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The Great Tumaco, Colombia Earthquake of 12 December 1979

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Summary. Southwestern Colombia and northern Ecuador were shaken by a shallow-focus earthquake on 12 December 1979. The magnitude 8 shock, located near Tumaco, Colombia, was the largest in northwestern South America since 1942 and had been forecast to fill a seismic gap. Thrust faulting occurred on a 280- by 130-kilometer rectangular patch of a subduction zone that dips east beneath the Pacific coast of Colombia. A 200-kilometer stretch of the coast tectonically subsided as much as 1.6 meters; uplift occurred offshore on the continental slope. A tsunami swept inland immediately after the earthquake. Ground shaking (intensity VI to IX) caused many buildings to collapse and generated liquefaction in sand fills and in Holocene beach, lagoonal, and fluvial deposits.

At approximately 3 a.m. (7:59:04.3 coordinated universal time) on 12 December 1979, Colombia and Ecuador were shaken by a major earthquake located just offshore and southwest of Tumaco, Colombia. The shock, approximately magnitude 8, was the largest in that part of South America since 1942. The earthquake had been forecast to fill a seismic gap. Tectonic movement of the Pacific Ocean floor triggered a tsunami that raked part of the adjoining Colombian coast. A 200-kilometer stretch of the coast between Tumaco and Buenaventura, Colombia, subsided; uplift occurred offshore on the continental slope. Ground shaking collapsed or seriously damaged hundreds of buildings and caused extensive liquefaction and ground failure in coastal southwestern Colombia.

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The Earthquake

The 12 December earthquake occurred offshore approximately 80 km southwest of Tumaco (Fig. 1). It was a shallow-focus shock (assigned depth of 33 km) with a surface wave magnitude (M_s) of 7.9 (National Earthquake Information Service) to 8.1 (Instituto Geofísico, Bogotá) and was located on the continental shelf, landward of the Colombia trench. Ocean crust of the Nazca plate (the eastern Pacific Ocean floor), which is being obliquely subducted at the trench, is underthrusting the continent at a rate of approximately 90 millimeters per year (*1*). Progressively deeper earthquakes in the subduction zone define a segment of oceanic lithosphere going down beneath Tumaco and dipping 35° toward S60°E (*2*). The P wave radiation pattern and locations of aftershocks (body wave magnitudes of 4 to 6) recorded within 27 days of the earthquake indicate that thrust faulting occurred on a roughly rectangular patch (280 by 130 km) of the subduction zone. The patch lies offshore and extends northeast from the main shock near the Ecuadorian border to Isla Gorgona (Fig. 1). One P-wave nodal plane of the focal mechanism strikes N28°E and dips 60°NW. This plane is quite well constrained by the radiation pattern of the P waves. The second plane dips gently to the southeast. First motions of P waves limit the strike of this plane to between N4°W and N52°E. This nodal plane probably corresponds to the fault plane of the earthquake along which the Nazca plate is underthrusting coastal Colombia. Rupture propagation (the direction of rupture along the fault plane) was apparently unilateral to the northeast: the epicenter of the main shock lies at the southwest end of the aftershock zone.

Residents of Tumaco, El Charco, and other coastal villages reported several distinct, closely spaced episodes of ground shaking, suggesting a succession of large shocks as the earthquake proceeded. Seismograms of the earthquake are contaminated by a succession of overlapping P and S wave arrivals.

Seismic Gap

The Tumaco earthquake was forecast by Kelleher in 1972 (*3*). The earthquake rupture largely filled a gap in the shallow seismic zone of northern Ecuador and southwestern Colombia where no sizable earthquakes had occurred since a magnitude 8.7 earthquake struck on 31 January 1906. Kelleher noted that a series of large shallow-focus earthquakes were progressing northward along the Ecuador-Colombia coastline, rebreaking the presumed rupture area of the 1906 earthquake (Fig. 2). In 1942, a magnitude 7.9 earthquake occurred near Esmeraldas, Ecuador. In 1958, a magnitude 7.8 earthquake occurred farther north near the Ecuador-Colombia border. These two rupture zones abut each other; Kelleher concluded that the direction of rupture during each large earthquake was probably toward the north or northeast. A considerable area northeast of the 1958 zone, which apparently ruptured during the 1906 event, was not affected by the earthquakes of 1942 and 1958. This is the area that Kelleher considered to be a "region of relatively high earthquake risk." His forecast proved correct. The

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12 December Tumaco earthquake ruptured most of that gap, breaking northeastward from the terminus of the 1958 rupture zone.

Tsunami

Minutes after the 12 December earthquake, part of the Pacific coastline of Colombia was swept by a tsunami that almost destroyed San Juan, 60 km north of Tumaco (see cover photograph). The tsunami crashed into the small village, overtopping the barrier island on which it stood. Waves swept houses inland, casting several into a lagoon behind the island. At least 220 people, mostly children, were killed. The tsunami blasted through the first floor of the two-story colegio, ripping the infilled walls from the frame. The wave strewed concrete blocks, desks, and other debris across the playing field behind the school. A pile of trees and wreckage and a zone of withered leaves and grass killed by salt water outlined high splash marks north and south of San Juan. Eyewitnesses report that the sea withdrew minutes after the earthquake, returning 10 to 15 minutes later in a succession of three to four waves. The highest wave rose nearly 2.5 meters above the former high-tide position, flooding part of the village with more than 2 meters of water.

The tsunami reportedly damaged other fishing villages near San Juan and destroyed the pier at Isla Gorgona. Elsewhere tsunami damage was less. At Tumaco, waves lifted several ships from their moorings and carried them several hundred meters inland up the river channel. The northern coastline of Tumaco was locally inundated, shallowly flooding a number of houses. The highest wave rose only about 0.8 m above the former high-tide position. Residents report that the sea withdrew immediately after the earthquake, just as it did at San Juan, before the arrival of the first wave. Continued seismic sea-wave activity was observed in Tumaco harbor until about noon. Newspaper reports that El Charco and Iscuandé were flooded by tsunami-dammed coastal rivers were false. Tsunami damage undoubtedly would have been greater had the waves not arrived at lowest tide. The December 1979 tidal range for southwestern Colombia was approximately 1.3 m.

The tsunami appears to have been caused by movement of a large area of the continental shelf and slope encompassing the epicenter of the main shock northeast of Esmeraldas. A wave recession was the first seismic sea-wave activity observed at Esmeraldas, about 75 km south of the epicenter, only 5 to 6 minutes after the earthquake (*4*). A positive first wave reached the tidal gauge at Buenaventura, Colombia, nearly 370 km northeast of the epicenter, at 4:38 a.m., 1

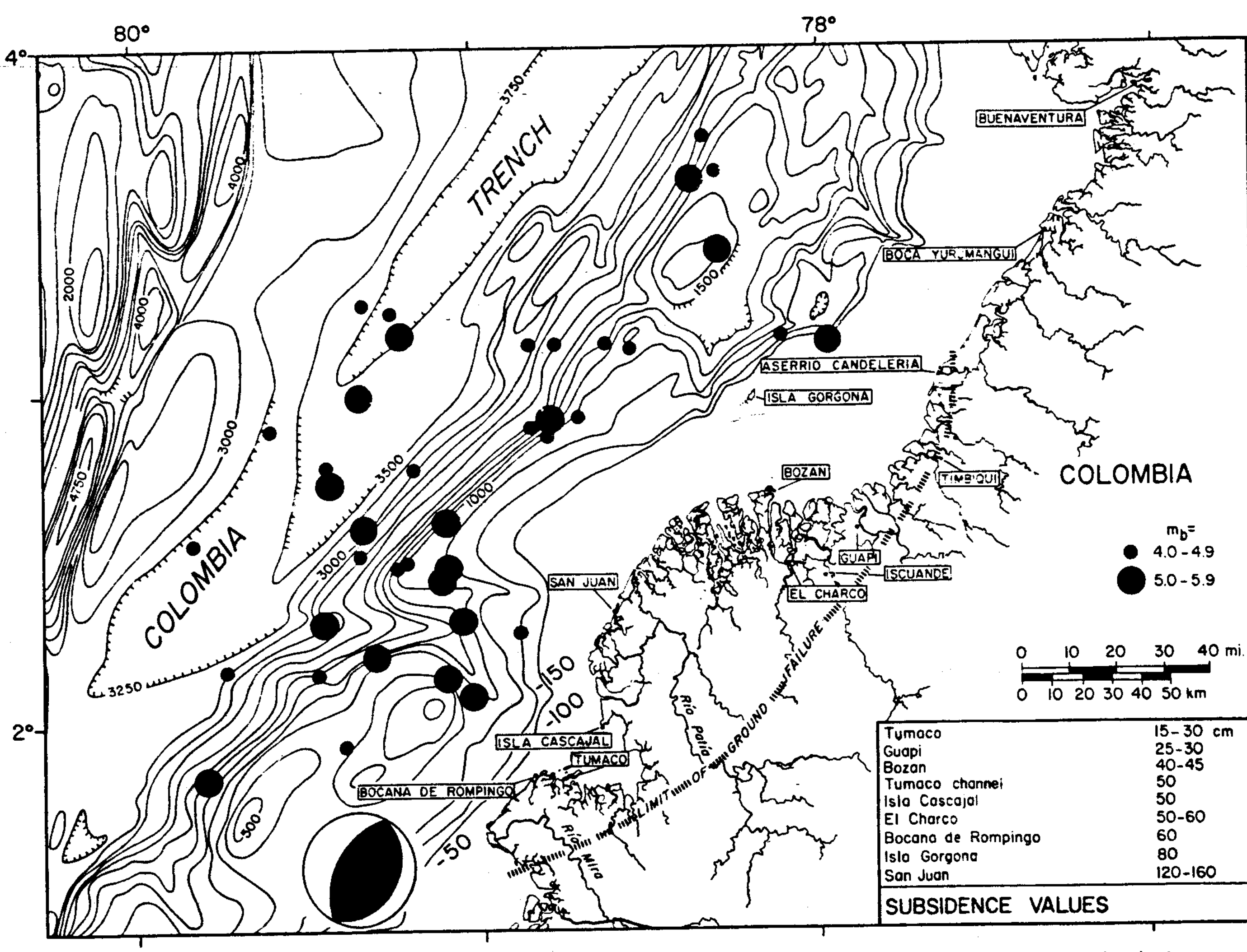

Fig. 1. Location of the 12 December 1979 Tumaco earthquake and its aftershocks (see Table 1). The preferred focal mechanism is shown at the epicentral location for the main shock. Coastal areas adjoining the aftershock zone were tectonically depressed (shaded contours) as much as 1.6 m. Subsidence values for specific localities are given in the inset. Ground shaking caused liquefaction and ground failure as far as 50 km inland shown by approximate limit of ground failure sketched on the map. Bathymetry (in meters) after Lonsdale and Klitgord (*11*). Abbreviation: m_b = body wave magnitude.

hour and 39 minutes after the main shock. (The tsunami arrival was not recorded at Tumaco, because the tidal gauge was destroyed by earthquake shaking.) Miyabe's inverse-refraction method (5) was used to trace the two wave fronts backward from the coast to their sources. The tsunami source area appears to have been at least 120 km in length. The Esmeraldas wave recession probably traveled no more than 10 to 20 km. The positive Buenaventura wave could have originated at the edge of the continental shelf west of San Juan, 300 km southwest of Buenaventura.

Crustal Uplift and Subsidence

Tsunamis accompanying subduction-zone earthquakes generally result from sudden thrust upheaval or subsidence of the continental shelf and slope. The source areas of these tsunamis roughly correspond to the areas of crustal deformation (6). The continental margin is thrust seaward and uplifted, with elastic horizontal extension and subsidence behind (7). Tsunami waves with an initial downward (recession) motion are radiated from a subsided region of the sea bottom; conversely, waves with an initial upward (positive) motion are radiated from an uplifted region (6). During the Alaskan earthquake of 1964 (M_s 8.4) and the Chilean earthquake of 1960 (M_s 8.3), the continental margins of the two subduction zones subsided nearly 2 m in broad asymmetric downwarps (7). Elongate and parallel to nearby trenches, these downwarps were flanked by zones of marked uplift (as much as 12 m) at the edge of the trenches. Minor and possibly localized uplift occurred on the landward side.

During the Tumaco earthquake, the length of the Pacific coast of Colombia from the Ecuadorian border north to at least Guapi subsided as much as 1.6 m (Fig. 1). An unknown amount of uplift occurred offshore on the edge of the continental shelf.

Subsidence. Coastal areas of southwestern Colombia adjacent to the presumed area of faulting (the aftershock zone) tectonically subsided as much as 1.6 m, causing an apparent sea-level rise along at least a 200-km stretch of the Colombian coastline north of the Ecuadorian border (Fig. 1). Trees and shrubs were drowned, and several coastal villages now flood locally. Rows of palm trees planted above high tide are partly submerged. Fresh water grasses and shrubs near the beach have been poisoned by rising salt water. Numerous playas, formerly dry at high tide, are now continually underwater. Streets and houses in San Juan, which subsided about 1.2 to 1.6 m, are inundated by more than a meter of water at high tide. Cattle corrals near the mouth of the Río Patía were ripped apart by the advancing surf. Sectors of Tumaco, which sank about 0.15 to 0.30 m, are now shallowly flooded by extremely high tides. An 0.8-m rise of sea level at Isla Gorgona has permanently flooded a mud flat between that island and a nearby rock, Gorgonilla.

Subsidence apparently occurred largely at the time of the earthquake. Observers report that sea-level changes were first noted with the high tide after the earthquake. In the dark of the morning of 12 December the profound subsidence of San Juan and neighboring areas went unnoticed until the arrival of the tsunami. Had the island not subsided, the highest wave would have risen only 0.9 m above the former high-tide position. Gradual submergence may have occurred over much of the region affected by the Tumaco earthquake before it struck. The first line of trees along most of the Colombian coast from at least Boca Yurumanguí (southwest of Buenaventura) south to the Ecuadorian border is dead or dying. Many tree trunks stand well out from the shore, partly submerged. The trees have lost most of their leaves, appearing to have died some months before the earthquake. The trees may have been killed by erosion of the coast by waves or

Table 1. Preliminary hypocenters of the Tumaco, Colombia earthquake and its aftershocks determined by the National Earthquake Information Service, U.S. Geological Survey, through 7 January 1980. All depths held at 33 km.

Day	Origin time	Latitude	Longitude	Magnitude m_b	Magnitude M_s
		December 1979			
12	7:59:04.3	1.584°N	79.386°W	6.4	7.9
12	8:14:52.3	2.596°N	79.317°W	5.5	
12	8:32:05.4	2.426°N	79.081°W	5.3	
12	11:53:48.9	2.309°N	79.435°W	5.3	
12	12:3:45.2	1.501°N	79.450°W	4.9	
13	2:1:36.5	3.224°N	79.219°W	4.8	
13	4:46:45.8	2.137°N	79.075°W	5.2	
13	5:37:47.4	2.601°N	79.326°W	4.9	5.9
13	13:16:53.0	2.995°N	79.322°W	5.0	
13	17:53:10.2	1.946°N	79.385°W	4.2	
13	22:40:30.7	1.846°N	79.792°W	5.0	
14	6:14:11.7	2.465°N	79.062°W	5.0	
14	6:16:06.2	2.617°N	79.074°W	5.2	
14	7:13:33.8	2.490°N	79.188°W	4.6	
14	8:42:23.6	2.776°N	79.421°W	4.8	
15	3:51:42.1	3.142°N	78.760°W	4.4	
15	10:55:31.3	2.170°N	79.723°W	4.3	
15	15:23:32.7	3.164°N	79.191°W	5.2	
15	20:1:50.5	2.886°N	78.820°W	4.8	
15	20:26:22.8	2.724°N	79.403°W	5.1	4.7
15	20:37:17.9	3.141°N	78.606°W	4.9	
16	8:17:23.3	3.113°N	78.543°W		
17	2:16:47.4	3.632°N	78.275°W	4.7	
17	6:10:48.2	2.860°N	78.772°W		
17	10;58:09.6	2.479°N	79.208°W		
18	7:46:51.9	2.768°N	79.153°W	4.9	
18	8:43:16.3	2.542°N	79.816°W	4.5	
20	2:8:34.0	3.156°N	78.092°W	4.6	
21	1:49:17.2	2.270°N	78.867°W	4.5	
21	19:43:32.7	3.127°N	78.818°W		
21	23:2:14.0	3.131°N	77.940°W	5.0	
23	8:47:21.1	3.409°N	78.272°W	5.0	
24	12:46:04.8	2.302°N	79.030°W	5.1	5.3
25	14:55:58.2	2.157°N	79.453°W	4.9	
28	15:6:59.5	3.746°N	78.306°W	4.8	
29	22:8:03.6	2.207°N	79.276°W	5.0	
31	11:58:39.3	3.615°N	78.360°W	5.1	
31	23:07:23.5	2.095°N	79.015°W	5.3	5.5
		January 1980			
2	19:4:02.9	2.881°N	79.599°W	4.9	
3	3:37:18.8	3.249°N	79.308°W	4.5	
6	4:0:14.3	2.909°N	78.689°W	4.6	
7	0:33:37.5	2.921°N	78.775°W	5.1	4.6

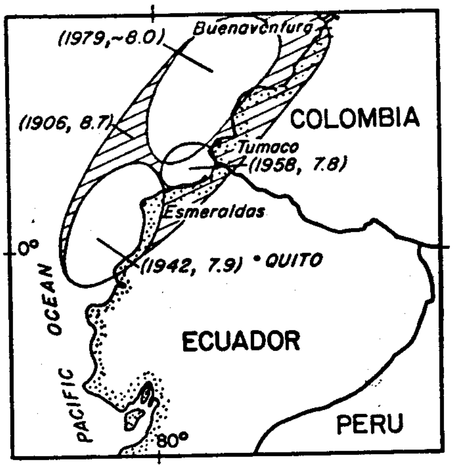

Fig. 2. Estimated rupture zones of large earthquakes during this century in northwestern South America (3). The 1906 rupture was reconstructed largely from intensity reports, and the 1942, 1958, and 1979 ruptures from aftershock zones. Note that the 1942 and 1958 zones abut closely without significant overlap. The main shock of the 1979 Tumaco earthquake lies within the aftershock zone of the 1958 earthquake. Magnitudes (M_s) of pre-1979 shocks after Geller and Kanamori (12) and Kanamori (13).

drowned because of regional coastal subsidence before the earthquake. Much evidence favors coastal subsidence. First, the kill appears to have been areally simultaneous and certainly occurred no earlier than 1966 since aerial photographs reveal no dead trees at the coast between 1961 and 1966. Second, similar shoreline submergence occurred before the Alaskan earthquake of 1964 and the Chilean earthquake of 1960 (7). Radiocarbon-dated terrestrial plants killed by transgression of the sea in Alaska indicate that submergence of part of the earthquake-affected region took place at a rate that averaged roughly 6 mm per year for about 930 years. The probable cause was diastrophic downbuckling or downwarping of the continental margin atop the subducting oceanic plate.

Geologically, the entire Pacific coast from Buenaventura south to Esmeraldas appears to have been subsiding throughout the Holocene and late Pleistocene. No elevated marine terraces are exposed along this stretch of coast although terraces are present to the north and south (8). Low, broad alluvial plains, meandering rivers, barrier islands, and lagoons form the coastline. Low hills of Tertiary sediments near the coast appear to be partly submerged in late Quaternary alluvium. Tributaries on the southwest side of the Río Patía northeast of Tumaco are drowned. Lakes formed in the courses of the streams open directly into the Río Patía and are apparently impounded by regional shallowing of stream gradients.

Uplift. An unknown amount of uplift must have occurred offshore on the edge of the continental shelf. Initial tsunami wave recessions, radiated from subsided areas, were observed at Esmeraldas, Tumaco, and San Juan. However, a positive wave reached Buenaventura first. That wave originated at an uplifted region of the sea bottom. The area of uplift must be landward of the Colombia trench, but west of Isla Gorgona and the subsided coast.

Intensity

An areal earthquake intensity survey (the first in Colombia) was made after the Tumaco earthquake, and residents were canvassed by a mailing of the revised U.S. Geological Survey earthquake questionnaire. Zones of obvious damage were visited: news reports were culled for descriptions of ground-shaking effects. With 30 percent of the questionnaires returned, it appears that the Tumaco earthquake strongly shook much of southwestern Colombia and northern Ecuador (Fig. 3). The earthquake was felt as far away as Santa Marta, Bucaramanga, and Carimagua, Colombia. Near the coast, intensities of IX (modified Mercalli scale) were felt at the mouth of the Río Patía and in El Charco and Tumaco. An intensity of VII was sustained as far eastward as the foot of the Cordillera Occidental. In the western mountains, intensities were generally VI to VII. Several towns in the mountains (for example, Sotomayor and Sandoná) reported exceptionally high damage (intensities VII to VIII), perhaps due to local topographic amplification. El Charco, a river town approximately 170 km northeast of the main shock, was hardest hit (intensity VIII to IX). Almost 90 percent of the town's buildings were damaged or destroyed; many wood-frame buildings were tilted and twisted. Ground shaking there may have been intensified by the sawdust fill on which the town is reportedly constructed. At Iscuandé and Guapi, only 10 and 26 km away, respectively, shaking intensities reported were only VII. In Tumaco, the largest city near the epicenter, many reinforced-concrete and wood-frame buildings built on fill along the margin of the

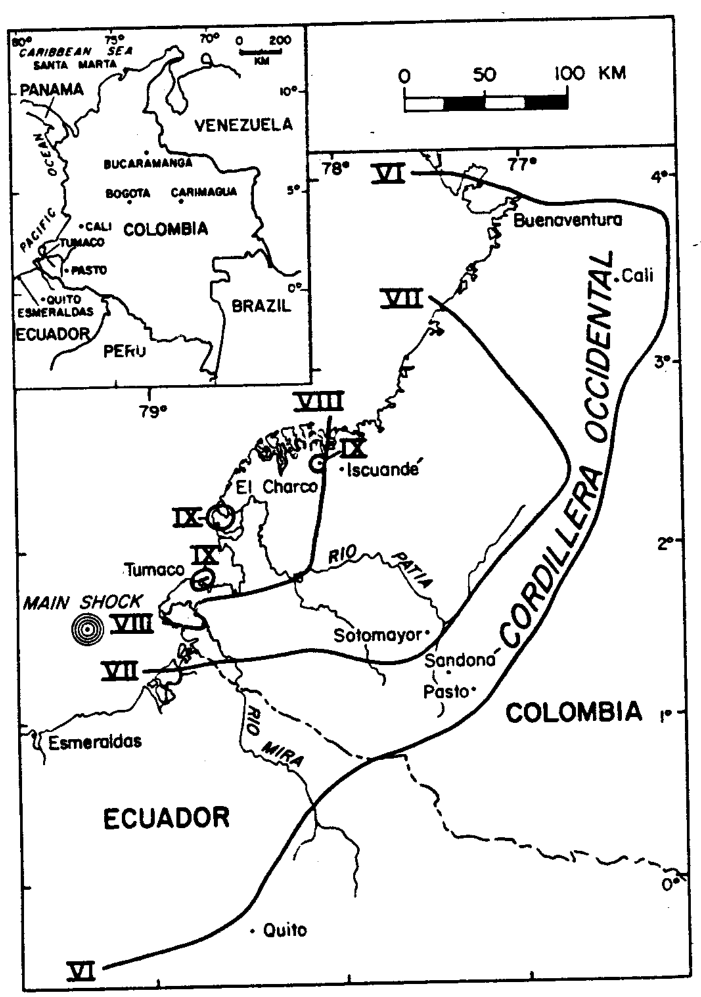

Fig. 3. Preliminary intensity (modified Mercalli scale) map of 12 December 1979 Tumaco earthquake. The earthquake strongly shook southwestern Colombia and northern Ecuador, damaging buildings as far east as the Cordillera Occidental, the westernmost range of the Colombian Andes.

island city, including the four-story Hotel Americano, were seriously damaged by ground shaking or by ground failure (intensities VII to IX). Few buildings in Tumaco's interior suffered structural damage (intensities VII to VIII).

Liquefaction and Ground Failure

Seismic shaking generated soil liquefaction (the transformation of a granular soil to a liquefied state) in many areas along the coast between the Ecuadorian border and Guapi and inland as far as 50 km (Fig. 1). Consequences of liquefaction included slope failures by lateral spreading and slumping, loss of bearing strength, ground cracks, and sand boils. Unconsolidated units affected by liquefaction included poorly compacted sand fills, sandy beach and lagoonal deposits, and sandy channel and floodplain deposits. These deposits are Holocene, mainly late to very late Holocene. The age and types of unconsolidated deposits affected and the general distribution of liquefaction with respect to the zone of seismic energy release are consistent with those observed during past earthquakes (*9*).

In and near Tumaco, soil liquefaction caused lateral spreading, slumping, settlement of poorly compacted fills, and loss of bearing strength beneath buildings. The single road linking inland Colombia to Tumaco was cut by lateral spreading, slumps, and settlement of the filled grade over a 14-km stretch just south of Tumaco. Lateral spreading caused the severing of pipelines, leaving most of that community without running water for weeks after the earthquake. Ground failures undercut foundations, pulled apart several small buildings, and in a few places carried entire structures several meters downslope into the sea. On the northeast side of Tumaco, liquefaction reduced soil strength beneath a small frame building on timber stilt-piles. Some of the piles sank 1 m or more, tilting and wrecking the building. Local residents report that soils at that site were a boiling quagmire of sand and water at the time of failure.

At San Juan, lateral spreading of beach deposits rent the foundation of a new cathedral (a reinforced-concrete structure), shifting part of the footings about 1 m to the east. The building was further damaged by ground shaking and the subsequent tsunami. Inhabitants report that liquefaction effects, including sand boils and ground cracks, were pervasive in many parts of the island community. The tsunami and high tides obliterated most evidence of these disturbances. Only a few sand boils and ground cracks remained at the time of our visit in late January 1980. Similar obliteration occurred in most coastal areas, leaving only a jumbled fraction of the total effects for us to observe.

Liquefaction of channel and floodplain deposits generated sand boils and ground cracks along many rivers in southwest Colombia. One exceptionally large sand boil, partly submerged in a channel at the mouth of the Río Patía, had a throat approximately 5 m in diameter and a cone 20 m in diameter. Fissures associated with slumps and lateral spreading were common, but not continuous, in river banks as far as 50 km from the coast. Displacements across fissures reached several meters in some places. The larger fissures were destructive to the few frame buildings and shacks they intersected.

Rockfalls and rockslides developed on steep slopes in the serrated low hills of Tertiary sandstone south of the Río Patía. These failures were most abundant near the coast, diminishing in number with distance inland. We saw no slides farther inland from the coast than 40 km. A few were reported along the Pan American Highway in the Cordillera Occidental north of Pasto, about 150 km from the sea.

Future Earthquakes

The 1979 Tumaco earthquake may not have been the last of those forecast by Kelleher to fill the Ecuador-Colombia seismic gap. The aftershock zone of the earthquake may not have filled the gap completely (Fig. 2). A ship captain's report (*10*) that Buenaventura harbor was nearly 1.6 m shallower after the 1906 Tumaco earthquake suggests that faulting in 1906 extended northward to the port. If the report is correct, then the 1979 Tumaco earthquake failed to break the northernmost part of the 1906 rupture. This remaining seismic gap might rupture in another shallow, large-magnitude earthquake. That event could be expected to break northward from the northeast edge of the 1979 aftershock zone, near Aserrío Candeleria.

History suggests that another series of large, shallow-focus earthquakes along the Ecuador-Colombia coastline may begin in this century near Esmeraldas. The 1942 Esmeraldas earthquake (M_s 7.9), the first of the latest series of northward-progressing earthquakes in the Ecuador-Colombia seismic gap, followed the 1906 earthquake by only 36 years. In the 38 years since 1942, there have been no large-magnitude earthquakes near Esmeraldes. Another shallow-focus ($\sim M_s$ 8) could recur in this new seismic gap at Esmeraldes before the balance of the 1906 seismic gap is filled near Buenaventura.

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