CHAPTER 4

THE JULY 16, 1990 LUZON EARTHQUAKE

4.1 Overview of the earthquake and its aftermath

On July 16, 1990 a catastrophic earthquake of 7.7 Magnitude with epicenter near Rizal City hit Luzon causing 1,666 casualties and extensive damage (Fig. 4.1). The event was interpreted by PHIVOLCS as a multiple-shock quake with two major epicenters along the Philippine and Digdig Faults. A 120 km-long major ground rupture between Gabaldon in Dingalan Bay and Kayapa (30 km E of Baguio) and two minor rupture zones NW of Rizal City were associated with the ground-shaking. Along the major surface faulting the ground underwent a horizontal left lateral strike-slip motion, with maximum displacement of 6.2 meters, unprecedented this century (Sharp, USGS-PHIVOLCS Report, 1990).

Death and devastation induced by the tremors were accompanied by considerable damage in Central and Northern Luzon Buildings and infrastructure facilities collapsed in Baguio City, in the coastal

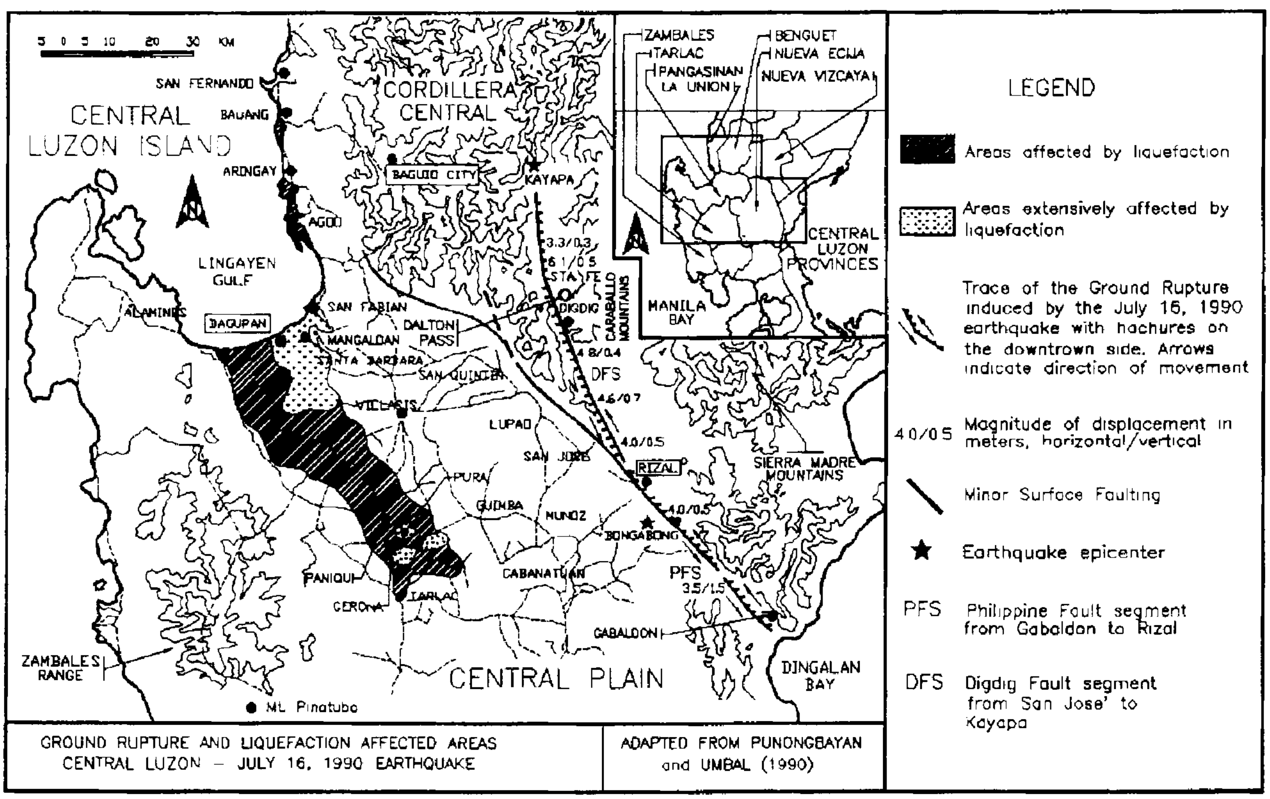


Fig. 4.1 – *Overview of Luzon 1990 earthquake area, adapted from Punongbayan and Umbal (1990).*

zone between Agoo and San Fernando in La Union (Lingayen Gulf) and in many localities in the Central Plain (Fig. 4.1). The entire zone near and along the ruptured fault segments was rocked the same day by further tremors.

Secondary short-range effects of the quake included landslides and liquefaction, both on a regional scale, while long-range effects involved a widespread sub-crustal block rearrangement in Northern and Central Luzon where two dormant volcanoes awakened during 1991.

The quake had an impressive and extensive environmental impact, triggering countless mainly shallow-seated landslides in the Cordillera Central and Caraballo Mountains. The slope materials mobilized by the tremor caused almost complete disruption of the transportation network in the region. Roads, highways and other communication systems in hilly and mountainous areas of western Luzon were severely damaged, thus blocking the immediate rescue efforts. From Metro Manila up to Abra province (Northwestern Luzon) there were signs of devastation. The impact on natural slopes can be regarded as one of Luzon's major disasters and as an example of landform evolution highly accelerated by the interaction of ground shaking and seasonal downpours.

Liquefaction occurred in a 70-km long and 20-km wide strip in Pangasinan and Tarlac provinces (Fig. 4.1). Sand boils, fountains and fissures were reported in the coastal areas of San Fernando in La Union province and in numerous other locations SW and W of the ground rupture in the Central Valley. Dagupan City on the Gulf of Lingayen was catastrophically damaged, while towns and villages in the Central Plain were badly affected.

After the major events of July 16, the region was rocked by further tremors and the ground continued to shake for months. The aftershock swarm was interpreted in terms of subcrustal block readjustment of Western and Central Luzon and mainly involved the Cordillera Central Mountains and the Central Plain rock basement.

For months a large number of tremors struck Baguio province where the fault pattern is comparatively more intricate. The final result of the underground rearrangement was the compression of shallow volcanic chambers and subsurface fractures some tens of kilometers west of the ruptured fault segment. Taal volcano (60 km SW of Manila) resumed activity in May 91 with the warming up of the central cone and smoke emissions. Mount Pinatubo (110 km NW of Manila) exploded in June 1991 with the widespread deposition of ejecta, after the volcano had been dormant for about 400 years. As a consequence of the eruption a region-wide blanket of light gray ash covered volcanic slopes and surrounding flatlands in the Central Plain. Then the transformation of the ash mantle into a fluid mass by heavy rains induced devastating lahars (mudflows) during 1991 and following monsoon seasons.

From July 1990 to October 1991 Central and Northern Luzon provinces were, thus, hit by interrelated disasters. The sequence of these catastrophic events was responsible for some thousands of deaths while a greater number of people were injured.

Over two million local inhabitants suffered, becoming homeless or jobless as a result of the damage to buildings, infrastructure and local activities. The agricultural potential of the region and the physical environment were drastically affected.

The damage to the economy of the Philippines by the quake, the eruption and their interaction with seasonal rains has been estimated at several billion US$, but long-term effects will be felt for years to come.

4.2 Geotectonic framework of Luzon

Out of the six morpho-tectonic units recognized in Luzon (Chapter 3), the Central Cordillera, Caraballo Range and Central Plain were most directly involved during the quake, but the major role was played by the Philippine Fault.

A 120-km segment, including part of the Philippine and the entire Digdig lineament, broke at the ground surface between Gabaldon and Kayapa during the July 1990 earthquake. The rupture, however, is considered to have continued underground for a further 50-100 km along the Abra Fault, which is presently considered as the northern extension of the Digdig Fault (Fig. 3.5). Although the importance of the Philippine Fault has been known since the end of the last century, its direction of motion was long a matter of controversy. The actual left-lateral strike slip motion was definitely proved by Allen in 1962 and is considered by Ringenbach et al. (1991) to result from the tangential component of the oblique convergence between the Eurasian and Philippine Sea plates. According to these workers a complex evolutionary process took place in Northern Luzon during the Miocene-Quaternary.

Left lateral displacement in the Middle Miocene-Pleistocene period occurred along the Philippine Fault which at that time presumably comprised several parallel N20W trending faults. During the Pleistocene the fault system was warped in Central Luzon, thus finally resulting in the present setting: the Philippine Fault with N140E strike and the N10-20E oriented splays with a typical tangential shape. Bending and subsequent horse-tailing attitude of the splays are attributed to the Middle to Late Eocene emplacement of the basaltic Benham Rise, which culminates 3,000 m above the surrounding depressions in the west Philippine Sea Basin (Lewis et al., 1983). According to Pinet and Stephan (1989) the initiation of the Philippine Fault took place in the Middle Miocene and the first strike-slip motion began in Upper-Middle Miocene times.

4.3 Seismicity levels within the Pacific Region and the Philippines

Before describing the Luzon earthquake, this section presents an overview of the trend of seismicity levels in the Pacific Region during the last 30 years and of the historical seismicity data for the Philippines. The earthquakes in the Pacific Region mainly occur along the Plate margins and intra-plate events are very few.

Figure 4.2 (upper sketch) shows the number of earthquakes per year (Magnitudes above 4) from 1964 to 1991 within the region including the Pacific Plate and adjacent smaller plates. In each column the lower part represents events on the Asian side, the upper part events on the American side.

The Meridian 150W has been used to separate the seismic events along the eastern and western boundaries of the Pacific Plate.

The position of this Meridian in the Gulf of Alaska approximately coincides with the northernmost zone of the East Pacific Ridge (Fig. 3.2), which is the major tectonic lineament of the region and divides the Plate into a western portion moving towards Asia (7-8 cm/year) and an eastern zone moving towards the Americas. The lower sketch in Figure 4.2 helps to visualize the boundaries of the zones involved.

The whole comumns (events within the entire Pacific Region) show a decreasing trend in the period 1965-77, with a minimun of 3,820 quakes in 1977; a sizable increase in seismicity occurs from 1978 onward, with a maximum of 6,290 quakes in 1986 and an average of 6,085 events per year in the period 1985-91.

In general, the seismicity along the coast of the Americas (upper part of the columns) decreases from about 1,500-1,600 to 900 events per year during 1964-1978 (with a minimum of 817 events in 1977); it is nearly stable within the narrow range of 1,124-1,175 quakes from 1979 to 1986, rising to 1,500-2,000 events in the 1987-91 period.

By comparison, the seismicity level along the western margin of the Plate (lower part of the columns) is mainly in the range of 3,200-3,300 events per year during 1964-1979, increases from 3,370 events in 1979 to 4,551 in 1985, and fluctuates in the range 4,090-4,540 events during the 1987-91 period.

Considering the overall seismicity of the Pacific region as broadly derived from the sum of earthquakes occurring along the western and the eastern boundaries of the plate, the Asian side appears to have been affected by a sizable increase in seismicity, compared to the American side, during 1977-86. The contribution to the western Pacific from the Aleutian Island Arc is not significant since the number of events per year, between 1964 and 1991, has a little variation over that period in the Aleutian Basin.

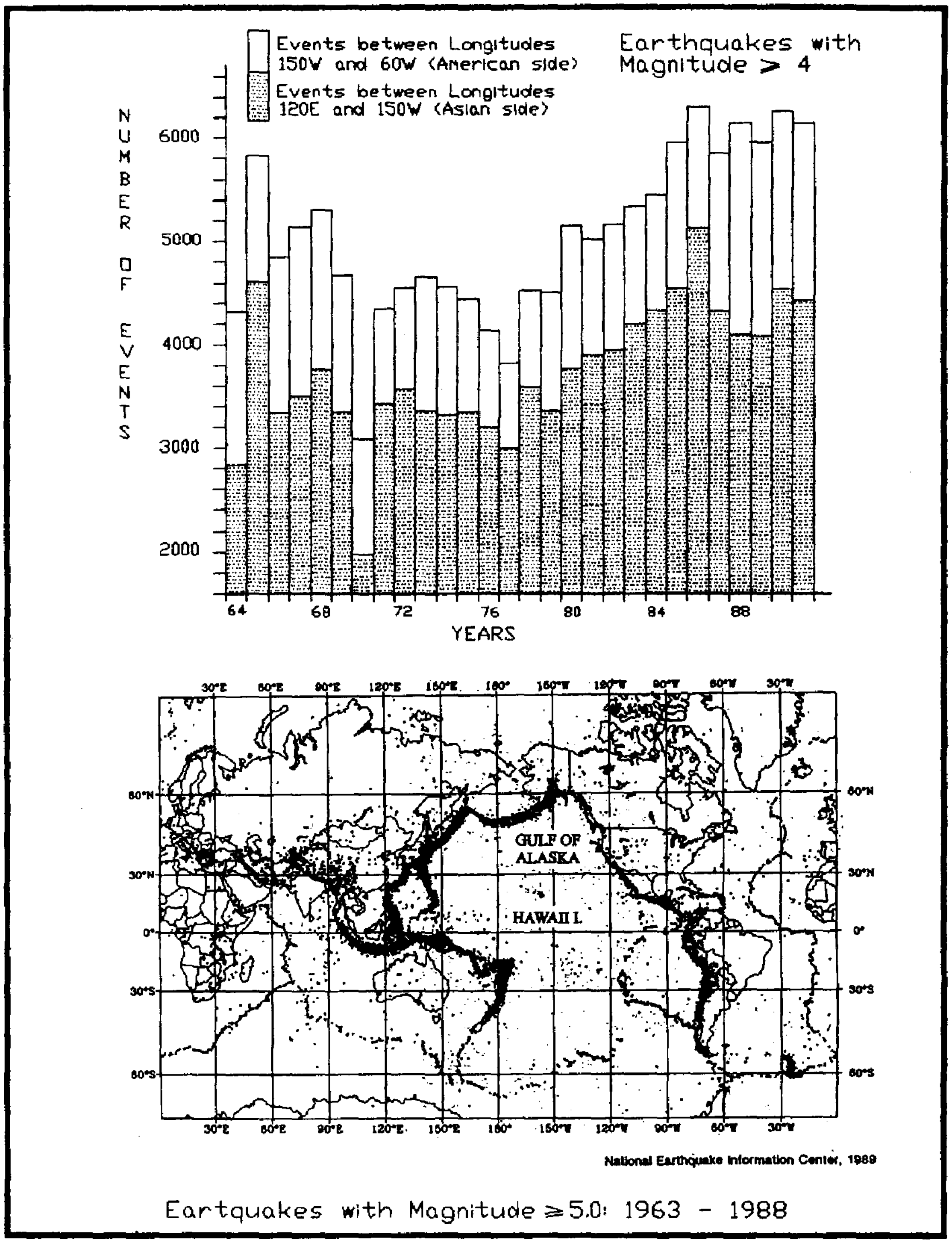


Fig. 4.2 – *The histogram (top) shows the number of earthquakes per year concerning the entire Pacific Region (whole columns), the western part of the Pacific Plate (lower columns) and the eastern part of the Plate (difference in height between the two), during the 1964-1991 period. The number of yearly earthquakes (above Magnitude 4) was derived from the catalogue of the International Seismological Centre (U.K.). The lower sketch (USGS-NEIC) visualizes the Pacific region and the areas to which histogram is related, that is Longitudes 120E - 60W (Lat. 75S-75N) for the entire Pacific Plate, Longitudes 120E - 150W for its western portion and Longitudes 150W - 60W for the eastern part.*

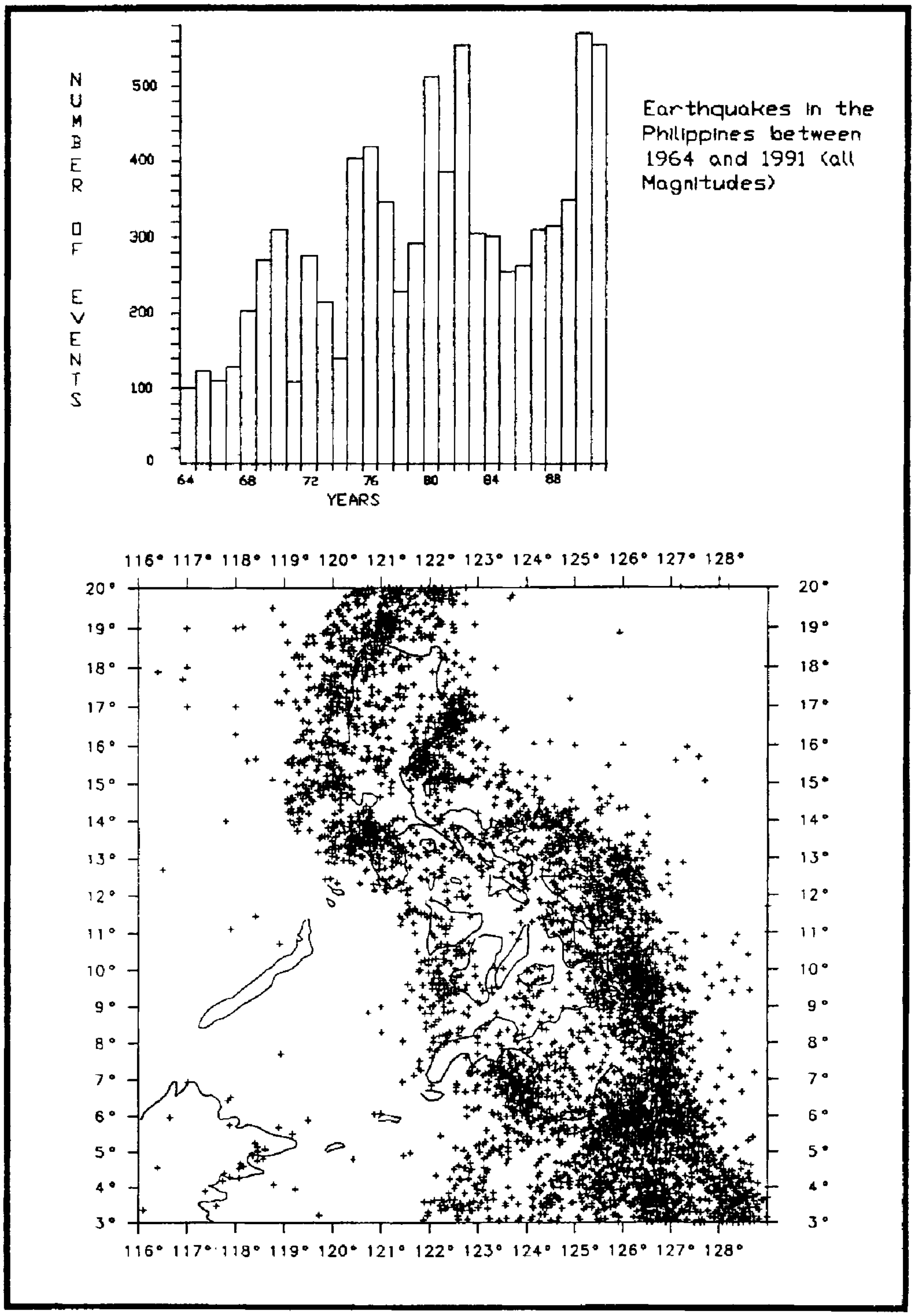


Fig. 4.3 – *Histogram (top) of the yearly number of earthquakes in the Philippines (all Magnitudes) during the period 1964-1991 (International Seismlogical Centre, U.K.). The lower sketch (ING), which visualizes the reference area, shows earthquake epicenters in the 1964-1988 period.*

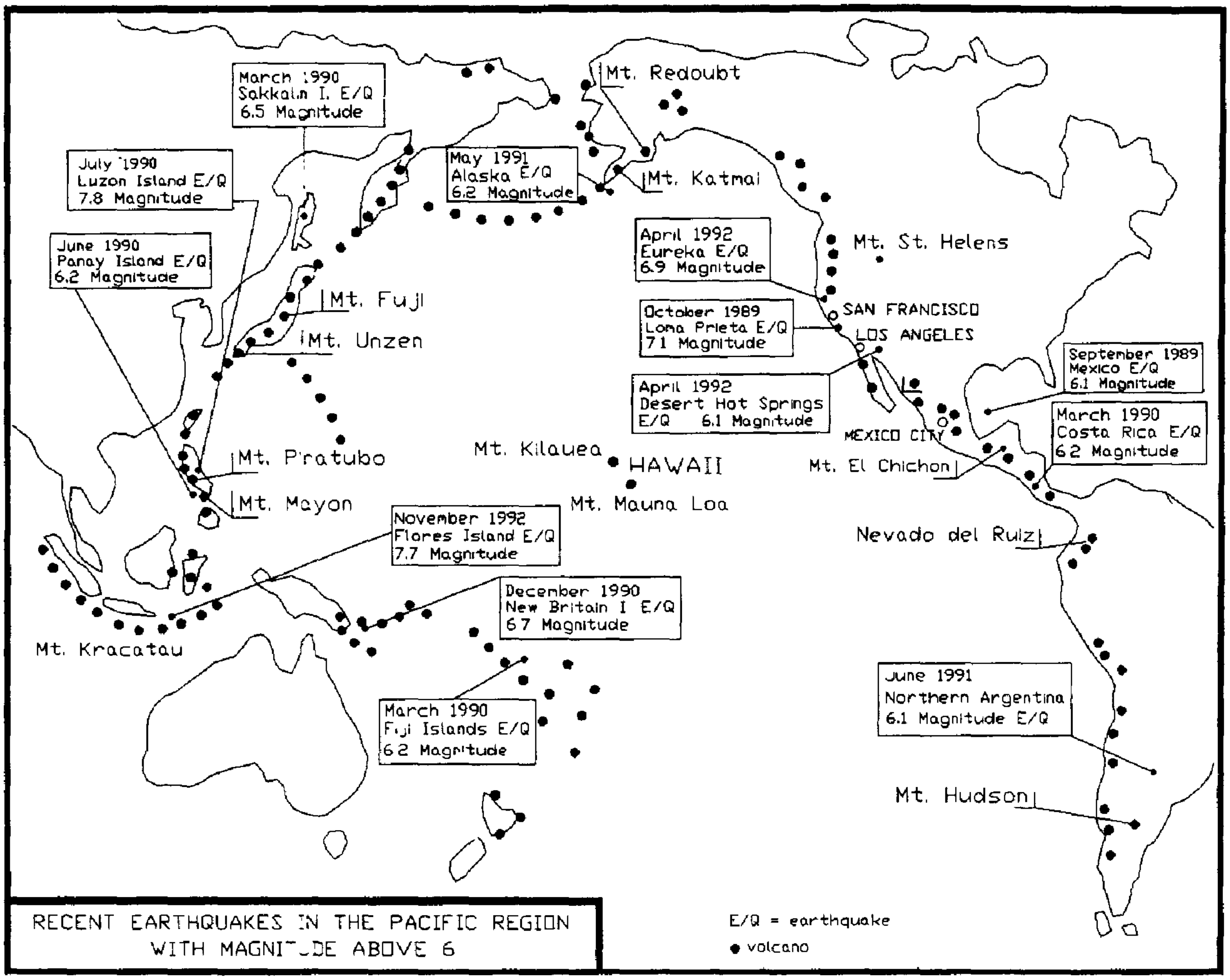


Fig. 4.4 – *Strong earthquakes in the Pacific Plate region, 1989-1992.*

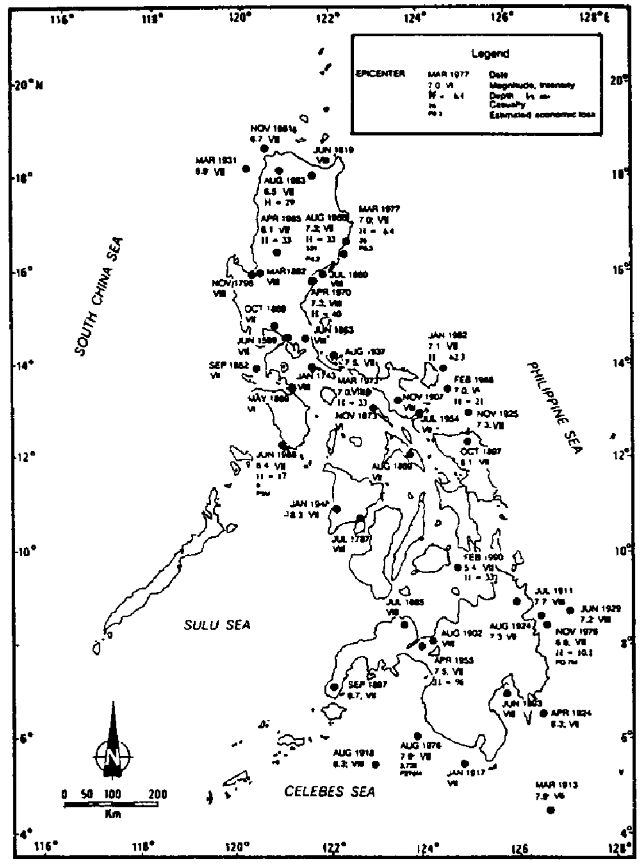
Figure 4.3 (upper sketch) illustrates the number of earthquakes per year in the Philippines (all Magnitudes) during the period 1964-1991. The seismicity of the Archipelago shows a marked increase from 1964 onward, with critical periods (and destructive earthquakes) in 1970, 1976, 1982 and 1990-91 (see Table 2.1).

The location and Magnitude of strong earthquakes in the Pacific during the 1989-1992 period is shown in Figure 4.4. An essential source of information on seismicity in the Philippines is the Catalogue of Philippine Earthquakes, 1589-1899 by William Repetti (1946). This summarizes seismic activity during the period of Spanish occupation. A more recent source is volume IV by SEASEE (1985) which lists all available data up to 1985. The oldest earthquake record concerning the Philippines is dated 1589.

Historical data show that the archipelago was shaken by frequent quakes of various intensities, with many destructive events between 1589 and 1988 (Fig. 4.5). Except for the events during this century, the location of the previous strong quakes is based on damage distribution and other historical information provided by Spanish sources.

Figure 4.6 shows revised locations of epicenters of the major historical earthquakes along the Philippine Fault zone. Because of differences in the interpretation of data and the consequent location of epicenters, Figures 4.5 and 4.6 are not directly comparable.

Fig. 4.5 – *Distribution of epicenters of major earthquakes (M › 6 and/or Intensity › VI) in the Philippines, 1599-1988 (Earthquake and Tsunami, PHIVOLCS, 1990). Intensity is based on the Rossi-Forel scale (Appendix C).*



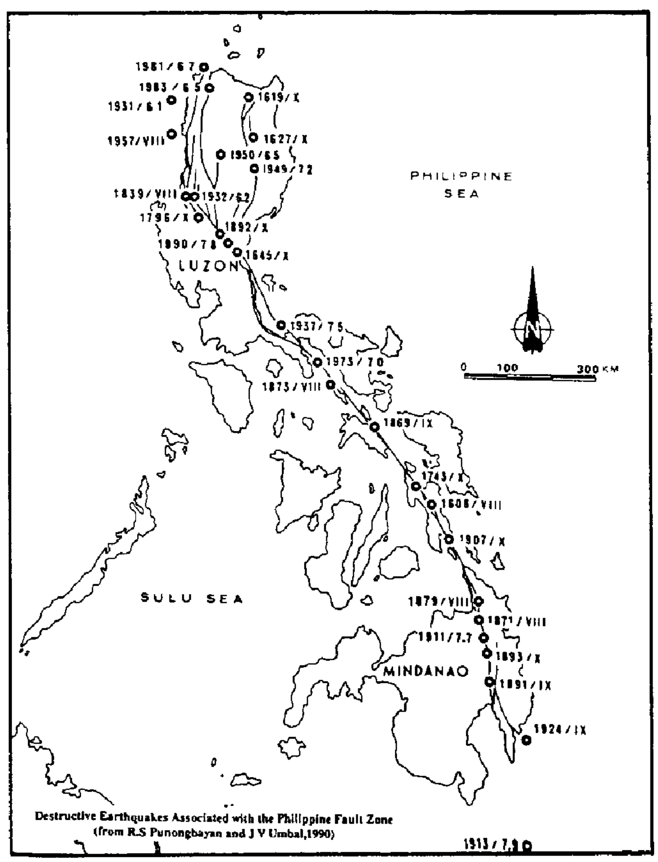


Fig 4.6 – *Destructive earthquakes along the Philippine Fault zone during the last four centuries (Punongbayan and Umbal, 1990)*

4.4 Focal mechanisms

A great step forward was made in the clarification of focal mechanisms with the recognition of subduction zones affecting both sides of the archipelago and the strike-slip movement along the Philippine Fault. Additional useful information was derived from the identification of numerous other tectonic lineaments. The revised seismic hazard analysis for the Philippines by Su (1988) includes hazard maps for the Archipelago with different levels of expected horizontal ground acceleration for some given annual probability of exceedence, namely for 0.1% and 0.01% a.p.e. These maps are based on source zones or seismogenic maps which are also incorporated in the aforecited paper.

By combining seismographic data (epicenter, focal depth, magnitude) with the most recent information on tectonics and geology, the Philippine Archipelago was divided into 18 earthquake generators or source zones (Appendix B). The revised approach adopted by Su is based on 3872 earthquakes in the Archipelago from 1964 to 1983 and follows the methodology proposed by Cornell (1968) and Algermissen (1982).

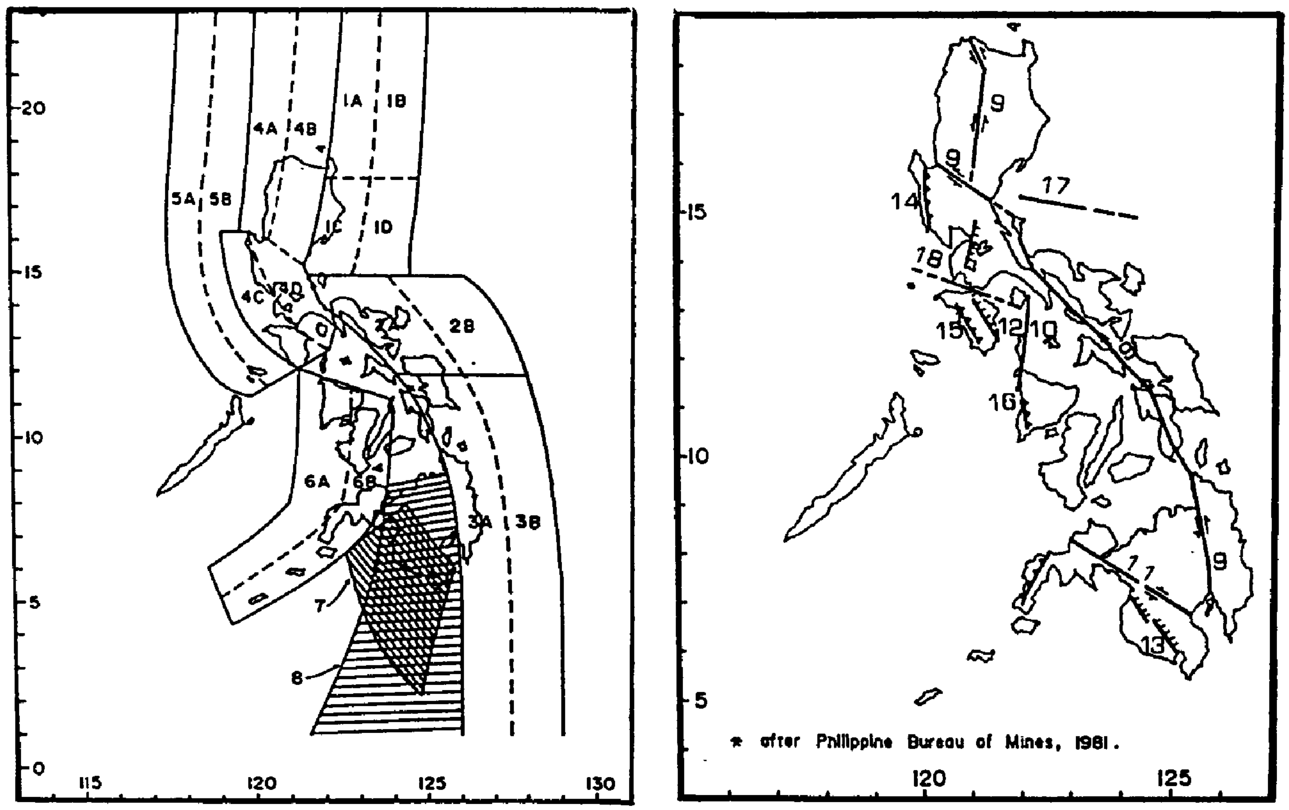


Fig. 4.7 – *Earthquake Source Zones 1 to 8 and 9 to 18 (Su, 1988), Reprinted by permission of Kluwer Academic Publishers.*

Figure 4.7 shows Source Zones from 1 to 8 (left sketch), which are basically related to focal mechanisms of the thrust and strike-slip types, and to mechanisms associated with Benioff zones and trenches. Figure 4.7 illustrates also the major tectonic lineaments in the Philippines treated as finite-width Source Zones from 9 to 18 (right sketch). These include transcurrent, normal and thrust faults (according to the Philippine Bureau of Mines, 1981).

4.5 The 1990 Luzon Earthquake

At 4.26 pm on July 16, 1990, Central Luzon was struck by a catastrophic earthquake having a Magnitude of 7.7 (Intensity VIII, Rossi-Forel scale, Appendix C), with epicenter near Rizal City and a focal depth of 24.8 km (NEIC). The event caused widespread damage and 1, 666 deaths. The worst affected towns were Baguio, Agoo, Dagupan, Aringay and Pura; Tarlac, Cabanatuan, Rizal and Manila were marginally damaged (Fig. 4.1).

The quake, which was felt over an area of about 500,000 sq. km, was accompanied by a 120-km long ground rupture between Gabaldon and Kayapa along the Philippine and Digdig Faults. A sub-surface rupture is believed to have propagated 50-100 km further North, in Northern Luzon (Sharp, USGS-PHIVOLCS Report, 1991), probably along the Abra River Fault (Fig. 4.8), as suggested by the distribution of aftershocks until February 1991.

Two minor surface ruptures, shown in Figure 4.9, were also induced by the quake along the north-western portion of the Philippine Fault and splays in the area between Rizal City and Lingayen Gulf. Also shown in the figure are the areas affected by the destructive quakes of 1645, 1796, 1892 in Central Luzon.

The movement along the major rupture zone, between Gabaldon and Kayapa, was left-lateral with horizontal displacement up to 6.2 m (near Capintalan) and vertical movement between 0.2 and 2.2 m. The horizontal slip mostly exceeded 3 m.

Figure 4.10, by comparison, shows the displacements in California along the San Andreas Fault during the 1979 and 1940 earthquakes. According to Sharp (USGS, Professional Paper 1254) a 5.8 m maximum horizontal displacement, scaled from aerial photographs, was calculated for the 1940 quake in a zone near the Mexican border.

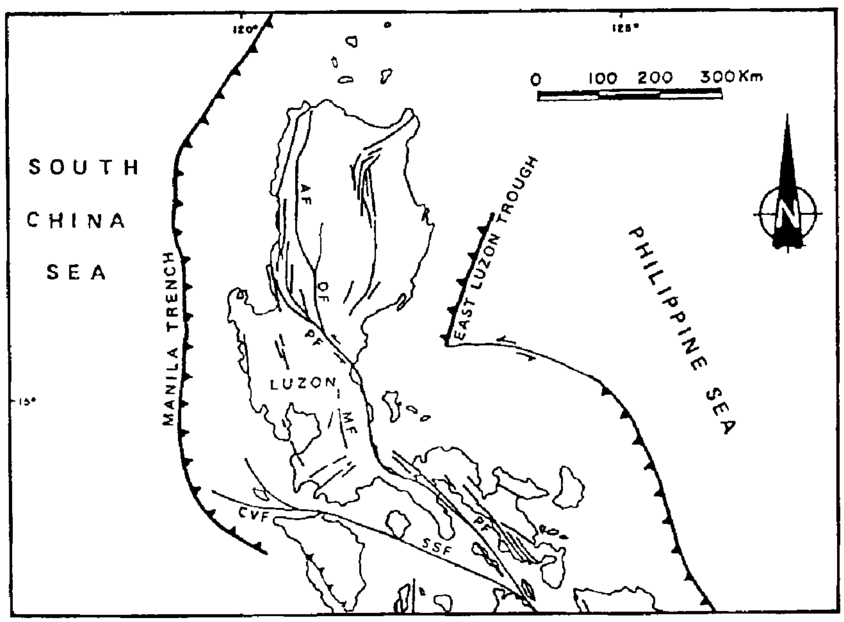


Fig.4.8 - *Major tectonic lineaments in Luzon (PF = Philippine Fault, DF = Digdig Fault, AF = Abra Fault, MF = Manila Fault), from Punongbayan and Umbal (1990).*

Figure 4.11 shows the alignment of Dalton Pass road (Pan-Philippine or Maharlika Highway), which runs along the ruptured Digdig Fault segment for about 40 km. Figure 4.12 shows the geometric details of the ground rupture in Figures 4.13 through 4.15, where the fault crosses the road in the section between San Jose' and Santa Fe'.

The ground rupture started SE of Rizal City and proceeded in jerks, following the zones of weakness of the major lineaments. The strike-slip motion occurred along the Philippine Fault segment connecting Gabaldon to Rizal and along the Digdig Fault between Rizal and Kayapa (Fig. 4.9). The bifurcation point, where the ground rupture splits into a northern and a northwestern segment, is located near Rizal. Horizontal and vertical displacements along the minor surface ruptures West of Digdig Fault (in the localities of San Josè-Lupao-San Quintin and San Manuel-Rosario) were minimal (Fig. 4.1), compared with the slip motion between Gabaldon and Kayapa.

According to eyewitness reports in Baguio and Manila, the earthquake consisted of two major shocks with a pause of 2 minutes and 54 seconds (Punongbayan et al., 1991). The first event at 4.26 pm with epicenter near Rizal was classed as having a Magnitude of 7.7 (NEIC) and lasted over 45 seconds. Soon after ground shaking began, recording instruments went off-scale, thus no records are available for the pause and the second shock felt by people in various localities.

Figure 4.16 shows Isoseismal lines, ground rupture and the area affected by landslides (Punongbayan and Torres, 1990).

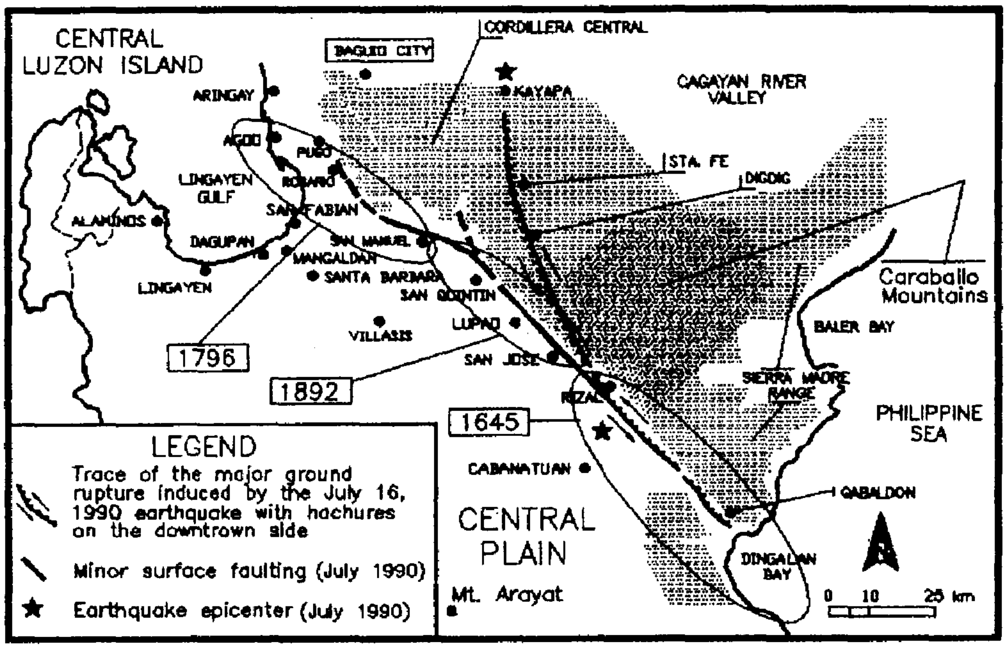


Fig. 4.9 – *Location of the Major Ground Rupture and minor surface faultings in Central Luzon associated with the July 1990 earthquake and the areas affected by the 1645, 1796, 1892 earthquakes.*

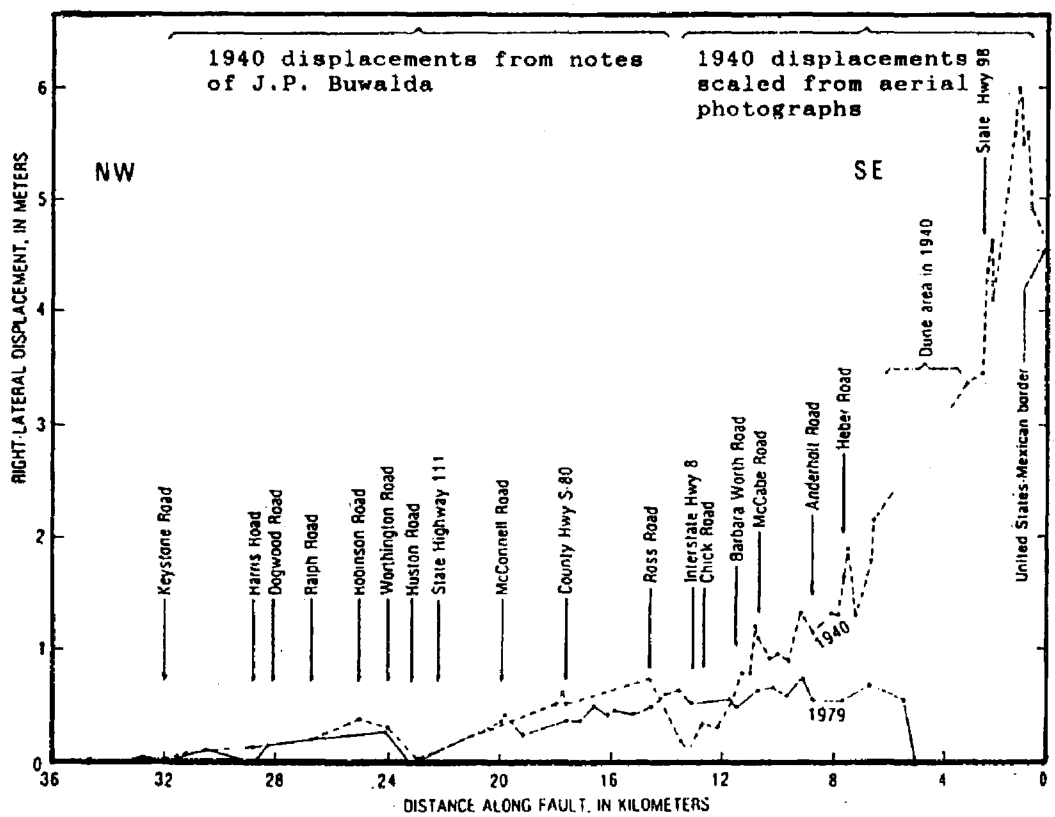


Fig. 4.10 – *Right-lateral displacements in California, along the San Andreas Fault, as a consequence of 1940 and 1979 earthquakes (Sharp, USGS Professional Paper 1254).*

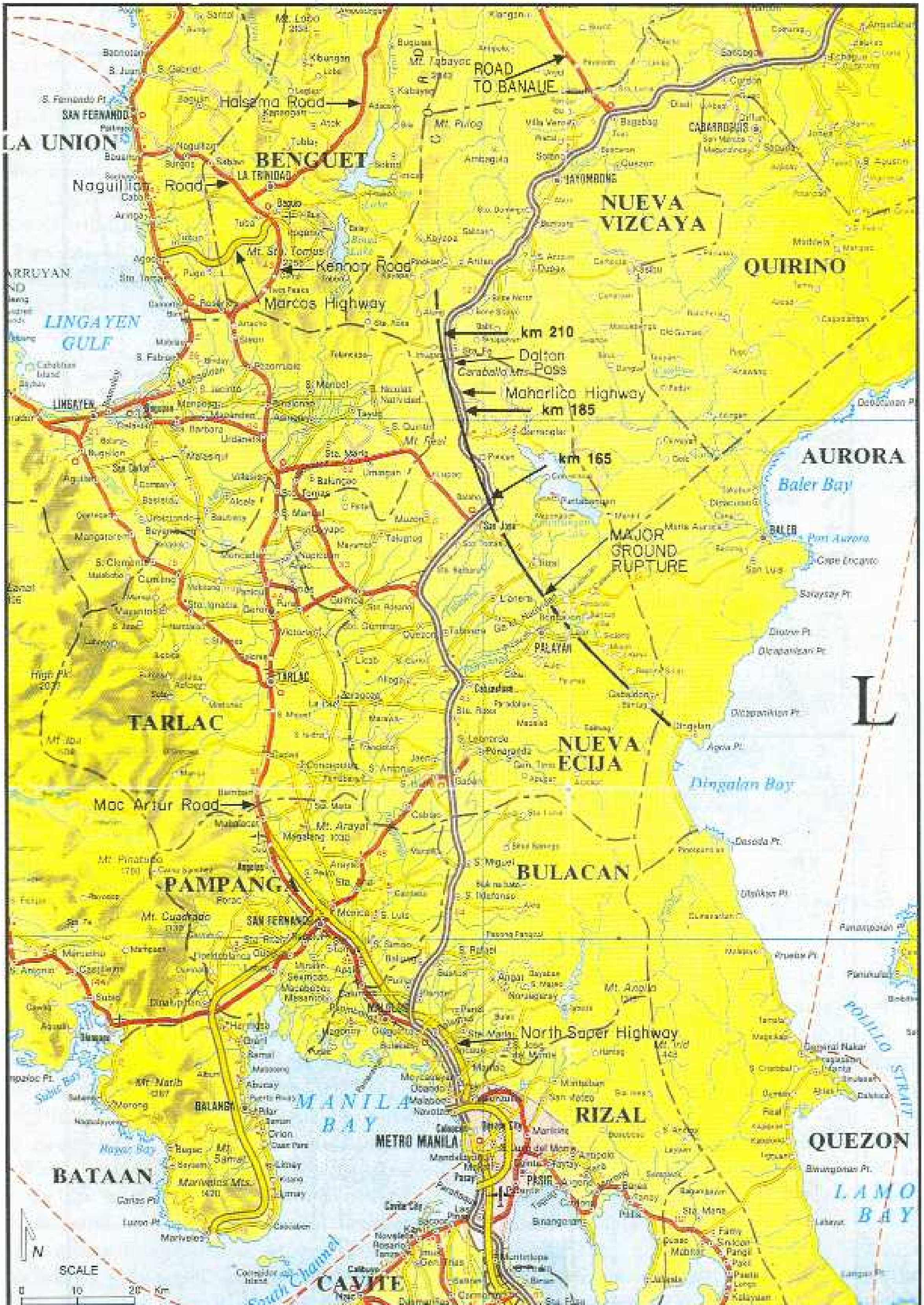


Fig. 4.11 – *Map of Central Luzon with the location of the major roads affected by the quake. The section between San Jose' and Santa Fe', km 165 to km 205, of the Dalton Pass Road (Maharlika Highway) crosses the Major Ground Rupture several times (Figures 4.13 through 4.15).*

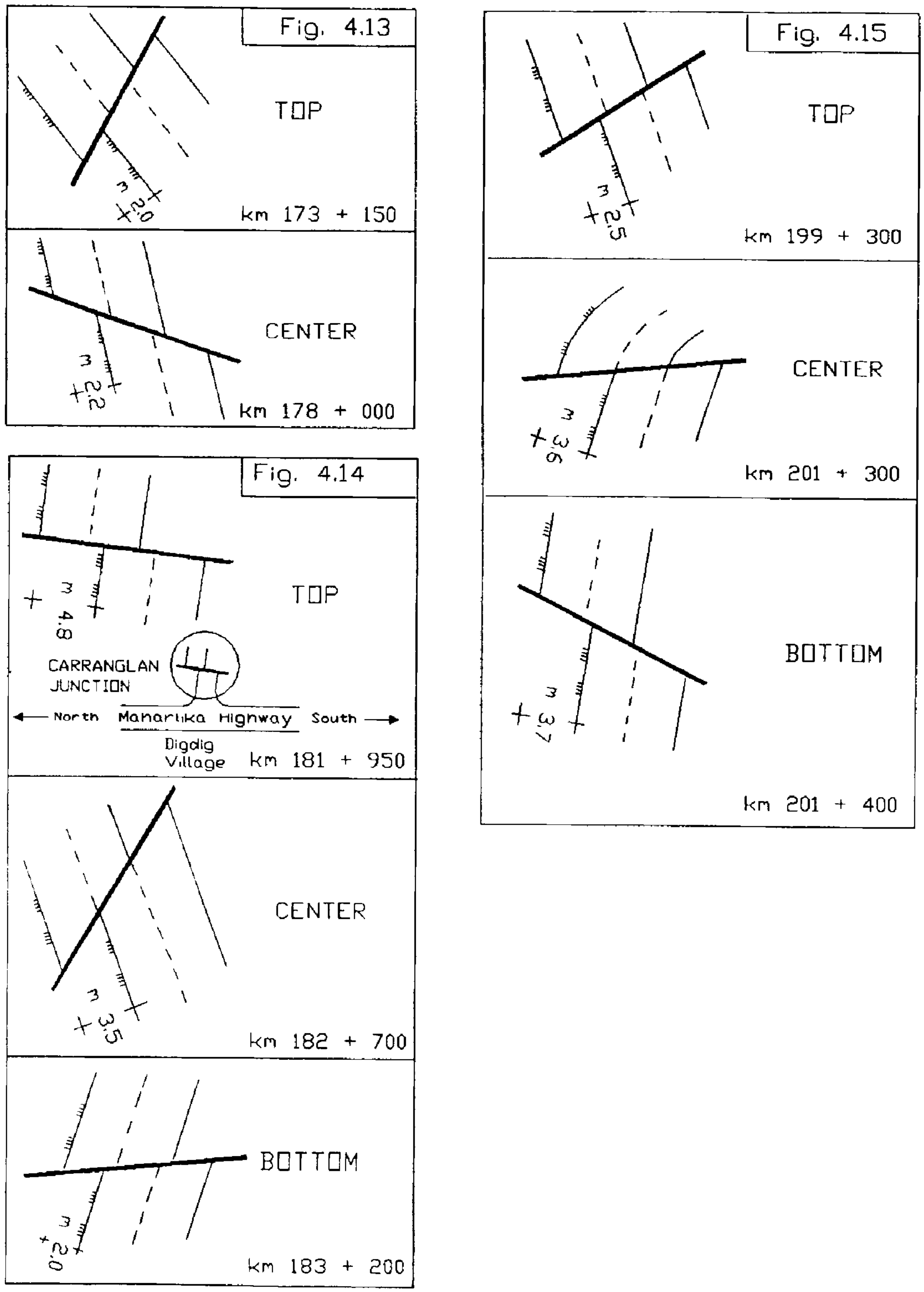


Fig. 4.12 – *Geometric sketches of the broken rigid pavement shown in Figures 4.13 through 4.15, due to the ground rupture (Dalton Pass road). The apparent horizontal slip is related to the margin of the cement concrete slabs.*

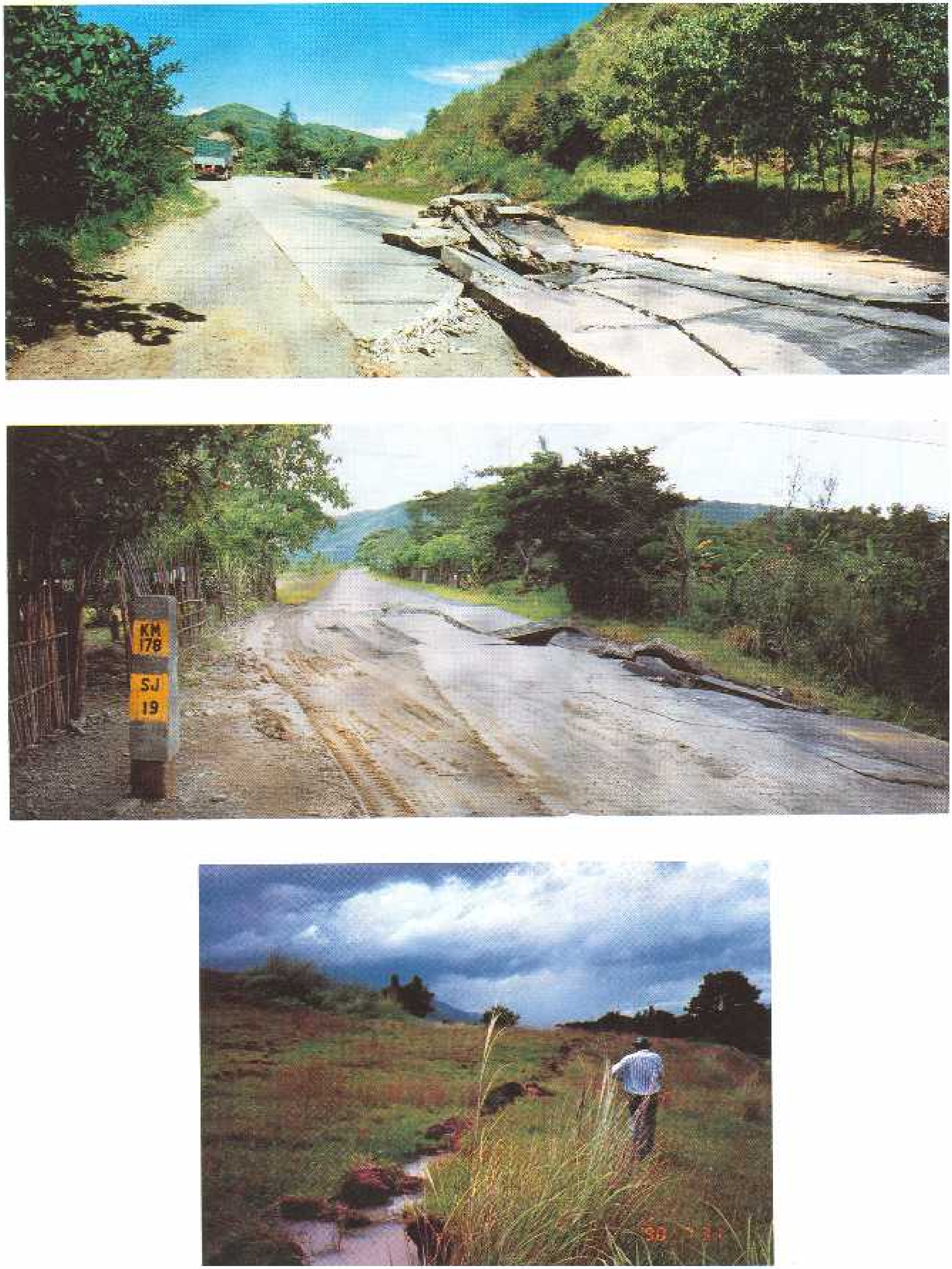


Fig. 4-13 – *Ground ruptures damaging the Dalton Pass road at km 173+150 (top), km 178+000 (center) and near km 180 (bottom). Courtesy of DPWH and Katahira.*

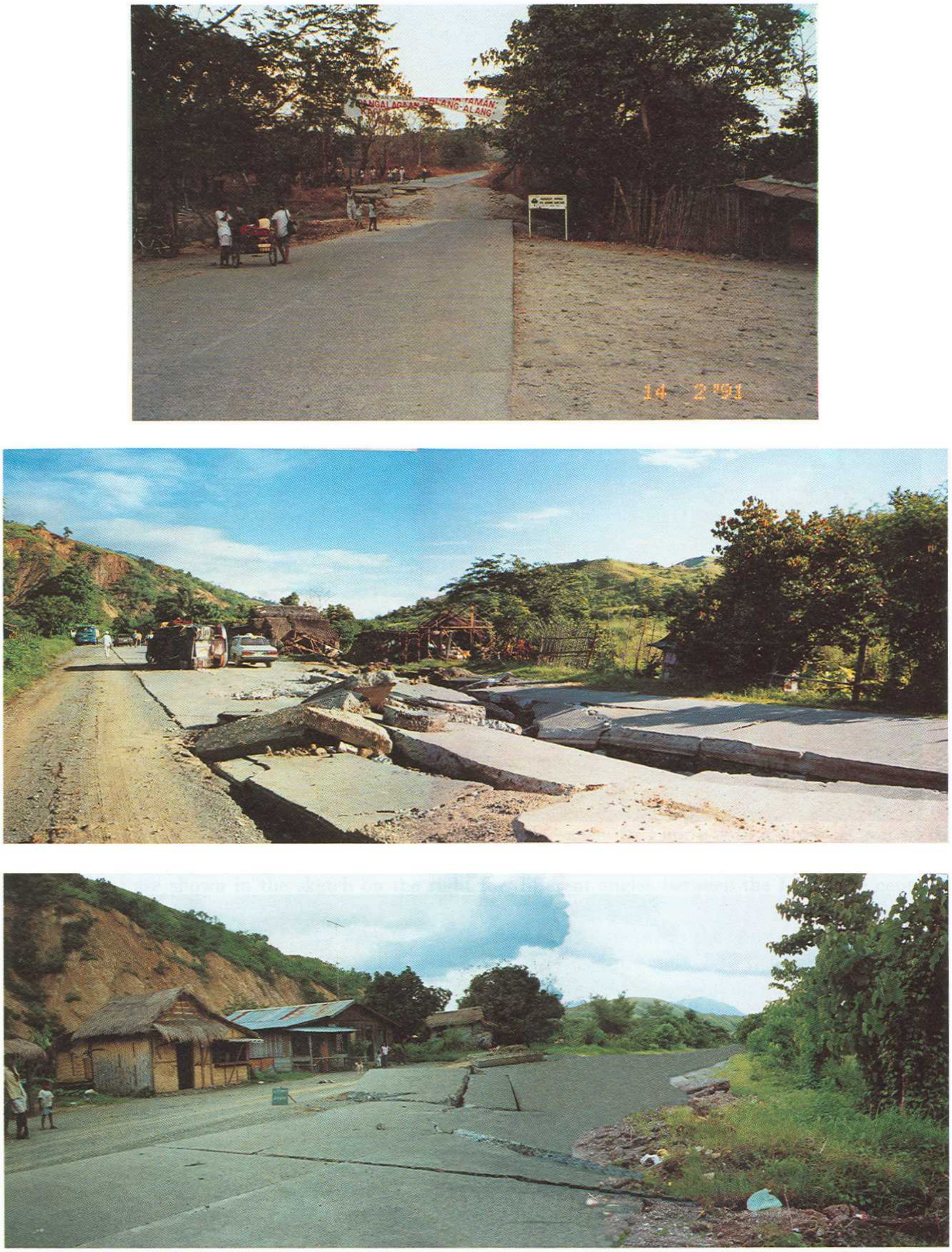


Fig. 4.14 – *Faulting in Digdig, at the junction for Carranglan village (km 181+950 of the Maharlika Highway), with 4.8 m horizontal and 1.5 m vertical displacements (top). Fault crossing the road at km 182+700 (center) and at km 183+200 (bottom). Courtesy of DPWH and Katahira.*