Margins Volcano Field trip to Arenal and Guanacaste June 22-26, 2007

Study this picture of Arenal well. Note that it does indeed have a summit. Sometimes the peak is actually clear of clouds!

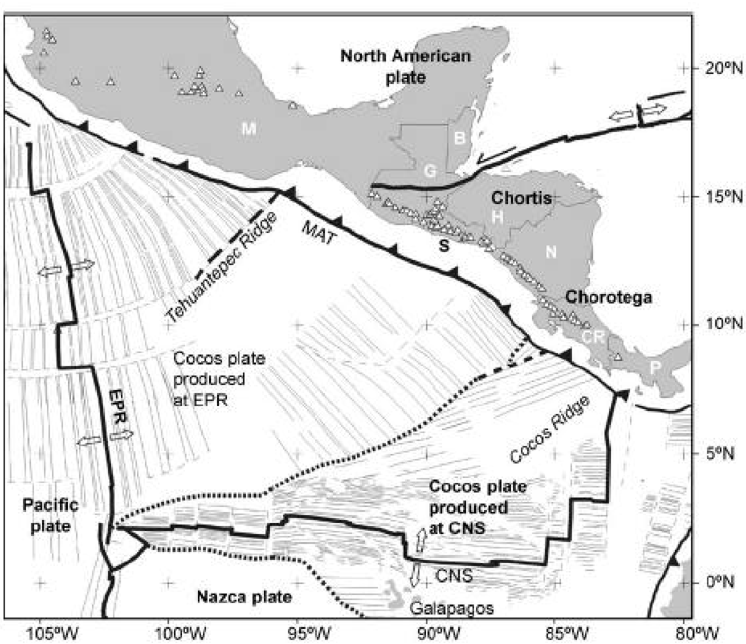

Plate Tectonic setting of Central America showing plates, Cocos crust produced at East Pacific Rise (EPR) Cocos-Nazca spreading center (CNS), triple junction trace (heavy dots), and Middle America Trench (MAT). The countries are labeled as follows: Mexico (M), Belize (B), Guatemala (G), El Salvador (S), Honduras (H), Nicaragua (N), Costa Rica (CR) and Panama´ (P). (from Vogel et al 2004 and Rogers et al., 2002)

Margins 2007 Field trip to active volcanoes

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You may start the field trip by downloading all the files and folders in the MarginsVolcFieldTrip folder at: http://rockbox.rutgers.edu/~carr/MarginsVolcFieldTrip/
The list of publications is unbalanced. The Regional Geochemistry folder is overweighted with the work of the field trip leaders. The folders on the volcanoes are heavily skewed because there is a huge mass of literature on Arenal. Erupting volcanoes draw a lot of attention and most Arenal publications begin in the year 1968 with the first recorded eruption of Arenal! Active volcanoes are grey but the field trip leaders have all worked on green volcanoes, those covered with jungle, and spent difficult hours in the red mud (what the volcanoes become with tropical weathering). Red mud makes scary roads, which often require tire chains and/or excellent drivers. G. Alvarado has spent much time in the white, the tephra aprons that blanket the approaches to the volcanoes. For example, your flight will touch down on the Tiribi Tuff, a pyroclastic flow about 330 Ka old with a volume of roughly 35 $km^{3.}$ This is the most recent large tephra in Costa Rica and is the creator of the fertile (and flat) Valle Central, which hosts most of Costa Rica's population.

The field trip will cover green, grey and white volcanic settings. We decided to put more enjoyment in the trip and sacrifice the difficulties caused by the red mud that results from deep tropical weathering.

The trip will be hot (near Arenal and in Guanacaste and cold because the La Condessa Hotel can be quite chilly because it is at about 1700 m asl.. It sits on one of the most recent flows of Barva volcano, the Los Angeles flow) Therefore, during a meeting break you can get a head start on the field trip by examining one of the lava outcrops on/near the hotel grounds. If you must sample it, please find an ugly spot, preferably out of the Hotel grounds. A moderate length walk takes you up to one of the cinder cones that produced the flow, which is now a local park (bring rain gear!). You go up the road from the hotel until the pavement ends and the park is on your right hand side, about 2 km from the hotel. The flow may well be the same as the B7 sample in the GAGeochem file at http://www.rci.rutgers.edu/~carr/ If so, then it is a TiO_2-rich (1.57 wt %) basalt.

The post meeting field trip will be wet. Rain is a given, just expect it, but, more usefully, both hotels have pools. On the first full day we do not plan to bathe at a hot spring (the Tabacon Resort is too dangerous), but on the next two days we plan breaks at hot springs, so have bathing suits and a towel near at hand.

Overview

Travel Overview:

Refer to the sketch map below: the Margins meeting is on the south slope of Barva volcano, approximately at the center of the baseline of the red triangle marking Barva. After the meeting, I believe we will travel north through the divide between Poás and Barva (the bus driver will decide). When we reach the Caribbean coastal plane, we will turn west toward Fortuna, which is located immediately east of Arenal. Once off the volcanoes, the geology is mostly recent alluvium. On day 1 we will go first to the east side of Arenal, then circle counter-clockwise to the west side. On day 2 we travel from Fortuna to Liberia (located near the 'n' in Rincón). We travel along the north side of Arenal, cross the dam making the Arenal reservoir/lake, then follow the north shore of the lake. From the dam to where we leave the lake shore, the geology is Tertiary volcanics with a thin cap of Arenal ash/tephra deposits. The Tertiary rocks are part of the Aguacate group and their age is poorly known but likely late Miocene, early Pliocene. We stop at Cerro Chopo, located west of the west end of the lake and near the western edge of the Monteverde volcanic front (yellow). After Cerro Chopo we drive west through the city ofCañas where we join the Panamerican highway to drive NW to Liberia. We detour to drive into Miravalles volcano. On the third day we examine a recent hot lahar on the north flank of Rincón (driving through the pass between Rincón and Orosí-Cacao). We will also examine the Monteverde age domes at the southwest slope of Rincón.

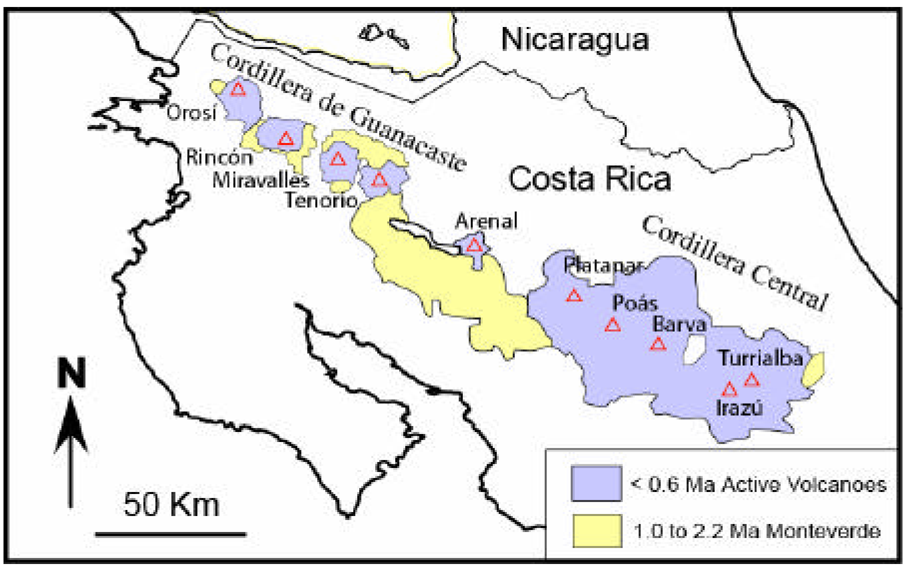


Figure 1. Locations of the two most recent volcanic fronts in Costa Rica; the active volcanic front and the Monteverde volcanic front. These volcnic massifs coincide in the Cordillera de Guanacaste and in the Cordillera Central. However, between the two Cordilleras the active front has only one small volcanic center (Arenal-Chato-Los Perdidos) whereas the Monteverde front consists of a massive range centered about 15 km trenchward of Arenal. This shift in the volcanic front coincided with a lull in volcanic activity between 1.0 Ma and 0.6 Ma.

Margins motivation

The NSF Margins program seeks to coordinate efforts to better solve problems. One motivation for the selection of Nicaragua and Costa Rica for a Margins focus area was the pronounced geochemical change along the strike of the Central American volcanic belt. Ba/La is a good representative of the geochemical change because the relative ease of measuring Ba and La has allowed a large data set. The current best quality data for Ba/La in Central America are shown in Figure 2.

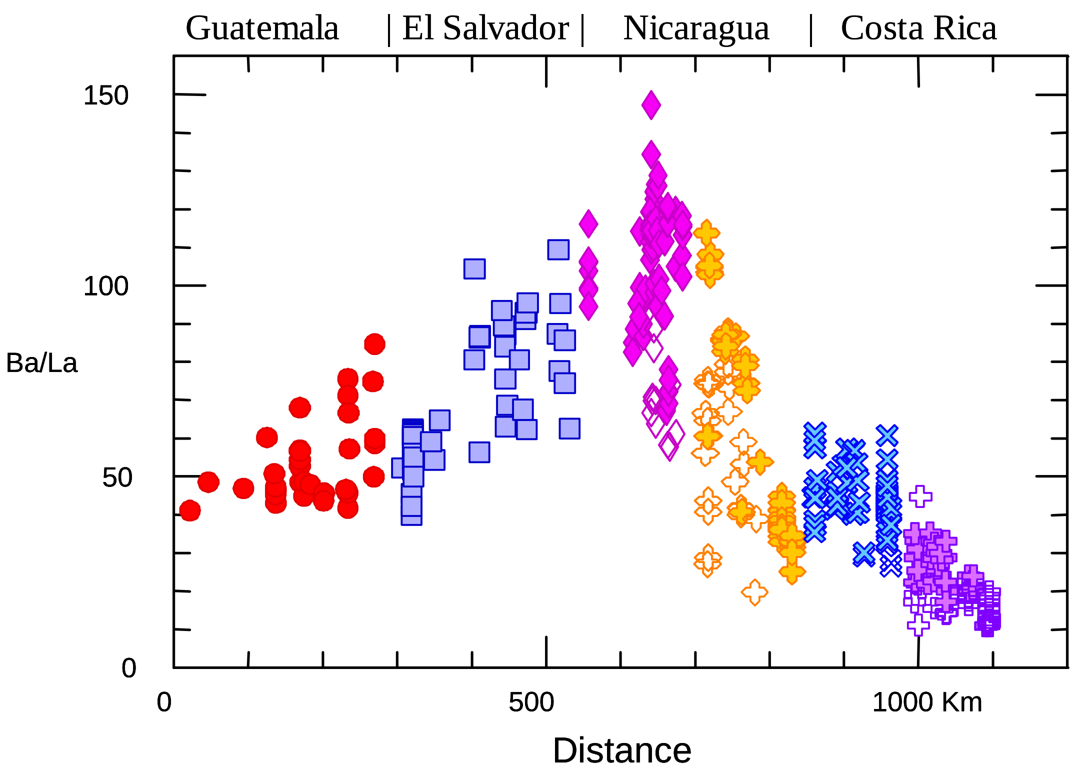


Figure 2. Regional geochemical variation along the Central American volcanic front (VF). Symbols change at breaks in the VF, most of which are right-steps between discrete volcanic lines. (see Figure 4)
The open symbols are HFS-rich samples that have markedly smaller HFS depletions that typical VF volcanics (filled symbols).

The field trip begins in the purple crosses at Barva, whose samples are centered at 1037 km. Arenal is marked with blue crosses at 958 km. Cerro Chopo is at 939 km, Miravalles at 904 km and Rincón de la Vieja at 882 km. Therefore, Arenal and the Cordillera de Guanacaste (Orosí, Rincón de la Vieja, Miravalles and Tenorio) are part of the southeastward decrease in Ba/La from its peak around 640 km to its minimum near 1100 km. However, within the Guanacaste segment by itself, there is no gradient in Ba/La.

In both the Cordillera Central segment (purple crosses) and the Cordillera de Guanacaste segment (blue Xs), there is little geochemical variation among the volcanoes (See Figure 3). There is also little variation within the western Nicaragua segment (magenta diamonds). There is very large change within the eastern Nicaragua segment (yellow crosses), but otherwise the Ba/La variation is stepwise, like the volcanic front (See Figure 4)

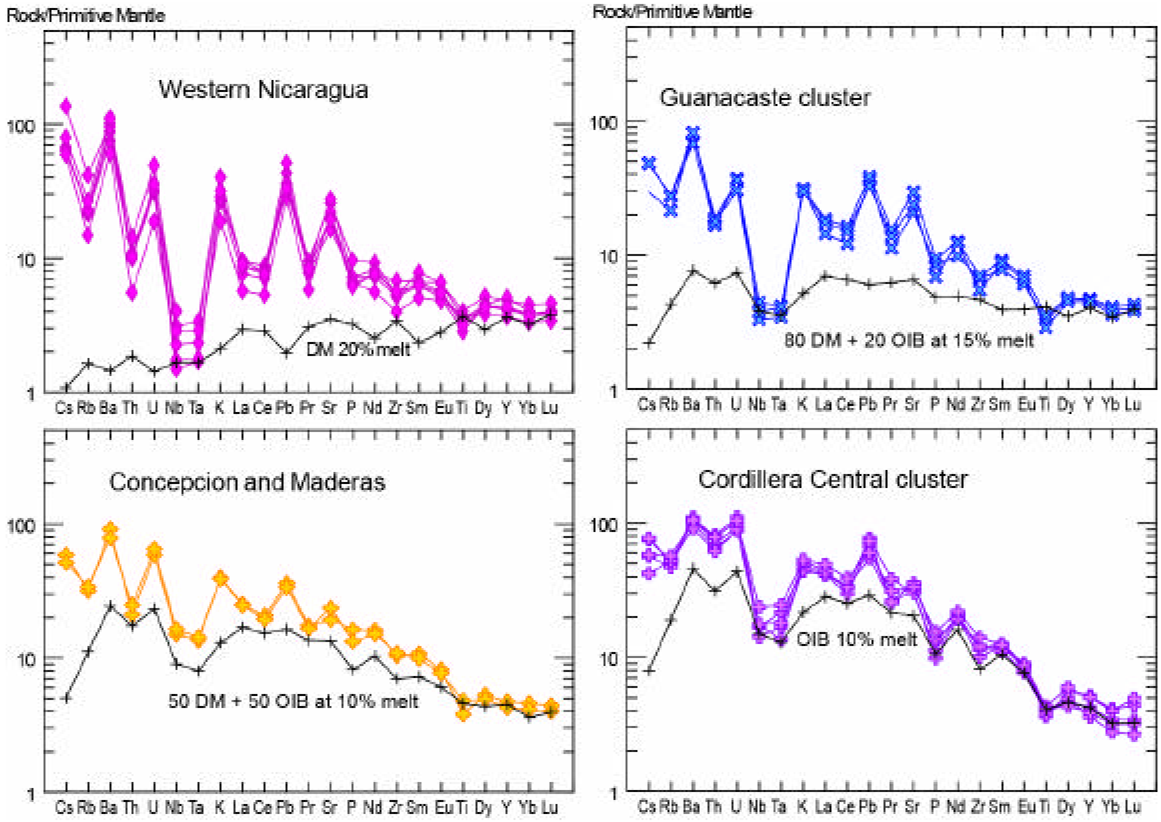


Figure 3.Geochemistry of volcanic groups/segments in Nicaragua and Costa Rica. Each line is an average for a particular volcano. Note the lack of variation within a segment and the overall change in the spider-diagram shapes. The black lines are models of mantle derived contribution.

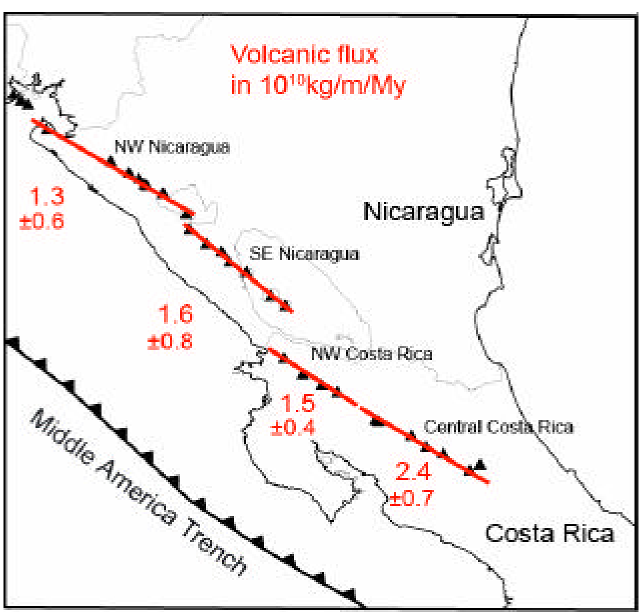


Figure 4. Volcanic segments and their flux over the last 0.6 My. Note the right steps separating the three northernmost segments. The break between NW Costa Rica (Cordillera de Guanacaste) and Central Costa Rica (Cordillera Central) is picked just NW of Arenal because Arenal shares the Pb isotopic signature of Central Costa Rica. Arenal's major and trace element geochemistry is not distinctly like either Guanacaste of the Cordillera Central

The flux of volcanic output is nearly the same along Central America. The Guanacaste segment has about the same volcanic flux as the two volcanic lines in Nicaragua. A higher volcanic flux is suggested for the large volcanoes of the Cordillera Central but the errors are large, and so the fluxes are not significantly different.

Some problems to consider

The field trip travels through a region where rapid progress has been made recently in geochronology, geophysics, geochemistry and volcanic stratigraphy.

Ar-Ar age dating revealed distinct pulses of volcanic activity, separated by lulls (Gans et al., 2002 & 2004; Carr et al., 2007). There is a suggestion that the construction of ignimbrite plateaus in Guanacaste, the Bagaces group of Pliocene age and the Liberia tuffs of Quaternary age, may have alternated with eruptions with the edifice building basaltic to andesitic lavas. This speculation requires much more field work and dating.

New work in central Costa Rica (Gazel, Margins meeting 2007) reveals that the geochemistry of Tertiary volcanic fronts (e.g. Sarapiqui arc and Aguacate arc in central Costa Rica) is significantly different from the currently active volcanic front. The older rocks are similar to the modern (and Tertiary Coyol arc) volcanics of Nicaragua. The odd Galapagos-like geochemistry of modern volcanics in central Costa Rica is a new phenomenon, entering the arc record about 5 Ma bp. Understanding the geographic-geochemical pattern in Figure 2 will be enhanced by further study of the Tertiary volcanics (the red mud).

The distribution of volcanic production over the last 600 Ka has not been uniform along the arc. Instead, each volcanic line or segment has one or two very large volcanoes, flanked by progressively smaller ones. On the field trip we start at Barva and end at Rincón, so we go down and then up, in terms of volcano size over distance (Figure 5).

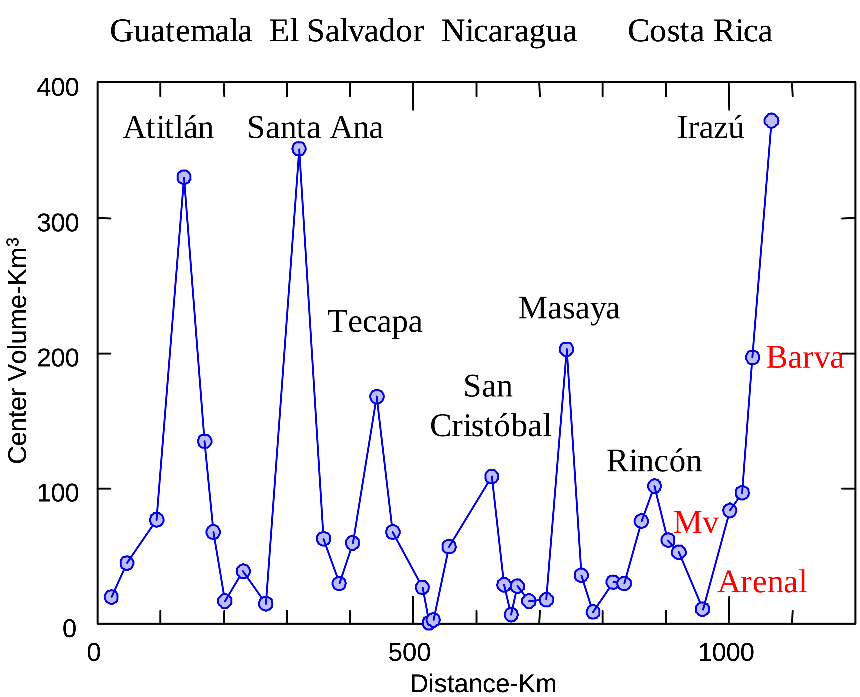


Figure 5. Distribution of volcanic output (lavas and tephras) along Central America during the last 600 Ka.

What causes the lognormal distribution of volumes and the apparent 150 km ‘wavelength’ in the volume distribution?

Note to GPS Users

This field trip was designed away from the field with mostly just our memories. Some of the localities can be exactly located but others will be found (again) on the fly. If you have a GPS you can "locate" some of the stops for us! However, there are some difficulties.

The 1:50,000 scale maps of Costa Rican quadrangles have a convenient 1 km grid. Unfortunately the grid is not UTM but is a Lambert grid using the Clarke Spheroid of 1866 (NAD27), Fundamental de Ocotepeque). To make your GPS locate places on the Costa Rican km grid, you need to go to User UTM Units (on a Garmin at least) and enter the following settings.

Cuadrícula Lambert Norte (See **panfleto_Garmin** in Images and Maps on web site)
Origen de longitud: 84º 20.000'
Escala: 0.99996
Falso Este: 499800 metros
Falso Norte: -885244 metros
Datos de mapa (datum): NAD27 Central

We have also used:
Map Datum User DX=263 DY= -476 DZ= -75 DA= -69 DF=-0.0000373
Longitude origin: 84.20 W
Scale 0.9999560
False East 500000
False North -885625.4

In collecting Costa Rican samples it is advisable to record both the Latitude-Longitude (WGS 84 is the default datum for lat-lon on my Garmin GPS) and the Costa Rican Lambert grid (based on a NAD27 Central America-El Salvador datum). There is 7 to 15 m error in the switch to the CR grid, most likely because it is a conical not a cylindrical projection like UTM. The error is much worse (up to 200 m) if you use the WGS84 datum with the User UTM Units defined above, so be careful! It is easy to return to an outcrop, if it is plotted in the Lambert map grid accurately, and therefore the Lambert grid values are essential. Of course, most of the samples collected in years past lacked the amazing satellite-based precision now available.

Day one- Arenal an active and dangerous young stratovolcano

Background

Arenal ended a more than 200 year period of repose in 1968 with a devastating directed blast that destroyed a large area west of the volcano, mapped as $utAC_{1968}$ in Figure D1a. Since that blast, lava flows have erupted nearly continuously, helping give rise to a "steady-state volcanism" concept (Wadge, 1984). The thick pile of lava generated since 1968 has been followed by the volcanology group at OVISCORI at the National University of Costa Rica, by ICE, the Costa Rican Electricity Institute and by G. Wadge and students (Figure D1b). The changes in lava chemistry have been closely monitored (Figure D1c). The 1968 juvenile tephra and the early lavas (Stage 1) have high Al_2O_3 content and are best explained as a fractionated residue of the previous batch of magma, which was similarly rich in alumina. Around 1971, the new batch of magma (Stage 2, whose arrival, most likely caused the 1968 blast, began to erupt. It is notably richer in MgO. The nearly continuous eruption of lava over nearly 40 years has attracted considerable attention and study, with most results favoring a two-stage history. Stage 1 is usually interpreted as a closed system fractional crystallization process leading to a chemically zoned magma body whose upper zone was enriched in water, leading to the directed blast. The Stage two lavas have changed slightly with time, leading to models of open system fractionation with replenishment accompanying crystallization. The lava fields of the current eruption have been accessible for most of the duration of the eruption but now the volcano is producing rare but potentially fatal pyroclastic flows and it is no longer safe to climb the volcano. We will try to provide access to one of the lowermost flows.

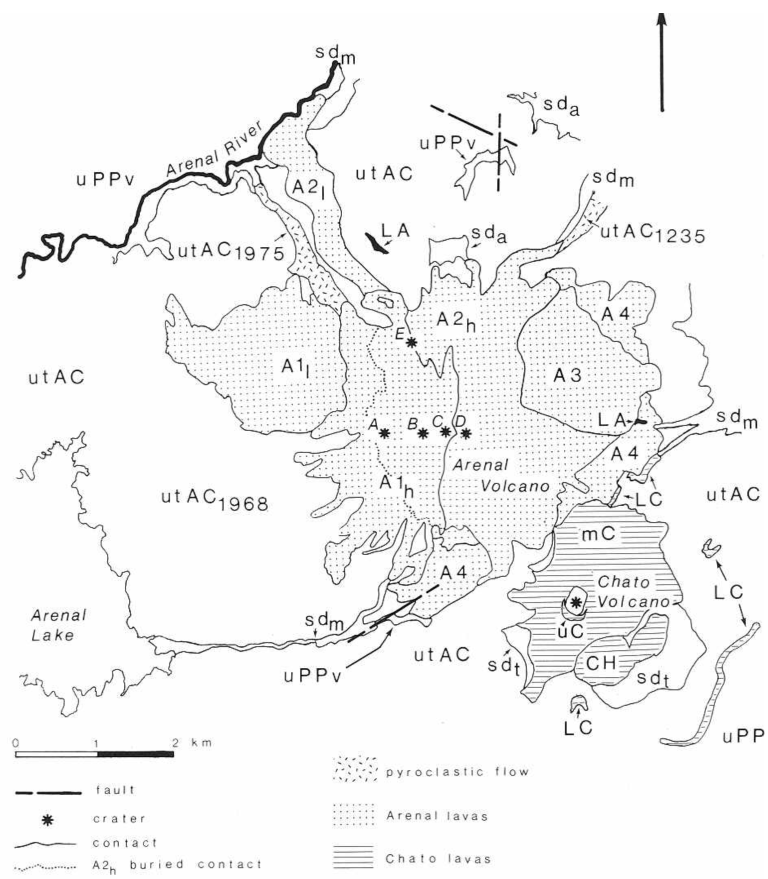


Figure D1a. Geologic map of Arenal by Borgia et al. (1988.)

A-B-C-D-E are craters. D is the pre1968 summit crater. E is boca for the 1525 flow, (unit $A2_l$). Crater A produced lava flows during1968-1973 but lava activity is now from Crater C, whose height varies with eruptive activity but can be higher than the original crater.

Borgia et al. (1988) recognized 5 lava units: A1-the lavas since 1968; A2-lavas with thin soil and "Palmito" palm; A3-well developed soil and "Coyure" palm; A4-well forested; LA (lower Arenal)- rare outcrops with no clear correlations.

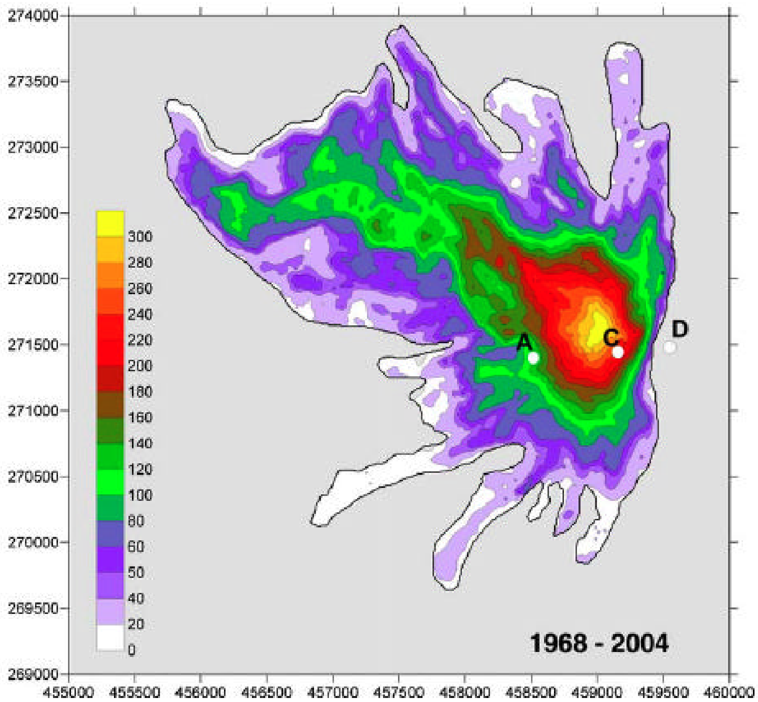


Fig. D1b. Isopach map of lava flow thicknesses from September 1968 to March 2004. Contour interval is 20m. Craters A, C and D are marked. Taken from Wadge (2006)

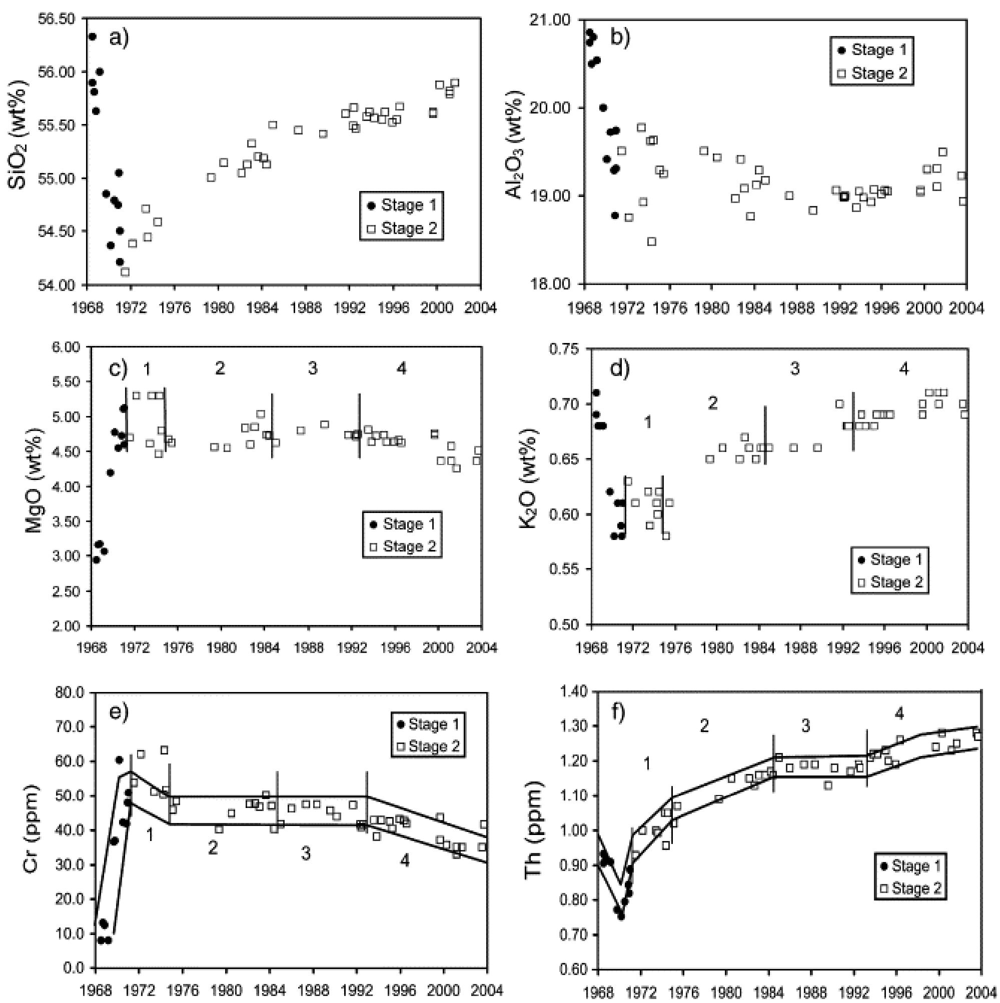


Fig. D1c. Major and trace element concentrations vs. time. Vertical bars in c-f mark the boundaries between Phases 1 and 4 of Stage 2. The curve in e-f illustrates the trends that we modeled. The width of these trends reflects the “geological error” namely, the variance of magma composition at any time. Taken from Ryder et al. (2006).

Arenal's eruptive history goes back 7000 years, so the strong focus on the current eruption may be biasing the models of Arenal's magmatic evolution. Alvarado and Carr have both worked on the older units, both the lavas, tephras and gabbroic-dioritic inclusions. The foundation of Arenal's eruptive history was a quarry (Tajo) dug into the thick tephra, West of the volcano (The prevailing winds are from East to West and the Tephra thicknesses generally follow this pattern). Bill Melson and co-workers established a the tephra history from El Tajo. Unfortunately this type locality is now submerged beneath the Arenal Reservoir. Melson found nine tephra layers will soils developed on most of them. ET1 is the layer deposited in 1968. It has a negligible thickness and can no longer be found at most tephra localities. Although the blast cause many fatalities it did NOT BECOME part of the GEOLOGIC RECORD! We therefore expect that many important events in Arenal's history have not been recorded!

The ET1 to ET9 sequence reveals a remarkable alternation between dacitic tephras (ET2, ET4-5, ET7 and ET9) and basaltic tephras (ET3, ET6 and ET8). ET3 and ET4 have little soil development between them and may represent an inverted magma chamber with the silicic tephra (ET4) erupting just before the basaltic tephra (ET3). The other basalt to dacite sequences are interrupted by soils so the ET4 to ET3 transition is unusual. The classic El Tajo sequence only goes back about 3200 years. Much subsequent work has extended Arenal's history back to about 7000 years. The table below (Soto and Alvarado, 2006) summarizes the Arenal tephra history and provides a new nomenclature in which the older units are given lower numbers. Thus ET-2 becomes AR-20. This can be confusing but The table here is the Rosetta stone.

Table 2
Summary of characteristics of the main Arenal tephra fall eruptions

Layer	Date B.P. (0=1950 A.D.)	Calendar age	Repose period[a] (years)	% SiO_2	Volume (km^3)	VEI[b]	Eruption type
AR-22 [ET-1]	–	1968 A.D.	530	56–57[c]	0.003[d]	3[c]	Vulcanian
AR-21 [UN-10]	510	1440 A.D.	40	53–55	?	?	Vulcanian?
AR-20 [ET-2]	550	1400 A.D.	380	62–63	0.44	4	Plinian
AR-19 [ET-3]	930	1020 A.D.	0	49–53	0.90	4	Violent strombolian
AR-18 [ET-4]	930	1020 A.D.	270[e]	55–60	0.27	4	Subplinian
Upper AR-17 [ET-5]	1200[e]	750 A.D.	0	56–58	0.045	3	Subplinian
Lower AR-17 [ET-5]	1200[e]	750 A.D.	50[e]	60–62	0.12	4	Subplinian
AR-16 [ET-6]	1250[e]	700 A.D.	50[e]	51–53	0.19	4	Violent strombolian
AR-15 [ET-7]	1300	650 A.D.	100[e]	56–61	0.38	4	Plinian
AR-14 [ET-8M]	1400[e]	550 A.D.	120	51–52	0.15[f]	4	Violent strombolian
AR-13 [ET-8B]	1520	430 A.D.	600	55	0.20[f]	4	Subplinian
AR-12 [ET-9N]	2120	170 B.C.	100[e]	60–63	0.35[f]	4	Plinian
AR-11 [ET-9A]	2220[e]	270 B.C.	110[e]	51–56	0.15[f]	4	Subplinian
AR-10 [ET-9B]	2330	380 B.C.	870	52	0.15[f]	4	Violent strombolian
AR-9 [ET-9]	3200	1250 B.C.	200[e]	58	>0.13	4	Plinian
AR-8 [ET-10]	~ 3400[e]	1450 B.C.	200[e]	50–55	0.15[f]	4	Subplinian
AR-7 [ET-11]	~ 3600[e]	1650 B.C.	600[g]	51–59	0.15[f]	4	Subplinian
AR-6 [ET-12]	4200[g]	2250 B.C.	550[g]	50–56	0.20[f]	4	Subplinian
AR-5 [ET-13]	4750[g]	2800 B.C.	550[g]	51–54	0.15[f]	4	Violent strombolian
AR-4 [ET-14]	5300[g]	3350 B.C.	550[g]	53	0.20[f]	4	Violent strombolian
AR-3 [ET-15]	5850[g]	3900 B.C.	550[g]	54	0.15[f]	4	Violent strombolian
AR-2 [ET-16]	6400[g]	4450 B.C.	610[g]	–	?	?	?
AR-1	7010	5060 B.C.	–	62	?	4?	Plinian?

[a] Between major eruptions, since other minor or extrusive ones could have occurred.
[b] VEI as explained in text.
[c] Alvarado et al., this volume.
[d] Sáenz, 1977.
[e] Approximate interpolation between near known ages of other eruptions.
[f] Volumes estimated from similar eruptions, according to isopach comparisons.
[g] Gross interpolation between known ages of other eruptions.

The tephras sequence is paralleled by a lava sequence. Borgia et al. (1988) defined four lava fields (A1-the present flow field to A4-the oldest mapable lava field) and an undivided group called LA. In the new terminology LA is ARL-1, A4 is ARL-2, etc until A1 is ARL-5. The figure below from Soto and Alvarado (2006) summarizes Arenal's eruptive history.

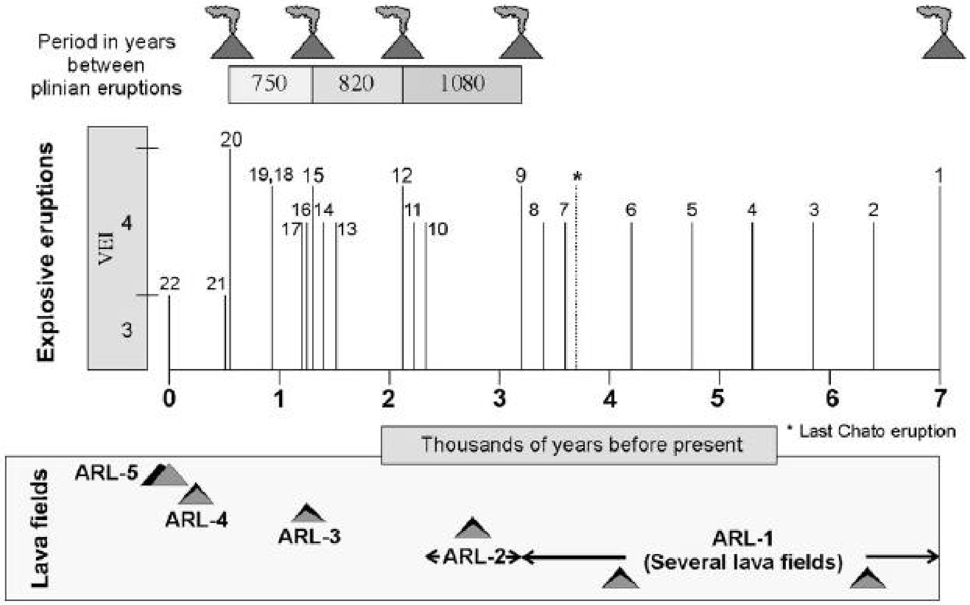


Figure D1d. Eruptive history of Arenal from its birth 7000 yr bp.

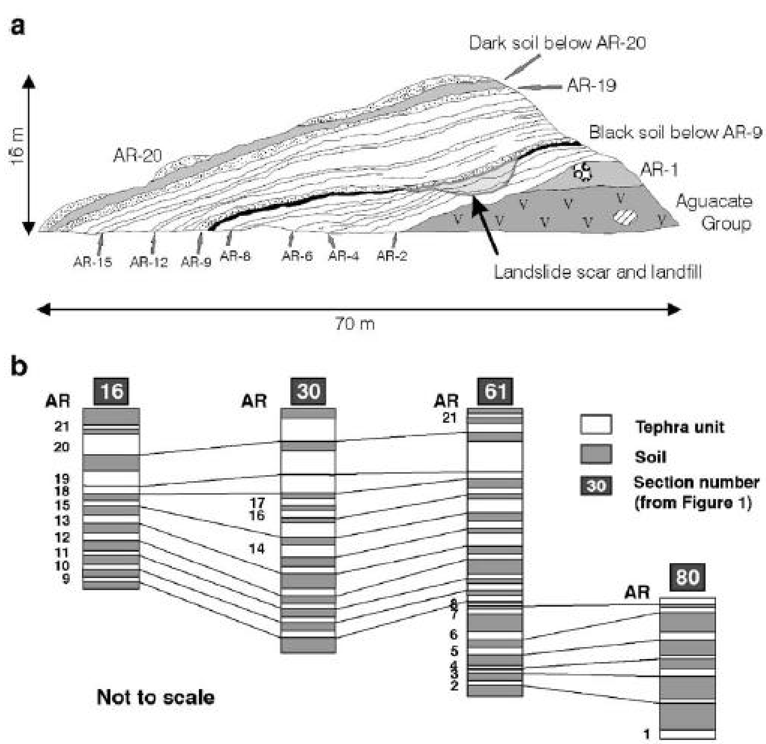


Fig. D1e. Tephra sequence 6 km west from Arenal, on the east embankment of Sangregado Dam.

The lava fields (using the A1 to A4 terminology of Borgia et al. (1988)) alternate between alumina rich (HAG) and alumina poor (LAG) groups (A4-HAG, A3-LAG, A2-HAG and A1-LAG) Borgia et al. (1988) proposed that the alternating dacitic-basaltic tephras and the HAH-LAG lava fields were temporally linked and formed a repeating sequence: Dacitic tephra-HAG lava-LAG lava-Basaltic tephra. Subsequent field work showed that this highly regular sequence is not found in reality. Nevertheless, during the last 3000 years some combination of processes allowed crystal-liquid movements to give rise to three distinct chemical-eruptive groups, Dacitic-andesitic tephras, basaltic andesite lavas and basaltic tephras (Figure D1f). Before 3000 years the volcano produced unimodal tephras with a composition similar to the basaltic andesite lavas. Something happened about 3000 years ago that made Arenal generate interesting alternations of tephra and lava types. Thus much remains to be done.

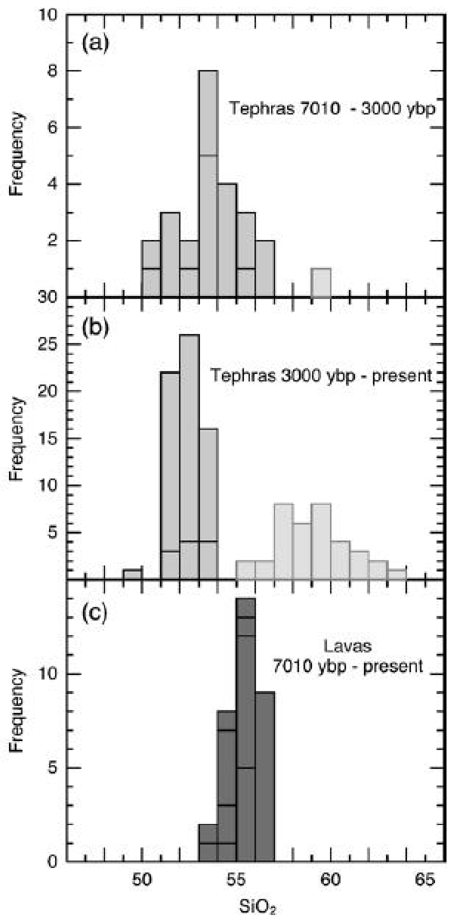


Fig. D1f. (a) Tephras erupted between 7010 and 3000 years B.P. show a relatively unimodal SiO_2 composition with one sample from unit ET11 with an elevated SiO_2. (b) Tephras erupted between 3000 years B.P. and the present show a bimodal distribution of SiO_2. (c) The lavas erupted during Arenal's entire history show a unimodal SiO_2 distribution that is similar to that of the older tephras (a) and lie in the gap between the bimodal distribution of the younger tephras. The plotted SiO_2 has been normalized to 100 wt.%.

Louise Bolge made two detailed examinations of Arenal's tephra history (Bolge et al. 2004; and Bolge et al. 2006). In the lush tropical setting of Arenal, the half-life of a tephra lapillus is short so care must be exercised from sampling through interpretation of the data. The clarity provided by stratigraphic position, especially at more distant (and complete) localities is almost negated by weathering (worse on small lapilli) and the fact that most tephra units have stratigraphic compositional zoning, which can be obscured in a distal outcrop. Bolge used thin section examination and geochemical ratios to eliminate the most altered samples and then used averaging, whenever possible, to define the geochemical history of the tephra. The ratios of highly incompatible elements that revealed a coherent temporal variation involve the weathering resistant high field strength (HFS) elements, Nb, Ta, and especially Zr, Hf.

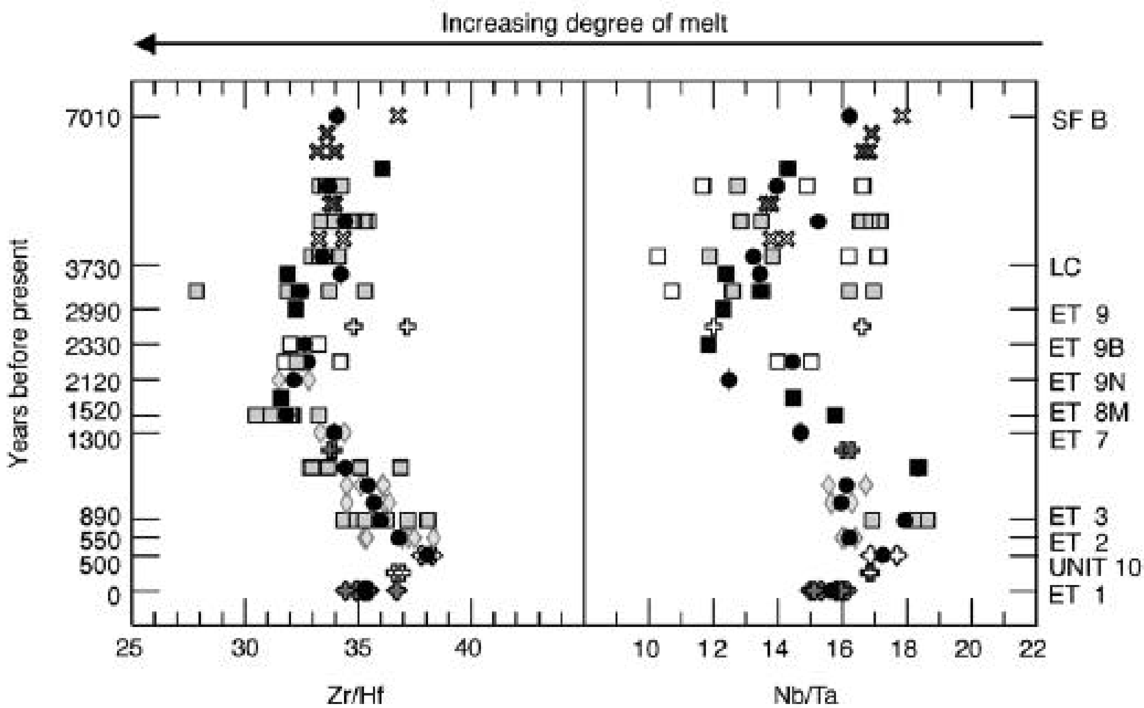


Fig. D1g. Zr/Hf and, to a lesser extent, Nb/Ta indicate changes in the degree of melting over time. Initially, the degree of melting increased from 7000 years B.P. to approximately 3000 years B.P.. The degree of melting then decreased from 3000 years B.P. to the present. The high Nb/Ta variance in the older tephras may reflect the large variation in the TiO_2 in those tephras. Average values for the tephras are presented as filled black circles.

Arenal Stops

Stop 1. Lower Chato Unit at Rio Fortuna. This is perhaps the base of the Arenal-Chato volcanic pile, somewhere around 30 to 40 ka. It looks like a typical Arenal flow.

Stop 2. Block and ask flows from Arenal. Depending on the quarry, this will be located on either the A4 or A3 map unit of Borgia et al. (1988).

Drive by. Rio Tabacon Resort, a case of extreme hazard for tourists

Stop 3. Basal tephra from Arenal (AR-1). "From bottom to top, AR-1 is composed of: (a) a block and ash flow (thickness: 1 m), with gray (SiO_2 62% silica. Data hereafter are from Bolge et al., 2006, and/or unpublished data) dense subangular juvenile clasts (~15 cm), rare andesitic and altered lithics (~5%, b30 cm), in a matrix with abundant organic matter and carbonized trunks; (b) a sequence of light gray pyroclastic surges and flows with cm-to-mm scale laminations and accretionary lapilli (7 m); (c) a gray to pink indurated tuff with isolated lithics and accretionary lapilli (pyroclastic flow and surge deposit?, 5.5 m); and (d) a reddish-brown tuff with abundant accretionary lapilli, some internal structures and isolated lithics (5 m). The calibrated age of one of the trunks in layer a, is 7010+170-130 B.P." from Soto and Alvarado (2006).

This is a small outcrop with difficult access.

Drive by/picture stop. Bomb crater from the 1968 directed blast. We may crawl under the barbed wire and take a close look, depends on timing and rain etc.

Stop 4. Enter the National Park and Hike to the 1995 lava flow and the 1993 pyroclastic flows. This will be the longest hike today. If the volcano is too active we will seek an alternate outcrop.

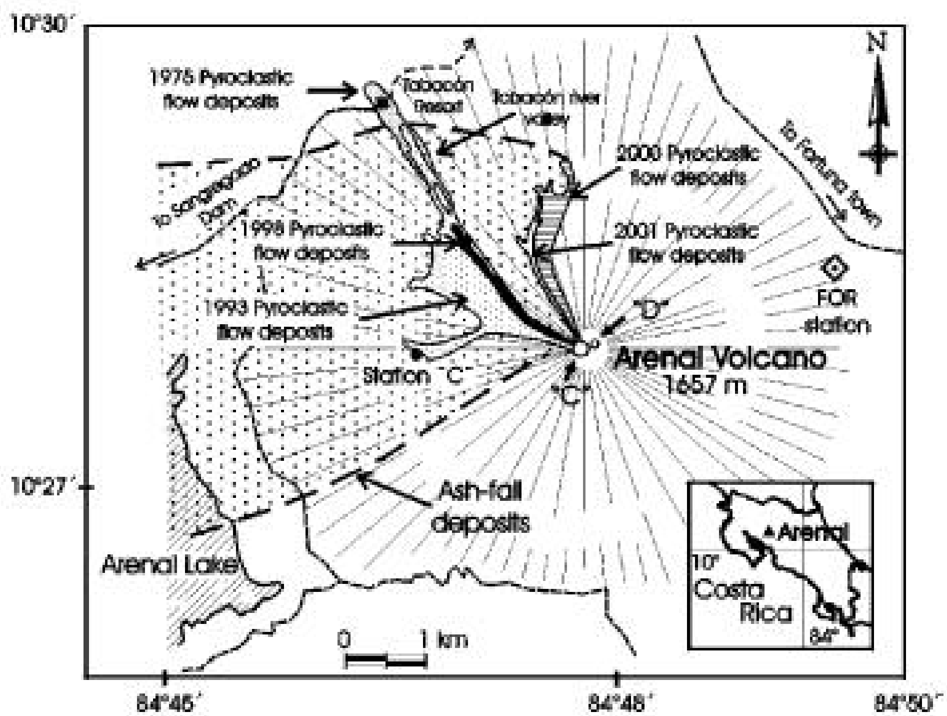


Fig. D1h. Location map of Arenal volcano and its craters ''*C*'' (active) and ''*D*'' (inactive), including station C with its tiltmeter measurement, the distribution of the pyroclastic flow and ash-fall deposits, and the location of Tabacón Resort and the seismic station, FOR. The *dotted lines* are roads. (from Alvarado and Soto, 2002).

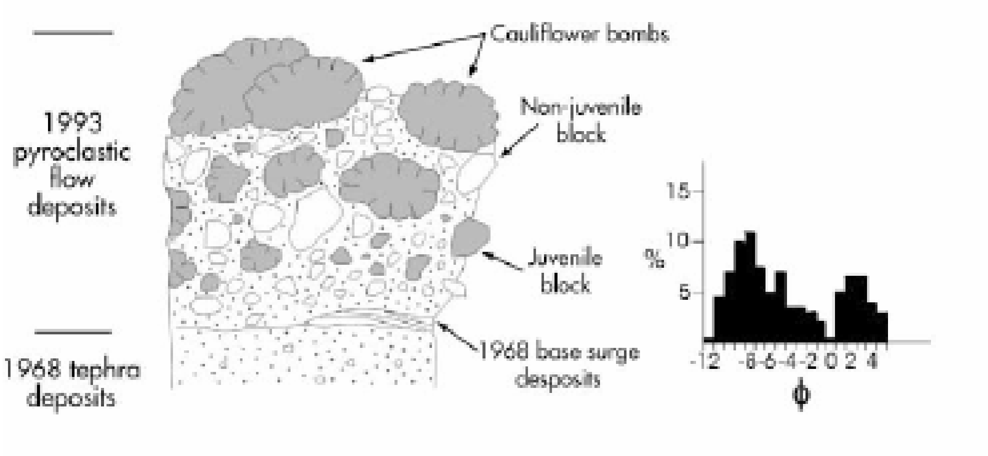


Fig. D1i. Schematic columnar section showing the 1993 pyroclastic flow deposits with the two main gradational units with a crude inverse grading. A representative grain-size histogram illustrating the bimodal grain-size distribution. (from Alvarado and Soto, 2002).

Stop 5. A comprehensive section of Arenal tephra stratigraphy at El Castillo. The initial type section, El Tajo, is under the Arenal Reservoir (Embalse).

Stop 6. Canopy tour for those who can spend the money. Coffee for the rest. This tourist attraction has a spectacular view of Arenal (weather permitting). A Canopy tour begins tepidly enough with a gentle ride up the rain forest covered mountainside (the geology is 1-2 My old volcanics). Descent is via a series of six zip lines, one of which is almost a km long. The zip lines criss-cross a spectacular gorge so you are speeding along in a harness, attached to a wire more than 100 m above the ground. If you fear heights or have physical disabilities, I suggest you join me for coffee and a snack at the base lodge. Carr and Gazel did this last year and I loved it. The volcano was clear and it quite spectacular.

Stop 7. (depending on time). The earth filled dam creating the Arenal Embalse is part of a clever hydroelectric and irrigation scheme. The drawback is that the dam is almost on the volcano. We can discuss the problem of living and building important engineered structures in a land of volcanoes and earthquakes.

Day two - Arenal to Miravalles (Cordillera de Guanacaste)

Depart hotel with bag lunch and luggage and drive toward Tilaran

We cross the Sangregado Dam and follow the shore of the Arenal lake-reservoir. The grey outcrops (thin and on the top) are the Arenal tephras. The red muddy looking outcrops are Tertiary volcanics of uncertain age, (part of Aguacate group). After the bus climbs up from the lake and the windmills become visible, we reach younger volcanics, roughly 1.0 to 2.2 my, This is the previous volcanic front (Monteverde front), which nearly coincides with the present one. During the next two days we will examine the current volcanic front (600 ka and younger), the Monteverde front (2.2 to 1.0 Ma), and several silicic tephras, many of which (the Bagaces formation) are older than the Monteverde VF.

Windmills are located at the west end of the structural depression that also holds the Arenal Lake. This is one of the few low areas allowing Caribbean air to easily cross to the Pacific, the adjacent low area is Lake Nicaragua. The wind's southernmost outlet is at the Golfo de Papagayo, which gives the wind a name, "the Papagayo wind." The wind causes upwelling in the Pacific and high plankton productivity, primarily offshore of Nicaragua. The abundance of organic mater may contribute to the geochemical variation of Central American volcanoes because ^{10}Be can be attached to organic fragments, resulting in a high ^{10}Be deposition offshore of Nicaragua. Masaya volcano in Nicaragua has the highest output of ^{10}Be found at any volcano in the world. Is it related to the wind? We don't know, this is just a speculation.

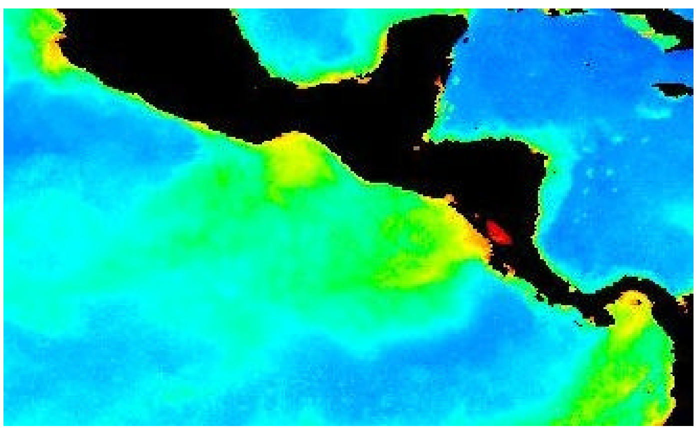


Figure D2 a. SeaWiFS winter (2000-2001) Level 3 chlorophyll image, showing the increased productivity corresponding to the Tehuano (south of Mexico), Papagayo (west of Nicaragua), and Panama (south of Panama) wind jets. http://disc.gsfc.nasa.gov/oceancolor/scifocus/oceanColor/papagayo.shtml.

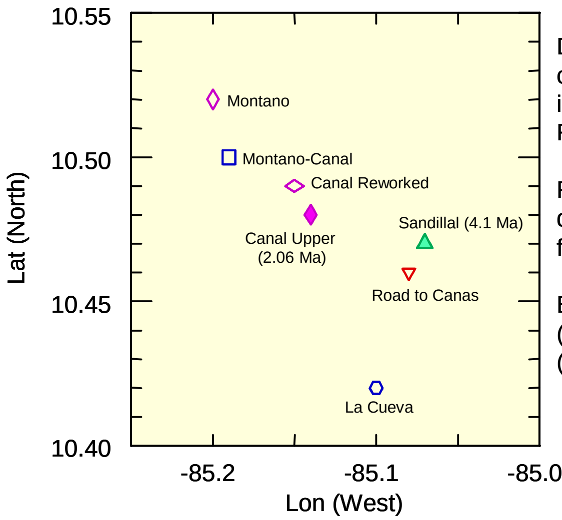
Ignimbrite Plateaus of Guanacaste

As the bus drops down from the windmill area to the Panamerican highway, we enter an extensive area of Ignimbrites plateau. Although the reality is much more complex, to first approximation, the older plateau is the Bagaces group, whose ignimbrite units are commonly welded. The Bagaces extends the length of the Guanacaste range and the sources are not well understood. The younger ignimbrites were intitially called the Liberia Tuff or Rio Liberia formation. These ignimbrite are unwelded or weakly welded. The source of some of these units is the Guayabo caldera between Rincon de la Vieja and Miravalles.

The Guanacaste ignimbrites are being studied by the Vogel-Patino group at Michigan State University, who graciously provided the brief summary that follows.

Ignimbrites near Cerro Chopo

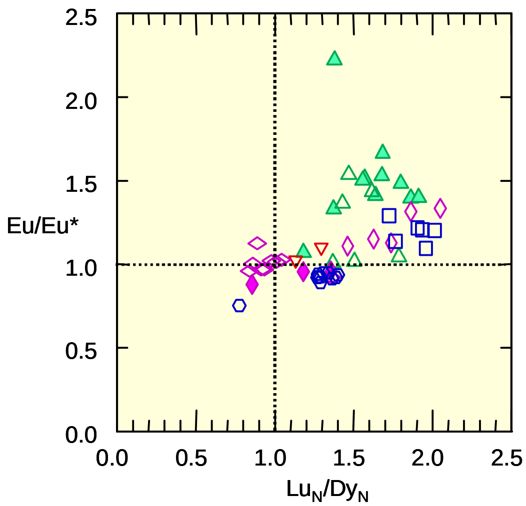
The ignimbrite deposits in the area near Cañas and Cerro Chopo represent some of the oldest silicic units in the region; the only older units (>4.1 Ma) belong to Bagaces Formation that outcrops west of the Panamerican Highway (see abstract by Szymanski et al., 2007 presented at the meeting). The ignimbrites near Cerro Chopo consist to two units, Sandillal (4.1 Ma; dacite-rhyolite with amphibole) and Montano (2.06 Ma; rhyolite without amphibole). The silicic deposits in this region have not been studied in detail, but preliminary interpretations of geochemical data lead us to the following conclusions: 1) In addition to the two dated units, there is a third ignimbrite deposit in the region that has a wider SiO_2 content than the two dated units (andesite to rhyolite) and higher Nb/Ta ratios (>15); 2). The older unit, Sandillal, has the lowest Nb/Ta (<5), a range of positive Eu/Eu* anomalies and depleted MREE patterns; 3) Samples from the upper canal outcrop, where the dated Montano sample was collected, have Nb/Ta ratios that fall in two different populations, some are in the Sandillal group, while the dated Montano sample has higher Nb/Ta (~9). To understand the geochemical evolution of these units, there is need to answer simple questions such as; what is the volume of each ignimbrite, what is age of the third unit, how are these three units related?

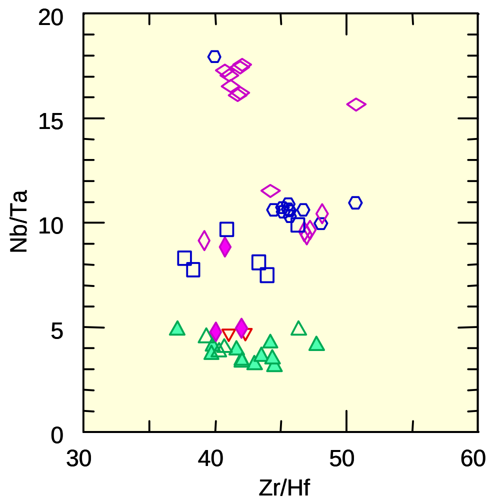


Distribution of sample locations: samples collected near Cerro Chopo. Cerro Chopo is located to the east of the Sandillal and Road to Canas outcrops.

Fill symbols = outcrops that have been dated (e.g, filled triangle dated out crop for Sandillal)

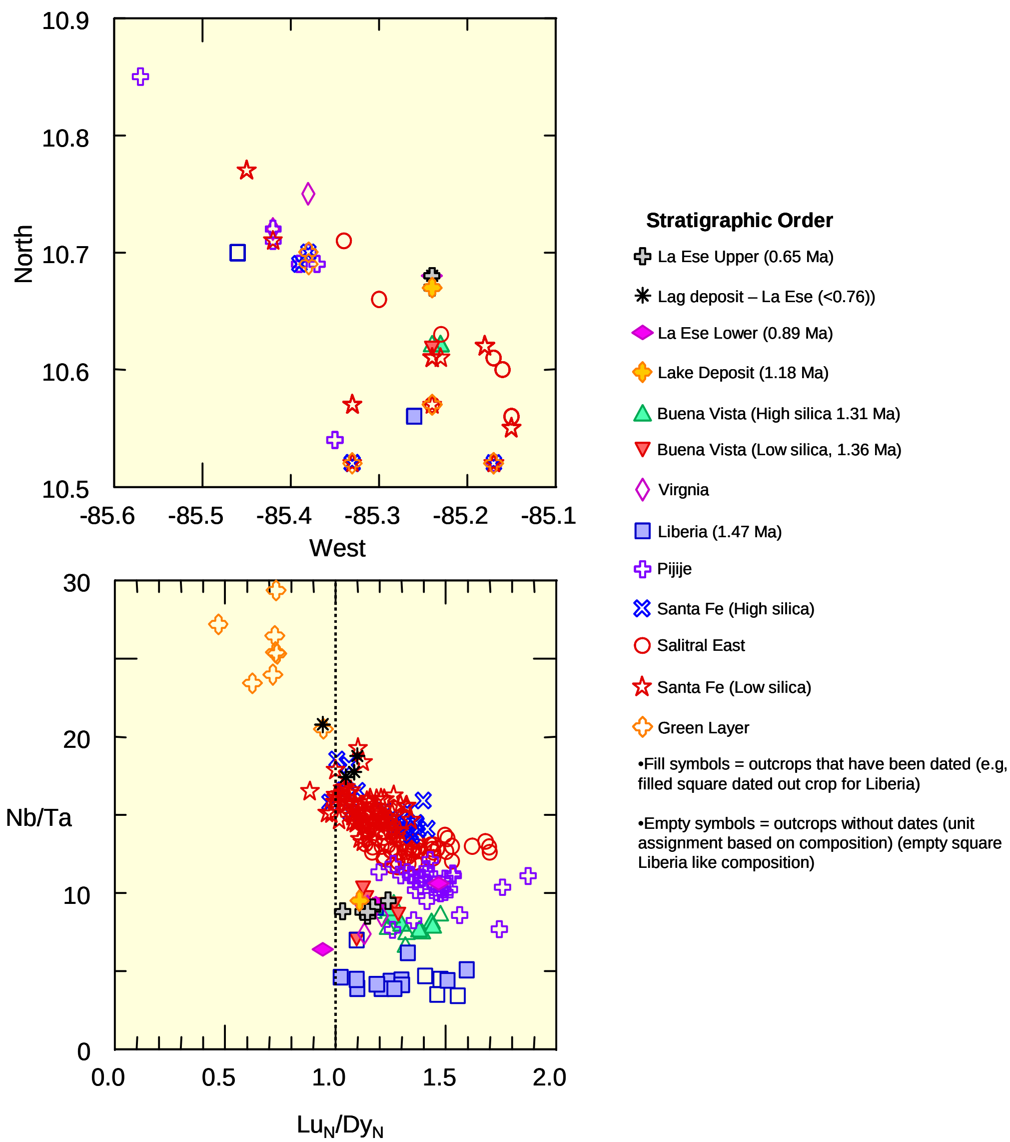
Empty symbols = outcrops without dates (unit assignment based on composition) (empty triangle Sandillal like composition)





Guachapilin-Guayabo Ignimbrites:

The silicic deposits that outcrop along the road to Miravalles represent the youngest ignimbrites in the Guanacaste region, between ~2 Ma and 0.65 Ma. It is assumed that these units are related to the Guachapilin and Guayabo calderas. The lower part of the section (>1.2 Ma), assumed to be associated with the Guachapilin Caldera, have been studied in more detail (Deering 2005 and in press). Guachipelin eruptive products are divided into two groups, dacites and rhyolites; the rhyolites are characterized by the presence of biotite. Seven units were defined using the Nb/Ta ratio, which has a significantly wide range, from 4 to 30, and is interpreted to reflect contributions from more than one intermediate source. Most of these units also display extensive geochemical and petrological evidence of mixing, a common phenomenon in other ignimbrites in Costa Rica. The distinct geochemical characteristics of these deposits and the stratigraphic occurrence of each flow unit require both limited fractional crystallization within units coupled with melt extractions and extensive mixing. Hence, individual melts would reside in relatively close proximity in subvolcanic zones for extended periods prior to the inception of a particular eruptive event. Considering the temporal (<0.75 Ma) and spatial (single caldera) constraints of this sequence of eruptions, significant chemical variations of the magmas have occurred.



Guanacaste stops

Stop 1 Cerro Chopo

(first two stops are on the Cañas Quadrangle)

This quarry cuts a cinder cone that produced a large lava flow which extends primarily north, across the highway. The flow is disappointingly altered along thin joint planes. The quarry provides an opportunity to see the inside of a volcano. **However, beware of the steep quarry faces, a collapse could well be fatal. Have a look up close where the slope appears least steep.**

Cerro Chopo is more than 1. M yrs old and has typical calc-alkaline geochemistry (L. Patino & T. Vogel, personal communication). It may well be one of the last active vents of the Monteverde volcanic front. It is a substantially eroded volcano that does not have the typical cinder cone shape, so much of it must have been eroded prior to the construction of the topographic map.

Some interesting aspects of the cone are unresolved. First, if you can juggle, here is your chance to acquire a neat set of volcanic bombs with spherical shapes. Why spheres? Anyone know? We thought spherical bombs might be a new detail to report but, as usual, we were too late. Charles Darwin recorded them at Reunion Island in the central Atlantic on his way to the Galapagos. Nevertheless they are odd. One that we sawed open had an angular core surrounded by two layers of lava, which made the the bomb spherical.

Note the fine layering of the exposed cone sections. It looks like the work of a draftsman. Up close the layers commonly have reverse grading with the larger clasts on top. This type of grading can be generated by landsliding, but, if so, would you expect such fine layers with such large length scales?

Stop 2 Tephra section in Bagaces Frm below Cerro Chopo

The tephra deposits below Cerro Chopo include a neat outcrop, partly pictured here, that includes several units, some structure, and rapid lateral facies changes in one of the upper units. There is a lot to see. Tell us what you find. Note: the lower and upper pyroclastics flows exposed here are both 4.1 Ma. (T. Vogel pers. comm.)

Travel Note
After the tephra stop, we got on the Pan American highway atCana?s and traveled NW past the colcanoes, Tenorio and Miravalles. The Arenal irrigation project made possible many hectares of rice and other agriculture. The land is mostly white because of all the tephras. To approach Miravalles, we turned onto the road to Upala.

Stop 3. La Ese tephra? ***(Tierras Morenas Quadrangle)***
We will try to stop briefly at a quarry with two distinctive tephra units. (We have to find this outcrop on the fly so we may miss it.)

Stop 4. La Ese, overlook of Guayabo caldera, Volcans Miravalles and Rincón de la Vieja.
(***most remaining stops on Miravalles Quadrangle)***
With luck we will have lunch here.

The volcanoes of the Guanacaste range are built on a base of 2.2 to 1.0 My old lava and tephra, the Monteverde volcanic front. Remnants are clearly seen to the SW of the large volcanoes. A significant pause followed the Monteverde eruptions until a young generation of lava flow field construction began at about 600 ka. ***Discuss the volcanic history.***

Now turn our attention to the plumes of steam from the Monteverde geothermal plant
Discuss geothermal exploration and exploitation.

Drive through the Miravalles geothermal system and observe the power generation engineering works

Stop 5 Debris avalanche deposits at Miravalles. ***(possibly onTierras Morenas Quadrangle)***
Stop in a place with hummocky topography and discuss sector collapse, directed blasts and the distinctive topography generated.

Stop 6. Las Hornillas
Visit a new hot swimming pool, near/in the fumaroles and mud volcanoes. The price is 1.6 US$/person. We did not include this cost in our field trip estimate.

Drive to Hotel El Sitio, get settled in. Swim. Go to restaurant in Liberia for dinner.

Day three - Rincón de la Vieja

Rincón de la Vieja is the largest volcano in the Cordillera de Guanacaste (the NW Costa Rica segment). It has a complex summit with numerous vents aligned roughly NW, in nearly the same strike as the volcanic line. This is a dangerous volcano that has erupted mildly in historic time but produced pyroclastic flows in recent prehistoric time. We plan to examine prehistoric andesitic scoria flows, recent (1991-1995) hot acid lahars, a Montevede age dome and more.

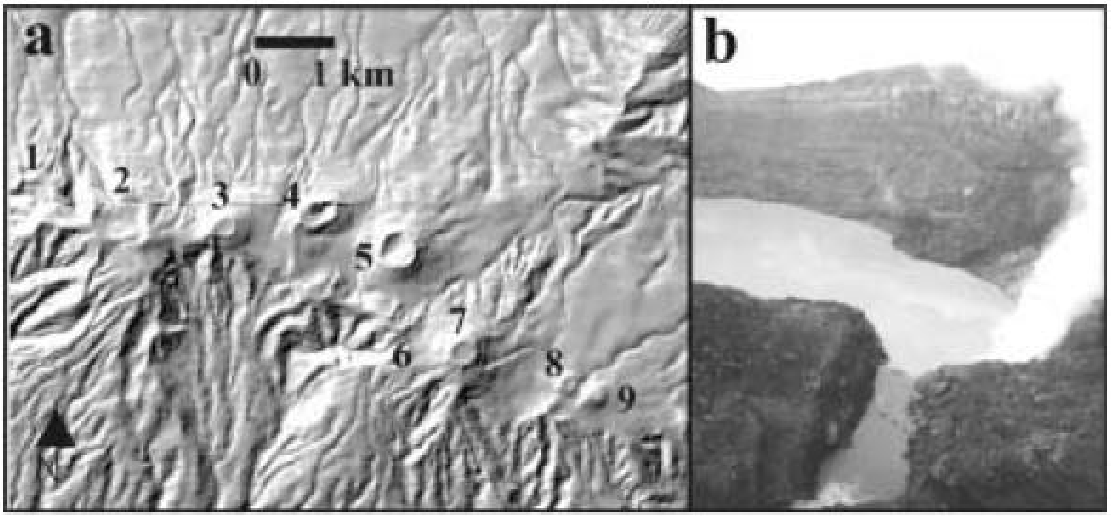


Fig. D3-1: a) Digital elevation model of the summit of Rincón de la Vieja, with 9 volcanic structures. Number 3 is the Von Seebach cone, 4 is the cráter Activo and 5 is Rincón de la Vieja
b) The cráter Activo with the hot lake in 1995. From Soto et al. (2003).

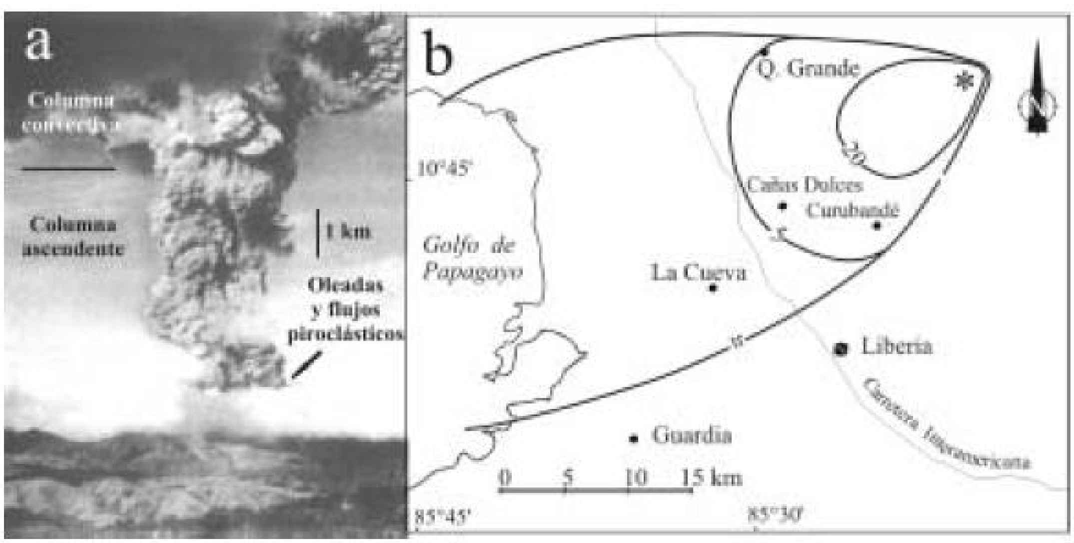


Fig. D3-2: a) Vulcanian eruption of 17 January 1967 (15:20, local time), looking from Curubandé (Foto cortesía de Óscar Li).
b) Cumulative ash thickness isopachs (in mm, tr = trace) from eruptions 1966-70.

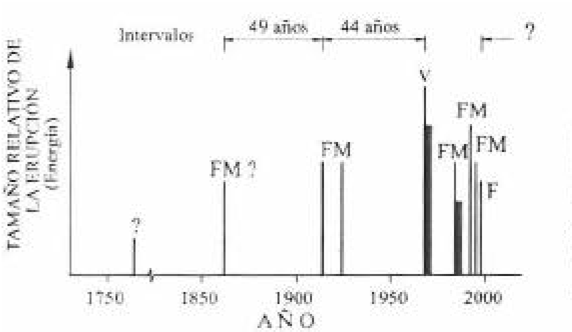


Fig. D3-3: The historic record (Soto et al. 2003) indicates increasing intensity and frequency of activity.

Rincón de la Vieja stops (the order of stops may change)

Stop 1 North Flank andesitic pyroclastic flows and recent lahars *(Cacao Quad)*

We take the bus to the Caribbean side of Rincón, to view the deposits of pre-historic pyroclastic flows and historical lahars.

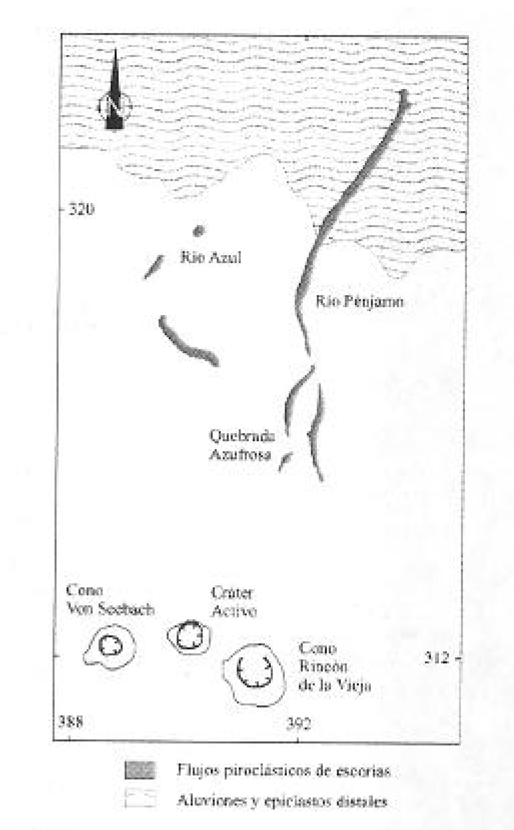


Fig. D3-4. Distribution of the scoriacious flows on the north side of the volcano. These flows are restricted to the valleys of the rivers Azul and Pénjamo. (Soto et al. 2003)

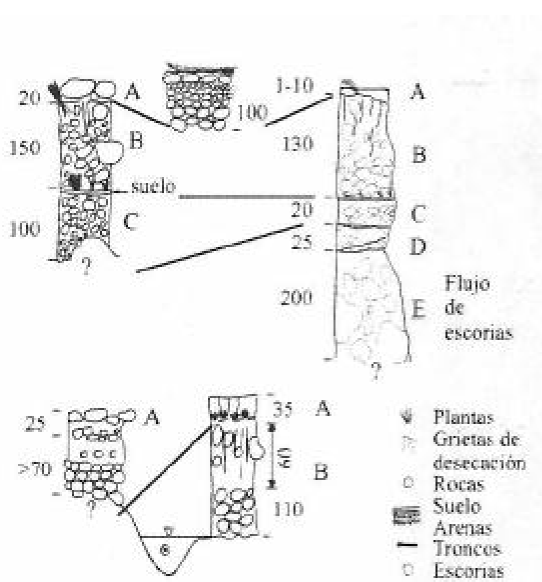


Fig. D3-5. Columnar sections and correlation of the lahars (thicknesses in cm) produced by Rincón de la Vieja up to November, 1995. (A), May 1991 (B), unknown data (C & D), Flow of scoria 1520 bp in the Pénjamo river.

Stop 2 Debris avalanche deposit from Cerro Cacao (part of Orosí-Cacao complex)

Examine debris avalanche deposit from Cacao. (Discus sampling in rain forest conditions?)

Stop 3 The dome complex near Cañas Dulces. ***(Curubande Quad)***

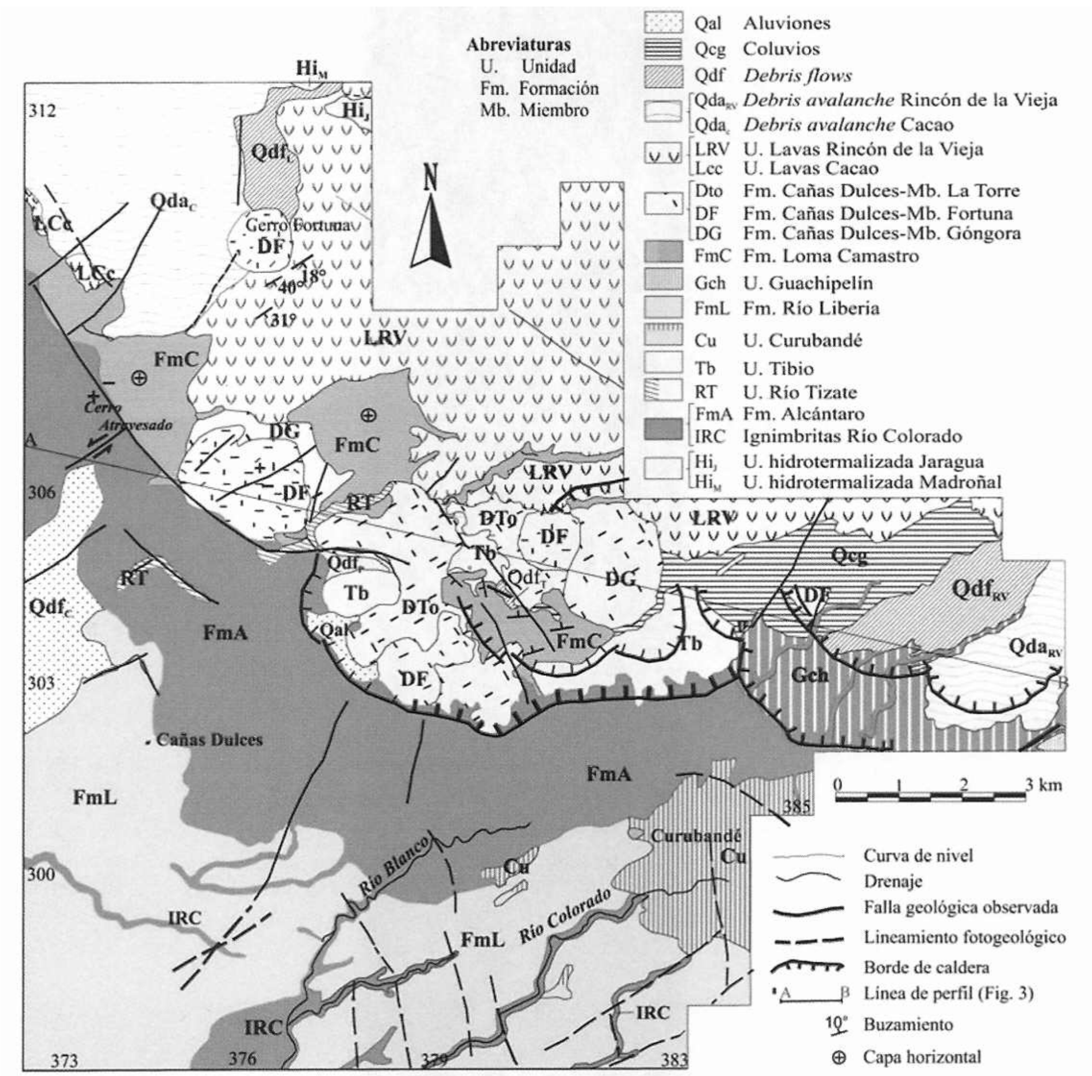


Fig. D3-6. Geologic map of Cañas Dulces area from Zamora et al. (2004).

Stop 4 The 1.6 Ma lava fronts near the domes and near Cuesta del Diablo

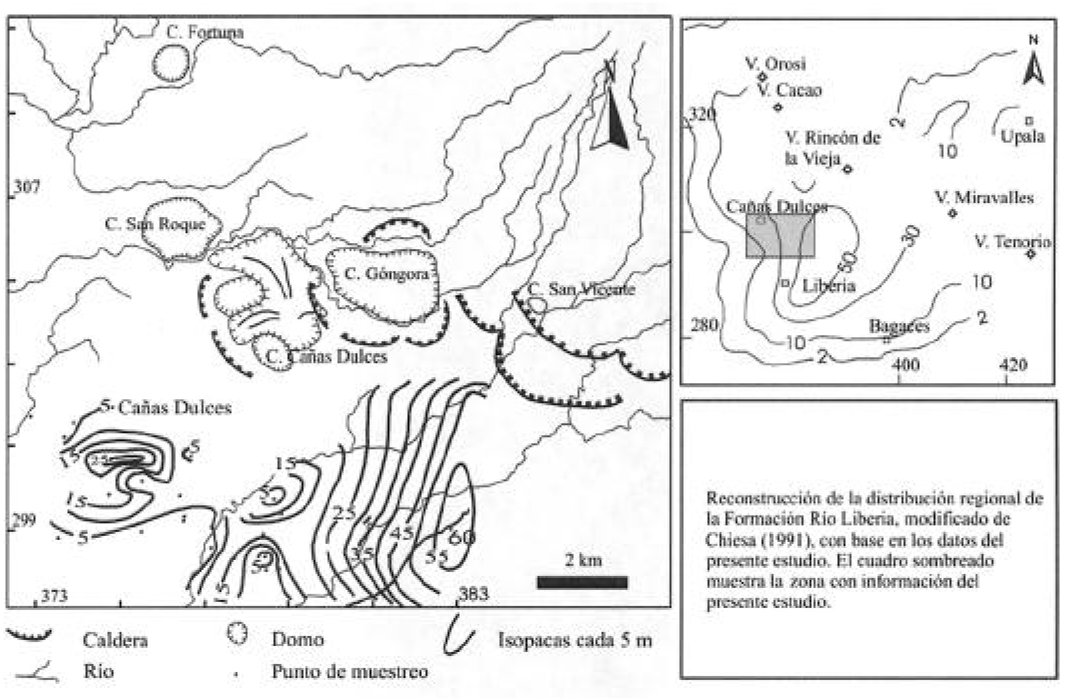


Fig. D3-7. Thickness variation of the Rio Liberia formation, indicating likely source between Rincón de la Vieja and Miravalles. from Zamora et al. (2004).

Stop 5. Hot Springs, geothermal phenomena and late lunch at Finca Borinquen.

Lavas outcropping just north of the hot spring are 1.6 ±Ma, so are part of Monteverde volcanic front.

Day four - Liberia to San Jose with a possible stop at the Tiribi tuff.

Return to San Jose and have lunch en route. Perhaps there is a seafood restaurant near Caldera, Costa Rica's main port for container ships. After lunch we can stop and see the ignimbrites of Tiribí near La Garita.

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