POPAYAN EARTHQUAKE OF 31 MARCH 1983
GEOLOGIC AND SEISMOLOGIC ASPECTS

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INTRODUCTION

This brief report summarizes the geologic and seismologic aspects of the Popayan earthquake, Department of Cauca, Colombia (Figure 1). The engineering aspects are presented in a separate article by Luis E. Garcia and Alberto Sarria, of the University of the Andes, Bogota. A comprehensive report is being prepared in Colombia by a team of Colombian scientists and engineers, and will be published there within the next few months, probably under the auspices of INGEOMINAS. The publication will be noted in the EERI Newsletter when it is completed; possibly it will be translated and published by the EERI.

This preliminary report is based on two visits to Popayan, where I worked with the Colombian team of seismologists, geologists, and engineers for 6 days as they made their assessment of the earthquake. Much of what I report is based on their work. I want to thank the team leaders, Paulo Lugari, Alberto Sarria, Francisco Zambrano, Abigail Orrego, Michael James, and Hasjergen Meyer, for their cooperation in sharing information and ideas about the earthquake. Their studies have been comprehensive: mapping of the intensity levels in the region, operation of a five-station micro-earthquake array for 4 to 5 weeks after the main event, geologic mapping of active faults in the region, magnetic and gravity profiles across the main regional faults, mapping of ground cracks and Quaternary deposits near Popayan, soils investigations in Popayan, including several borings, and structural engineering studies of the damaged buildings.

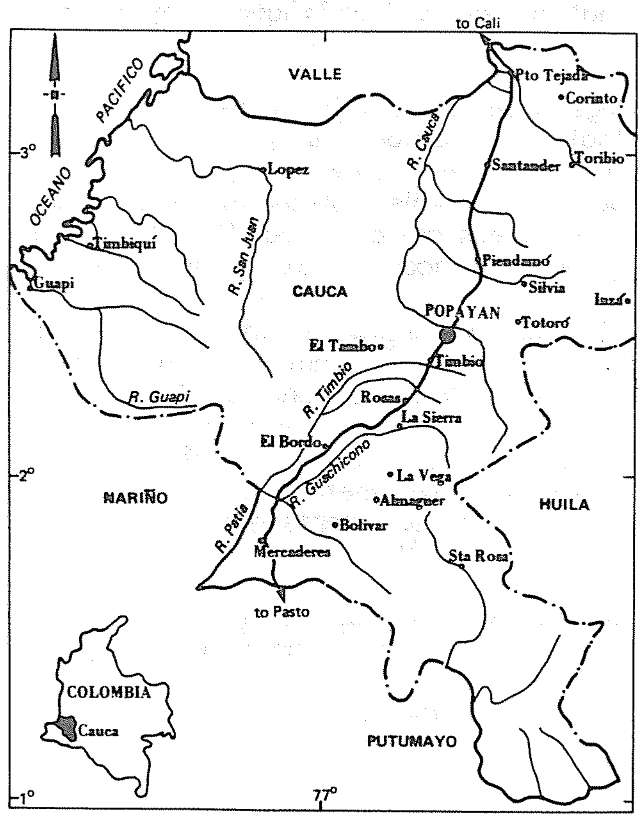


Figure 1. Location map

THE EARTHQUAKE

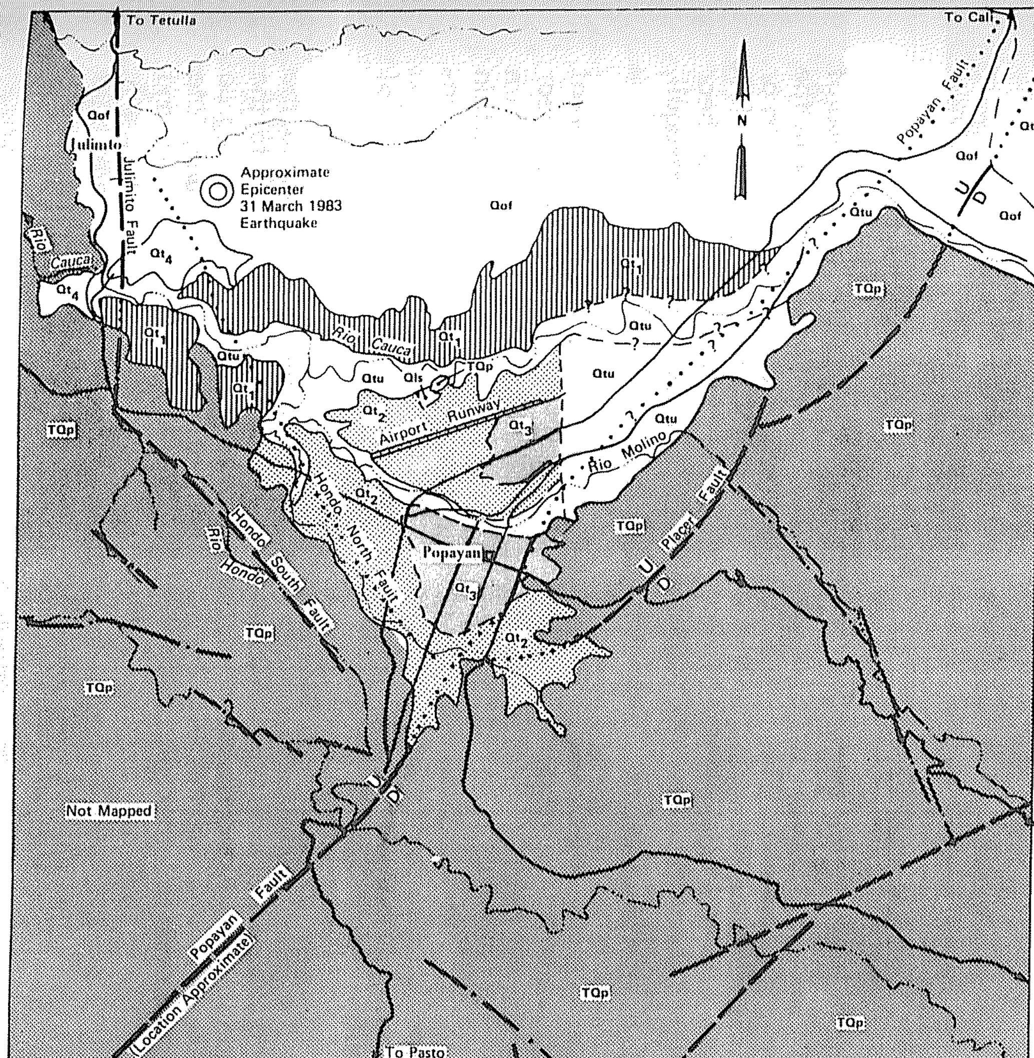
On 31 March 1983, at 13:12:51.4 Greenwich mean time (8:12 AM local time), an earthquake severely shook Popayan. The epicenter was 5 km northwest of Popayan and had a magnitude (M_B) of 5.5. Aftershocks were between 5 and 12 km deep, suggesting that the earthquake occurred at approximately 8 to 10 km depth (H. Meyer, 1983, oral communication). Even though the earthquake was small, more than 250 people were killed (many in an old church that partially collapsed), and damage to Popayan and towns in the region totaled approximately 400 million dollars. Residents report that the initial shock was vertical and very strong, knocking some people to the ground. This was followed by lateral movements both north-south and east-west.

The damage in the area around Popayan was mapped by Hans Meyer and his team of students. The isoseismal of intensity VII to VIII extended northeast, making a 25-km-long elipse from Popayan on the south, to Piendamo on the north.

The earthquake intensity in Popayan, according to Dr. Sarria, was VII to VIII, and locally IX to possibly X. Building damage was extensive, but not pervasive. The damage was concentrated in certain areas and much of the damage was to older, colonial homes of adobe bricks and thick mud-walls. Some newer buildings, one to several stories high, collapsed or partially collapsed. These generally were made with reinforced concrete columns and floors, and hollow-tile brick dividing walls. Many similar structures of both types survived without apparent damage, suggesting that the damage was influenced by the local geology.

Preliminary mapping of the Quaternary deposits and preliminary analysis of soil borings made by the soils engineers in Popayan for buildings throughout the city indicate that soil conditions partly controlled the damage. At least some of the newer structures that were badly damaged appear to have been built on poorly consolidated soils, particularly soils that contained significant organic layers from old swamp deposits. These areas are on a specific alluvial terrace unit, shown as Qt_2 on Figure 2. No liquefaction occurred during the earthquake.

The earthquake was accompanied by extensive surface cracking. Most cracks, as mapped by Michael James, are in the area north of Popayan in a north-trending zone at least 2 km wide and 2 1/2 km long. Tens of cracks have been mapped by INGEOMINAS in the airport runway (Figure 3), at the army base north of the runway (Figures 4 and 5), and in the streets between the airport and the city. Each of the cracks are a few meters to tens of meters long and are open as much as a few millimeters. Displacements generally are consistent: northeast side up a few millimeters, and left slip, also of a few millimeters. Heavy damage to the buildings at the army base, and possibly elsewhere, in part may have been due to cracking of the foundations and walls along these cracks. The cracks were probably caused by a combination of subsidence within alluvial deposits (unit Qt_2 on Figure 2), and propagation and dispersion of the displacement of the fault that is below the sediments in the basin at Popayan.



EXPLANATION

Road

River or stream

Contact; dashed where approximately located, querried where location is uncertain

Quaternary fault; dashed where approximately located, dotted where hidden, querried where location is uncertain

Lineament (possible fault)

Qls — Landslide

Qtu — Terrace and terrace deposit, undifferentiated. Includes alluvium from the present rivers

Qt1, Qt2, Qt3, Qt4 — Terrace and terrace deposit (generally debris flows) of the Rio Cauca. Deposits interfinger with locally derived stream deposits along margins (probably middle to late Quaternary in age)

Qof — Debris flow fan (lahar?) of the Rio Cauca; includes several different-age fans (probably middle Quaternary in age)

TQp — Popayan Formation – a thick sequence of lahars, ignimbrites, and volcanic ash (probably latest Miocene, Pliocene, and early Quaternary(?) in age)

NOTES:

1. Geology mapped from aerial photographs and some field reconnaissance
2. Base traced from aerial photographs of August 1961, numbers 6451, 6453, 6455 and 6466

0 — 3 — 6 km

Approximate Scale

Figure 2 GEOLOGIC MAP OF POPAYAN, COLOMBIA, AND VICINITY

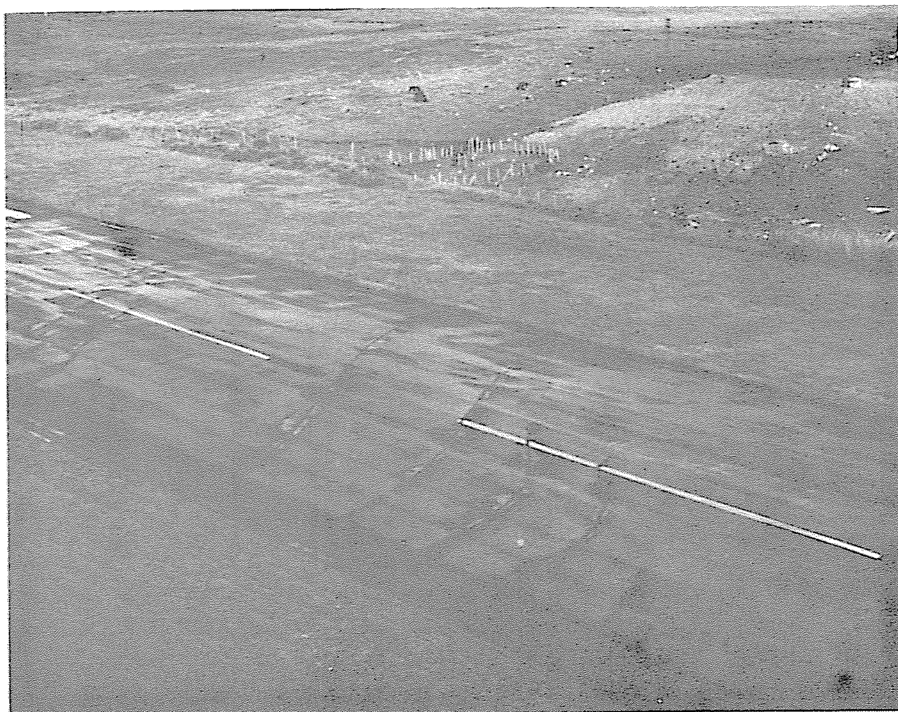


Figure 3. Cracks in the airport runway, Popayan

SEISMIC GEOLOGY

Southern Colombia is an active tectonic area (Figure 6) dominated by subduction of the Nazca plate below the South American plate. Earthquakes associated with the subduction have been common. The 31 March 1983 earthquake, however, was on or closely associated with the Romeral fault zone. This late Cenezoic fault zone follows an ancient subduction zone, Early Cretaceous in age, called the Dolores shear zone. The Dolores shear zone and the Romeral fault zone extend from Guayaquil, Equador, to Barranquilla, Colombia, more than 1500 km.

Popayan is located along the Romeral fault zone. This fault has many different branches that are capable of generating earthquakes in the region. Two are near Popayan: the Popayan fault is beneath the city, and the Placer fault is 1/2 to 2 km east of Popayan. A cross-fault, called the Julimito-Hondo North fault, passes within 1 km of the southern margin of the city and is very close to the earthquake epicenter, located near Julimito by Hans Meyer. The earthquake could have occurred on the Julimito-Hondo North fault, on the Popayan fault, or on another buried branch of the Romeral fault.

Several branches of the Romeral fault zone were known to be active prior to the Popayan earthquake. Studies done by Woodward-Clyde Consultants (WCC) to the north, near Medellin, concluded that the Romeral fault has a low to moderate degree of activity. The evidence for this activity includes faulted debris-flow fans, late Quaternary in age, and microseismic activity. In the areas near Armenia and Manizales, the Romeral fault displaces Quaternary volcanic lahar deposits. A magnitude 6 1/4 earthquake less than 30 km deep occurred 30 km west of Manizales on 8 September 1935, and may have been on the Romeral fault. To the north, near Sincelejo, close to the Caribbean Coast, the fault displaces Pliocene to early

Figure 4. Crack in the street at the army base, Popayan. The water pipe below the street, where the hole is located, was ruptured.

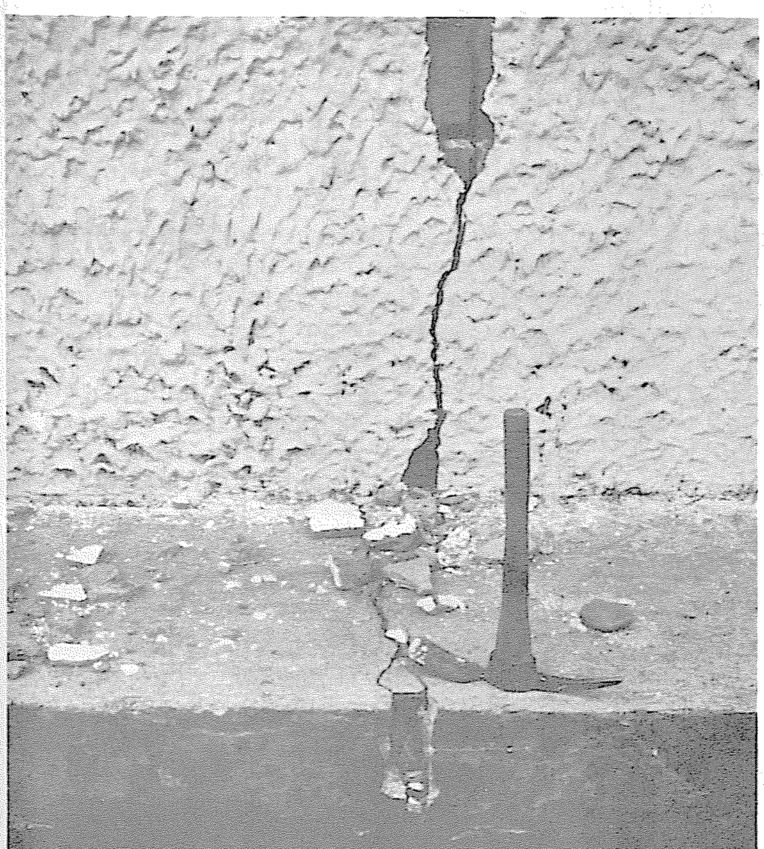
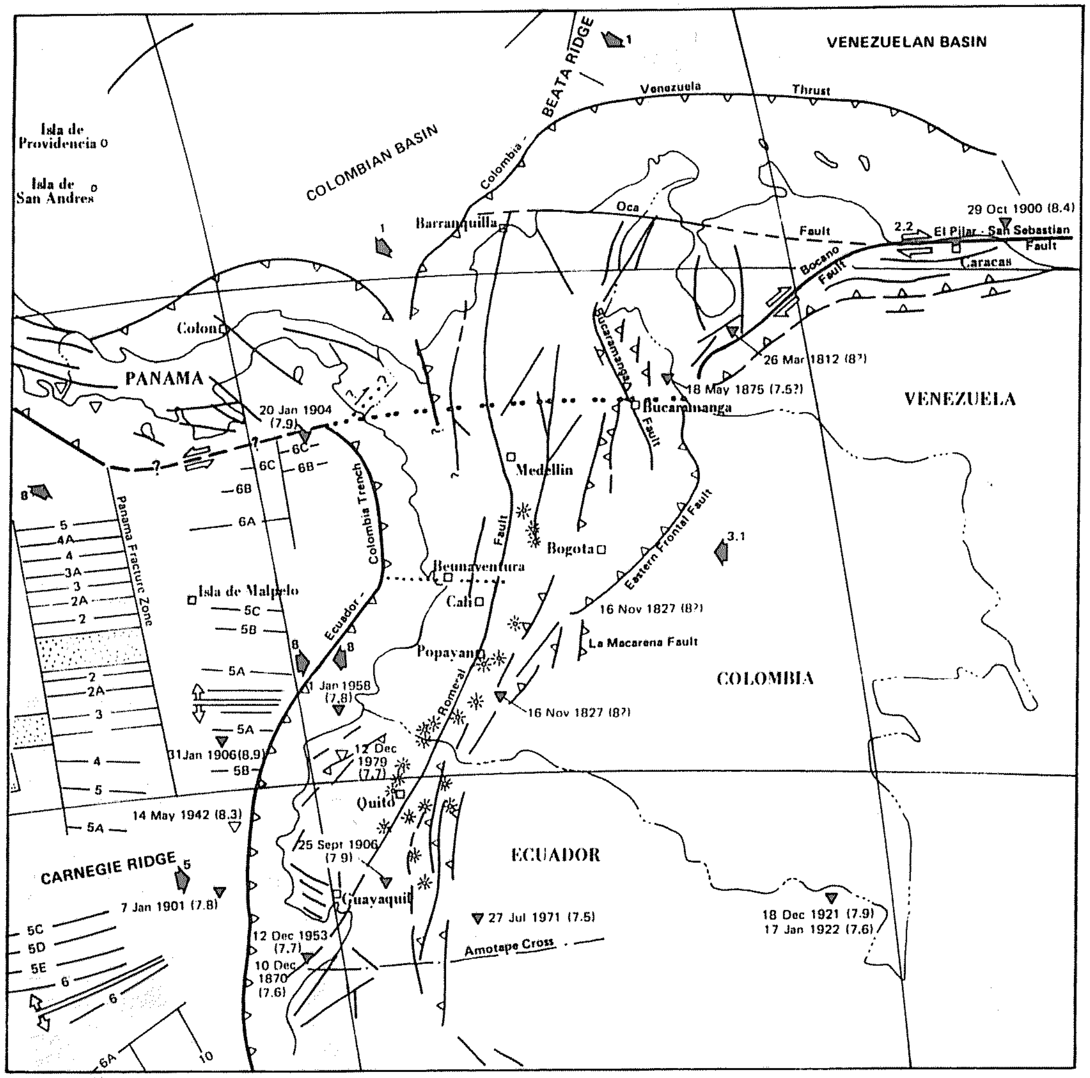


Figure 5. Crack in cement foundation and brick wall of house at the army base, Popayan.



EXPLANATION

Active spreading ridge. Pattern shows oceanic crust formed during past 1 million years.

Active transform fault, generally the principal fault. Arbitrarily drawn where boundary is covered by uncoupled crustal slabs; dashed where approximately located.

Subduction zone. The surface trace of a Benioff seismic zone; barbs on upper plate; dashed where approximately located.

Discontinuity in subduction.

Northern limit of subduction of Nazca plate below South American plate.

Relative plate motion in cm/yr at strike slip, converging, and diverging plate boundaries, chiefly after the model of Minster and Jordan (1978).

Absolute plate motion in cm/yr, chiefly after Minster and Jordan (1978).

06 May 1953 (7.6) — Earthquake epicenter (M_S 7.5 and greater).

Active volcano (historical and Holocene).

Magnetic Lineations — Magnetic anomalies. Numbers refer to correlations to geomagnetic polarity time scale.

Inactive spreading ridge.

Major intraplate fault, arrows show direction of displacement. barbs are on upper plate of thrust faults. Faults shown in Colombia are those having Pliocene and Quaternary displacements. Faults in adjacent countries are these having post-Triassic displacements (after Drummond, 1981).

NOTE: Map modified from Drummond and others (1981).

0 250 500 km

Figure 6 TECTONIC MAP OF COLOMBIA

Quaternary deposits. The 26 December 1942 earthquake, located near Sincelejo, was of magnitude 6.5 (MM VIII) at a shallow depth (33 km), and may have occurred on the Romeral fault. Near Cali and Palmira, the Romeral fault is a steep reverse to thrust fault that displaces late Quaternary debris-flow fans. Trenching of these fans by WCC and Integral-Planes in 1982 and early 1983 revealed the faults and showed that the vertical displacement was a few meters to several tens of meters. In the Popayan area, Orrego and Marin[1] suggested that the displacements on the Pan American Highway in the Timbio area, 25 km southwest of Popayan, were tectonic in origin. Similarly, in 1982, Woodward-Clyde, in their studies of the Romeral fault with Integral-Planes, found evidence of Quaternary displacement of as much as 500 m, east side up, in the Popayan Formation (Pliocene to early Quaternary in age). The faulting extends from Rosas and Popayan on the south, to Piendamo and Puerto Tejada on the north.

After the Popayan earthquake, when the Popayan area was examined in detail to locate specific active faults, the Placer, Popayan and Julimito-Hondo North faults were discovered (Figure 2). Other branches of the Romeral fault are present east of the mapped area and through the town of Silvia. Faulting of the Popayan Formation by a secondary fault of the Placer fault was found west of Popayan (Figure 7). The displacements in the surface of the Popayan Formation are evident when they are of a few tens of meters (Figure 8); near Piendamo the displacement is approximately 500 m. At Popayan, the Popayan fault and the Julimito-Hondo North fault displace the Popayan Formation down to the north and west an unknown amount, forming the alluvium-filled depositional basin at Popayan. In addition, the Rio Cauca alluvial and debris-flow fans, which are middle to late Quaternary in age, are faulted and warped where they overlie the Placer and Julimito-Hondo North faults. The Rio Cauca fan deposits over the Placer fault are faulted and warped approximately 10 m, east side down. The same deposits over the Julimito fault are also displaced approximately 10 m, north side down.

OTHER EARTHQUAKES

Many earthquakes have affected Popayan. The most devastating, as summarized by Ramirez[2], occurred in 1560, 1736, 1827, 1906 and 1979. The 1906 and 1979 earthquakes were large events that occurred off the coast of Colombia, on the subduction zone. The 1560 and 1736 events may also have been subduction-zone events offshore, but intensity reports are too sketchy to tell (T. Turcotte, 1983, oral communication). The 1827 event caused extensive damage throughout southern Colombia, and was followed by a series of earthquakes felt in Popayan until 1841. This earthquake was probably deep, and was clearly inland from the coast. The historical record suggests that local, shallow earthquakes have occurred near Popayan prior to the 1983 event, but the information to date is insufficient to determine.

1 Orrego, A., and Marin, P., 1981, Problemas geologicos de la carretera panamexicana en el tramo Timbio-Rosas y alrededores de la sierra, departamento del Canea: Revista CIAF, Bogota, v. 6, no. 1-3, p. 373-390.

2 Ramirez, J.E., 1975, Historia de los terremotos en Colombia: second edition, Instituto Geografico Agustin Cadazzi, Bogota, 250 p.

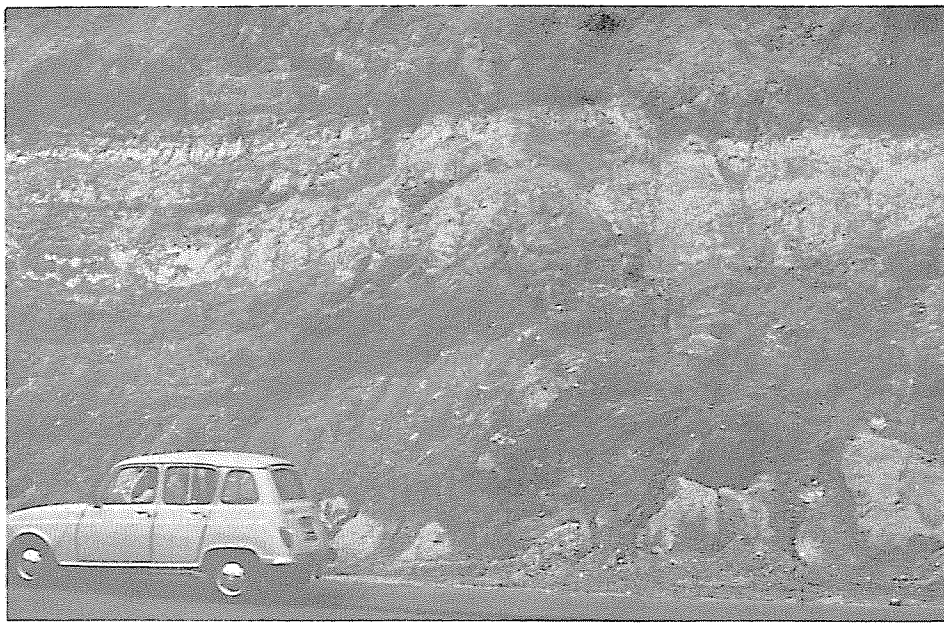


Figure 7. Secondary fault of the Placer fault displacing volcanic units in the Popayan Formation. The photograph was taken on the road to Purace, east of Popayan.

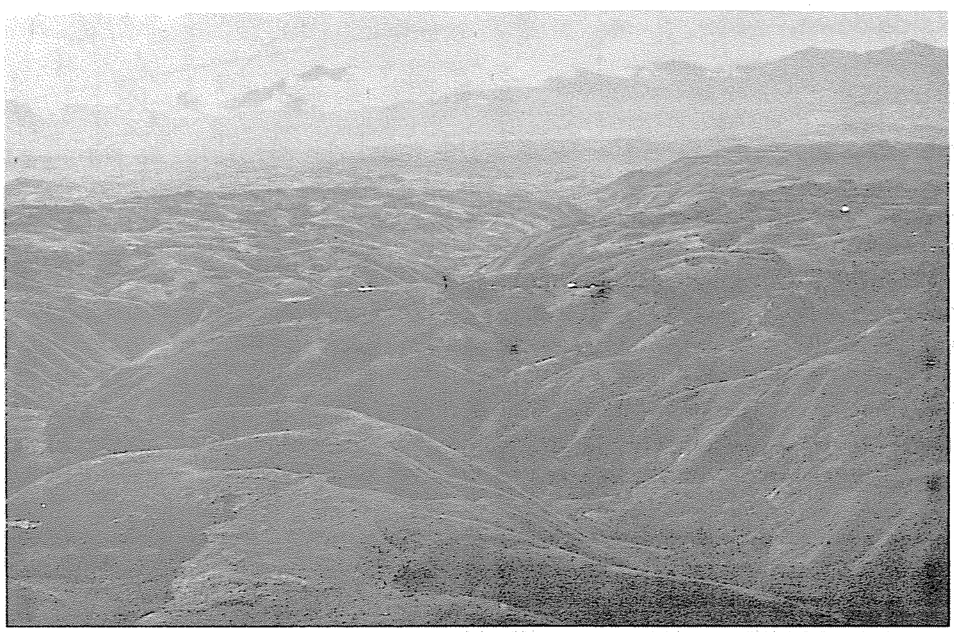


Figure 8. Fault (middle distance) that displaces the surface of the Popayan Formation south of Popayan.

CONCLUSIONS

Popayan is built over the Popayan and Placer faults, branches of the Romeral fault. Because the Romeral fault is known to be active along much of its length, the 1983 Popayan earthquake, M_B 5.5 at a depth of 8 to 10 km, was not a surprise. Such an earthquake (or larger) could occur anywhere along the Romeral fault. The effects of the earthquake were typical of those that are found following earthquakes close to major population centers where earthquake resistance was not considered in the design of structures.

No liquefaction or surface faulting was evident from the event. The wide zone of ground cracking that occurred during the earthquake is believed to be due to subsidence in a particular alluvial unit, and possibly was related to fault displacement at depth below the alluvial units. The most damage to modern buildings also occurred on the same alluvial terrace.