THE MEXICALI VALLEY EARTHQUAKE OF 9 JUNE 1980
J.G. Anderson and R.S. Simons, editors

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1. Introduction

J.G. Anderson and R.S. Simons

On June 9, 1980, at approximately 03:28:20 GMT (June 8, 1981, 8:28PM, local time), an earthquake of magnitude $M_L = 6.1$ (Hutton et al., 1981); $m_b = 5.6$ and $M_s = 6.4$ (Pearson, 1981) occurred in the Mexicali Valley, Northern Baja California, Mexico. The instrumental epicenter was located approximately 10km southeast of the town of Guadalupe Victoria, near the surface trace of the Cerro Prieto fault (Figure 1.1). This event was followed by various aftershocks of lesser magnitude, some of them felt as far away as Mexicali (La Voz de Mexicali, June 10, 1980). In the Mexicali Valley, the Cerro Prieto fault may be the main boundary between the Pacific plate and the North American plate. At the northern end of the Cerro Prieto fault (as it is currently mapped), the fault is offset from the Imperial fault in an en echelon manner. Since 1852, at least 12 earthquakes with magnitudes comparable to or larger than the June 1980 event have affected the area shown in Figure 1.1. At least five of these were of magnitude 7 or greater. The causative faults are not generally known with certainty.

The main shock of June 1980 was recorded at seven nearby strong motion accelerograph stations (analog and digital) operated jointly by the Instituto de Ingeniería at Universidad Nacional Autónoma de México (UNAM) and the Institute of Geophysics and Planetary Physics (IGPP) at the University of California at San Diego. Roughly four hours after the main event, investigators from IGPP and the Centro de Investigaciones Científicas y de Educación Superior de Ensenada (CICESE) commenced deployment of a portable array of seven analog and 12 digital recorders to monitor the aftershock sequence. Personnel from these three institutions along with scientists from the U.S. Geological Survey, California Institute of Technology, the University of California, Riverside, and other institutions participated in reconnaissance of the area for evidence of geologic effects or structural damage. This report summarizes some of the results which have been obtained. Many of these reports have been, or will eventually be published in a more complete form elsewhere. Our hope is that these summaries will provide the EERI community with a useful compilation of information about the earthquake and its effects.

One of the notable features of this earthquake is the absence of surface rupture commensurate with the magnitude and inferred fault dimension, as documented by Prince et al., Sharpe, and Suarez et al. It would not be surprising if surface displacements have appeared since the field investigations reported here, as a result of creep.

Another notable feature is the strong motion accelerogram from the town of Victoria, adjacent to the fault. It is not clear whether the extent of the damage in Victoria would have been anticipated from the accelerations which were recorded there.

We thank each of the authors for providing these summaries.

2. Main Shock Location and Fault Mechanism

José Frez

Local and regional data have been used to determine the hypocenter of the main event. The regional data consist of readings of P-wave arrivals from the CalTech-USGS Southern California network, from a few strong motion stations operated jointly by UNAM and IGPP, UCSD, and from three stations operated by CICESE. Difficulties in estimating the hypocenter include an azimuthal gap of almost 180° around the focus and strong lateral heterogeneities in the structure so that it is difficult to construct a laterally homogeneous structure which can be considered representative of this region. The program HYPO-71 (Lee and Lahr, 1975) is used in these calculations.

Station corrections obtained from well-recorded aftershocks of this event and from the Mexicali earthquake of October 15, 1979, were used to partially overcome these difficulties. We considered several alternative velocity models in these numerical experiments. The final model used for location calculations is given in Table 2.1. The result of several numerical experiments puts the hypocenter at about 32°13′ ± 2°N, 115°03′ ± 2°W, with a focal depth of
Figure 1-1. Locations of Strong Motion Stations in Mexico which Recorded the June 9, 1980 Earthquake.

Figure 2-1. Focal Mechanism of the June 9, 1980 Earthquake (Main Event).
Table 2.1

Layered Structure Mentioned in this Study

<table>
<thead>
<tr>
<th>Depth to top of layer (km)</th>
<th>P-Velocity (km/sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0</td>
<td>2.25</td>
</tr>
<tr>
<td>1.5</td>
<td>3.50</td>
</tr>
<tr>
<td>3.0</td>
<td>4.50</td>
</tr>
<tr>
<td>4.5</td>
<td>5.65</td>
</tr>
<tr>
<td>6.0</td>
<td>6.00</td>
</tr>
<tr>
<td>13.0</td>
<td>6.80</td>
</tr>
<tr>
<td>14.0</td>
<td>7.20</td>
</tr>
<tr>
<td>20.0</td>
<td>7.80</td>
</tr>
</tbody>
</table>

12km ± 4km, and the origin time at 03:28:19.7 ± 0.7. The resultant epicenter is plotted in Figures 1.1 and 3.1.

We used 75 teleseismic observations of compressional or dilatational first motions of P-waves to find the focal mechanism. The solution is well constrained and gives a vertical fault with a strike of about 303° and right-lateral motion (Figure 2.1). The solution may allow the presence of a small dip of the fault and some dip-component of the motion.

Possible foreshock activity was recorded by RESNOR, the regional network that CICESE maintains to study the seismicity of the northwest of Mexico. There were a couple of events during the first days of June and at least seven shocks in the focal area of the main event on June 7.

3. Aftershock Locations and Fault Mechanisms

Victor Wong and José Frez

The aftershock activity reported here was recorded by a local network of six portable stations; some additional data was provided by three stations from RESNOR. Figure 3.1 shows all the stations used in this study. The local network operated until June 15.

All sufficiently well-recorded events were located by using the program HYPO-71 (Lee and Lahr, 1975). Both P and S phases were used when available. Given preliminary locations, we then used the arrival-time residuals to edit the data.

It is difficult to assess the accuracy of the locations, especially considering that only four to eight stations were used in the calculations. To minimize the errors, we selected those cases where the distribution of the stations was nearly uniform in azimuth and the arrival-time residuals were well-behaved. Additionally, we made several numerical experiments to test the effect of putting different structures and initial solutions in the hypocenter determinations. The results of these experiments show that individual solutions may vary up to distances of about 4km, however the general patterns reported here are quite stable.

The aftershock epicenters (Figure 3.1) appear to occupy two regions of high activity. One is concentrated as a nest in the neighborhood of the station SON. The other spreads from the northwest end of the Cerro Prieto fault toward the southeast end of the Imperial fault and may be composed of a sequence of several nests. Figure 3.1 also indicates a gap in the aftershock activity between the location of the main event and the regions described above. Independent hypocenter determinations made by California Institute of Technology indicate that very few events occurred in this gap. Therefore, this feature can be considered real.
Figure 3-1. Locations of Portable Stations and Aftershocks of the June 9, 1980 Earthquake.
Figure 3-2. Depth and Time Distribution of the Aftershocks of the June 9, 1980 Earthquake, Plotted as a Function of Distance Along the Fault (NW-SE).
The epicentral distribution shown in Figure 3.1 follows the general pattern of the seismicity recorded in the Imperial Valley where the seismic activity tends to concentrate at the offsets in the major strike-slip faults of the region (Johnson, 1979). Particularly, the aftershock distribution of Figure 3.1 is similar to results obtained from microseismicity studies of the northwest end of the Cerro Prieto fault (Reyes, 1979; Albores et al., 1980).

A vertical profile along the Cerro Prieto fault (Figure 3.2b) shows that the two regions with large numbers of aftershocks occur at different depths, the activity becoming deeper as we go away from the northwest end of the fault. The determination of hypocenter depth is structure dependent; however, numerical experiments suggest that the general trend shown in Figure 3.2b is real although the computed depths may vary when dissimilar structures are used in the hypocenter locations. The same change in depth for the seismicity near the northwest end of the Cerro Prieto fault has been reported by Reyes (1979); the study of the aftershock sequence of the Mexicali earthquake of October 15, 1979 also indicates an analogous behavior (Chávez and González, 1981), i.e. — a decrease in the depth of the aftershocks at the ends of the faults, in this case, the Imperial fault.

In Figure 3.2a, we can see the positions of the epicenters in relation to time. Due to instrumental problems, we started to locate the aftershocks 24 hours after the occurrence of the main event. Determinations made by the California Institute of Technology partially cover this gap by locating 23 aftershocks in this interval of time. Three of these aftershocks are estimated to be very near the main event, all the others being in the region of high seismicity defined above. The migration of aftershocks shown in Figure 3.2a starts at the northwest end of the Cerro Prieto fault, then the activity propagates—with increasing depth— to the southeast, and finally the end of the fault becomes predominantly active again. Chávez and González (1981) report also a systematic migration in the position of the aftershocks for the Mexicali earthquake of October 15, 1979; they found that the activity sequentially covers the entire Imperial fault.

We were not able to obtain composite focal mechanisms for the nests that are observed in Figures 3.1 and 3.2. Uncertainties found in the instrumental phase of several stations of our network account for this situation. Similar uncertainties precluded us from studying the magnitude distribution of the sequence of aftershocks.

Summarizing, we believe that the main event excited aftershocks in several preexisting nests at the northwest end of the Cerro Prieto fault, but no significant activity in the immediate neighborhood of the main event. The change in depth of the aftershock activity could be related to larger temperatures at the end of the fault, i.e., near a postulated spreading center. A further interpretation of these results, as well as those regarding the time migration of aftershocks and concerning focal mechanisms of this and other earthquakes in this area, is a matter of further research.

4. Strong Motion Accelerograms


The locations of all strong-motion accelerographs in Mexico which recorded significant data from the main event on June 9 are shown in Figure 1.1. Digital accelerograms were obtained on a Terra Technology DCA-310 at Chihuahua and on Kinematics DSA-1 cassette recorders at Victoria and Cucaph. The analog accelerographs are all Kinematics SMA-1 film recorders. Three of the SMA-1s were located at the same site, monitoring three different levels of the hospital building in Mexicali. All stations were situated to the northwest of the instrumentally-determined epicenter for the main shock (Figure 1.1).

Table 4.1 lists the coordinates of all stations which produced data, including U.S. stations, the peak accelerations observed, epicentral distances and other information. The analog recording from Cerro Prieto is reproduced in Figure 4.1 and the digital recording from Chihuahua is reproduced in Figure 4.2. The digital recording from Victoria is discussed in greater detail in the succeeding section.
Table 4.1
Accelerograms, June 9, 1980, Mexicali Valley Earthquake

<table>
<thead>
<tr>
<th>Station</th>
<th>Coordinates</th>
<th>Component</th>
<th>Peak Accel. (gals)</th>
<th>Epicentral Dist.</th>
<th>Closest Dist.†</th>
<th>$M_L$ ††</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Victoria</td>
<td>32.289ºW 115.103ºN</td>
<td>50º up 320º</td>
<td>772# &gt;980# 833#</td>
<td>7 2 6.2</td>
<td>Partially inoperative Clipped</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cerro Prieto</td>
<td>32.421ºW 115.301ºN</td>
<td>45º up 225º</td>
<td>663 301 565</td>
<td>31 7 6.1</td>
<td>Triggered on S-wave</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chihuahua</td>
<td>32.484ºW 115.240ºN</td>
<td>down 192º 102º</td>
<td>69 95 151</td>
<td>35 14 6.1</td>
<td>Other horizontal inoperative</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cucapah</td>
<td>32.545ºW 115.235ºN</td>
<td>85º up</td>
<td>75 59</td>
<td>40 20 5.9</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SAHOP</td>
<td>32.618ºN 115.438ºW</td>
<td>10º up 280º</td>
<td>72 42 59</td>
<td>54 31 6.2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aeropuerto</td>
<td>32.651ºW 115.332ºN</td>
<td>45º up 225º</td>
<td>23 19 30</td>
<td>55 33</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HOSPITAL</td>
<td></td>
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<td></td>
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</tr>
<tr>
<td>Ground</td>
<td>32.641ºN 115.471ºW</td>
<td>270º up 180º</td>
<td>44 32 46</td>
<td>59 35 6.3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Second Story</td>
<td>90º up 0º</td>
<td>57 44 111</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Roof</td>
<td>90º up 0º</td>
<td>118 66 179</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bonds Corner</td>
<td>32.693ºN 115.338ºW</td>
<td>230º up</td>
<td>100## 59 38</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>USA</td>
<td>140º</td>
<td>10## 130##</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Calexico USA</td>
<td>32.669ºN 115.492ºW</td>
<td>315º up 225º</td>
<td>40## 30## 40##</td>
<td>65 41</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>El Centro Array #11 USA</td>
<td>32.752ºN 115.594ºW</td>
<td>230º up 140º</td>
<td>40## 30## 50##</td>
<td>78 55</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

†Distance measured to northern limit of Cerro Prieto Fault on Figure 1.1 for sites to north.
††Based on closest distance.
#Largest values from recovered sections of the record (see text).
##Estimated peak acceleration from original record rather than from digitization; therefore prone to revision.
Figure 4.1. Accelerogram recorded on the Kinematics SMA-I at Cerro Prieto from the June 9, 1980 Earthquake.

Figure 4.2 Accelerogram recorded on the Terra Technology BCA 310 at Chihuahua from the June 9, 1980 earthquake and its first aftershock.
Figure 4.3 Pier housing the accelerograph at the Cerro Prieto site.

Figure 4.4 Pier housing the accelerograph at the Chihuahua site.

Figure 4.5 Detail of pier housing the accelerograph at the Chihuahua site.
Except for the site at Cerro Prieto, all accelerographs are at an elevation within a few meters of sea level, and are underlain by alluvium. The Cerro Prieto accelerograph is on the basaltic Cerro Prieto volcano, at an elevation of 170m. The instruments at Victoria, Cerro Prieto, Chihuahua, Cucapah, and Aeropuerto are all mounted on concrete piers, inside aluminum protective cases. Posts which are anchored into the same concrete piers can be used for mounting the WWVB antenna or solar panels. Figure 4.3 shows the Cerro Prieto site, and Figures 4.4 and 4.5 show the Chihuahua site.

The analog accelerograms from the Mexican sites at Hospital, SAHOP, and Cerro Prieto have been digitized by UNAM. The digital accelerograms, and equally spaced interpolations of the digitized analog accelerograms (100 points per second), have been forwarded to EDIS at Boulder, Colorado for distribution. These versions have been corrected only for the gain of the instrument, not for dynamic properties (Mena et al., 1980). Based on these digitizations, and the method of Kanamori and Jennings (1978), we have derived the estimate of \( M_L \) from each accelerogram shown in Table 4.1; the average \( M_L = 6.1 \), in agreement with the estimate given by Hutton et al. (1981).

Because the epicenter (Figure 1.1) is southeast of Victoria, and the aftershocks are centered in the vicinity of the town of Delta (Figures 3.1 and 1.1) northwest of Victoria, we infer that rupture during this earthquake propagated toward the northwest, past the accelerograph at Victoria, and generally toward the other six accelerograph sites. As discussed by Sharp (Section 7) and Suarez et al. (section 8), there was no observed surface rupture near Victoria. Thus the distance between the station and the Cerro Prieto fault is unknown. Our estimate of 2—3km is based on the location of the Cerro Prieto fault as shown in Figure 1.1.

The record from Chihuahua shows a strong burst of high frequency energy beginning about 29 sec after the instrument triggered. We here refer to this as an aftershock, even though strong shaking from the "main shock" was continuing at the time this event was recorded. Attempts to locate this aftershock have not yet been entirely successful, but it definitely originated at a location closer to Chihuahua than to Victoria. Although this aftershock causes the largest amplitudes which were recorded at Chihuahua and Cucapah, we can rule out the hypothesis that the accelerographs at Hospital and SAHOP were only triggered by the aftershock. Timed accelerograms from U.S. stations at Bonds Corner and Calexico show that the main shock was much stronger than the aftershock near the international border.

5. The Strong Motion Record from Station Victoria
Richard S. Simons

The recording device closest to the 9 June 1980 main event was a strong motion instrument (1 g digital Kinematics DSA-1) in the town of Guadalupe Victoria, approximately 10km northwest of the instrumentally-determined epicenter and close to the Cerro Prieto fault (Figure 1.1). The accelerograph recorded continuously for 3 min 20 sec after it was triggered. The three largest aftershocks on the record arrived 45 sec, 1 min 40 sec, and 2 min 5 sec after the instrument triggered.

The first 12 seconds of the record from station Victoria could not be recovered from the digital cassette in the normal manner, presumably because the tape is affected in places by low magnetization level. Subsequent inspection by Kinematics suggested that this resulted from an accumulation of dust on the record heads (S. Pauly, personal communication). In any case, the quality of the recording improves with time from the beginning. The recovery of good data was helped substantially upon playback at the Kinematics laboratory in Pasadena by careful adjustment of head skew and tape pressure against the heads. Further improvement was obtained via computer software at the Institute of Geophysics and Planetary Physics in La Jolla. The essential function of the program was to keep the data bit stream synchronized, since a principal manifestation of the low-magnetization problem is that bits are occasionally lost from the stream, thereby altering the expected positions of perfectly good bits. Resynchronization is
Figure 5-1. Vertical Component of Acceleration Recorded at Station Victoria from the June 9, 1980 Earthquake. Dotted segments replace data not recoverable from tape (see text).

Figure 5-2. Horizontal (N40°W) Component of Acceleration Recorded at Station Victoria from the June 9, 1980 Earthquake. Dotted segments replace data not recoverable from tape (see text).
Figure 5-3. Velocity of N40°W Component at Station Victoria from the June 9, 1980 Earthquake. This trace was computed by finding the velocity response of a damped (0.7 critical) single degree of freedom oscillator with free period 10 seconds to the accelerogram in Figure 5-2.
Figure 5-4. Velocity Response Spectrum of the Vertical Component of Motion at Station Victoria from the June 9, 1980 Earthquake, Computed Two Different Ways (See Text) and Compared with a Vertical Recording from the October 15, 1979 El Centro Event.

Figure 5-5. Velocity Response Spectrum of a Horizontal Component of Motion (N40°W) at Station Victoria from the June 9, 1980 Earthquake, Computed Two Different Ways (See Text) and Compared with a Horizontal Recording from the October 15, 1979 El Centro Event.
accomplished by attention to the frame synch words, word synch bits and parity bits encoded on the tape by the Kinometrics recorder.

The WWVB time code and the two pulse-per-second interval time code recorded on the tape have been recovered and serve to verify that the time scale of the recovered data is essentially intact. Only a few samples have been lost in some of the 'gaps' (bad segments connecting the real data). The overall result is that on Channels 2 and 3 (vertical and N40°W) the total amount of data lost is 1.33 and 1.63 seconds, respectively, or about 9 and 11 percent of the major activity (~15 seconds). The total amount of data lost in Channel 1 is somewhat greater, and that accelerogram is consequently not presented here. The WWVB radio time code gives a trigger time for the accelerogram of 03:28:23.6. Because of emergent first motions, the initial P-wave was not recorded.

The recovered vertical and N40°W components of motion at station Victoria are reproduced in Figures 5.1 and 5.2 (uncorrected for system response). Unrecoverable segments are represented by horizontal dotted lines at the level of zero counts. In Figure 5.1, the vertical acceleration can be seen to reach or exceed 1 g at least six times in the positive direction and once in the negative direction. In one 0.25 sec segment (approximately four seconds after the beginning of the record), the instantaneous vertical acceleration exceeds 1 g four times at frequencies as low as 10Hz. The horizontal acceleration reaches a peak of 0.85g and exceeds 0.5g at various times spanning an interval of ~9 seconds.

The records shown (with data values set equal to zero in the gaps) have been integrated for velocity. The horizontal velocity is reproduced in Figure 5.3. The overall appearance of the integrations, as well as the fact that the peak velocities are reached prior to any major gaps in the data, lend credence to the validity of these peak values as lower limits for the station. The peak vertical velocity is thus at least 34.3cm/sec; peak horizontal velocity is at least 50.8cm/sec.

Acceleration response spectra have been computed for the Victoria vertical and N40°W components, in two different ways. One way was to treat the accelerograms shown in Figure 5.1 and 5.2 (with 0.1sec-fill in the unrecoverable sections) as continuous time series, just as was done when integrating for velocity. The other way was to select from each record a set of valid, contiguous segments representing the principal activity (seven segments in the case of the vertical, nine for the horizontal) and to compute the acceleration response for each segment individually. The individual response spectra were then superimposed and the overall response spectrum for a component taken as the envelope of its individual segment spectra. These two techniques give an almost identical result in the short-period part of the spectrum (Figures 5.4 and 5.5), with the 'composite' spectrum gradually showing less energy than the 'total' one as periods increase beyond about 0.2 seconds. Tests comparing the response spectrum of an unimpaired record with a composite spectrum formed from a set of randomly-chosen segments from it confirm that the result is invariant at the shorter periods.

Figures 5.4 and 5.5 include comparisons of the Victoria response spectra with the highest vertical and horizontal response spectra obtained from the 15 October 1979 Imperial Valley earthquake.

6. Observations of Damage and Intensity

J. Prince, E. Mena, I. Mora, J. Brune, L. Alonso, F. Vernon

The epicentral area of the earthquake lies in a zone of irrigated farming land where important buildings designed to withstand earthquakes are nonexistent with the exception of the Cerro Prieto Geothermal Plant, located near the northern end of the Cerro Prieto fault (Figure 6.1). The area is crisscrossed by irrigation canals and a railroad embankment follows a direction approximately parallel to the fault.

Most of the damage to engineering works was concentrated in a relatively small area of about 30km long by 6 to 8km wide, astride the fault trace, which follows a general NW-SE direction after starting about 2km SE of the geothermal plant and reaching close to the town of Rito as shown in Figure 6.1. In the following paragraphs a brief description is given of the
damage observed in this area within one week of the earthquake.

Cracking of the ground was observed near the towns of Delta, Pescaderos and Murguia (6.1). In this area no preferred direction of the cracks and no signs of permanent displacement could be ascertained: cracks both parallel and normal to the fault were found, as well as some at about 45° in a general N-S trend. One of these crossed the railroad track near Delta, and constitutes one of the few examples where permanent displacement was clear, the evidence being the lateral deformation of the rails, (Figure 6.2). The dark patch in the track is the new ties and shows the extent of the portion where the rails were bent, although a much longer section (hundreds of meters) of the track to both sides had to be retamped and releveled.

In the town of Delta two cracks about 100m long and about 65m from one another were found. The intermediate block appeared to have settled 5 to 10cm, with no lateral displacement. The adobe houses built across either trace were among the most heavily damaged in the town although few collapses occurred even among this extremely weak type of construction (Figure 6.3). Some other houses built with reinforced concrete block experienced cracked walls but withstood the shaking without more significant damage.

In Pescaderos ground fissures seem to have been of decreasing magnitude. One produced cracks in the walls of the town school (one-story welded steel frame) and one unreinforced section collapsed outwards. No damage to the frame was found.

The longest ground crack was followed by one of the authors (EM) for about 7km and its general trend, nearly normal to the fault, is shown by a dotted line in Figure 6.1. It was located about 200m SE of the crossing of the Colorado River by the railway and the road leading (NW) by Murguia. The trace of this crack is oriented to the NE at distances from the river of from a few to hundreds of meters. At the farthest points from the river the trace across the fields could be followed without difficulty although at several of the nearest points it seemed to widen up to about 1m which, in all probability, reflects a certain slumping of the river slope being combined with the breaking of the ground.

More than fifty sand boils due to liquefaction of shallow saturated sands were found in the area near Delta and more than ten near Rito; many of them seemed to be related to surface breaking. Some of these boils were still producing salty water five days after the earthquake. The largest boils (Figure 6.4), were located by a crack about 5km west of Delta near the canal indicated "Nuevo C. Delta" in Figure 6.5.

One of the authors (EM) inspected over 75km of the irrigation canals shown in Figure 6.5 in the vicinity of the fault line. They are composed of soil embankments lined on the sides and bottom with concrete slabs. The main types of damage to these structures are depicted in Figures 6.6 and 6.7. The first shows the result of cracking of the embankment and rapidly increasing leaks that eventually washed away the earthen support of the lateral concrete slabs.

The damage mechanism for the type of failure shown in Figure 6.7 is less clear. Some observations seemed to indicate a rotation of the sloping slab about its bottom edge, whereas in other parts there appeared to be only a widening of several inches between the embankments. In any case, the resulting water leaks washed away so much material from the embankments that the mode of failure is not completely clear.

Figure 6.5 presents in heavy line those canals that were put out of service by the earthquake, and Figure 6.8 shows the traces of ground cracks that produced damage at the points the canals were intersected (this map was provided by the irrigation authorities in the Mexicali region).

Finally, the highest structure in the limited area strongly shaken by the earthquake was the church tower shown in Figure 6.9. This tower was demolished a few weeks after the earthquake because it was concluded that the damage at mid-height of one of the corner concrete columns not only was difficult to repair satisfactorily but was a sign of undesirable weakness.

More detailed information about effects on soils and damage to housing and other man-made structures can be found in Mena et al. (1980) and Jaime (1980).
Fig. 6.2
Deformed Rails Near Delta

Fig. 6.3
Damaged Adobe Houses
Near Fault Trace

Fig. 6.4
Sand Boils 5 km West of Delta
Figure 6.5

Irrigation Canals, with damage indicated
Fig. 6.6
Cracked Embankment of Irrigation Canal

Fig. 6.7
Damaged Irrigation Canal

Fig. 6.9
Damaged Church Tower
Zonas de daños principales, enmarcados por los círculos

Figure 6.8 Location of damages in the irrigation canals.
Given the sparse construction in the affected area, the scarcity of reliable witnesses and the high concentration of damage related to adverse soil behavior, no attempt was made to define isoseismals or intensity for this earthquake.

7. Surface Ruptures Observed at Ejido Saltillo, Baja California after the Mexicali Valley Earthquake of 9 June, 1980

R.V. Sharp

Following the 9 June 1980 earthquake near Victoria, Baja California, J. J. Lienkaemper and I briefly investigated the Imperial fault in California to determine whether a new pulse of after slip of the 15 October 1979 earthquake might have been triggered by the new seismic event. On June 12, we checked the Imperial fault in Mexico for evidence of new displacement, as well as several locations along the Cerro Prieto fault in the epicentral region (Figure 7.1). On returning by way of Ejido Saltillo, our car reported a vertical offset in the pavement of Pascualitos—Pescaderos highway with a provocative jolt. The local farmers’ knowledge of new ruptures greatly expedited our subsequent observations, which are briefly summarized here.

The observations and measurements of displacement were made in the field without benefit of detailed maps or aerial photographs. Several days later, I reconstructed the traces of new rupture on aerial photographs from memory and photographs taken in the field. These traces are shown in Figure 7.2. Although some of the breaks are located precisely with respect to road intersections, etc., many may be only within several tens of meters of their actual positions.

Description of surface fractures. The fractures at Ejido Saltillo broke the ground surface discontinuously along a north-northwest-trending zone for at least a kilometer near the west side of the settlement. At the southeast end of the zone where they were best developed, and at the highway, the fractures grouped in the left-stepping en echelon pattern that is characteristic of right-lateral surface faulting. At other locations, the en echelon pattern was not obvious, and at some places the principal component of displacement appeared to be vertical rather than horizontal.

Locality A: The surface fractures at this location were pristine on June 12, and they showed the greatest displacement that we found. The breaks consisted of an en echelon series of slightly gaping fissures oriented about north-south, and the zone of breaks trended about 10°—15° west or north (Figure 7.3). Pre-earthquake harrow-disc grooves in this field provided reference marks from which the displacement could be determined accurately; at A the largest component of slip, 16.5cm, was right lateral in sense, and the vertical component, up on the west, was 10cm. At most other places in this field, the horizontal component was much less and the vertical component appeared to be nearly zero.

The breaks died out southward within this field but we did not determine their extent accurately. We checked the north levee of Canal Delta Numero Uno and found no rupture. If other undiscovered breaks occurred closer to the epicenter, they were not continuous with those in this field.

Locality B: This location is at the only concrete-lined canal in the zone of surface breaks. The canal showed evidence of slight buckling, and we judged that the side east of the buckle may have raised slightly. The canal remained straight, so that horizontal slip here was apparently absent. There was a small hairline extensional crack crossing the east levee about normal to its length. This crack may have been caused by shaking rather than displacement of the ground.

Locality C: A line of surface cracks here was observed by residents after the earthquake, but they were not visible at the time of our inspection. Although billowing dust raised by traffic passing on the adjacent dirt road accounted for obliteration of narrow cracks, we detected no obvious sign of vertical displacement of the dust-covered ground surface that would have been more difficult to obscure.
Figure 7.1. Regional map showing the epicenter of the 1980 Victoria earthquake, surface ruptures at Ejido Saltillo, and the traces of the Imperial and Cerro Prieto faults. Dotted line represents Canal Delta Numero Uno.
Figure 7.2 Map of fault features at Ejido Saltillo. Light lines indicate the following cultural features: single solid lines - land boundaries, edges of fields, drainage ditches, and irrigation canals; double solid lines - pavement of Pascualitos - Pescaderos highway; double dashed lines - unpaved secondary roads and levee roads. Heavy lines represent new surface fractures and other possible fault traces: solid lines - fractures observed on ground surface in this investigation; dashed lines - observed fractures whose extents were not determined, and fractures that were observed by residents but were obliterated before our investigation; dotted line - pronounced lineament in cultivated field that is visible on aerial photographs. Letters at arrows indicate localities discussed in the text.
Figure 7.3 Offset crop rows at locality A. View toward west-southwest. Pen lying on ground on near side of fracture gives scale.

Figure 7.4 En echelon fractures and vertical deformation at locality D. View is toward north.
Locality D: The pavement of Pascualitos—Pescaderos highway was broken by a set of left-stepping en echelon fractures (Figure 7.4) that coincided with the crest of a zone of vertical displacement at least 2 meters wide. Although the fractures appeared to be relatively fresh, it is possible that new movement enlarged preexisting fractures. The sense of the vertical displacement was down to the west, and the painted line showed no obvious horizontal shift. The profile of deformation and the position and pattern of the cracks was similar to that observed at the Brawley fault zone that broke in the Imperial Valley in 1975 and 1979.

Neither cracks nor vertical displacement could be detected on the dirt shoulders of the pavement, thus casting doubt on the significance of the deformation in the pavement. However, the location of the break in the pavement is exactly at the intersection of dirt roads converging from the north and south. The volume of traffic over these dirt roads and on the shoulders of the highway was sufficient to have erased fractures in the three days before our visit, but not so for the obliteration of vertical relief comparable to that in the pavement. I conclude that most of the vertical deformation occurred at unknown times before the Victoria earthquake and that vertical and horizontal components of new slip must have been either very small or broadly distributed.

Locality E: Among the myriad desiccation cracks that pervaded this periodically irrigated field, at least one crack among them showed relatively greater width (1–2cm) and vertical displacement across it (≈ 1cm down to the west). The crack was oriented a few degrees west of north and was located at the eastern crest of a slight downwarp visible in the grade of the crop rows. The rows were not offset horizontally. The overall appearance of these features was similar to that seen in some fields crossed by strands of the Brawley fault zone after the 1979 Imperial Valley earthquake. No attempt was made to trace this feature across the field, so I cannot place limits on its full extent here. However, it was not visibly continuous with the break at locality D at the time of our inspection.

Locality F: A narrow zone of minutely gaping extensional cracks formed along a row of trees bordering the dirt road at this locality. No evidence of vertical or horizontal shift was detected on these breaks. Although they were not traced to the north and south, the next road that crossed the projection of these fractures about 100m farther north showed no obvious sign of new disturbance.

Locality G: This field was not checked for new rupture because at the time of our visit we were unaware of the pronounced contrast in the appearance of vegetation on aerial photographs of this field. I have no direct evidence that this photolineament is fault related, but I show it in Figure 7.2 because of its remarkably suggestive position and orientation with respect to the breaks that were observed farther south. No other photolineaments along the line of new breaks or along its projections were detected.

**Discussion.** These breaks appear to be primary tectonic features because: (1) no evidence of liquefaction or other secondary breakage of the ground surface was observed around Ejido Saltillo; (2) the left-stepping en echelon pattern of rupture was well developed at localities A and D; and (3) the deformation in the pavement at locality D suggested that movement of a similar kind had occurred before the 1980 Mexicali Valley earthquake.

A fault along these breaks might be related to the Imperial fault whose southernmost documented rupture in the 1940 Imperial Valley earthquake lies about 8km to the northwest. Because field checking of the 1940 rupture south of that point was cursory, there is no definite information on whether additional fault strands at the location of Ejido Saltillo might have been active in 1940. In his book *Elementary Seismology* (p.494), C.F. Richter mentions (without discussion) reports of additional 1940 faulting south of the mapped Imperial fault rupture, as well as north-south cracks visible on 1941 aerial photographs; whether the 1980 breaks at Ejido Saltillo coincide with any of these is unknown at present.

No clearly defined scarp was detected at any location along the new ground ruptures. However, land grading and leveling associated with the agricultural activity and road construction could have completely erased a predevelopment scarp if the relief on it was small. There is
some suggestion in the layout of roads in Ejido Saltillo that the line of new surface breaks might once have been a natural boundary or barrier.


F. Suarez V., K.E. Sieh, W.E. Elders

The June 9, 1980 earthquake ($M_L = 6.1$) occurred on the Cerro Prieto fault located in the Mexicali Valley (Figure 8.1). A day and a half after the event, the area was inspected both from the air and on the ground.

The aim of the aerial reconnaissance was to obtain evidence of possible slippage of the Cerro Prieto fault as well as other phenomena related to the earthquake.

We did not observe any tectonic feature which could be related to the Cerro Prieto fault, no fresh scarps or fractures clearly indicating tectonic slip.

We found a lot of damage in the agricultural areas as well as in the small towns and villages located in the valley. The damage increases from the Cerro Prieto volcano (where scattered sandblows and fissures were observed) to the southeast and concentrates around the village of Pescaderos (Figure 8.1) and then decreases south from this point.

The ground reconnaissance started in the Cerro Prieto geothermal field where some fractures and sandblows were found just east of the Geothermal Electrical Plant (photo 1). A geologist from the Coordinadora Ejecutiva de Cerro Prieto finished a structural map of the area around the geothermal field and found three different sets of fractures. One set of fractures is oriented north-south, a second one has a general strike east-west and the third set of fractures has a northeast-southwest orientation. He believes that the northeast-southwest, and the east-west sets are tectonic features. We think that none of these fractures or cracks are tectonic; instead they could be features developed due to a liquefaction process.

The owner of a ranch near the Geothermal Plant told us that the shaking of the ground was from north to south and south to north. If he is right, we can infer that the zone of fractures is a result of a shaking perpendicular to the direction of the fractures and the liquefied layer below came spurting up through the fractures. This effect can be seen in photo No. 2, where a sandblow is emitting cold water and some yellow crust around the crater has formed indicating that some kind of gas was associated with the crater.

The largest fractures seen in this area were found near drains or irrigation canals. These fractures seem to be purely extensional features associated with the canals and also with the shallow liquefied layer. Perhaps, the digging of the canal involved removal of a significant portion of the overlying stiff silt of clay. The failure took place along the weakest part of the overlying stiff material (photo 3). We did not see any major damage to structures moving south of the geothermal field and passing the towns of Delta and Oaxaca. However, immediately upon leaving Oaxaca the road at the southeast of the town had many extensional transverse cracks (photo 4). Some of these cracks showed right lateral movement of about 2cm. Following this main road, we drove for about 5km looking for some evidence of the Cerro Prieto fault. Using seismic evidence alone, (Reyes 1979), this is a place where the fault can be traced, and therefore this should be the site to look for any tectonic features related to the fault; unfortunately, we could not find any of these features.

The general damage increased substantially from Olachea to Pescaderos, besides the damage in the agricultural areas (photo 5); the destruction in Pescaderos was very high. The damage here was definitely more severe than what we observed elsewhere; a quick view shows that 13 out of 39 adobe houses suffered major damage (including complete collapse) and this was also the case of two out of 19 concrete block houses (photos 6,7,8). It was also in this area where the railroad was warped and bridges were affected to the point that the rail traffic was interrupted for several days (photos 9,10).

According to Allen (personal communication) the Cerro Prieto fault can be seen on the surface south of Pescaderos. He describes a low scarp near to an old school within a cotton
Figure 8.1 General map of the Mexicali Valley. Sites visited during the ground reconnaissance, and schematic illustration of damages and earthquake related features observed.
Photo No. 1 Sandblows located at the main entrance of the Cerro Prieto Geothermal plant. 48 hours after the earthquake, many of these structures were emitting water. The general orientation of the sandblows at this particular point was E-W.

Photo No. 2 A typical sandblow developed within a cultivated field after the earthquake. According to the owner of the ranch, some of the water that came up with the sand was hot and, in fact, killed his tomatoes.

Photo No. 3 A large fracture (100m long) found 2km SE from the Cerro Prieto Geothermal plant, just west of irrigation canal located behind the bush on the right side of the picture.
Photo No. 4 Transverse cracks found on the main highway at the southeast end of Oaxaca. Some of these cracks show a right lateral displacement of 2cm with a vertical component of about 5—7cm.

Photo No. 5 Several views of a drain located north of Pescaderos observe the collapse of these structures and all the fractures developed after the earthquake.

Photo No. 6 An adobe house in Pescaderos partially destroyed.
Photo No. 7 An adobe house in Pescaderos, complete collapse of the structure.

Photo No. 8 A totally destroyed concrete block house in Pescaderos Village.

Photo No. 9 The rails were bent between Olachea and Pescaderos. This photo is courtesy of David Chavez, a CICESE seismologist.
Photo No. 10 Damage in the railroad bridge. The abutment moved one meter with respect to the bridge structure.

Photo No. 11 Large slumping at the northwest side of the Colorado bridge, 50m before the toll-gate. On the opposite site, the bridge drops about 10–20cm.

Photo No. 12 A fresh fracture found in the main highway just east of Murguía railroad station. The fracture shows a right lateral displacement of 1–2cm. The location coincides with the trace of the Cerro Prieto fault.
field which represents the superficial trace of the fault; however, we did not see any faulting or features which can be related to the fault. We observed damage in the canals, which were completely drained as well as many fractures in the bottom of the concrete-line canals, which apparently allowed the water to drain out.

The earthquake damage decreased south from Pescaderos and no severe damage was observed in the towns of Plan de Ayala, Coahuila and Mesa, this being the last site visited to the south. Perhaps the most notorious damage was observed at the south end of the Colorado Bridge. Here we found a drop of about 10-20 cm and large slumping before the toll gate (photo 11).

Traveling to the north toward Mexicali we finished the survey just east of the Murguía railroad station. At 2.5 km driving west of this section and from where the highway bends, we found cracks which were perpendicular to the roadway showing a right lateral motion of about 1 cm (photo 12). Near this point, we found a dirt roadway crossing this highway. Perpendicular to the roadway we found a 6 m wide zone of fracturing. One crack in the middle of this zone shows a right lateral motion of about 1 cm. We also observed here cracks within the cultivated fields which are primarily slumping features. The shapes of these cracks are arcuate and oriented in various directions. One of these fractures found at the last site was oriented N37°W and showed a displacement of about 1 cm in the right lateral sense. The importance of this feature is that its location is within a narrow zone which matches with the trace of the Cerro Prieto fault.

Taking into account the evidence described above we suggest a tectonic slip of about 1 cm for the Mexicali Valley earthquake. However this has to be taken as a preliminary result. Through all our survey, we did not find any surficial manifestation of the Cerro Prieto fault. It is difficult to understand these results, especially if we compare this earthquake with others which have occurred in the same region. Three important cases are: the December 1934 Santa Clara earthquake, the May 1940 Imperial earthquake, and the October 1979 Mexicali earthquake. The first one is associated with the Cerro Prieto fault; the last two, with the Imperial fault. All three events produced surface indications of fault motion. At present this difference in behavior is not well understood and therefore it is necessary for further geological and geophysical research to clarify this point.

9. References


