This thesis, "San Miguel Volcano and its Volcanic Hazards", El Salvador, Central America, is hereby approved in partial fulfillment of the requirements for the Degree of **MASTER OF SCIENCE IN GEOLOGY.**

DEPARTMENT of Geological Engineering
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Abstract

San Miguel is a 2130 m high composite volcano in Eastern El Salvador. It has been active for perhaps 10,000 years, and has built a symmetrical cone with upper slopes of more than 40 degrees. Its activity is strombolian, marked by spatter and ash eruptions from its summit crater and lava flows that come mainly from flank vents. The entire volcano consists of basaltic and basaltic andesite materials. Historic activity has been marked by ~26 eruptions in 304 years, including a total of 8 flank lava flows with a volume of ~0.51 km^3. San Miguel's ashfalls are mainly found west of the cone, because winds are predominantly easterly. Most ash eruptions in historic times have been quite small. Small debris flows, apparently triggered by heavy rains on San Miguel's steep slopes have occurred several times in the past two decades, especially on the western slopes of San Miguel's cone. A large ashfall eruption resulted in a major ashfall west of San Miguel 1800 years ago. Several thousands of years ago San Miguel apparently had a major collapse, creating a debris avalanche and a crater amphitheatre facing westward. This amphitheatre has since been filled with pyroclastic materials from strombolian summit eruptions.

Hazards that can be expected from future activity at San Miguel include:

1. Renewed summit eruptions consisting of gas and ash emissions and, ballistic bombs which would cause severe hazards in the steep summit region and ash fallout in the areas mainly to the west of the large cone.

2. A lava flow eruption with accompanying spatter and bombs from a flank vent which may result in a lava flow as long as 11 km.

Unlikely hazards that could occur from San Miguel include:

1. An intense summit eruption could cause a lava flow to descend the cone from the summit crater and break up to form a dangerous block and ash flow.

2. Collapse of the San Miguel could occur which would result in a devastating debris avalanche and possibly an accompanying pyroclastic flow.

Within this study, I have assembled information needed for modern hazards assessments due to future activity at San Miguel Volcano. I have also prepared preliminary hazards maps of various types, with the help of many people. The goal is to mitigate hazard by providing information to those who live near the volcano.

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1.0 Introduction

Volcanoes pose a threat to people who live near them because of many dangerous kinds of activity that they may present. El Salvador has numerous volcanoes which have been historically active and many are considered likely to erupt again [Figure 1]. Among these, San Miguel, because of its stature [2130 m], frequent activity and proximity to San Miguel, El Salvador's second largest city is an important focus for hazard evaluations. This report utilized geological field studies, evaluated digital topography and weather information, and assembled geochemical and radiometric age information to produce hazard zone maps and recommendations of volcanic hazards that can be expected from future eruptions of San Miguel volcano.

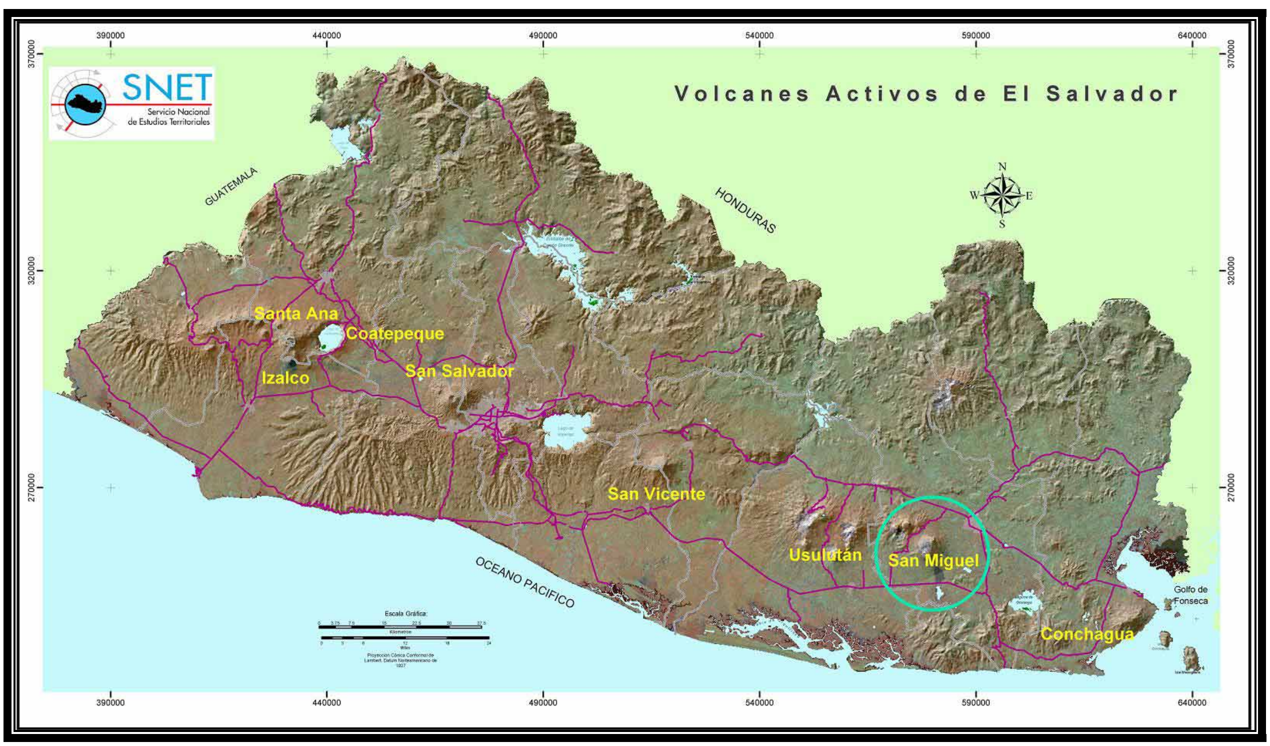


Figure 1. Map of the active volcanoes of El Salvador, including San Miguel [circled].

1.1 Location and Geological Setting

San Miguel Volcano is part of the Volcanic Front, a segmented line of active volcanoes that is parallel to the Middle America Trench, a deep ocean feature that marks the boundary between the Cocos Plate and the Caribbean Plate [Figure 2]. Earthquakes occur along this plate boundary and especially along a deepening seismically active belt between the Trench and the volcanic front that marks the descent of the Cocos Plate underneath the Caribbean Plate. At a depth of about 150 km beneath the volcanic front, melting of the Cocos Plate occurs [Figure 2a] and these liquids induce melting of the rocks above and this melt rises further and may reach the surface forming volcanoes. The structure of the rocks at the surface, especially faults that crack the brittle crustal rocks, influence the rise of magma. In El Salvador the volcanic front is found along the southern edge of a structure called the Median Trough [Figure 3] or the Salvador Graben [Williams and Meyer-Abich, 1955; Wiesemann, 1975].

San Miguel [13°26'2"N; 88°16'9"W] is a 2130 m high cone with a volume of 58 km^3 [Carr et al, in press]. It is conical in shape [diameter ~12 km] with an 800 m summit crater and steep upper slopes (more than 40 degrees near the summit] that gradually become gentler [<10 degrees at 11 km from the crater] with distance from the crater increases. The cone is situated on the flank of another volcano called Pacayal [Figure 4], to the NW of San Miguel. San Miguel's shape [Figure 5] resembles the form of a composite volcano, like many others in El Salvador [San Vicente, Usulután, San Salvador, Izalco] and Central America [Agua, Fuego and Santa María in Guatemala; San Cristobal, Telica, Momotombo and Concepción in Nicaragua].

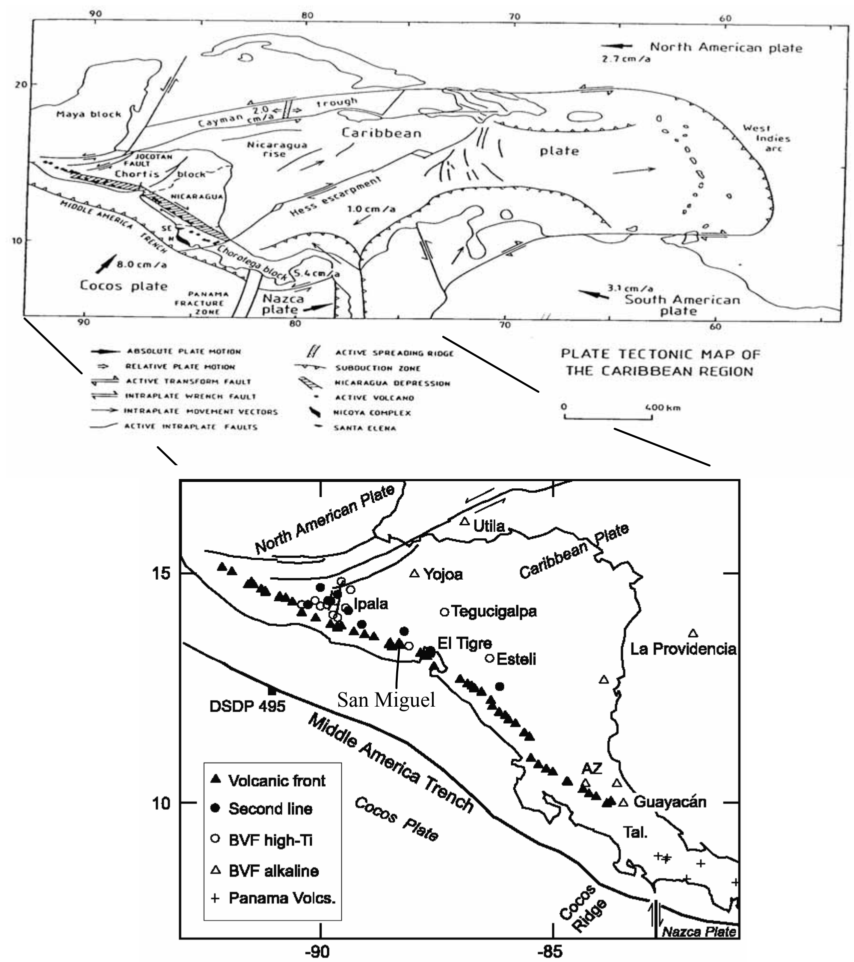


Figure 2. Maps showing the Plate Tectonic context of Central America [From Weinberg, 1992] and the volcanic front [From Carr et al., in press]

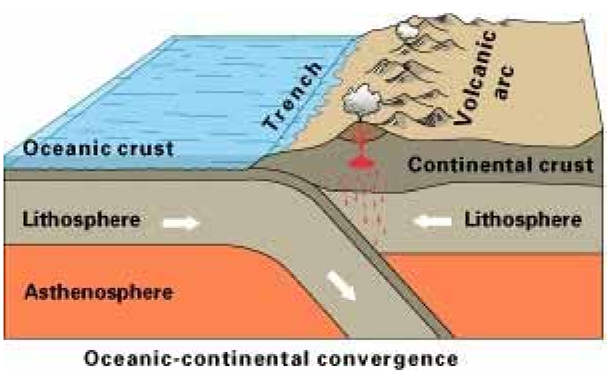


Figure 2a. Melting of the Cocos Plate induces melting of the rocks forming volcanic arc [Courtesy of USGS].

Figure 3. El Salvador's Tectonic Structural setting, showing the patterns of major faults associated with active volcanoes along the Median Trough of El Salvador.Faults from Wiesemann [1975].

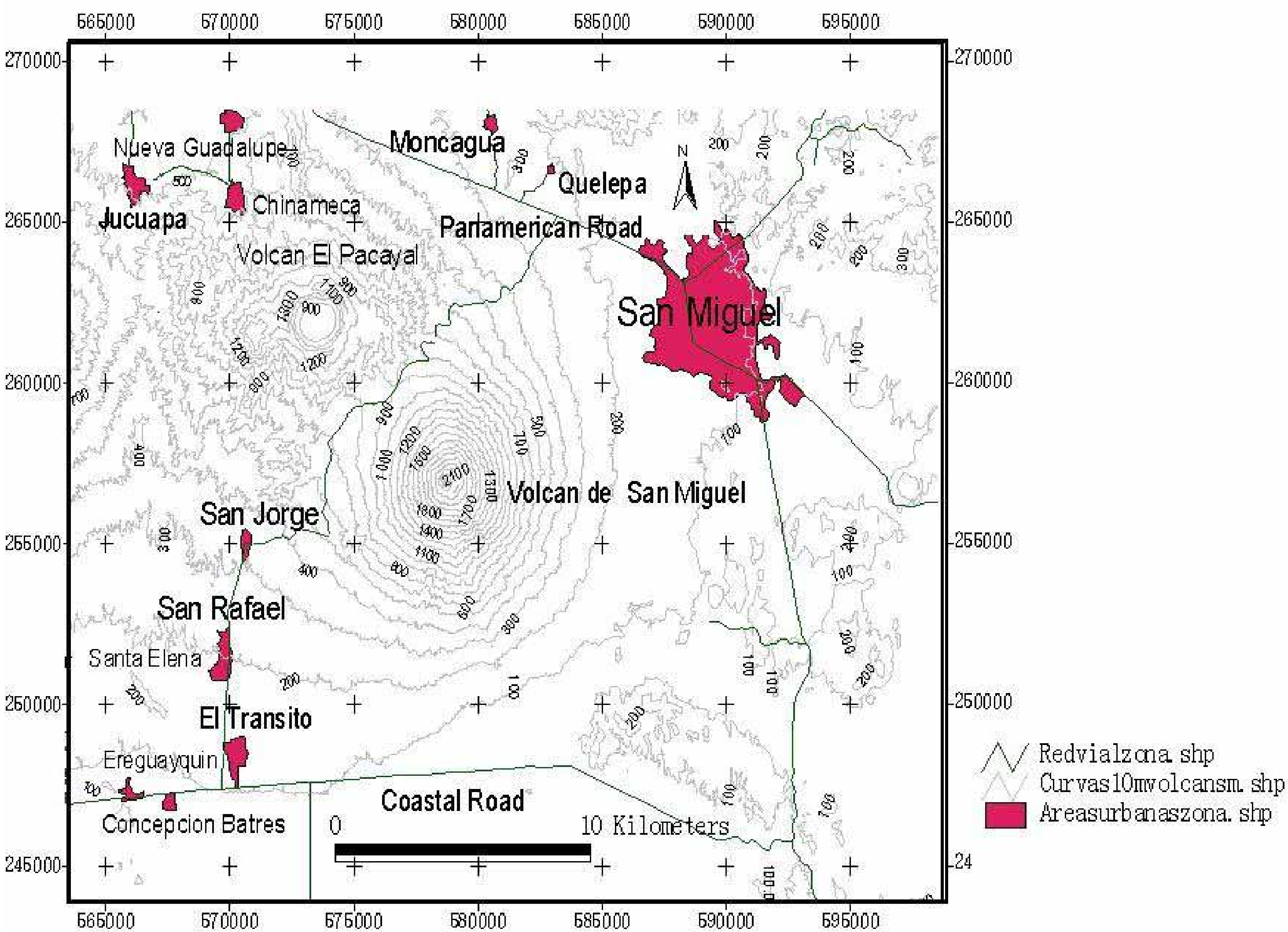


Figure 4. Contour map of San Miguel Volcano area, showing the asymmetric form of San Miguel which formed on the side of another volcano, Volcán El Pacayal.

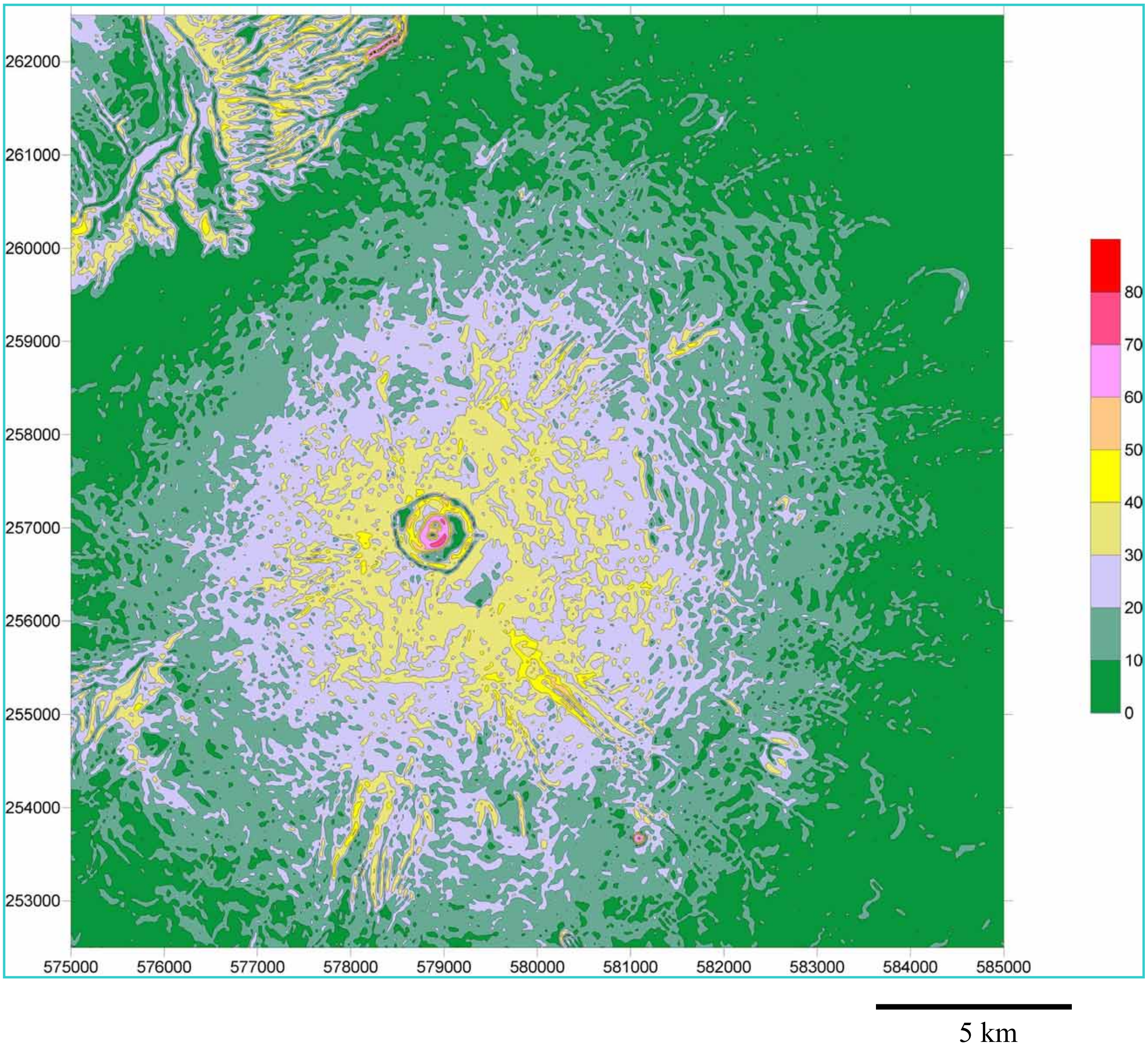


Figure 5. Slope map of San Miguel Volcano. San Miguel's shape resembles the form of a composite volcano, like many others in El Salvador. Note that slopes tend to be steeper on the upper parts of the cone and that many are >40 degrees [slope in degrees].

The steeper upper slopes of San Miguel suggest that the deposits on the upper slopes are welded together because they were emplaced at a high temperature and because unwelded volcanic materials form cones with slopes of about 30 degrees or less (Wood, 1980). The eruptions of San Miguel's summit are called Strombolian [after the volcano Stromboli in

Italy] and produce volcanic ash and fountains of fiery clots of magma which weld together and flow down the slopes as lava flows. It also erupts lava flow from vents far down on its slopes. The cone of San Miguel has a shoulder which can be outlined on its upper slopes [Figure 6]. This break in slope probably reflects the existence of an older cone which was partly destroyed in a catastrophic event thousands of years ago [Photo 1].

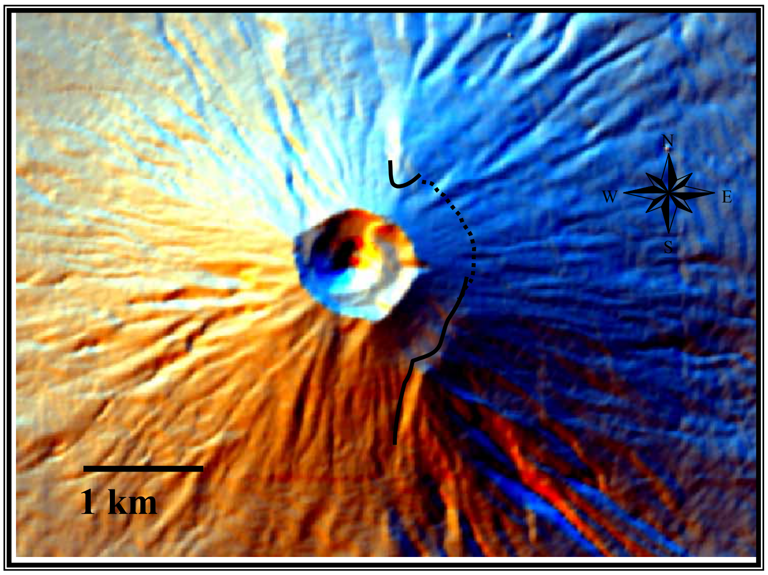


Figure 6. Summit cone showing the amphitheatre feature

Photo 1. View from West flank, the older cone [1] and the young summit cone

1.2 Geological Deposits of San Miguel Volcano

A simplified geological map of San Miguel (Figure 7] shows the areas covered by deposits from San Miguel's activity. It also delineates areas covered by historic lava flows and some structural features including faults and the amphitheatre on the north and east side of the cone, facing westward. The overall picture of San Miguel as depicted by the geological map is that it represents a cone made up of mainly lava flows on its lower flanks and lavas and welded spatter on its upper slopes. The volcano is more complex than a single cone because the amphitheatre scar represents the trace of a remnant amphitheatre that existed at some point in San Miguel’s history. Thus much of the eastern slope of the present San Miguel is older than the western slope. A younger cone has filled the hole which was present in the area west of the amphitheatre scar.

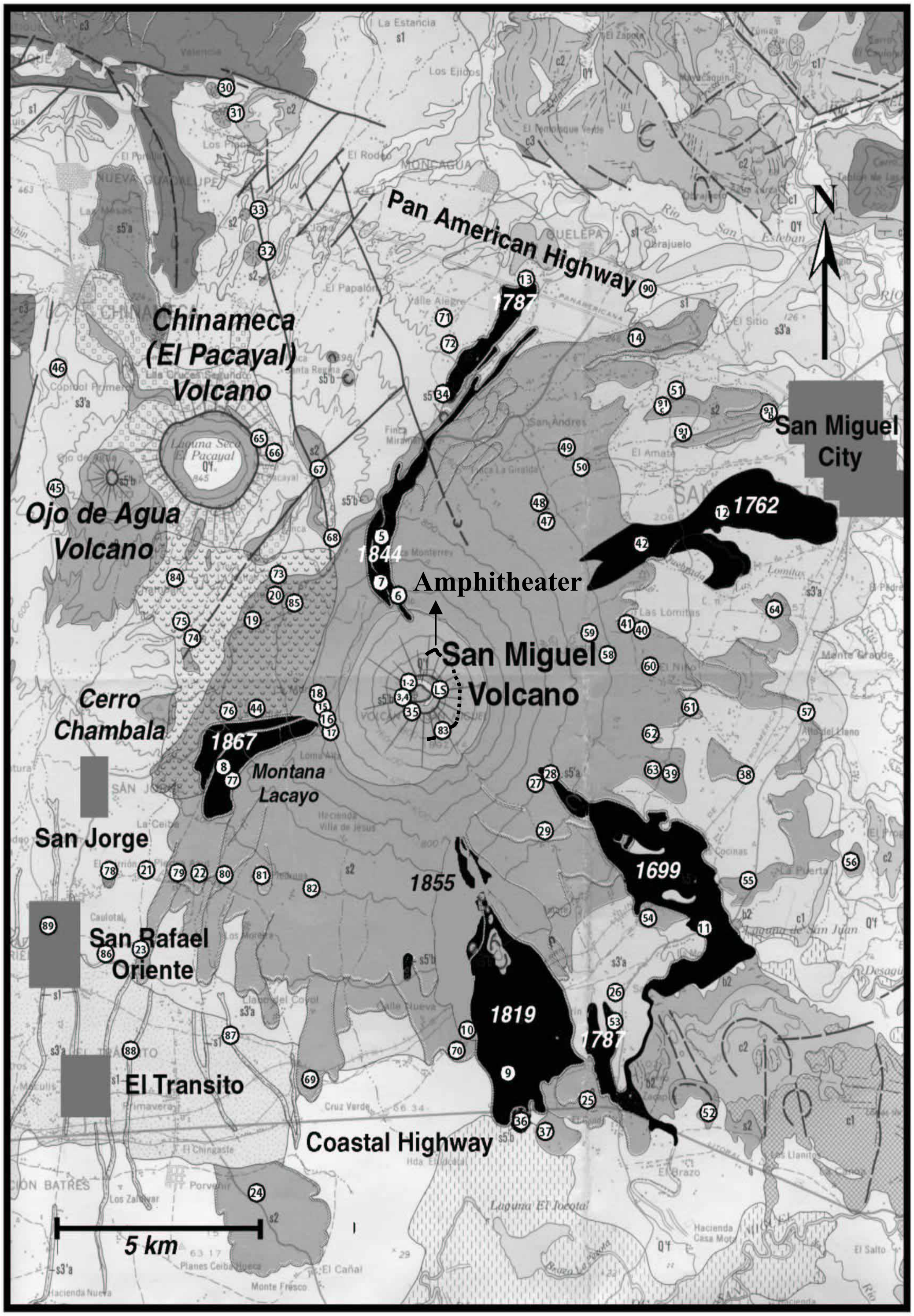


Figure 7. Geological Map based on data from Wiesemann [1975] and Chesner et al [2003]. Numbers are sample and stratigraphic section locations.

1.2.1 Historic lava flows

San Miguel volcano has experienced at least 26 eruptions during the last 304 years and thus is considered one of the most active volcanoes in El Salvador [Appendix A, historic activity].

Meyer Abich [1956] and Martínez [1977] have reported that 11 lava flows have occurred from San Miguel from 1699 to 1976. Eight flows erupted from flank vents and 3 eruptions consisted only of lava fountains confined to the summit crater. A few lava flows have been produced from obvious fissures located in the volcano flanks [Figure 7].

1. The two largest flows were erupted in 1699 and 1819 from vents and fissures at about 400 m. altitudes.
2. The 1819 flow traveled about 4 km from its vent at 400 m.a.s.l, whereas the 1699 lava flow traveled about 8 km downslope from its source at 480 m asl. Both flows crossed the Coastal Road and descended to about 40 m above sea level. The greater runout distance of the 1699 flow can be attributed to it starting at a higher elevation and becoming channelized in a narrow paleo-valley. These lavas spreaded out to a maximum distances of about 2 km perpendicular to their flow direction as they descend the volcano
3. Two lava flows were erupted in 1787 by low [300 - 400 m. a.s.l] flank vents along N and SSE of the summit. To the north the 1787 flow crosses the Panamerican Highway between Moncagua and Quelepa.
4. The 1855 flow only traveled a short distance [~1 km] from its source at about 800 m elevation on the south flank.

The northern flank was also the site of vents for historic lava flows. An important historic fissure lava flow occurred in 1762, erupted from the northeast flank at about 200 m altitude. This flow traveled about 6 km from the source, descending to 120 m a.s.l. near San Miguel city. The eastern rural edge of the city of San Miguel is built directly upon this lava flow and has spread approximately 1 km up its path. This flow was less confined than the northern flank flows and is up to 1.5 km wide. In 1844, lavas issued from 14 vents? [Williams and Meyer-Abich, 1955] along a fissure between 1000 and 1300 m.a.s.l eventually producing a 7 km long lava flow. In 1848, a narrow lava flow about 0.5 km in width was emitted and flowed NE about 3 km. Although two distinct flows were erupted from separate vent areas, they are reported as different phases of the same eruption by Simkin and Siebert [1994].

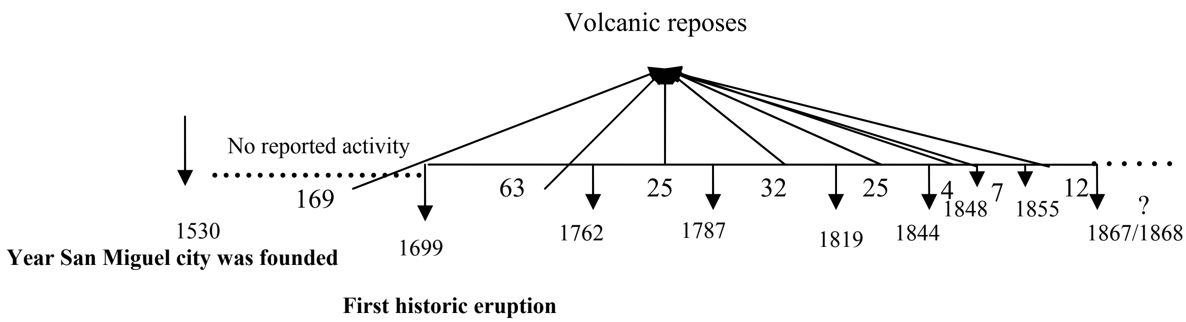
The youngest flank lava flows from San Miguel occurred in 1867- 1868 on the WSW flank. This lava was erupted from poorly defined vent, probably at about 1000 m.a.s.l, flowed 2 km west towards the town of San Jorge, then turned south and flowed another 1.5 km.

To the west of the 1867 lava, is the eroded Montaña Lacayo, which is covered by highly vesicular grey scoria..

Since 1844 all eruptions have occurred from San Miguel's summit. Lava fountains confined to the floor of the summit crater without producing lava flows on the side of the cone were reported in 1884, 1930 and 1976. Thus, vent location has apparently and generally migrated upwards on the edifice with time [Chesner, et al., 2003], although it is possible that lava eruptions at the summit also occurred in the earlier historic period. Figures 8 and 9 show the historic sequence of lateral and central vent lava flows and its eruptive repose. Table 1 includes estimations of lava effusion volumes and other data about historic lava flows.

Eruptive sequence of lava ejected from [1699 to 1867]

Sequence of individual flank lava flows



1867 – 1699 = 168 years. Time of flank eruptions
8 eruptions in 169 years of activity:
168/8 = 21, during this time 1 fissure eruption occurred about each 21 years
63 years was the maximum repose between flank eruptions
2003 - 1867 = 136 years since last flank eruption, more than twice the maximum repose known.

Figure 8. Periodicity of flank flows

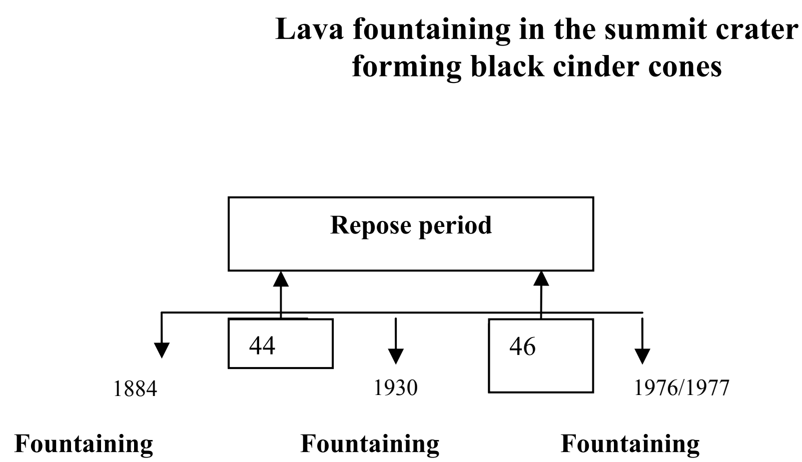


Figure 9. Historic summit lava fountaining episodes

VOLCÁN DE SAN MIGUEL [2130 m]: Historical lava flows

Date	Source	Strike	l.w.t.[km]	Altitude [asl] of the source	Approx. Volume [Km^3]	% SiO_2	Commentaries
1699	Fissure -flank SE	S15`E	7x2x0.015	400	0.21	51.52	Largest historical fissure lava flow, thickness ~15 m
1762	Fissure - flank NE	E	5.1x1.3x0.01+1.16x1x0.01	200	0.078	50.71	Hazardous lava flow, reached ~2 km from San Miguel city, thickness about 10 m
1787 Sep. 21 – 23	Fissure - flanks N and S	NNE y SSE	2.71x1.5x0.005 + 3x0.6x0.005	300 – 600	0.029	51.18	Interesting fissure lava flows on both N and S, flanks thickness about 5 m
1819 Jul 18	Fissure -flank S	SSE	5x2.5x0.01	300	0.125	51.64	Hazardous fissure lava flow, blocked the Coastal road to the south of the volcano, thickness approx 10 m

1844 Jul 25 - 09 Oct	Fissure - flank N	N15E	8x0.7x0.008	1,120	0.0448	51.44	Fissure eruption accompanied by rumbles, thickness approx 8 m
1855 Dec 01 – 15	Fissure -flank S	SSE	1.5x0.5x0.01	600 – 800	0.0075		Small fissure eruption, accompanied by earthquakes and rumbles
1867 Dec 14 - 16 Feb 1868	Fissure -flank W	WW-SW	4x1x0.005	800 -850	0.02	51.79	Moderate probable fissure eruption, accompanied by ash emission. Thickness approx 5 m and ash fall toward to NW, earthquakes and rumbles were reported
			Total magma emitted = 0.51 km^3				

Table 1. Notes on Historic Flank lava flow eruptions [Martínez, et al., 1977]

1.2.2 Prehistoric lava flows

Most of the mass of San Miguel Volcano is made up of basaltic lava flows which are similar to the historic flows. On the north and northwest flank tephras can be seen interlayered with lava flows, while on the southwest and southeast slopes mainly lava flows and debris flow deposits are found. Within the areas of the cone of San Miguel the morphology of many prehistoric flows can be readily seen [Figure 10]. Overall in most localities, 80% or more of the mass is lava. Many of these flows terminate at distances of 5-10 km from the summit; only three flows extend as far as 11 km. Even in the walls of the summit crater, lava flows are the dominant rock type [Figure 11].

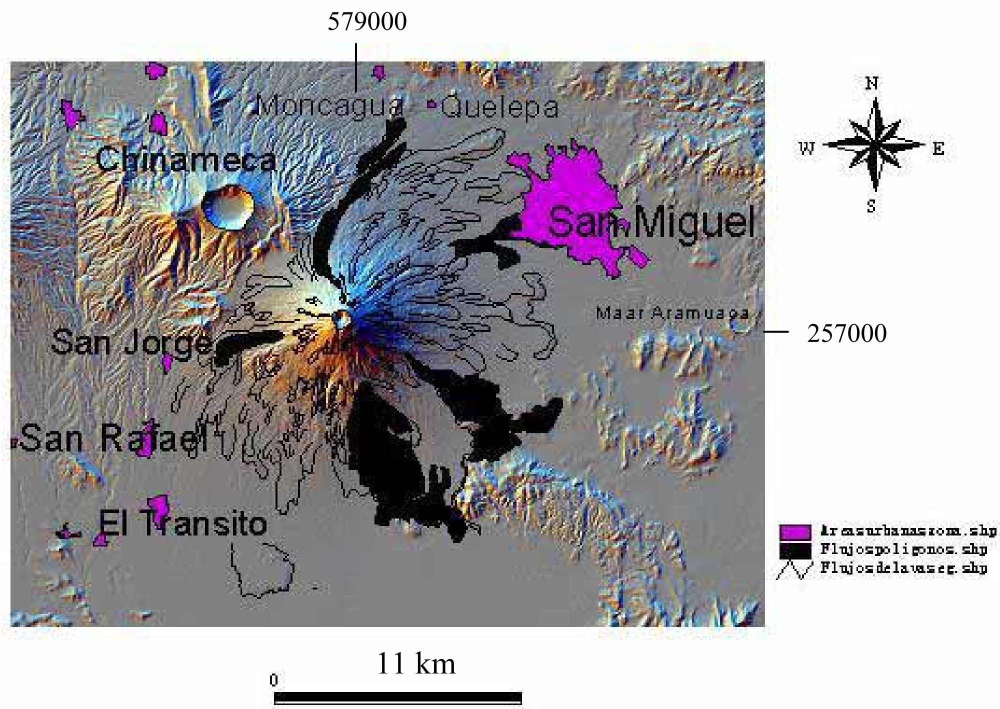


Figure 10. Morphology of many historic and prehistoric lava flows of San Miguel Volcano

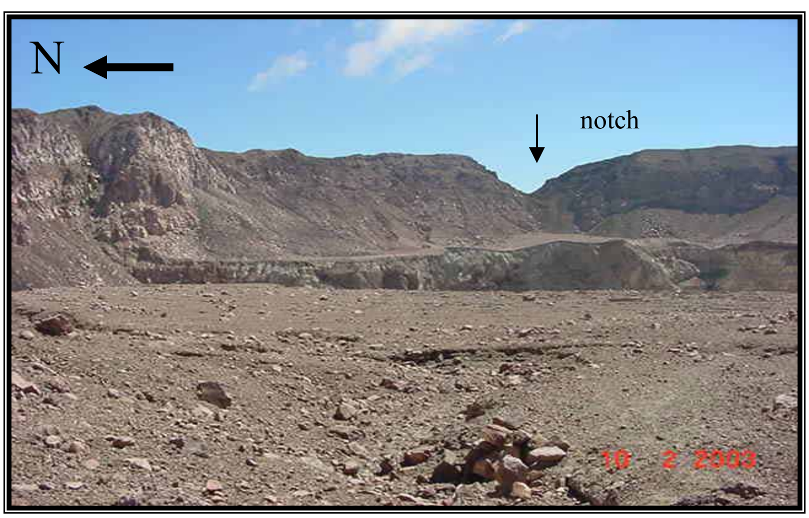


Figure 11. View from West to East within the summit crater of San Miguel. The notch at the east side of the crater is visible and a sequence of lava flows dips to east. The central crater is in the middle.

1.2.3 Pyroclastic flows

Although pyroclastic flow and surge deposits are rare at San Miguel, they do occur in a few places. On the east flank a relatively young deposit with typical characteristic of pyroclastic flows was found in the area of Finca Santa Lucía [See Photo 2].

Photo 2. Typical block and ash flow deposit located at Finca Santa Lucia [Long 584100 Lat. 258800], East flank of the volcano and to 5 km from West San Miguel city.

Deposit location:

Topo map San Miguel 2556 II

Scale 1:50,000; Feb 1985 [CNR, ES]

The deposit is rich in sand and contains a sandy matrix facie which dominates in some places, and also a block facies, with angular and triangular blocks [max size = 1 m, containing ~10% olivine crystals and plagioclase matrix; sample 41 in figure 7]. It is interpreted as a block and ash flow. Unfortunately, no charcoal was found for dating. Indeed, this appears to be the youngest of at least three pyroclastic flows identified on the eastern flank. Two older pyroclastic flow deposits were found [~3 m thick] and covered by 2 meters of soil [at sites sites 40, 60, very close to the other occurrence]. They were recognized as block and ash flow deposits by their quenched, bread crust blocks.

Two more possible occurrences were found in the same area, but were highly weathered [sites 58 and 62]. There are no reports of historic block and ash flows at San Miguel, and these deposits could be the result of activity on the earlier precollapse cone of San Miguel. These materials have a higher SiO_2 content than most San Miguel lavas. Although some are in close proximity to one another, variable geochemistry suggests that they are distinct deposits.

There are also pyroclastic flows and surges on San Miguel's SW flank. Chesner et al; [2002] identified two older deposits of pyroclastic flows on San Miguel's southwest flank. One was sampled in Quebrada La Ceibita o La Ceiba [site 23], about 9 km from the summit where it is 40 cm thick. Another similar deposit occurs about 1 km to the west in Quebrada El Aguacate [site 86].

During recent field work during June and July of 2003, three tentatively correlated outcrops with phreatomagmatic surges [Figure 12] were identified SW of the summit. One is located west of the summit crater, one in Barrio Nuevo Paris and the other in Rio Batres. They are typical, fine grain cross bedded phreatomagmatic surges, gray in color. These could represent a potential hazard for people living to the west of the volcano. The stratigraphic correlation is shown in figure 12.

Stratigraphic correlation of pyroclastic flows to the west of San Miguel volcano

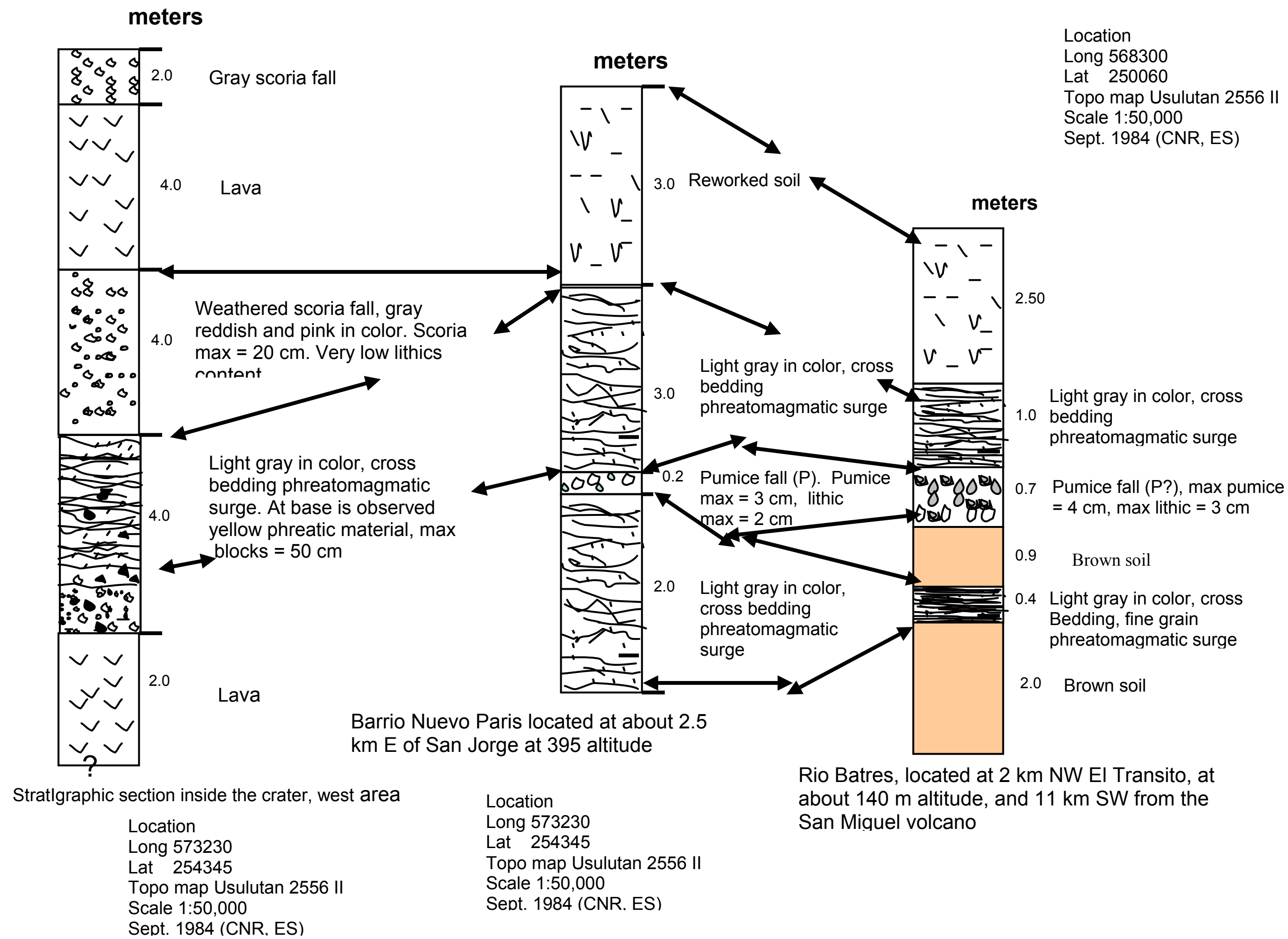


Figure 12. Pyroclastic flows deposit associated with San Miguel Volcano

1.2.4 Historic debris flows

Occasionally heavy seasonal rains have mobilized scoria from high on the upper northwestern flank of the volcano. These scoria dominated debris flows have descended the volcano in a NNW direction damaging a few homes and/or crossing the main road to San Jorge between Cantón El Volcán and La Placita. The source regions for these debris flows are located in the region of slopes >40 degrees [Figure 5]. These originate from an over steepened, highly oxidized area of scoria located on the upper northwestern portion of the cone [Photo 3, 4; Figure 13]. Debris flows were reported in 1985, 1988, 1992, 1994, 1999, 2000, and 2001 [Geólogos del Mundo, 2001; Table 2]. These debris flows are not related to eruptive activity and have been relatively small without causing major damage. They have presented the local population with minor loss of property and are mostly a short-term inconvenience [Table 2]. Cantón El Volcán and Cantón Conacastal, both have been periodically affected by small debris flows during the rainy season [Figure 13].

The steep slopes of the upper cone of San Miguel could potentially be the source of larger debris flows, especially following very heavy rains.

Photo 3 and 4. Volcanic debris located on NNW flank the volcano, about 1945 m altitude. Left is the top of Quebrada La Arenera, showing a large amount of volcanic debris. To the right, are drainages toward to Cantón El Volcán [3000 people].

Table 2. - Characteristics of some historic debris flows reported at Volcán de San Miguel [Modified from Geólogos del Mundo, 2001].

Date	Drainage	Source	Deposit and thickness	Flood	Damages
19/06/1945	La Quebradona	Heavy storm	-	yes	Houses and road buried
06/05/1951	La Silva y Mª Chavez	Heavy storm	Hyper concentrate (1 m)	yes	Road was buried
05/1965	La Arenera	Heavy storm	Blocks and debris (2 m)	yes	Houses and road buried
15/09/1965	La Arenera	Heavy storm	(1 m)	-	-
08/05/1975	La Piedrita	Rain	Hyper concentrate (1 m)	No	Child killed
07/05/1985	La Placita	Rain	Blocks and debris (1.5 m)	yes	Houses and road buried
28/09/1992	La Arenera	Rain	Hyper concentrate (1.5 m)	yes	Houses and roads buried
26/08/2000	La Arenera	Heavy storm	Blocks and debris (1.5 m)	yes	Houses and roads buried
06/09/2001	La Arenera	Rain	Hyper concentrate 1 m	No	Retaining wall

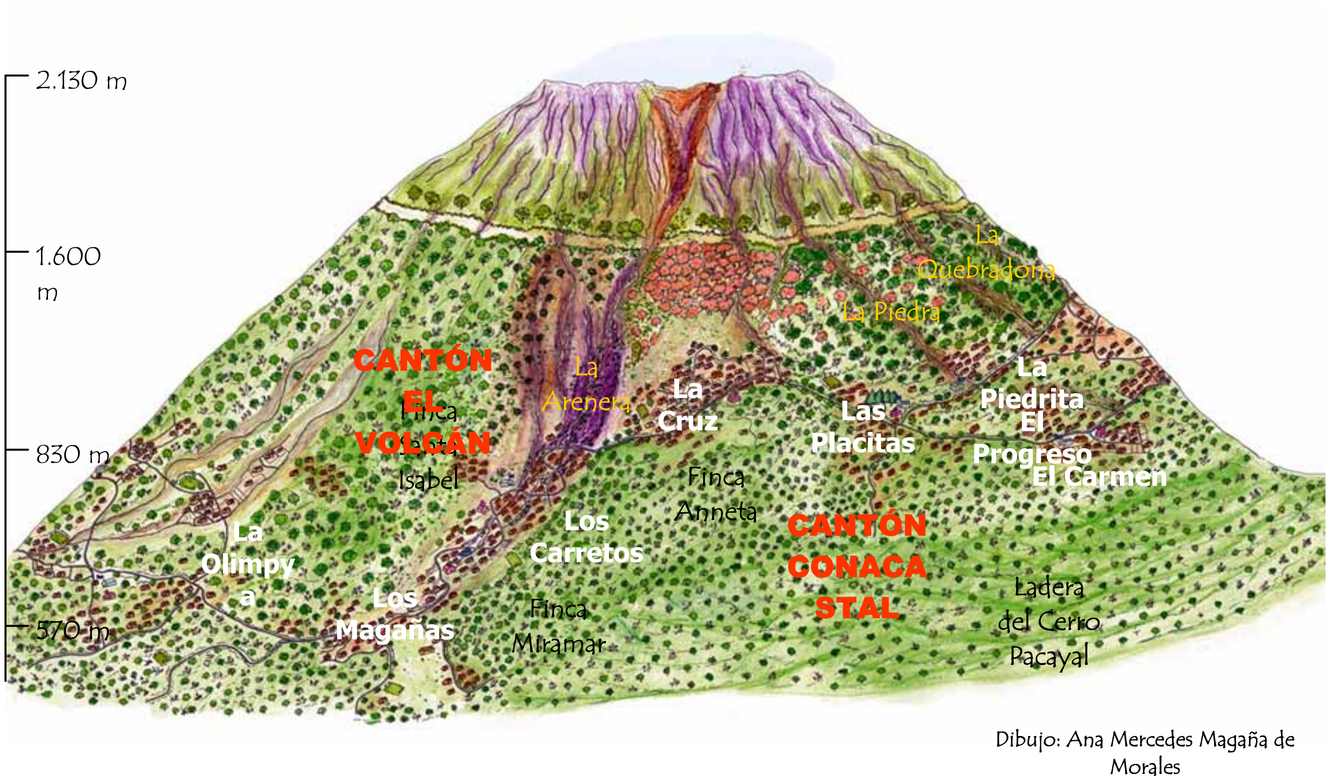


Figure 13. Sketch of San Miguel's North flank, showing areas affected by debris flows [Courtesy of Geólogos del Mundo, 2001].

1.2.5 Prehistoric debris flows

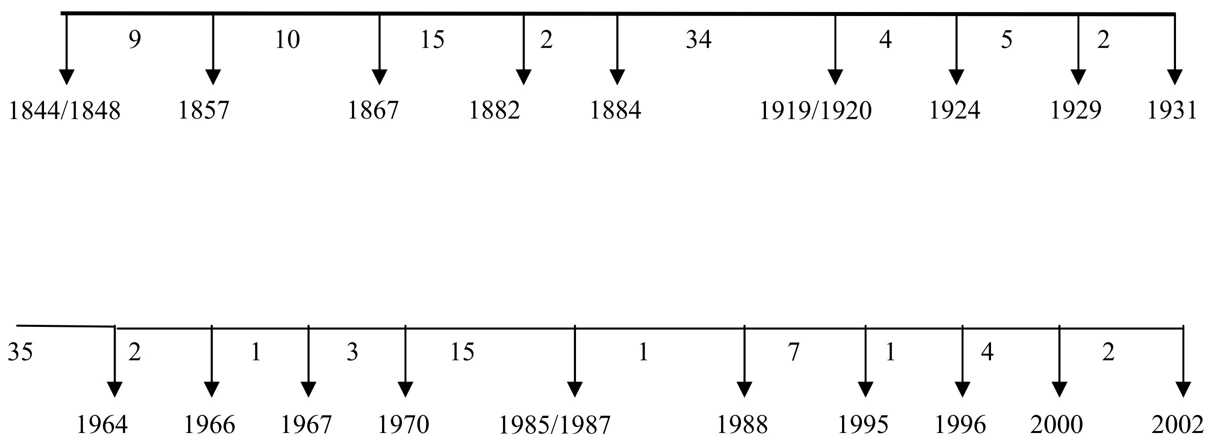
Several debris flows deposits occur in ravines on the southwestern flanks of the volcano. Indurated laharic deposits were found in the Quebrada La Quebradona on the west flank of San Miguel about 3.5 km from the summit [site 44 in figure 7]. Further down slope in Quebrada La Ceibita o La Ceiba indurated lahars deposits are exposed 7.5 and 10 km from the summit [sites 21 and 23 in figure 7]. The stratigraphic position of the lahars at these two localities, below several soils and tephras, suggests that they are prehistoric in age. The furthest outrunning of most distal debris flows occur at Quebradas El Clavo [site 88 in figure 7] and El Llano [site 87 in figure 7], about 11 km from the summit, at elevations of 140 and 160 m respectively. All of these consolidated lahar deposits appear to have originated from transport of volcanic debris by rain water, which forms from rains falling on thick accumulations of scoria, mud and ash on the western portion of the upper cone.

1.2.6 Historic tephra fall

Minor explosive tephra eruptions have occurred at least 18 times from 1844 to present. Most of the tephra falls have been the result of small explosions, producing minor ash falls that were rapidly erased from the geological record. A few coarse historic and prehistoric pyroclastic fall deposits have been identified on the western flanks of the volcano, in the direction of the prevailing winds. On this flank, the upper portion of the cone is covered with a thicker sequence of gray reddish scoria fall deposits [Photo 5]. The only possibly significant historic explosive eruption at San Miguel volcano occurred in 1970. Deposits associated with this event has not been identified, but ash fell up to 20 km from the volcano. Frequent minor ash falls and infrequent thicker scoria falls collectively indicate that the historic tephras have mostly been volumetrically insignificant at San Miguel. The historical sequence [figure 14] of ashfalls shows that approximately every 9 years a small ash eruption has occurred.

Photo 5. Thick sequence of scoria fall at 1950 m altitude at northwest flank of the volcano.

Volcán San Miguel historical sequence and repose time of ash eruptions



Ash emissions since 1844 to 2003:

2003 – 1844 = 159 years

~ 18 events, then 159/18 = 8.83, ~9
According to historic activity, small ash falls are periodic events at San Miguel Volcano, they have had occurred each 9 years, some times less frequently.

Figure 14. Eruptive sequence and repose time of ash emissions

From 1844 to present, minor gas emissions and smaller ash falls have been occurred at least 18 times. The most significative historic ash eruption occurred from March 30 to April 05, 1970.

Ashe from this eruption were dispersed about 10 km to NW of the volcano. This eruption was studied by Stoiber and Rose [1974]. In their study they reported a total volume of ash emitted of 75,000 m^3, with a weight of ~$0.1x10^6$ Ton [Appendix B].

Periodically smaller ash eruptions and associated gas emissions have been periodically reported: 1882, 1884, 1919 - 1920, 1929, 1931, 1964, 1966, 1967, 1985, 1987, 1988, 1995, 2000 and 2002 [Smithsonian Institute, 2003]

1.2.7 Prehistoric tephra deposits

Dark gray to black, mafic tephra layers, and many thin gray tephra layers are located northwest of the summit of San Miguel, Pacayal and Limbo volcanoes.

One massive deposit of black to grey scoria fall marks the most significant episode of explosive activity at San Miguel volcano during the last 1800 years.

Tephra fall unit is found in several locations between San Miguel, El Pacayal, Ojo de Agua, Cerro Limbo and Cerro Chambala volcanoes and is named "Alpina Tephra fall ", because it is thickest in the Finca Alpina, about 3.5 km from San Miguel's summit. This fall deposit was mapped throughout an area of about 117 km^2, where it was spread with a dispersal axis to the west of San Miguel crater [Figure 15]. The Alpina scoria layers range 30 cm to 5 m thick in the dispersal area. The scoria fall has a low lithic content and has beds which include both normal and inverse grading, and is basaltic, containing about 1 % of crystals and is basaltic with plagioclase crystals. The deposit is a typical basaltic scoria fall with grain sizes ranging from ash to blocks, having scoria fragments ranging up to 10 cm in diameter at Finca Alpina close to the crater and 2 cm at about 12 km from the summit along the Santa Elena Road [See Figures 16, 17, 18, 19, 20, 21]. The volume of the fall deposit is about 0.51 km^3 dense rock equivalent. This is the youngest explosive eruption of significant size from San Miguel volcano, as all other ashfalls are no more than a few percentage of this mass. The Alpina Tephra [Figure 16] is overlain by about 40 cm of gray ash and about 20 cm of white ash from Ilopango caldera, 421 – 526 AD, Dull et al, 2003]. At Montaña Lacayo a sample of wood was retrieved from a buried soil horizon above the Alpina tephra fall [Figure 17], . The wood was ^{14}C radiocarbon dated by

William Scott from USGS, and yielded an of 320 – 440 AD. This suggests that the Alpina unit was erupted approximately 100 years before Ilopango eruption [Ilopango Caldera is located to 120 km to the west, and the distal fall from Ilopango is known in many parts of El Salvador].Therefore Alpina tephra age is ~ 1800 years' old. Field studies suggest that the Alpina Tephra Fall probable was erupted from San Miguel summit after a small summit collapse.

Chemical analysis of several tephra samples from the Alpina show a positive chemical correlation with other San Miguel rocks. Chesner et al.[2000, 2002]) collected samples about 3.5 km west of the summit [See figure 7, T16, T19, T44A, T 44B] and tephras on the Northwest flank [T74, T752,T757, T65,T 66, T45]. They have been geochemicaly linked to Alpina tephra fall.

A preliminary isopach map from Alpina tephra fall was prepared. The map shows the distribution, thickness and axis dispersal of this tephra [Figure 15]. From this isopach map, the volumes of tephra fall were estimated using areas and thickness distribution [Table 4].

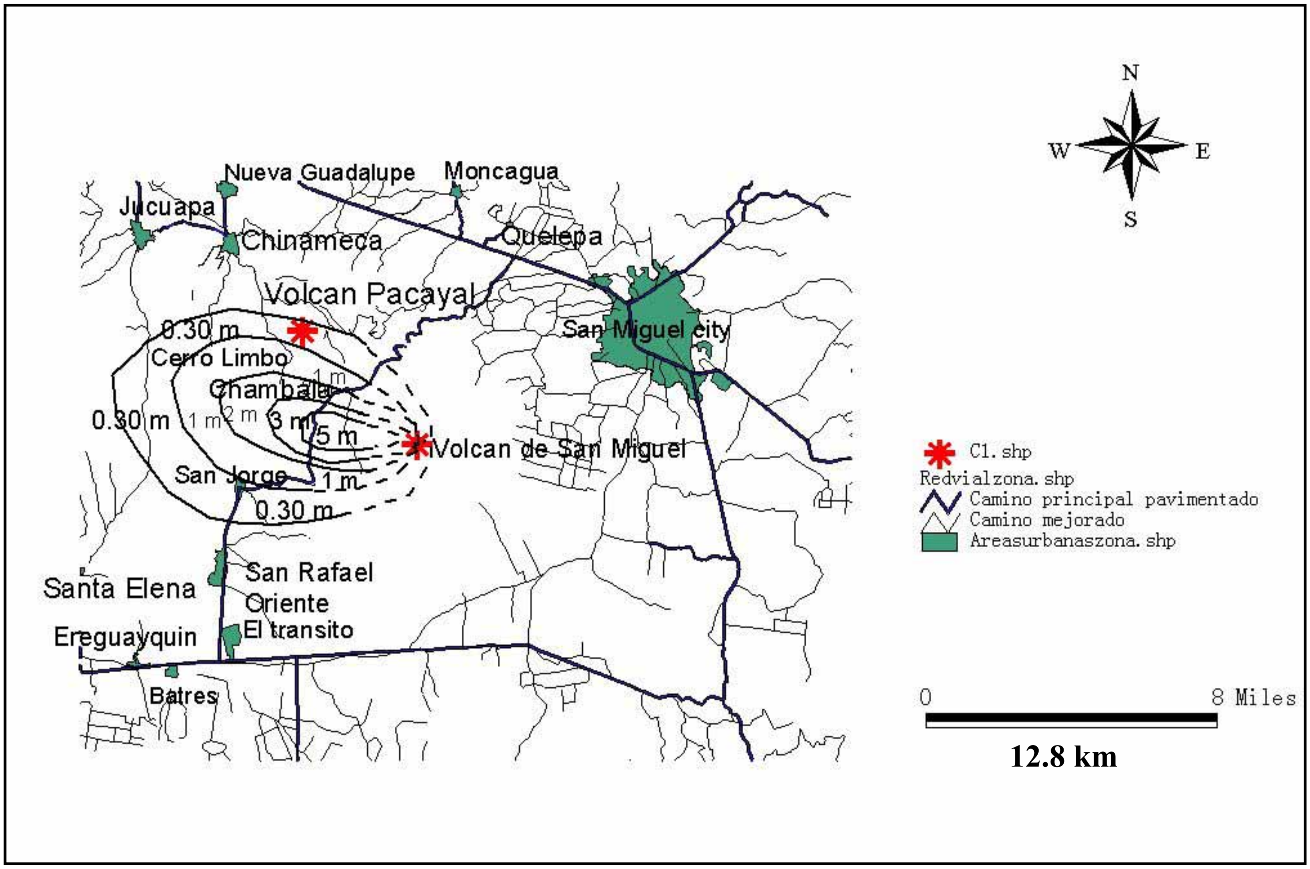
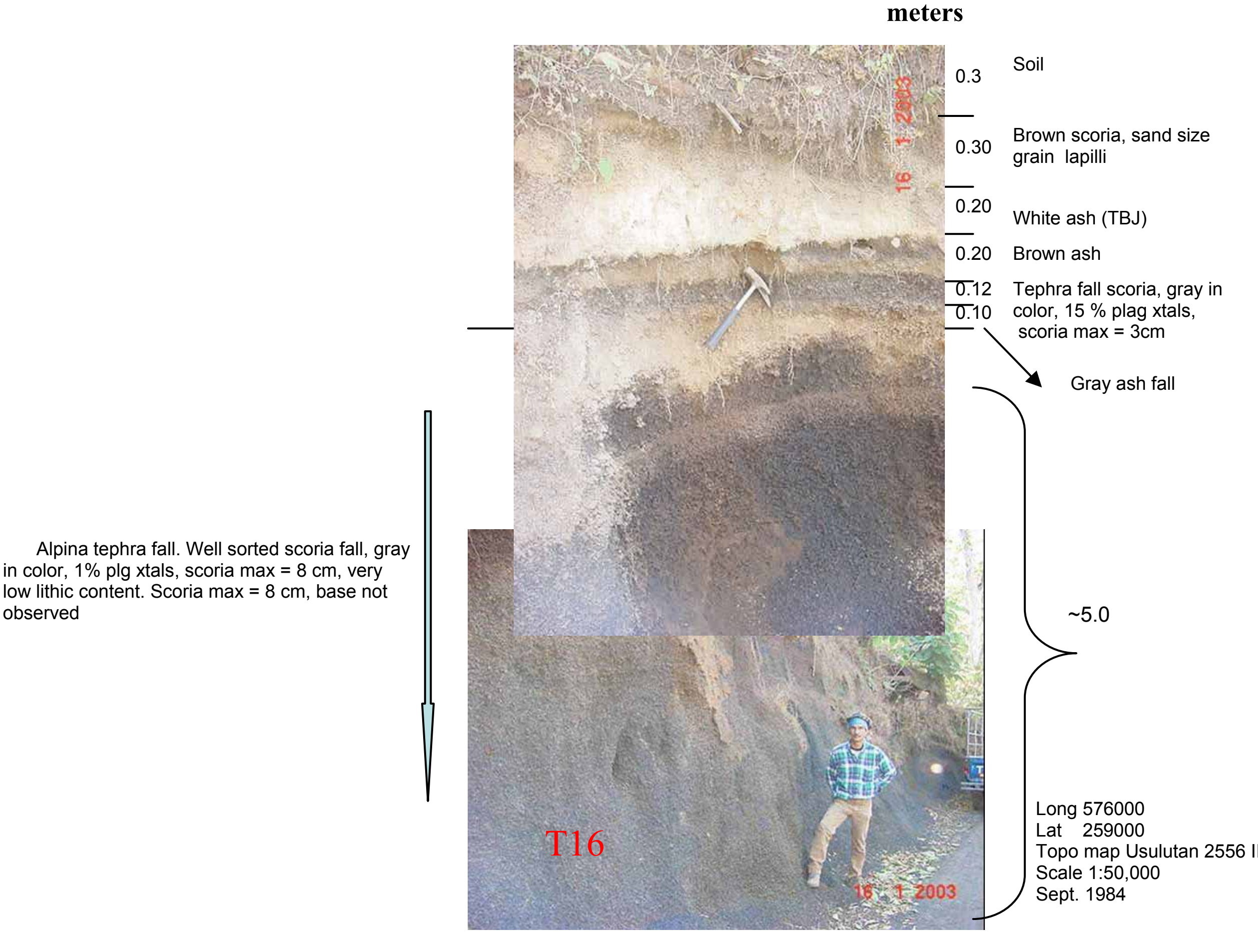
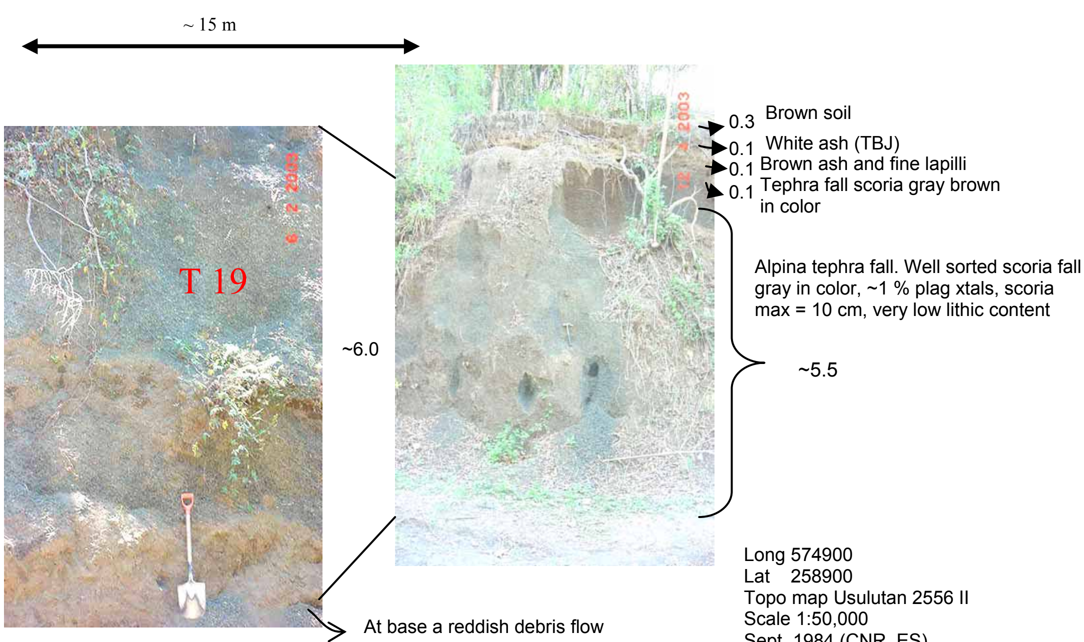


Figure 15. Isopach map showing deposits and distribution of Alpina Tephra Fall.

Figure 16: "Finca Alpina" tephra fall, to 3.5 km west from crater



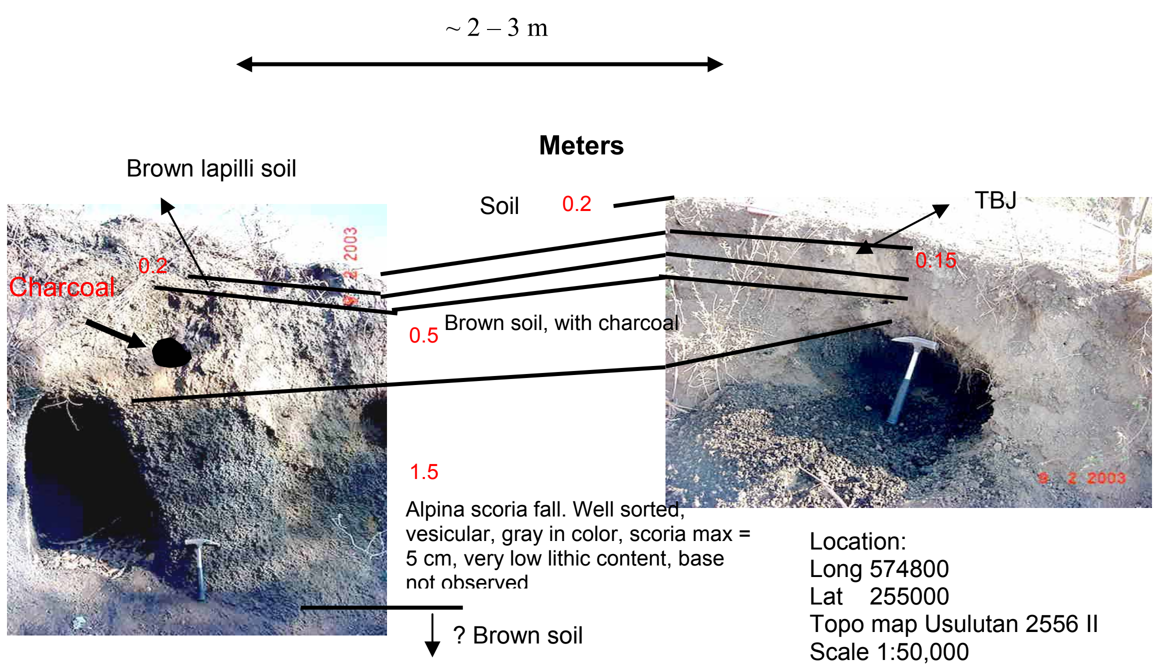
Outcrop at "Finca Alpina", road toward to Finca Lacayo



Outcrop to 300 m from Cemetery Placitas, road toward to San Jorge

Alpina tephra fall

Charcoal Sample site

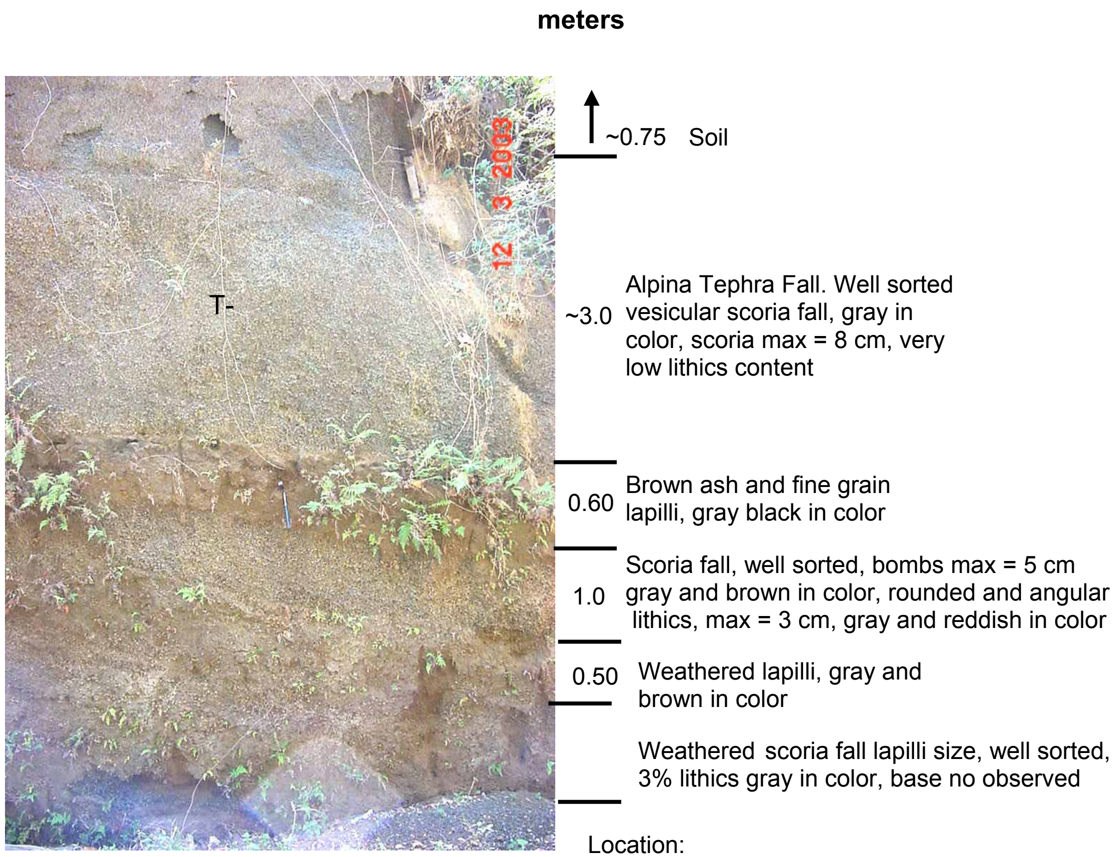


Location:
Long 574800
Lat 255000
Topo map Usulutan 2556 II
Scale 1:50,000
Sept. 1984 (CNR, ES)

Montaña Lacayo, ~1 km West La Quebradona. Alpina Tephra Fall deposit beneath a soil contained a charcoal [sample age 320 – 440 AD, dated in this study by William Scott, USGS, 2003].

Figure 17. Area Montaña Lacayo, Charcoal sample

Alpina tephra: Located to 6 km west from San Miguel crater

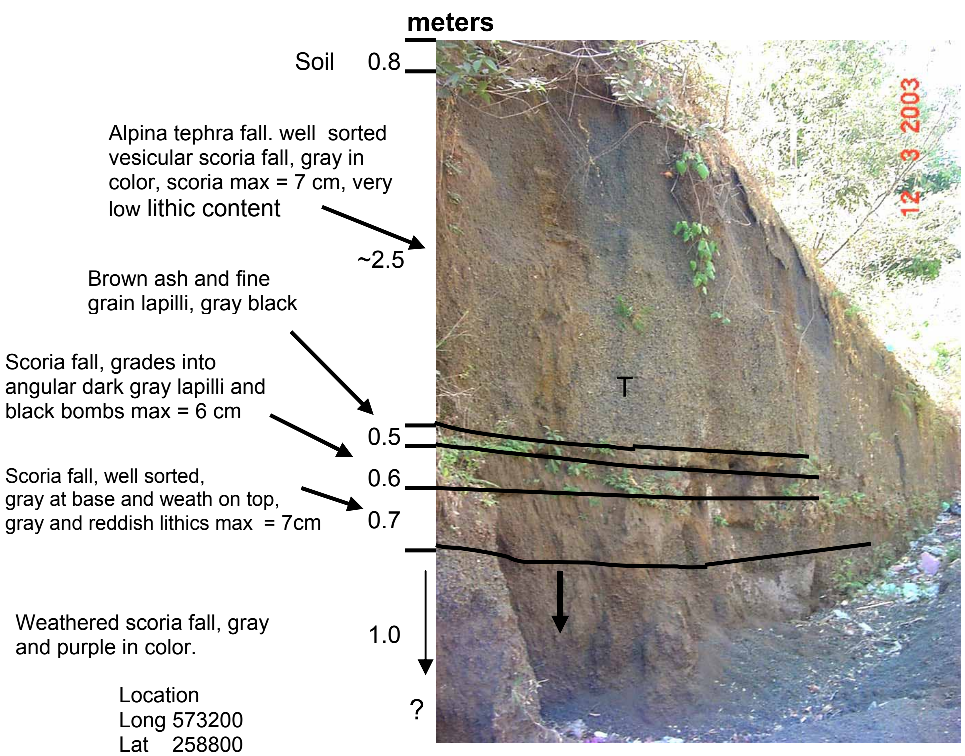


Outcrop 200 m West from fumarolic field, toward Cantón and Caserío Chambala [Sample T-74]

Location:
Long 573300
Lat 258300
Topo map Usulutan 2556 II
Scale 1:50,000
Sept. 1984 (CNR, ES)

Figure 18. Tephra deposits, on top of the Alpina tephra fall at Finca Cancy

Alpina tephra: At Cantón and Caserío Chambala, about 8 km west from San Miguel volcano crater



Location
Long 573200
Lat 258800
Topo map Usulutan 2556 II
Scale 1:50,000
Sept. 1984 (CNR, ES)

Outcrop at Canton and Caserío Chambala [Sample Chesner T-75]

Figure 19. Tephra deposits, on top of the Alpina Tephra Fall

Alpina tephra fall: At about 9 km NW from San Miguel crater

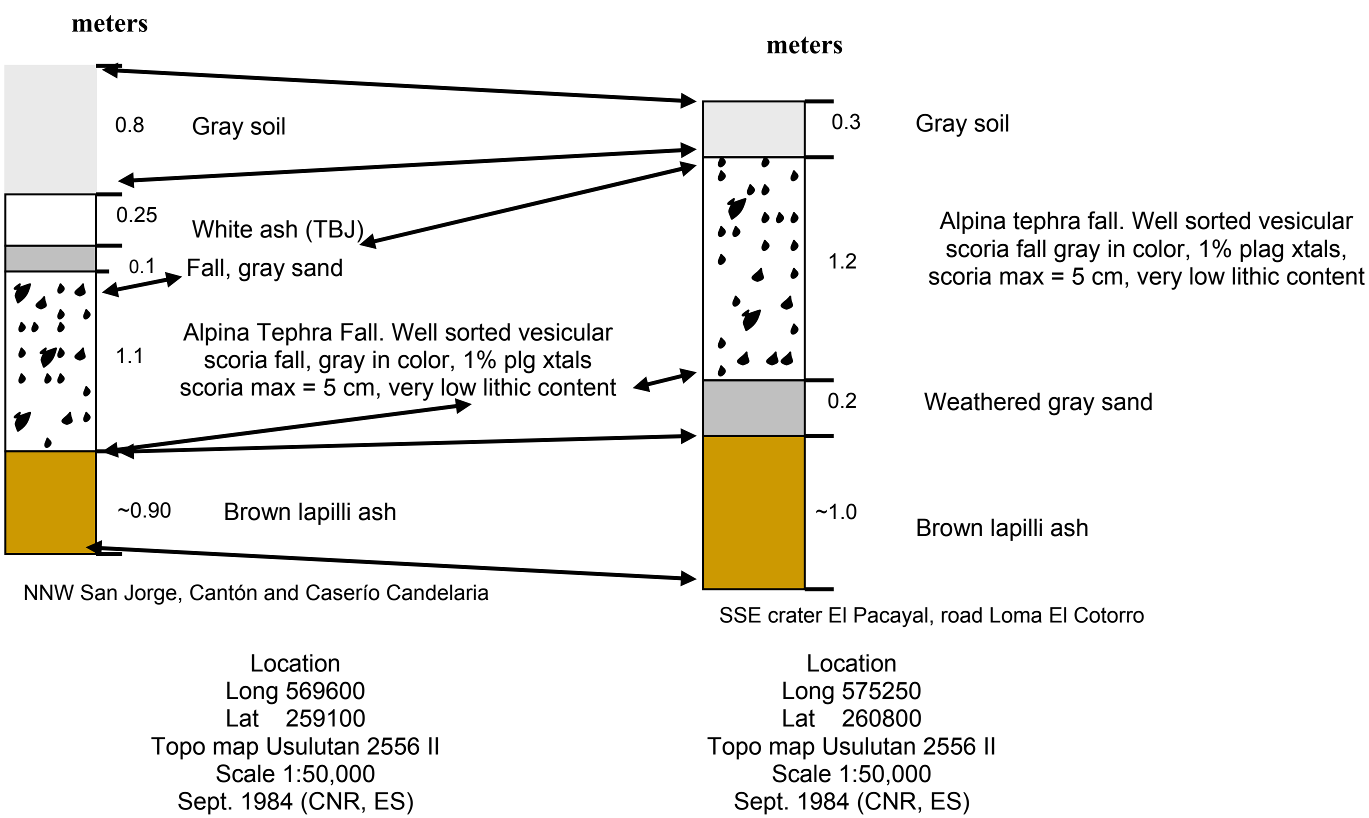
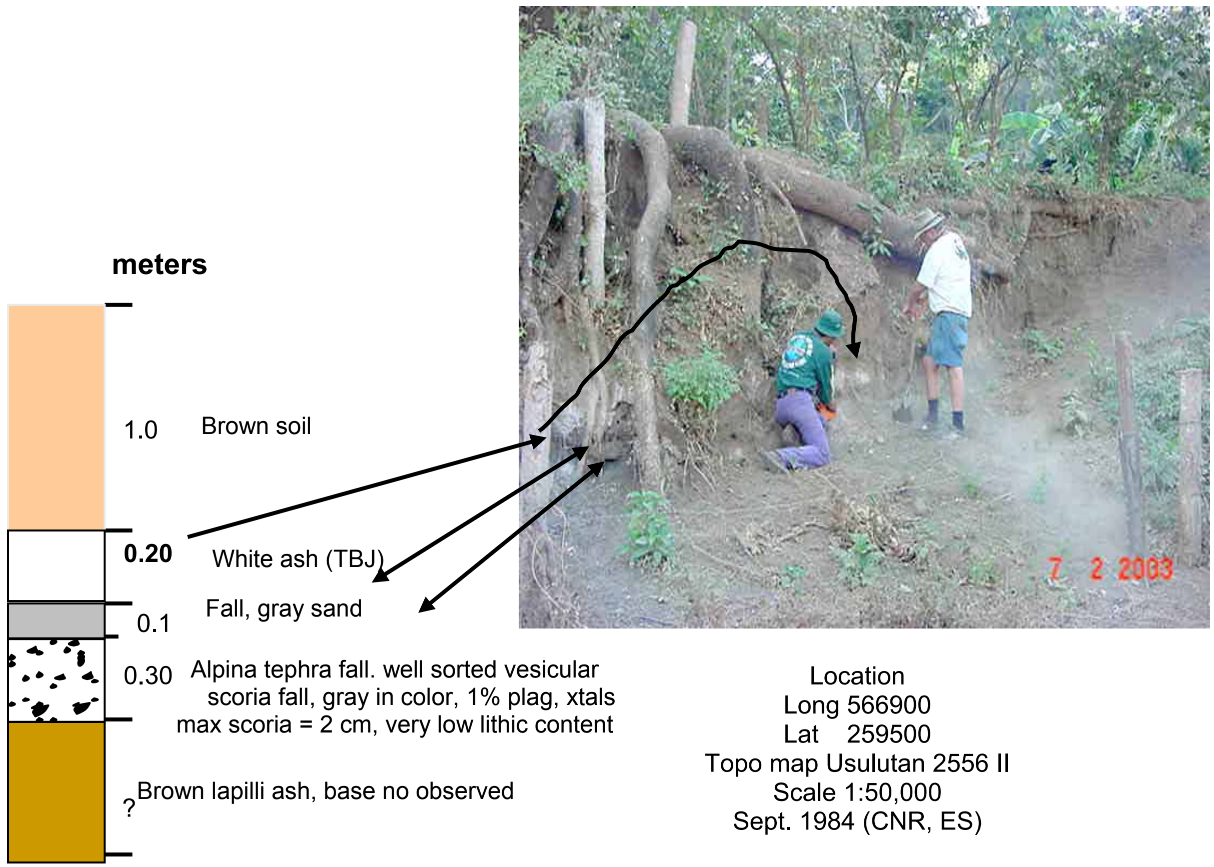


Figure 20. Stratigraphic correlation, showing deposits of Alpina Tephra and TBJ

Alpina tephra : At about 12 km WNW of San Miguel volcano crater



Santa Elena area, toward to Jucuapa - Chinameca

Figure 21. Stratigraphic sequence, showing deposits of Alpina tephra fall just beneath the TBJ from Ilopango Volcano, located 120 km west from San Miguel summit.

Alpina tephra fall, estimated volumes

Thickness (meters)	**Mapped area (km^2)**	**Volume [km^3]**
5	15	0.075
3	24	0.072
1	70	0.7
0.3	117	0.351

Magma Vol = 1.20 km^3

Tephra density = 1110 kg/m^3 [Analysis from laboratory of Universidad Politécnica de El Salvador, 2003].

Basalt density = 2600 kg/m^3

Density = m/v , magma vol = Tv = 1.20 km^3

Tephra density (Td) =1110 kg/m^3 ; mT = Tv x Td = 1.20x1110 = 1332 km^3 x kg/m^3

Basalt density = 2600 kg/m^3 = m/v; mT/Basalt density = V = 0.51 km^3

, : Bulk Rock Equivalent volume [BRE] = V = 0.51 km^3

Table 3. Alpina Tephra Fall volume estimate.

At Barrio Nuevo Paris [Figure 22], the Alpina fall deposits, TBJ and phreatomagmatic surges from San Miguel Volcano are found at 2.5 km from city of San Jorge

Outcrop located at ESE of San Jorge toward to Placitas

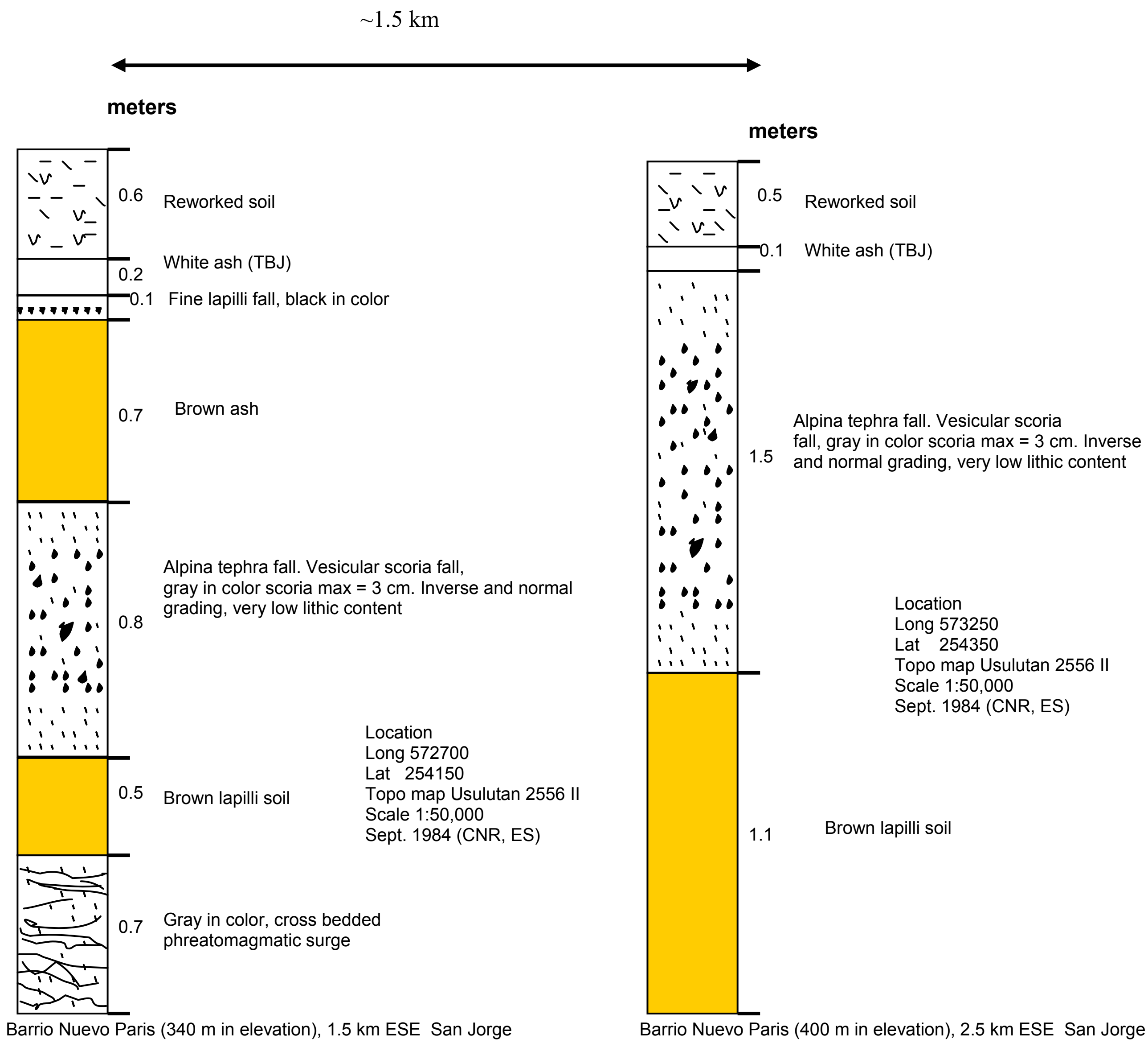


Figure 22. Alpina Tephra Fall, TBJ and phreatomagmatic surges towards San Jorge

1.2.8 Debris Avalanche

- Possible collapse and related deposits

Field work at San Miguel area and interpretation of aerial photos suggest that the upper region of an ancestral San Miguel cone may have collapsed. There are three lines of evidence consistent with the collapse of San Miguel cone: [1] Two arcuate "shoulders" located on the upper northeastern and southeastern flank between 1800 and 1900 m altitude [Photo 6 and 7]. This observation is congruent because the portion of the volcano below the shoulders has slightly different slopes and morphology from the upper cone above the shoulders. Aerial photos [8 and 9] also show features that suggest a possible past volcano collapse. [2] The present summit cone [Tephra cone] shows a fresher erosional morphology, which suggests that it is a young cone inside of an older crater and its steeper slopes and unconsolidated pyroclastic deposits appear to cover an older cone. [3].

Debris avalanches deposits were found at San Rafael Oriente, 11 km southwest of the summit. These are mixed with block and ash flow materials, and compositionally these appear to come from San Miguel.

The bed is very well exposed in a limited region near Quebrada San Jorge and Barrio La Merced. The debris avalanche underlies ~2 km^2 of the area Barrio La Merced in the margins of Quebrada San Jorge [Figure 23]. Age determinations of this deposit could not been made as datable carbon could not be found. The deposit is unstratified, unsorted and massive, and comprised of sub angular gray boulders up to 2 m in diameter mixed with a brown ash, and reddish scorias, and has typical characteristics of debris avalanches [Siebert, 1996], which includes jigsaw fractures, and variable purple, orange matrix of pebble – sized clasts and sandy material. The deposit is closely associated with a block and ash flow of basaltic andesite composition. There is no discernable contact between the block and ash flow and the debris avalanche and we interpret them to be part of the same event. We compared the geochemical composition of the block and ash flow and San

Miguel rocks both have similar basaltic compositions [Sample 89 in figure 7]. The age and composition of debris avalanche rocks are unknown, but hand specimen observations show that the primary blocks of both the block and ash flow and the debris avalanche are porphyritic olivine basalt similar to San Miguel lavas and this suggests that the source of the debris avalanche source is San Miguel volcano. The existence of this deposit on the west side of San Miguel may be associated with the amphitheatre [see again figure 6] which appears to face west, and suggest that the collapse of the older San Miguel cone to the west gave rise to the block and ash flow and debris avalanche. The limited exposure of this deposit may be due to its being covered with materials associated with eruptions from the younger cone of San Miguel, which have now filled the old amphitheatre and practically obscured it [Photos 7 and 8].

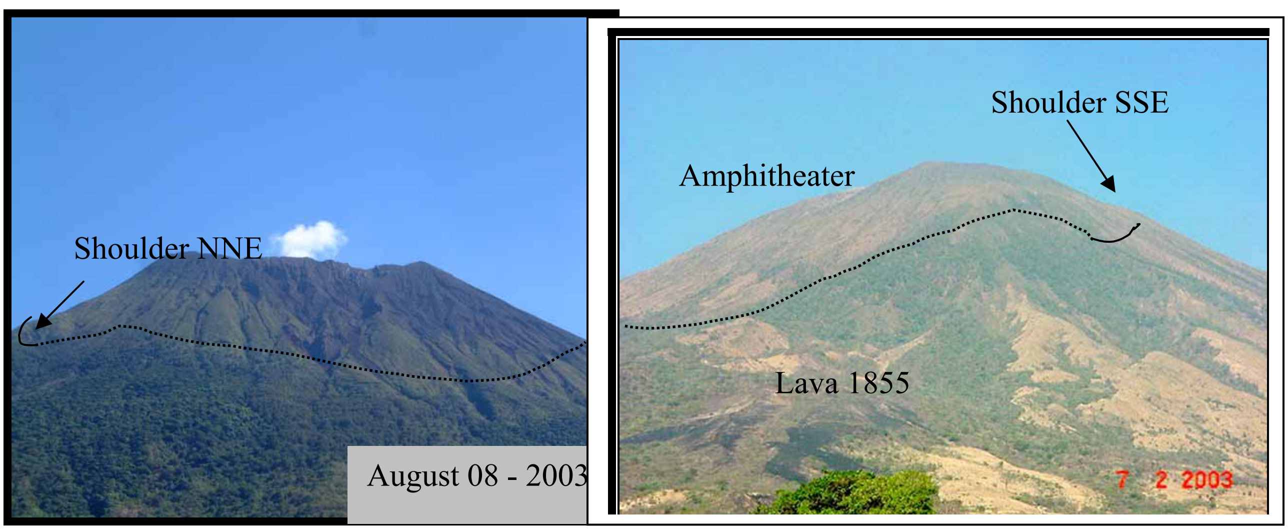
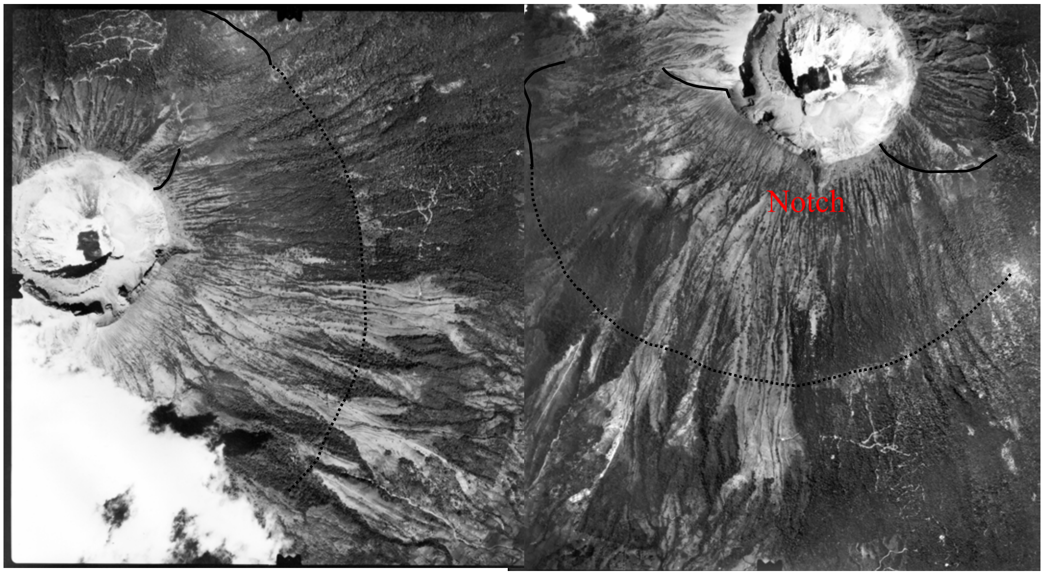


Photo 6 and 7. To the left view from north flank, right view from southwest flank.



Phot 8. Left southeast flank [Aerial photo, 1976]. **Photo 9**. Right east flank [Aerial photo, 2001]. Both photos show areas [dashed lines] that are thought to have been caused by volcano collapse. In the right photo, the fill lines on top suggest other summit collapse, probably about 1800 years ago, associated with Alpina tephra explosion. The notch and younger lava flows dominate this flank.

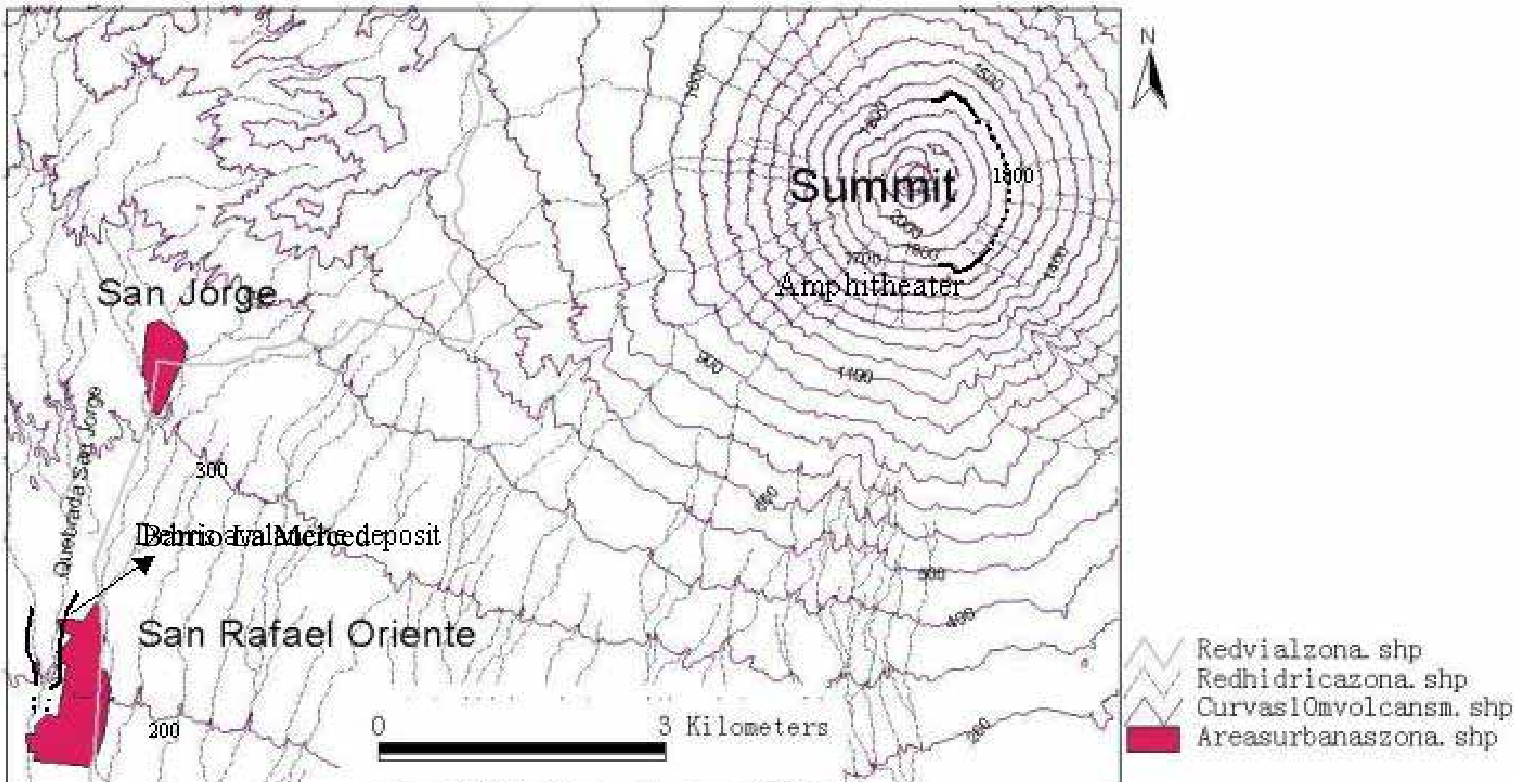


Figure. 23.Topographic map [1:50000] showing location of debris avalanche deposits located at San Rafael Oriente, 11 km to the west of the crater, and the outline of the old summit amphitheatre.

Eleven km to the SW of the San Miguel summit there are several deposits that are also probably associated with the edifice collapse. Figure 24, shows 3.5 m thick layer, which is a block and ash flow overlain by tephra fall from both Pacayal and San Miguel eruptions. Figure 25 shows the stratigraphic intercalation between San Miguel and Pacayal volcano. In fact, the block and ash flow deposit is apparently mixed with debris avalanche material [Figure 23]. Debris avalanche features are shown in [photos 10 and 11].

Stratigraphic section at San Rafael Oriente, Quebrada San Jorge, Barrio La

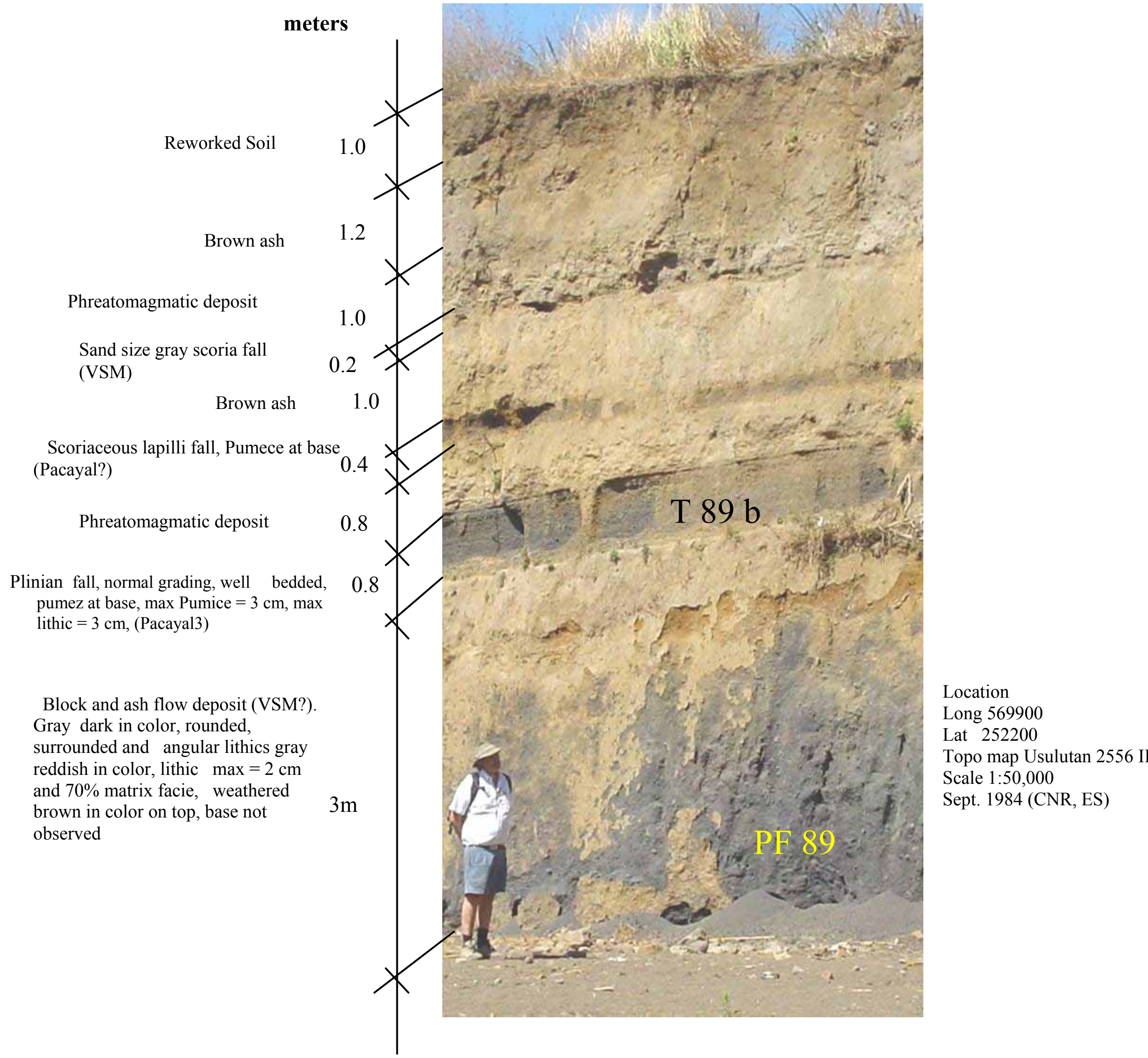


Figure 24. Stratigrafic sequence of deposits associated with San Miguel and Pacayal

Stratigraphic sequence at San Rafael Oriente, Quebrada San Jorge, Barrio La merced.

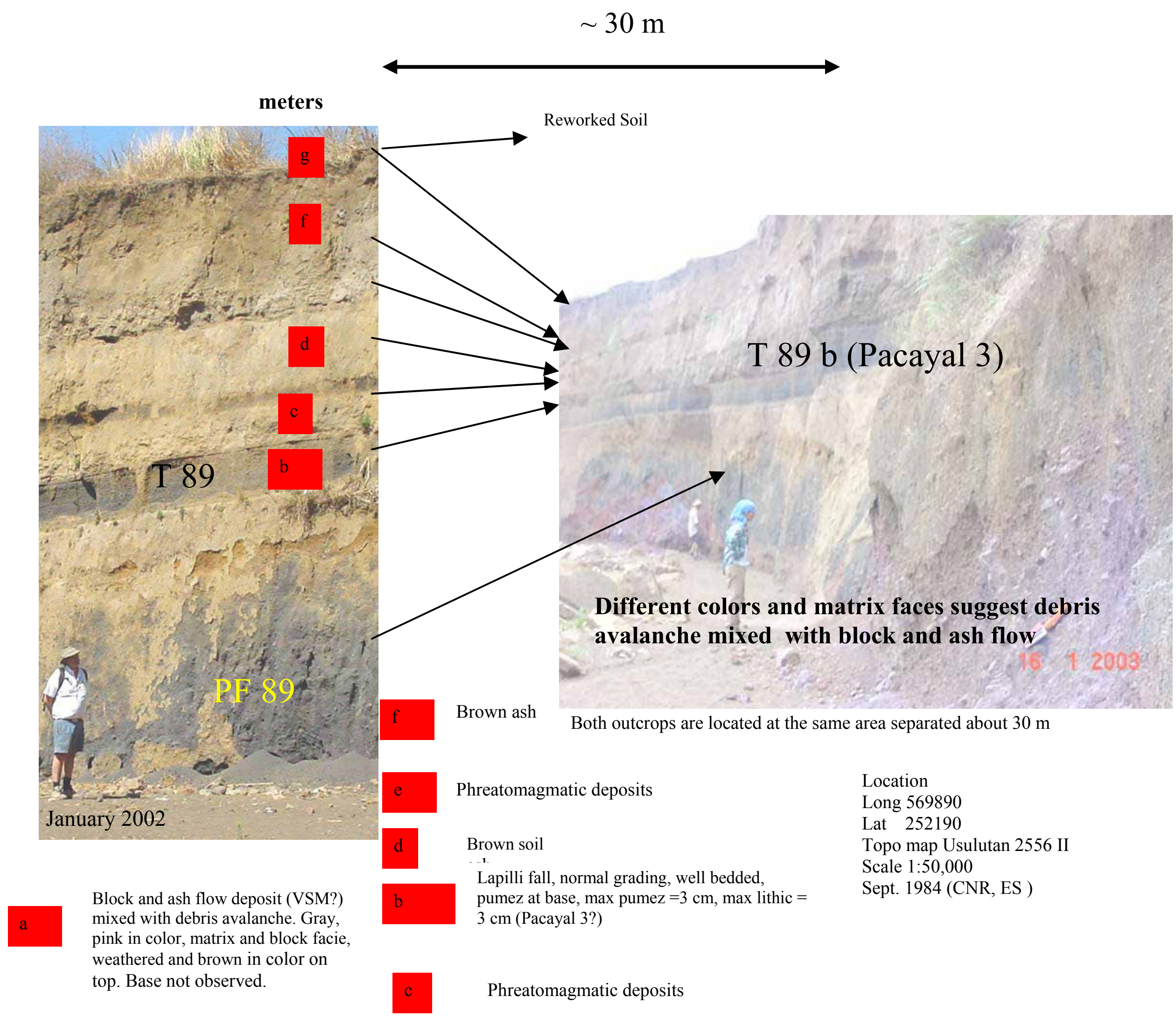


Figure 25. Deposit correlation. To the right outcrops of block and ash flow mixed with debris avalanche materials.

1000 m

Photo 10, 11.Debris avalanche deposits. To the left is a deposit about 4m thick which is sand matrix gray, purple and reddish in color, supporting blocks. The right photo shows typical jigsaw fractures of blocks about 2 m in diameter.

1.2.9 Observations at the summit

The summit cone [dashed lines] above the break of slope at 1800 m is composed mostly of gray and reddish coarse scoria, blocks, volcanic bombs, thin lava flows, phreatomagmatic and phreatic deposits [Photo 12]

Photo 12. View from northwest flank. On top, the young spatter cone defined by dash lines. At about 1950 m altitude [Photo 13], the slopes of this young cone show tephra sequences of over 50 m thick interlayer with thin lava flows [1].

Photo 13. North flank on top. Thicker tephra deposits [1] and thin lava flows

San Miguel's summit crater is about 800 m in diameter and actually has a depth of ~330 m. [Photos 14, 15]. On August 05, 2002 a large rock fall was heard all around of the volcano and produced a buoyant ash cloud.

Photo 14, 15. Left. Open conduit with its typical gas emission before rock collapse.
Right conduit stopper and weak fumaroles.

The outer crater walls are steep [~80 degrees], but allow access to a bench about 100 m below the outer crater rim at about 2000 m. asl. A lower, inner bench occurs in the western part of the outer crater. The deep inner crater [Photo 15] is about 300 m in diameter and has vertical walls. A distinct notch occurs in the eastern side of the outer crater. This notch affords access to the upper bench from where it was possible to collect a stratigraphic sequence of 22 lava flows [Chesner et al, 2003].

The crater rim tends to be higher on the east side, because this sequence of thin 2 m thick lava flows s are exposed dipping to the east, which suggest that the upper cone was higher in the past, probably about 2200 altitude. I suppose that collapse formed the current 800 m crater from Strombolian explosions associated with the "Alpina tephra fall", about 1800 years ago. Landslide, lava flow collapses and tephras thus likely to flow from the crater toward to the north, northwest and also to the east using the notch on the east site of the crater. In contrast, thicker thick scoria beds interlay red with thin lava flows were found in others areas around the crater rim, many of them over 12 m thick.

1.2.10 Structural features

Subduction between the Cocos and Caribbean plate is the main cause of historic and prehistoric volcanic activity in this region (Figure 26). Within the countries of Nicaragua and El Salvador, prominent troughs or grabens are found which are aligned parallel to the volcanic front. The tectonic structure of El Salvador is dominated by two major structural systems, first by a WNW trending set that together form a graben-like structure (Figure 3) called the Medial Trough. The second major structural trend is a NW – SE system of faults, which sometimes trend more northerly. Williams and Meyer-Abich (1955); and CEL - GENZL (1995) state that San Miguel is located at the southern side of the "Medial Trough". Other active volcanoes in El Salvador, such as Santa Ana, San Salvador, San Vicente and Berlin are located inside this tectonically active geological structure.

The pattern of variability of volcanoes along the Central America volcanic front has been studied by Carr et al (in press) and is shown in figure 27. The front is segmented into sections with different alignments and offsets. The entire length of El Salvador is a single segment, with a boundary occurring at the Bay of Fonseca, east of San Miguel. There are systematic changes in the volumes of the various volcanic front centers with two volumetric peaks in El Salvador, one at Santa Ana in western El Salvador and another at Tecapa, just to the west of San Miguel. The height of volcanoes and the thickness of the crust seem to decrease as one moves from west to east from Guatemala to El Salvador. San Miguel's height [2130 m] is consistent with that trend, which suggest that somehow crustal thickness influences the height that magma can be erupted. It also suggests that as long as the San Miguel cone keeps its current stature, flank eruptions are likely to be the most voluminous.

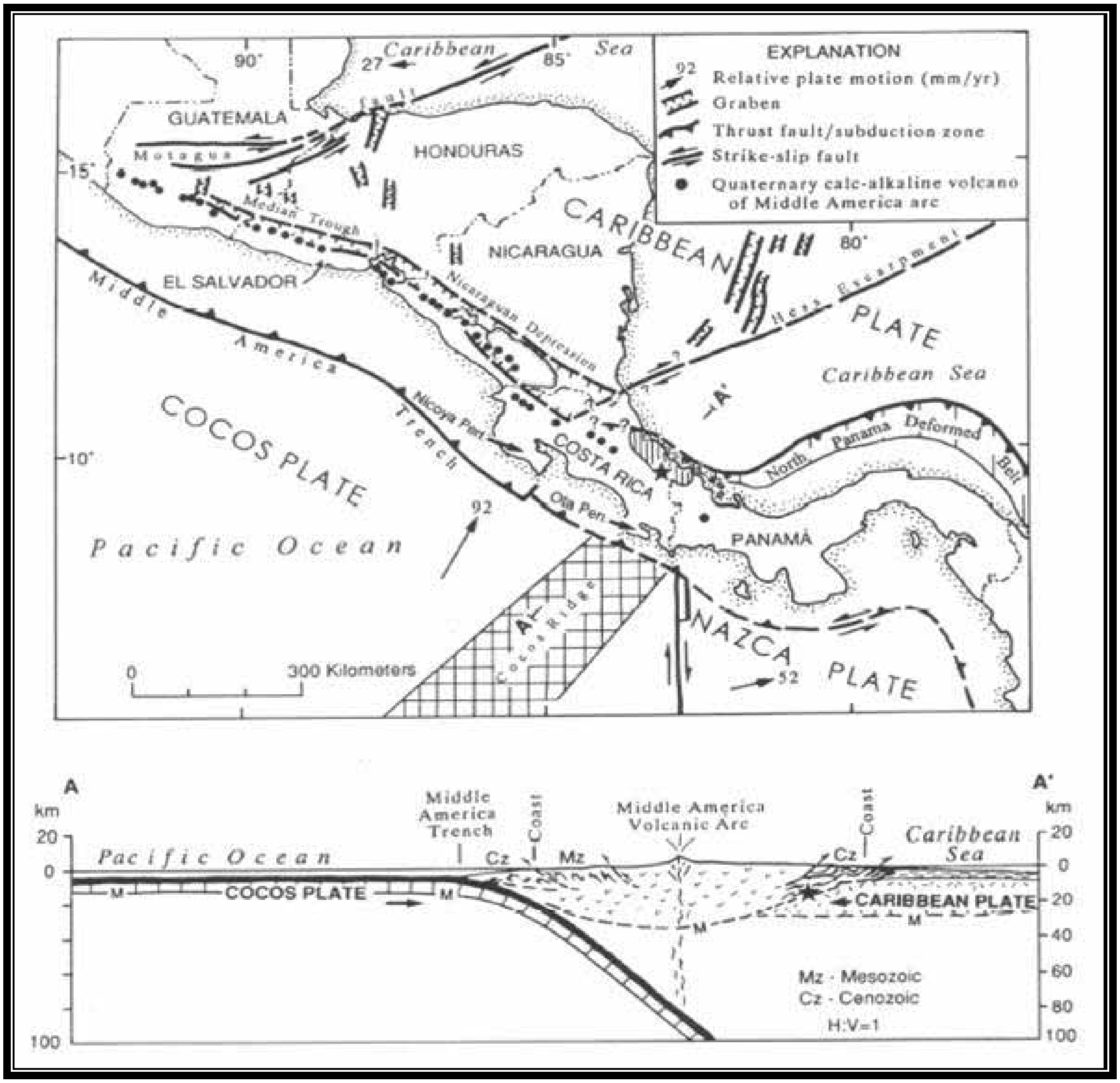


Figure 26. Plate Tectonic Setting of Central America [Plafker and Ward 1992]. The cross section of the subducting Cocos plate and the location of the Medial Trough of El Salvador.

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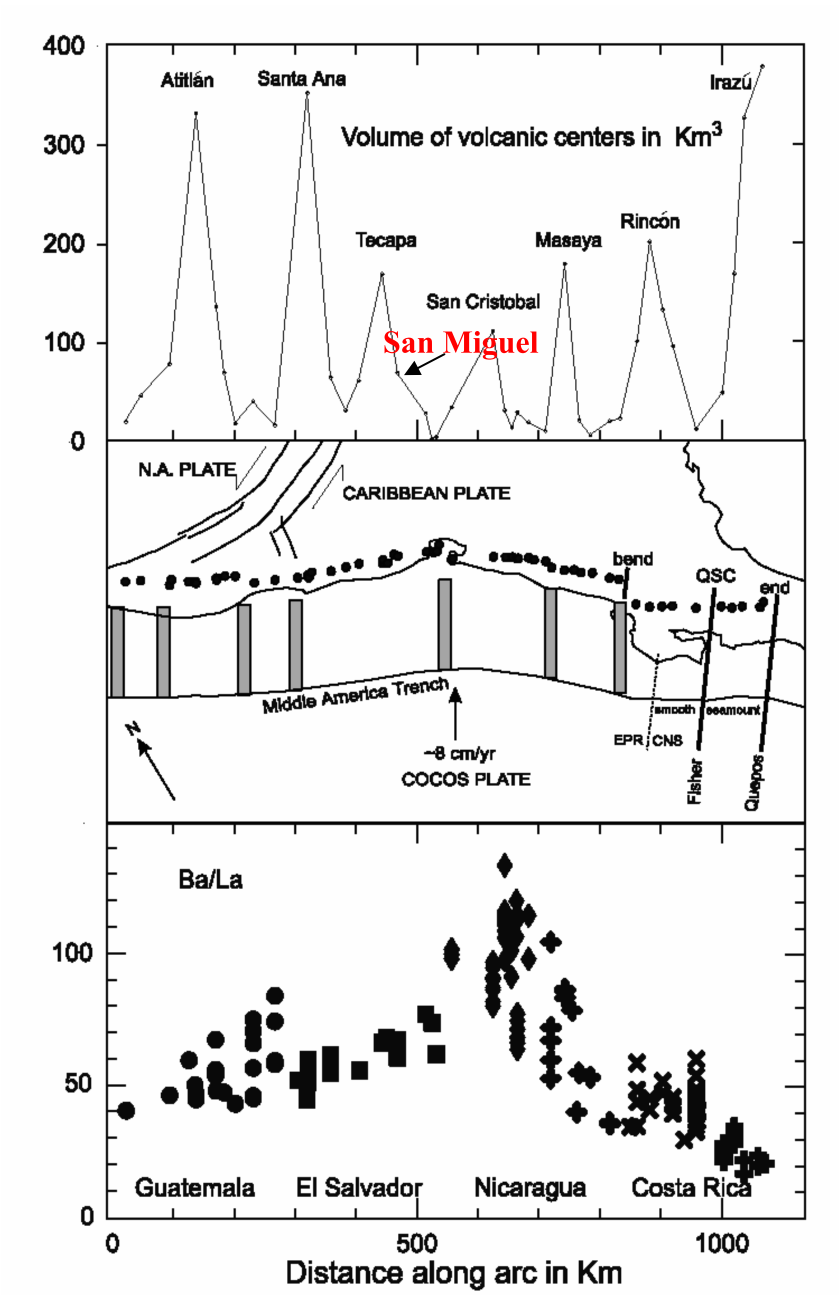


Figure 27. Segmentation of the volcanic front and systematic differences in volumes of volcanoes along the front, segmentation of the volcanic front and systematic Ba/La differences of erupted lavas [Carr et al., in press].

San Miguel Volcano is built on the side of Pacayal, an andesitic volcano with an obvious crater which is located immediately to the NW [Figure 28]. Pacayal seems geomorphologically older than San Miguel based on erosional valley development. Pairing of volcanic centers has been noted at many places in Guatemala and El Salvador by Halsor and Rose [1988]. In each case, an older volcano is located to the north of a younger, more southerly one. In all cases the southerly member of the pair is more active and more mafic in composition. Thus the Pacayal/San Miguel pair follows a familiar pattern. NNW trending diagonal fractures cross the Median Trough and are thought by Meyer-Abich [Figure 29] to have guided fissure eruptions at San Miguel, as well as at San Salvador volcanoes. Wieseman, [1975] concluded that in El Salvador in general a conjugated system to the WNW major trend is a nearly N – S fault system which occurs as fissures and alignments of eruptive vents as is true for the Santa Ana volcanic complex and San Salvador, San Vicente, Berlin and San Miguel volcanoes. Another, less usual NE – SW fault system occurs only in the central and the eastern part of El Salvador, and to the north of San Miguel volcano [Figure 3]. San Miguel's edifice is composed of two major cones which are difficult to discern. The Ancestral cone is preserved to the east of the summit, and the younger cone is basically formed by loose tephra and thin lava flows which filled an amphitheatre - like relict of the collapse of the ancestral cone. Both cones together form a classic symmetrical cone shape [Figure 28]. Small tephra cones and many fresh lava flows can be found around the volcano flanks. The shape of the cone is controlled by spatter on the upper slopes. At the summit the slope is close to 50 degrees whereas on the flanks is less than ~ 20 degrees. On the flank, lava, mud and pyroclastic flows control the slopes [figure 5]. Two shoulder remnants are located on the northeast flank at 1800 m altitude, and other on the southeast flank, at about 1900 m altitude [Figure 6]. Both are shoulders are associated with a collapse of the ancestral edifice. The southeast shoulder presents an elongated flat-topped ridge area of about 200 m. long, which is covered by fresh scoria fall. During our field observations we found the contact zone between both different cones, besides a tephra cone which suggests recent strombolian activity in this shoulder area.

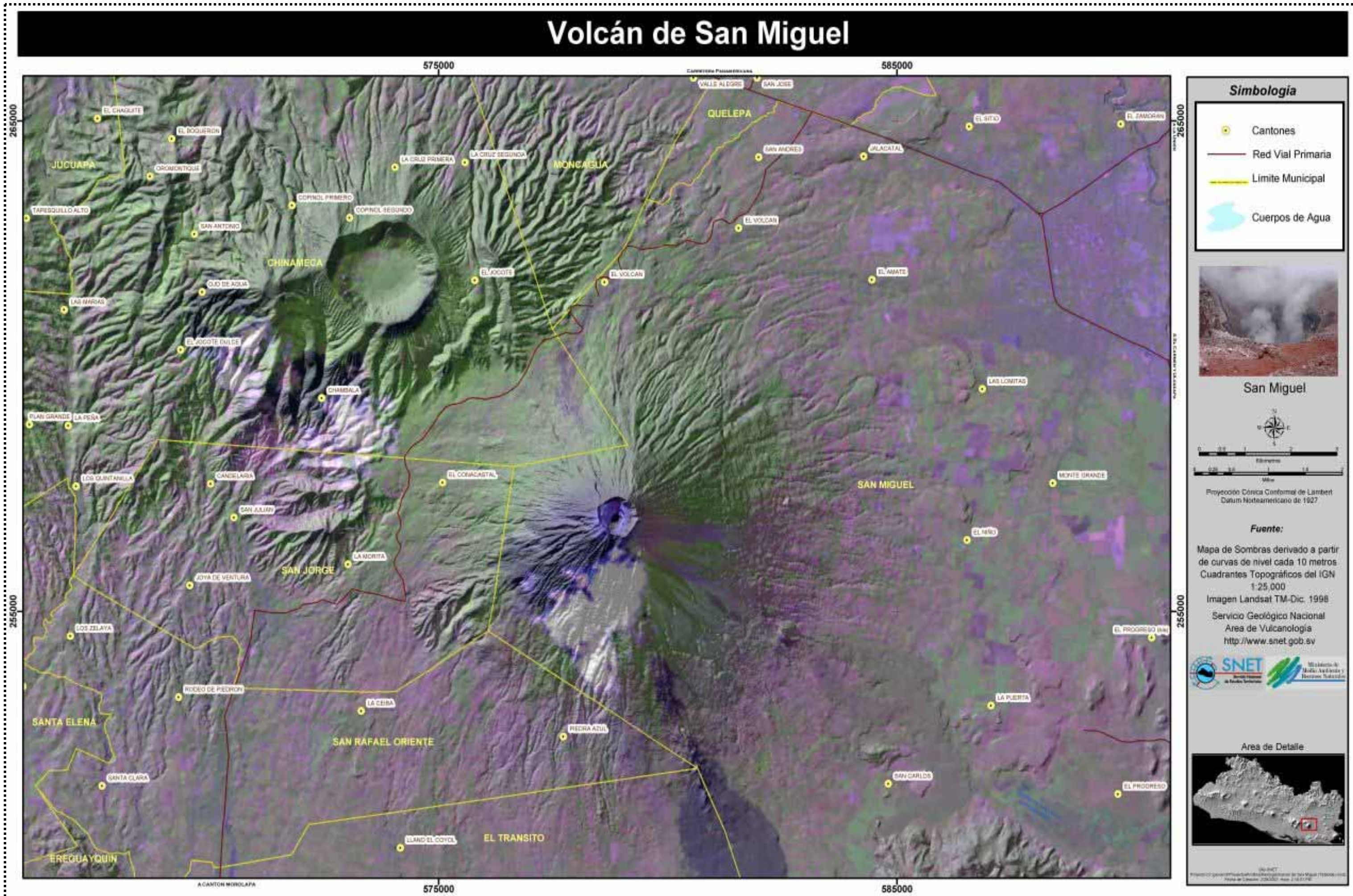


Figure 28. Shaded relief map of San Miguel, showing the geomorphological shape of the volcano and its relationship wih Pacayal Volcano located to the NW.

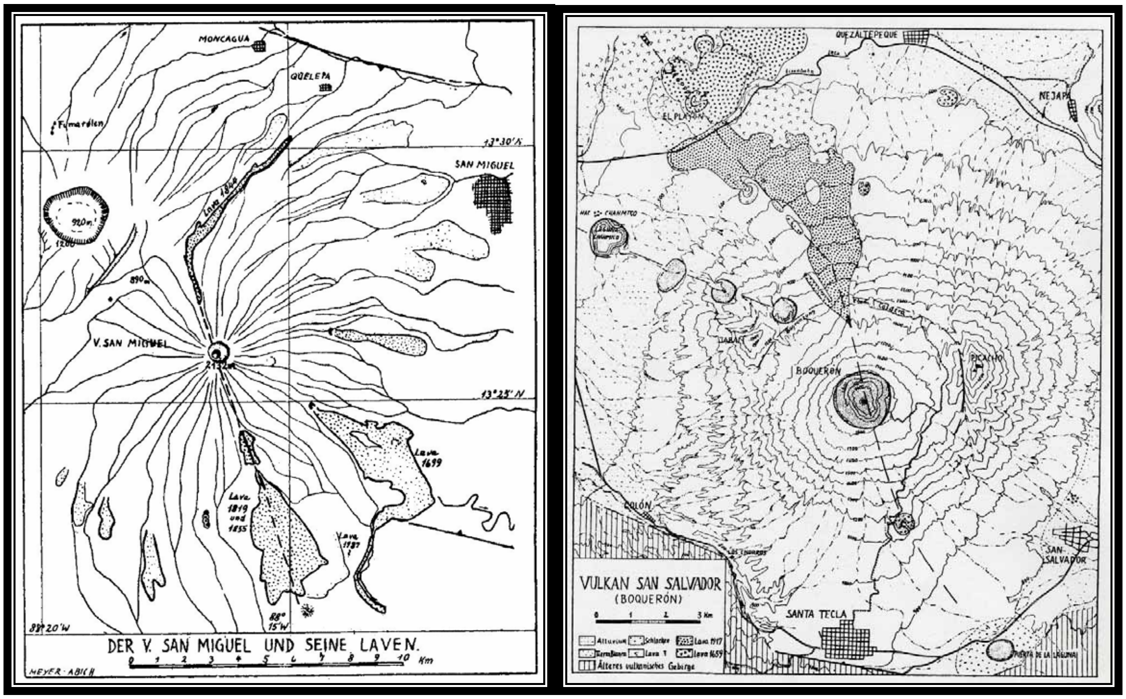


Figure 29. Sketch map of San Miguel showing fault pattern trending NNW at San Miguel [left], and a similar map of San Salvador Volcano, [From Meyer –Abich,1956].

1.3 Age of San Miguel Volcano

Based on intercalations of geological units and radiometric age dates we can estimate the age of San Miguel Volcano. A summary of these relationships is presented in figure 34. Based on geomorphology, San Miguel appears to be built on the side of an older volcano, Pacayal, which looks more deeply eroded [Figure 28]. The fall deposits of both volcanoes intercalate and are compositionally different and we know that the activity of both centers was partly simultaneous. Pacayal rocks include ignimbrites and tephra falls, which change due andesites, dacite to rhyodacite; and are different to San Miguel rocks which are basaltic, basaltic - andesitic in composition.

Studies by Comisión Ejecutiva Hidroeléctrica del Rio Lempa and Geothermal Energy New Zealand [CEL - GENZL,1995] in Berlin and Pacayal volcanoes suggest that approximately at the end of the Pleistocene and early Holocene both volcanoes were in eruption.

However, this information is not yet confirmed by ages from Pacayal and San Miguel [^{14}C and Ar/Ar] of intercalated deposits from Berlin caldera eruptions: Blanca Rosa, Twins fall and El Hoyon surges help constrain San Miguel [figure 30]. During our field work we found charcoal just above a tephra erupted by San Miguel volcano and the age was calculated by Radiometric ^{14}C presented in Table 4. Calibration dates using OXCAL program are presented in Appendix C.

Taken together these data show that San Miguel is probably entirely younger than 50 ka, and is possibly mostly less than 10 ka.

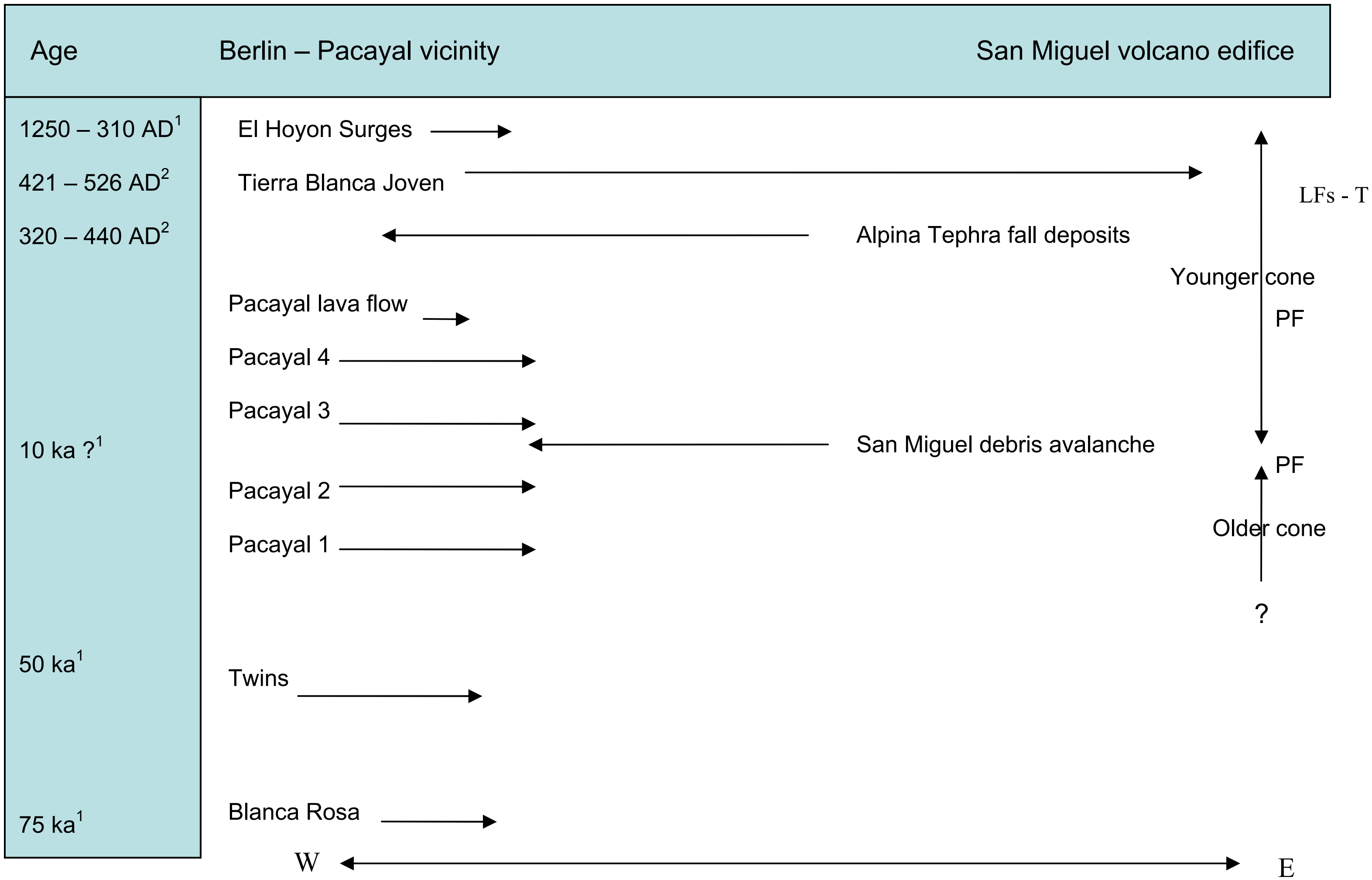


Figure 30: Schematic drawing showing stratigraphic intercalations west of San Miguel and radiometric age determinations of samples.

1 = CEL - GENZL, 1995 LFs - T: Lava flows - Tephras

2 = New ^{14}C dates [See table 4] PF: Pyroclastic flows

Table 4. Radiometric ages used in this study [Modified from CEL – GENZL, 1995].

Sample identification	**Radiocarbon (^{14}C age, years BP)**	**Calibrated date (^{14}C age, years)**	**Ar/Ar (ka)**	**Reference**
El Hoyon surges (Berlin)	710+-50	1250 – 1310AD	-	GENZL (1995)
TBJ Ilopango	-	421 – 526 AD		Dull et al., 2003
DEC-31 Charcoal at Montañaa Lacayo (VSM)	1660+-60	320 – 440 AD	-	Scott, pers, comm
Twins fall (Berlin)	48300+-2700	50,500 – 43,800 BP	-	GENZL (1995)
Blanca Rosa fall (Berlin)	-	-	75+-10	GENZL (1995)

Berlin and Pacayal volcanic complex is showing in [Figure 31].

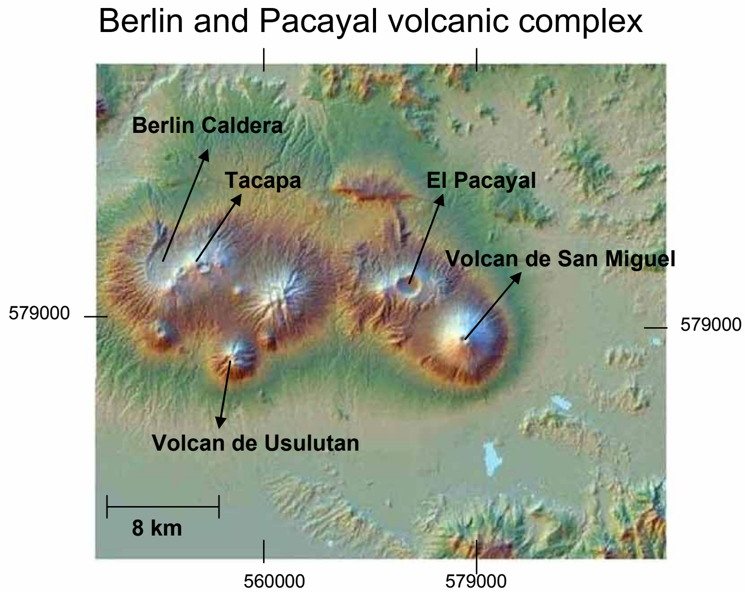


Figure 31. San Miguel is part of Berlín and Pacayal volcanic complex

1.4 Chemical composition of the products of San Miguel and nearby volcanoes.

In a study by Chesner et al.[2003] which was part of the field effort associated with this report, 145 samples were taken from San Miguel volcano and its vicinity, including lavas, tephras, and pyroclastic flows. The samples were analyzed by XRF for major and trace elements at Washington State University [Johnson, et al., 1999]. All of these results are included in the Appendix 5 of this report, and the sample locations are all plotted in Figure 7.

These lavas and tephras are all dark gray to black in color with porphyritic in textures, containing phenocrysts olivine, plagioclase, and some orthopyroxene. Chesner [2003], suggests that a few samples have up to 2% magnetite phenocrysts. Indeed all samples associated with San Miguel have olivine and plagioclase and can be described as basalts, and basaltic andesites. The chemical variation diagrams, figure 32, show that compositionally San Miguel's rocks are basalts and basaltic andesites and are all remarkably similar in composition. I did not notice any significant differences between the historic lavas and the prehistoric ones, or between summit and flank rocks, or between tephras and lava flows. The most silicic of San Miguel rocks, including a block and ash flow [sample 40] and samples from lava flows [samples 25, 38, 39A, 39B, 61, 63, 59, 64], [figure 7, and appendix D]. They are basaltic andesites [53-56% SiO_2], that were collected from the southeast flank. Chesner [2003], believes that these rocks are the only samples of San Miguel that contain phenocrystic magnetite. According to Chesner`s observations, the magnetite was fractionated prior to crystallization of these rocks. Thus, this group of prehistoric samples may owe their distinctive geochemical signature to elevated fO_2 associated with an older and different magmatic plumbing system than all the subsequent lavas.

Only a few found samples had SiO_2 percentages >55 wt %, and most of these were samples from the east flank, which could represent older materials erupted before collapse of the ancestral cone. Thus, these is quite strong evidence that future eruptions of San Miguel will be basaltic or basaltic andesitic with a SiO2 content of 50-54 wt %. This means that lava flows and strombolian styles of activity are likely to prevail.

No systematic geochemical trends of age or vent elevation were evident. The most mafic lavas are: [1] the 1762 flow that underlies the western area of the city of San Miguel; [2] an olivine/pyroxene rich flow [sample 14], located on Pan American Highway about 11 km San Miguel crater; [3] and two blocks taken from the southwestern flank [samples 69 and 82]. Thus, the most mafic lavas appear to have been erupted from the northeastern and southwestern sectors of the volcano, which is associated with fissures crossing the volcano. Although all historic and prehistoric rocks are basaltic or basaltic andesitic, exceptions are two lava flows [samples 49 and 64], which have 55.66 and 54.11 wt % SiO_2 . Individual blocks analyzed from seven separate block and ash flow outcrops ranged from 51 to 55% SiO_2 . A block and ash flow deposit of particular interest is the thick deposit sampled in Quebrada San Jorge to the west the town of San Rafael Oriente [sample 89]. This block and ash flow deposit is geochemically very similar to other block and ash flow deposits, and lavas that originated from San Miguel. This similarity shows that the pryoclastic flow and debris avalanche was derived from San Miguel.

Figure 33 shows variation diagrams of major element oxides plotted vs MgO. The variation trends shown for San Miguel rocks are typical of basalts and basaltic andesites. As MgO decreases, SiO_2, Na2O, K_2 O rise and TiO_2, FeOt and CaO fall in patterns that suggest the crystallization of olivine and pyroxene. This probably reflects the existence of a shallow [2-10 km deep?] magma body beneath San Miguel where minor amounts of differentiation occurs before eruption.

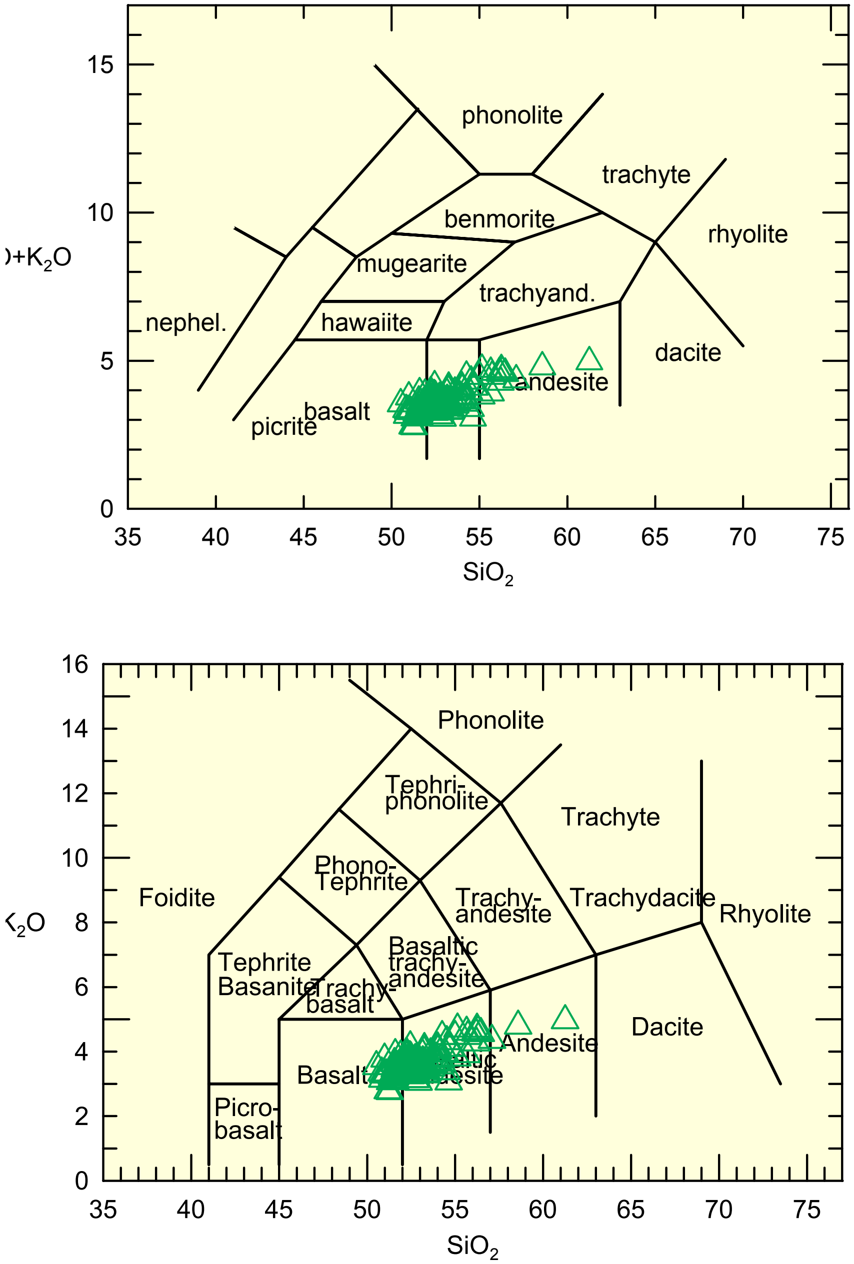
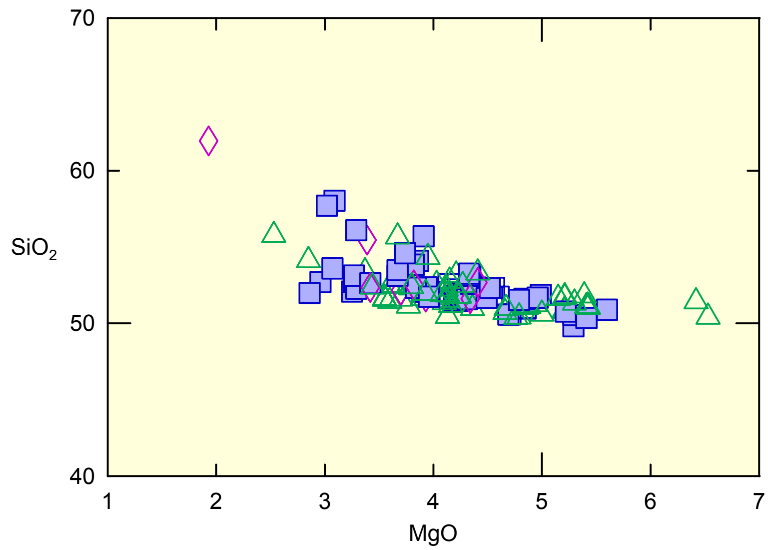


Figure 32. Total alkali- silica plot of San Miguel volcano: Lavas, tephras, pyroclastic flows, both historic and prehistoric (Chesner et al, 2003). Fields of rock names by Cox, et al., [1979] and Lebas, et al., [1986] respectively.



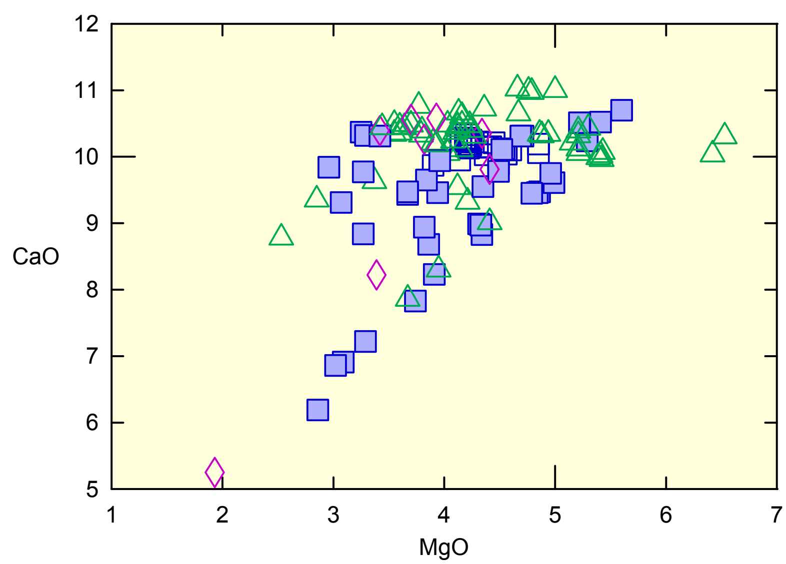


Figure 33. MgO–SiO_2 and MgO–CaO plots for San Miguel Rocks. Triangles are flank lavas, filled squares are tephras, open squares are summit lavas, and diamonds are pyroclastic flows. There is no systematic difference between any of the groups.

I also compared the composition of San Miguel's rocks with those of other nearby volcanoes. Chemical data from Carr et al [1981], CEL - GENZL [1995] and Chesner [2003], have been used in this comparison. The chemical plot of Pacayal rocks [Appendix E], reveals andesites to dacites with a substantially higher SiO2 content. They are thus significantly more evolved than samples erupted from San Miguel and do not follow the same trends on variation diagrams. Some of them [See appendix E] include six distal scoria cones and domes [30, 31, 32, 33a, 33b, 71, 72a, 72b] sampled to the north of San Miguel that are andesitic and presumed to have been derived from the Pacayal volcanic system.

Two andesitic tephra samples [46A, 46B] collected west of Pacayal Volcano and one andesitic tephra sample collected northeast of San Miguel [90] apparently also come from Pacayal volcano. Other samples were excluded from further San Miguel analysis, including [67] rock samples from Pacayal. Three more andesitic tephras [T-75 -1, T-75-3, T-75-4, and T-89b] to the southeast Pacayal are also presumed to be Pacayal tephras.

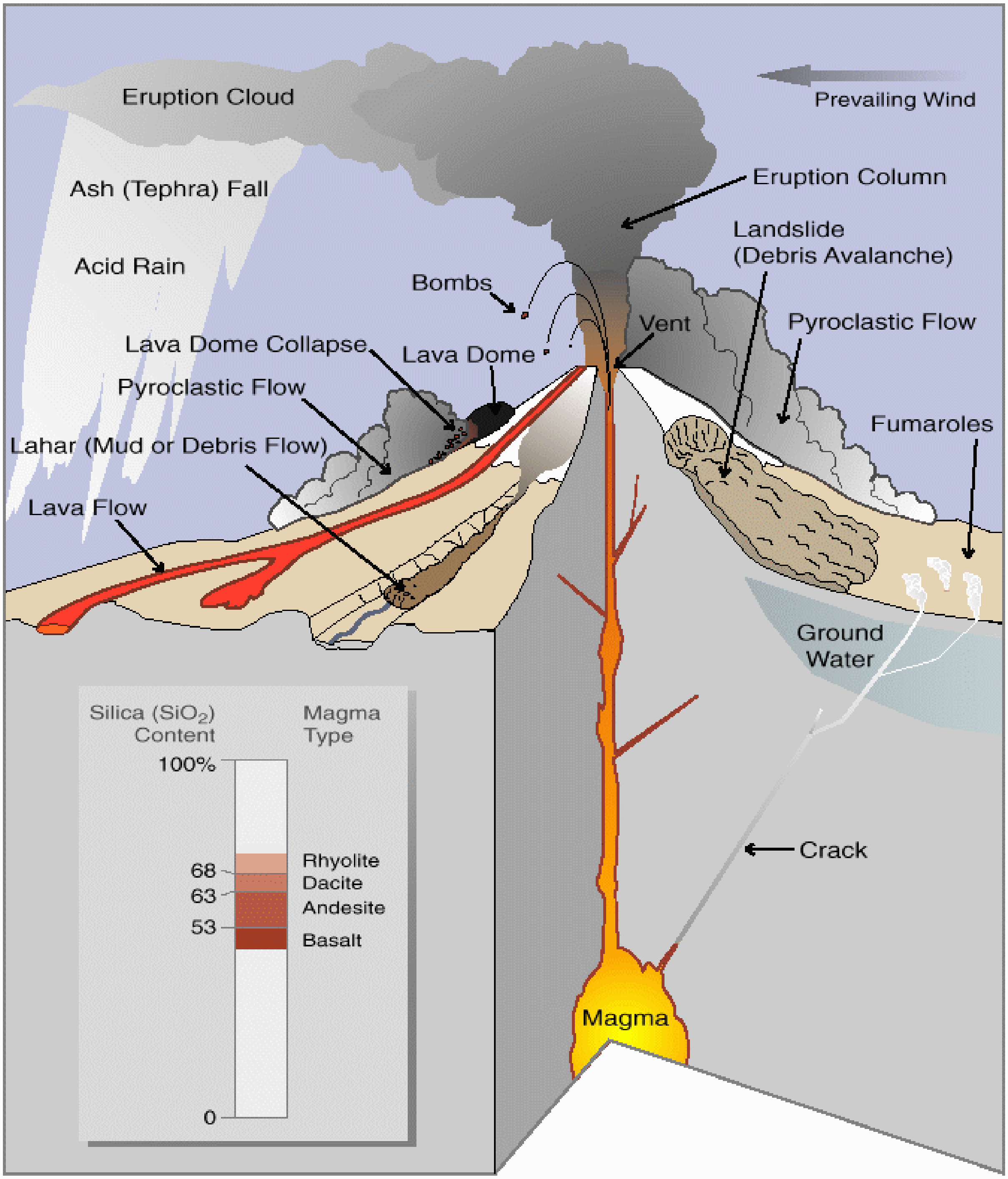
2.0 Hazards of Composite Volcanoes

San Miguel is a composite volcano. Tilling [1985] explains that some of the Earth's grandest mountains are composite volcanoes -- sometimes called stratovolcanoes. They are typically steep-sided, symmetrical cones of large dimensions, built of alternating layers of lava flows, volcanic ash, cinders, blocks, and bombs and may tower more than 3000 m above their bases. Some of the most conspicuous and beautiful mountains in Central America are composite volcanoes, including Santa Maria, Fuego and Agua in Guatemala, San Vicente and San Salvador in El Salvador and Momotombo and San Cristobal in Nicaragua.

Like most composite volcanoes, San Miguel has a crater at the summit which contains a central vent. Lavas, either flow down from the summit through breaks in the crater wall, or issue from fissures on the flanks of the cone. Solidified lava within the fissures, forms dikes that act as ribs and greatly strengthen the cone.

The essential feature of a composite volcano [Figure 34] is a conduit system through which magma rises to the surface from a reservoir deep in the Earth's crust. The volcano is built up by the accumulation of material erupted through the conduit and increases in size as lava, cinders, ash, etc., are added to its slopes.

The various volcanic hazards associated with composite volcanoes are shown in Figure 34. Most of them have occurred at San Miguel volcano in the past and will likely occur in the future.



Volcanoes produce a wide variety of natural hazards that can kill people and destroy property. This simplified sketch shows a volcano typical of those found in the Western United States and Alaska, but many of these hazards also pose risks at other volcanoes, such as those in Hawaii. Some hazards, such as lahars and landslides, can occur even when a volcano is not erupting. (Hazards and terms in this diagram are highlighted in bold where they are discussed in the text below.)

Figure 34. Major Hazards of Composite Volcanoes [USGS, Nov. 20 - 2003]

[a] Lava flows

If magma degasses enough before it reaches the Earth's surface, it may erupt passively to form lava. The predominant historic eruptive product at San Miguel has been basaltic lava flows which are rather fluid and can travel several kilometers down slope from a vent. Lava flows commonly move down to slope as streams of molten rock, from a few meters thick. The rate at which lavas flow depends chiefly upon their chemical composition. Basaltic "aa" and block lavas of the kind produced by San Miguel Volcano can move from a few tens of meters per hour, and can be compared with "aa" lavas as observed in Hawaii, which can sometimes move rapidly, at tens of meters per minute. Although lava flows can be extremely destructive, they typically are not life threatening. People and animals can usually walk out of the path of advancing flow. However, fronts sluggish lava flow moving across steep the slopes can sometimes collapse and generate blocks of hot debris that cascade down slope, break apart, and form hazardous, fast – moving pyroclastic flows or surges.

Prehistoric and historic lava flows have flowed down all the flanks of San Miguel Volcano. Lava flows which have descended to San Miguel city and other towns around the flanks of San Miguel were erupted from flank vents on several occasion between 1699 and 1868 and traveled as far as 11 km from their vents.

[b] Tephra fall

As magma approaches the surface of a volcano, its dissolved gases are released. If the gas is released rapidly, the magma can be broken explosively into small fragments and be dispersed into the atmosphere. Fragments from such eruptions, which range in size from ashes [< 2 mm] to lapilli [from 2 mm to 64 mm] and ballistic projectiles [more than 64 mm], are collectively called Tephra. This pyroclastic materials form deposits that blanket broad areas downwind from a volcano. Deposit thickness and particle size generally decrease away from the vent, yet a deposit can cover large areas, tens to hundreds of kilometers from the source. The largest tephra blocks and bombs called ballistic projectiles, fall to the ground within a few kilometers or meters of the vent.

Tephra falls seldom threaten life directly, except within a few kilometers of a vent.

Large ballistic fragments are capable of causing death or injury by impact. Large projectiles may still be hot when they land, and can start fires if they fall onto combustible material. Most injuries and fatalities from tephra falls occur when the tephra accumulations are thick, or are saturated by rainfall, and thus are heavy enough to collapse buildings roofs. Fine tephra suspended in the air can irritate eyes and respiratory systems and exacerbate pulmonary problems, especially in the elderly and infants.

Indirect effects of tephra falls can be perhaps more disruptive than the direct effects of tephra falls. Even thin accumulations of tephra fall can significantly disrupt social and economic activities over broad regions. Tephra plumes can create darkness, even on sunny days, and tephra falls can reduce visibility and navigability on highways [Major et al., 2001]. Tephra ingested by vehicle engines can clog filters and increase wear of internal parts. Deposits of tephra can short-circuit or break electric transformers and power lines, especially if the tephra is wet, sticky, and heavy. Tephra can contaminate surface-water drinking supplies, plug storm- and sanitary-sewer systems, and clog irrigation canals. Even thin tephra accumulations may ruin sensitive crops. A serious potential danger of tephra stems from the threat of even small, dilute tephra clouds to jet aircraft that fly into them. Ingestion of even small amounts of tephra into jet engines can cause them to malfunction and lose power.

Lessons learned from the 1980 eruption of Mount St. Helens in the United States can help government's institutions, businesses, and citizens to prepare for future tephra falls erupted by San Miguel Volcano., [Major et al., 2001]. Communities downwind of Mount St. Helens experienced significant disruptions in transportation, business activity, and services from fallout form as little as 5 millimeters of tephra. The greater the amount of tephra falls, the longer it takes a community to recover. As perceived by residents, tephra falls of less than 5 millimeters were a major inconvenience, whereas falls of more than 150 mm constituted a disaster [Major, 2001]. Nonetheless, all of the downwind communities affected by Mount St. Helens resumed normal activity within about two weeks of the event. Eruptions of San Miguel Volcano, both from the central and lateral vents have deposited several tephras layers. Although many layers are relatively thin [less than several centimeters thick] more than 12 km to the northwest of the volcano, an eruption that occurred about 1800 years ago, [Alpina tephra fall], deposited a tephra deposit that is 0.30 meter thick on the Santa Elena road, 12 km northwest of the volcano. This fall deposit is basaltic in composition, a light frothy fragment of exploded magma, which indicates that gas – rich magma intruded from the mantle and erupted violently. The composition, textures, and distributions of other tephra layers, especially those erupted during explosive eruptions were phretomagmatic and involved interactions of magma and water.

[c] Debris flow

Also named **Lahars or Mudflows,** these are flowing masses of mud, rock, and water that look much like flowing concrete. They are produced when water mobilizes large volumes of loose mud, rock, and volcanic debris. Commonly, landslides and debris avalanches transform into lahars as they move down valleys. Lahars, like floods, inundate floodplains and submerge houses and other structures in low-lying areas. They can travel many tens of kilometers at speeds of tens of kilometers per hour. Lahars can destroy or damage everything in their paths through burial or impact. They follow river valleys and leave deposits of muddy sand and gravel that can range from a few to tens of meters thick. They are particularly hazardous because they travel farther from a volcano than any other hazardous phenomenon, except tephra, and they affect stream valleys where human settlement and usually dense. In some instances, landslides and lahars can clog a channel or block a tributary channel and impound a lake behind the blockage. Commonly, the impounded water will spill over the blockage, quickly cut a channel, catastrophically drain the lake, and generate a flood that moves down valley endangering people and property. Breaching of the blockage may occur within hours to months after impoundment. Like floods, lahars range greatly in size. The smallest debris flow occurs most frequently (perhaps every year), whereas the largest one occur on the order of centuries to millennia. The size of lahars is controlled by both the amount of water and the amount of loose sediment or volcanic debris available. Large debris avalanches or eruptions can dump tens to hundreds of millions of cubic meters of sediment into channels and produce large lahars. Small landslide or ash eruptions produce smaller lahars. Large lahars have not been yet reported at San Miguel volcano, but could occur because massive debris deposits are located in drainages, mostly to the north, northwest flank, and because the slopes of the cone are very steep. They are most likely to occur as ash or other erupted materials accumulatic on the high slopes of the volcano. Heavy rains are the most common lahars trigger and these could come days, weeks, or months after the debris has been emplaced on the cone.

Landslides and lahars can cause problems long after the event that formed. Once landslides and lahars fill stream channels with sediments, the stream begin to eroded new paths, and the new stream channels can be highly unstable and shift rapidly as sediment is eroded and moves farther down valley. Rapid stream shifting can cause rapid and dramatic bank erosion. Furthermore, because stream channels are clogged with sediment, they, have less ability to carry water. As a result, relatively small floods, which may have previously passed unnoticed, can pose potentially significant threats to people living in low – lying areas. In general, people living in low- lying areas along river valleys are most susceptible to these secondary affects from landslides and lahars, yet areas on higher ground adjacent to river channels apparently safe from flooding, may also be threatened by bank erosion. Examples from many volcanoes around the world show that the effects of sediments deposition by landslides and lahars in stream channels can persist for years to decades [Major et al., 2001].

At San Miguel Volcano, mudflows occur from transport of volcanic debris deposited inside the radial drainage system of the volcano. They are produced by heavy rains during the rainy season. Although we know that larger lahars have occurred in prehistoric times, during historic times they have been rather small. Major et al. [2001] have produced a Lahar Hazard Zonation Map for San Miguel Volcano [Figure 35].

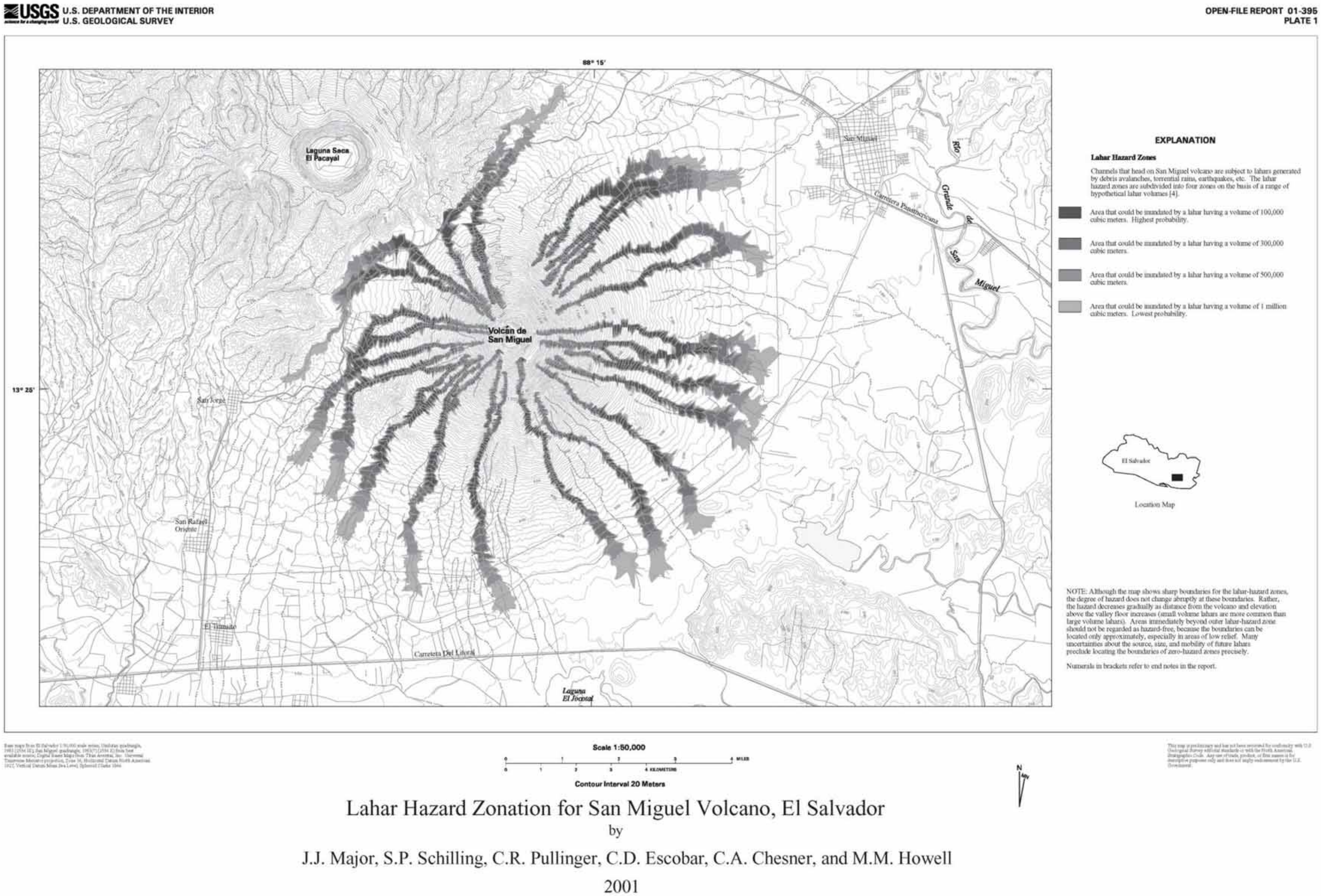


Figure 35. Lahar Zonation Map for San Miguel volcano [Major et al., 2001]. This map is based on lahar modeling done with LAHARZ [Iverson et al., 1998]

[d] Pyroclastic flows

Sometimes the mixture of hot gases and volcanic rock particles produced by explosive eruptions is denser than air, and instead of rising above the vent to produce tephra, this dense mixture behaves like a fluid, stays close to the ground, and flows down slope. If the mixture is made up mostly of rock particles, it has a high density and its path will be confined to topographically low areas, much as topography will control the flow of water. This type of dense flow is called **Pyroclastic flows**. The mixture is made up mostly of gas with a small proportion of rock fragments, latter it will have a lower density and its path will be less controlled by volcano topography. This type of gas-rich mixture is called a **Pyroclastic surge**. Pyroclastic flows and surges also produce ash clouds that can rise thousands of meters into the air, drift downwind, and transport tephra for tens of kilometers or more away from a volcano. When lava flows descend very steep slopes they sometimes break up into avalanches and a type of pyroclastic flow called a block and ash flow can develop. Block and ash flows consist of both pyroclastic flows and surges. Pyroclastic flows and surges often occur together, and both are exceedingly hazardous. They move at such high speeds, 50 to 150 kilometers per hour that escape from their paths is very difficult or impossible. Temperatures in pyroclastic flows and surges commonly are more than 500˚ C degrees. Owing to their high density, high velocity, and high temperature, pyroclastic flows can destroy all structures and kill all living things in their paths by impact, burial, or incineration. Although Pyroclastic surges are more diluted and less dense than pyroclastic flows, surges can affect larger areas and still be very destructive and lethal. People and animals caught in pyroclastic surges can be killed directly by trauma, severe burns, or suffocation.

When magma encounters a lake near or at the surface pyroclastic surges can result. This happened in the past at San Miguel, when there was a crater lake present but it is unlikely to occur in the near future because the crater is now dry.

Fortunately, at San Miguel volcano this kind of hazard is unlikely and only a few pyroclastic flow deposits have been identified. There are no historic occurrences of pyroclastic flows. But field evidence suggests that pyroclastic flows are not a common eruptive event. Block and ash flows from collapse of the leading edge of lava flows are highly unlikely from lavas erupted from the flank vents on the middle to lower portions of the volcano, where slopes are less steep, and lavas have turned to block. If block and ash flows were to occur, they would mostly likely be generated, from flows which came from the summit and descend the steep upper slopes of the cone, where breakup of the flows into block and ash flows would be likely. It is less likely that pyroclastic flows would be derived from vertical eruption column collapse during a vulcanian or subplinian eruption similar to those of Fuego, Guatemala. Pyroclastic flows generated in this manner could occur on any flank of the volcano. However, the San Miguel notch in the eastern summit crater and NNW ring of the crater, both could act as a funnel flows towards San Miguel city and Las Placitas and Cantón el Volcán.

Pyroclastic flows and surges have occurred during prehistoric time, at least three times at San Miguel volcano. Indeed, phreatomagmatic surge deposits about two meters thick are well exposed inside the central vent, related to an old crater lake. More than two prehistoric eruptions are associated with phretomagmatic activity which produced more than 0.50 m thick about 10 km northwest the volcano. However, no historic pyroclastic flows have been produced by San Miguel volcano, which suggest that this hazard is unlikely.

[e] Gas emission [Degassing]

All magmas contain gases that are released both during and between eruptions. Volcanic gases consist mainly of water vapor but also include carbon dioxide and compounds of sulfur and chlorine, as well as minor amounts of several other gases.
Generally, volcanic gases are diluted rapidly downwind from the vent, but within a few kilometers of a vent they can endanger life and health if concentrations are high and exposure is prolonged. Eyes and lungs of people and animals can be injured by acids, ammonia, and other compounds.

People and animals can suffocate in denser-than-air gases like carbon dioxide, which pond and accumulate in closed depressions. The greatest hazards arising directly from gases emitted by San Miguel are near the summit crater, and thus of concern to those who work or recreate within the crater. Outside the summit crater, San Miguel city and others populated towns are directly exposed to volcanic gases emitted by the volcano, but these effects are diluted by distance and atmospheric mixing.

A widespread, indirect, hazard arising from volcanic gases emitted by San Miguel volcano involves formation of acid rain. This acid water resulting from emission of volcanic gases has damaged local Fincas of coffee plantation, particularly around San Miguel and Santa Ana volcano. An excessive acidification of rainfall can occur when sulfur compounds combine with water vapor and droplets and form sulfuric acid that is deposited during heavy storms. If such acid is sufficiently concentrated it can damage crops, reduce land productivity, and pollute surface water.

[f] Volcanic landslides

The slopes of a volcano can become unstable and fail catastrophically, generating a rapidly moving large **landslide** called a **debris avalanche** [Simkin et al., 1994]. Slope instability at volcanoes can be caused by many factors. Magma rising upward through a volcano can push aside older volcanic rock and deform and steepen the flanks of a volcano, or warm acidic ground water can circulate through cracks and porous zones inside a volcano, alter strong rock to weak slippery clay, and gradually weaken the volcano structure and make it susceptible to collapse. Volcano's slopes can also fail without direct involvement of magma. Unexpected earthquakes, torrential rains, or steam explosions can trigger slope failures, but these failures are commonly smaller in volume than those triggered by magmatic intrusion. A debris avalanche can attain speeds in excess of 150 kilometers per hours; generally, the larger the avalanche, the faster and farther it can travel. Small-volume debris avalanches typically travel only a few kilometers from their source, but large-volume debris avalanches can travel tens of kilometers from a volcano. Debris avalanches destroy everything in their paths and can leave deposits up to 10 meters to more than 100 meters thick on valley floors. In many of these events, significant pyroclastic flows occur at the same time as the debris avalanches, as was the case at Mount St Helens in 1980. Deposits of debris avalanches have been recognized at numerous volcanoes such as Pacaya and Cerro Quemado in Guatemala, and Santa Ana and San Vicente volcanoes in El Salvador.

There is field evidence of one prehistoric collapse at San Miguel volcano. However, no deposits of large debris avalanches have yet been recognized, which suggests catastrophic collapsed. Nevertheless, although such events are unlikely, San Miguel volcano is periodically affected by large tectonic earthquakes such as those of 1951 and 2001, and because of its steep slopes, the possibility of a future flank collapse cannot be dismissed. Most stratovolcanoes and contain areas of altered rocks, faults, fractures, and other discontinuities mainly within their summit regions [Siebert et al., 1996] which could lead to collapses. A typical example that can help us understand San Miguel possible collapses is Mount St Helens volcano in the United State [Figure 36]. This understanding is important because it represents potential hazards to people and it properties close to stratovolcanoes.

Figure 36. Mount St Helen`s collapse [http://web.mala.bc.ca/earle/msh/; Nov 21, 2003].

3.0 Hazard Maps

3.1 Main hazards expected

The hazards associated with San Miguel Volcano are: [1] Tephra fall; [2] Ballistic projectiles; [3] Lava flows; [4] Pyroclastic flows; [5] Debris flows and Landslides.

Among the scenarios for renewed eruptive activity at San Miguel are:

[1] summit eruptions because historic data and volcano monitoring suggest that current activity is focused on the summit crater. Moderate to small phreatomagmatic or magmatic explosions with tephra fall and ballistic projectiles, including lava fountaining and lava flows which possibly may break up and produce block and ash flows that would rush down the steep upper flanks of the volcano.

[2] flank eruptions consisting of basaltic lava flows emerging from radial fissures and accompanied by tephra fall. The volumes of possible flows could exceed the volume erupted during the last 304 years in a single event [~0.51km^3];

[3] During or following summit activity, debris flows should be expected. These would result from scoria, blocks and ash on the upper slopes, remobilized by rainwater. Because these would commonly be triggered by heavy rains, they should be expected, especially in the first rainy season following activity. Debris flows may also be generated without an eruption from intense storm runoff of erodible scoria deposits within drainages, such as have occurred on small scales in recent years.

[4] Because of its steep upper slopes, slope failures and rock avalanches could potentially occur at San Miguel, even without eruptions. Landslides at San Miguel's summit and likely because of the influence of factors such as crater fractures, rock alteration and gravitional forces acting during magma intrusion and/or earthquakes.

Consequently, a conservative approach to hazards assessment requires us to assume, until there is specific evidence to the contrary, that San Miguel's future activity will be similar to historic strombolian events and of intensities as large or greater than the eruptions of 1699, 1762, 1844 and April 05, 1970.

Future eruptions are certain. Although we do not know when the next one will occur, it should be planned for. The hazard maps delineate areas that are likely to be at risk (hazard zones) during an eruption. The new maps update and refine previous assessments, taking into account both recent experience at erupting volcanoes and topographic, hydrologic, and geologic changes occurring at San Miguel.

3.2 Methodology

A scale called the **Volcanic Explosivity Index** (VEI), considers the volume of material erupted, the height of the eruption cloud, the duration of the main eruptive phase, and other parameters to assign an intensity ranging from 0 to 8 on a logarithmic scale. For example, the 18 May 1980 eruption of Mount St. Helens, which destroyed 632 km^2 of land, expelled 1.4 km^3 of magma, and produced an eruption column that rose to 24 km, was assigned a VEI of 5. On the other hand, the last large eruption from the Yellowstone caldera, which occurred 600,000 years ago and expelled over 1000 km^3 of magma, would be assigned a VEI of 8. However, many or most volcanic eruptions have VEIs from 0 to 2 [http://www.nrcan.gc.ca/gsc/pacific/vancouver/volcanoes/05_haz_e.php], Nov 12, 2003. San Miguel's historic eruptions VEI are classified as 0 to 2 by the Smithonian Institution.

[http://www.volcano.si.edu/world/volcano.cfm?vnum=1403-

10=&VErupt=Y&VSources=Y&VRep=Y&VSub=Y&volpage=erupt], November, 12, 2003.

San Miguel hazard maps are based on a methodology which includes factors such as [1] type of volcano; (2) historic and prehistoric activity; (3) patterns of reposes; and [4] number of eruptive events. This information was compiled from recent studies by Major et al.[2001] , Chesner et al. [2003], Vallance et al.[2001] and Delgado et al.[2002, 2003]. The hazards were assessed based on the [1] Stratigraphic sequence and character of eruptions, especially historic and prehistoric. Field exposures show that San Miguel volcano has recently produced mostly fissure lava flows and tephra fall [2] chemical analysis of rocks, suggesting that the volcano is mostly basaltic in composition.

For each map there are three hazard zones: High, Moderate and Low. The *high hazard zone* of each map encloses proximal areas a few km from the summit, which would be affected by moderate activity similar to historic events. Thus “high hazard zones” means most likely zones to be affected. The most likely hazardous events at San Miguel are small debris flows, ash eruptions and lava flows.

A bigger magnitude eruption of San Miguel volcano would likely affect people and infrastructure at distances of several to about 8 km from the eruptive vent. The *moderate hazard zone* for each map is defined assuming a moderate to large basaltic eruption, including tephra fall, ballistic projectiles, debris flows, lava flows and pyroclastic flows. During at least the last 159 years, no eruptions on this scale have occurred. The last event of this scale produced the Alpina Tephra Fall [~1800 years ago].

The *low hazard zone* considers the possibility of large basaltic explosive activity, similar to Cerro Negro in Nicaragua [1992 eruption] or Fuego in Guatemala with a high column

(> 10 km) and tephra volume of 0.6 km^3 [Hill et al., 1998]. This kind of event has much more extensive hazard zones and are less likely to occur.

3.3 Tephra fall hazards and winds at San Miguel

Tephra fall hazards are controlled by the variable height of eruption [1 – 15 km] columns which are expected during San Miguel's strombolian and vulcanian eruptions [Rose, Ewert and Delgado; 2003, per. Comm..]. Fallout is also strongly influenced by prevailing winds [Appendix 6]. Upper-level wind patterns in Guatemala between 3,000 and 15,000 meters altitude are strongly seasonal [Mercado and Rose, 1988]. Similar wind patterns with less marked seasonal variations occur in El Salvador. Simulations of San Miguel tephra falls, including seasonally averaged wind conditions [figures 37- 40, and appendix G] can distribute ash to distances of >120 km which would affect El Salvador's International Airport. Fallout is also strongly influenced by prevailing winds [Appendix F]. Upper-level wind patterns in Guatemala between 3,000 and 15,000 meters altitude are strongly seasonal [Mercado and Rose, 1988]. Similar wind patterns with less marked seasonal variations occur in El Salvador. In general ashes are carried to the west and produce elongated fallout blankets. In the dry season and especially from January to March, westerly winds dominate at higher altitudes, so fallout is more widely distributed (Figure 40). Surface winds may also affect tephra distributions, and their patterns are diurnal as well as seasonal. In summary, all sectors around San Miguel volcano can be affected by tephra fall, but areas to the west are much more likely to be affected than others, depending upon the season in which an eruption occurs. The historic record of ashfalls from San Miguel also suggests that ash is carried westward more frequently. The cities of Usulutan and Chinameca have received fallout especially frequently, but easterly fallout has been reported at the city of San Miguel.

3.3.1 Effects of ashfall on people and infrastructure.

The most notable problems that result from ashfall are destruction of crops and damage to roofs from excessive ash weight. Tephra falls of 10 to 20 cm or more can potentially cause roofs to collapse. Roof collapse is more likely if rains accompany tephra fall. Contamination of drinking water supplies is also a possible problem for San Miguel, which has had substantial soluble F in some of its modern ashes [Stoiber and Rose, 1974]. There are also considerable health problems possible from breathing fine ash. Complete obscuring of sunlight and strong electrical fields which prevent radio communications are additional problems which should be anticipated in areas up to 20 km downwind from San Miguel volcano during explosive eruptions. Thick accumulations of ash can significantly affect forestry and agriculture. Ash can rip of the leaves from trees and bury small plants. Ash-covered trees and crops are difficult to work because of the potential damage to harvesting and cultivation equipment and vehicles caused by the ash. Wind and moving equipment also redistribute the ash, prolonging the problems. However, the long-term impact of ash can actually be beneficial, as ash enriches the soil. Furthermore, fine ash from plinian clouds affect aircraft, especially Jets. In Mexico City, in June 30, 1997, the airport was closed and the aviation community was immediately alerted about the ash fallout from Popocatepetl volcano, located 72 km southeast of the city. Such closures have happened several times in recent years at city of Guatemala.

3.3.2 Preliminary Map of Ash Fall Zones

Based on hypothetical eruption, using an ashfall modeling program [J. Ewert, pers. comm, 2003] I found that with a volume of 0.01 km^3 , column height = 9 and 0.1 km^3 of ash for column height of 14 km, fallout from San Miguel is possible from up to 120 km downwind. On the basis of prehistoric eruptions, tephra fall deposits from San Miguel could be 1 cm thick or more within 120 km of source, 2 cm thick or more within 24 km of the source, and ~ 4 cm thick or more within 12 km of source {Figures 37, 38, 39, 40]. The simulations use wind data [Appendix F] and assume simple particle fall physics.

The areas outlined are the entire modeled region and isopach lines are mapped within this field.

Tephra falls of 10 to 20 cm or more can potentially cause roofs to collapse. Roof collapse is more likely if rains accompany tephra so that it is wet. Numerous people live within areas that could be affected by tephra from San Miguel Volcano.

Addtional simulations of ash fall for January and August considering column high of 3, 6, and 16 km are presented in Appendix G.

Scenario 1. Column height 3 km and ash volume of 0.02 km^3

Scenario 2. Column height 6 km and ash volume of 0.07 km^3

Scenario 3. Column height 16 km and ash volume of 0.6 km^3 .

Solid colors represent 40 mm fall during dry season and 30 mm during wet season, areas that enclose roof collapse hazard zones. Dashed lines represent 5 mm of ash fall down wind.

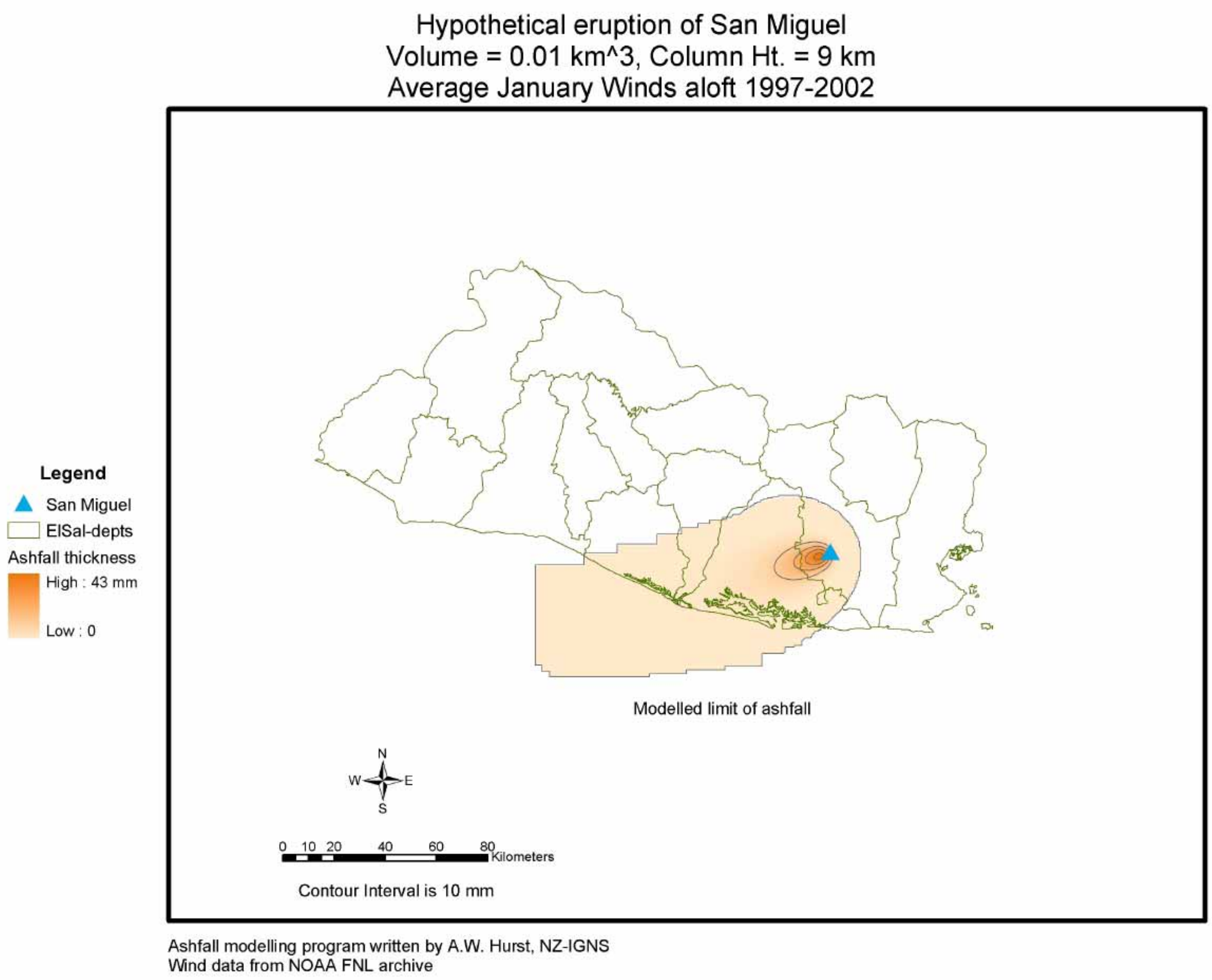


Figure 37: Ashfall hazard zone map for moderate eruption intensity during the dry season. From Ewert, USGS – CVO, 2003.

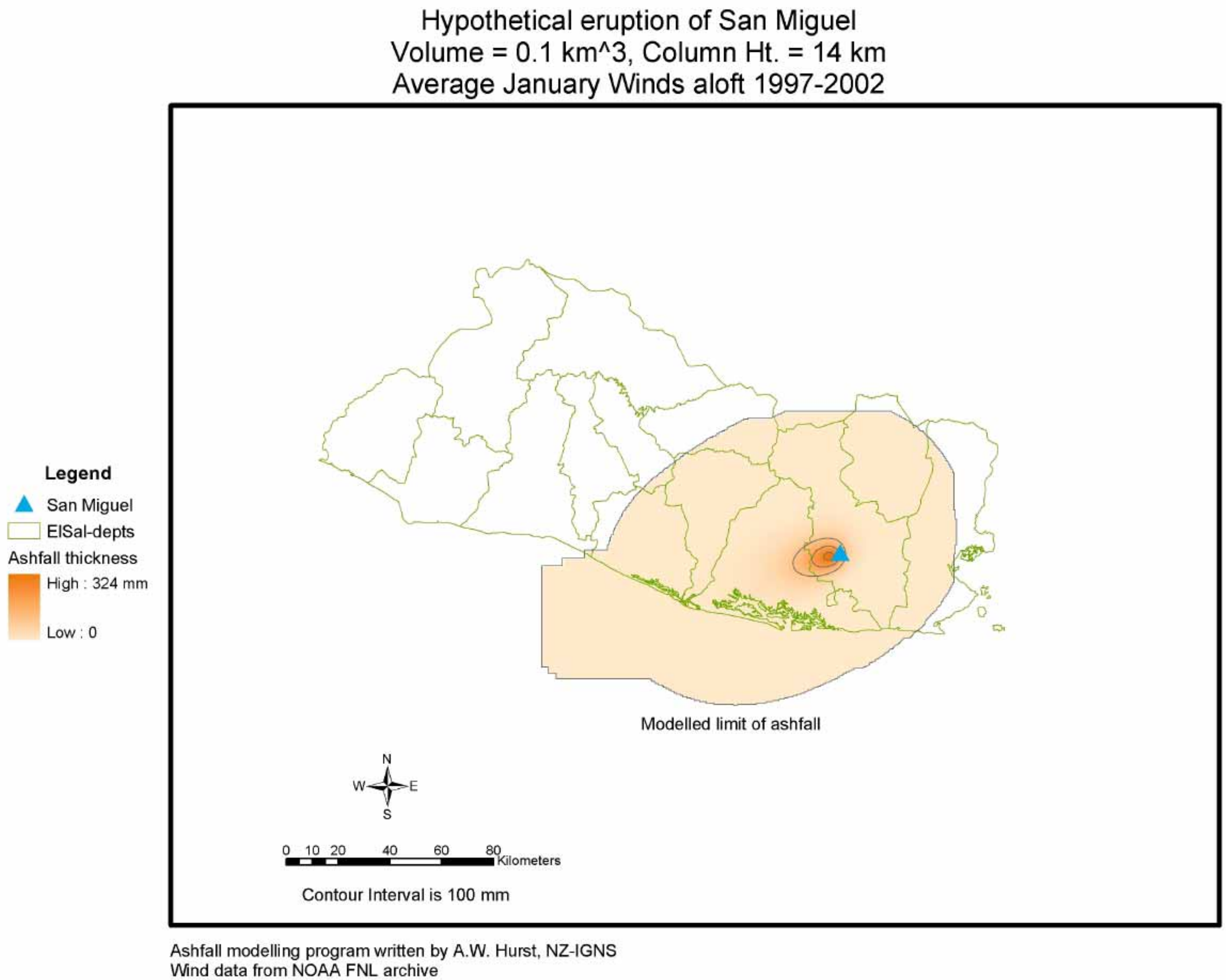


Figure 38: Ashfall hazard zone map for a large eruption in the dry season. From Ewert, USGS – CVO, 2003.

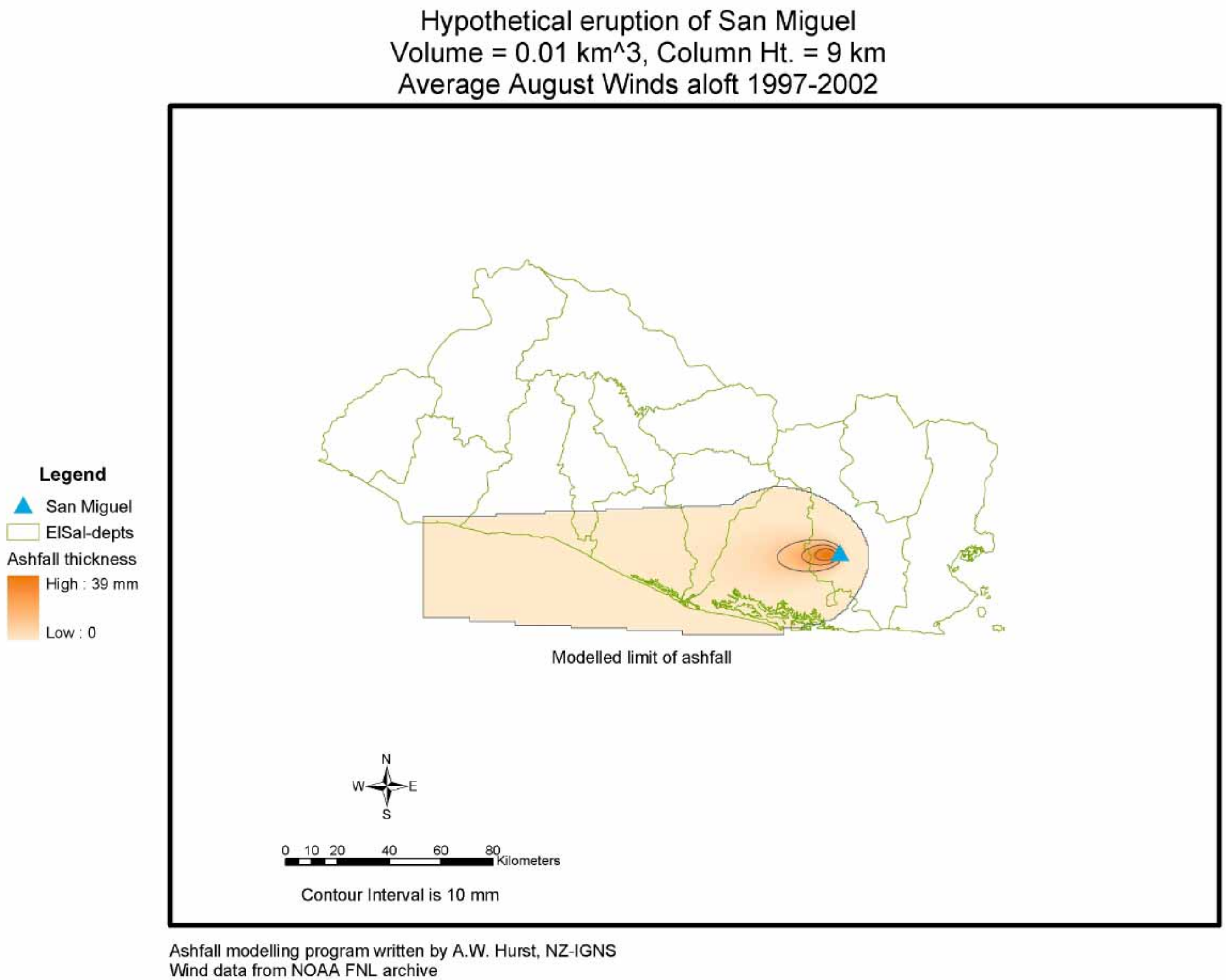


Figure 39: Ashfall hazard zone map for a moderate eruption during the rainy season. From Ewert, USGS – CVO, 2003.

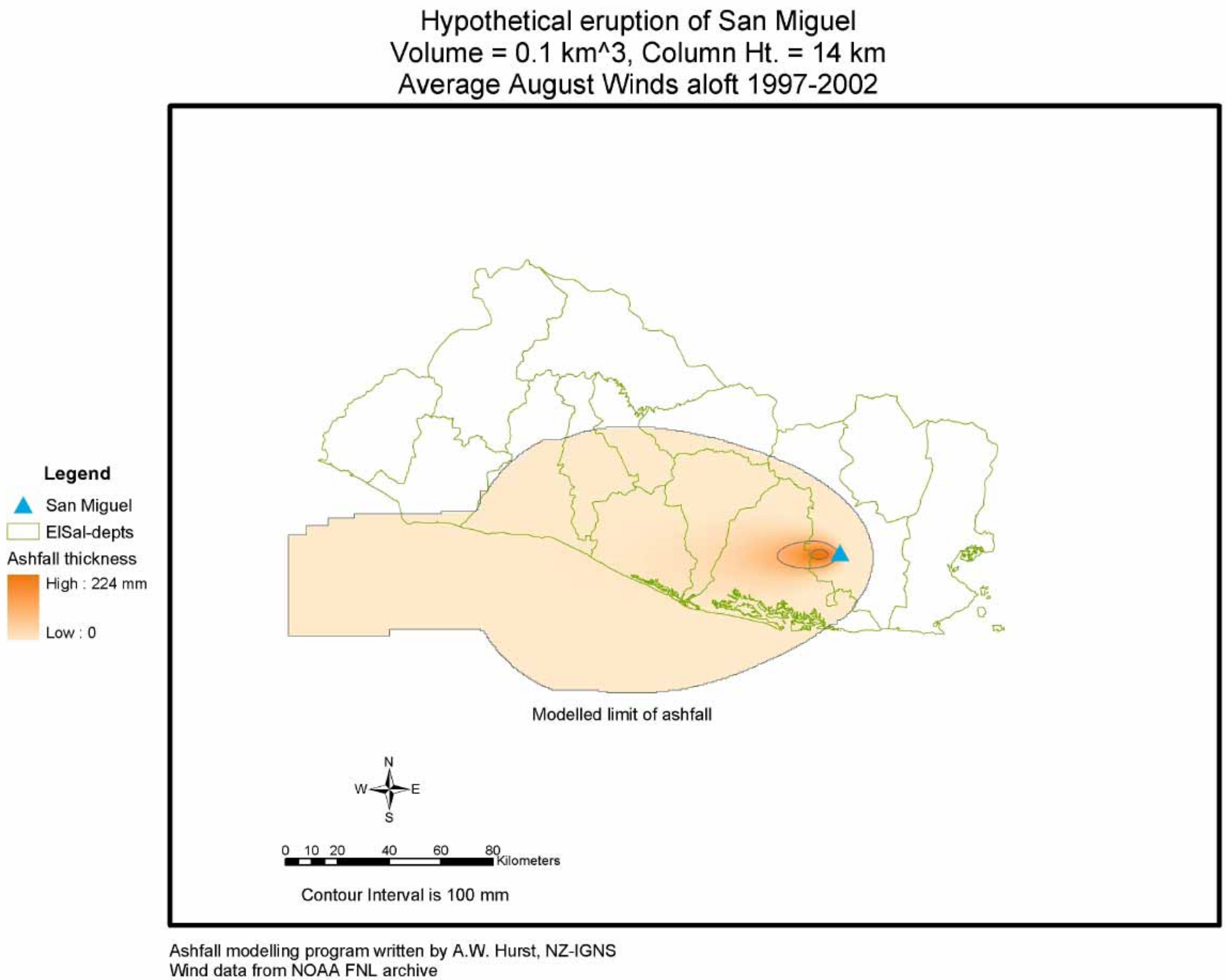


Figure 40: Ashfall hazard zone map for a larger eruption during the rainy season. From Ewert, USGS - CVO, 2003.

3.3.3 Ballistic projectile fall hazards

Ballistic projectiles [e.g. volcanic blocks and bombs] are the larger pieces of magma that are unaffected by winds and are thrown directly from the vent. At San Miguel volcano, blocks have been observed to have been thrown at distances less than 1 km from the vent. The simulation of hazards zone by ballistic projectiles [Figure 41] was prepared by using the program ballistic fall [H. Delgado, UNAM, 2003]. The ballistic projectiles hazard map outlines areas that could be affected by bombs and blocks from eruptions that are smaller and most likely [High hazard zone] or larger and less likely [moderate and low hazard zones].

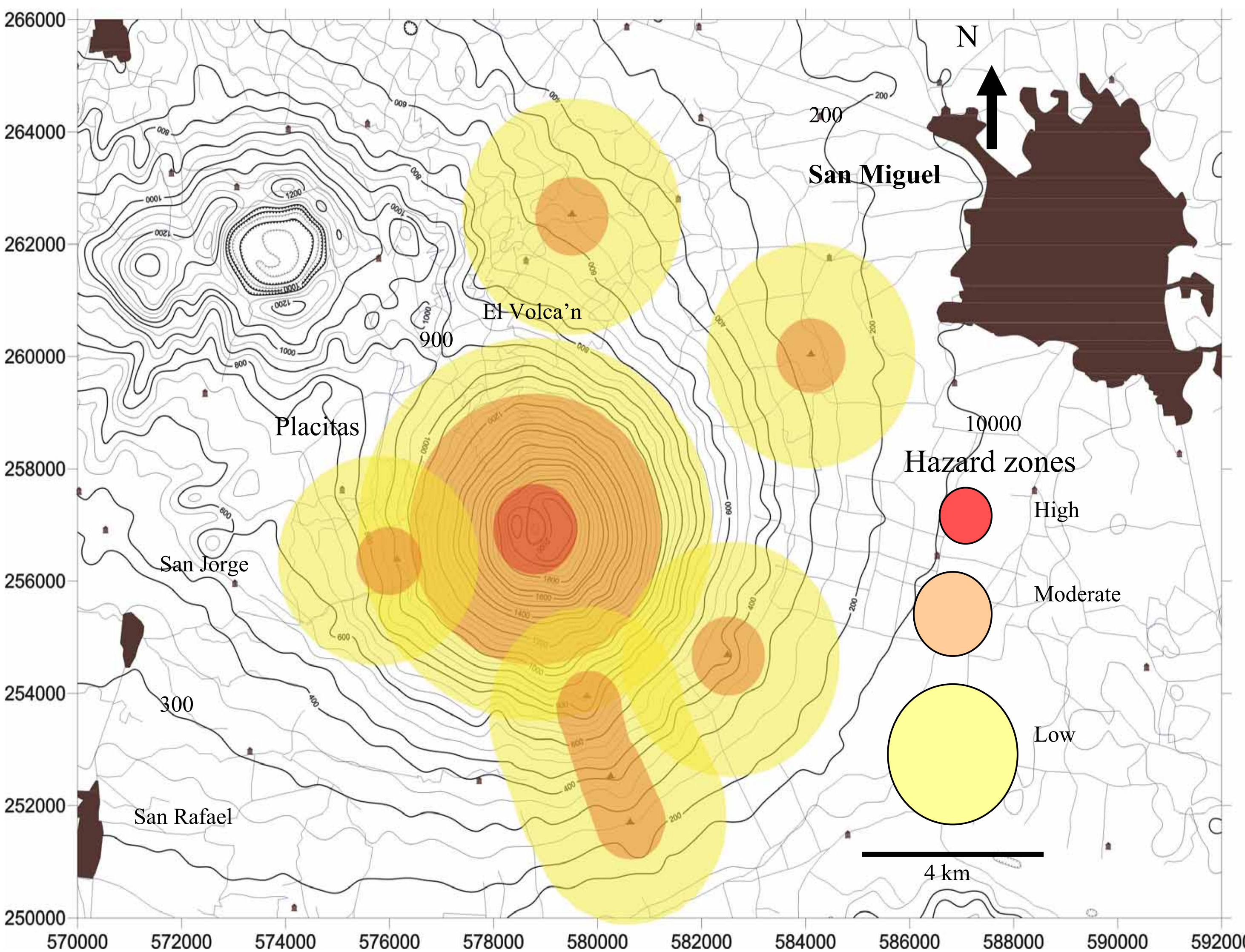


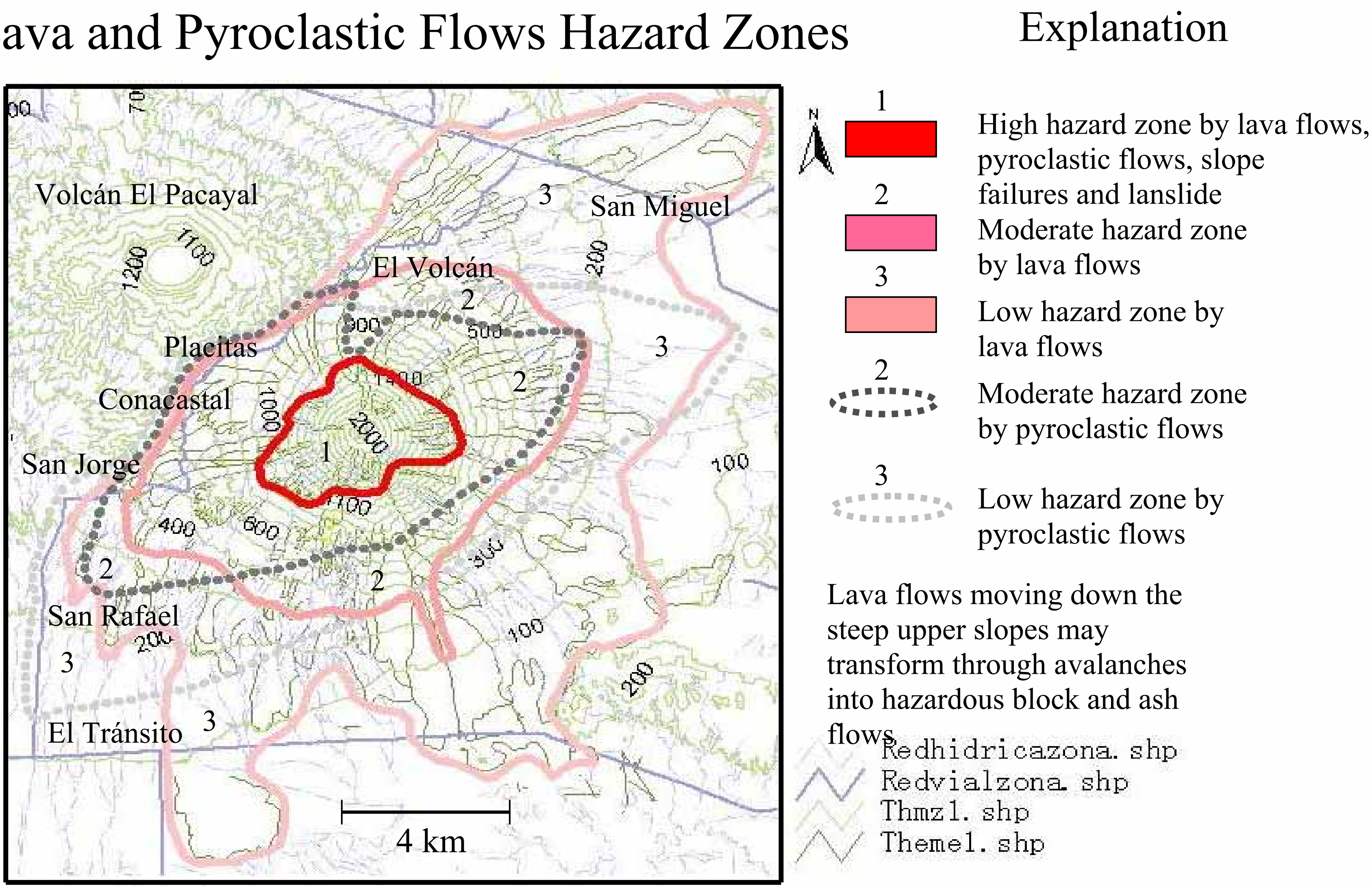
Figure 41. Model map, showing hazard areas of ballistic projectiles fall.

3.4 Lava Flows Hazard Map

Like the ballistics projectiles, lava flows may be erupted from the summit or from flank vents. San Miguel's summit is likely to produce lava fountains and small lava flows, which can be channeled downs lope by any of the 10 summit radial ravines. Lava flows moving down the steep upper slopes of San Miguel (averaging 40 to 50 degrees) may transform from avalanches into hazardous block and ash flows.

Flank fissure eruptions are also likely and have occurred repeatedly. A fissure is a "surface of fracture or a crack in rock along which there is distinct separation". [http://volcano.und.nodak.edu/vwdocs/vwlessons/kinds/kinds.html].These have led to extensive block lava flows. At San Salvador volcano (120 km W) both summit and flank vents were active in the same eruption in 1917. The length of lava flows observed at San Miguel typically ranges from 2 to 10 km. However, some prehistoric lava flows were found 11 km from the central vent [See figure 7]. The lava and pyroclastic flows hazard map is presented in figure 42.

Lava and Pyroclastic Flows Hazard Zones



Volcán de San Miguel

Figure 42. Map of lava and pyroclastic flow hazards at San Miguel Volcano

Volcán de San Miguel: Debris flows Hazard Zones

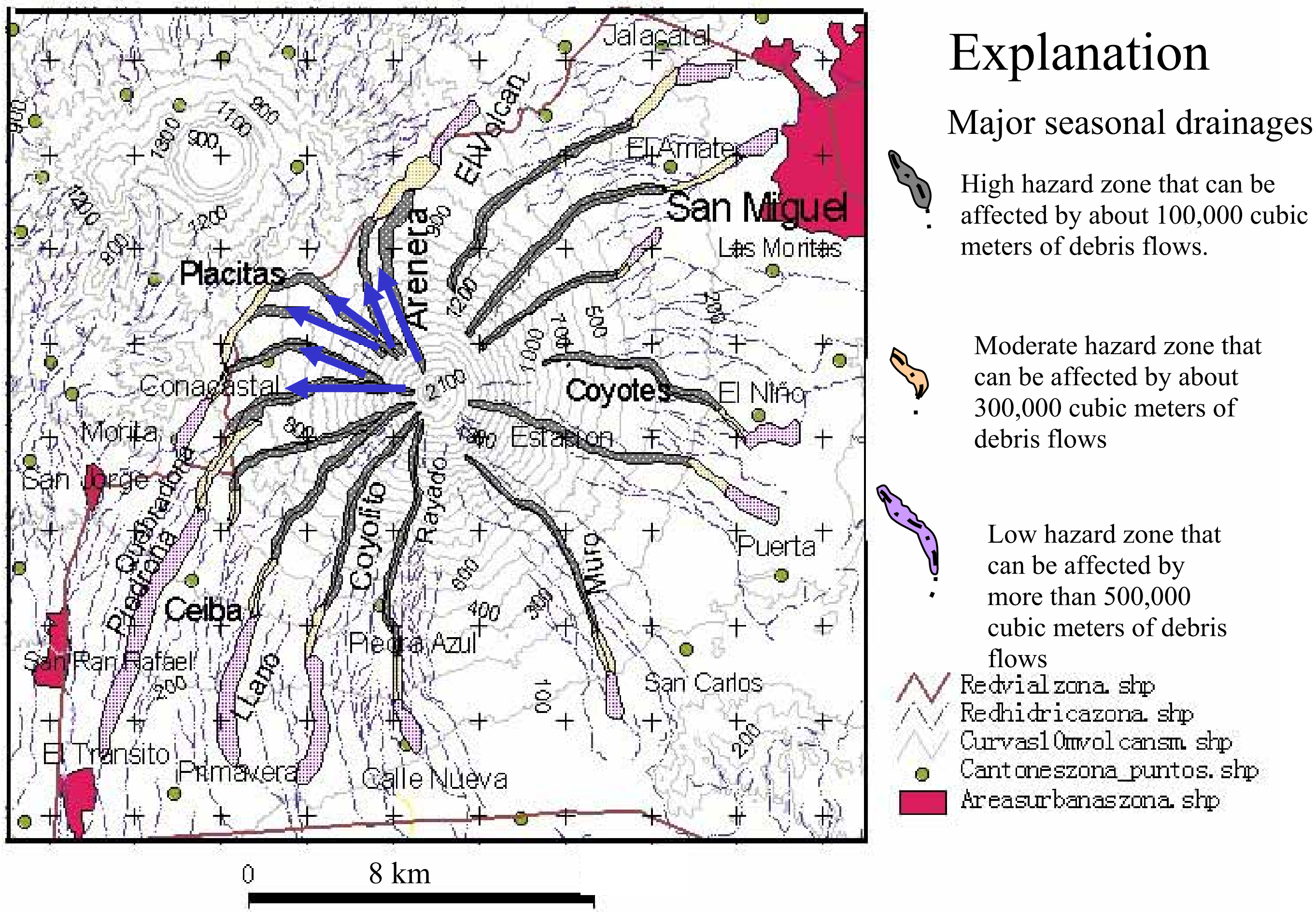


Figure 43. Simplified Debris flows Hazard Map [Modified from Major et al., 2001]. Barrancas with arrows are those which have experienced historic debris flows and are judged move likely to have future lahars.

The map of lahar zones [Figure 43] is based on the work of Major et al (2001) (figure 35), which was defined by modeling lahar volumes of 100,000; 300,000; 500,000 and 1 millon cubic meters and using mathematical and digital cartographic techniques described in the program LAHARZ [Iverson et al., 1998]. These four lahar volumes were used to compute the estimated extent of inundation down stream from a source area [Major et al., 2001]. Although undated lahar deposits have been identified at San Miguel volcano and 8 small debris flows have descended by the flanks of the volcano within the past 18 years, the volume of these events is poorly known.

3.5 Rainfall records

Records of monthly and annual rains were recorded from 1961 to 2003 by rain guages at Finca Santa Isabel [Figure 44 and 45]. These records show clearly the rainy and dry seasons of El Salvador. This seasonality is significant because lahars which are generated from rain are only likely during the rainy season. Especially heavy rains are especially important for lahar generation. For example, heavy rainfall from Hurricane Mitch was ~1.9 m total in October 1998. In spite of this, no lahars resulted, perhaps because the rains were distributed over several days. Data obtained from five additional rain guages [table 5] at a range of altitudes on San Miguel show that altitude dependence of rainfall amounts are not very great. We can evaluate the incidence of small rain induced debris flows using some historic data over a 43 year period, during which 7 small debris flows were noted, each triggered by torrential rains (1985, 1988, 1989, 1992, 1994, 1999 and 2001 [Figure 45]. These events affected the north, northwest and southwest sides of the summit, and travelled downs slope for distances of about 6 km. They damaged houses at Cantón El Volcán and Cantón El Carreto, and along the main road that leads to San Jorge. Distal lahar deposits were found as far as 11 km from the summit, at elevations of 140 m and 160 m respectively.

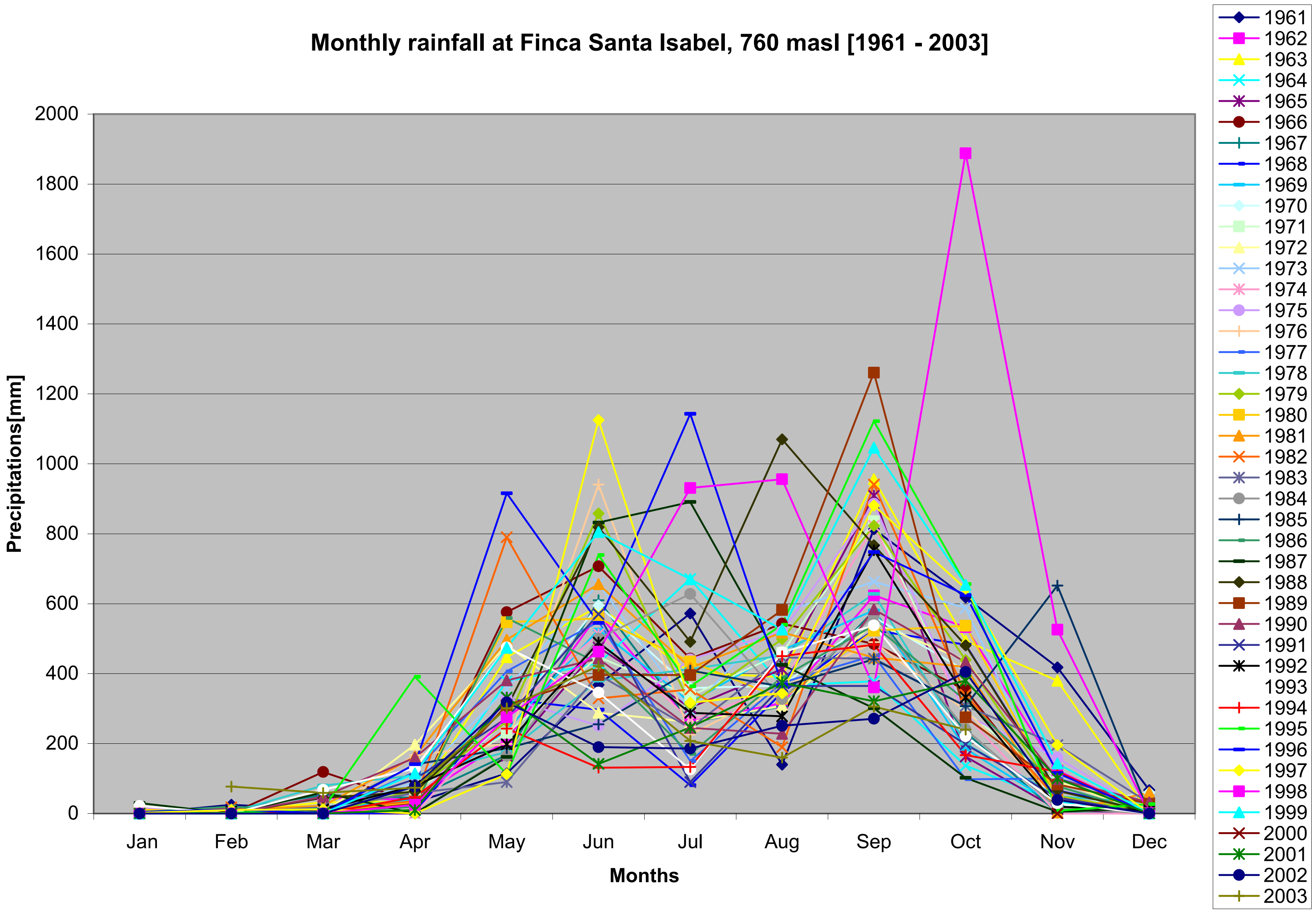


Figure 44. Monthly precipitation at San Miguel Volcano from 1961 to 2003, showing the monthly average concentration of rain [Data courtesy of Prieto SA, 2003]

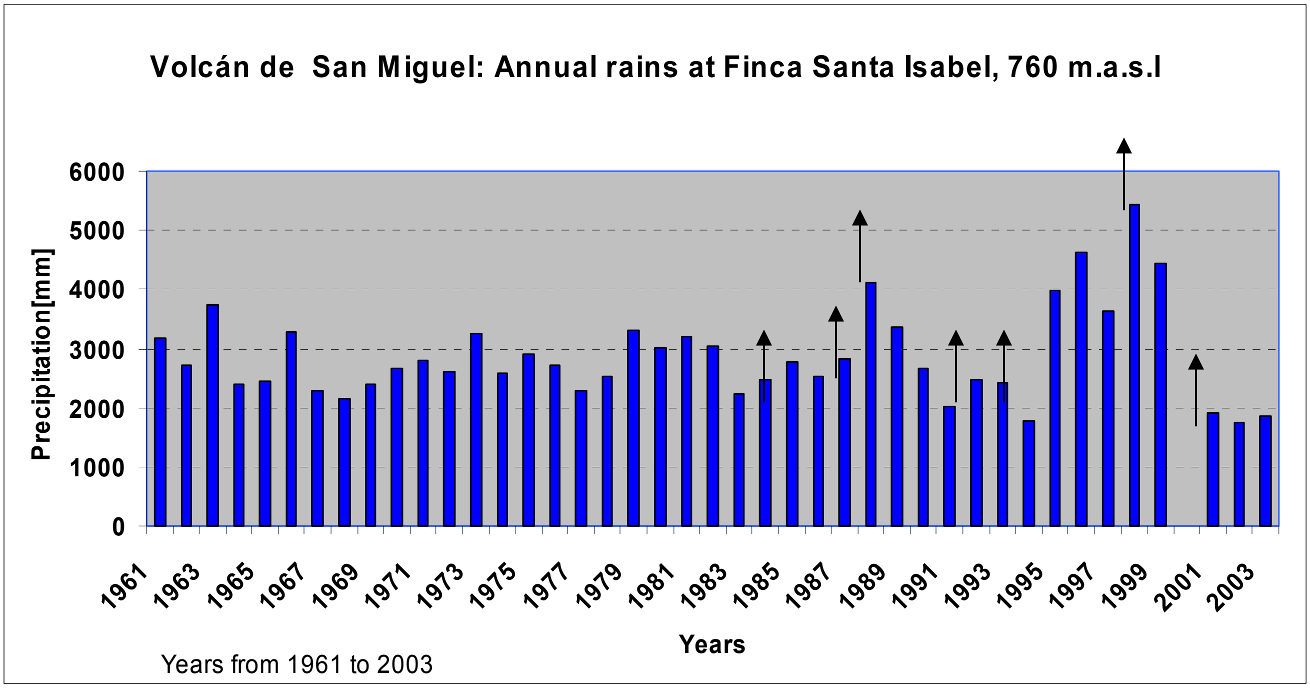


Figure 45. Annual rains at San Miguel volcano. Rain guage is located at 740 m.a.s.l on the North flank of the volcano [Long 578600; Lat 261000]. Years with arrows are those have experienced historic debris flows. Note the heavy rain registered in 1998, the year of hurricane Mitch.

Table 5. Name and location of gauges stations at NW from San Miguel Volcano.

Nº	Name	Long	Lat	Altitude	Lat N	Lon W
5	San Isidro	575300	262000	1000	13 28 35	88 17 58
8	La Placita	575500	258900	810	13 27 14	88 17 45
9	Tres mil pies	575800	256600	860	13 27 00	88 17 38
10	Cuatro mil pies	578200	255000	1155	13 24 28	88 16 58
11	Cinco mil pies	578300	255400	1322	13 24 41	88 16 52

Topo map scale 1:50,000

Quadrangle Usuluta’n

Sheet 2556 III, June 2001

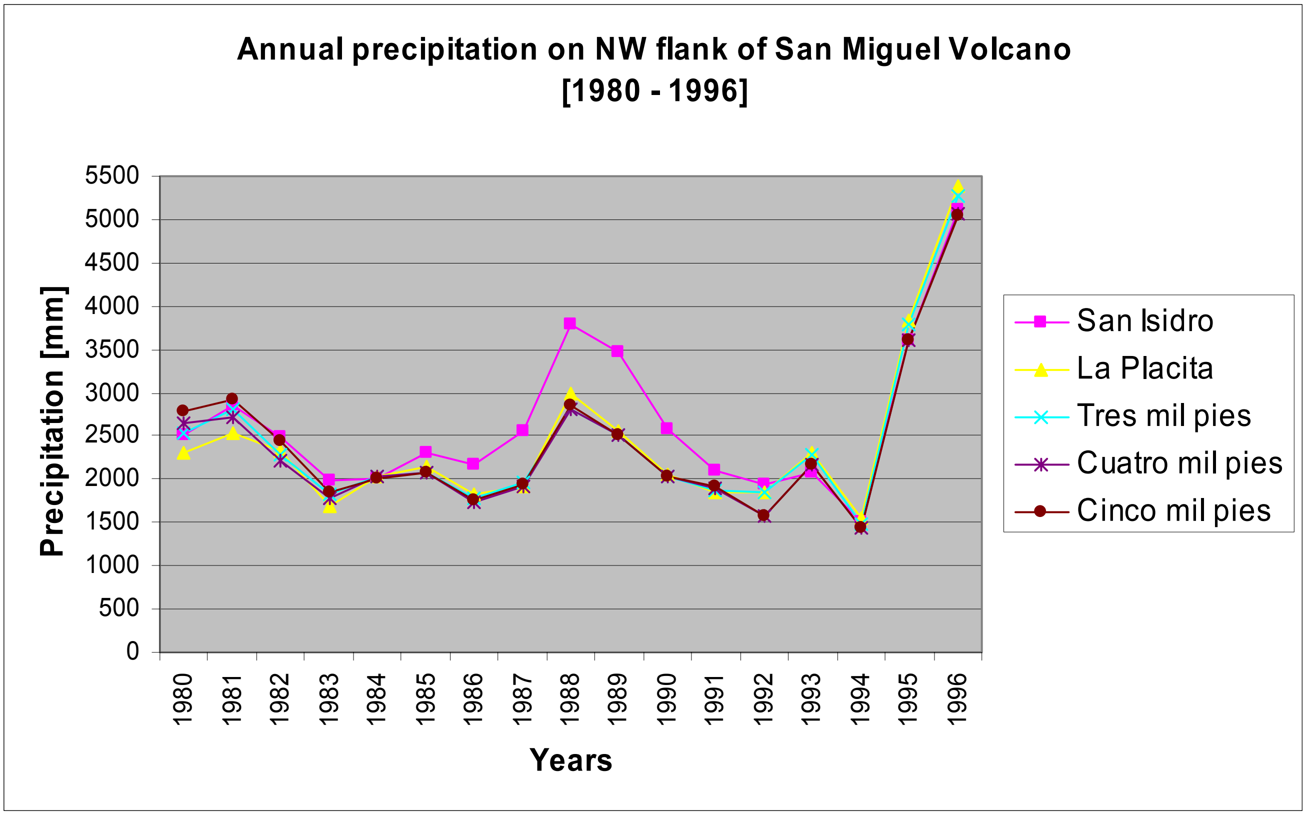


Figure 46. Annual precipitations at San Miguel from 1980 to 1996. Five gauges station are located on NW flank of the volcano. The exception is the San Isidro station which is located at Pacayal Volcano. The other four is installed on the San Miguel edifice [Data were obtained from Ing. Crespín. Prieto SA].

4.0 Hazards likely from future activity at San Miguel--summary

Based on eruptive activity of the past 1700 years, future eruptive activity at San Miguel volcano will most likely be eruptions from the summit crater. Most probably these will consist of relatively small explosions and ballistic and tephra falls. Summit activity could also lead to lava flows. Because the volcano has steep slopes, lava flows descending the cone from the summit could break up and transform into pyroclastic flows.

Debris flows, triggered by heavy rains, and earthquakes, can occur on any flank of the volcano. It is most likely that debris flows will be confined to within about 8 kilometers of the summit of the volcano. However, large lahars could travel more than 10 kilometers away from the summit.

Lateral flank vents along fissures could erupt block and bombs at short distances approximately from 100 to 200 m and produce blocky lava flows which extend as far as 10 kilometers.

San Miguel has erupted with relative violence at least once from the summit, as recently as 320 AD, and could do so again in the future. Explosive eruptions are more dangerous than those that generate lava flows or cinder cones. During intense summit eruptions the eruption column could collapse and produce pyroclastic flows. Such pyroclastic flows and pyroclastic surges could simultaneously affect multiple sectors of the volcano, as well as produce thick tephra falls and lahars that could affect areas far from the summit. Ash from an eruptive column more than 10 km height could be carried far downwind, and affect the international airport located 120 km to the west of the volcano.

5.0 Hazard forecasts and warnings

- Magma rising under a volcano prior to an eruption causes changes that can readily be detected by modern instruments and visual observations.
- Volcanic monitoring using different techniques is vital in order to understand how the volcano works and how to make possible forecasts.
- Volcano monitoring in El Salvador is important to document the “baseline” pattern

of behavior so that volcanic unrest can be confidently recognized when it occurs. The current national seismic network can detect a significant swarm of earthquakes at San Miguel volcano and they would be noticed quickly.

- Seismic swarms of small earthquakes are generated as rock breaks to make room for rising magma or as heating of fluids increases underground pressures.
- Heat from the magma can increase the temperature of ground water and raise temperatures of hot springs and steaming from fumaroles; it could also generate small steam explosions at San Miguel Volcano (see figure 47, a schematic drawing of the interior of San Miguel).
- The composition and volume of gases emitted by fumaroles can change as magma nears the surface, and injection of magma into a volcano mgama chamber can cause swelling or other types of surface deformation.
- The historic record at San Miguel suggests that notable seismic activity and rumbles would be likely to occur a few days before eruptions.
- An increase in seismicity near or beneath the volcano should prompt deployment of additional seismometers to better locate earthquakes, and stimulate other monitoring as volcano deformation and geochemical techniques that examine signs of volcanic unrest.
- The current period of low activity at San Miguel does not mean that vigorous activity is unlikely. This is common during periods of repose
- During the past 27 years, following the last strombolian fountaining in 1976, San Miguel has only experienced small steam explosions and gas emissions, minor ash fall and rock avalanches which have had little effect on people.
- Eight flank lava flows have been emitted between 1699 and 1867, strongly

suggesting that this kind of event will occur again.

- Although substantial advances have been made in volcano monitoring, often scientists can make only very general statements about the probability, type, and scale of an impending eruption.
- Precursory activity can go through accelerating and decelerating phases, and sometimes will die out without an eruption.
- Government officials and the public must realize the limitations in forecasting eruptions and must be prepared to cope with such uncertainty.
- Despite advances in volcano monitoring and volcanic hazard assessment, it is still difficult, if not impossible, to predict the precise occurrence of an eruption or volcanic collapse triggered by magma intrusion, earthquakes or heavy rains. Therefore, El Salvador through institutions as Servicio Nacional de Estudios Territoriales [SNET}, Comité de Emergencia Departamental [COED] and Ministerio de Educación [MINED], must work together to develop strategies for mitigating hazards that are potentially lethal events in these hazard zones, and can occur with little or no warning.

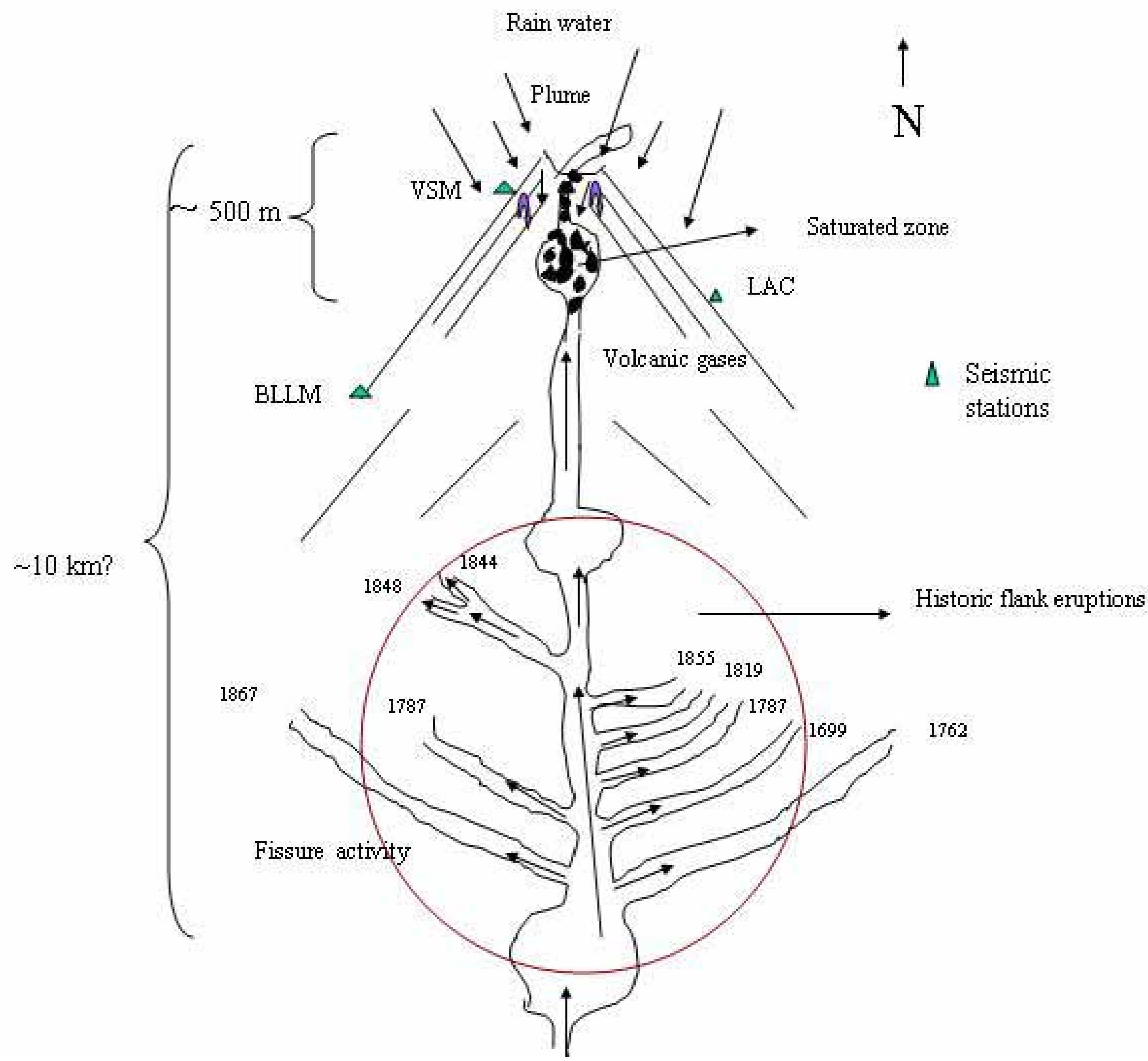


Figure 47. Idealized sketch of the internal structure of San Miguel Volcano. Important feature are flank lava flows [within scale].

- Around San Miguel Volcano, mostly north, northwest and southwest flank local governments, communities, businesses, and citizens must plan ahead in order to mitigate the effects of future volcanic eruptions, basically flank lava flows, ballistic projectiles, tephra fall and debris flows.

- Long-term mitigation efforts must include the use of information contained in the hazard maps when making decisions about land use and location of critical facilities. Future development should avoid areas judged to have an unacceptably high risk or be planned and designed to reduce the level of risk.
- When San Miguel erupts or threatens to erupt, a rapid, well-coordinated emergency response is needed. Such a response will be most effective if citizens and public officials have a basic understanding of volcano hazards and have planned the actions needed to protect communities.
- Because a volcanic eruption can occur within days or months after the first precursory activity and because some hazardous events, such as explosions and landslides can occur without warning, suitable emergency plans should be made in advance.
- Although it has been more than 136 years since San Miguel volcano erupted flank lava flows, it is unknown when it will erupt again, and public officials need to consider issues such as public education, land-use planning, communication and warning strategies, and evacuations as part of a response plan.
- Especially important is the developing of a plan of action based on the knowledge of relatively safe areas around homes, schools, and workplaces.

6.0 Conclusions

1. San Miguel volcano is certain to erupt again, and the best way to cope with future eruptions is through advanced planning in order to mitigate their effects.
2. San Miguel rocks are all basalts and basalt andesites. Future eruptions of San Miguel will be basaltic or basaltic andesitic with SiO_2 content of 50-54 wt %. The composition of San Miguel means that highly explosive eruptions are less likely than they would be if the SiO2 content were higher.
3. Explosive eruptions and associated lava flows from San Miguel's summit may pose the biggest threat to people living down the volcano, because they would occur at high elevation and descend by gravity to populations below.
4. Eight fissure eruptions occurred approximately every 20 years for 169 years but during the last 135 years this pattern has been broken. Nonetheless prospects for more flank lava flows are very likely in the future centuries.
5. All sectors around San Miguel volcano can be affected by tephra fall, but overall the western flank is more likely to be affected owing to the higher probability of easterly winds.
6. Strombolian summit activity can be expected in the future, includind blocks, bombs and ash emissions associated with small to moderate magmatic and phreatic activity. This could create ballistic and volcanic gas hazards.
7. Historic records indicate that small to moderate explosions and debris flows from summit area should be expected at least every 9 years.

8. If block and ash flows were to occur, they would likely be generated from flows which came from summit and descended the steep upper slopes of the cone, where breakup of the flows into block and ash flows would be likely.

Communication with People

The most important goal of volcanic hazards work is to avoid deaths. Because the hazards may be unfamiliar to people, it is necessary that El Salvador civil protection institutions work together preparing information such as posters, magazine articles, papers, presentations, and conferences which communicate to the public about the volcano and its hazards. It is especially important that this information be shared with people who live in the volcanic hazard zones and beyond.

Education of community leaders is good strategy for risk communication, because they have influence in their neighborhoods. Teachers in rural schools have also great affinity with local people. We suggest that good coordination with teachers, community leaders and the remainder of the community is the best way to prepare for volcanic hazardous event.

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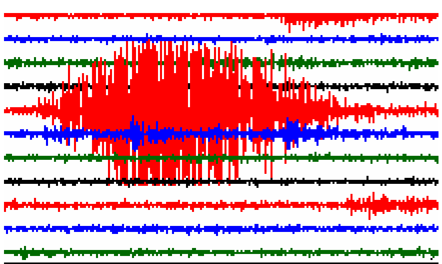
APPENDIX A: HISTORIC ACTIVITY OF SAN MIGUEL VOLCANO

GENERERAL INFORMATION ABOUT VOLCAN SAN MIGUEL EL SALVADOR, AC

Location	Longitud:579000 W Latitude: 257000 E
Volcano Type	Basaltic, basaltic – andesitic strato volcano
Summit Elevation	2130 m.a.s.l (6986 feet)
Last lava eruption	December 1976
Last small phreatic eruption	January 16 - 2002
Volcano Status	Historical
VEI (Volcano Explosivity Index, GVP report)	1 –2 :{1 is small; 2 is moderate}
Number of moderate (VEI = 2) eruptions from 1699 to present (2003)	~12
Eruption Type	Mild strombolian [Thorpe, 1982]
Current seismic activity 	An average of 100 to 500 Long Period (LP) event per day are registered by two seismic station located ont the volcano. Sporadic spasmodic tremor and sporadic volcanotectonic event also occurred. The current volcanic activity basically is associated with small phreatic explosions, gas emission and rock avalanche, (SNET, 2003).
Volcano volume	58 km³ (Carr et al., in press)

Erup tion data	**Volcanic activity**	**VEI**	**Reference**
1510e	70 –80 years before 1586		GVP (2002)
1586	Active. Gases on the summit		Ponce (1586); Sapper & Termer (1933); Meyer Abich (1956)
1693	Active. **An earthquake** and **strong rumble** were felt at San Miguel city. Gases on top the volcano	1	Jimenez (1951)

*1699	**Lava flow** First historic eruption from SSE flank.. **A Strong earthquake** was felt to 60 km far the volcano. **Strong rumbles** before an during eruption..	2	Sapper (1925); Jimenez (1951); Meyer Abich (1956); Larde (1960); Martínez (1977)
04 Oct. 1717	**Strong earthquake** was felt in San Miguel city, related with the volcano, but not eruptive activity.	1	Sapper (1925)
*1762	**Lava flow**. Significative eruption from East flank, lava stooped near the city	2	Sapper (1925); Jimenez (1951); Meyer Abich (1956); Larde (1960); Martínez (1977)
*21 – 23 Sept. 1787	**Lava flow**. Significative lateral eruption from SSE and NNE flank. Its crossed Litoral Road and now is buried by 1819/1855 lava flows	2	Sapper (1925); Jimenez (1951); Meyer Abich (1956); Larde (1960); Martínez (1977)
08 Feb. 1793	Active. **Earthquakes** at San Miguel city, minor gas emission	1	Martínez (1977)
Janua ry 1798	Active.**An earthquake** at San Miguel area and minor gas emission	1	Martínez (1977)
*18 Jul. 1819	**Lava flow**. Significative lateral eruption from South flank. Obstruction of Litoral Road. Gas emissions from the summit crater	2	Sapper (1925); Jimenez (1951); Meyer Abich (1956); Larde (1960); Martínez (1977)
*25 Jul - 09 Oct 1844	**Lava flow**. Significative lateral eruption from about 14 vents? located along NNW flank. Two days before of the eruption **many rumbles** were listen by people.	2	Meyer Abich (1956); Larde (1960); Martínez (1977)

1844 – 1845 - 1847 - 1848	Active. Minor periodical **explosion from central vent with ash and gas emission**	1	Dollfus & Monserrat (1868); Meyer Abich (1956); Larde (1960); Martínez (1977)
*1848	**Lava flow**. Small lateral eruption from NNE flank	1	Larde (1960); Martínez (1977)
*01 – 15 Dec. 1855	**Lava flow**. Small lateral eruptions from SSE flank. **Small earthquakes** and **strong rumbles** were felt at San Miguel city	2	Dollfus & Monserrat (1868); Meyer Abich (1956); Larde (1960); Martínez (1977)
06 – 10 – Nov. 1857	Active. **Earthquakes** were felt at San Miguel city. **Minor explosive** , ash and blocks eruptions	2?	Larde (1960); Martínez (1977)
09 Apr. 1866	Active. **Minor gas and ash explosions**	1	Meyer Abich (1956)
**14 Dec. 1867 to 16 Feb. 1868	**Significative eruption**. Lava flow and ash fall**.** Probable lateral eruptions from SW flank. Periodical **strong rumbles** were reported, after and during eruption	2	Meyer Abich (1956); Larde (1960); Martínez (1977)
Dec. 1882	Active. **Minor explosive** ash eruption	1	Sapper (1925); Martinez (1977)

**25 Jan. 1884	**Lava fountain and small explosions from the central vente.** Moderate amount of ash fall during many days. A black gray cinder cone was formed inside the crater	2	Sapper (1925); Meyer Abich (1956); Martínez (1977)
27 Apr. 1897	Active. **Minor gas and explosions**	1	Meyer Abich (1956
***10 Dec. 1919 to Jan. 1920	Active. Just after an **earthquak**e, small explosions, ash and gas emission.	2	Sapper (1925); Meyer Abich (1956); Larde (1960); Martínez (1977)
14 August 1920 - 1924	Active. Periodical minor **explosions and ash fall**	1	Sapper (1925); Meyer Abich (1956); Martínez (1977)
***Aug. 1929	Active. **Small explosive eruption** from 3 central vent. Blocks erupted to 250 m high, minor ash emission	2	Meyer Abich (1956); Martínez (1977)
**End of Jan. 1930	Active. Small e**xplosive eruption.** A single conduit was formed and red lava spatters fall on the amphitheaters of the crater. Minor ash fall	2	Meyer Abich (1956); Martínez (1977)
March and Jun. 1931	Active. The crater was incandescence during night.		Meyer Abich (1956); Martínez (1977)
***02 Jun. 1931	Active. **Minor explosions**. Ash fell at San Miguel city	1	Martínez (1977)

21 Oct. 1954	Active. Gas emission. A steam column rise ~300 m. The activity was associated with a distant **earthquake** reported in San Salvador capital	1	Meyer Abich (1956); Martínez (1977)
23 Oct. 1964	Active**. Small explosions.** Ash fell to the west from the volcano	1	Meyer Abich (1956); Martínez (1977)
10 Nov. 1965	Active. Very steamy fumaroles. In the inner crater three small explosion were listened	1	Stoiber and Rose (1966)
***22 Feb. 1966	Dennis Eberl found 1.5 m thick of ash in the central crater. A men at the Finca Santa Isabel report an **explosion and ash emission** early morning Feb. 22	2	Stoiber and Rose (1966); Martínez (1977)
Jul. 1966	Active. **Minor ash emission.**	1	Stoiber and Rose (1966); Martínez (1977)
***05 Jan. 1967	Active. **Minor ash eruption**. Ash fell to the West and SW from the volcano	1	Martínez (1977)
***30 Mar. to 05 Abr. 1970	Active. **Significant ash eruption.** Ash (0.0008 km^3) fell to 10 km to NW from the volcano	2?	Stoiber and Rose (1966); Martínez (1977)
*02 - 12 Dec. 1976	**Lava pound** inside the crater.	1	Martínez (1977)

*28 Feb. 1977	**Lava fountain** inside the crater. A cinder cone was formed, lava emitted ~$1.4x10^6$ m^3 .	1	Martínez (1977)
1985 to 1987	Active. Periodical small explosions. Gas and ash emission associated with phreatic activity?	1	Escobar (1993)
Dec. 1988	Active. Small **freatic activity and ash emission.** Rumbles were reported by people live near the volcano	1	Escobar (1993)
Dec 1989 to Abr. 1992	Active. **Periodical gas emission**	1	Escobar (1993)
Jan, Feb, and Mar. 1995	Active. Small **phreatic activity**. Minor ash and gas emission. Small earthquakes were reported	1	Escobar (1993)
28 Dec 1996	Active. Small **freatic activity,** ash and gas emission	1	Escobar (1993
08 Jan 2000	Active**. Small phreatic explosion.** Probable SO_2 emission and volcanic dust, the plume height was ~200 m above the summit	1	Pullinger and Chesner (2000)

16 Jan. 2002	Active. **Small phreatic explosion,** volcanic dust was found around the crater	1	SNET (2002)
05 – 08 Aug. 2002	Active. Significant rocks collapse inside the crater. The open conduit was buried in a 85 %, the fumaroles were stopper.	1	SNET (2002)
28 Sept. 2002	Active. Fumaroles start again inside the conduit.	1	SNET (2002)

* Only Lava
** Lava and ash
*** Only ash/gas

APPENDIX B: CHEMICAL COMPOSITION OF ASH EMITTED IN 1970 ERUPTION AND MINERALS OF FUMAROLES

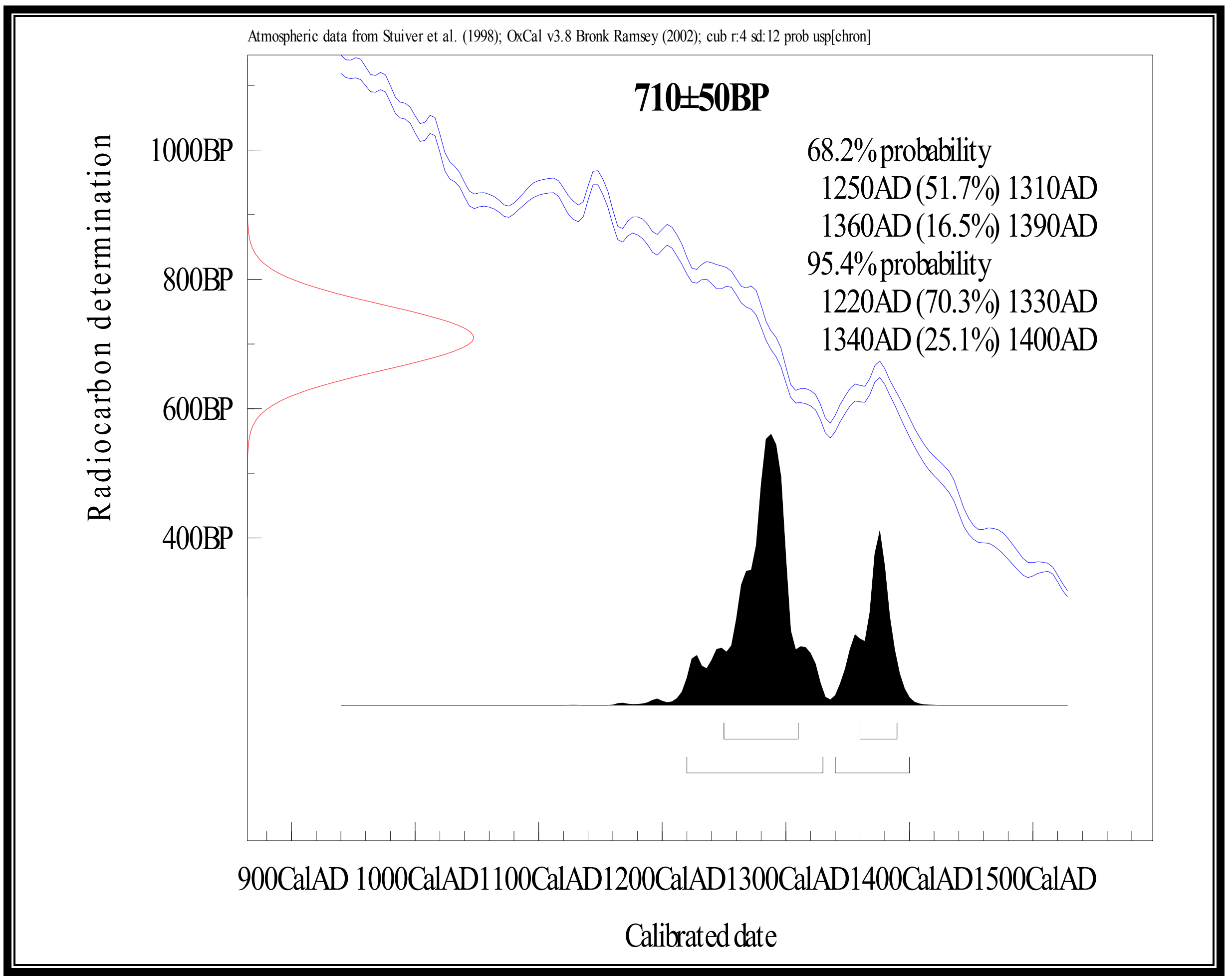
Chemical composition of ash samples and crater fumaroles [Stoiber and Rose, 1974].

Ash and fumaroles chemical composition			
Element	PPM	Minerals at fumaroles	
Cl	711		
Fl	0.9	S	sulfur
SO4	304	CaSO4	Anhidrita
Na	256	Na,K Al_3 $(SO4)_2$ $(OH)_6$	Natroalunita)
K	1.7	CaSO4(H_2O)	Gypsum
Ca	200	Na_2 Mg(CaSO4).4H_2 O	Bloedita
Mg	228		
Zn	0.7		
Cu	5		
Mn	14		

APPENDIX C: CALIBRATION DATE USING OXCAL PROGRAM

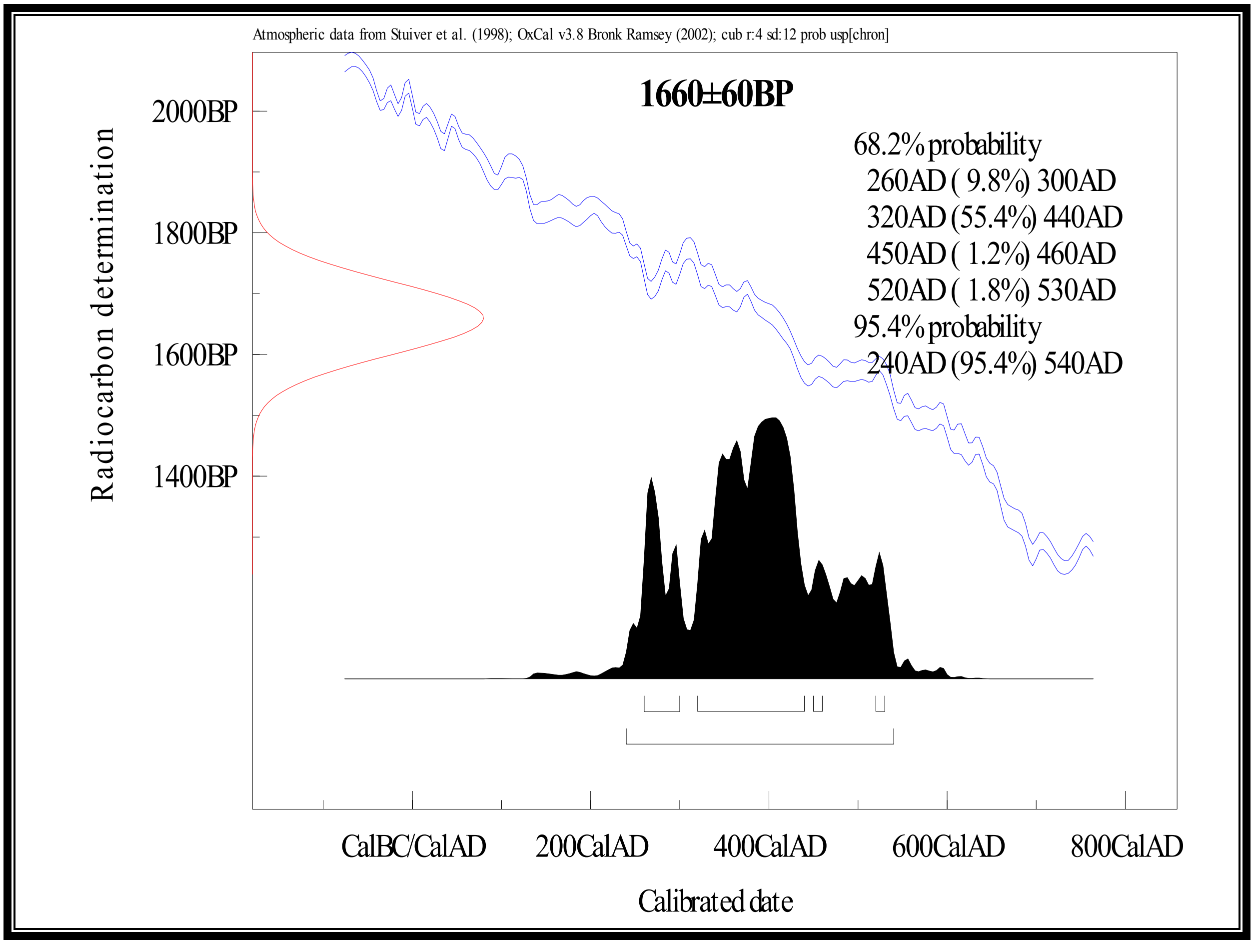
Calibrated date using OXCAL program

El Hoyon surges (Berlin)



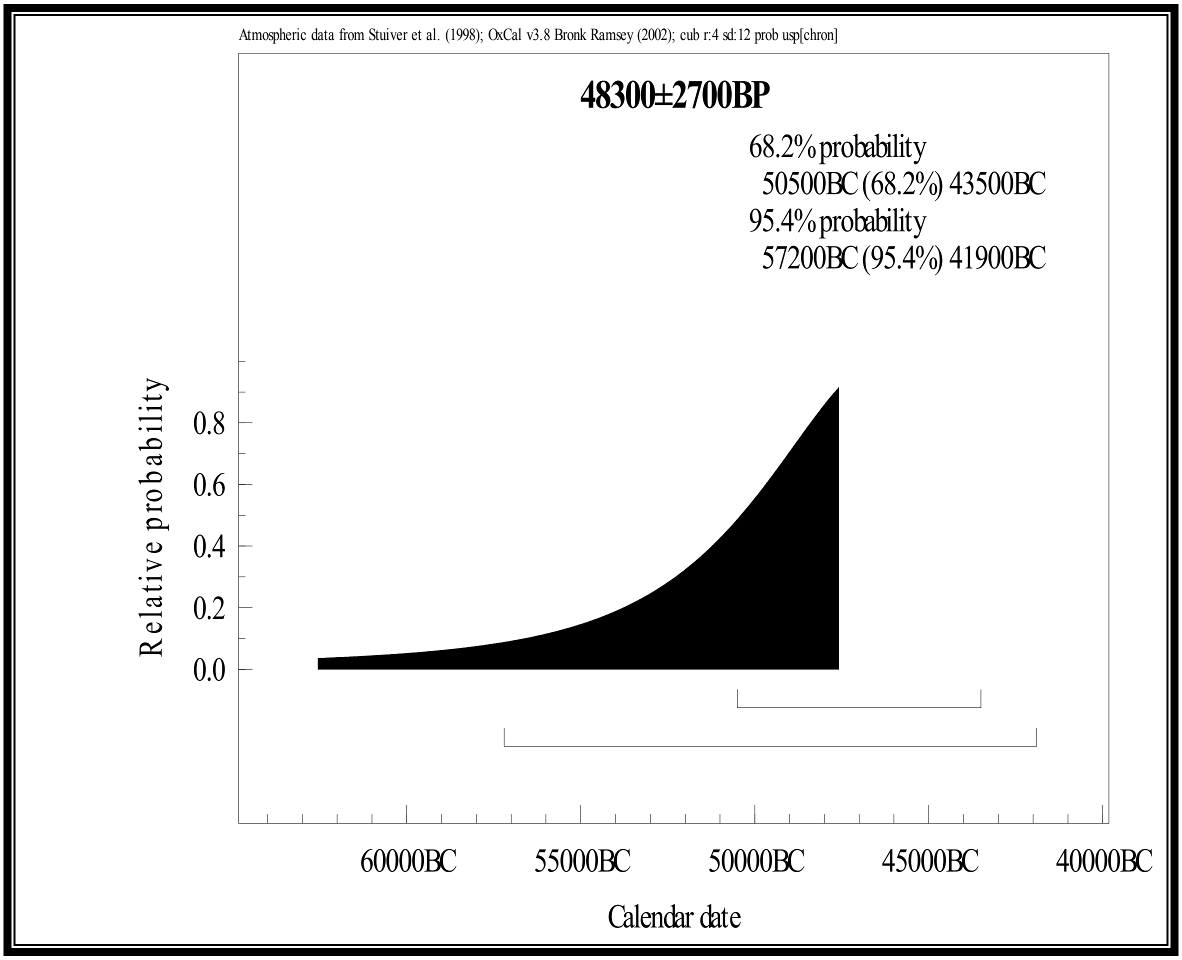
Calibrated date for sample El Hoyon surge [Berlin volcano eruption]

DEC - 31



Calibrated date for sample charcoal DEC – 31 [Volcán de San Miguel]

Twins



Calibrated date for sample Twins [Berlin volcano]

APPENDIX D: CHEMICAL COMPOSITION OF ROCKS OF BERLIN AND PACAYAL COMPLEX, INCLUDING SAN MIGUEL VOLCANO [Carr, 1981, CEL, 1995, Chesner, 2003].

BE – Berlin complex

SAMPLE	S60	S96A	BE10	BE11	BE14	BE15	BE18	BE19
Jcode	8	8	8	8	8	8	8	8
Kcode	1	1	0	1	1	2	3	3
Lcode	1	1	1	1	1	1	1	1
Volcname	Berlin	Berlin	Loma Pacha	Taburete	Oromontique	El Tigre	Usulutan	Usulutan
lat	511	486	525	478	579	615	577	582
long	511664	486632	525547	478556	579616	615585	577561	582560
Lava	lava	lava	lava	lava	lava	lava	lava	lava
K/Ar (Ma)	1.3$\pm$0.7		0.05$\pm$0.06?		0.1$\pm$0.09	0.147$\pm$0.05		0.216$\pm$0.04
author	GENZL95	GENZL95	GENZL95	GENZL95	GENZL95	GENZL95	GENZL95	GENZL95
SiO[2]	51.33	50.57	62.31	50.71	49.44	51.16	50.49	51.69
Al[2]O[3]	17.94	19.37	17.94	19.89	19.65	18.76	20.89	19.40
TiO[2]	1.16	1.09	0.39	0.94	0.96	0.90	1.01	0.98
Fe[2]O[3]	10.94	10.50	5.30	10.10	11.01	10.19	9.72	10.05
FeO								
MnO	0.18	0.22	0.26	0.22	0.19	0.21	0.20	0.21
CaO	9.54	9.83	5.48	9.64	9.55	9.94	10.00	9.23
MgO	4.16	3.58	1.69	4.11	5.05	4.49	3.62	4.07
K[2]O	1.38	1.17	1.68	0.99	0.66	1.03	0.79	0.96
Na[2]O	3.01	3.36	4.59	3.16	3.28	3.09	3.10	3.20
P[2]O[5]	0.35	0.32	0.35	0.23	0.21	0.22	0.17	0.20
Ni	10	7		6	9	7	3	5
Cr	8	6		6	4		3	
V	296	295	28	208	250	245	189	181
Ba	703	737	1007	595	442	538	412	452
Rb	28	19	36	15	9	18	13	18
Sr	467	541	654	648	596	594	673	619
Zr	152	135	104	85	91	92	74	84
Y	28	27	23	20	15	18	17	22
Nb	33	25	25		16			12
Ga	19	18	19	14	19	17	18	17
Zn	104	96	94	74	80	77	64	62
Pb	8	11	12	4	4	8	7	7
La	10	13	18	7	6			
Ce	27	24	35	16	13	18	18	15
Co								
Th	5					1		

BE – Berlin complex

SAMPLE	BE20	S157	S287	BE22	BE23	BE24	BE25	BE26
Jcode	8	8	8	8	8	8	8	8
Kcode	3	1	3	1	1	1	1	1
Lcode	1	1	1	1	1	1	1	1
Volcname	Usulutan	Taburete	El Tigre	Tecapa	Tecapa	Tecapa	Hoyon	Tecapa
lat	585	508	623	561	547	547	522	562
long	585562	508582	623632	561638	547635	547635	522644	562654
Lava	lava	lava	lava	lava	lava	lava	lava	lava
K/Ar (Ma)					0.10 ± 0.02?			
author	GENZL95	GENZL95	GENZL95	GENZL95	GENZL95	GENZL95	GENZL95	GENZL95
SiO[2]	49.13	50.10	53.07	58.09	56.99	56.88	54.92	60.79
Al[2]O[3]	19.21	18.73	18.66	17.83	17.54	17.35	18.18	17.55
TiO[2]	1.10	0.92	0.86	0.70	0.79	0.81	0.81	0.60
Fe[2]O[3]	11.48	10.62	9.93	7.43	8.08	8.38	8.70	6.17
FeO								
MnO	0.21	0.21	0.20	0.19	0.18	0.18	0.18	0.17
CaO	10.10	9.87	8.11	7.06	7.43	7.40	8.08	6.09
MgO	5.02	5.69	4.06	2.97	3.37	3.39	3.94	2.40
K[2]O	0.71	0.76	1.24	1.82	1.87	1.87	1.47	2.09
Na[2]O	2.88	2.94	3.64	3.70	3.56	3.55	3.53	3.95
P[2]O[5]	0.16	0.17	0.23	0.20	0.19	0.19	0.18	0.19
Ni	8	14	6	3	6	7	9	3
Cr	5	23	3		5	4	4	
Sc								
V	261	270	198	109	163	160	173	94
Ba	367	507	596	770	836	781	676	895
Rb	15	13	20	39	44	44	33	51
Sr	621	531	563	513	493	484	497	479
Zr	69	77	123	113	119	129	131	139
Y	16	17	21	24	25	26	19	24
Nb	14	18	19	18	24	21	15	17
Ga	16	23	13	17	16	21	19	14
Cu								
Zn	60	84	81	59	62	60	65	61
Pb	4	7	8	11	6	9	7	8
La		7	9	11	11	14	8	11
Ce	13	17	22	29	23	25	21	37
Co								
Th			2	3	5	1	2	3

Berlin – Pacayal complex

SAMPLE	BE27	BE45	BE46	S102B	S125	S179A	S179B	BE29
Jcode	8	8	8	8	8	8	8	8
Kcode	1	0	0	1	1	1	1	4
Lcode	1	2	2	2	1	2	2	1
Volcname	Tecapa	El Hoyon	Tecapa	Hoyon	Tecapa	Las Palmas	Las Palmas	Pacayal
lat	542	524	534	519	544	504	504	748
long	542655	524635	534640	519623	544666	504615	504615	748637
Lava	lava	lava	scoria	scoria	lava	scoria	scoria	lava
K/Ar (Ma)								
Ar-Ar (Ka)								
C14 (ybp)								
author	GENZL95	GENZL95	GENZL95	GENZL95	GENZL95	GENZL95	GENZL95	GENZL95
SiO[2]	57.13	54.10	54.11	57.82	53.62	51.78	62.21	64.02
Al[2]O[3]	17.74	18.14	18.37	18.22	18.45	20.02	16.88	17.34
TiO[2]	0.77	0.82	0.83	0.66	0.79	0.85	0.77	0.65
Fe[2]O[3]	7.89	9.07	9.09	8.09	9.19	10.26	7.01	4.93
FeO								
MnO	0.15	0.19	0.19	0.19	0.19	0.20	0.19	0.14
CaO	7.20	8.62	8.38	6.78	8.69	9.86	4.42	5.21
MgO	3.57	4.30	4.37	2.76	4.41	3.71	1.67	1.39
K[2]O	1.85	1.32	1.31	1.81	1.28	0.60	2.11	1.85
Na[2]O	3.53	3.26	3.18	3.43	3.18	2.60	4.35	4.27
P[2]O[5]	0.17	0.17	0.17	0.26	0.20	0.11	0.39	0.20
Ni	7	9	9	5	10	6		
Cr		5	5		6	5		
Sc								
V	167	201	219	111	200	289	59	62
Ba	859	657	666	990	574	435	1037	994
Rb	41	28	28	41	28	14	46	36
Sr	479	509	471	519	550	504	375	405
Zr	116	118	119	141	111	63	166	113
Y	22	19	18	25	19	18	35	31
Nb	17	13		19	22	24	29	21
Ga	19	12	17	17	17	20	20	14
Cu								
Zn	62	72	72	75	73	98	96	62
Pb	7	8	7	11	6	3	10	14
La	14	8	7	16	9	7	17	13
Ce	26	23	23	41	18	10	48	29
Co								
Th				1		1	3	1

Berlin – Pacayal complex

SAMPLE	BE30	BE61	BE65	S171	S262	S293	BE05	BE06
Jcode	8	8	8	8	8	8	8	8
Kcode	4	0	4	4	4	4	1	1
Lcode	1	1	1	1	1	1	2	2
Volcname	Pacayal	Moncagua	Lolotique	Pacayal	Cimarron	Lolotique	Berlin	Berlin
lat	725	752	717	713	776	687	466	466
long	725644	752688	717705	713668	776626	687700	466738	466738
Lava	lava	lava	lava	lava	lava	lava	pumice	pumice
K/Ar (Ma)		0.89±.0.4						
Ar-Ar (Ka)								
C14 (ybp)								
author	GENZL95	GENZL95	GENZL95	GENZL95	GENZL95	GENZL95	GENZL95	GENZL95
SiO[2]	59.98	70.53	57.56	66.77	55.39	51.38	57.37	58.35
Al[2]O[3]	16.82	15.81	16.55	16.08	19.62	21.93	17.66	17.93
TiO[2]	0.88	0.33	1.13	0.66	0.92	0.86	0.79	0.85
Fe[2]O[3]	7.79	2.17	9.45	4.18	7.66	8.16	8.15	7.59
FeO								
MnO	0.19	0.09	0.19	0.16	0.18	0.16	0.20	0.21
CaO	5.92	2.85	6.24	3.55	8.85	10.45	6.55	6.49
MgO	2.44	0.54	2.47	1.06	2.68	3.13	2.47	2.48
K[2]O	1.36	3.10	1.62	2.12	0.99	0.51	2.11	2.05
Na[2]O	4.35	4.51	4.36	5.21	3.54	3.29	4.27	3.65
P[2]O[5]	0.27	0.07	0.42	0.21	0.18	0.13	0.41	0.41
Ni			4		3	5	3	
Cr	4				3		3	
Sc								
V	129	21	179	18	194	189	123	136
Ba	750	1435	940	1055	534	345	980	1005
Rb	23	59	26	38	17	9	54	51
Sr	437	272	469	357	494	655	485	491
Zr	121	215	160	137	90	54	158	157
Y	27	31	39	35	22	14	34	38
Nb	22	21	31	34	16		24	37
Ga	20	13	16	16	18	18	17	16
Cu								
Zn	87	40	108	74	83	54	98	104
Pb	2	25	10	9	5		9	11
La	10	17	16	13			17	20
Ce	20	44	34	34	11	7	41	43
Co								
Th		3	2	2			2	

Berlin complex

SAMPLE	BE07	BE08	S132E	S132G	S133B	S133F	BE02	S180
Jcode	8	8	8	8	8		8	8
Kcode	1	1	1	1	1		1	1
Lcode	2	2	2	2	2		2	2
Volcname	Berlin	Berlin	Berlin	Berlin	Berlin	Berlin	Berlin	Berlin
lat	466	466	466	466	466	466	502	502
long	466738	466738	466738	466738	466729	466729	502652	502652
Lava	pumice	pumice	pumice	pumice	pumice	pumice	pumice	pumice
K/Ar (Ma)								
Ar-Ar (Ka)					81±14	98±10		75±10
C14 (ybp)								
author	GENZL95	GENZL95	GENZL95	GENZL95	GENZL95	GENZL95	GENZL95	GENZL95
SiO[2]	61.43	61.46	60.61	64.01	64.10		66.57	65.70
Al[2]O[3]	17.30	17.28	17.51	17.25	17.31		16.68	17.76
TiO[2]	0.77	0.76	0.86	0.68	0.69		0.59	0.66
Fe[2]O[3]	5.96	5.91	6.76	4.97	4.96		3.83	4.07
FeO								
MnO	0.20	0.21	0.21	0.19	0.18		0.21	0.18
CaO	4.81	4.91	5.38	4.19	4.24		3.19	3.16
MgO	2.03	1.95	2.15	1.32	1.31		1.08	1.06
K[2]O	2.30	2.32	2.00	2.80	2.79		2.54	2.29
Na[2]O	4.87	4.85	4.22	4.31	4.13		5.12	4.91
P[2]O[5]	0.33	0.33	0.31	0.28	0.31		0.20	0.21
Ni								
Cr								
Sc								
V	68	69	66	33	35		22	25
Ba	1029	1074	1038	1299	1277		1211	1271
Rb	49	50	43	61	62		50	46
Sr	415	419	453	363	366		332	346
Zr	143	143	128	177	178		159	154
Y	37	35	32	40	40		38	40
Nb	32	31	23	37	35		25	29
Ga	18	17	20	17	19		19	14
Cu								
Zn	102	101	103	92	97		82	86
Pb	10	11	14	13	14		13	8
La	15	15	12	18	20		17	17
Ce	40	38	34	38	43		38	36
Co								
Th	3	3	3	2	2			3

Berlin – Pacayal complex

SAMPLE	BE31	BE34	BE35	BE37	BE38	BE42	BE43	BE50
Jcode	8	8	8	8	8	8	8	8
Kcode	4	4	4	4	4	4	4	4
Lcode	2	2	2	2	2	2	2	2
Volcname	Pacayal	Pacayal	Pacayal	Pacayal	Pacayal	Pacayal	Pacayal	Pacayal
lat	704	704	704	704	704	524	524	747
long	704631	704631	704631	704631	704631	524647	524647	747679
Lava	pumice	pumice	pumice	pumice	pumice	pumice	pumice	scoria
K/Ar (Ma)								
Ar-Ar (Ka)								
C14 (ybp)								
author	GENZL 95	GENZL9 5	GENZL9 5	GENZL9 5	GENZL9 5	GENZL9 5	GENZL9 5	GENZL9 5
SiO[2]	64.99	62.18	62.40	59.66	60.19	64.80	60.79	61.21
Al[2]O[3]	16.39	16.78	16.70	17.00	16.82	16.91	17.82	16.95
TiO[2]	0.78	0.83	0.83	0.89	0.85	0.78	0.93	0.87
Fe[2]O[3]	5.11	6.25	6.23	8.05	7.78	5.64	7.04	6.64
FeO								
MnO	0.18	0.19	0.18	0.20	0.19	0.18	0.20	0.19
CaO	4.31	5.19	5.17	5.97	5.91	4.53	5.60	5.68
MgO	1.47	2.03	2.05	2.55	2.49	1.69	2.26	2.28
K[2]O	1.87	1.56	1.56	1.29	1.37	1.46	1.16	1.35
Na[2]O	4.63	4.72	4.60	4.14	4.32	3.77	3.94	4.54
P[2]O[5]	0.28	0.28	0.28	0.26	0.27	0.23	0.26	0.28
Ni								
Cr				3	4	3	4	3
Sc								
V	41	92	90	142	129	57	101	108
Ba	1027	881	848	741	756	930	765	776
Rb	32	28	26	22	24	30	22	24
Sr	380	413	415	447	436	392	445	433
Zr	123	102	110	121	120	112	118	99
Y	35	32	33	30	27	33	29	28
Nb	27	21	23	21	17	23	24	17
Ga	17	20	20	22	23	18	14	13
Cu								
Zn	87	92	89	97	92	88	93	90
Pb	8	7	7	5	7	7	6	10
La	13	10	12	9	8	13	14	5
Ce	29	23	26	21	27	27	26	22
Co								
Th	2		3	1		2	1	

Berlin – Pacayal complex

SAMPLE	S233D1	S233D2	BE44	BE48A	BE55	BE57	BE58	BE71
Jcode	8	8	8	8	8	8	8	8
Kcode	4	4	5	4	4	4	4	4
Lcode	2	2	2	2	2	2	2	2
Volcname	Pacayal	Pacayal	San Miguel ?	Pacayal	Pacayal	Pacayal	Pacayal	Pacayal
lat	703	703	524	749	755	762	797	775
long	703631	703631	524647	749680	755683	762694	797719	775732
Lava	pumice	pumice	scoria	pumice	pumice	pumice	pumice	pumice
K/Ar (Ma)								
Ar-Ar (Ka)								
C14 (ybp)								
author	GENZL95	GENZL95	GENZL95	GENZL95	GENZL95	GENZL95	GENZL95	GENZL95
SiO[2]	60.78	64.84	60.82	67.45	67.10	67.90	69.98	61.19
Al[2]O[3]	17.23	16.54	17.52	15.99	16.04	15.74	15.97	16.87
TiO[2]	0.87	0.74	0.89	0.56	0.60	0.53	0.49	0.73
Fe[2]O[3]	7.42	5.74	7.23	3.92	3.97	3.62	2.93	6.46
FeO								
MnO	0.19	0.17	0.19	0.12	0.13	0.12	0.12	0.16
CaO	5.51	4.19	5.73	3.98	4.07	3.91	3.00	6.04
MgO	2.18	1.45	2.45	1.40	1.49	1.38	0.89	2.52
K[2]O	1.28	1.69	1.15	2.37	2.36	2.44	2.53	1.99
Na[2]O	4.27	4.42	3.77	4.07	4.11	4.21	3.98	3.85
P[2]O[5]	0.26	0.22	0.26	0.13	0.13	0.14	0.12	0.17
Ni	4	4	3	3	4	3		4
Cr								
Sc								
V	93	43	118	51	59	51	41	105
Ba	785	989	731	1234	1233	1273	1381	1024
Rb	21	30	24	48	47	47	53	37
Sr	433	375	438	301	301	300	247	408
Zr	144	125	127	162	161	156	185	110
Y	33	36	27	31	31	32	35	25
Nb	20	23	27	31	33	28	23	18
Ga	15	20	15	16	20	13	19	21
Cu								
Zn	94	95	94	55	57	61	58	64
Pb	9	6	5	8	9	10	13	2
La	12	14	10	17	14	17	19	11
Ce	25	40	18	38	31	33	31	26
Co								
Th			1	3		2	4	3

Berlin – Pacayal complex

SAMPLE	BE79A	S162B	S257A	S108B	S223S	S147A	S223TU	S223TL
Jcode	8	8	8	8	8	8	8	8
Kcode	4	4	4	0	0	0	4	4
Lcode	2	2	2	2	2	2	2	2
Volcname	Pacayal	Pacayal	Pacayal	Pacayal ?	Pacayal ?	?	Pacayal	Pacayal
lat	736	723	799	553	645	615	645	645
long	736661	723695	799653	553685	645670	615706	645670	645670
Lava	pumice	pumice	pumice	pumice	pumice	pumice	pumice	pumice
K/Ar (Ma)								
Ar-Ar (Ka)								
C14 (ybp)								
author	GENZL 95	GENZL9 5	GENZL9 5	GENZL9 5	GENZL9 5	GENZL9 5	GENZL9 5	GENZL9 5
SiO[2]	65.82	66.93	69.77	61.85	61.27	66.08	65.12	66.82
Al[2]O[3]	16.19	16.22	15.64	16.72	16.68	16.24	17.04	16.79
TiO[2]	0.63	0.58	0.53	0.91	0.93	0.70	0.69	0.71
Fe[2]O[3]	4.46	4.09	2.94	6.91	7.12	5.13	4.61	4.22
FeO								
MnO	0.13	0.13	0.12	0.19	0.19	0.21	0.16	0.16
CaO	4.51	4.36	3.13	5.32	5.62	3.11	4.49	3.96
MgO	1.80	1.58	1.00	2.08	2.23	0.94	1.34	1.15
K[2]O	2.20	2.25	2.57	1.55	1.45	2.66	2.05	2.09
Na[2]O	4.11	3.71	4.19	4.18	4.23	4.75	4.24	3.87
P[2]O[5]	0.14	0.15	0.13	0.28	0.27	0.18	0.26	0.23
Ni	4							
Cr	4				3			
Sc								
V	75	67	40	101	113	19	51	36
Ba	1179	1196	1302	875	844	1296	1166	1195
Rb	45	48	53	30	27	53	41	43
Sr	316	320	260	411	410	302	397	356
Zr	146	145	179	105	131	172	146	158
Y	30	31	34	32	30	39	34	35
Nb	23	27	24	20	22	28	24	24
Ga	23	11	18	17	20	18	20	20
Cu								
Zn	59	56	58	103	108	101	90	85
Pb	5	11	8	7	4	17	6	8
La	16	16	17	12	11	18	19	17
Ce	38	32	38	28	25	40	40	36
Co								
Th	2	3	2	2	2	4		

Berlin complex

SAMPLE	S95	S93	S146	S174	US-1	US-2	US-3	TE-4
Jcode					8	8	8	8
Kcode					3	3	3	1
Lcode								
Volcname	El Hoyon	Pacayal	Berlin	Berlin	Usulutan	Usulutan	Usulutan	Tecapa
lat	521	505	554	543	13.42	13.42	13.42	13.5
long	521639	505613	554723	543675	88.47	88.47	88.47	88.5
Lava	paleosoil	charcoal	charcoal	lava	lava	lava	lava	lava
K/Ar (Ma)				0.88±0.1				
Ar-Ar (Ka)								
C14 (ybp)	710±50	48300±2700	35690±520					
author	GENZL95	GENZL95	GENZL95	GENZL95	carr/ru	carr/ru	carr/ru	carr/ru
SiO[2]					52.8	49.1	51.3	51.8
Al[2]O[3]					19.7	18.4	19.9	17.9
TiO[2]					0.77	1.08	0.89	0.93
Fe[2]O[3]					2.75	3.39	2.93	5.34
FeO					6.26	7.9	5.85	4.6
MnO					0.15	0.19	0.13	0.14
CaO					9.14	10.41	9.79	9.32
MgO					3.21	5.1	3.35	4.53
K[2]O					0.93	0.7	1.01	1.24
Na[2]O					3.51	2.89	3.25	3.14
P[2]O[5]					0.28	0.17	0.27	0.2
Ni					14	11.96	14	13.41
Cr					22	4.33	14	7.3
Sc					0	25.79	0	27.97
V					156	342.7	208	281.9
Ba					533	378.8	481	567.5
Rb					12	11.4	15	25.8
Sr					656	592.5	724	564
Zr					0	69.25	0	97.41
Y					0	20.73	0	23.13
Nb					0	3	0	2.3
Ga					0	0	0	0
Cu					0	112.7	0	112.5
Zn					0	0	0	0
Pb					0	4.041	0	3.48
La					0	5.52	0	8.51
Ce					0	15.57	0	21.33
Co					0	0	0	0
Th					0	0.753	0	1.25

Berlin complex

SAMPLE	TE-5	TE-6	TE-7	TE-8	TE-9	TE-10	Be-6	Be-10
Jcode	8	8	8	8	8	8	8	8
Kcode	1	1	1	1	1	1	1	1
Lcode								
Volcname	Tecapa	Tecapa	Tecapa	Tecapa	Tecapa	Tecapa	Berlin	Berlin
lat	13.5	13.5	13.5	13.5	13.5	13.5		
long	88.5	88.5	88.5	88.5	88.5	88.5		
Lava	lava	lava	lava	lava	lava	lava	lava	lava
K/Ar (Ma)								
Ar-Ar (Ka)								
C14 (ybp)								
author	carr/ru	carr/ru	carr/ru	carr/ru	carr/ru	carr/ru	ELC 94	ELC 94
SiO[2]	51.2	52.6	51.5	55.8	57.9	54.4	49.69	50.11
Al[2]O[3]	18.2	18.1	18.2	17.5	17	17.4	17.61	18.37
TiO[2]	0.94	0.88	0.91	0.77	0.73	0.78	1.05	1.13
Fe[2]O[3]	3.67	2.4	2.8	1.71	2.71	2.89	11.59	12.23
FeO	6.45	6.87	6.87	5.99	5.02	5.85		
MnO	0.14	0.15	0.18	0.19	0.1	0.13	0.18	0.2
CaO	9.23	8.75	9.03	7.41	7.18	8.28	9.66	9.11
MgO	4.24	3.75	4.21	3.15	3.12	3.77	3.93	3.2
K[2]O	1.33	1.3	1.09	1.71	1.98	1.57	1.27	1.39
Na[2]O	3.12	3.28	3.19	3.48	3.46	3.25	2.97	3.14
P[2]O[5]	0.3	0.27	0.29	0.25	0.25	0.27	0.38	0.41
Ni	15	15	14	7	13	24	167	574
Cr	14	14	35	10	14	16	323	1139
Sc	0	0	0	0	0	0	23	20.3
V	245	227	238	168	184	208	293	292
Ba	559	639	590	758	859	731	661	703
Rb	25	18	13	29	34	25	24.9	33.6
Sr	636	582	629	537	470	466	493	562
Zr	0	0	0	0	0	0	122	126
Y	0	0	0	0	0	0		
Nb	0	0	0	0	0	0	3.01	3.16
Ga	0	0	0	0	0	0		
Cu	0	0	0	0	0	0	217	246
Zn	0	0	0	0	0	0	115	121
Pb	0	0	0	0	0	0		
La	0	0	0	0	0	0		
Ce	0	0	0	0	0	0		
Co	0	0	0	0	0	0	32.7	44.1
Th	0	0	0	0	0	0		

Berlin complex

SAMPLE	Be-11	Be-12	Be-14	Be-15	Be-16	Be-17	Be-18	Be-20
Jcode	8	8	8	8	8	8	8	8
Kcode	1	1	1	1	1	1	1	1
Lcode								
Volcname	Berlin	Berlin	Berlin	Berlin	Berlin	Berlin	Berlin	Berlin
lat								
long								
Lava	lava	lava	lava	lava	pumice	pumice	pumice	pumice
K/Ar (Ma)								
Ar-Ar (Ka)								
C14 (ybp)								
author	ELC 94	ELC 94	ELC 94	ELC 94	ELC 94	ELC 94	ELC 94	ELC 94
SiO[2]	53.63	50.52	49.14	53.06	57.4	55.92	59.58	61.92
Al[2]O[3]	17.9	17.12	18.64	18.43	15.58	16.17	16.22	15.86
TiO[2]	0.79	1.11	0.94	0.79	0.76	0.82	0.77	0.6
Fe[2]O[3]	9.7	12.51	11.6	9.92	6.72	7.75	6.82	4.95
FeO								
MnO	0.17	0.21	0.18	0.16	0.15	0.17	0.16	0.17
CaO	8.16	9.2	9.94	8.36	4.52	5.24	4.83	3.27
MgO	3.86	4.14	4.89	3.67	1.91	2.25	1.8	1.08
K[2]O	1.38	1.21	1.04	1.29	1.23	1.02	1.29	2.22
Na[2]O	3.27	3.14	2.91	3.19	2.8	3.16	3.78	4.48
P[2]O[5]	0.23	0.34	0.25	0.22	0.25	0.24	0.24	0.22
Ni	206	225	259	416	44.8	271	37	81.3
Cr	392	431	504	806	83.1	535	70.7	164
Sc	17.7	24.5	21	17.2	14.3	16.5	15.6	9.8
V	236	341	307	264	79.7	105	73.7	28.2
Ba	659	631	435	630	749	649	795	1096
Rb	30.3	25.9	19.9	27.8	30.3	21.7	26.4	44.3
Sr	494	520	571	520	398	429	404	360
Zr	96.9	107	72.4	92.7	107	97.8	104	141
Y								
Nb	2.25	2.65	1.68	2.29	2.55	2.39	2.53	3.01
Ga								
Cu	102	157	130	108	42.4	40.8	31.8	14.7
Zn	84.3	122	83.2	81.5	87.7	89.5	89	81.6
Pb								
La								
Ce								
Co	35.2	36.8	40.2	45.2	15.3	22.7	10.5	8.26
Th								

Berlin – Pacayal – San Miguel

SAMPLE	Be-21	Be-22	Be-23	Be-24	SM-1	SM-3	SM-4	SM-5
Jcode	8	8	8	8	8	8	8	8
Kcode	1	4	4	4	5	5	5	5
Lcode								
Volcname	Berlin	Pacayal	Pacayal	Pacayal	San Miguel	San Miguel	San Miguel	San Miguel
lat					13.433	13.433	13.433	13.433
long					88.267	88.267	88.267	88.267
Lava	pumice	pumice	pumice	pumice	lava	lava	lava	lava
K/Ar (Ma)								
Ar-Ar (Ka)								
C14 (ybp)								
author	ELC 94	ELC 94	ELC 94	ELC 94	carr/ru	carr/ru	carr/ru	carr/ru
SiO[2]	61.97	61.54	60.99	53.98	53.1	52.8	54.7	50.1
Al[2]O[3]	15.36	15.55	15.98	18.33	19.8	16.9	19.8	18.7
TiO[2]	0.55	0.63	0.64	0.77	0.79	1.19	0.84	1.06
Fe[2]O[3]	4.51	5.05	5.25	7.31	3.05	3.12	2.71	3.88
FeO					4.71	7.59	5.01	6.32
MnO	0.15	0.13	0.14	0.15	0.14	0.18	0.15	0.16
CaO	2.84	3.74	3.91	5.37	9.16	9.21	9.07	10.37
MgO	0.84	0.99	1.05	1.67	2.79	4.12	2.31	4.06
K[2]O	2.33	2	1.85	0.97	1.1	0.94	1.19	0.82
Na[2]O	4.24	3.53	3.52	2.57	3.27	3.12	3.47	2.88
P[2]O[5]	0.19	0.23	0.26	0.26	0.25	0.28	0.22	0.3
Ni	216	182	170	220	12	14	74	11
Cr	424	365	328	420	13	22	16	29
Sc	8.8	11.1	11.4	14.6	0	0	0	0
V	23.8	42.3	45.5	120	175	368	174	323
Ba	1161	1172	1088	855	588	556	661	492
Rb	49.1	44.6	38.9	24	11	11	13	8
Sr	326	378	368	380	533	440	484	502
Zr	154	163	148	120	0	0	0	0
Y					0	0	0	0
Nb	3.5	4.28	3.77	3	0	0	0	0
Ga					0	0	0	0
Cu	20.9	29.7	30.3	56	0	0	0	0
Zn	84.7	84.4	77.1	81	0	0	0	0
Pb					0	0	0	0
La					0	0	0	0
Ce					0	0	0	0
Co	13.3	13	13.2	20.5	0	0	0	0
Th					0	0	0	0

San Miguel

SAMPLE	SM-6	SM-7	SM-8	SM-9	SM-10	T46A	T46B	CC30
Jcode	8	8	8	8	8	8	8	8
Kcode	5	5	5	5	5	5	5	5
Lcode						2	3	3
Volcname	San Miguel	San Miguel	San Miguel	San Miguel	San Miguel	San Miguel? ???	San Miguel? ???	N PL
lat	13.433	13.433	13.433	13.433	13.433			
long	88.267	88.267	88.267	88.267	88.267			
Lava	lava	lava	lava	lava	lava	scoria	scoria	scoria
K/Ar (Ma)								
Ar-Ar (Ka)								
C14 (ybp)								
author	carr/ru	carr/ru	carr/ru	carr/ru	carr/ru	Chesner	Chesner	Chesner
SiO[2]	53.1	51.1	50.5	52.1	50.7	58.03	54.1	59.49
Al[2]O[3]	18.4	19.7	19.2	17.3	19.5	16.45	18.09	16.9
TiO[2]	0.91	0.97	0.96	1.16	1.02	1.071	0.998	0.919
Fe[2]O[3]	1.67	2.45	3.38	3.47	0.88	8.54	9.2	6.71
FeO	7.13	6.57	6.62	7.41	8.01			
MnO	0.18	0.18	0.17	0.17	0.18	0.202	0.19	0.192
CaO	9.57	10.31	10.97	9.53	10.56	6.91	8.68	5.99
MgO	4.1	3.38	4.78	4.12	3.39	3.09	3.86	2.45
K[2]O	0.91	0.87	0.64	0.96	0.92	1.15	0.91	1.45
Na[2]O	2.98	2.93	2.89	3.16	2.92	3.32	2.82	4.25
P[2]O[5]	0.27	0.23	0.17	0.3	0.26	0.234	0.216	0.302
Ni	11	12.52	18.65	20	12	2	3	1
Cr	19	14.37	20.63	25	33	11	19	3
Sc	0	33.2	36.74	0	0	40	35	26
V	268	302.8	332.9	359	325	264	274	119
Ba	534	526.3	410.7	613	534	670	531	793
Rb	10	15.5	13.4	18	14	19	15	23
Sr	481	523.5	514.3	456	521	417	474	444
Zr	0	81.69	68.74	0	0	94	76	105
Y	0	23.96	19.88	0	0	29	25	32
Nb	0	2.6	2.9	0	0	3.6	6.4	4.2
Ga	0	0	0	0	0	20	19	17
Cu	0	212.6	183	0	0	190	143	26
Zn	0	0	0	0	0	95	83	98
Pb	0	3.337	3.256	0	0	1	1	2
La	0	8.61	6.05	0	0	1	1	16
Ce	0	20.93	14.85	0	0	14	16	22
Co	0	0	0	0	0			
Th	0	0.714	0.726	0	0	0	5	1

San Miguel

SAMPLE	CC31	D32	D33A	CC33B	CC34	CC36	CC37	CC43
Jcode	8	8	8	8	8	8	8	8
Kcode	5	0	0	5	5	5	5	5
Lcode	3	3	3	3	3	3	3	3
Volcname	N PL	N PL	N PL	San Miguel? ???	San Miguel	S San Miguel?	S San Miguel?	San Miguel? ???
lat								
long								
Lava	scoria	lava	lava	scoria	scoria	scoria	scoria	scoria
K/Ar (Ma)								
Ar-Ar (Ka)								
C14 (ybp)								
author	Chesner	Chesner	Chesner	Chesner	Chesner	Chesner	Chesner	Chesner
SiO[2]	62.07	60.52	60.97	59.5	50.46	55.14	54.75	51.41
Al[2]O[3]	16.77	16.87	16.54	16.92	18.99	18.87	19.33	17.61
TiO[2]	0.891	0.873	0.921	0.909	0.986	0.853	0.846	0.771
Fe[2]O[3]	6.17	6.79	6.62	6.82	10.01	7.68	7.59	9.53
FeO								
MnO	0.19	0.185	0.183	0.191	0.177	0.168	0.166	0.186
CaO	3.94	5.99	5.67	6.02	10.41	8.5	8.7	10.03
MgO	1.55	2.51	2.13	2.52	4.13	3.04	3.02	6.42
K[2]O	1.94	1.37	1.48	1.43	0.7	1.11	1.1	0.62
Na[2]O	4.16	4.4	4.43	4.01	2.85	3.4	3.29	2.66
P[2]O[5]	0.336	0.273	0.267	0.275	0.168	0.218	0.216	0.154
Ni	3	0	0	0	4	2	2	30
Cr	0	3	2	7	25	13	10	125
Sc	32	33	33	31	36	32	24	35
V	56	131	131	130	329	210	195	245
Ba	1450	804	860	816	421	650	631	382
Rb	34	22	24	25	13	18	18	9
Sr	355	425	406	432	482	453	465	462
Zr	146	103	107	104	59	89	89	54
Y	40	31	32	31	20	26	26	18
Nb	4.9	4.1	4	4.9	2.4	3.9	3.4	2.6
Ga	18	17	20	18	18	18	21	14
Cu	53	42	40	20	212	140	137	104
Zn	96	92	100	93	83	83	81	76
Pb	3	4	4	5	0	5	5	1
La	0	10	19	18	0	10	1	0
Ce	27	34	14	26	10	19	24	10
Co								
Th	2	1	4	3	5	2	3	0

San Miguel

SAMPLE	FL5	1844	FL6	FL7	FL8	FL9	FL10	FL11
Jcode	8	8	8	8	8	8	8	8
Kcode	5	5	5	5	5	5	5	5
Lcode	3	3	3	3	3	3	3	3
Volcname	San Miguel	San Miguel	San Miguel	San Miguel	San Miguel	San Miguel	San Miguel	San Miguel
lat								
long								
Lava	lava	lava	lava	lava	lava	lava	lava	lava
K/Ar (Ma)								
Ar-Ar (Ka)								
C14 (ybp)								
author	Chesner	Chesner	Chesner	Chesner	Chesner	Chesner	Chesner	Chesner
SiO[2]	51.44	51.59	52.55	51.58	50.79	51.64	51.13	51.52
Al[2]O[3]	19.76	19.84	18.82	19.59	18.32	19.71	19.47	19.07
TiO[2]	0.958	0.964	0.993	0.958	0.992	0.958	0.971	1.025
Fe[2]O[3]	9	8.83	9.26	9.1	9.91	8.77	9	9.16
FeO								
MnO	0.171	0.17	0.181	0.17	0.191	0.17	0.174	0.18
CaO	10.45	10.48	10.05	10.34	10.05	10.49	10.76	10.46
MgO	3.6	3.7	4.03	3.55	5.21	3.55	3.77	4.12
K[2]O	0.86	0.86	0.78	0.85	0.76	0.86	0.85	0.82
Na[2]O	2.92	2.96	2.83	2.93	2.67	2.89	2.8	2.71
P[2]O[5]	0.23	0.228	0.194	0.226	0.193	0.229	0.22	0.204
Ni	4	4	5	4	12	4	6	4
Cr	26	26	25	26	22	27	30	28
Sc	33	36	43	34	35	34	40	40
V	297	293	316	283	319	282	305	316
Ba	506	515	498	514	475	515	501	484
Rb	14	13	12	13	14	14	14	15
Sr	486	487	459	488	447	489	468	475
Zr	76	76	68	78	69	77	76	72
Y	24	25	24	24	23	25	24	24
Nb	2.7	3.6	2.8	4.1	3.3	3.5	3.3	3.1
Ga	21	18	21	19	20	22	23	19
Cu	201	199	192	183	191	203	216	197
Zn	86	84	91	84	93	82	87	83
Pb	3	3	5	0	1	2	0	2
La	6	5	6	0	16	12	5	8
Ce	12	17	17	19	20	32	18	4
Co								
Th	1	1	2	3	4	0	2	2

San Miguel

SAMPLE	FL12	FL13	FL14	FL15	FL17	FL18A	FL18B	FL20
Jcode	8	8	8	8	8	8	8	8
Kcode	5	5	5	5	5	5	5	5
Lcode	3	3	3	3	3	3	3	3
Volcname	San Miguel	San Miguel	San Miguel	San Miguel	San Miguel	San Miguel	San Miguel	San Miguel
lat								
long								
Lava	lava	lava	lava	lava	lava	lava	lava	lava
K/Ar (Ma)								
Ar-Ar (Ka)								
C14 (ybp)								
author	Chesner	Chesner	Chesner	Chesner	Chesner	Chesner	Chesner	Chesner
SiO[2]	50.71	51.18	50.4	51.69	50.98	51.11	51.22	51.62
Al[2]O[3]	19.66	19.41	18.61	19.18	19.27	18.77	18.91	19.35
TiO[2]	0.903	0.975	0.805	1.017	0.946	0.983	0.983	1.01
Fe[2]O[3]	9.07	9.43	9.17	9.2	9.16	9.71	9.44	9.41
FeO								
MnO	0.176	0.177	0.178	0.178	0.178	0.185	0.186	0.174
CaO	11.02	10.61	10.3	10.48	10.72	10.32	10.34	10.21
MgO	4.66	4.16	6.53	4.03	4.36	4.88	4.94	3.9
K[2]O	0.64	0.69	0.58	0.8	0.69	0.78	0.79	0.86
Na[2]O	2.55	2.8	2.43	2.75	2.79	2.62	2.74	3.04
P[2]O[5]	0.154	0.17	0.145	0.199	0.169	0.189	0.189	0.203
Ni	7	4	25	4	5	10	7	4
Cr	29	25	41	30	25	26	29	19
Sc	30	37	30	31	39	40	37	39
V	319	305	273	316	327	304	312	300
Ba	405	425	387	468	437	461	462	502
Rb	12	12	8	13	12	14	13	16
Sr	488	487	430	479	467	452	446	496
Zr	56	60	55	72	62	67	67	74
Y	20	21	19	24	22	23	23	24
Nb	2.1	2.4	2.7	2.7	2.8	2.2	1.9	3.3
Ga	22	19	20	19	21	20	17	20
Cu	189	212	147	205	141	236	211	184
Zn	83	84	84	84	87	88	85	85
Pb	2	2	4	0	2	1	4	2
La	19	11	10	5	12	13	12	11
Ce	22	19	10	24	1	20	15	6
Co								
Th	2	3	0	0	2	2	2	2

San Miguel

SAMPLE	FL22	FL24	FL25	FL27	FL28	FL29	FL38	FL39A
Jcode	8	8	8	8	8	8	8	8
Kcode	5	5	5	5	5	5	5	5
Lcode	3	3	3	3	3	3	3	3
Volcname	San Miguel	San Miguel	San Miguel	San Miguel	San Miguel	San Miguel	San Miguel	San Miguel
lat								
long								
Lava	lava	lava	lava	lava	lava	lava	lava	lava
K/Ar (Ma)								
Ar-Ar (Ka)								
C14 (ybp)								
author	Chesner	Chesner	Chesner	Chesner	Chesner	Chesner	Chesner	Chesner
SiO[2]	51.84	52.25	53.16	52.43	51.35	52.5	53.38	52.76
Al[2]O[3]	19.1	18.04	18.91	19.7	19.43	19.93	20.34	20.23
TiO[2]	1.023	1.045	0.865	0.948	0.984	0.947	0.756	0.762
Fe[2]O[3]	9.12	9.86	8.98	8.45	9.08	8.57	7.77	7.83
FeO								
MnO	0.178	0.196	0.178	0.165	0.174	0.165	0.171	0.162
CaO	10.45	9.54	9.32	10.36	10.37	10.44	9.63	10.11
MgO	4.12	4.12	4.21	3.6	4.1	3.64	3.37	4.15
K[2]O	0.83	0.82	0.83	0.91	0.79	0.88	0.78	0.54
Na[2]O	2.88	3.12	2.92	2.72	2.77	2.85	2.92	2.95
P[2]O[5]	0.204	0.174	0.176	0.184	0.192	0.178	0.166	0.136
Ni	5	3	6	6	5	4	6	7
Cr	26	17	17	16	21	18	11	16
Sc	36	36	34	42	38	39	29	31
V	319	341	256	281	322	272	199	236
Ba	474	498	521	491	462	485	455	369
Rb	13	11	15	15	13	13	13	6
Sr	475	454	470	474	471	479	537	493
Zr	71	66	73	73	68	72	63	46
Y	24	24	23	23	23	24	20	17
Nb	2.7	3.1	2	3.6	3.1	3.5	3.1	2.7
Ga	19	21	18	19	20	18	17	17
Cu	196	279	156	191	190	169	104	51
Zn	85	86	87	79	91	76	77	75
Pb	1	2	4	4	0	1	1	0
La	0	0	0	6	13	0	2	3
Ce	19	0	23	5	21	20	17	5
Co								
Th	2	2	3	2	4	3	3	2

San Miguel

SAMPLE	FL39B	FL42	FL44D	FL44E	PF23	PF40	PF41	T-51
Jcode	8	8	8	8	8	8	8	8
Kcode	5	5	5	5	5	5	5	5
Lcode	3	3	3	3	4	4	4	4
Volcname	San Miguel	San Miguel	San Miguel	San Miguel	San Miguel	San Miguel	San Miguel	San Miguel
lat								
long								
Lava	lava	lava	lava	lava	scoria	scoria	scoria	scoria
K/Ar (Ma)								
Ar-Ar (Ka)								
C14 (ybp)								
author	Chesner	Chesner	Chesner	Chesner	Chesner	Chesner	Chesner	Chesner
SiO[2]	52.33	50.39	50.89	51.06	52.17	55.45	51.72	52.08
Al[2]O[3]	20.77	19.76	18.65	18.78	20.1	17.49	20.12	20.85
TiO[2]	0.738	0.914	0.976	0.983	0.874	0.961	0.872	0.842
Fe[2]O[3]	7.71	9.19	9.63	9.48	8.67	8.69	8.29	8.47
FeO								
MnO	0.156	0.177	0.189	0.185	0.16	0.189	0.163	0.159
CaO	10.33	10.99	10.12	10.34	10.56	8.22	10.58	10.37
MgO	3.79	4.76	5.21	4.86	3.7	3.39	3.93	3.25
K[2]O	0.55	0.65	0.73	0.8	0.69	1.04	0.71	0.64
Na[2]O	2.84	2.58	2.62	2.59	2.66	3.44	2.77	2.69
P[2]O[5]	0.133	0.158	0.182	0.188	0.166	0.206	0.156	0.163
Ni	6	7	14	7	3	1	7	4
Cr	16	29	21	28	20	11	19	15
Sc	29	39	35	41	33	32	28	32
V	236	310	316	316	295	267	274	239
Ba	369	394	458	462	429	601	450	480
Rb	6	9	11	14	10	17	10	11
Sr	503	485	451	450	481	446	508	507
Zr	45	55	65	68	62	91	60	63
Y	17	20	23	23	21	26	21	19
Nb	2.4	2.6	2.5	3	4.5	4.2	2.3	1.9
Ga	20	18	20	21	17	19	18	22
Cu	156	180	179	205	104	170	172	171
Zn	75	83	88	87	78	86	75	82
Pb	0	0	0	0	0	1	5	4
La	11	16	0	4	5	0	14	15
Ce	12	2	21	22	27	14	6	20
Co								
Th	0	2	0	2	4	1	2	0

San Miguel

SAMPLE	T-65a	T-65b	T-65c	T-65d	T-65e	T-65f	T-65g	T-65h
Jcode	8	8	8	8	8	8	8	8
Kcode	5	5	5	5	5	5	5	5
Lcode	4	4	4	4	4	4	4	4
Volcname	San Miguel	San Miguel	San Miguel	San Miguel	San Miguel	San Miguel	San Miguel	San Miguel
lat								
long								
Lava	scoria	scoria	scoria	scoria	scoria	scoria	scoria	scoria
K/Ar (Ma)								
Ar-Ar (Ka)								
C14 (ybp)								
author	Chesner	Chesner	Chesner	Chesner	Chesner	Chesner	Chesner	Chesner
SiO[2]	52.7	52.7	51.86	53.6	51.68	52.58	52.36	52.33
Al[2]O[3]	20.42	20	18.24	19.29	18.51	19.02	19.24	19.14
TiO[2]	0.817	0.84	0.89	0.88	0.886	0.878	0.948	0.891
Fe[2]O[3]	8.29	8.76	10.31	8.97	10.2	9.5	9.55	9.47
FeO								
MnO	0.167	0.171	0.199	0.18	0.197	0.185	0.189	0.178
CaO	9.84	9.77	9.61	9.31	9.75	9.55	9.46	9.65
MgO	2.96	3.27	4.99	3.07	4.96	4.35	3.94	3.84
K[2]O	0.69	0.69	0.59	0.78	0.53	0.67	0.57	0.66
Na[2]O	2.83	2.74	2.49	3.11	2.67	2.59	2.65	2.67
P[2]O[5]	0.188	0.185	0.168	0.201	0.144	0.17	0.159	0.172
Ni	0	3	7	1	6	3	4	2
Cr	12	10	15	9	23	17	15	15
Sc	27	28	34	34	46	42	40	35
V	196	236	283	231	293	265	245	272
Ba	506	507	444	534	401	480	453	492
Rb	12	10	8	12	8	10	7	12
Sr	529	508	469	517	458	469	472	475
Zr	68	68	60	74	54	64	64	65
Y	21	21	20	23	19	21	23	22
Nb	2.3	2.2	1.6	3.8	1.9	1.5	1.8	1.5
Ga	21	19	19	21	21	20	17	18
Cu	162	165	164	173	169	165	189	180
Zn	82	86	94	89	90	88	91	91
Pb	1	0	1	2	3	4	2	0
La	7	2	25	13	1	14	23	2
Ce	21	12	15	0	17	20	14	20
Co								
Th	3	1	0	1	4	2	1	2

San Miguel

SAMPLE	T-65i	T-66g	T-66h	T-68g	T-71	T-72a	T-72b	T-74a
Jcode	8	8	8	8	8	8	8	8
Kcode	5	5	5	5	5	5	5	5
Lcode	4	4	4	4	4	4	4	4
Volcname	San Miguel	San Miguel	San Miguel	San Miguel	San Miguel? ???	San Miguel? ???	San Miguel? ???	San Miguel
lat								
long								
Lava	scoria	scoria	scoria	scoria	scoria	scoria	scoria	scoria
K/Ar (Ma)								
Ar-Ar (Ka)								
C14 (ybp)								
author	Chesner	Chesner	Chesner	Chesner	Chesner	Chesner	Chesner	Chesner
SiO[2]	50.54	50.35	51.75	53.84	60.31	58.92	62.79	51.53
Al[2]O[3]	19.63	19.54	19.27	18.2	16.53	16.46	16.6	16.7
TiO[2]	0.841	0.826	0.925	0.925	0.865	0.909	0.712	1.131
Fe[2]O[3]	9.7	9.68	9.6	9.16	6.92	7.35	5.08	11.42
FeO								
MnO	0.173	0.172	0.176	0.178	0.174	0.191	0.161	0.212
CaO	10.49	10.52	9.94	8.94	5.89	6.05	4.75	9.45
MgO	5.29	5.41	3.96	3.82	2.37	2.51	1.44	4.79
K[2]O	0.48	0.49	0.63	0.94	1.46	1.5	1.8	0.76
Na[2]O	2.24	2.25	2.35	3.09	4.02	3.89	4.28	2.81
P[2]O[5]	0.129	0.125	0.154	0.185	0.237	0.278	0.285	0.197
Ni	15	15	7	5	1	2	1	7
Cr	27	24	29	19	8	0	2	29
Sc	30	38	45	31	30	34	17	48
V	254	255	251	268	133	129	47	369
Ba	358	341	434	551	838	853	1000	513
Rb	6	7	12	14	25	27	32	12
Sr	442	445	444	448	421	439	406	427
Zr	53	51	70	79	110	108	135	71
Y	17	18	21	23	31	33	38	26
Nb	2.7	1.4	2.8	3.5	3.4	3.5	4.4	2.7
Ga	19	19	17	18	18	18	16	22
Cu	161	155	187	167	44	35	23	237
Zn	85	80	89	92	88	100	90	104
Pb	3	0	5	2	3	8	6	5
La	4	1	7	9	14	16	14	11
Ce	9	8	24	8	44	31	18	23
Co								
Th	0	1	2	2	4	2	1	2

Miguel

SAMPLE	T-74b	T-74c	T-74d	T-74e	T-74f	T-74g	T-75-1	T-75-2
Jcode	8	8	8	8	8	8	8	8
Kcode	5	5	5	5	5	5	5	5
Lcode	4	4	4	4	4	4	4	4
Volcname	San Miguel	San Miguel	San Miguel	San Miguel	San Miguel	San Miguel	San Miguel	San Miguel
lat								
long								
Lava	scoria	scoria	scoria	scoria	scoria	scoria	scoria	scoria
K/Ar (Ma)								
Ar-Ar (Ka)								
C14 (ybp)								
author	Chesner	Chesner	Chesner	Chesner	Chesner	Chesner	Chesner	Chesner
SiO[2]	53.1	50.77	50.89	51.66	53.12	53.49	55.7	52.27
Al[2]O[3]	16.5	19	18.84	18.21	18.91	18.95	17.27	20.37
TiO[2]	1.18	0.864	0.875	1.012	0.896	0.881	0.987	0.933
Fe[2]O[3]	11.06	9.64	9.4	9.97	9.12	9.16	9.31	9.04
FeO								
MnO	0.209	0.176	0.177	0.183	0.174	0.171	0.189	0.165
CaO	8.83	10.51	10.7	9.78	9.43	9.47	8.23	10.32
MgO	4.34	5.22	5.6	4.49	3.67	3.67	3.91	3.29
K[2]O	0.89	0.58	0.65	0.83	0.85	0.88	1.11	0.73
Na[2]O	3.07	2.45	2.43	2.6	2.64	2.71	3.12	2.72
P[2]O[5]	0.23	0.163	0.165	0.209	0.18	0.183	0.2	0.172
Ni	3	14	16	8	3	3	5	2
Cr	27	35	36	27	16	11	18	18
Sc	47	34	38	44	34	37	37	25
V	374	269	277	267	268	274	266	258
Ba	564	405	391	547	536	527	629	482
Rb	13	11	11	15	15	15	22	13
Sr	420	457	469	459	418	419	430	518
Zr	78	57	61	81	78	79	91	66
Y	27	19	20	24	23	23	26	22
Nb	3.7	1.8	3.1	3.1	2.3	2.5	3.2	1.9
Ga	19	19	18	20	21	20	20	17
Cu	243	176	177	218	186	186	171	202
Zn	105	86	82	84	93	95	90	81
Pb	2	2	0	0	5	3	2	3
La	18	5	10	16	19	1	3	11
Ce	24	20	6	15	29	3	21	16
Co								
Th	0	4	0	1	2	3	3	0

San Miguel

SAMPLE	T-75-3	T-75-4	T-75-5	T-75-6	T-75-7	T-89a	T-89b	T-90
Jcode	8	8	8	8	8	8	8	8
Kcode	5	5	5	5	5	5	5	5
Lcode	4	4	4	4	4	4	4	4
Volcname	San Miguel	San Miguel	San Miguel	San Miguel	San Miguel	San Miguel	San Miguel	San Miguel????
lat								
long								
Lava	scoria	scoria	scoria	scoria	scoria	scoria	scoria	scoria
K/Ar (Ma)								
Ar-Ar (Ka)								
C14 (ybp)								
author	Chesner	Chesner	Chesner	Chesner	Chesner	Chesner	Chesner	Chesner
SiO[2]	54.59	57.7	53.13	52.63	52.31	53.26	56.1	61.64
Al[2]O[3]	16.85	17.01	19.51	20.39	19.54	17.44	16.72	16.47
TiO[2]	1.173	0.938	0.922	0.865	0.853	1.063	1.101	0.846
Fe[2]O[3]	10.72	8.74	9.21	8.27	9.09	10.65	10.13	6.5
FeO								
MnO	0.222	0.188	0.174	0.167	0.174	0.208	0.219	0.172
CaO	7.83	6.86	8.84	10.31	10.11	8.97	7.22	5.45
MgO	3.74	3.02	3.27	3.42	4.52	4.33	3.29	2.08
K[2]O	0.81	1.3	0.63	0.65	0.62	0.71	0.98	1.57
Na[2]O	3.02	3.41	2.34	2.88	2.61	2.92	3.29	4.12
P[2]O[5]	0.196	0.207	0.149	0.171	0.163	0.166	0.225	0.248
Ni	4	4	6	1	7	2	4	5
Cr	10	10	13	12	25	14	7	5
Sc	34	35	37	36	30	40	37	29
V	263	201	216	256	273	332	222	114
Ba	580	759	502	464	447	465	658	900
Rb	13	27	13	9	9	12	16	28
Sr	429	416	407	495	469	457	433	404
Zr	86	110	82	59	58	65	95	117
Y	28	29	23	19	20	23	32	33
Nb	3.9	3.4	3.6	2.8	2.3	2.8	3.8	4.1
Ga	20	18	20	18	21	18	17	17
Cu	247	138	199	171	169	198	176	42
Zn	106	91	95	81	87	90	105	90
Pb	2	6	2	1	0	2	4	5
La	11	0	12	6	9	14	0	23
Ce	11	17	0	30	3	22	22	21
Co								
Th	2	3	2	3	2	1	0	2

San Miguel

SAMPLE	T-02	T-21	T-26	PF-58	PF-60	PF-62	PF-86	PF-89
Jcode	8	8	8	8	8	8	8	8
Kcode	5	5	5	5	5	5	5	5
Lcode	4	4	4	4	4	4	4	4
Volcname	San Miguel	San Miguel	San Miguel	San Miguel	San Miguel	San Miguel	San Miguel	San Miguel
lat								
long								
Lava	scoria	scoria	scoria	scoria	scoria	scoria	scoria	scoria
K/Ar (Ma)								
Ar-Ar (Ka)								
C14 (ybp)								
author	Chesner	Chesner	Chesner	Chesner	Chesner	Chesner	Chesner	Chesner
SiO[2]	42.06	51.99	71.37	52.52	61.95	51.61	52.67	52.35
Al[2]O[3]	15.65	20.57	14.61	19.65	15.94	19.24	18.51	20.22
TiO[2]	0.805	0.994	0.279	0.894	0.95	1.002	0.979	0.876
Fe[2]O[3]	8.48	10.26	2.12	9.17	7.13	9.62	9.39	8.8
FeO								
MnO	0.095	0.152	0.092	0.172	0.186	0.178	0.181	0.16
CaO	11.66	6.19	2.52	10.26	5.25	10.35	9.81	10.39
MgO	1.96	2.86	0.64	3.82	1.93	4.34	4.41	3.42
K[2]O	0.7	0.81	2.65	0.74	1.92	0.77	0.9	0.79
Na[2]O	1.9	2.41	4.05	2.84	4.32	2.86	2.65	2.84
P[2]O[5]	0.225	0.155	0.08	0.151	0.316	0.193	0.209	0.168
Ni	7	8	4	2	3	10	10	3
Cr	27	20	0	17	0	24	30	14
Sc	27	33	1	35	26	35	31	25
V	274	317	27	294	100	306	282	269
Ba	484	579	1147	467	997	480	565	467
Rb	11	15	56	12	37	12	16	14
Sr	515	470	248	488	390	473	449	468
Zr	66	75	149	63	136	69	78	69
Y	25	20	19	21	37	23	25	21
Nb	2.6	2	4	2.7	4.1	2.6	4.4	3.1
Ga	18	20	13	18	21	20	17	20
Cu	322	171	15	181	67	187	183	173
Zn	82	76	42	78	96	88	85	81
Pb	8	4	6	3	3	2	5	2
La	15	10	10	0	29	24	15	15
Ce	20	16	24	28	38	19	28	26
Co								
Th	2	0	1	3	2	1	1	2

San Miguel

SAMPLE	CC-52	CC-54	D-56	CC-83	FL-91a	FL-91b	FL-91c	FL-47
Jcode	8	8	8	8	8	8	8	8
Kcode	5	5	0	5	5	5	5	5
Lcode	4	4	3	4	3	3	3	3
Volcname	San Miguel	San Miguel	NO VSM	San Miguel	San Miguel	San Miguel	San Miguel	San Miguel
lat								
long								
Lava	scoria	scoria	lava	scoria	lava	lava	lava	lava
K/Ar (Ma)								
Ar-Ar (Ka)								
C14 (ybp)								
author	Chesner	Chesner	Chesner	Chesner	Chesner	Chesner	Chesner	Chesner
SiO[2]	55.31	50.98	60.97	51.05	51.68	51.64	51.8	51.75
Al[2]O[3]	20.09	20.43	16.37	18.3	19.27	19.09	18.57	18.48
TiO[2]	0.916	0.807	0.736	0.98	0.837	0.846	0.866	0.911
Fe[2]O[3]	7.48	8.76	6.18	10.39	9.2	9.5	9.62	9.72
FeO								
MnO	0.159	0.177	0.129	0.19	0.177	0.175	0.181	0.18
CaO	8.87	10.65	5.56	10.07	10.39	10.21	9.99	10.32
MgO	2.52	4.67	2.55	5.43	5.21	5.15	5.39	5.21
K[2]O	1.07	0.55	2.78	0.81	0.62	0.68	0.75	0.82
Na[2]O	3.5	2.69	3.36	2.62	2.7	2.71	2.72	2.59
P[2]O[5]	0.22	0.137	0.154	0.189	0.158	0.161	0.17	0.176
Ni	6	8	4	11	13	12	14	13
Cr	9	23	9	28	40	34	35	27
Sc	17	38	23	36	34	31	37	35
V	180	290	150	300	264	275	284	283
Ba	529	405	1090	456	434	430	448	485
Rb	20	7	62	13	10	10	12	13
Sr	406	490	342	446	475	475	464	443
Zr	97	46	180	69	57	60	59	69
Y	27	16	30	24	18	19	19	22
Nb	3.9	2	5.6	3	3.4	1	1.4	2
Ga	17	21	15	19	16	19	20	18
Cu	89	152	80	214	139	164	155	171
Zn	83	86	69	91	85	85	89	87
Pb	1	2	8	5	0	1	2	1
La	6	0	13	8	5	6	13	11
Ce	16	14	22	26	24	14	20	17
Co								
Th	2	3	4	4	2	1	5	4

San Miguel

SAMPLE	FL-48	FL-49	FL-50	FL-53	FL-55	FL-57	FL-59	FL-61
Jcode	8	8	8	8	8	8	8	8
Kcode	5	5	5	5	5	5	5	5
Lcode	3	3	3	3	3	3	3	3
Volcname	San Miguel	San Miguel	San Miguel	San Miguel	San Miguel	San Miguel	San Miguel	San Miguel
lat								
long								
Lava	lava	lava	lava	lava	lava	lava	lava	lava
K/Ar (Ma)								
Ar-Ar (Ka)								
C14 (ybp)								
author	Chesner	Chesner	Chesner	Chesner	Chesner	Chesner	Chesner	Chesner
SiO[2]	51.97	55.66	51.33	52.4	55.56	52.38	55.75	54.31
Al[2]O[3]	19.37	17.03	18.9	19.46	19.62	20.81	19.87	16.52
TiO[2]	1.037	1.036	0.9	0.956	0.852	0.846	0.834	1.133
Fe[2]O[3]	9.41	9.56	9.48	9.06	7.77	8.21	7.02	10.77
FeO								
MnO	0.183	0.197	0.177	0.169	0.206	0.15	0.154	0.213
CaO	10.18	7.86	10.43	10.39	8.57	10.44	8.78	8.3
MgO	3.93	3.67	5.3	3.8	2.4	3.44	2.53	3.95
K[2]O	0.8	1.02	0.78	0.95	0.77	0.78	1.21	1
Na[2]O	2.9	3.55	2.58	2.78	3.75	2.94	3.44	3.41
P[2]O[5]	0.204	0.236	0.177	0.192	0.209	0.172	0.227	0.212
Ni	6	0	17	7	1	4	3	6
Cr	20	12	21	19	10	13	9	20
Sc	42	37	35	28	27	36	28	45
V	315	266	271	280	186	246	169	315
Ba	519	608	484	510	533	470	663	611
Rb	11	15	12	14	9	10	20	17
Sr	476	455	454	479	541	505	466	435
Zr	72	82	68	74	58	65	95	81
Y	24	28	23	24	25	20	26	29
Nb	2.4	2.3	2.2	2.1	1.9	2.3	2.7	2.8
Ga	18	16	20	17	19	21	19	19
Cu	151	198	167	198	148	168	168	248
Zn	94	101	82	83	87	82	81	99
Pb	1	3	2	2	1	0	4	3
La	2	11	0	11	13	2	20	5
Ce	6	15	18	16	20	12	29	23
Co								
Th	0	2	1	0	0	2	4	3

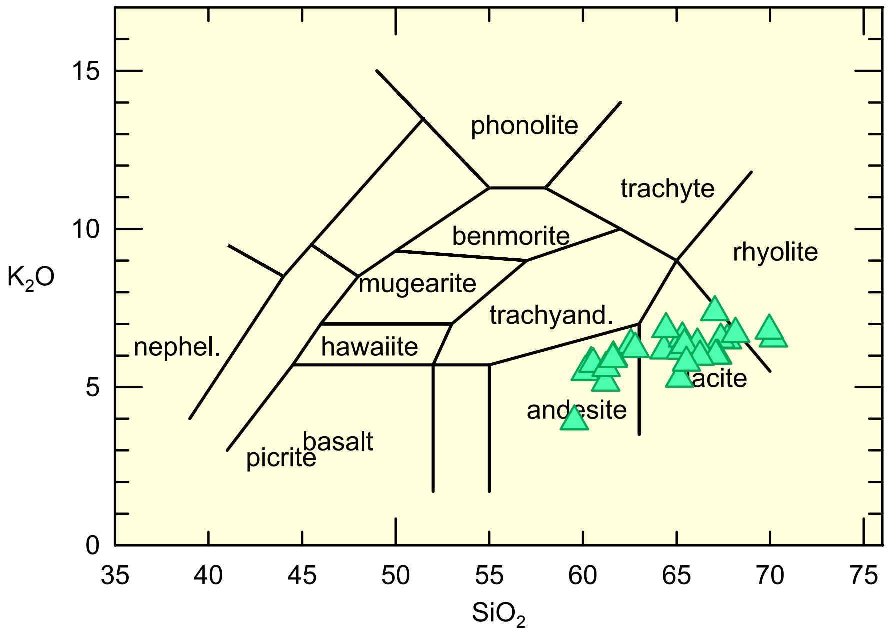
San Miguel

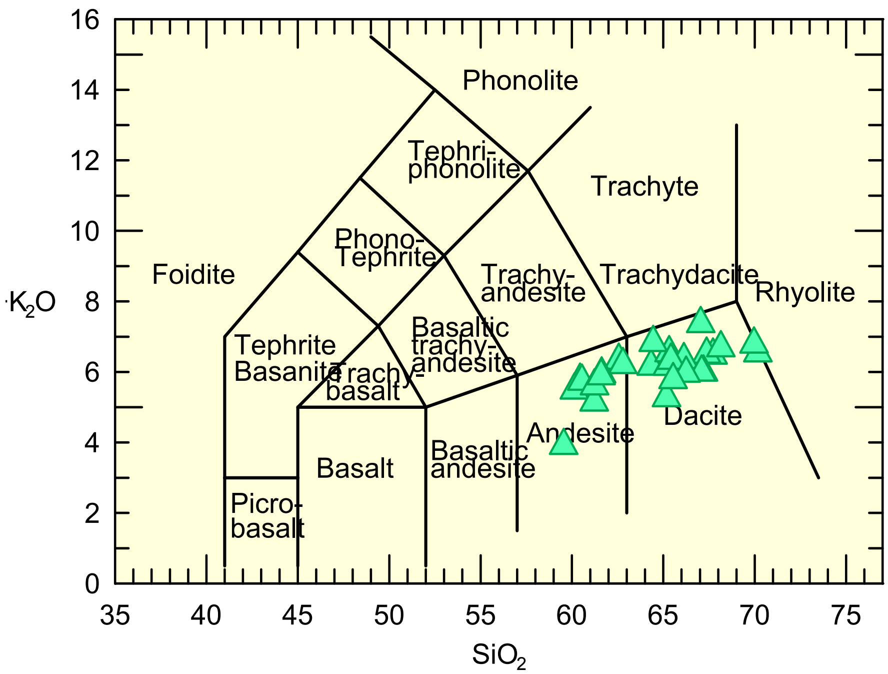
SAMPLE	FL-63	FL-64	FL-69	FL-70	FL-73	FL-76	FL-77	FL-78
Jcode	8	8	8	8	8	8	8	8
Kcode	5	5	5	5	5	5	5	5
Lcode	3	3	3	3	3	3	3	3
Volcname	San Miguel	San Miguel	San Miguel	San Miguel	San Miguel	San Miguel	San Miguel	San Miguel
lat								
long								
Lava	lava	lava	lava	lava	lava	lava	lava	lava
K/Ar (Ma)								
Ar-Ar (Ka)								
C14 (ybp)								
author	Chesner	Chesner	Chesner	Chesner	Chesner	Chesner	Chesner	Chesner
SiO[2]	53.3	54.11	50.42	51.87	51.91	51.1	51.79	52.48
Al[2]O[3]	16.97	20.48	19.46	19.61	19.14	18.27	18.74	18.85
TiO[2]	1.163	0.796	0.918	0.916	1.035	1.005	1.062	0.968
Fe[2]O[3]	10.4	7.79	9.78	8.95	9.63	10.27	9.9	9.25
FeO								
MnO	0.206	0.158	0.177	0.17	0.177	0.193	0.183	0.173
CaO	9.01	9.35	10.97	10.66	10.24	10.02	10.4	10.31
MgO	4.41	2.85	4.79	4.13	4.08	5.41	4.24	4.27
K[2]O	0.92	0.93	0.66	0.71	0.86	0.78	0.83	0.9
Na[2]O	3.14	3.34	2.61	2.78	2.98	2.75	2.9	2.71
P[2]O[5]	0.225	0.213	0.158	0.174	0.21	0.2	0.208	0.207
Ni	5	4	7	6	5	14	5	11
Cr	25	8	27	30	21	24	28	21
Sc	45	28	32	35	36	39	32	30
V	377	187	313	300	310	315	322	273
Ba	551	593	405	432	501	487	506	522
Rb	12	14	11	10	15	12	15	17
Sr	421	520	491	472	491	448	478	470
Zr	76	77	56	62	74	70	73	74
Y	26	24	20	22	24	24	24	24
Nb	2.4	1.8	1.5	1.3	3.2	2.8	2.8	2.3
Ga	19	20	17	18	18	21	21	20
Cu	224	129	185	178	230	212	225	182
Zn	100	79	84	84	88	96	92	86
Pb	1	3	0	0	3	2	2	4
La	11	9	7	4	6	10	0	8
Ce	14	18	13	17	10	23	28	12
Co								
Th	0	0	0	0	2	2	2	0

San Miguel

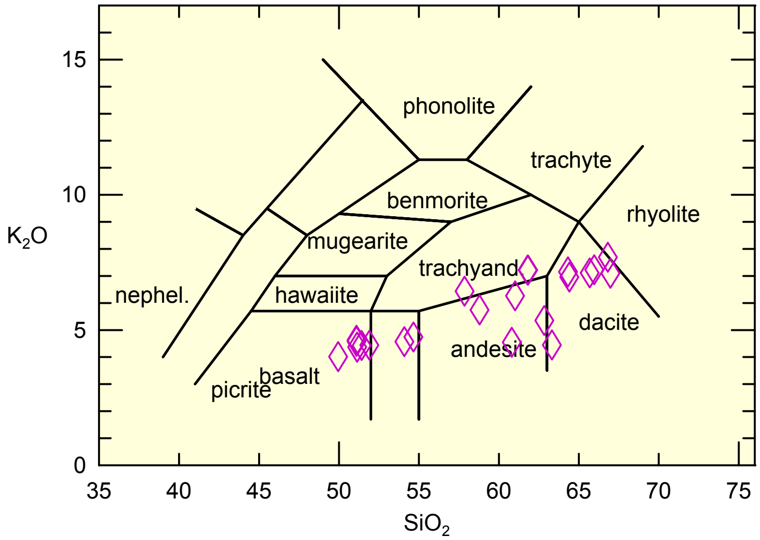
SAMPLE	FL-79	FL-80	FL-81	FL-82	PL-67
Jcode	8	8	8	8	8
Kcode	5	5	5	5	4
Lcode	3	3	3	3	3
Volcname	San Miguel	San Miguel	San Miguel	San Miguel	Pacayal
lat					
long					
Lava	lava	lava	lava	lava	lava
K/Ar (Ma)					
Ar-Ar (Ka)					
C14 (ybp)					
author	Chesner	Chesner	Chesner	Chesner	Chesner
SiO[2]	51.13	51.78	51.17	50.61	63.1
Al[2]O[3]	18.12	18.79	19.33	19.56	16
TiO[2]	1.017	1.045	0.986	0.908	0.788
Fe[2]O[3]	10.48	9.88	9.72	9.68	5.49
FeO					
MnO	0.193	0.181	0.178	0.178	0.164
CaO	9.96	10.47	10.48	11	4.48
MgO	5.42	4.23	4.16	5	1.44
K[2]O	0.79	0.83	0.76	0.65	2.1
Na[2]O	2.73	2.84	2.76	2.61	4.58
P[2]O[5]	0.203	0.207	0.185	0.156	0.323
Ni	14	7	8	10	3
Cr	21	26	23	32	5
Sc	41	42	31	36	19
V	317	316	306	305	51
Ba	506	497	460	395	1083
Rb	13	15	13	10	35
Sr	446	482	485	488	390
Zr	73	74	66	56	145
Y	25	24	23	20	40
Nb	2.8	2.1	2.8	2.5	3.6
Ga	16	20	19	14	20
Cu	202	224	180	193	30
Zn	98	88	85	82	93
Pb	2	0	1	1	4
La	1	7	0	8	16
Ce	15	19	11	22	35
Co					
Th	0	0	2	0	2

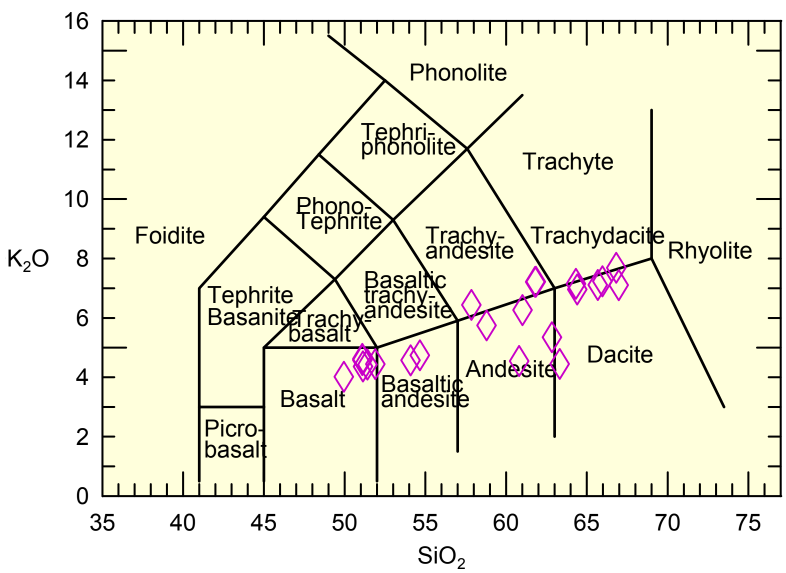
PPENDIX E: CHEMICAL PLOTS OF PACAYAL, TECAPA AND USULUTAN ROCKS



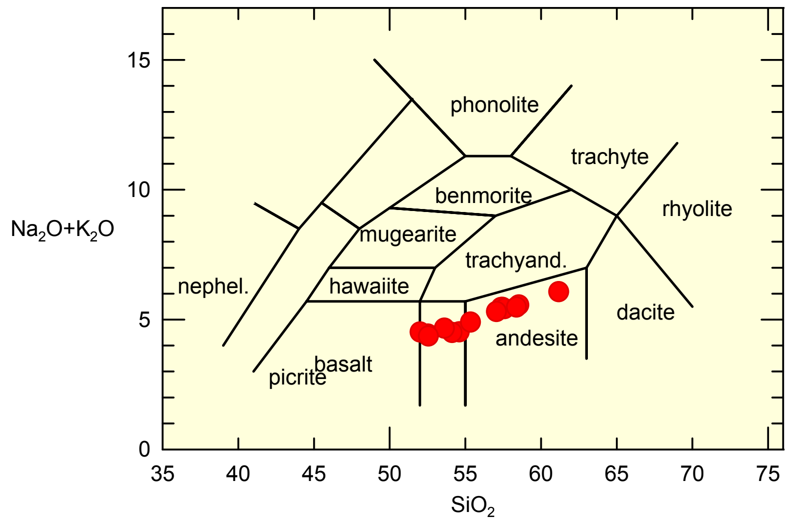


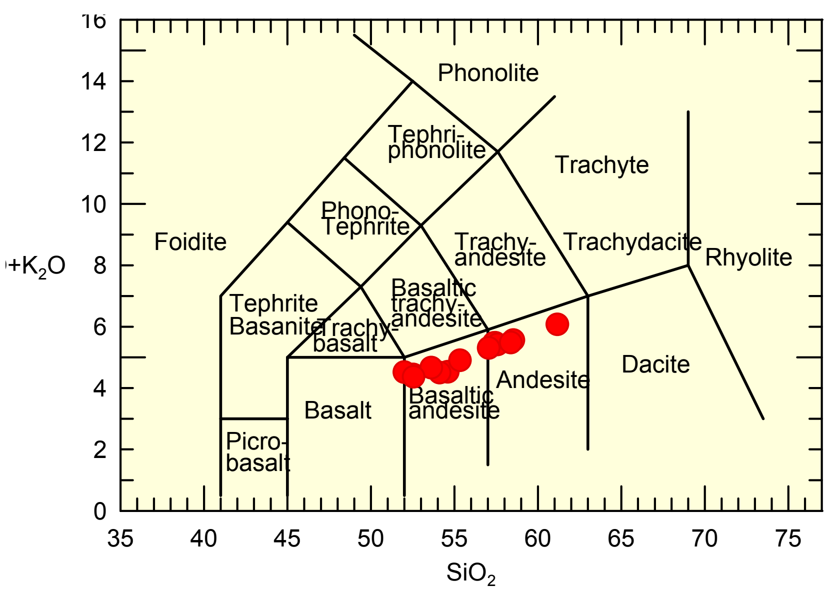
Total alkali–silica plot of **Pacayal rocks** (GENZL, 1995, Carr, 1981). Field of rock names by Cox, et al., (1979) and Lebas, et al., (1986) respectively.



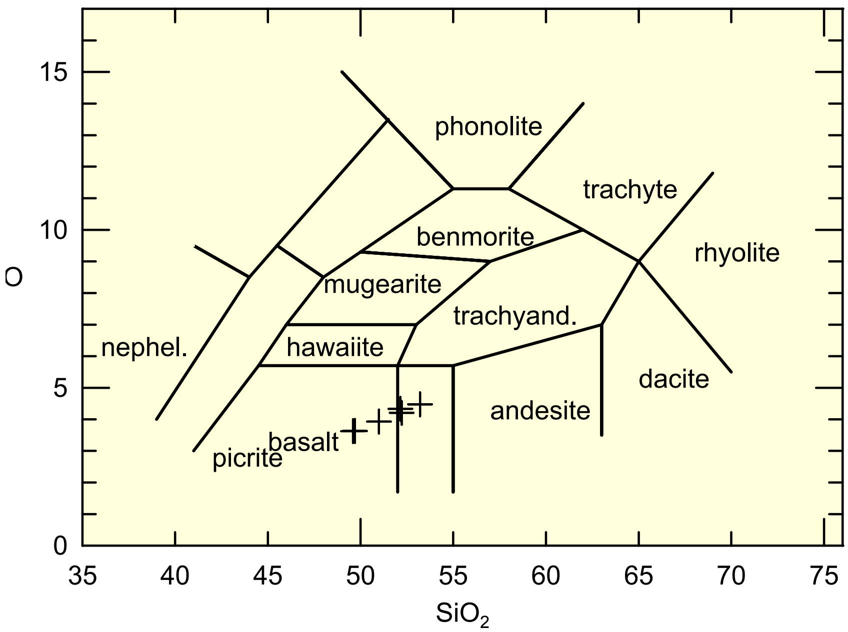


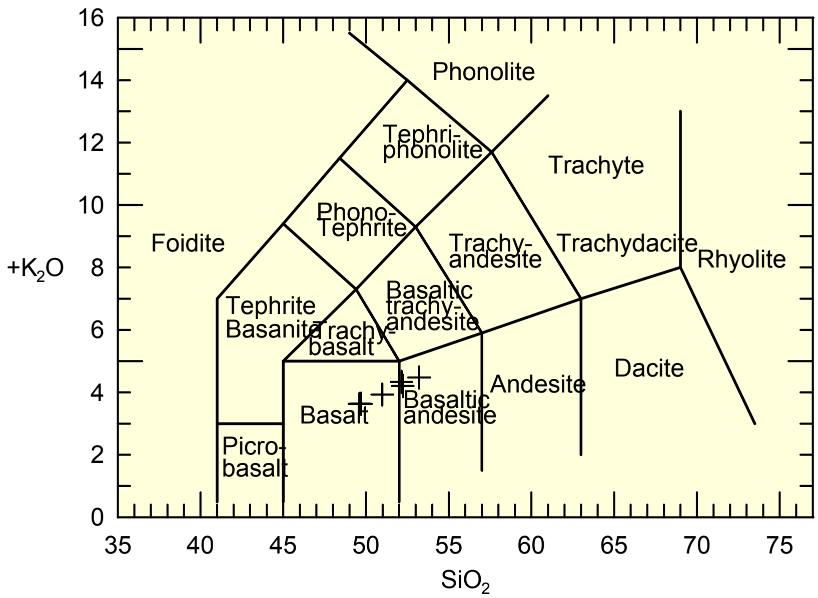
Plot of **Berlin Volcanic Rocks**, ranging from basalt to dacites [Carr, 1981 and GENZL, 1995].





Plot of **Tecapa Volcanic Rocks**, ranging from basaltic to andesites [Carr, 1981 and GENZL, 1995].





Plot of **Usulután Volcanic Rocks**. They are basaltic andesites [GENZL, 1995 and Carr, 1981].

APPENDIX F: WIND DATA, FROM NOAA [COURTESY OF DR. JOHN EWERT, USGS, 2003]

San Miguel Winds 1997-2002

January

Level	Elevation (m)	U-component (m/s)	V-component (m/s)	Velocity (m/s)	Azimuth
1	107	-3.79	-2.94	4.8	52
2	793	-6.88	-3.97	7.9	60
3	1523	-7.74	-3.10	8.3	68
4	3153	-5.86	-0.56	5.9	85
5	5867	-1.09	0.87	1.4	129
6	7579	3.31	1.22	3.5	250
7	9669	8.61	4.15	9.6	244
8	10917	10.76	6.22	12.4	240
9	12417	12.46	7.38	14.5	239
10	14217	11.79	5.73	13.1	244
11	16550	3.12	2.25	3.8	234
12	20533	-2.75	0.23	2.8	95
13	26275	-4.10	0.23	4.1	93

February

Level	Elevation (m)	U-component (m/s)	V-component (m/s)	Velocity (m/s)	Azimuth
1	105	-3.47	-1.99	4.0	60
2	791	-6.61	-3.12	7.3	65
3	1522	-7.09	-2.62	7.6	70
4	3151	-5.00	-0.57	5.0	84
5	5868	-1.78	0.36	1.8	101
6	7583	2.18	0.99	2.4	246
7	9672	7.85	4.43	9.0	241
8	10917	10.26	6.65	12.2	237
9	12408	12.63	7.82	14.9	238
10	14200	12.52	6.42	14.1	243
11	16567	4.52	2.50	5.2	241
12	20567	-1.84	0.29	1.9	99
13	26283	-1.83	0.62	1.9	109

March

Level	Elevation (m)	U-component (m/s)	V-component (m/s)	Velocity (m/s)	Azimuth
1	98	-2.49	-1.07	2.7	67
2	785	-5.54	-1.82	5.8	72
3	1517	-6.01	-1.86	6.3	73
4	3150	-3.95	-1.22	4.1	73
5	5871	-1.77	-0.40	1.8	77
6	7588	2.22	-0.46	2.3	282
7	9682	8.73	1.21	8.8	262
8	10925	11.04	4.35	11.9	249
9	12417	12.19	6.47	13.8	242
10	14217	11.42	4.26	12.2	250
11	16592	3.00	1.36	3.3	246
12	20567	-1.20	0.46	1.3	111
13	26308	-4.41	0.11	4.4	91

April

Level	Elevation (m)	U-component (m/s)	V-component (m/s)	Velocity (m/s)	Azimuth
1	96	-1.48	-0.26	1.5	80
2	785	-4.41	-1.11	4.5	76
3	1519	-5.14	-1.66	5.4	72
4	3155	-4.81	-1.65	5.1	71
5	5878	-3.51	-0.23	3.5	86
6	7598	-1.62	-1.07	1.9	57
7	9698	3.24	-0.05	3.2	271
8	10925	5.90	2.02	6.2	251
9	12417	7.34	4.42	8.6	239
10	14217	6.53	3.49	7.4	242
11	16608	-0.05	0.66	0.7	176
12	20592	-2.83	0.09	2.8	92
13	26392	-7.41	0.27	7.4	92

May

Level	Elevation (m)	U-component (m/s)	V-component (m/s)	Velocity (m/s)	Azimuth
1	92	-1.49	-0.28	1.5	79
2	781	-3.68	-0.66	3.7	80
3	1518	-4.68	-0.65	4.7	82
4	3157	-4.22	-0.55	4.3	83
5	5881	-2.39	0.68	2.5	106
6	7599	-1.32	0.57	1.4	113
7	9703	1.57	1.00	1.9	238
8	10983	3.54	1.77	4.0	243
9	12442	5.26	2.50	5.8	245
10	14242	5.93	1.39	6.1	257
11	16608	0.28	-0.88	0.9	342
12	20625	-5.85	-0.08	5.8	89
13	26417	-13.20	0.46	13.2	92

June

Level	Elevation (m)	U-component (m/s)	V-component (m/s)	Velocity (m/s)	Azimuth
1	95	-1.68	-0.52	1.8	73
2	784	-4.02	-0.91	4.1	77
3	1518	-5.78	-0.29	5.8	87
4	3158	-5.97	0.95	6.0	99
5	5877	-4.94	1.16	5.1	103
6	7595	-3.85	0.79	3.9	102
7	9698	-2.91	-0.12	2.9	88
8	10975	-2.36	-0.90	2.5	69
9	12433	-1.78	-1.65	2.4	47
10	14233	-1.89	-2.68	3.3	35
11	16600	-4.45	-2.59	5.1	60
12	20692	-10.82	0.10	10.8	91
13	26475	-18.34	0.25	18.3	91

July

Level	Elevation (m)	U-component (m/s)	V-component (m/s)	Velocity (m/s)	Azimuth
1	100	-3.07	-1.51	3.4	64
2	789	-6.40	-2.32	6.8	70
3	1522	-8.71	-1.58	8.9	80
4	3161	-8.78	0.37	8.8	92
5	5877	-6.72	0.60	6.7	95
6	7589	-4.61	0.29	4.6	94
7	9690	-2.69	-0.22	2.7	85
8	10958	-1.91	-0.67	2.0	71
9	12417	-0.97	-0.90	1.3	47
10	14208	-1.41	-1.13	1.8	51
11	16583	-5.73	-1.16	5.8	79
12	20708	-14.11	-0.15	14.1	89
13	26517	-21.75	0.42	21.8	91

August

Level	Elevation (m)	U-component (m/s)	V-component (m/s)	Velocity (m/s)	Azimuth
1	96	-2.47	-1.12	2.7	66
2	786	-5.67	-1.95	6.0	71
3	1520	-8.24	-1.59	8.4	79
4	3160	-8.63	0.38	8.6	93
5	5876	-7.03	0.63	7.1	95
6	7591	-5.27	0.21	5.3	92
7	9695	-3.90	-0.67	4.0	80
8	10983	-3.37	-1.17	3.6	71
9	12425	-2.87	-1.37	3.2	64
10	14217	-4.21	-1.21	4.4	74
11	16592	-7.64	-1.00	7.7	83
12	20708	-14.66	-0.01	14.7	90
13	26483	-21.68	0.45	21.7	91

September

Level	Elevation (m)	U-component (m/s)	V-component (m/s)	Velocity (m/s)	Azimuth
1	90	0.54	0.51	0.7	227
2	778	-0.26	0.46	0.5	151
3	1511	-1.38	0.20	1.4	98
4	3150	-2.81	0.52	2.9	100
5	5866	-3.94	0.64	4.0	99
6	7585	-4.38	-0.16	4.4	88
7	9688	-4.87	-1.65	5.1	71
8	10950	-5.29	-2.76	6.0	62
9	12433	-6.06	-3.77	7.1	58
10	14225	-8.15	-4.86	9.5	59
11	16600	-8.83	-3.11	9.4	71
12	20683	-12.28	-0.20	12.3	89
13	26450	-18.85	0.59	18.9	92

October Level	Elevation (m)	U-component (m/s)	V-component (m/s)	Velocity (m/s)	Azimuth
1	90	-0.82	-1.42	1.6	30
2	778	-2.57	-2.11	3.3	51
3	1511	-4.09	-1.74	4.4	67
4	3149	-4.16	-0.45	4.2	84
5	5868	-4.19	-0.38	4.2	85
6	7587	-4.03	-0.69	4.1	80
7	9693	-3.55	-0.85	3.6	76
8	10975	-3.95	-0.61	4.0	81
9	12433	-4.70	-0.46	4.7	84
10	14225	-5.65	-0.93	5.7	81
11	16583	-4.30	-1.77	4.7	68
12	20642	-8.17	0.04	8.2	90
13	26392	-14.69	0.63	14.7	92

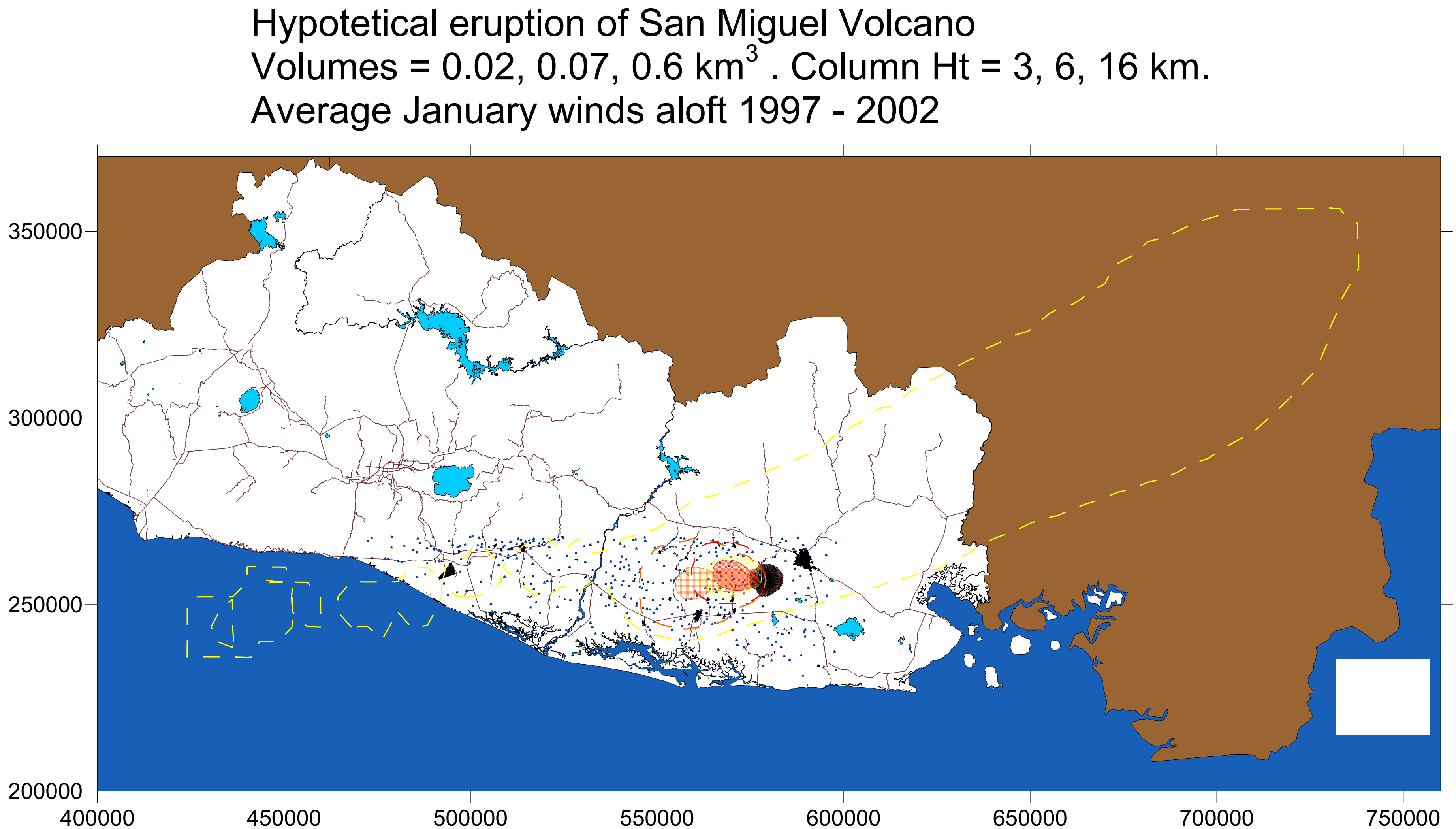
November

Level	Elevation (m)	U-component (m/s)	V-component (m/s)	Velocity (m/s)	Azimuth
1	96	-2.01	-2.74	3.4	36
2	783	-4.48	-3.87	5.9	49
3	1515	-6.07	-3.15	6.8	63
4	3150	-5.46	-1.02	5.6	79
5	5868	-4.57	0.46	4.6	96
6	7588	-3.32	0.72	3.4	102
7	9690	-1.20	1.99	2.3	149
8	10975	-0.42	3.51	3.5	173
9	12408	-0.12	5.39	5.4	179
10	14208	0.31	5.44	5.5	183
11	16583	-0.35	1.60	1.6	167
12	20583	-5.20	-0.24	5.2	87
13	26342	-9.53	0.39	9.5	92

December

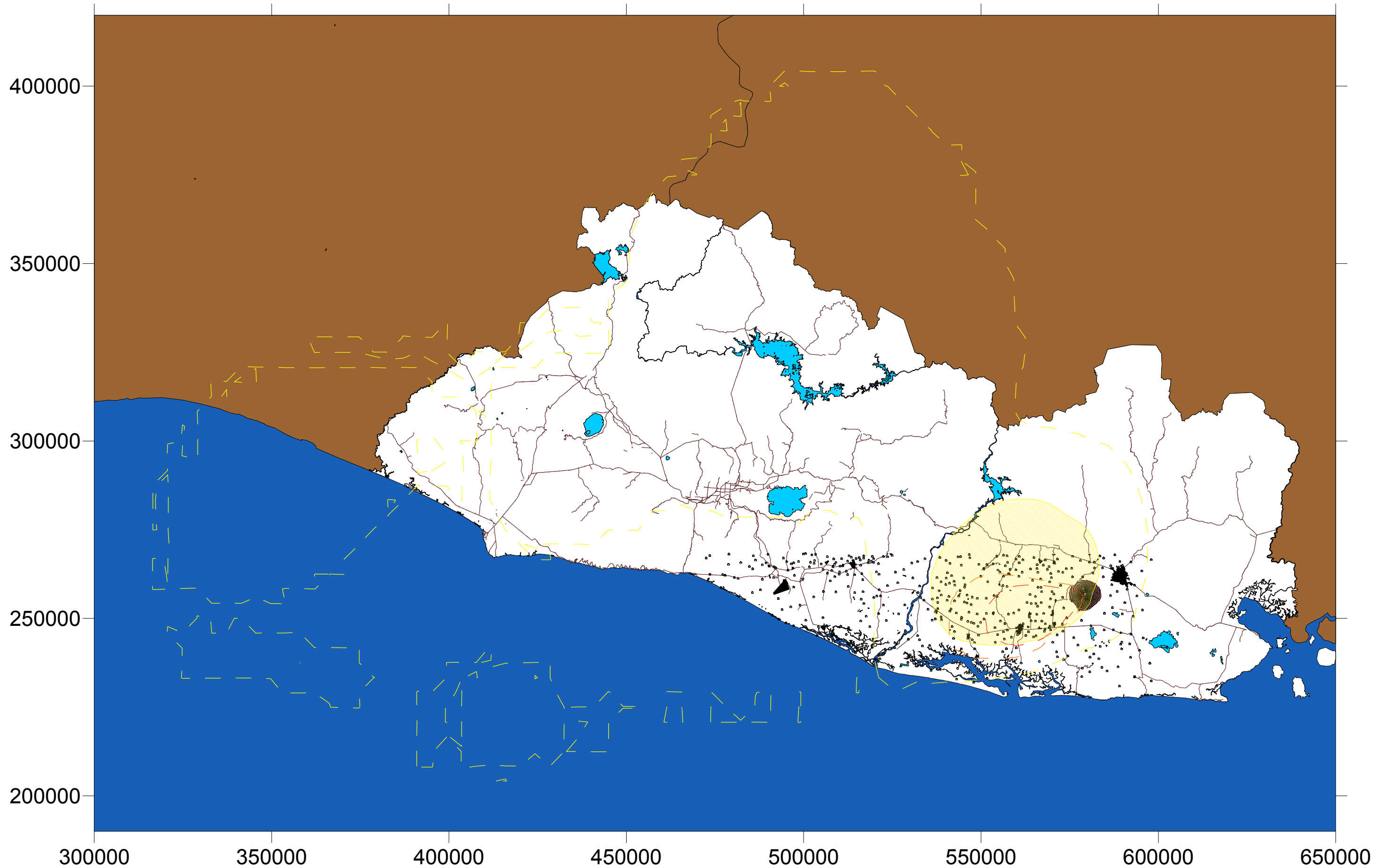
Level	Elevation (m)	U-component (m/s)	V-component (m/s)	Velocity (m/s)	Azimuth
1	101	-3.11	-3.61	4.8	41
2	788	-6.01	-4.93	7.8	51
3	1518	-7.28	-3.77	8.2	63
4	3153	-5.51	-1.10	5.6	79
5	5872	-2.84	0.80	2.9	106
6	7587	-0.39	2.04	2.1	169
7	9683	2.33	4.51	5.1	207
8	10942	3.09	6.57	7.3	205
9	12425	3.46	8.62	9.3	202
10	14200	5.32	7.70	9.4	215
11	16567	2.62	3.99	4.8	213
12	20558	-3.88	0.13	3.9	92
13	26275	-5.22	0.63	5.3	97

APPENDIX G: COMPUTING SIMULATIONS OF ASHFALL



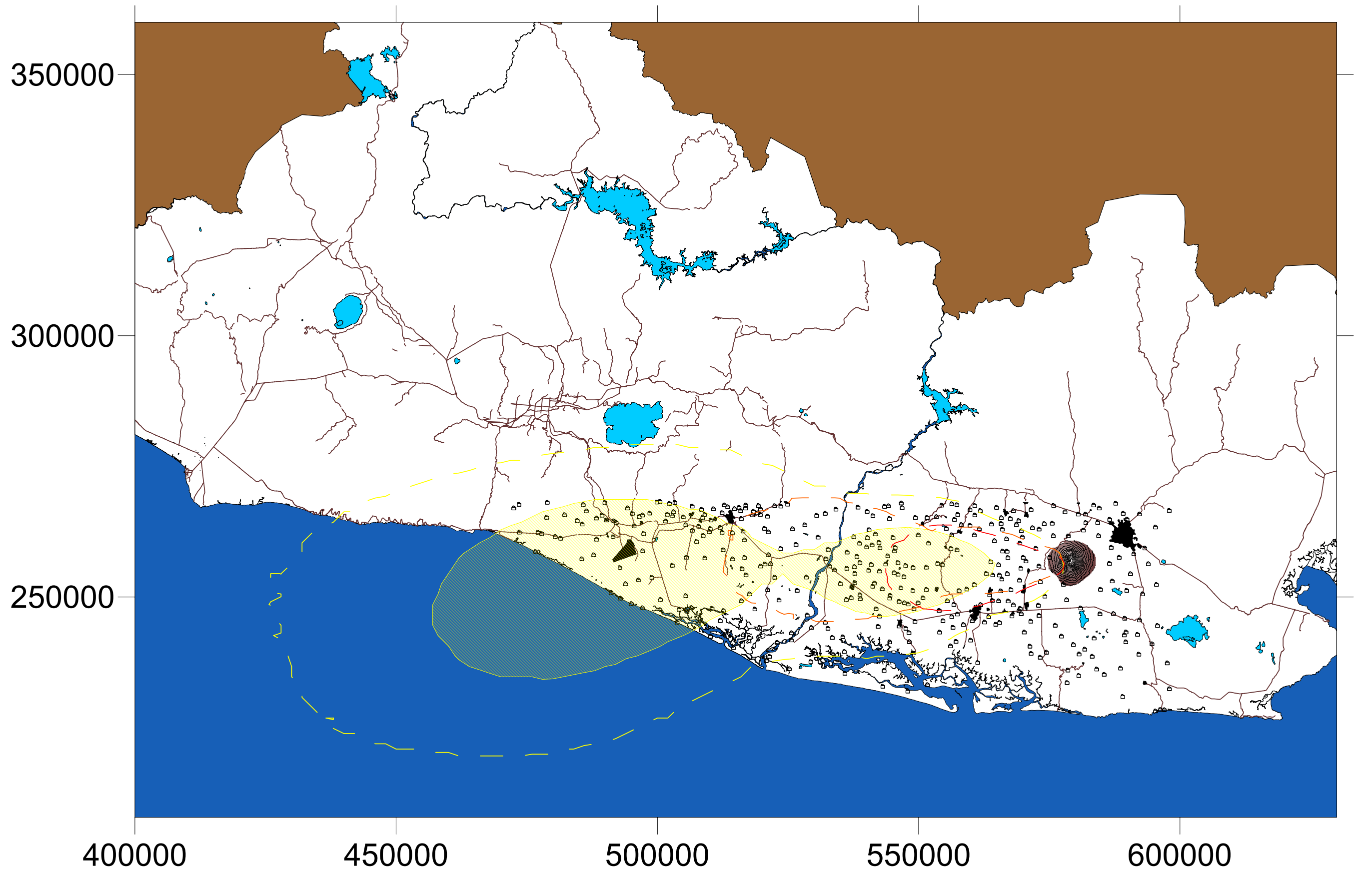
Ahfall thickness: solid colors 40 mm [dry season], dash lines 5 mm of ashfall down wind. From Delgado, UNAM. 2003.

# Hypotetical eruption of San Miguel Volcano
Volumes = 0.02, 0.07, 0.6 km^3 . Column Ht = 3, 6, 16 km.
Average April winds aloft 1997 - 2002



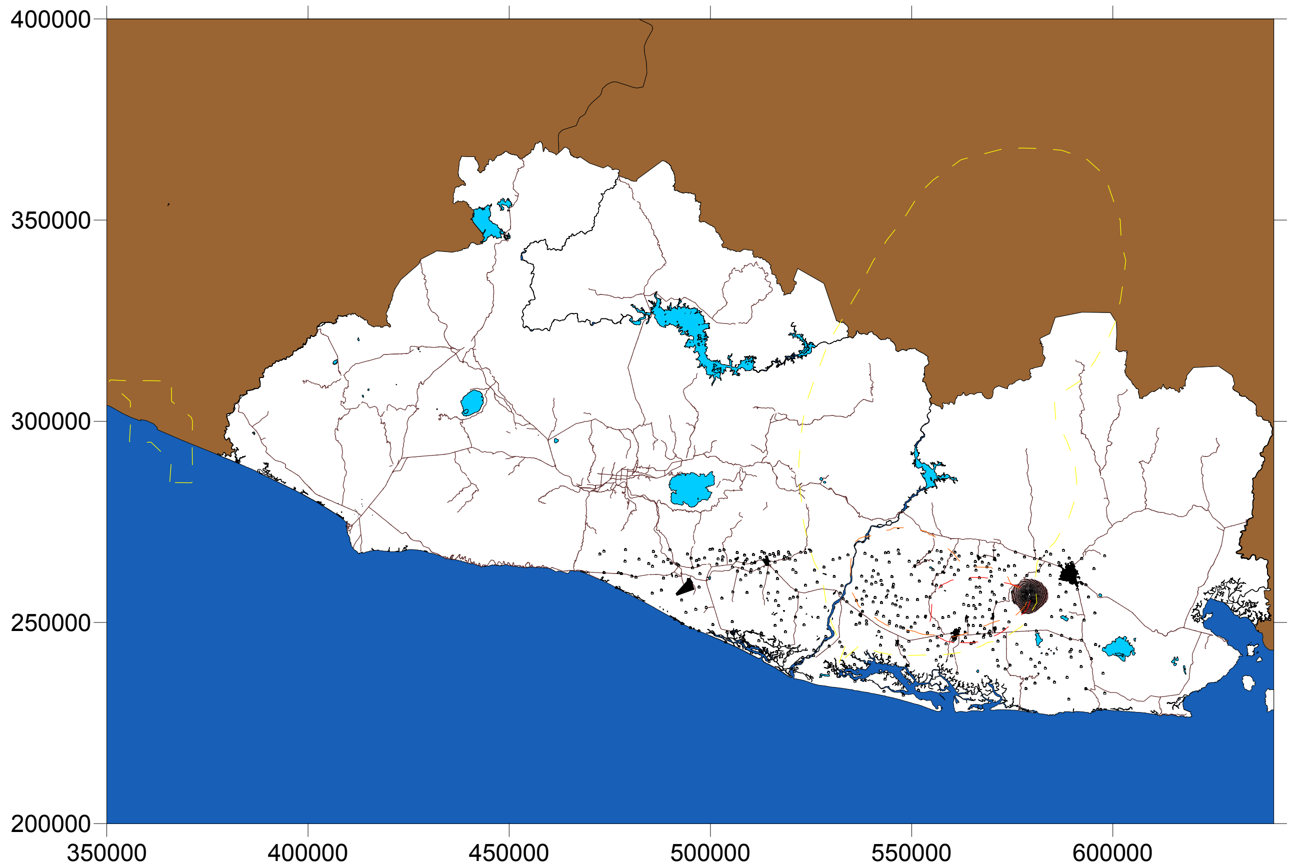
Ahfall thickness: solid colors 40 mm [transitional season], dash lines 5 mm of ashfall down wind.
From Delgado, UNAM. 2003.

Hypotetical eruption of San Miguel Volcano
Volumes = 0.02, 0.07, 0.6 km^3 . Column Ht = 3, 6, 16 km.
Average August winds aloft 1997 - 2002



Ahfall thickness: solid colors 40 mm [rain season], dash lines 5 mm of ashfall down wind. From Delgado, UNAM. 2003.

Hypotetical eruption of San Miguel Volcano
Volumes = 0.02, 0.07, 0.6 km^3 . Column Ht = 3, 6, 16 km.
Average December winds aloft 1997 - 2002



Ashfall thickness: solid colors 40 mm [transitional season], dash lines 5 mm of ashfall down wind.
From Delgado, UNAM. 2003.

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