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COSTA RICA VOLCANO PROFILE

by

Cynthia M. Stine[1]

Norman G. Banks[1]

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[1]U.S. Geological Survey
David A. Johnston Cascades Volcano Observatory
5400 MacArthur Blvd.
Vancouver, WA. 98661

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COSTA RICA VOLCANO PROFILE

By Cynthia M. Stine and Norman G. Banks

INTRODUCTION

Volcanic eruptions have caused considerable damage in Costa Rica in the past and they are certain to do so again in the future. In developing countries, the number of victims of natural catastrophes increases approximately 6% a year, a rate approximately double that of population growth (Masure, in press). Population increases accompanied by deforestation, agriculture and rapid, poorly planned urbanization cause further encroachment onto the slopes of volcanoes, greatly increasing the population at risk from eruptions. However, future losses can be minimized through preventative planning.

A necessary first step in this planning is the analysis of current and existing preparedness for occurrence of natural disaster, followed by an active program in response to this analysis. For volcano hazard mitigation, this first step includes geologic evaluation and demographic studies, followed by land-use zoning, public education, monitoring for early warning, and establishment of alarm, evacuation, and rescue systems.

This report provides background data that should be useful in the evaluation of and preparation for volcanic hazards in Costa Rica. It is intended to serve as an information source for donor nations and to assist their efforts in preparation for unrest at high-risk volcanoes. Included are descriptions of the geologic setting and current evaluation of activity, hazards, and risk for each active volcano in Costa Rica. Their locations and general geographic information are provided with descriptions of historical eruptions. Volcano monitoring stations that could be precisely located appear on the maps. Map references have been included for each volcano; sources of maps and aerial photographs are noted in the section entitled Geologic organizations and information sources. Also included are evaluations of the near-field population at risk and a listing of in-country geologic and civil defense organizations with their current activities and status in preparedness. This general information about Costa Rica should facilitate a rapid response to a future volcanic emergency and be useful in activities that prepare for these crises.

Information sources were the demographic and scientific literature, resident contributors, and on-site reconnaissance by the authors. Collection of the data was jointly supported by the U.S. Geological Survey's Volcano Crisis Assistance Team (VCAT) and the Office of Foreign Disaster Assistance (OFDA) through the USGS/OFDA Volcano Early-warning and Disaster Assistance Program (VDAP). The in-country contributors included Jorge Barquero, Rudolfo Van der Laat, Federico Guendel, and Eric Fernández of Observatorio Vulcanológico y Sismológico de Costa Rica (OVSICORI), and Sergio Mora and Guillermo Alvarado of Instituto Costarricense de Electricidad (ICE).

An effort was made to obtain current, reliable data; however, hazard mitigation activities in Costa Rica are in progress and conditions can change faster than updates can be issued. Therefore, this report is preliminary and will be subject to updates as information becomes available.

BACKGROUND

Costa Rica occupies one of the geologically most active areas in the world and is therefore susceptible to a variety of natural hazards including damaging earthquakes, landslides, and volcanic eruptions. The Costa Rican volcanic chain arises from the convergence of the Cocos and the Caribbean tectonic plates (fig. 1). The volcanic front, located approximately 125 km northeast of the Middle America Trench (MAT), consists of 200 volcanoes or remnants of once active volcanoes (Alvarado, 1987). Many have produced voluminous pyroclastic flows indicative of explosive, silicic volcanism. Historically, six volcanoes have been active in Costa Rica: Rincón de la Vieja and Arenal, in the Cordillera Guanacaste, and Poás, Barva, Irazú, and Turrialba, in the Cordillera Central (fig. 2). Orosí, Cacao, Miravalles, Tenorio, and Platanar have not erupted in historical times but have active fumaroles and hot springs or are located close to large population centers and therefore pose a potential threat (Table 1).

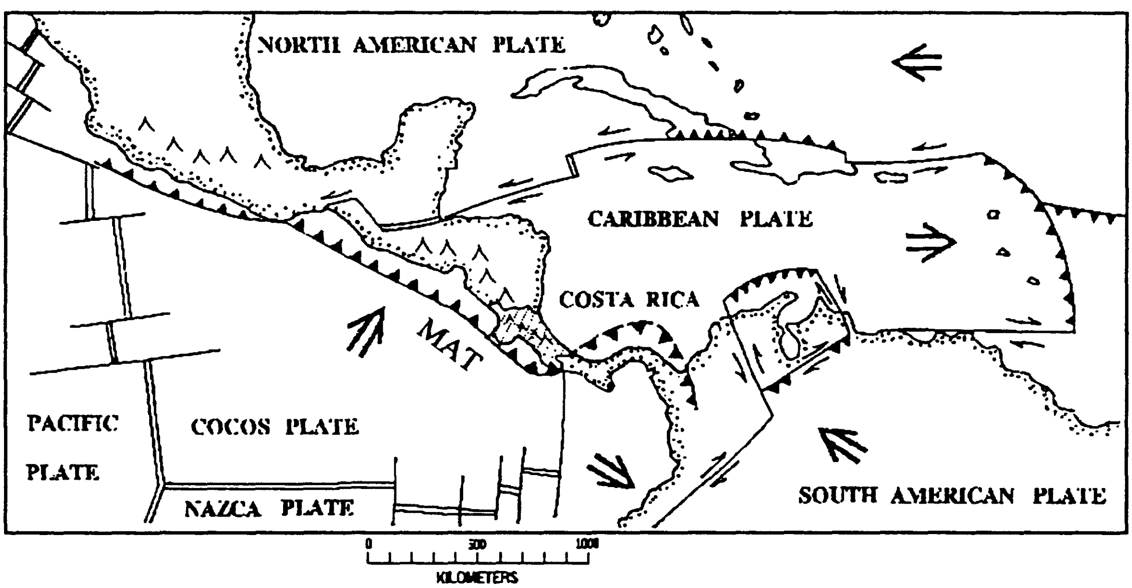

Figure 1. Diagram depicting the tectonic setting of Central America. Double lines indicate spreading axis, lines with teeth indicate subduction zones, arrows indicate direction of relative plate motion. Redrawn from Prosser, 1983.

The area most vulnerable to volcanic hazards is the Valle Central (Central Valley). Its northern margin is formed by 4 volcanoes, and it is the most densely populated region in Costa Rica with over 50% of the country's population. An eruption could seriously impact the Costa Rican economy for years after it occurs. In addition to direct impact on population, thick ash deposits can devastate agricultural production and affect transportation and electrical lines; flooding and mudflows can destroy roads and damage hydroelectric installations. Eruptions of Irazú could destroy the country's telecommunications system located at the summit. Poás has caused extensive agricultural damage as recently as 1989-91, and reactivation of Turrialba and Barva would directly threaten several population, industrial, and agricultural centers. Potential indirect economic damage to the nation is harder to evaluate but would include lost revenue from crops that cannot be harvested or delivered, and the increased cost of importing additional products (Krinsley, in press). Another volcano of potential concern is Arenal where a large

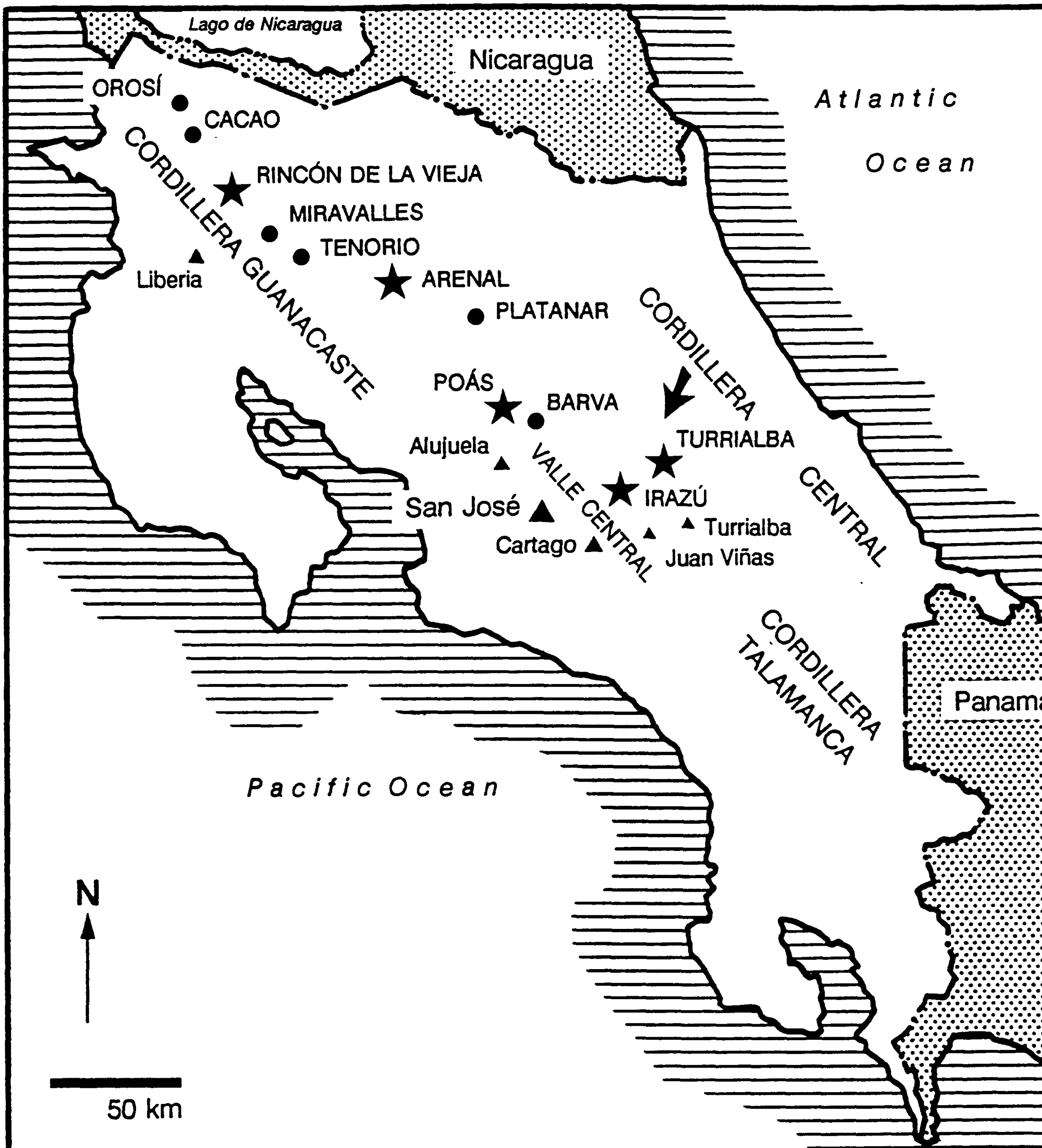

Figure 2. Map of Costa Rica, locations of the volcanoes, the Cordillera Guanacaste, the Cordillera Central, and the Valle Central. A star (*) represents a historically active volcano.

TABLE 1

VOLCANO	ELEVATION (METERS)	LOCATION (CORDILLERA)	LATITUDE LONGITUDE	DIAMETER (KM)	VOLUME (KM^3)	HISTORICAL ACTIVITY	DAMAGE($)/ DEATHS
OROSÍ	1440	GUANACASTE	10.98 N 85.47 W	9	55	NONE	NONE/NONE
CACAO	1659	GUANACASTE	10.93 N 85.45 W	8	16	NONE	NONE/NONE
RINCÓN DE LA VIEJA	1806	GUANACASTE	10.83 N 85.33 W	8.2	130	YES	NONE/NONE
MIRAVALLES	2028	GUANACASTE	10.75 N 85.15 W	8	120	NONE	NONE/NONE
TENORIO	1916	GUANACASTE	10.67 N 85.02 W	11	95	NONE	NONE/NONE
ARENAL	1633	GUANACASTE	10.47 N 84.73 W	5.4	15	YES	.85 MIL/80
PLATANAR	2183	CENTRAL	10.30 N 84.37 W	11	50	NONE	NONE/NONE
POÁS	2704	CENTRAL	10.20 N 84.22 W	17.4	95	YES	.5 MIL/NONE
BARVA	2894	CENTRAL	10.13 N 84.08 W	16.6	255	YES	UNKNOWN/ UNKNOWN
IRAZÚ	3432	CENTRAL	09.89 N 83.85 W	22	300	YES	UNKNOWN/40
TURRIALBA	3335	CENTRAL	10.03 N 83.77 W	13	290	YES	NONE/NONE

4

eruption could damage the Sangregado Hydroelectric Plant, which supplies 60% of the electricity for the country.

Costa Rica is among the best-prepared Latin American countries to deal with future unrest at its volcanoes. A dedicated cadre of geoscientists, technicians, and students has been actively pursuing evaluation and mitigation of the seismic and volcanic hazards of the country for decades. Three main scientific groups are major contributors: Observatorio Vulcanológico y Sismológico (OVSICORI) affiliated with the Universidad Nacional (UNA), Instituto Costarricense de Electricidad (ICE), and the Universidad de Costa Rica (UCR). Through self-motivation and donor-country support, these organizations possess the trained staffs and instrumentation required to adequately deal with the anticipated seismic and volcanic unrest in Costa Rica. Their combined capabilities in seismic, deformation, and geochemical monitoring programs are among the best in Latin America. In spite of these major accomplishments, Costa Rica is not thoroughly prepared for the onset of volcanic unrest at all of its high-risk volcanoes. There are, for example, few detailed geologic maps of Costa Rican volcanoes, few hazard-zonation maps, and coordination between the two main geoscience groups has at times been poor.

Long-term donor-country support and training in the use of instrumentation that has already been provided to Costa Rica are needed to maintain a successful assistance program. Parts for volcano monitoring equipment are difficult or impossible to obtain locally and are expensive to import. Equipment that has been brought on line must be maintained and not allowed to fall into disuse when installation phases of the programs are completed. In addition, donor-country assistance is needed to expand and upgrade current capabilities.

TECTONIC SETTING

Costa Rica is located on an active, convergent plate boundary where the Cocos Plate is being subducted to the northeast beneath the Caribbean Plate. One consequence of this subduction is an 1100-km-long, NW-SE-trending volcanic chain that stretches from Mexico through the middle of Costa Rica (Weyl, 1980). The part of this chain in northwest Costa Rica is referred to as the Cordillera de Guanacaste and is offset about 40 km to the southwest from the Nicaraguan chain. The remainder of the Costa Rican volcanoes, southeast of the Cordillera de Guanacaste, are located in the Cordillera Central (Stoiber and Carr, 1973). There are no active volcanoes in Costa Rica south of the Cordillera Central.

GENERAL DESCRIPTION OF VOLCANIC HAZARDS

Tephra fall

Many volcanic eruptions produce airborne tephra which is dispersed in fan-shaped patterns downwind of the vent. In the proximal areas, death related directly to tephra fall is rare. However, death and other losses from indirect causes including collapse of roofs, breakage of electrical and communications lines, contamination of water supplies, damage to machinery and airplanes, and destruction of agricultural grazing land and crops can be extensive (Scott, 1989). Tephra deposition accompanied or followed by heavy rainfall can generate destructive mudflows. Conditions that favor generation of such mudflows may last long after ash is deposited. In Costa Rica the prevailing wind directions will direct most tephra fall deposits to the west of the source volcano. Thus, the heavily populated Valle Central, the location of the capital city, San José, could be severely impacted by a large eruption of any of the four volcanoes forming the northeastern border of the valley. During the 1963 eruption of Irazú, tephra was deposited in the capital, 24 km from the summit. The Costa Rican Ministry of Agriculture estimated that tephra from this eruption damaged 112,000 acres of land (Murata and others, 1966).

Pyroclastic flows and surges

Pyroclastic flows and surges are gravity-driven flows of hot (300 to 800 degrees C) pyroclastic material and gases which destroy everything in their path. Small to moderate-sized flows tend to travel unrestrained by topography near their sources but often become channelized on or beyond the flanks of a volcano. They travel at velocities ranging from 30 to 300 km/hr (Scott, 1989). In 1968, Arenal produced violent explosions and small pyroclastic flows that killed 80 people living within 5 km of the summit (Melson and Sáenz, 1973). Large pyroclastic flows can remain unrestrained by topography for tens or even hundreds of kilometers from their vents. The pyroclastic flow associated with the blast at Mount St. Helens traveled in this manner for as many as 30 km. There have not been any large pyroclastic flows in Costa Rica during historical times; however, huge ash flow sheets are the dominant Quaternary volcanic product by volume in Costa Rica (Weyl, 1980).

Mudflows

Mudflows are hot or cold, water-saturated debris flows that can originate on the flanks of a volcano. They are confined to drainages and outflow fans but can travel quite far at speeds up to 110 km/hr (Blong, 1984). Mudflows pose a great threat to downstream populations, which may be lulled into a false sense of security owing to their great distance from the volcano.

Mudflows may be primary or secondary in origin. Primary mudflows are generated by eruptions through crater lakes, overrunning and incorporation of streamflow by pyroclastic flows, and melting of ice and snow by pyroclastic flows. Secondary mudflows occur through breaking of natural and man-made dams or through mobilization of pyroclastic deposits by torrential rainfall.

Historical and prehistorical records indicate that mudflows frequently affected the Valle Central. Large destructive mudflows would most likely result from the remobilization of erupted ash, pumice, and pyroclastic-flow deposits by heavy rainfall. Such events occurred during the Irazú eruption of 1963-1965, in which over 20 people were killed and 400 homes, some factories, a major highway, and a railway line were destroyed. (Murata and others, 1966). Loss of life can be minimized through prior warning, evacuation, land-use zoning, and the construction of barriers and diversion channels.

Lava flows

Lava flows are not expected to cause many deaths in Costa Rica. Most move slowly, and the majority do not travel far beyond the flanks of a volcano. Due to the slow advance of most lava flows, a warning period of hours to days is usually provided. However, they do cause great property damage, and the stratigraphic record reveals that many Costa Rican volcanoes have produced large lava flows in the past and are therefore likely to do so in the future. Effects of lava flows include damage to structures by ignition, exerting force on and destroying walls, and burial. They also cut off roads, railway lines, and electric and water supplies (Blong, 1984). Collapse of the front of a thick lava flow can generate pyroclastic flows that travel at high velocity several kilometers and advance far beyond lava flow.

Debris avalanches

Debris avalanches are caused by the collapse of a portion of a volcano; they completely destroy everything in their path. Debris avalanches may travel over 100 km/hr and have caused over 20,000 fatalities in historical times (Siebert, 1984). Some travel over 10 km from their sources; several can be traced for 50 to 100 km and cover areas of 500 to 1500 km^2. Slope failure associated with debris avalanches can trigger explosive activity, such as a lateral blast, by releasing the pressure of a hydrothermal-magmatic system. Associated hazards include rapid introduction of volcanic debris into drainages, which can generate destructive mudflows. There may also be generation of secondary mudflows through the impoundment of streams and failure of debris dams. Historical records indicate that catastrophic debris avalanches have occurred 6 times in the last century (Siebert, 1984). In Costa Rica, prehistoric debris avalanches occurred at Miravalles, Cacao, and Turrialba in late Quaternary time. The probability of a debris avalanche increases where portions of a volcanic edifice are hydrothermally altered and where the upper flanks are oversteepened. Debris avalanches can occur by simple gravitational collapse or be triggered by intrusive activity or by shaking associated with local or regional earthquakes.

Volcanic gases and acid rain

Volcanic gases and acids released directly from a vent or created through interaction of the gases with the atmosphere include carbon monoxide, carbon dioxide, sulfuric acid, hydrochloric acid, hydrofluoric acid, carbonic acid, and ammonia. The effect of these gases and acids generally decreases downwind of the vent. Rain passing through a gas-laden plume absorbs these pollutants and can consequently contaminate and acidify water supplies. Acid rain can burn vegetation, and cause eye and respiratory problems. Gas and acid components adsorbed on tephra particles frequently cause digestive or more serious problems for grazing animals (Blong, 1984). In 1988, increased fumarolic activity at Poás produced acid vapors that damaged vegetation and caused continuing health problems for nearby inhabitants. Coffee crop losses were estimated to be in excess of $0.5 million (SEAN, Barquero, 1989, v. 14, no. 3).

Ballistic projectiles

Ballistic projectiles are fragments of rock and lava of variable size that are ejected from a vent at high speeds. Trajectories of these projectiles are generally not affected by the wind. Fragments become finer-grained with distance from the vent. The greatest hazard is from the force of impact and heat (Scott, 1989). Grass and forest fires sometime accompany impact of hot ballistics. These types of projectiles were a major source of destruction in the 1968 eruption of Arenal.

Earthquakes

Volcanic earthquakes are associated with the movement of magma in volcanic areas and frequently precede or accompany eruptions. If volcanoes are adequately monitored, earthquake trends can be used to forecast eruptions. Large volcanic earthquakes can cause damage.

Observatorio Vulcanológico y Sismológico (OVSICORI) of the Universidad Nacional (20 stations) and Instituto Costarricense de Electricidad (ICE)-Sección de Sismología e Ingenieria Sísmica, in association with the Universidad de Costa Rica (15 stations), have been monitoring both tectonic and volcanic seismicity in Costa Rica for decades.

Atmospheric Shock Waves

Some eruptions produce strong atmospheric shock waves when volcanic material and gases are ejected at high velocity from the vent. The energy of a shock wave decreases with distance from a vent; however, damage to buildings and windows has occurred as far as 10 km from the vent. Some eruptions are reported to have broken windows hundreds of kilometers from the source (Scott, 1989).

INDIVIDUAL VOLCANOES from North to South

OROSÍ (sometimes referred to as Góngora which is actually the name of another cone southeast of Orosí)

GENERAL GEOLOGIC SETTING: Orosí is a composite volcano located 17 km SW of the Nicaraguan border at the NW end of the Cordillera de Guanacaste (fig. 2, 3). The most recently active vent is one of 4 clustered, eroded cones (Mooser and others, 1958). The crater, breached to the southwest, is large and poorly preserved. Also in the area is Cerro Orosilito, a small cone to the southeast between Orosí and Cacao, and a cluster of Tertiary cones 7 km to the WNW.

ERUPTIVE STYLE AND HAZARDS: There are very few geological data available to evaluate Orosí. The most recent dated event, based on radiocarbon dating, is a large lahar which moved south from the summit around 4000 ybp (Melson and others, 1988).

EVALUATION OF ACTIVITY AND RISK (1989): All deposits from Orosí are very old (thick well-developed soils), and the slopes are deeply dissected and covered with forests. There have been no geophysical or visual signs of activity. Therefore, the probability of an eruption in the foreseeable future is very small. However, sector collapse has a higher probability. The oversteepened slopes are deeply weathered and soil-covered, and old megabreccia deposits, occurring to the west of the volcano, indicate predisposition for such events at Orosí (field reconnaissance by Banks).

There are no geologic studies available with which to evaluate eruption recurrence intervals or potential for large infrequent eruptions. Eruptions are reported for 1844 and 1849 although Orosí was at the time and still is covered with thick vegetation (Mooser and others, 1958), however, these reports are probably in error. A study of the historical record indicates that these eruptions took place at Rincón de la Vieja which is located approximately 20 km SE of Orosí in a remote part of Costa Rica (Barquero, J., pers. comm., 1988).

PROXIMAL POPULATION AT RISK: The area is remote, therefore few people in the near field are at risk. The volcano is located in the Guanacaste National Park, and future development of the area will be restricted.

OROSÍ*

QUADRANT	POPULATION 0-5 KM	POPULATION 5-10 KM
NE	-	63
SE	-	24
SW	-	-
NW	-	39

(Data from G. Alvarado, ICE)

* Population figures are for quadrants. Populations located along drainages are at the greatest risk.

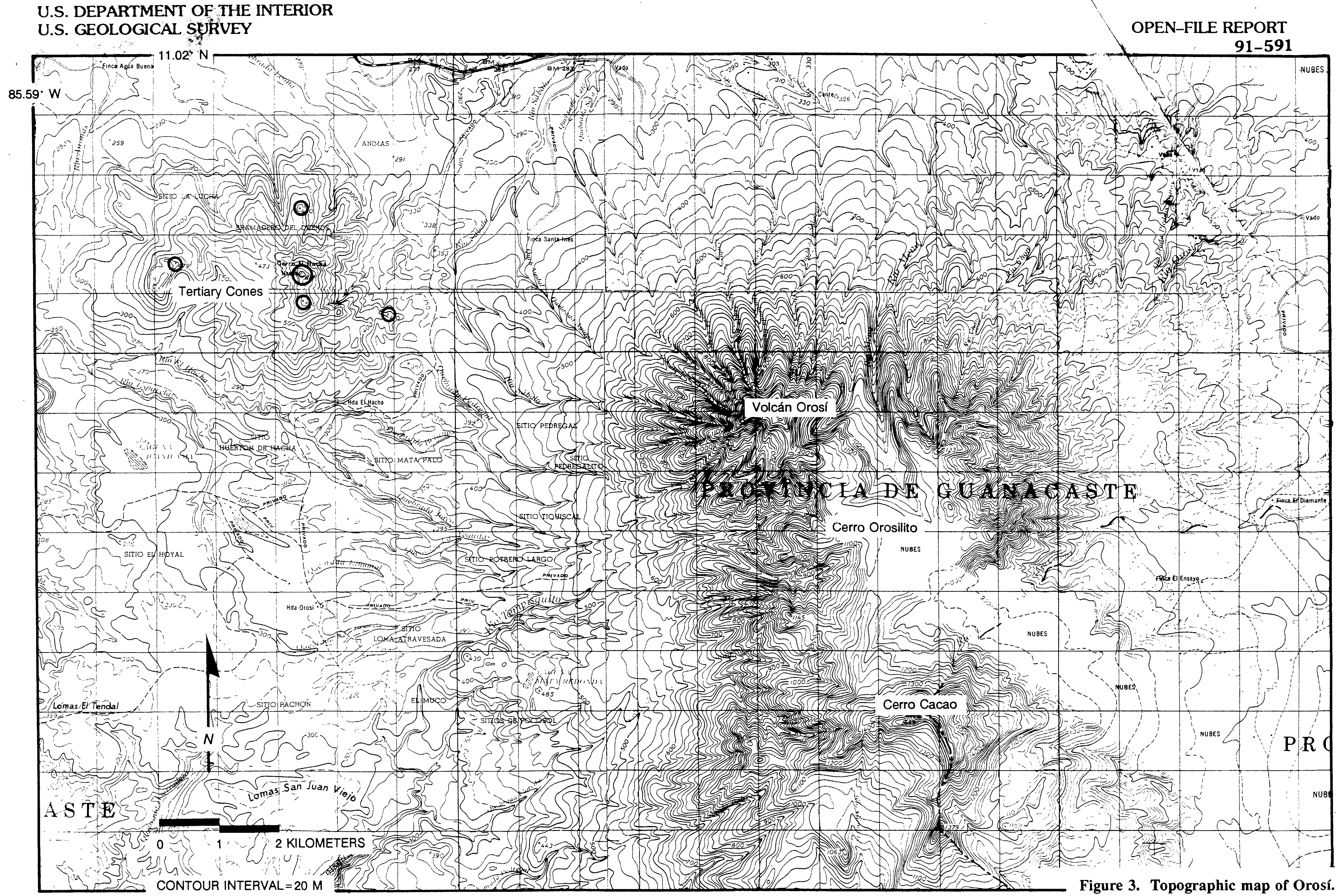

Figure 3. Topographic map of Orosí.

This map is preliminary and has not been reviewed for conformity with U.S. Geological Survey editorial standards. Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

GENERAL VOLCANO INFORMATION

TYPE OF VOLCANO: Stratovolcano
LATITUDE: 10.98 N
LONGITUDE: 85.47 W
LOCATION: Cordillera de Guanacaste, 37 km N of Liberia
ELEVATION AT SUMMIT: 1440 m
ELEVATION AT BASE: 400 m
RADIUS: 4.5 km
ESTIMATED VOLUME OF VOLCANIC EDIFICE: 55 km^3 (Carr, 1984)
CRATER DIAMETER: Approx. 1 km and deeply eroded (Alvarado, 1989)
CRATER DEPTH: Deeply eroded
ESTIMATED AGE OF VOLCANO: Approx. 400,000 years (Alvarado, 1989)
ROCK TYPE: Plagioclase-rich basaltic andesite and olivine basalt (Alvarado, 1989)
THERMAL MANIFESTATIONS: None
HISTORICAL ERUPTIONS: None
ACCESS: There is poor road access to the base of the cone from the west by horseback or 4-wheel drive vehicle.

MONITORING

SEISMIC MONITORING: None
DEFORMATION MONITORING: None
GAS AND FUMAROLE MONITORING: None

SIGNS OF RECENT UNREST: None
GENERAL GEOLOGIC MAP: None
HAZARD MAP: None
TOPOGRAPHIC MAPS:

- Cacao, Sheet 3048 IV, 1977, Ministerio de Obras Publicas y Transportación (MOPT), San José, Costa Rica, 1:50,000.
- Bahía de Salinas, Sheet 3049 II, 1965, Instituto Geográfico Nacional, San José, Costa Rica, 1:50,000.
- Orosí, Sheet 3149 III, 1966, Instituto Geográfico Nacional, San José, Costa Rica, 1:50,000.
- Murcielago, Sheet 3048 I, 1965, MOPT, San José, Costa Rica, 1:50,000.

AERIAL PHOTOGRAPHS (Orosí):

DATE	SCALE	ROLL NUMBER	FLIGHT LINE	FRAME NUMBERS
1977	1:35,000	R119	-	9219A-9236

GEOLOGIC WORKERS (Name, specialty, date referring to publications found in Bibliography):

- Alvarado, general geology, petrology, 1984, 1989
- Barquero, J., historical eruption record, unpublished
- Carr, physical and geochemical characteristics, 1984
- Melson, radiocarbon dating, 1986, 1988

CACAO

GENERAL GEOLOGIC SETTING: Cerro Cacao is located in the Cordillera de Guanacaste, 6 km SE of Volcán Orosí (fig. 2). The volcano is deeply eroded, has well developed soils, and is covered with thick vegetation (fig. 4). The crater is breached to the southwest and contains a dome. A smaller cone, Volcán Pedregal, breached to the west, is located 3 km SW of Cacao.

ERUPTIVE STYLE AND HAZARDS: Debris avalanche deposits from Cacao occur 3.5 km SW of the volcano in the Río Góngora valley and are believed to be 6000 years old (Castillo, 1977). Altered rhyolite, perhaps part of an earlier silicic dome, is found in these deposits. An eroded dome occurs in the breach left by the debris avalanche, and a thin 3,500 year old tephra-fall deposit from Rincón de la Vieja overlies the avalanche deposits (Melson and others, 1986). No other geologic data are available for Cacao.

EVALUATION OF ACTIVITY AND RISK (1989): The flanks of Cacao are deeply dissected and covered by thick, well-developed soils. There have been no geophysical or visual signs of historical unrest. The presence of rhyolite on the southwest flank, perhaps the remnant of an old dome transported in a debris avalanche, suggests that the volcano may have been highly explosive in the late Quaternary.

PROXIMAL POPULATION AT RISK: The area is remote, therefore few people are at risk.

CACAO

QUADRANT	POPULATION 0-5 KM	POPULATION 5-10 KM
NE	-	66
SE	-	99
SW	3	24
NW	-	-

(Data from G. Alvarado, ICE)

GENERAL VOLCANO INFORMATION

TYPE OF VOLCANO: Stratovolcano
LATITUDE: 10.93 N
LONGITUDE: 85.45 W
LOCATION: Cordillera de Guanacaste
ELEVATION AT SUMMIT: 1659 m
ELEVATION AT BASE: 700 m
RADIUS: 4 km
ESTIMATED VOLUME OF VOLCANIC EDIFICE: 16 km^3
CRATER DIAMETER: Deeply eroded
CRATER DEPTH: Deeply eroded
ESTIMATED AGE OF VOLCANO: Approx. 400,000 years (Alvarado, 1989)

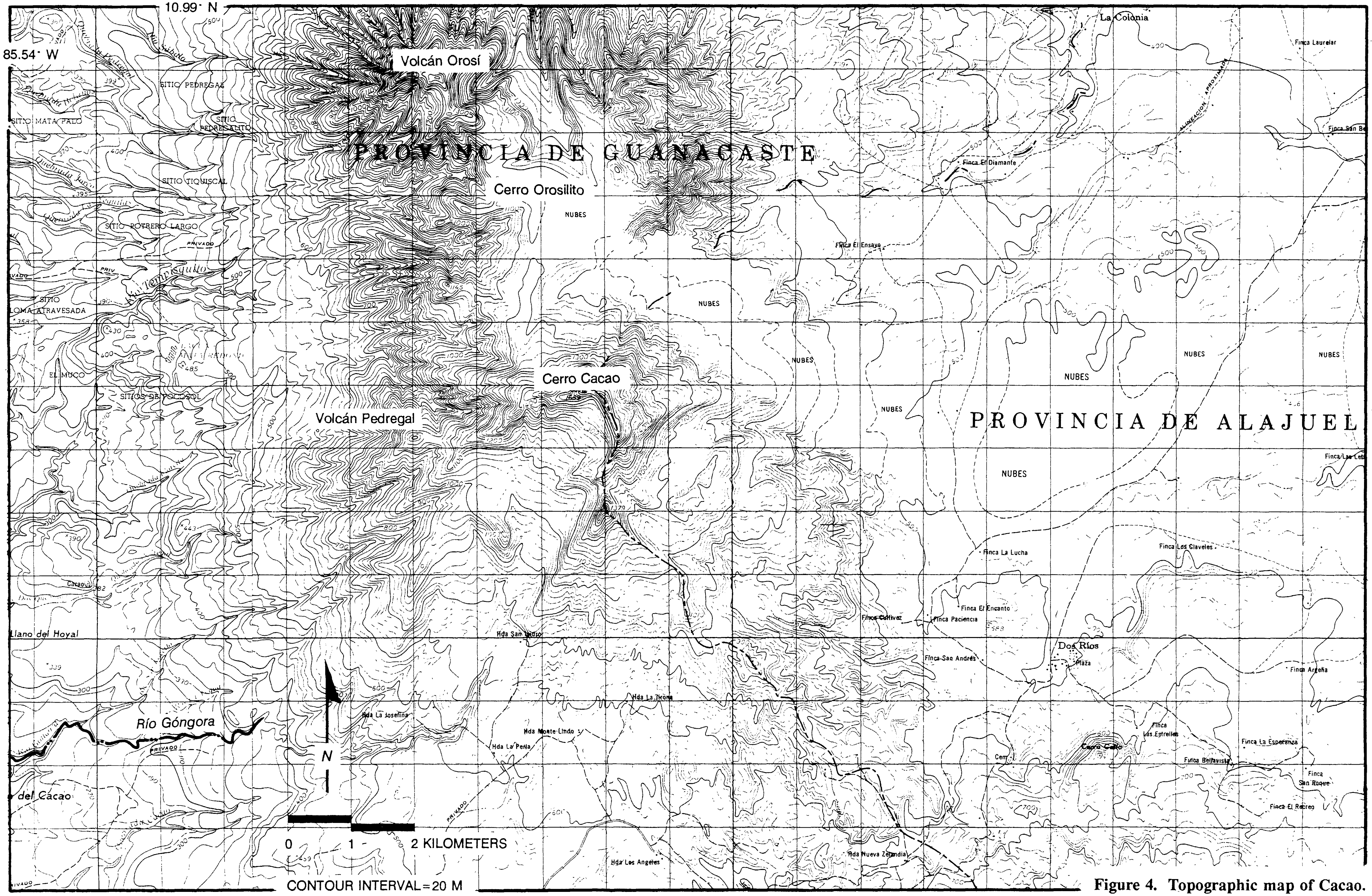

Figure 4. Topographic map of Cacao.

ROCK TYPE: Augite andesite and rhyolite (Alvarado, 1989)
THERMAL MANIFESTATIONS: None
HISTORICAL ERUPTIONS: None
ACCESS: There is poor access from the west to the base of the cone by 4-wheel drive vehicle.

MONITORING

SEISMIC MONITORING: None
DEFORMATION MONITORING: None
GAS AND FUMAROLE MONITORING: None

SIGNS OF RECENT UNREST: None
GENERAL GEOLOGIC MAP: Yes, 1:50,000 by Castillo R. (1977)
HAZARD MAP: None
TOPOGRAPHIC MAPS:

- Cacao, Sheet 3048 IV, 1977, MOPT, San José, Costa Rica, 1:50,000.

AERIAL PHOTOGRAPHS (Cacao):

DATE	SCALE	ROLL NUMBER	FLIGHT LINE	FRAME NUMBERS
1977	1:35,000	R119	-	9219A-9236

GEOLOGIC WORKERS (Name, specialty, date referring to publications found in Bibliography):

- Alvarado, general geology, 1989
- Barquero, J., historical eruption record, unpublished
- Castillo, reconnaissance geology, 1977
- Kempter, geology, unpublished

RINCÓN de la VIEJA

GENERAL GEOLOGIC SETTING: Rincón de la Vieja is located in the Cordillera de Guanacaste, 30 km south of the Nicaraguan border. It consists of a large composite volcano with a series of 9 aligned cones and craters forming a NW-SE-trending ridge (Alvarado, 1989) (fig. 2, 5). The youngest craters are to the northwest and suggest a northwestward migration of activity. The older craters are hydrothermally altered. The most recently active crater is located 1 km NW of the main cone and contains a crater lake. The Von Seebach Cone and the Volcán Santa Maria are part of the volcanic complex. Healy (1969) suggested that a series of escarpments on the southern and eastern flanks of the volcano (I and II in fig. 5) are remnants of a caldera with a diameter of 15 to 20 km. Carr and others (1985) provide further evidence for the existence of a large caldera. They noted that an extensive ignimbrite sheet slopes gently to the south away from the volcano. The presence of fresher, younger escarpments exposed on the west and east flanks (III and IV in fig. 5) led Carr and others (1985) to suggest that a younger 5 km-diameter caldera is nested within the larger one. The arcuate ridge of cones and craters occurs along the projected northern rim of this structure. A geothermal area, called Las Pilas, occurs at the projected intersection of these younger scarps on the south flank of the volcanic edifice. Cerro Fortuna, a Quaternary dome complex with active fumaroles, is located 12 km WSW of Rincón de la Vieja.

ERUPTIVE STYLE AND HAZARDS: The stratigraphic sequence of historical and late prehistoric deposits is dominated by plinian to sub-plinian tephra deposits and two-pyroxene andesitic lava flows (Kempter and Benner, 1989). The last plinian eruption was estimated at 4000 ybp by radiocarbon dating (Melson, 1988, pers. comm.) Recent eruptions have been explosive but have been small and confined to the upper slopes of the cone with accessory debris produced by phreatic eruptions dominating over juvenile material.

EVALUATION OF ACTIVITY AND RISK (1989): The volcano has active fumarolic areas and has had several small phreatic eruptions between 1983 and 1987. OVSICORI recorded increased seismicity accompanying many of these events. In addition, they recorded harmonic tremor in March 1987, prior to an eruption that produced small mudflows from ejected lake water (Barquero and Fernández, 1987). Owing to extensive hydrothermal alteration and steep upper slopes, there exists the possibility of a sector collapse or mudflows on the north flank of the volcano (Kempter, pers. comm., 1989). Based on the historical record, the probability of a large, explosive eruption is small unless future geophysical evidence signals the movement of magma bodies beneath the edifice.

PROXIMAL POPULATION AT RISK: The south slope of the volcano is in a national park and consequently the near-field population at risk is small. Development on the upper slopes of the volcano is restricted. Increasing numbers of people are cultivating the land on the north slope. This area is at risk from mudflows.

RINCÓN DE LA VIEJA

QUADRANT	POPULATION 0-5 KM	POPULATION 5-10 KM
NE	-	60
SE	-	66
SW	-	27
NW	-	87

(Data from G. Alvarado, ICE)

GENERAL VOLCANO INFORMATION

TYPE OF VOLCANO: Stratovolcano
LATITUDE: 10.83 N
LONGITUDE: 85.33 W
LOCATION: Cordillera de Guanacaste, 24 km NNE of Liberia
ELEVATION AT SUMMIT: 1806 m
ELEVATION AT BASE: 750 m
RADIUS: 4.1 km
ESTIMATED VOLUME OF VOLCANIC EDIFICE: 130 km^3 (Carr, 1984)
CRATER DIAMETER: 250 m
CRATER DEPTH: 80 m to lake level
ESTIMATED AGE OF VOLCANO: No information
ROCK TYPE: Pyroxene andesite (Kempter and Benner, 1989)
THERMAL MANIFESTATIONS: Thermal springs are located on the SW flank: Hornillas, Azufrales, Boriquen, and Las Pilas. These features are aligned in a NW-SE direction, parallel to faulting in the area (Alvarado, 1989).
HISTORICAL ERUPTIONS:

1844 - No details (Barquero, pers. comm.)
1849 - No details (Barquero, pers. comm.)
1860 - Ash eruption (Mooser and others, 1958)
1863 - Ash eruption for 3 days (Alvarado, 1989)
1812 - Steam and ash eruption (Alvarado, 1989)
1922 - Ash eruption (Barquero and de Dios Segura, 1983)
1966 - Ash eruption (Barquero and de Dios Segura, 1983)
1967 - Steam and ash eruption (Alvarado, 1989)
1969 - Steam and sulfur emissions (Alvarado, 1989)
1969 - Gas and ash emissions (Alvarado, 1989)
1970 - Ash eruption (Alvarado, 1989)
1983 - Phreatomagmatic eruption deposited tephra (to SE, S, and SW) 1.5 km from summit and generated a small mudflow in the Río Penjamo (Barquero and de Dios Segura, 1983)
1986 - Small phreatic eruption (Barquero and Fernández, 1987)
1987 - Small phreatic eruption, small mudflow in Quebrada Azufrada and Río

Penjamo (Barquero, pers. comm.)

1991 - Small phreatic eruption generated mudflows, ash deposited 14 km NW of summit (Fernández, pers. comm.)

ACCESS: Road from Liberia to Las Pilas, 3 hour walk to summit.

MONITORING

SEISMIC MONITORING: Yes

TYPE: One station, telemetered (OVSICORI)

LOCATION: 2 km SW of summit

DURATION: Since 1983

DEFORMATION MONITORING: Yes

TYPE: Spirit-level tilt, 2 stations (OVSICORI)

LOCATION: No information

DURATION: Since 1982, every 10 weeks

TYPE: Electronic tilt, 1 station (OVSICORI)

LOCATION: No information

DURATION: Every 12 weeks (read by hand-held meter)

GAS AND FUMAROLE MONITORING: None

SIGNS OF RECENT UNREST: Occasional seismic swarms have occurred since 1983. Phreatic eruptions occurred in 1986, 1987, and 1991.

GENERAL GEOLOGIC MAP: In preparation by Kurt Kempter of Louisiana State University and A. Chesada of Universidad de Costa Rica.

HAZARD MAP: In preparation by Kurt Kempter (LSU)

TOPOGRAPHIC MAPS:

- Curubandé, Sheet 3148 III, 1977, MOPT, San José, Costa Rica, 1:50,000.
- Cacao, Sheet 3048 IV, 1977, MOPT, San José, Costa Rica, 1:50,000.

AERIAL PHOTOGRAPHS (Rincón de la Vieja):

DATE	SCALE	ROLL NUMBER	FLIGHT LINE	FRAME NUMBERS
1976	1:20,000	R097	L11	4345-4394
1977	1:35,000	R119	-	9214-9236

GEOLOGIC WORKERS (Name, specialty, date referring to publications found in Bibliography):

- Alvarado, general geology, petrology, 1989
- Barquero, J., and de Dios Segura, historical eruption record, 1983
- Carr, and others, geologic mapping, physical and geochemical characteristics, 1984, 1985
- Healy, geologic mapping, 1969
- Kempter and Benner, geologic mapping, petrology, geochemistry, 1989
- Melson, radiocarbon dates, 1986

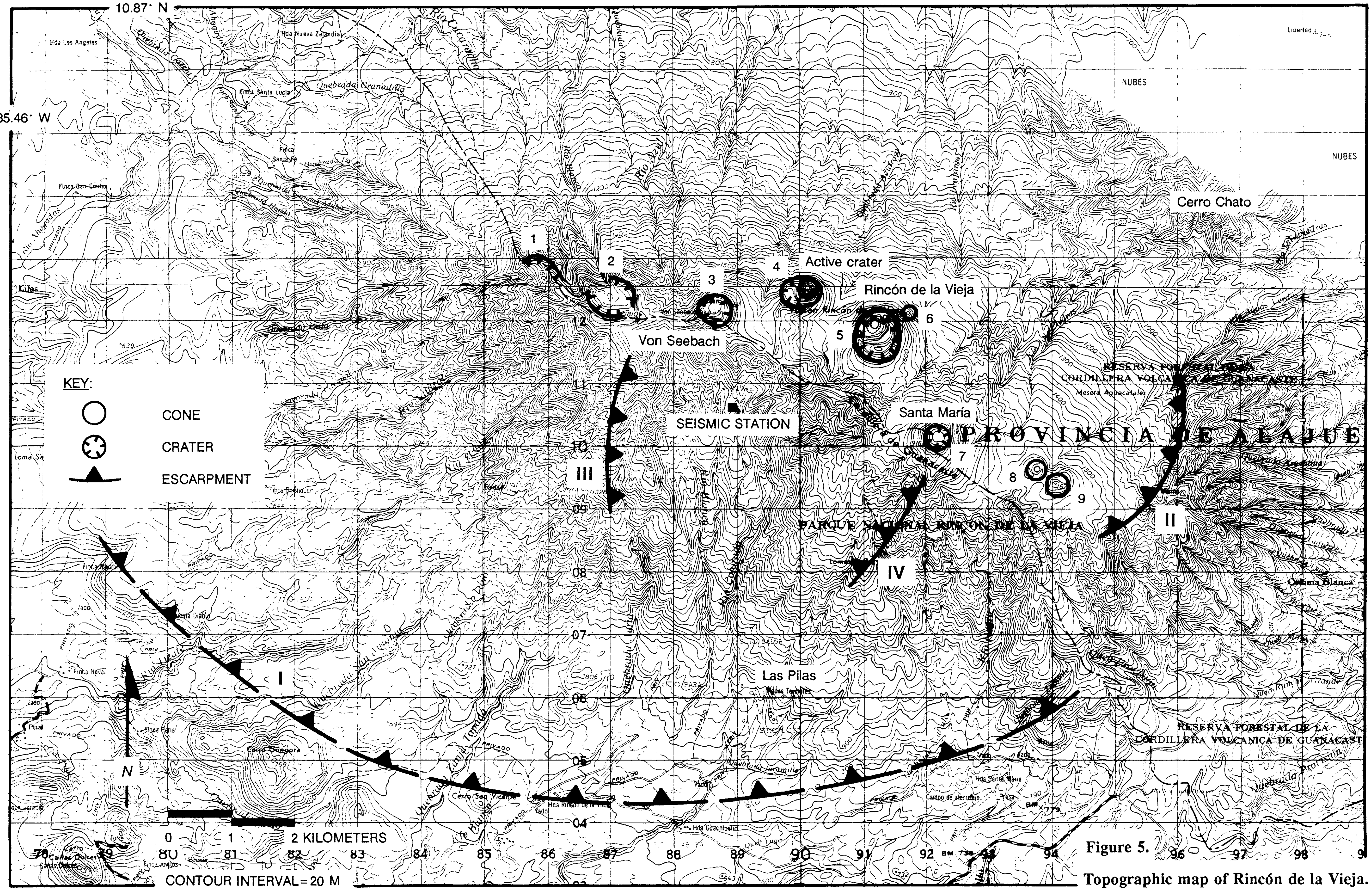

Figure 5.
Topographic map of Rincón de la Vieja.

This map is preliminary and has not been reviewed for conformity with U.S. Geological Survey editorial standards. Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the

MIRAVALLES

GENERAL GEOLOGIC SETTING: Miravalles is located in the Cordillera de Guanacaste, 34 km ENE of the town of Liberia. The volcano is deeply eroded and covered by vegetation. Six vents are aligned in a NE-SW direction along a system of faults and fractures (fig. 2, 6). The centers are younger in the SW direction, and the most recent lava flow is located on this flank. A small active fumarolic area (300 m^2) called Las Hornillas is located on a prehistoric debris avalanche on the southwestern flank (fig. 6). The youngest edifice buries the northeast rim of the Guayabo Caldera, which is over 8 km in diameter and the source of thick 600,000 ybp pyroclastic deposits found to the west and north (Alvarado, 1989).

Four hundred thousand years ago, faulting formed a large N-S-trending graben across Guayabo Caldera. This was followed by a second eruptive collapse of the rim of the caldera about 200,000 years ago. The growth of the current Miravalles cone within the Guayabo Caldera began about 50,000 years ago with fissure eruptions. The most recent lava flows are 7,000 years old. These predate the debris avalanche containing andesite blocks found on the SW flank. A pyroclastic deposit overlies the debris avalanche (Alvarado, pers. comm., 1989).

ERUPTIVE STYLE AND HAZARDS: Miravalles is part of a volcanic center having a history of more than 600,000 years of recurrent caldera collapse. Eruptive activity has occurred within the last 7,000 years, and the area still supports a significant geothermal system.

EVALUATION OF ACTIVITY AND RISK (1989): Activity in historical times has been fumarolic and seismic. The planned Miravalles Geothermal Project (ICE) located near Las Hornillas on the debris avalanche will be producing 55 MW of electricity by 1992 (Barquero and Alvarado, 1988). Geophysical and visual monitoring should be in real time and at levels appropriate to the population and facilities at risk.

PROXIMAL POPULATION AT RISK: A small population is at risk. The proposed geothermal plant will be located on the prehistoric debris avalanche.

MIRAVALLES

QUADRANT	POPULATION 0-5 KM	POPULATION 5-10 KM
NE	-	114
SE	-	141
SW	30	734
NW	105	321

(Data from G. Alvarado, ICE)

GENERAL VOLCANO INFORMATION
TYPE OF VOLCANO: Stratovolcano
LATITUDE: 10.75 N
LONGITUDE: 85.15 W

LOCATION: Cordillera de Guanacaste, 34 km ENE of Liberia
ELEVATION AT SUMMIT: 2028 m
ELEVATION AT BASE: 700 m
RADIUS: 4 km
ESTIMATED VOLUME OF VOLCANIC EDIFICE: 120 km^3 (Carr, 1984)
CRATER DIAMETER: Eroded, no remnants of crater
CRATER DEPTH: Not applicable
ESTIMATED AGE OF VOLCANO: 50,000 ybp (Alvarado, pers. comm., 1989)
ROCK TYPE: Hypersthene-augite andesite to basaltic andesite (Alvarado, 1989)
THERMAL MANIFESTATIONS: Fumaroles and hot springs are located SW of the summit in an area called Las Hornillas (Alvarado, 1989). Commercial geothermal field under development.
HISTORICAL ERUPTIONS: None
ACCESS: Paved road from Bugaces to Guayabo (base of the volcano)

MONITORING

SEISMIC MONITORING: Yes
TYPE: Eight stations; telemetered since 1983 (ICE)
LOCATION: 1.) 4.6 km WSW of summit (permanent); 2.) 12.5 km SW of summit (permanent); 3.) 10.3 km SSW of summit (permanent); 4.) 5.5 km S of summit (permanent); 5.) 5.7 km NNW of summit (portable); 6.) 13 km WSW of summit (portable); 7.) 15 km SW of summit (portable); 8.) 8 km SW of summit (portable)
DURATION: Since 1977

DEFORMATION MONITORING: Yes
TYPE: EDM, 2 stations (ICE)
LOCATION: No information
DURATION: No information
TYPE: Trigonometric leveling (ICE)
LOCATION: No information
DURATION: Since 1983
TYPE: Spirit-level tilt, 4 stations (ICE)
LOCATION: 1.) 3.7 km SW of summit, 2.) 4.5 km SW of summit, 3.) 6.5 km SW of summit, 4.) 7 km SW of summit
DURATION: No information
TYPE: Gravity, LaCoste instrumentation (ICE, Open University, England)
LOCATION: Network inside Guayabo Caldera
DURATION: Since 1985

GAS AND FUMAROLE MONITORING: Yes, temperature and water chemistry of exploration wells (ICE). Frequency of measurements is unknown.

SIGNS OF RECENT UNREST: None, the only historical activity has been fumarolic and background seismicity (Barquero, 1987).
GEOLOGIC MAP: Yes, detailed, 1:50,000 (Santana, 1977)
HAZARD MAP: None
TOPOGRAPHIC MAPS:
- Miravalles, Sheet 3148 II, 1966, U.S. Army Map Service, Washington, D.C., 1:50,000.

AERIAL PHOTOGRAPHS (Miravalles):

DATE	SCALE	ROLL NUMBER	FLIGHT LINE	FRAME NUMBERS
1977	1:25,000	R114	L3	16304
1977	1:35,000	R119	-	9219-9236
1979	1:25,000	R136	-	14020-14023

GEOLOGIC WORKERS (Name, specialty, date referring to publications found in Bibliography):

- Alvarado, general geology, 1989
- Barquero, J., historical eruption record, unpublished
- Barquero, R., monitoring, general geology, 1989a
- Santana, geologic mapping, 1977

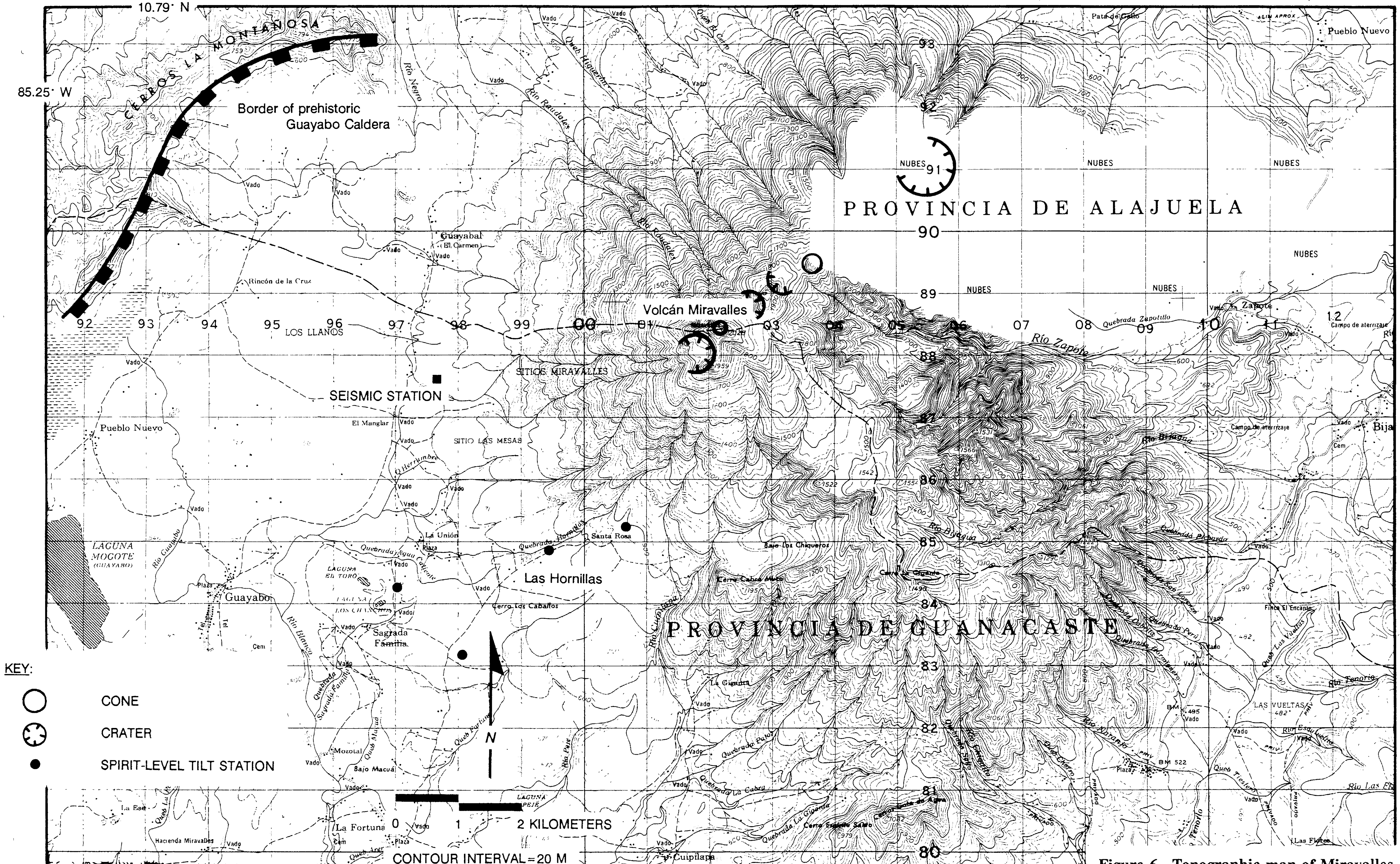

Figure 6. Topographic map of Miravalles.

This map is preliminary and has not been reviewed for conformity with U.S. Geological Survey editorial standards. Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

TENORIO

GENERAL GEOLOGIC SETTING: Tenorio, located in the Cordillera de Guanacaste (fig. 2, 7), 10 km north of the Laguna de Arenal, has not erupted in historical times. The complex consists of 4 volcanic cones aligned in a NW-SE direction (Alvarado, 1989). The cones, from the NW to SE consist of 1) a series of domes, 2) Cerro Montezuma, which has a double crater, 3) a dissected cone whose crater is breached to the NE, and 4) Tenorio, the active cone which also has a double crater. The morphologies of both of these craters and their lava flows are well-preserved, indicative of eruptive activity in the recent past. The northwestern crater is the most recently active (Alvarado, 1989).

ERUPTIVE STYLE AND HAZARDS: Deposits of lava flows, pyroclastic surges, pyroclastic flows, and mudflows indicate a variety of eruptive styles and hazards.

EVALUATION OF ACTIVITY AND RISK (1989): There have been no overt signs of unrest; however, there are active hot springs and fumaroles on the flanks of the volcano, and the youngest features have youthful morphology. Deposits on the west flank of Tenorio are deeply weathered and covered with .5 to 1 m of well-developed soil with no obvious tephra units.

PROXIMAL POPULATION AT RISK: There is a small population located to the west and northwest of the volcano.

TENORIO

QUADRANT	POPULATION 0-5 KM	POPULATION 5-10 KM
NE	-	129
SE	-	36
SW	41	249
NW	-	543

(Data from G. Alvarado, ICE)

GENERAL VOLCANO INFORMATION

TYPE OF VOLCANO: Stratovolcano
LATITUDE: 10.67 N
LONGITUDE: 85.02 W
LOCATION: Cordillera de Guanacaste
ELEVATION AT SUMMIT: 1916 m
ELEVATION AT BASE: 600 m
RADIUS: 5.5 km
ESTIMATED VOLUME OF VOLCANIC EDIFICE: 95 km^3
CRATER DIAMETER: 250 m
CRATER DEPTH: 50 m
ESTIMATED AGE OF VOLCANO: No information

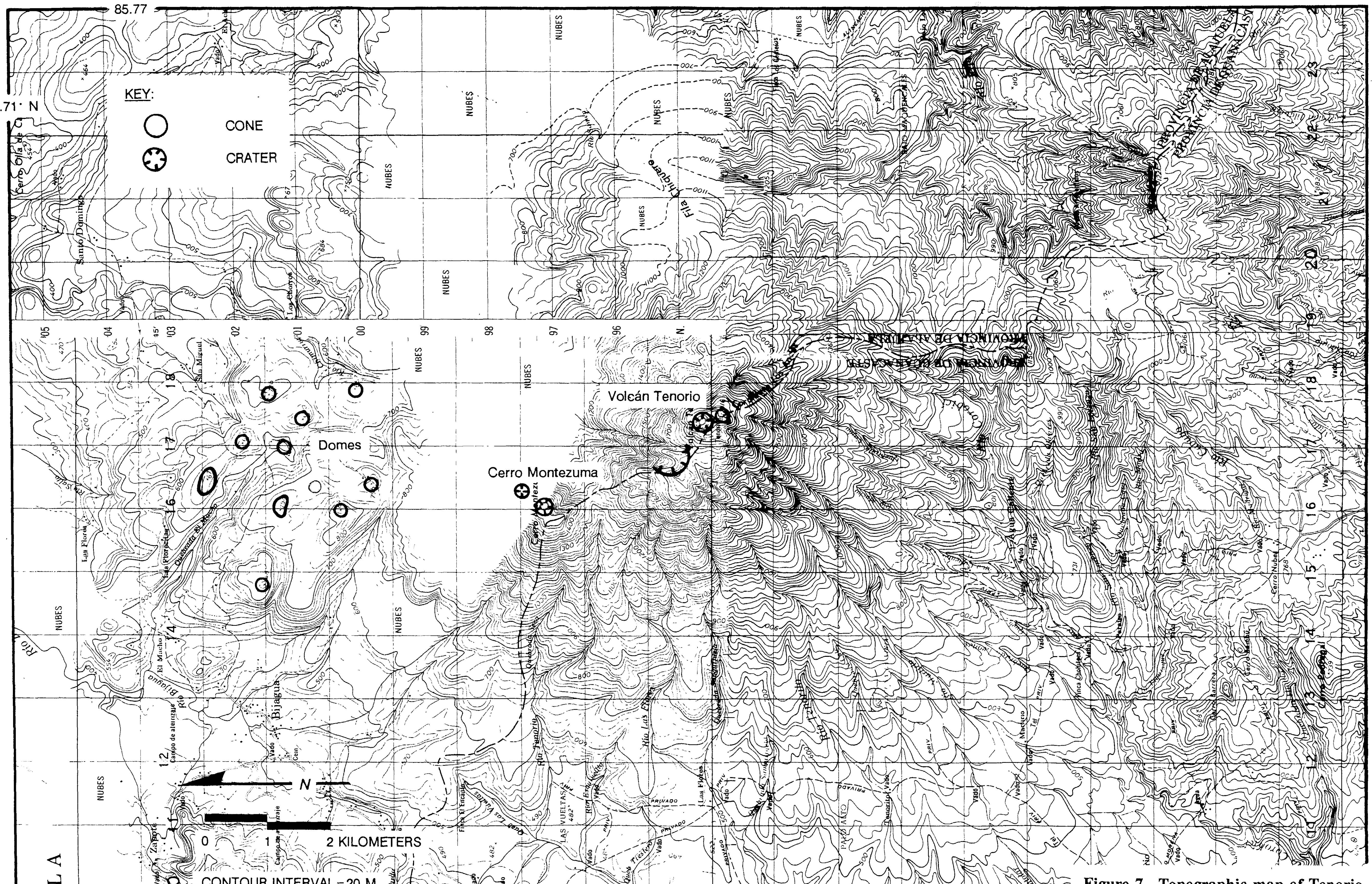

Figure 7. Topographic map of Tenorio.

This map is preliminary and has not been reviewed for conformity with U.S. Geological Survey editorial standards. Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

ROCK TYPE: Augite-hypersthene andesite and olivine basalt (Alvarado, 1989)

THERMAL MANIFESTATIONS: Fumaroles named Los Quemados cover 2500 m^2 and are located on the northeast flank of the volcano at 965 m; hot springs named La Casa are located 1 km to the north.

HISTORICAL ERUPTIONS: None

ACCESS: Canas Road leads to Bijagua at the base of the volcano.

MONITORING

SEISMIC MONITORING: None

DEFORMATION MONITORING: None

GAS AND FUMAROLE MONITORING: Hot springs have been sampled for Ph, temperature, sulfur, chloride, and fluoride (OVSICORI). Frequency of measurements is unknown.

SIGNS OF RECENT UNREST: None

GEOLOGIC MAP: Yes, reconnaissance, 1:50,000, (ICE). There is also a reconnaissance geomorphology study at 1:50,000 (OVSICORI).

HAZARD MAP: None

TOPOGRAPHIC MAPS:

- Miravalles, Sheet 3148 II, 1966, U.S. Army Map Service, Washington, D.C., 1:50,000.
- Tierras Morenas, Sheet 3147 I, 1966, U.S. Army topographic Command, Washington, D.C., 1:50:000.
- Arenal, Sheet 3247 IV, 1965, Instituto Geográfico Nacional, San José, Costa Rica, 1:50,000.
- Guatuso, Sheet 3248 III, 1965, Instituto Geográfico Nacional, San José, Costa Rica, 1:50,000.

AERIAL PHOTOGRAPHS (Tenorio):

DATE	SCALE	ROLL NUMBER	FLIGHT LINE	FRAME NUMBERS
1977	1:35,000	R119	-	9215-9218

GEOLOGIC WORKERS (Name, specialty, date referring to publications found in Bibliography):

- Alvarado, general geology, 1989
- Barquero, J., historical eruption record, unpublished
- Bravo, geomorphology, 1989

ARENAL

GENERAL GEOLOGIC SETTING: Arenal is located at the east end of Laguna de Arenal in the Cordillera de Guanacaste. It is an active, symmetrical, small-volume cone growing 3 km northwest of the dissected remains of a smaller inactive volcanic center, Cerro Chato (fig. 2, 8). The active cone is largely composed of basaltic-andesite lava flows with subordinate tephra deposits (Melson, 1982). Arenal is thought to have begun erupting about 3000 years ago (Borgia and others, 1988), giving an average eruption rate of .01 km^3/year. Until 1968, Arenal was considered inactive. But on July 29, 1968, after 10 hours of felt earthquake activity, an eruption destroyed 12 km^2 of forest and formed 3 new craters on the western flank. These 3 craters and the main fumarolic area are arranged along a NW-SE fissure. Pyroclastic flows were emplaced in major drainages, killing 78 people; ash was deposited to the west. The explosive phase was followed by the extrusion of a blocky lava flow (Minakami and Utibori, 1969) which has continued during 23 years since the onset of activity. Losses have been estimated at $850,000. Older pyroclastic deposits more voluminous than those produced in 1968 are seen on the flanks.

ERUPTIVE STYLE AND HAZARDS: The 1968 eruption was characteristic of the volcano's typical eruptive style as suggested by the stratigraphic record: long periods of repose (300 ± 150 years), followed by a short, intense plinian explosive phase that produces small-volume pyroclastic flows and then grades into a largely effusive phase. At least 9 such eruptions have occurred over the past 3000 years (Borgia and others, 1988).

EVALUATION OF ACTIVITY AND RISK: The Sangregado Hydroelectric Dam, located 6.5 km WNW of the summit on the Río Arenal, produces 60% of the electricity for Costa Rica. Tephra events and mudflows could seriously impact the dam and surrounding settlements. Very young appearing mudflows on the east flank of Arenal near the Río Burio may indicate high potential for destruction of the downstream town of La Fortuna (pop. 3000). There also is a possibility that moderate sized debris avalanches could impact the lake and dam through collapse of part of the steep flanks. The blocky lava flow continues to be extruded accompanied by frequent explosions of gas, vapor, ash, and ballistic fragments. As long as this activity continues, risk in the near field from ballistic fragments remains high, and in 1988, one climber was killed and another was injured by such projectiles. Acid rain from the summit gas plume renders the western slopes unsuitable for agriculture. Because only small-volume pyroclastic flows and tephra deposits are known in the geologic record, voluminous pyroclastic eruptions are not anticipated (Field reconnaissance by Banks).

PROXIMAL POPULATION AT RISK: The population at risk is relatively low. The Sangregado Hydroelectric Dam, 6.5 km WNW of the summit, and the towns of La Fortuna, east of the summit in the Río Burio valley are at risk if there is renewed intense activity.

ARENAL

QUADRANT	POPULATION 0-5 KM	POPULATION 5-10 KM
NE	129	582
SE	39	-
SW	24	-
NW	-	228

(Data from G. Alvarado, ICE)

GENERAL VOLCANO INFORMATION
TYPE OF VOLCANO: Stratovolcano
LATITUDE: 10.47 N
LONGITUDE: 84.73 W
LOCATION: Guanacaste Cordillera
ELEVATION AT SUMMIT: 1633 m
ELEVATION AT BASE: 550 m
RADIUS: 2.7 km
ESTIMATED VOLUME OF VOLCANIC EDIFICE: 15 km^3 (Carr, 1984)
CRATER DIAMETER: 100 m
CRATER DEPTH: 20 m
ESTIMATED AGE OF VOLCANO: 3000 ybp (Borgia and others, 1988)
ROCK TYPE: Andesite, and basaltic andesite (Alvarado, 1989)
THERMAL MANIFESTATIONS: Fumaroles are located at the summit and on the north flank.
HISTORICAL ERUPTIONS:
1525 - 0.17 km^3 of eruptive products (Melson and Sáenz, 1973)
1968 - 0.09 km^3 of eruptive products, continuously active to present, pyroclastic flows, ash and lava eruptions (Melson and Sáenz, 1973)
ACCESS: E-W road on north side of volcano, from the town of La Fortuna.

MONITORING
SEISMIC MONITORING: Yes
TYPE: One station, telemetered (OVSICORI, 2 more projected)
LOCATION: 1 km from crater (OVSICORI)
DURATION: Since 1984 (OVSICORI)
TYPE: Two stations, telemetered (ICE)
LOCATION: FORTUNA (FOR.), 4 km E of summit; and CHIRIPA, 22.2 km E of summit
DURATION: Since 1974
DEFORMATION MONITORING: Yes
TYPE: Spirit-level tilt, 12 stations (OVSICORI)
LOCATION: PALMA, 3.5 km N of summit; PEÑA, 4 km NNW of summit; TABACON, 3.8 km NW of summit; FINCA, 4.5 km NW of summit; GRITA, 4 km WNW of summit; PERICO, 3 km W of

summit; B-OESTE, 1.9 km W of summit; D-OESTE, 3.5 km W of summit; PAUL-BOX, 3 km SW of summit; FERRETO, 3 km SSW of summit; PLUMA, 3.25 km E of summit; TAJO, 3 km NE of summit

DURATION: Since 1982, measured every 10 weeks.

TYPE: Spirit-level tilt, 9 station (ICE)

LOCATION: B, 1.8 km W of summit; C, 2.2 km WSW of summit; D, 3.3 km WSW of summit; E, 2.2 km N of summit; F, 2.8 km N of summit; G, 3.4 km NNW of summit; I, 1.8 km NE of summit; J, 2.5 km NE of summit; K, 3.2 NE of summit

DURATION: Since 1982

TYPE: Electronic tilt, 2 stations (OVSICORI)

LOCATION: near C-OESTE, 2.1 km W of summit; HIDALGO, 3.7 km NE of summit

DURATION: Every 2 weeks since 1983 (read by hand-held meter)

TYPE: EDM (OVSICORI), 2 lines, measured every 2 weeks

LOCATION: West side and east side

DURATION: Since 1984

TYPE: Gravity (ICE)

LOCATION: Stations are arranged in a line E and W of the volcano; additional stations are located to the N of the summit.

DURATION: No information

GAS AND FUMAROLE MONITORING: Yes

- 6 sites for geochemical sampling of water (OVSICORI)
- 9 sites for geochemical sampling of water (ICE)
- 6 sites for radon cups since 1981 (OVSICORI).
- 7 stations to measure acid rain (OVSICORI).
- In affiliation with Dr. J.L. Cheminee of the Centre Nationale Francais de l'Investagation Scientifique and OVSICORI, measurements of gas, condensates, fumarole temperatures, compositions, and proportions of isotopes since 1979.
- Frequency of measurements varies from 2 to 8 weeks.

SIGNS OF RECENT UNREST: Eruptive activity continues since 1968. Lava flow is still being emitted; summit explosions and light ashfalls occur frequently.

GEOLOGIC MAP: Yes, Malavassi, detailed, 1:10,000, 1980

HAZARD MAP: 1:50,000, Being developed by Eduardo Malavassi, Guillermo Alvarado, and Andrea Borgia.

TOPOGRAPHIC MAPS:

- Fortuna, Sheet 3247 II, 1981, MOPT, San José, Costa Rica, 1:50,000.
- Tilaran, Sheet 3246 IV, 1982, MOPT, San José, Costa Rica, 1:50,000.
- Arenal, Sheet 3247 IV, 1965, Instituto Geográfico Nacional, San José, Costa Rica, 1:50,000.
- Monterrey, Sheet 3247 I, 1969, U.S. Army Topographic Command, Washington, D.C., 1:50:000.

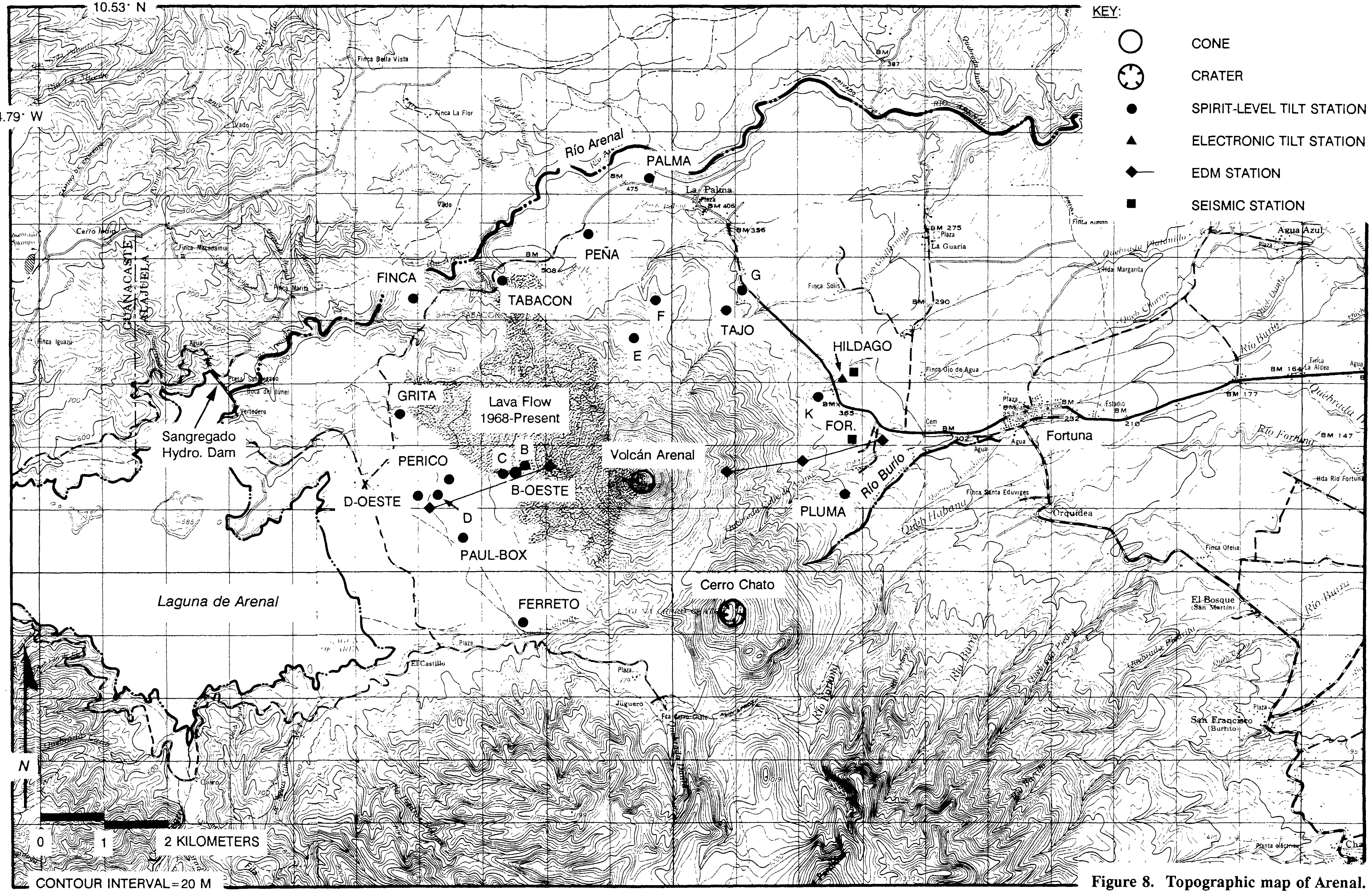

Figure 8. Topographic map of Arenal.

This map is preliminary and has not been reviewed for conformity with U.S. Geological Survey editorial standards. Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

AERIAL PHOTOGRAPHS (Arenal):

DATE	SCALE	ROLL NUMBER	FLIGHT LINE	FRAME NUMBERS
1988	1:30,000	R251	-	43753-43577

GEOLOGIC WORKERS (Name, specialty, date referring to publications found in Bibliography):

- Alvarado, general geology, 1989
- Barquero, J., historical eruption record, unpublished
- Borgia, structure, stratigraphy, petrology, 1983, 1988
- Carr, physical and geochemical characteristics, 1984
- Casadevall, plume geochemistry, 1984
- Corrado, lava flow dynamics, 1984
- Fudali, eruption dynamics, 1977
- Malavassi, geology, petrology, 1979, 1982
- Melson, geology, geochemistry, eruption cycles, radiocarbon dates, 1973, 1982, 1984, 1986; on-going eruption monitoring
- Minakami, geology, eruption chronology, 1969
- Reagan, geochemistry, 1987
- Stoiber, tectonics, 1973
- Wadge, eruption rates, 1982a, 1983

PLATANAR

GENERAL GEOLOGIC SETTING: Cerro Platanar is the northernmost volcano in the Cordillera Central, located 25 km north of the Valle Central (fig. 2). The volcano appears to have been built within an old caldera (Alvarado, 1989). The age of Platanar's activity is unknown. The crater is breached, probably by erosion, to the NW (fig. 9), and the topography of the walls and floor of the crater is subdued and strongly modified by erosion associated with heavy annual rainfall. The crater floor is terminated by a steep cliff, perhaps the edge of an old crater-filling lava lake. There is, however, a thin layer of phreatic ash to the west, probably from an eruption within the past 3000 years. All exposed lava flows are deeply weathered and covered by thick soil. There is no sign of hummocky terrain in the adjacent Río Platanar valley or in the town of Quesada, 8 km from the summit, to suggest that a debris avalanche contributed to breaching of the crater. However, terraces that may be underlain by old mudflows extend through and beyond the town (Field reconnaissance by Banks). Porvenir, a small stratovolcano located 3 km south of Platanar, and Cerros Palmira, a cluster of highly eroded Quaternary volcanoes located 12.5 km south of Platanar, are located within the same caldera. Volcán Viejo and the Caldera de Río Segundo are located southeast of Platanar. According to Alvarado (1989) these features are eroded volcanic sediments, not volcanoes. However, there were 2 active fumaroles located in the vicinity of Viejo until 1960.

ERUPTIVE STYLE AND HAZARDS: Large prehistoric mudflow deposits extend from the deeply weathered, oversteepened crater walls down the Río Peje valley to the town of Florencia. Lack of geologic studies preclude further evaluation of the eruptive style and hazards but the thick, deeply weathered soils indicate dormancy or very long repose periods between eruptions.

EVALUATION OF ACTIVITY AND RISK (1989): The highest risk is from mudflows, debris avalanches, and airfall tephra. Due the prevailing wind direction, airfall deposits would be concentrated in the northern Valle Central.

PROXIMAL POPULATION AT RISK: Most of the population is located to the north and west of the volcano in the towns of Quesada and Aguas Zarcas. The major industries are vegetable and cattle farming.

PLATANAR

QUADRANT	POPULATION 0-5 KM	POPULATION 5-10 KM
NE	-	759
SE	12	63
SW	189	759
NW	48	1230

(Data from G. Alvarado, ICE)

GENERAL VOLCANO INFORMATION

TYPE OF VOLCANO: Stratovolcano
LATITUDE: 10.30 N
LONGITUDE: 84.37 W
LOCATION: Cordillera Central
ELEVATION AT SUMMIT: 2183 m
ELEVATION AT BASE: 1000 m
RADIUS: 5.5 km
ESTIMATED VOLUME OF VOLCANIC EDIFICE: 50 km^3 (Carr, 1984)
CRATER DIAMETER: (deeply eroded) Approximately 500 m
CRATER DEPTH: Not applicable
ESTIMATED AGE OF VOLCANO: Unknown
ROCK TYPE: Pyroxene andesite (Alvarado, 1989)
THERMAL MANIFESTATIONS: None
HISTORICAL ERUPTIONS: None
ACCESS: Follow Road #140 from Quesada to the NE. There are several unimproved roads from the southeast that lead up to 1440 m.

MONITORING

SEISMIC MONITORING: Yes
TYPE: One station, telemetered (OVSICORI)
LOCATION: No information
DURATION: No information

DEFORMATION MONITORING: Yes
TYPE: Spirit-level tilt, 2 stations (OVSICORI)
LOCATION: HUGO, 4 km SW of the summit; VARELA, 2 km SW of summit
DURATION: Since May, 1982, every 24 weeks. No changes have been observed.

GAS AND FUMAROLE MONITORING: None

SIGNS OF RECENT UNREST: Yes, there was felt seismicity in 1980, which was confirmed with a temporary seismic net (Guendel, pers. comm.).

GEOLOGIC MAP: Yes, 1:50,000, reconnaissance, by Guillermo Alvarado

HAZARD MAP: None

TOPOGRAPHIC MAPS:

- Aguas Zarcas, Sheet 3347 III, 1970, U.S. Army Topographic Command, Washington, D.C., 1:50:000.
- Quesada, Sheet 3346 IV, 1970, U.S. Army Topographic Command, Washington, D.C., 1:50:000.

AERIAL PHOTOGRAPHS (Platanar):

DATE	SCALE	ROLL NUMBER	FLIGHT LINE	FRAME NUMBERS
1961	1:25,000	R143	-	6636-6639
1977	1:35,000	R019	L3A	713-764

GEOLOGIC WORKERS (Name, specialty, date referring to publications found in Bibliography):

- Alvarado, general geology, 1989
- Barquero, J., historical eruption record, unpublished
- Paniagua and Soto, volcanic hazards, 1988

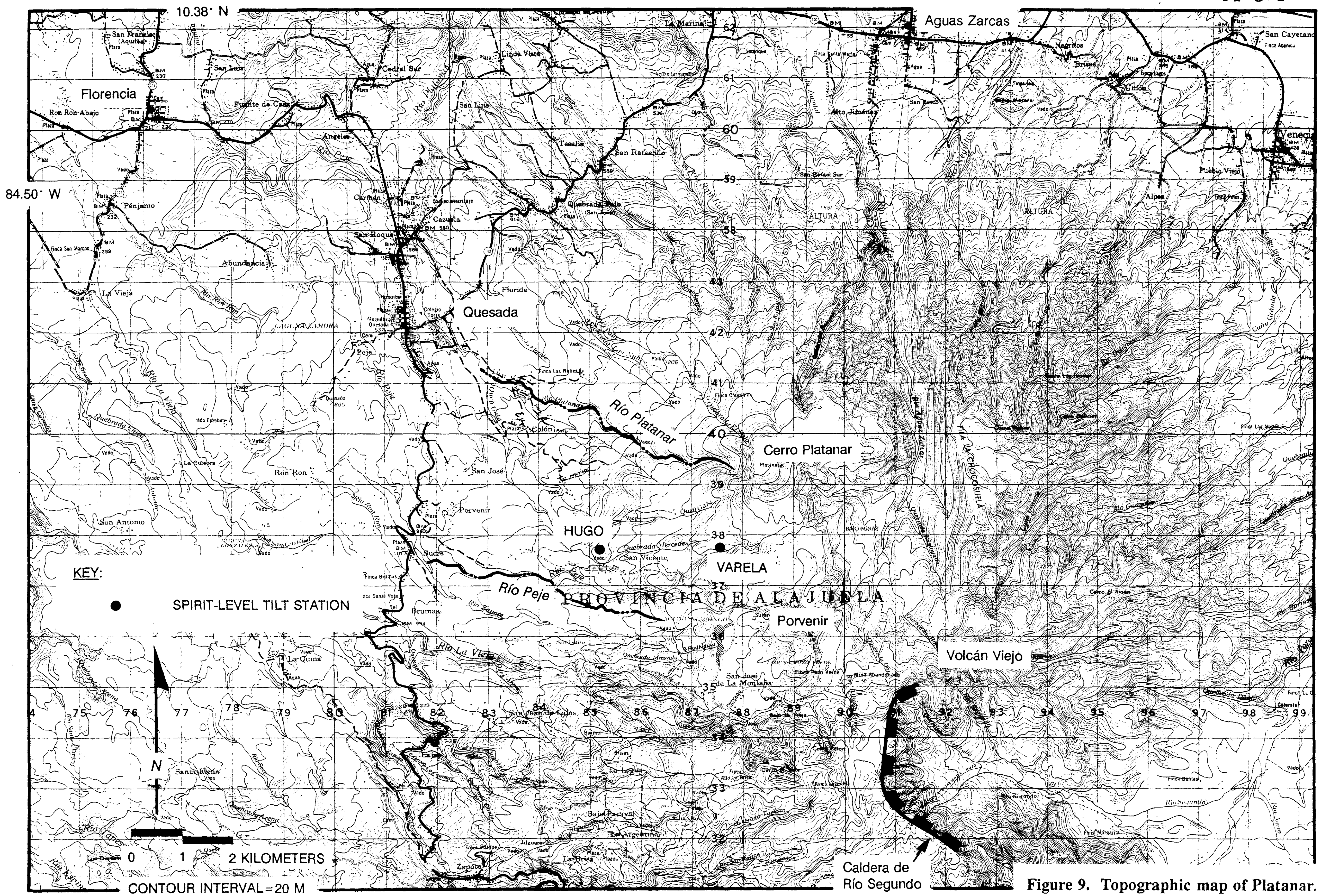

Figure 9. Topographic map of Platanar.

This map is preliminary and has not been reviewed for conformity with U.S. Geological Survey editorial standards. Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

POÁS (also referred to as Los Botos)

GENERAL GEOLOGIC SETTING: Poás is located at the northern margin of the Valle Central, 20.5 km north of the town of Alajuela. It is a large basaltic-andesite composite volcano with a rounded dome-like shape and gently sloping flanks (fig. 2, 10). Two poorly preserved nested calderas with diameters of 12 and 8 km are recognized by Mooser and others (1958). All historical activity has been phreatic and phreatomagmatic and has taken place within the inner caldera which formed >40,000 years ago. Several other features have developed since the calderas formed. Aligned from north to south are 1) the Von Frantzius Cone, an eroded composite cone with a crater breached to the south, 2) the Main Crater, a .8 km diameter collapse crater which contains the hot, acid Laguna Caliente, and 3) the Botos Cone, a cone smaller and younger than the Von Frantzius Cone which contains Laguna Del Poas, a cold freshwater lake (Prosser and Carr, 1987).

High annual rainfall has contributed to the deep weathering and erosion of the north slope of the volcanic edifice, and deposits on all the flanks are very deeply weathered, with no intermixed tephra in the 1- to 2-m-thick soil.

Volcán Congo and a series of lake-filled maars and small calderas, the largest of which is Laguna Hule lie on the lower northern flanks of the Poás complex, generally in alignment with the NNE-aligned craters and cones on Poás' summit (Alvarado, 1989). These maars and small calderas have youthful morphology and Melson (1988) reports a radiocarbon age of 5,140 ± 110 ybp for a pyroclastic-flow deposit from Volcán Congo. Similarly youthful features are not apparent on the southern flanks of Poás.

ERUPTIVE STYLE AND HAZARDS: A study by Prosser (1987) of recent summit lava flows defines three intermediate to mafic compositional cycles, each lasting from 1,000 to 10,000 years. Prosser observed that a new, intermediate lava sequence is associated with a change in location or structure of the active vent. Mafic lava compositions (50% SiO_2) signal the end of an eruptive cycle. An analysis of these trends indicates repeated fractionation of a slowly cooling magma chamber deep in the crust. The present cycle was initiated >7,540 years ago. Less than 7,000,000 m^3 of volcanic material has been produced in historical times.

Four types of activity have been observed historically at Poás: 1) phreatic geyser-like explosions at variable intervals, 2) violent, but small volume, phreatic eruptions that produce ash that falls as far as the Valle Central, 3) strombolian and effusive activity, and 4) quiet degassing (Prosser, 1983). In the Main Crater, the site of all historical activity, pyroclastic deposits are about twice as abundant as lava flows (Prosser, 1986).

Rymer and Brown (1987) have suggested that microgravity variations measured at Poás since 1983 indicate subsurface density changes have occurred. They conclude that the fluctuations in volume of gas in the underlying magma, a process driven by thermal convection cycles, can account for these changes.

EVALUATION OF ACTIVITY AND RISK: Poás has been frequently active since first explored by the Spanish in 1747. Eruptions have consisted of small phreatic and strombolian events and have deposited mud, ash, and pumice to a distance of 12 km (Walker, 1982). In 1971, the summit was made into a national park, which receives over 60,000 visitors per year. There is a high probability for small, infrequent phreatic and strombolian eruptions that create moderate to high hazards to visitors to the park in the summit area. However, the park is closed immediately following any signs of increased activity. Probability for a large eruption is low; also probability of large mass failures of the flanks is moderate on the N and E slopes, but low on the SW slopes (Field reconnaissance by Banks).

Distribution of tephra-fall deposits is controlled by the prevailing low-level northeasterly winds. As a result, deposits of future eruptions would most likely affect the southwestern flanks. Gas, acid rain, and acid leachate from ash and tephra have seriously impacted the local economy by damaging or destroying cash crops during past eruptions. Commercial coffee, sugar cane, fruit, and vegetable farms share the flanks of the volcano with livestock farms, all of which could suffer heavy losses through contamination of forage and water supplies.

The start of the last episode of activity began with increased gas temperature and seismic swarms in January 1981 and has continued through 1991. In June 1987, lake acidity increased by a factor of 4. Several 200- to 300-m-high, geyser-like eruptions occurred in March and April 1988. The crater lake disappeared in April 1989 and explosive activity deposited traces of lake sediments and lithic ash up to 20 km west of the summit (Guendel, pers. comm., 1989). Acid rain affected the economy and the health of the population located as far as 11 km from the summit on the NW flank of the volcano. Coffee plants and other vegetation died. In addition, many people are suffering from respiratory problems (Barquero, SEAN, 1989).

PROXIMAL POPULATION AT RISK: The summit area is a national park and receives 60,000 visitors a year (Prosser, 1983). Additionally, the southern and western flanks are populated with farms producing sugar cane, coffee, dairy products, strawberries, and commercial flowers.

POÁS

QUADRANT	POPULATION 0-5 KM	POPULATION 5-10 KM
NE	-	291
SE	-	810
SW	-	780
NW	-	264

(Data from G. Alvarado, ICE)

GENERAL VOLCANO INFORMATION

TYPE OF VOLCANO: Stratovolcano
LATITUDE: 10.20 N
LONGITUDE: 84.22 W
LOCATION: Central Cordillera, 35 km NW of San José
ELEVATION AT SUMMIT: 2704 m
ELEVATION AT BASE: 1200 m
RADIUS: 8.7 km
ESTIMATED VOLUME OF VOLCANIC EDIFICE: 95 km^3 (Carr, 1984)
CRATER DIAMETER: 1.5 km
CRATER DEPTH: 275 m
ESTIMATED AGE OF VOLCANO: >1 my (Sáenz, 1982)
ROCK TYPE: Andesite, basaltic andesite (Alvarado, 1989)

THERMAL MANIFESTATIONS: Fumaroles and a hot lake located in the Main Crater.
HISTORICAL ERUPTIONS:
1834 - Ash as far as 40 km to the southwest (Boza and Mendoza, 1981)
1838 - Eruption uncertain (Mooser and others, 1958)
1880 - Phreatic explosions (Mooser and others, 1958)
1907 - Phreatic explosions (Mooser and others, 1958)
1910 - Phreatomagmatic eruption, 8-km-high eruption cloud, ashfall in San José 33 km to the SW (Casertano and others, 1985)
1914 - Phreatic explosions (Mooser and others, 1958)
1914 - Phreatic explosions (Mooser and others, 1958)
1946 - Phreatic explosions (Hantke, 1951)
1952 - Phreatic explosions, the plume reached 7 km in altitude and ashfall was reported 15 km away (Barquero and Malavassi, 1982)
1961 - No details (Bull. of Volcanic Eruptions, 1964)
1963 - No details ((Bull. of Volcanic Eruptions, 1965))
1964 - Steam and ash eruptions (Krushensky and Escalante, 1967)
1967 - No details (Bull. of Volcanic Eruptions, 1972)
1969 - Phreatic explosions (Bull. of Volcanic Eruptions, 1972)
1972 - Explosions through crater lake (Bull. of Volcanic Eruptions, 1974, 1975)
1974 - Phreatic explosions (Bull. of Volcanic Eruptions, 1976, 1977)
1976 - Explosions through crater lake (Simkin and others, 1981)
1977 - A column of water, ash, and mud rose more than 1 km above the vent (McClelland and others, 1989)
1978 - explosions, gas emissions (McClelland and others, 1989)
1979 - Phreatic activity (McClelland and others,1989)
1980 - Continuous phreatic activity (McClelland and others,1989)
1987 - Phreatic activity (Barquero, pers. comm.)
1988 - Phreatic activity (Barquero, pers. comm.)
1989 - Phreatic activity (Barquero, pers. comm.)
1991 - Phreatic activity (Barquero, pers. comm.)
ACCESS: Paved road to the summit from the south

MONITORING
SEISMIC MONITORING: Yes
TYPE: One station, telemetered (OVSICORI)
LOCATION: POA2, 2 km SW of summit
DURATION: Since 1984
TYPE: Five stations (ICE)
LOCATION: No information
DURATION: Since 1991
TYPE: One station (UCR)
LOCATION: In park museum
DURATION: No information
DEFORMATION MONITORING: Yes
TYPE: Spirit-level tilt, 11 active stations (OVSICORI). No significant changes were detected during 1982-1987 nor during the phreatic activity of 1987-1988.
LOCATION: PICNIC, 200 m S of crater rim on the road; LANCE, 2 km SW of summit; SANTA ROSA, 10 km SW of summit; SAN JUAN

NORTE, 8 km SSW of summit; GUIDO, 9.5 km SSE of summit; SABANA REDONDA, 8 km SE of summit; OMAR, 4 km SE of summit; FLORY, 4.7 km SE of summit; TIROL-3, 5.1 km SE of summit; TERRANOVA, 5.8 km SE of summit; LA PAZ, 6.1 km SE of summit;

DURATION: Since 1982, measured every 10 weeks

TYPE: EDM, 1 line (OVSICORI)

LOCATION: Across crater

DURATION: Since 1984, measured every 10 weeks. No changes were detected from 1984 through 1987; slight line shortening was reported before the 1987-1988 phreatic activity.

TYPE: Electronic tilt, 2 stations (OVSICORI)

LOCATION: GUIDO, 9.5 km SSE of summit; PICNIC, 200 m south of the crater rim on the road. No changes larger than noise (10 urads) observed over period of measurements.

DURATION: Since 1984, measured every 2 weeks (read by hand-held meter)

TYPE: Leveling

LOCATION: 1) 15 km first order line from San Pedro to summit in 1974 and 1982 (no change) (OVSICORI); 2) 15 km 12 station trigonometric level line (French, March 1982); 3) 18 km radial line measured every 3 years (OVSICORI)

DURATION: Measured in 1982 and 1988

TYPE: Gravity, 18 stations, Rymer and Brown, of the Open University, Milton Keyes, U.K., cyclic variations spanning a 140 uGal amplitude change.

LOCATION: Net spans the Main Crater and crater rim

DURATION: Since 1983

TYPE: Crack measurement (OVSICORI)

LOCATION: No information

DURATION: No information

GAS AND FUMAROLE MONITORING: Yes

- Measurements of fumarole gas (sulfur, chloride, and fluoride) and temperature measurements at the summit every 4 weeks (OVSICORI, ICE)
- Measurements of the lake water: Ph, temperature, sulfur, chlorine, and fluorine (OVSICORI, ICE)
- 9 sites, radon cups measured every 2 weeks (OVSICORI)
- 7 site acid rain network measured every 2 weeks (OVSICORI)

SIGNS OF RECENT UNREST: Yes, increased lake temperature, fumarolic activity, acid rain, microgravity changes since 1985, currently in eruption.

GEOLOGIC MAP: Yes, Prosser (1983), unpublished M.S. thesis, 1:4,500. There is also a detailed 1:4,500 geomorphology map by OVSICORI.

HAZARD MAP: Yes, reconnaissance, 1:50,000 maps by both OVSICORI and Guillermo Alvarado, Gerardo Soto, and Sergio Paniagua of ICE.

TOPOGRAPHIC MAPS:

- Poás, Sheet 3346 I, 1970, U.S. Army Topographic Command, Washington, D.C., 1:50:000.
- Barba, Sheet 3346 II, 1965, U.S. Army Map Service, Washington D.C., 1:50,000.

- Quesada, Sheet 3346 IV, 1970, U.S. Army Topographic Command, Washington, D.C., 1:50:000.
- Naranjo, Sheet 3346 III, 1980, Instituto Geográfico Nacional, San José, Costa Rica, 1:50,000.

AERIAL PHOTOGRAPHS (Poás):

DATE	SCALE	ROLL NUMBER	FLIGHT LINE	FRAME NUMBERS
1988	1:30,000	R250	-	43211-43215

GEOLOGIC WORKERS (Name, specialty, date referring to publications found in Bibliography):
- Alvarado, general geology, 1989
- Barquero, J., historical eruption record, unpublished
- Brantley, lake chemistry, 1987
- Casadevall, plume geochemistry, 1984
- Casertano, magnetics, seismology, 1982, 1985, 1987
- Fernández, geochemistry, unpublished
- Krushensky and Escalante, geologic mapping, 1967
- Paniagua and Soto, volcanic hazards, 1988
- Prosser, geologic mapping, 1983
- Rymer and Brown, microgravity, 1987

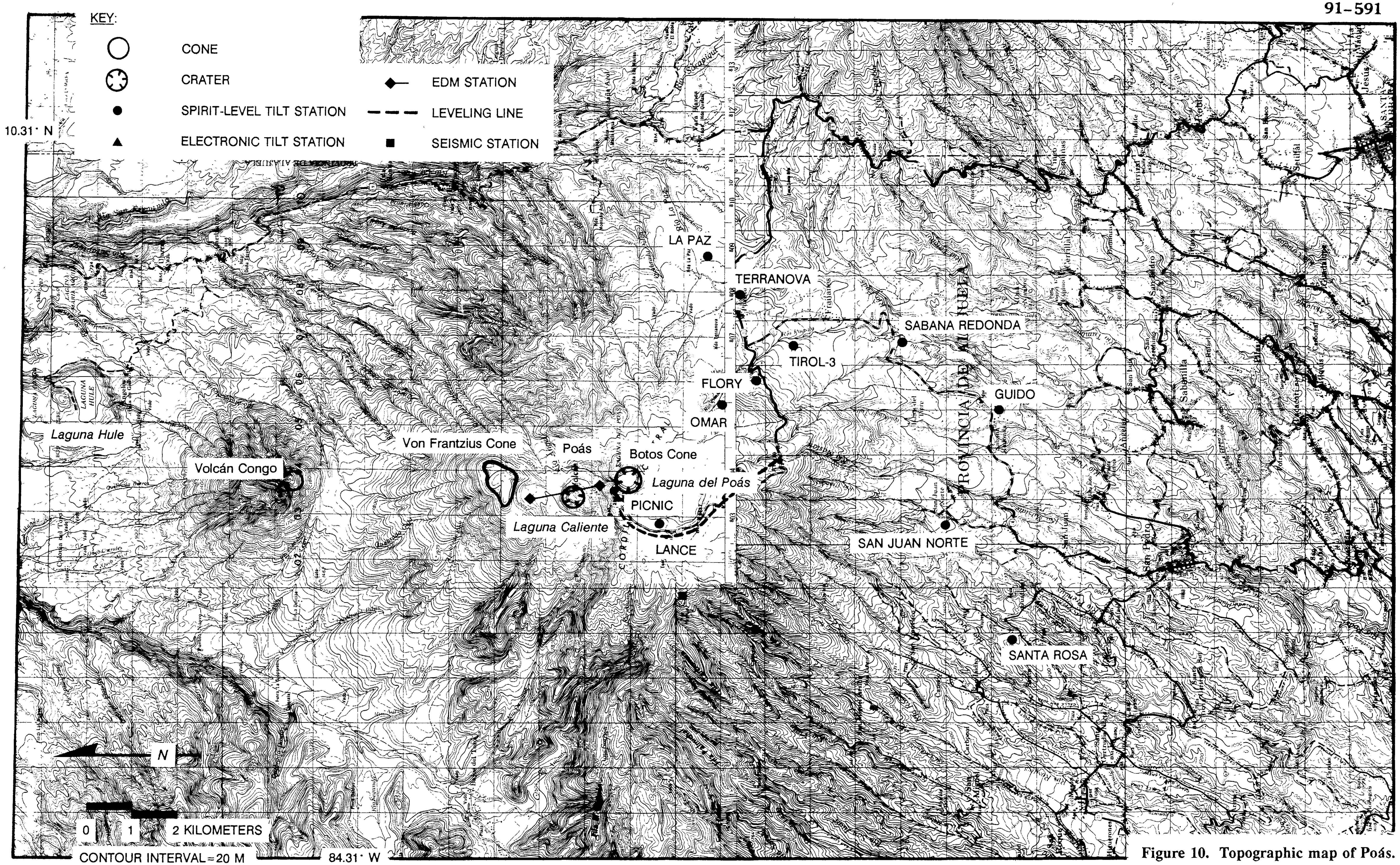

Figure 10. Topographic map of Poás.

BARVA (also spelled Barba)

GENERAL GEOLOGIC SETTING: Barva, located at the northern margin of the Valle Central 20 km north of San José, is a large composite volcano with many vents and parasitic cones (fig. 2, 11). A crater lake occupies one of the old vents. Basaltic-andesite lava flows alternate with thick pyroclastic beds. All deposits on the flanks are very deeply weathered, with tephra intermixed in the 1-2 m thick soil. However, overall weathering appears to be less than is the case for Poás. Thick pyroclastic-flow deposits occur on the western slopes (Field reconnaissance by Banks). Cerro Guararí, located 3.4 km from the summit of Barva, is the erosional remnant of an ancient cone (Alvarado, 1989). Cacho Negro, 9 km NNW of Barva, is the site of thermal springs. A cluster of ancient cones, Cerros Zurquí, is located 11 km SE of Barva (Alvarado, 1989).

ERUPTIVE STYLE AND HAZARDS: The stratigraphic record reveals large explosive eruptions have produced pyroclastic flows at Barva in prehistoric times. However, there are very few geological data available for evaluating Barva.

EVALUATION OF ACTIVITY AND RISK (1989): Barva has been quiet since colonial times, and there have been no indications of seismic or thermal activity. However, the probability of mudflows and mass failures of the flanks, with or without an eruption, is moderate on the east slopes, and lower on the west slopes (Field reconnaissance by Banks). Should an eruption occur, the long repose period and past history of dome formation and pyroclastic flows would elevate Barva to a high hazard status. Tephra dispersal would be dominantly controlled by the prevailing low-level northeast winds (depositing ash on the southwest flanks).

PROXIMAL POPULATION AT RISK: The southern and western flanks are moderately populated. The local economy is dominated by sugar cane, coffee, and dairy farms.

BARVA

QUADRANT	POPULATION 0-5 KM	POPULATION 5-10 KM
NE	15	-
SE	54	282
SW	138	2067
NW	93	561

(Data from G. Alvarado, ICE)

GENERAL VOLCANO INFORMATION

TYPE OF VOLCANO: Stratovolcano
LATITUDE: 10.13 N
LONGITUDE: 84.08 W
LOCATION: Central Cordillera, 23 km N of San José
ELEVATION AT SUMMIT: 2894 m

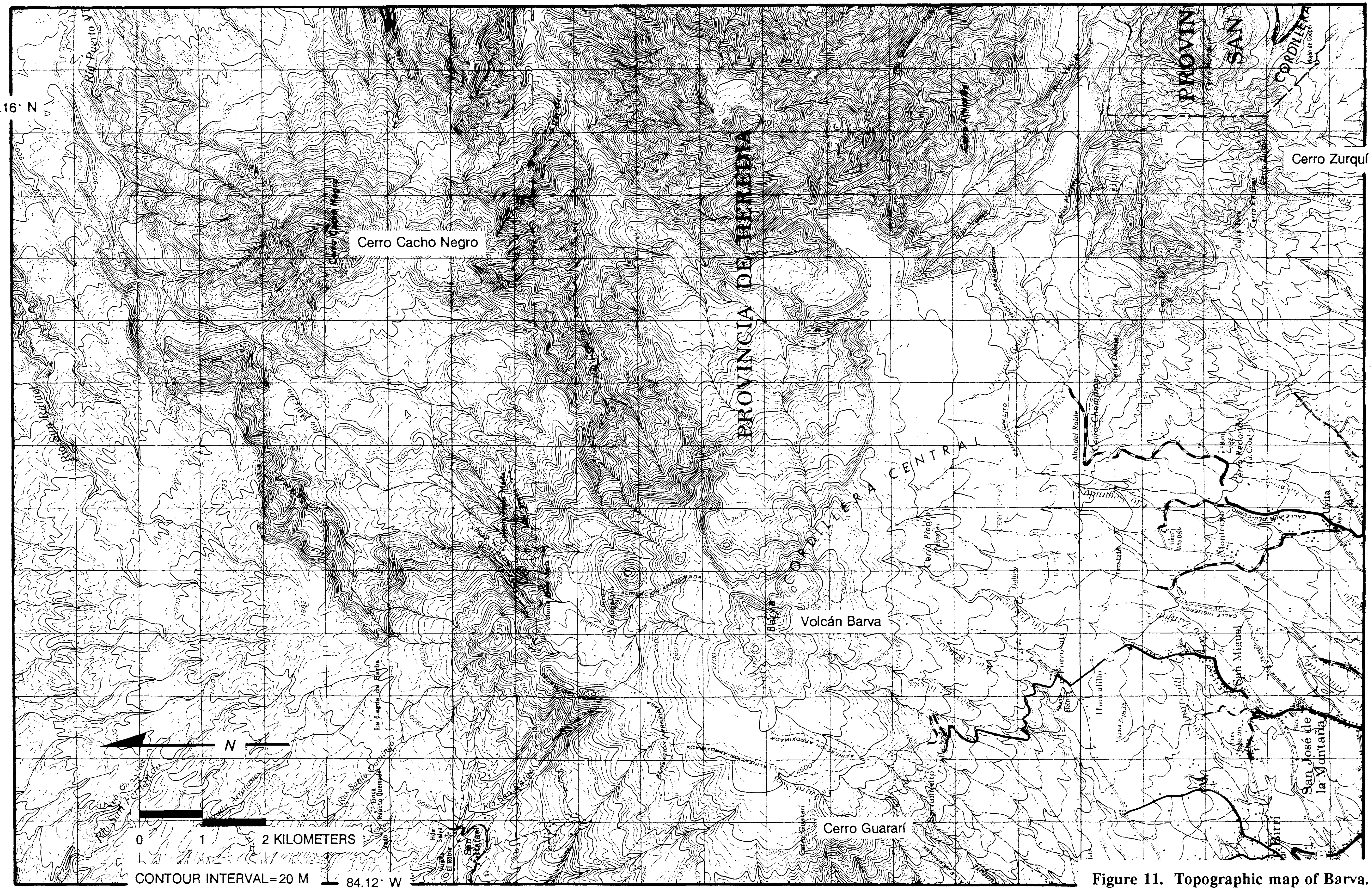

Figure 11. Topographic map of Barva.

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ELEVATION AT BASE: 1500 m
RADIUS: 8.3 km
ESTIMATED VOLUME OF VOLCANIC EDIFICE: 255 km^3 (Carr, 1984)
CRATER DIAMETER: .8 km
CRATER DEPTH: No information
ESTIMATED AGE OF VOLCANO: 1 million ybp (Alvarado, 1989)
ROCK TYPE: Basalt to andesite
THERMAL MANIFESTATIONS: Hot springs are located 4 km north of the summit.
HISTORICAL ERUPTIONS:
1770 or 1776 - Explosions (?) and mudflow in the Río Itiquís valley (Von Frantzius, 1981)
ACCESS: There is a road from the south to 2300 m.

MONITORING
SEISMIC MONITORING: None
DEFORMATION MONITORING: None
GAS AND FUMAROLE MONITORING: None
SIGNS OF RECENT UNREST? No

GEOLOGIC MAP: Yes, reconnaissance, 1:50,000 by Sergio Paniagua and Gerardo Soto.
HAZARD MAP: Yes, reconnaissance, 1:50,000, by Sergio Paniagua and Gerardo Soto.
TOPOGRAPHIC MAPS:
- Barba, Sheet 3346 II, 1965, U.S. Army Map Service, Washington D.C., 1:50,000.

AERIAL PHOTOGRAPHS (Barva):

DATE	SCALE	ROLL NUMBER	FLIGHT LINE	FRAME NUMBERS
1977	1:35,000	R003	L13	27-31

GEOLOGIC WORKERS (Name, specialty, date referring to publications found in Bibliography):
- Alvarado, general geology, 1969
- Barquero, J., historical eruption record, unpublished
- Paniagua and Soto, volcanic hazards, 1988

IRAZÚ (also referred to as Volcán de Cartago)

GENERAL GEOLOGIC SETTING: Irazú is the highest volcano in Costa Rica and is one of the most active. It forms part of the northern margin of the Valle Central 24 km due east of San José. The volcanic edifice is composed of interbedded deposits of ashfall, pyroclastic flows, mudflows, and lava flows produced at the central crater and at flank vents (fig. 2, 12). An old crater, Diego de la Haya, is located .5 km to the east of the present active crater. According to Sapper (1925) Diego de la Haya was the site of the 1723 eruption. Active fumaroles occur in the main crater and to the NW of the crater. Steep erosional escarpments are present north of the volcano. Cerro Alto Grande, located 4 km NE of the main crater, is an eroded stratovolcano. Cerros Noche Buena, Pasquí, Cabeza de Vaca, Retes, and Guardián are cinder cones on the south flank of Irazú (Alvarado, 1989).

ERUPTIVE STYLE AND HAZARDS: Only pyroclastic ejecta was produced during the 4 major historical eruptive periods (1723, 1726, 1917-21, and 1963-65). Very little of the ejecta was juvenile (Krushensky and Escalante, 1967). Ashfall is thick on the western and northwestern flanks of the volcano. The most recent lava flow occurred approximately 13,500 to 14,000 ybp (Murata and others, 1966). Mudflows and airfall are the greatest hazards.

EVALUATION OF ACTIVITY AND RISK (1989): The 1963-65 phreatic eruptions deposited ash and defoliated 95% of the upper drainages originating on the slopes of the volcano (Krushensky, 1972). The eruptive activity for nearly 2 years produced heavy ashfall that extended as far as the city of San José, 24 km west of the volcano (Murata and others, 1966). These deposits contaminated water supplies and impeded air and surface transportation. Dairy and tobacco farms, coffee plantations, and citrus orchards were severely affected. The surface of ash formed a thin impermeable crust that reduced the infiltration capacity of the soil. Runoff increased causing flash floods that incorporated ash and rock debris downstream (Waldron, 1967). Rain mobilized the ash and debris to generate secondary mudflows that swept down the Río Chiquito, killing 20 people and destroying many structures. Debris flows and erosion were also severe in the Río Reventado valley on the southwest slope where as many as 46 mudflows occurred during a 2-year period, one of which caused the death of at least 20 people and destroyed 400 houses and some factories (Krushensky, 1972). Loss of life was minimized through prior evacuation and river watches. The Río Tiribi, Río Durazna, and Río Virrilla drainages were similarly impacted but to a lesser degree.

PROXIMAL POPULATION AT RISK: The cone itself has been designated a national park. The park receives visitors throughout the year but remains in close contact with monitoring groups. In addition, the area south of the volcano in the Valle Central is moderately populated, and in the far field along the rivers draining the volcano, the population is dense. The western suburbs of Cartago on the Río Reventado are at high risk from flooding and mudflows.

IRAZÚ

QUADRANT	POPULATION 0-5 KM	POPULATION 5-10 KM
NE	63	216
SE	397	1287
SW	321	1536
NW	21	90

(Data from G. Alvarado, ICE)

GENERAL VOLCANO INFORMATION

TYPE OF VOLCANO: Stratovolcano
LATITUDE: 09.89 N
LONGITUDE: 83.85 W
LOCATION: Central Cordillera, 14 km NNE of Cartago
ELEVATION AT SUMMIT: 3432 m
ELEVATION AT BASE: 1600 m
RADIUS: 11 km
ESTIMATED VOLUME OF VOLCANIC EDIFICE: 300 km^3 (Carr, 1984)
CRATER DIAMETER: 200 m
CRATER DEPTH: 50 m
ESTIMATED AGE OF VOLCANO: Unknown
ROCK TYPE: Andesite, basalt
THERMAL MANIFESTATIONS: Las Fumarolas are located northwest of the primary crater.
HISTORICAL ERUPTIONS:

- 1723 - Ash eruption, mudflows, damage in Cartago. Observations include the smell of sulfur, felt earthquakes, a volcanic plume, red glow at the summit, glowing volcanic bombs, noise, and ash in Cartago. One explosion blew open doors and windows in Cartago (Alvarado, 1989)
- 1726 - No details (Mooser and others, 1958; Barquero, 1976)
- 1821 - Earthquakes, ash eruption (Sáenz and others, 1984)
- 1822 - Ash eruption (Barquero, 1976)
- 1842 - Fumarolic activity, ash eruption (Krushensky and Escalante, 1967)
- 1844 - Fumarolic activity (Barquero, 1976)
- 1847 - No details (Krushensky and Escalante, 1967)
- 1855-1959 - Fumarolic activity (Barquero, 1976)
- 1864 - Light ash reported in San José (Alvarado, 1989)
- 1870 - Fumarolic activity (Barquero, 1976)
- 1880-1888 - Fumarolic activity (Barquero, 1976)
- 1894 - No details (Alvarado, 1989)
- 1899 - No details (Alvarado, 1989)
- 1909 - Ash reported in San José (Alvarado, 1989)
- 1910 - No details (Alvarado, 1989)

1917-1924 - Phreatic eruption with dome extrusion, ash deposited as far as the Gulf of Nicoya (Alvarado, 1989)
1928-1930 - Ash eruptions (Barquero, 1976)
1933 - Ash reported in San José (Alvarado, 1989)
1939-1940 - Ash eruption (Barquero, 1976)
1953 - Fumarolic activity (Barquero, 1976)
1962 - Fumarolic activity (Barquero, 1976)
1963-1965 - Ash fell for several days in San José; rain mobilized ash created destructive mudflows (Murata and others, 1966)
1966-1978 - Fumarolic activity in the crater (Barquero, 1976)
1979-1989 - Fumarolic activity on the NW flank and elevated seismicity (Alvarado, 1989)

ACCESS: There is a road from Cartago north to the summit.

MONITORING

SEISMIC MONITORING: Yes

TYPE: One station, telemetered (OVSICORI)
LOCATION: 3.5 km from crater
DURATION: Since 1983

TYPE: One station, telemetered (ICE)
LOCATION: 1 km from crater
DURATION: since 1980

DEFORMATION MONITORING: Yes

TYPE: Spirit-level tilt, 10 stations (OVSICORI)
LOCATION: SAN GERARDO, 2.5 km NNE of the summit; LIEBRES, 3.5 km E of the summit; CASITA, 2 km E of the summit; PLAYA HERMOSA, .5 km S of the summit; TORRES, 1.7 km SW of the summit; GUARDIAN, 3.5 km S of the summit; PASQUI, 10.75 km S of the summit; MIRADOR, 6.75 km S of the summit; POTRERO CERRADO, 8 km SSW of the summit; TITORAL, 8.25 km SSE of the summit
DURATION: Since May, 1982, every 10 weeks. There has been no change since installation.

TYPE: Electronic tilt, 2 single axis (radial) Sperry tiltmeters (read by hand-held meter) (OVSICORI).
LOCATION: 1) PLAYA HERMOSA, poor data was obtained for 1982-1984, station has been moved to new site on 1.7 km SW of the summit named TORRES. There have been no changes since installation. 2) CASETA, installed in Jan 1986, is located at the guard house at Park Entrance 2 km ESE of the summit. There have been no changes since installation.
DURATION: Measured every 2 weeks since 1982

TYPE: EDM, 2 lines
LOCATION: One line crosses crater; no information on second line.
DURATION: Since 1984, measured every 2 years

TYPE: Leveling, first order, San José to the summit, by the Instituto Geográfico Nacional de Costa Rica
LOCATION: No information

DURATION: in 1949, 1961, 1964, 1966, 1982 and every 3 years thereafter; only small changes recorded.

TYPE: Gravity (Ken Hudmut, Dartmouth) and short leveling line radial to 1963 crater. Lamont-Doherty conducts current gravity measurements.

LOCATION: No information

DURATION: Every 3 years

GAS AND FUMAROLE MONITORING: Yes

- Fumarole gas and temperature measurements at the summit taken once yearly (OVSICORI).
- 5 sites, radon cups measures every 2 weeks (OVSICORI)
- Intermittent measurements of lake water Ph, temperature, sulfur, chlorine, and fluorine.

SIGNS OF RECENT UNREST: Yes, increased fumarolic activity sustained since 1982, seismic swarm in June 1982.

GEOLOGIC MAP: Yes, reconnaissance, 1:50,000 by Krushensky, R. (1972).

HAZARD MAP: Yes, reconnaissance, 1:50,000 by Paniagua and Soto (1986) and Alvarado (1987).

TOPOGRAPHIC MAPS:

- Cartago (Istarú), Sheet 3445 IV, 1968, U.S. Army Map Service, Washington D.C., 1:50,000.

AERIAL PHOTOGRAPHS (Irazú):

DATE	SCALE	ROLL NUMBER	FLIGHT LINE	FRAME NUMBERS
1978	1:35,000	R133	L219	13140-13148

GEOLOGIC WORKERS (Name, specialty, date referring to publications found in Bibliography):

- Alvarado, general geology, 1989
- Barquero, J., historical eruption record, unpublished
- Hudnut, geology and geophysics, 1983
- Krushensky, geologic mapping, 1973
- Mora, volcanic hazards, 1987
- Murata, geology, eruption chronology, 1966
- Paniagua and Soto, volcanic hazards, 1988

Figure 12. Topographic map of Irazú at scale 1:50,000. Filled circles indicate spirit-level tilt stations; open circles indicate electronic tilt stations; x indicates a seismic station.

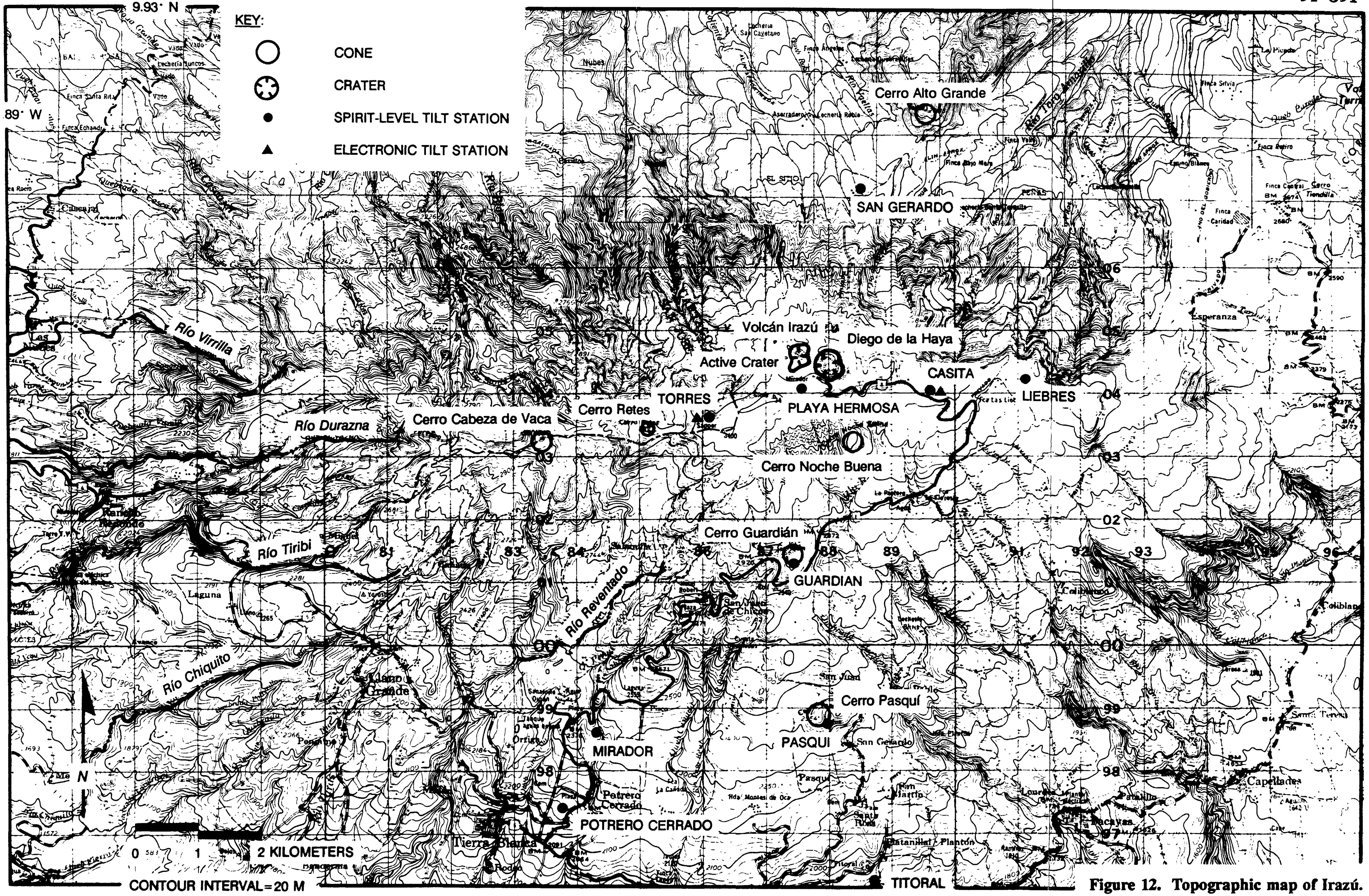

Figure 12. Topographic map of Irazú.

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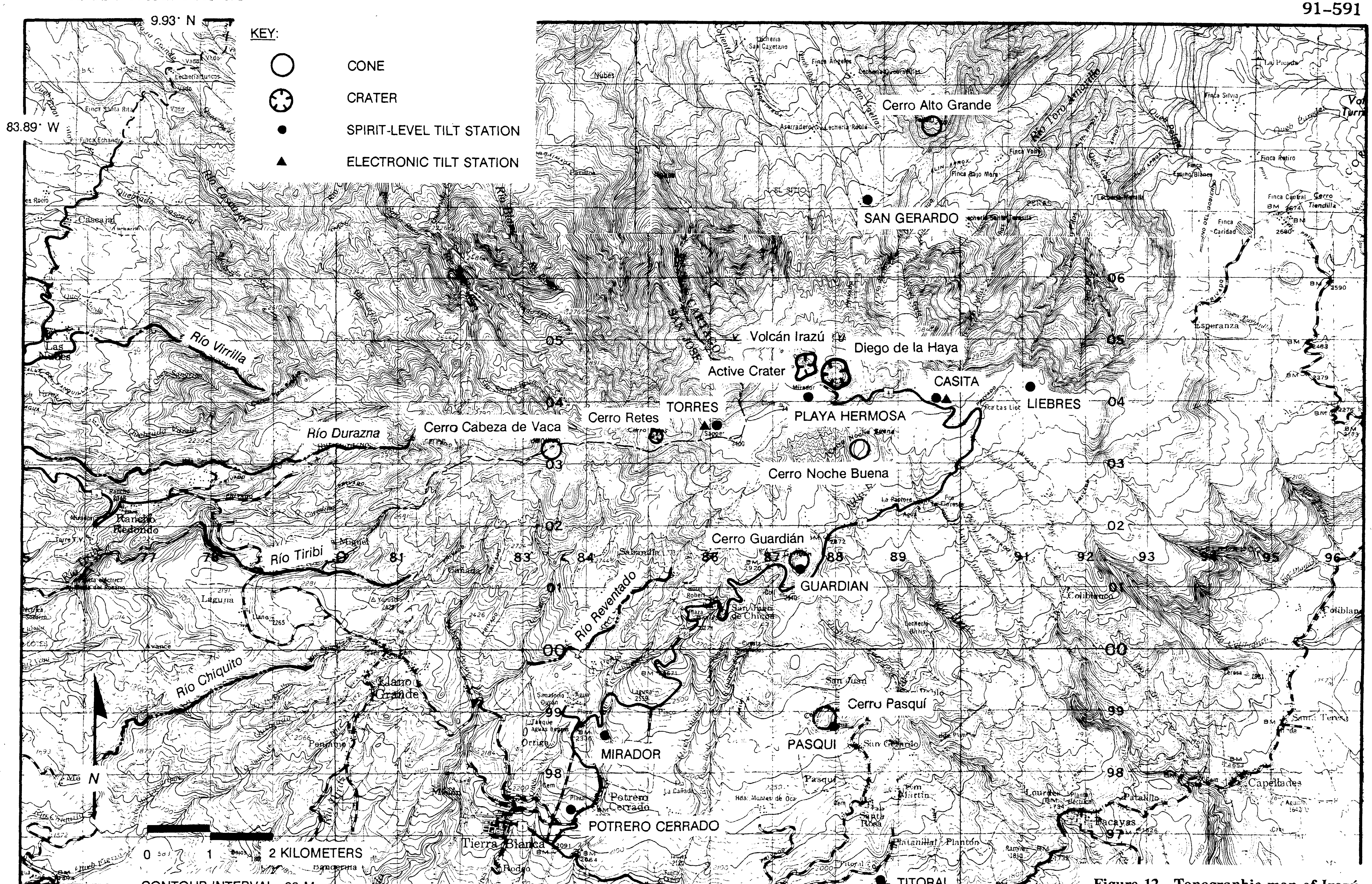

Figure 12. Topographic map of Irazú.

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TURRIALBA

GENERAL GEOLOGIC SETTING: Turrialba is the southeasternmost active volcano in Costa Rica. It forms part of the northeastern margin of the Valle Central and is located 15 km north of the towns of Juan Viñas and Turrialba (fig. 2). The current cone, with three well defined craters within a collapsed caldera, is built on a cluster of deeply eroded older volcanic edifices (fig. 13). The central crater is breached to the NE, probably the result of headward erosion, debris avalanches, and mudflows (Reagan, 1987). There are relatively recent lava flows on the northeast flank located between the Río Elia and Río Guacimo.

ERUPTIVE STYLE AND HAZARDS: Turrialba has erupted explosively 4 times in the last 2,000 years and currently supports solfataras. The most recent eruption occurred in 1864. Tephra-fall, pyroclastic flows, and mudflows accompanied all eruptions. One prehistoric lava flow on the NE flank extends 19 km from its vent. The rocks range in composition from basaltic andesite through dacite. Thicknesses and maturity of successive soils suggest that the repose periods are becoming progressively shorter (Reagan, 1987). The most recent eruption, in 1864-66, which deposited ash as far as San José, was preceded by several years of increased fumarolic activity and emission of sulfurous gas that destroyed vegetation northwest of the cone. Reagan (1987) also lists occurrences of significant magmatic eruptions about 8,250, 2,000, and 1,040 years ago, possibly after a hiatus that may have been longer than 60,000 years.

EVALUATION OF ACTIVITY AND RISK (1989): Turrialba is currently exhibiting fumarolic activity on the north wall of the central crater and in the southwest crater. A basaltic-andesitic eruption like that of 1864-66 is the most likely scenario for eruptions in the near future, and it is likely that they would produce pyroclastic surges which would devastate the summit area. Light ash would be deposited to the west as far as San José. Mudflows and pyroclastic surges would affect surrounding drainages such as the Ríos Toro Amarillo, Mercedes, Elia, Guacimo, Guayabo, Guayabito, and Aquiares (Reagan, 1987). The eruption of andesite would be more explosive and affect a larger area. In either case, there is a high probability of a debris avalanche and mudflows on the northeast flank of the volcano. The Río Elia and Río Guacimo valleys could be inundated by such events as far as the coastal plain (Reagan, 1987).

PROXIMAL POPULATION AT RISK: Population is concentrated to the south of the volcano.

TURRIALBA

QUADRANT	POPULATION 0-5 KM	POPULATION 5-10 KM
NE	27	45
SE	177	201
SW	126	186
NW	18	-

(Data from G. Alvarado, ICE)

GENERAL VOLCANO INFORMATION
TYPE OF VOLCANO: Stratovolcano
LATITUDE: 10.03 N
LONGITUDE: 83.77 W
LOCATION: Central Cordillera, 25 km NE of Cartago
ELEVATION AT SUMMIT: 3335 m
ELEVATION AT BASE: 1450 m
RADIUS: 6.5 km
ESTIMATED VOLUME OF VOLCANIC EDIFICE: 290 km^3 (Carr, 1984)
CRATER DIAMETER: (1) 0.1 km, (2) 0.45 km, (3) 0.35 km
CRATER DEPTH: (2) 50 m
ESTIMATED AGE OF VOLCANO: 75,000 ybp (Alvarado, 1989)
ROCK TYPE: Pyroxene andesite and basaltic andesite (Alvarado, 1989)
THERMAL MANIFESTATIONS: Continuously active fumaroles are located in the central and southeast crater.
HISTORICAL ERUPTIONS:
1723 - Fumarolic activity (Sapper, 1917; Alvarado, 1989)
1847 - Fumarolic activity (Sapper, 1917; Alvarado, 1989)
1853 - Fumarolic activity, incandescent material ejected (Sapper, 1917; Alvarado, 1989)
1855 - Fumarolic activity, flames at summit (Sapper, 1917; Alvarado, 1989)
1859 - Fumarolic activity (Sapper, 1917; Alvarado, 1989)
1861 - Fumarolic activity (Sapper, 1917; Alvarado, 1989
1864 - No details (Reagan, 1987)
1866 - Ash as far as Corinto, Nicaragua (Reagan, 1987)
ACCESS: There is a dirt road to the summit crater from the town of Turrialba.
MONITORING
SEISMIC MONITORING: Yes
TYPE: One station, telemetered (OVSICORI)
LOCATION: No information
DURATION: No information
DEFORMATION MONITORING: Yes
TYPE: Spirit-level tilt, 8 stations (OVSICORI)
LOCATION: LA SILVA, 2.4 km NW of summit; LA CENTRAL, 3 km SW of summit; LACHNER, 4.6 km SW of summit; FUENTE ARRIBA, 2.6 SSW of summit; FUENTE ABAJO, 3.7 km SSW of summit; SANTIAGO, 3.3 km E of summit; BONILLA, 8 km E of summit
DURATION: Since 1983, every 10 weeks, no change since installation
TYPE: EDM
LOCATION: No information
DURATION: No information
GAS AND FUMAROLE MONITORING: Yes
- Fumarole gas (sulfur, chlorine, fluorine) and temperature measurements at the summit every 8 weeks (OVSICORI)
- Fumarole temperature measurements (ICE)
- 3 sites, radon cups every 2 weeks (OVSICORI)
- 6 site, acid rain studies every 2 weeks (OVSICORI)

SIGNS OF RECENT UNREST: Fumarolic activity in the crater.
GEOLOGIC MAP: Yes, detailed of summit, by Reagan (1987). Also a detailed, 1:50,000 map by Soto (1985).
HAZARD MAP: Yes, detailed, 1:50,000, by Paniagua and Soto (1986) and Soto (1989). A land use and risk map at 1:50,000 is being developed by OVSICORI.
TOPOGRAPHIC MAPS:

- Carrillo, Sheet 3446 III, 1967, Instituto Geográfico Nacional, San José, Costa Rica, 1:50,000.
- Cartago (Istarú), Sheet 3445 IV, 1968, U.S. Army Map Service, Washington D.C., 1:50,000.
- Bonilla, Sheet 3446 II, 1965, Instituto Geográfico Nacional, San José, Costa Rica, 1:50,000.
- Tucurrique, Sheet 3445 I, 1965, U.S. Army Map Service, Washington D.C., 1:50,000.

AERIAL PHOTOGRAPHS (Turrialba):

DATE	SCALE	ROLL NUMBER	FLIGHT LINE	FRAME NUMBERS
1978	1:35,000	R133	L219	13140-13148

GEOLOGIC WORKERS (Name, specialty, date referring to publications found in Bibliography):

- Alvarado, general geology, 1989
- Barquero, J., historical eruption record, unpublished
- Duarte, geomorphology, demographics, unpublished
- Melson, radiocarbon, 1986
- Paniagua and Soto, volcanic hazards, 1988
- Reagan, geologic mapping, geochemistry, 1987, 1989

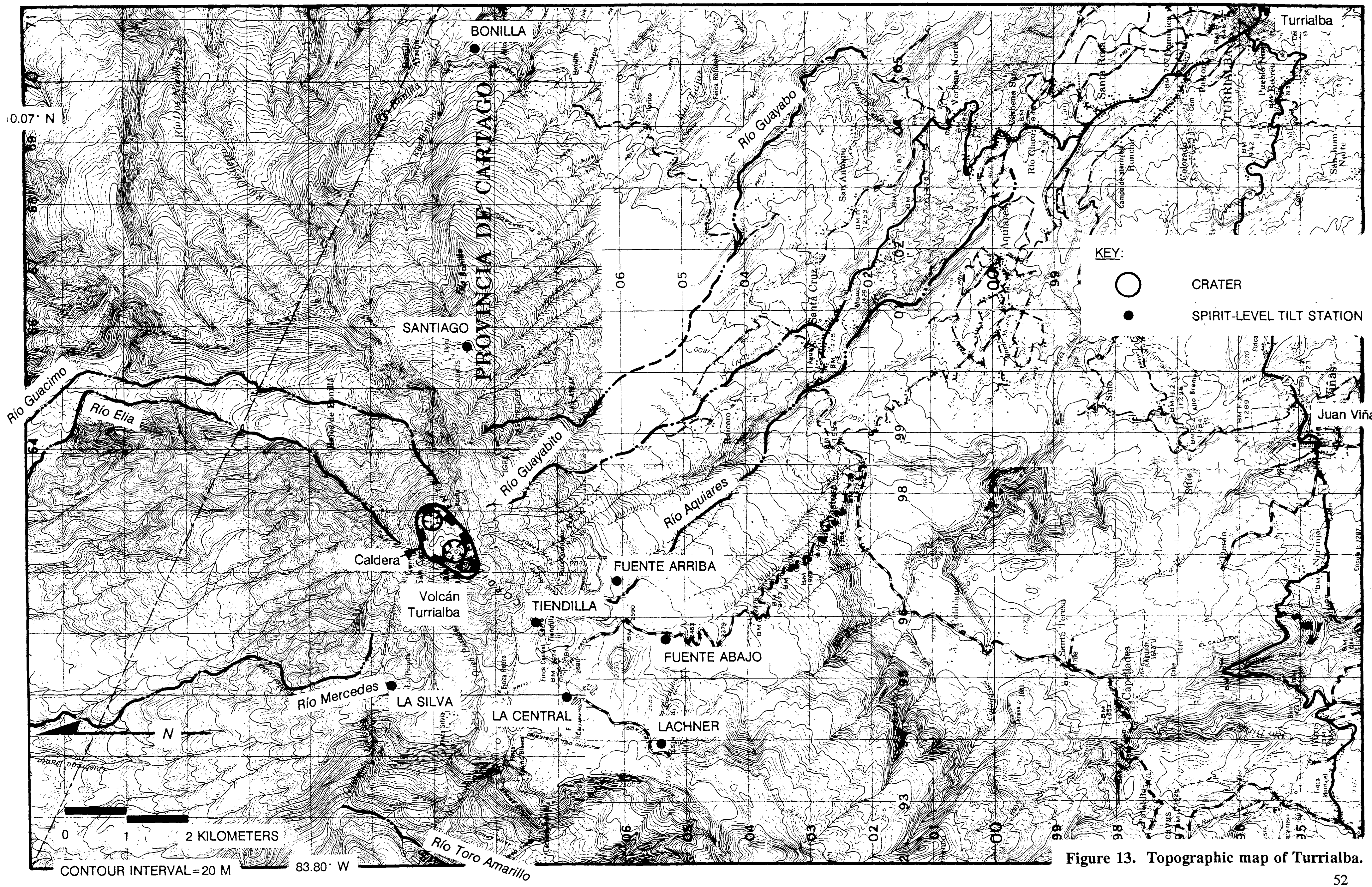


Figure 13. Topographic map of Turrialba.

This map is preliminary and has not been reviewed for conformity with U.S. Geological Survey editorial standards. Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

CIVIL DEFENSE HIERARCHY AND DISASTER PREPAREDNESS: According to the National Emergency Plan, the President directs the Civil Defense during a national emergency. An Executive Committee of Civil Defense is formed from representatives of the various ministries and selected government and private institutions. This plan has not been practiced. Most emergencies have been handled by the National Emergency Commission (CNE), which is under the jurisdiction of the Ministry of Public Works and Transportation (MOPT). The Executive Office of CNE oversees the use of emergency funds. The Emergency Operations Center is a communications office that maintains 24-hour contact with the Civil and Rural guards, the Electric Company (ICE), and the Red Cross to inform the CNE of possible emergencies.

OTHER RELIEF AGENCIES

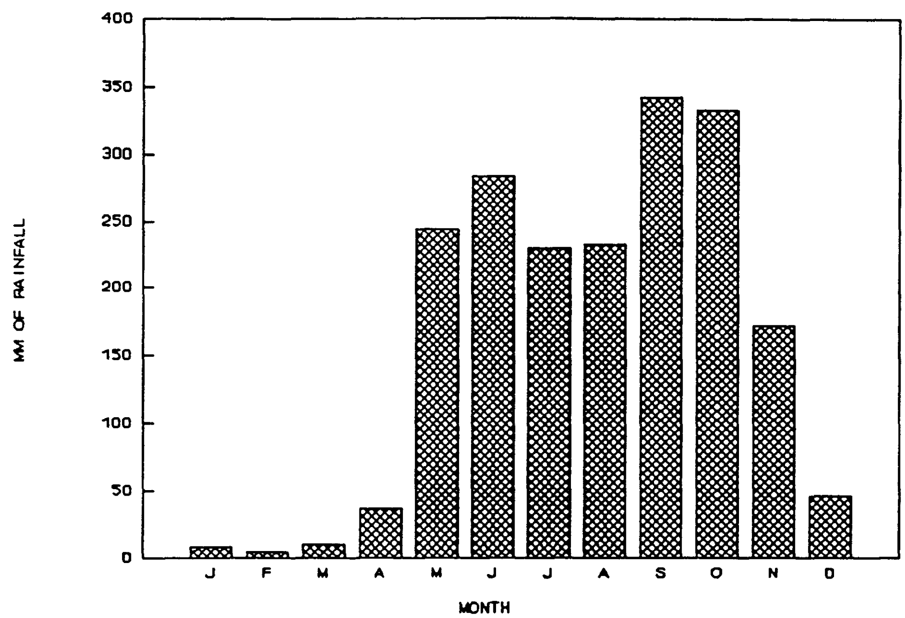
Costa Rican Red Cross (CRCR)
14th Ave. between 6th and 8th Streets
San José, Costa Rica
Telephone: 33-70-33

United Nations Development Program (UNDP)
Palais des Nations
CH-1211 Geneve 10 Switzerland
Telephone: 4122 7310-211, 7346-011
FAX: 4122 7335-623

GENERAL COUNTRY DATA

POPULATION: 2,460,226 (1984 Census)
TIME ZONE: = GMT - 6
CURRENCY: 109 colones = $1 (10-1-91)
PHONE EXCHANGE: US to CR, 011-506-(#)
CR to US, 116-(#)
RAINY SEASON: May to October
Mountains in the central highlands create a rainshadow effect that inhibits rainfall on the Pacific coast and the southern Guanacaste area.

PRECIPITATION (Monthly mean in mm)*: San José (1931-1960)
Lat. 9.93° N Long. 84.13° W, elevation 1,120 m



*From Schwerdtfeger, 1976, Climates of Central and South America

TEMPERATURE (Monthly mean in °C) AS A FUNCTION OF ELEVATION*:

Elevation (meters)	January	April	July	October
3,000	6.0	10.4	8.4	6.9
2,500	11.0	13.9	13.1	11.0
2,000	14.9	16.6	16.5	14.8
1,500	17.3	19.4	19.1	18.6
1,000	20.3	23.9	22.1	21.5
500	23.5	26.6	25.1	24.1
M.S.L.	27.8	28.9	28.0	26.7

*From Schwerdtfeger, 1976, Climates of Central and South America

ATMOSPHERIC PRESSURE: The trends are characterized by a double diurnal pressure wave. The minimums occur around 4 AM and 4 PM local time. The maximums occur around 10 AM and 10 PM local time.

WINDS: NE tradewinds (from NOAA, Monthly climatic data for the world)
*data for San José, Costa Rica

January	Direction* Speed**	No data
February	Direction Speed	No data
March	Direction Speed	79 32
April	Direction Speed	55 18
May	Direction Speed	105 4
June	Direction Speed	40 7
July	Direction Speed	No data
August	Direction Speed	No data
September	Direction Speed	No data
October	Direction Speed	No data
November	Direction Speed	No data
December	Direction Speed	No data

* in degrees
** meters per second

ELECTRIC SUPPLY: 110-120VAC, 60 Hz, single phase; 220-240VAC is available for larger appliances. Transformers are not needed when using U.S.-made electric products.

COMMUNICATIONS: Costa Rica has a well developed communications network. Nearly everyone has a radio and many have televisions. The Instituto Costarricense de Electricidad (ICE) manages the telephone system.

GEOLOGIC ORGANIZATIONS AND INFORMATION SOURCES: Geologic information and related technical resources are provided by a variety of organizations listed below. Four of these (ICE, UCR, OVSICORI, and UNA) are directly interested in and/or responsible for volcano/seismic hazards in Costa Rica.

- **Ministerio de Energia Minos y Petroleo**, under which is the Department of Geology and Mines. They produce generalized geologic maps at a scale of 1:200,000.

- **ICE** - Institute Costarricense de Electricidad; an autonomous organization with the longest history in seismologic studies in Costa Rica. They are located at Apdo. 10032-1000, San José, Costa Rica, Telephone - (506)207141; Telefax - (506)333871; Telex - (376)2140. In 1974, the Arenal seismic net (Red Sismológica Nacional, RSN) was established in coordination with the University of Texas at Galveston. In 1982, a national seismic net (RSN) was established. In 1990 it consisted of 15 stations located throughout the country. Four of these are located close to active volcanoes: Miravalles, Arenal, Poás, and Irazú. ICE also has 8 portable seismographs. ICE has published the Boletín del Observatorio Vulcanologíco del Arenal since 1988.

STAFF 1990 (from Directory of Volcano Observatories, WOVO)
Alvarado, Guillermo - Petrology, tectonics
Barquero, Rafael - Seismology
Barrantes, José Miguel - Electronics
Boschini, Ileana - Seismology
Calvo, Guido - Electronics
Cordero, Carlos - Topography
Fernández, José Francisco - Chemistry
Leandro, Carlos - Gravimetry and magnetometry
Mora, Sergio - Geological hazards
Soto, Gerardo - Geology, Turrialba

- **UCR** - Universidad de Costa Rica, San José - This organization is affiliated with ICE and has a bachelor-of-science program in geology.

STAFF 1989
Borgia, Andrea - Geology, Arenal
Fernández, Mario - Geology
Kussmaul, Sigfried - Geology and petrology
Montero, Walter - Seismology
Morales, Luis Diego - Seismology
Paniagua, Sergio - Volcanology

- **OVSICORI** - Observatorio Vulcanólogico y Sismológico de Costa Rica - This group has been publishing the Boletín de Vulcanología since 1979. They are located at Apdo 86, Heredia 3000, Costa Rica, Telephone - (506)374570, 376363; Telefax - (506)380086; Telex - (376)7550 UNAVI CR.

STAFF 1990
Barbosa, Vilma - Volcanic seismology
Barquero, Jorge - Director, Volcanology, geochemistry

Bravo, Juan - Geomorphology, La Fortuna, Tenorio
Brenes, Jorge - Geology, seismology
Duarte, Eliecer - Turrialba geomorphology, demographics
Fernández, Eric - Geochemistry
Gonzales, Victor - Coordinates with UNA, seismology, computer specialist
Guendel, Federico - Director, seismology
Hernández, Fernando - Geodesy, deformation
Malavassi, Eduardo - Petrology, Arenal, Quaternary cinder cones
Marino, Tomás - Geodesy, deformation
Mata, Antonio - Electronics
Montero, Carlos - Seismology
Protti, Marino - Seismology, tectonics
Rojas, Daniel - Electronics
Sáenz, Rodrigo - Volcanology
de Dios Segura, Juan - Seismology
Van der Laat, Rudolofo - Geodesy, deformation

- **UNA** - Universidad Nacional Autonoma, Campus Omar Dengo, Heredia. This organization is affiliated with OVSICORI.

Raccichini, Sergio - Volcanic hazards

Photographs and maps are available through:

Ministerio de Obras Publicas y Transportación (MOPT)
Avenida 20, Calles 9/11
San José, Costa Rica

Maps cost $4.00 each (1989). Arnold de Soto is a section head of Remote Sensing geology. Three-fourths of Costa Rica has Landsat coverage. Maps are also available through Inter-American Geodetic Survey (IAGS).

IGN (Instituto Gráfico Nacional) does first-order leveling.

OTHER EARTH SCIENTISTS and associated organizations involved in Costa Rican volcanology (Specialty listed after name)

Brantley, Susan (geochemistry, Poás)
Department of Geosciences
Penn State University
State College, PA 16802
USA

Brown, Geoff (microgravity, Poás)
Department of Earth Sciences
The Open University
Walton Hall
Milton Keynes, MK76AA, UK

Carr, Michael (geochemistry, Rincón de la Vieja, Arenal)
Department of Geology
Rutgers College
New Brunswick, New Jersey 03755
USA

Casadevall, Tom (geochemistry, Poás, Arenal)
U.S. Geological Survey
Denver Federal Center
P.O. Box 25046
Lakewood, CO 80225
USA

Casertano, Lorenzo (geochemistry, Poás)
Institute of Geology and Geophysics
University of Naples
Naples Italy

Cigolini, Corrado (petrology, Arenal)
Institute of Petrography
University of Turin
Via San Massimo 24
Turin, Italy

Corrado, G. (deformation, Arenal)
Instituto di Geologia e Geofisica
Universitá di Napoli
Largo S. Marcellino 10
Napoli, Italy

Escalante, G. (Irazú, Poás)
Costa Rican Civil Defense
San Jose, Costa Rica

Gill, Jim (geochemistry, Turrialba)
Earth Sciences Board
University of California
Santa Cruz, CA 95064
USA

Harlow, David (seismology)
U.S. Geological Survey
345 Middlefield Rd. MS-977
Menlo Park, CA 94025
USA

Kempter, Kurt (Rincón de la Vieja, Cacao)
Louisiana State University
Baton Rouge, La. 70803-4101
USA

Krushensky, R.D. (Irazú)
U.S. Geological Survey
National Center
Reston, VA 22092
USA

McNally, Karen (seismology)
University of Calif., Santa Cruz
1156 High St.
Santa Cruz, CA 95064
USA

Melson, William (eruption dynamics, Arenal)
Museum of Natural History
Smithsonian Institution MS-129
Washington, D.C. 20560
USA

Prosser, Jerome (petrology, Poás)
Texasgulf Minerals and Metals
239 South Elliott Rd.
Chapel Hill, NC 27514
USA

Reagan, Mark (Turrialba, hazards, petrology)
University of Iowa
Iowa City, Iowa 52242
USA

Rose, Bill (geochemistry)
Michigan Technological University
Houghton, MI 49931
USA

Rowe, Gary (geochemistry, Poás)
Department of Geosciences
Penn State University
State College, PA 16802
USA

Rymer, Hazel (microgravity, Poás)
Department of Earth Sciences
The Open University
Walton Hall
Milton Keynes, MK76AA, UK

Sheridan, Mike (stratigraphy)
SUNY at Buffalo, Geology Dept.
424 Ridge Lea Campus
Buffalo, NY 14260
USA

Sussman, David (geochemistry, Rincón de la Vieja)
UNOCAL Geothermal Division
3576 Unocal Pl.
P.O. Box 6854
Santa Rosa, CA 95406
USA

Wadge, G. (Arenal, deformation)
Department of Geography
University of Reading
White Knights, RG 6 2AB UK

Walker, George (stratigraphy)
Department of Geology
University of Hawaii
2525 Correa Rd.
Honolulu, HI 96822
USA

White, Randy (seismology)
U.S. Geological Survey
345 Middlefield Rd. MS- 977
Menlo Park, CA 94025 USA

EARTH SCIENCE ORGANIZATIONS

CEPREDENAC (volcanic hazards)
El Centro de Coordinacíon para la Prevencíon de desastres naturales en América Central
7a. Av. 14-57 Zona 13
Guatemala Cuidad, Guatemala, C.A.
Phone 502-2-313967, 314967
FAX 502-2-363944

Earthwatch
Brian Rosborough
680 Mount Auburn St.
P.O. Box 403
Watertown, MA 02272
Phone (617) 926-8200

Institut de Physique du Globe de Paris
Observatoires Volcanologiques (gas geochemistry)
J.L. Cheminee
4 place Jussieu
75252 Paris Cedex 05, France

Japan International Cooperation Agency (JICA)
P.O. Box 216
Mitsui Building
Shinjuku, Tokyo 163

RET Corporation (seismic engineering)
Deborah Reid-Jerez
6551 Loisdale Ct.
Springfield, VA 22150
Phone (703) 922-9713

Earth Science Organizations (con't)
USGS/OFDA Volcanic Disaster Assistance Program
Volcano Crisis Assistance Team
(volcanic hazards)
Cascades Volcano Observatory
5400 MacArthur Blvd.
Vancouver, WA 98661 USA
Phone (206) 696-7693
Fax (206) 696-7866

EMBASSIES

U.S. Mission in Costa Rica

Embassy of the United States and USAID Mission
Avenida 3 and Calle 1
San José, Costa Rica
Phone: 20-39-39
(APO Miami, Fl. 34020)

Office of Foreign Disaster Assistance maintains a regional office for Latin America in San José to perform assessments following disasters and to coordinate OFDA responses. The office is located at: USAID Annex, General Development Division, at the U.S. Embassy (tel. 33-86-45, 33-93-29, 24,54,14). This team of three disaster specialists maintains a portable, battery operated radio communications system and ten 4-wheel drive vehicles.

OFDA Regional Advisors

Bell, Paul
Bermudez, Ricardo
James, Alejandro

French Mission in Costa Rica

French Consulate
Calle 5, Avenidas 1/3 (No. 140)
San José, Costa Rica
Phone: 22-11-4
FAX: 3037600-2191
Telex: 3032191

Japanese Mission in Costa Rica

Japanese Embassy
Apdo. 501 E 10
145 San José, Costa Rica
Phone: 32-12-55
FAX: 313140
Telex: C.2205 A.2205 TAISI

Italian Mission in Costa Rica

Italian Embassy
Calle 29 Avenida 8 y 10
Casa 842 Ap 1729
San José, Costa Rica
Phone 24-65-47
FAX: none
Telex: 003762769, Ans: ITALDIPL

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