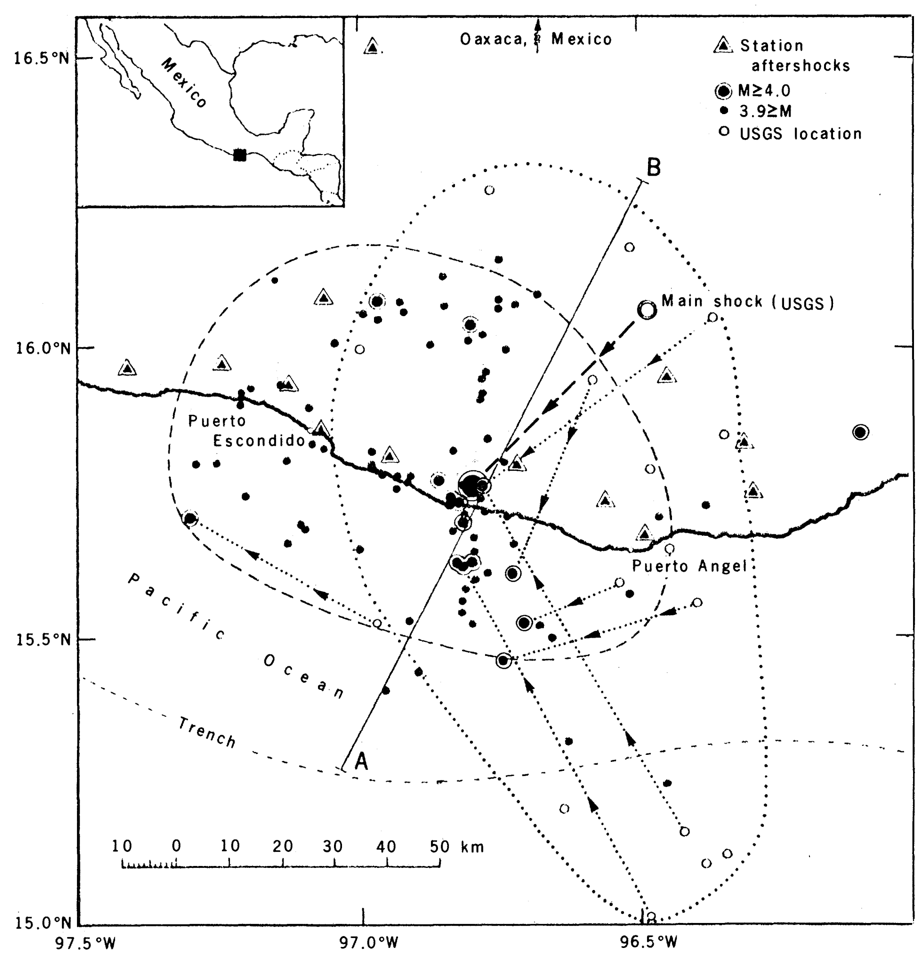
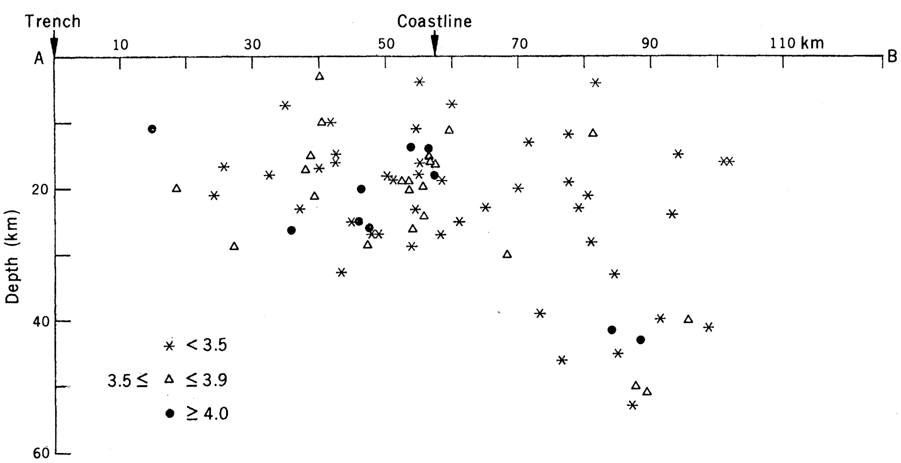
pattern similar to that observed preceding two large earthquakes (M_s = 7.5 to 7.75) in adjacent areas to the east (1965) and west (1968). An absence of small earthquakes, or a seismic "quiescence," in Oaxaca since 1973 was noted (*2*).

We have obtained well-constrained aftershock data from field operations in Oaxaca which confirm that the November 1978 earthquake ruptured approximately 80 percent of the seismic "gap" area designated by the forecasts. The data provided by the standard, but distant, worldwide array (*3*) and used in defining the gap for the forecasts, however, indicate that less than 50 percent of this area has broken. Our analyses also indicate that at least 65 percent of the area was seismically quiet for small to moderate, shallow earthquakes for at least 13 years prior to failure but became about six times larger in 1973 and was then noted (*2*).

The aftershock data discussed below cover a period beginning 32 hours after the main shock and lasting through 12 December. These data were obtained with portable field seismographs operated by the Instituto de Geofísica and the Instituto de Ingeniería, Universidad Nacional Autónoma de México, and by the California Institute of Technology. The station locations (Fig. 1) extend from Puerto Escondido (west) to Puerto Angel (east) and Oaxaca (north). Eighty-eight aftershocks with Richter magnitude M_L > 2.7 have been located by means of a half-space model with a compressional-wave velocity of α of 6.1 km/sec and a shear-wave velocity β of 3.52 km/sec.





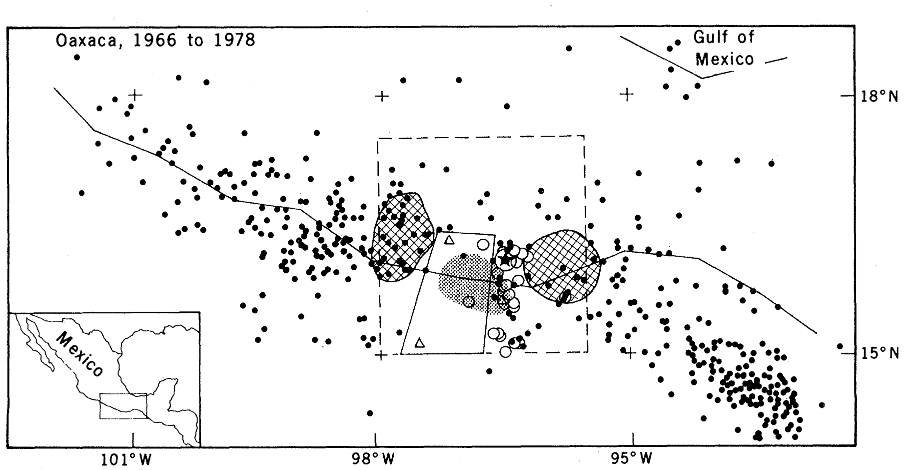


Fig. 1 (top). Aftershocks located by (i) the field seismograph array (1 to 12 December 1978) and (ii) the U.S. Geological Survey (USGS) (29 November to 8 December 1978) from worldwide stations. Dashed and dotted arrows indicate USGS locations of the same events. The aftershock areas from USGS data (dotted outline) and field array data (dashed outline) are outlined for comparison. Line *AB* defines the projection for Fig. 2. Fig. 2 (middle). Vertical projection of aftershock hypocenters, determined by the field array through line *AB* (Fig. 1); line *AB* is approximately parallel to the subduction vector of the Cocos plate beneath Mexico (*6*, *7*). Fig. 3 (bottom). All shallow (depth ≤ 60 km) seismic activity located by the U.S. Geological Survey for the Oaxaca region from 1966 to 1978. The 1965 and 1968 aftershock areas are crosshatched; open circles are the 1978 Oaxaca main shock and aftershocks through December 1978. The area of aftershocks located by the field seismograph array is the shaded area (center). The areas that were quiet since 1966 (solid outline) and since 1973 [dashed rectangle (*2*)] are also shown. Triangles indicate earthquakes in large quiet area preceding the 1978 main shock (*3*)

Although no detailed crustal study of the region is available, a reversed seismic refraction profile, made in 1974 between Pinotepa Nacional (about 100 km west-northwest of Puerto Escondido) and Lake Alchichica (about 400 km inland, perpendicular to the coast), shows a layer with a thickness of 20 km with $\alpha = 6.1$ km/sec (*4*). We determined M_L from earthquake coda durations using the relation given in (*5*).

The aftershock area based on these data (Fig. 1), which covers about 6000 km^2, is well defined by the activity of 1 to 3 December and does not appear to grow with time; it probably describes the horizontal projection of the rupture area of the main event. Locations of the main shock and 17 aftershocks (up to 8 December 1978) listed by PDE (*3*) are also shown in Fig. 1. The aftershock area determined from standard PDE locations is about 1.3 times larger and more elongated in the north-south direction than the area determined from our field array data. Eight of the 17 aftershocks listed by PDE occurred after 1 December. Seven of these events are shown with their corresponding locations obtained from our field array data (the eighth lies outside the figure area). The PDE locations differ from our locations by about 35 to 60 km; all PDE locations lie to the west, with four displaced to the north and three to the south. This probably explains the north-south elongation of the PDE aftershock area.

A projection of the events along a vertical plane through line *AB* (Fig. 1) is shown in Fig. 2, which is along a N30°E line, the approximate direction of the subduction vector of the Cocos plate below continental Mexico (*6, 7*). On this projection the events have increasingly deeper foci inland from the trench. These data suggest a 25° dip for that part of the subducting plate beneath Oaxaca, which is consistent with the results of earlier studies (*6, 8*). However, our half-space model and global models typically used for earthquake locations may yield systematic distortions of focal depths in complex subduction zone structures. The aftershock area measured at the surface increases to about 6500 km^2 when projected at the 25° angle (*9*). The aftershock area and M_s of this earthquake (7.8, PDE) are consistent with the relations predicted from worldwide data (*10*). An estimate of the average time periods between large earthquakes in this region can be calculated from the rate of plate subduction and the amount of slip in each earthquake. The subduction rate suggested for this region is 7.4 cm/year (*7*). The calculated slip in the Oaxaca earthquake is 148 cm; this figure is based on the seismic moment M_0 for surface waves at periods of 60 to 300 seconds (3.2×10^{27} dyne-cm) (*11*) and the aftershock area. The elastic rigidity is taken as 3.3×10^{11} dyne cm^{-2}. If there is no aseismic slip, the corresponding recurrence interval for an earthquake of this size could average 20 years.

All shallow (depth ≤ 60 km) seismic activity in the region (listed by PDE) for the period January 1966 to December 1978 is shown in Fig. 3. This figure also shows aftershock areas of earthquakes occurring on 23 August 1965 ($M_s = 7.5$ to 7.75) and 2 August 1968 ($M_s = 7.5$), as well as the area identified by Ohtake *et al.* (*2*), which was seismically quiet from 1973 to 1978. Some 65 percent of the gap width for large earthquakes bounded by the 1965 and 1968 rupture zones has been seismically quiet since 1966. The width of this quiet zone is approximately equivalent to the length of the aftershock zone determined from our field array data (shaded area in Fig. 3), whereas the PDE aftershocks for the 1978 sequence are concentrated along the eastern part of the unbroken area. This raises the possibility that the gap has not entirely broken at present since it is defined relative to PDE data. The ambiguity in PDE earthquake locations described above (35 to 60 km) is critical to the resolution of the locations, dimensions, and temporal durations of the zones of seismic quiescence and gap. In particular, small gaps may tend to be obscured by random uncertainties in locations. If the 13-year period of seismic quiescence were precursory to the recent earthquake, it would be reasonably consistent with proposed empirical magnitude-precursor time relations (*12*). On the other hand, the quiescent periods preceding the 1965 and 1968 events given in (*2*) are only about 1.5 to 2 years. The magnitude-precursor time relations thus may be quite different even for regions only a hundred kilometers apart, and relations based on data from different regions may have poor predictive value. That a seismic gap and a period of quiescence existed in Oaxaca is beyond doubt. The exact precursory nature of the quiescence, however, is unclear, as a result of ambiguities in the data and the absence of a definitive physical model relating seismicity patterns to the failure process. Future research should be directed toward combining analyses of the worldwide data with special field investigations to refine the information base available for studies of prefailure phenomena. The forecasts and the subsequent occurrence of the Oaxaca earthquake lead us to conclude that monitoring small to moderate earthquakes and associated seismicity patterns from worldwide stations is a useful tool for identifying special study areas of potential large earthquakes, especially in areas with little or no local seismographic coverage and despite relatively poor detection capability and uncertainties in event locations.

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