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The Cinotepeque Range of central El Salvador: Geology, magma origin, and volcanism

Vladislav Rapprich [1, 2] – Petr Hradecký [1]

[1] Czech Geological Survey, Klárov 3, 118 21 Praha 1, Czech Republic. E-mail: rapprich@cgu.cz, hradecky@cgu.cz
[2] Charles University, Faculty of Science, Institute of Petrology and Structural Geology, Albertov 6, 128 43 Praha 2, Czech Republic

Abstract. The Cinotepeque Range is a geological block in NW El Salvador with a complicated volcanic history. Due to the absence of data concerning the geological basement, it remains unclear when volcanic activity started in this zone. The oldest rocks found in the Cinotepeque Range are rhyolitic basal ignimbrites produced from unknown sources. Volcanic activity then proceeded with the silicic pyroclastic products of calderas, the activity of which can be traced up to the Holocene. It is difficult to identify the exact sources of individual pumiceous deposits. Their potential candidates are the three calderas Ilopango Antiguo, Old Coatepeque, and Chilamatal. Later, extrusions of lava sheets of "inferior" and "superior" andesites, interrupted by the deposition of agglomeratic pyroclastic flows, called "Rana", covered the majority of the landscape. The Rana pyroclastic flows were most probably produced from Texistepeque Caldera located between the towns of Santa Ana and Metapán. The youngest volcanism is represented in this area by monogenic volcanic cones. Source vents of these youngest volcanic products are situated mostly on faults that cut and displace all older volcanic rocks. Two different processes of magma origin occurred during the volcanic history of this part of El Salvador: a) during the first stage magma originated by flux melting at a subduction zone; b) during the next stage the decompressional melting in a back-arc environment occurred.

Key words: El Salvador, Cinotepeque Range, volcanostratigraphy, back-arc volcanism, Rana ignimbrite

Introduction

Geological research in El Salvador by the Czech Geological Survey began in the year 2003 with studies of the Conchagua Peninsula (Hradecký et al. 2003) and continued in the areas of Guazapa Volcano and Cinotepeque Range (Hradecký et al. 2004, Fig. 1). There is lack of geological knowledge of the Cinotepeque Range. The geological and volcanological interest in El Salvador is mainly focused on the active volcanic chain associated with the Central American Trench. Some geological observations from El Salvador in general, and of this area in particular, were presented by Weber et al. (1974), Wiesemann (1975), and Wiesemann et al. (1978) as the results of geological mapping of the country on the scale of 1 : 100 000, carried out by a German geological expedition during the years 1967–71.

Geological setting

Cinotepeque Range differs in its volcanic evolution from the geological block of Guazapa. It is situated north of Central Valley and east of Chilamatal Caldera, near the towns of Guazapa, Aguilares, San Juan Opico, San Pablo Tacachico, and Quezaltepeque. The range has been named after the dominant cone, Cinotepeque (665 m a.s.l.), which is situated in its northern part. The Cinotepeque Range is delimited by the Rio Lempa Valley in the north, by the Rio Acelhuate Valley to the east, and the northern boundary fault of the Central Valley depression on the south. On the west it passes continuously into the eastern slopes of the ?Pliocene Chilamatal Caldera. Acelhuate Valley is bound to the major N-S trending subsidence fault (fault *a*, Fig. 2), and is filled with pyroclactic and epiclastic material from the Ilopango Caldera. The Cinotepeque Block is uplifted in relation to the Guazapa Block along this fault.

The chain of volcanic cones of the Cinotepeque Range continues to the south across the northern boundary fault of the Central Valley depression (fault *b*, Fig. 2), to the surroundings of the town of Quezaltepeque. The volcanic edifices of the Cerro El Playón–Grandes Bloques System are situated to the west of Quezaltepeque town. These volcanic

Figure 1. Area of the geological research localized on a map of El Salvador. 1 – main cities, 2 – study area limits, 3 – calderas: a – Coatepeque, b – Ilopango, 4 – volcanoes of the volcanic front: c – Chingo, d – Santa Ana, e – Izalco, f – San Salvador, g – San Vicente, h – Usulutan, i – San Miguel, 5 – extinct volcanoes: k – Guazapa, l – Conchagua.

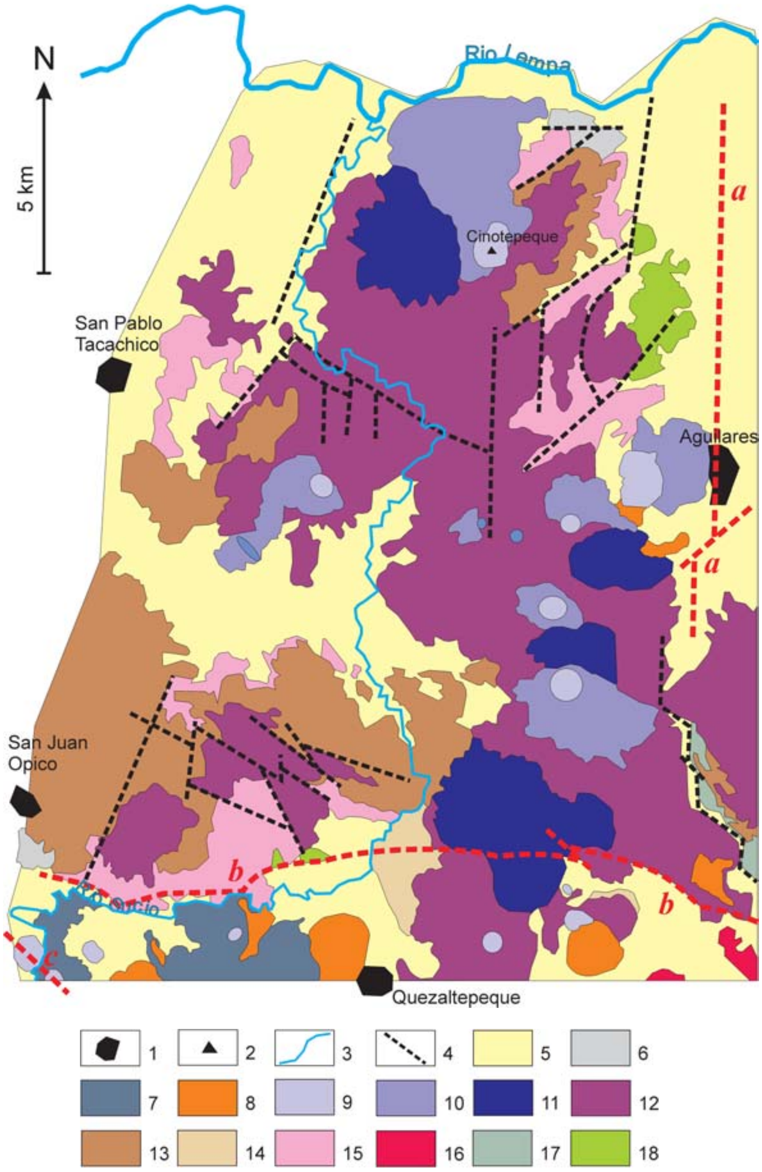


Figure 2. Simplified geological map of the Cinotepeque Range (after Hradecký et al. 2004, adapted): 1 – urban areas, 2 – dominant peak, 3 – river, 4 – major geological fault (those mentioned in text are in red: *a)* Rio Acelhuate valley Fault, *b)* Central Valley northern boundary fault and *c)* Cerro El Playón–Grandes Bloques Fault), 5 – sedimentary rocks (colluvial, fluvial, anthropogenic) almost alternating with Tierra Blanca and products of Coatepeque Caldera, 6 – deposits of debris avalanches, 7 – lavas of the El Playón – Grandes Bloques System, 8 – maar sequence, 9 – cinder cone, 10 – lava produced from cinder cone, 11 – lavas of smaller shield volcanoes and lava cones, 12 – Superior Andesites, 13 – Rana pyroclastic flows, 14 – San Antonio fall out tuffs, 15 – Inferior Andesites, 16 – lavas of Nejapa and Guaycume, 17 – Products of Ilopango antiguo, 18 – Basal Ignimbrites.

bodies are aligned along NW-SE trending fault (fault *c*, Fig. 2), which connects them with the magma chamber of the San Salvador Volcano. For additional information and geochemical data on the San Salvador Volcano and its adventive craters, see Sofield (1998, 2004).

There are neither written nor oral reports on the historical activity of the youngest cones of the Cinotepeque Range, but their juvenile shape and the freshness of their scoria fragments suggest that some are of Holocene age, and might even correspond to the period of historical settlement. Large areas of the southern part of Cinotepeque Range are covered with tuffs of the last Ilopango eruption – Tierra Blanca Jóven (TBJ). Some smaller amounts of Coatepeque tuffs also reach the western part of this range.

Methods

A new geological map on the scale 1 : 50,000 (see a simplified version in the Fig. 2) was compiled during eleven weeks of field work, supported by the study and interpretation of aerial photographs. Detailed mapping enabled the description of the spatial distribution of newly defined units. Documenting the observed sequence of individual members from numerous small-scale outcrops, and some larger ones, allowed us to work out the complex volcanostratigraphy of the Cinotepeque Range.

Laboratory investigations resulted in the petrologic characterization of the rock types. Silicate analyses were completed by roentgen-fluorescence analyses (XRF) for selected trace elements. All the analyses were carried out in the laboratories of the Czech Geological Survey in Prague. Analytical data were recalculated to a water-free base and plotted in diagrams using the GCDkit software (Janoušek et al. 2003). These diagrams were graphically corrected using CorelDraw software. The analytical data were grouped and interpreted according to affiliation with the individual volcanic sequences. The TAS diagram of Le Bas et al. (1986) and the Nb/Y–Zr/TiO_2 diagram of Winchester and Floyd (1977) were used for the classification of the rocks. For description of main geochemical characteristics, AFM (Irvine and Baragar 1971) and SiO_2–K_2O (Peccerillo and Taylor 1976) diagrams were used. Diagrams of MgO–Nb and MgO–Ba/La (after Walker et al. 2000) were constructed for distinguishing the volcanic rocks of the volcanic front ("VF") from those from behind the volcanic front ("BVF").

The volcanostratigraphy of Cinotepeque was evaluated and compared with that of the Conchagua Peninsula (Hradecký et al. 2003) towards understanding which stratigraphical units are of regional distribution, and which are only local.

Results

Geology and stratigraphy

The spatial distributions of the lithological units are shown on the geological map (Fig. 2). Sedimentary and volcanic sequences are arranged chronologically in the legend. For a better understanding of the stratigraphic relations, we draw attention to the proposed stratigraphical column in Fig. 3.

The oldest rock formation observed in the area of Cinotepeque Range is designated as the Basal Ignimbrite (Fig. 2, No. 18). This formation consists of strongly welded, rhyolitic ignimbrites that may be correlated with the Basal Ignimbrites on Zacatillo Island and Conchagua Volcano in eastern El Salvador (Hradecký et al. 2003). The Basal Ignimbrites occur in two separated areas of the Cinotepeque Range. Massive grey ignimbrites with black glassy fiamme (up to 3 cm) and tiny phenocrysts (quartz and feldspars up to 1mm across, clinopyroxene, orthopyroxene, and Fe-Ti oxides – all of X0 μm) occur in the vicinity of Atapasco village (SW margin of Cinotepeque Range – north of the town of Quezaltepeque). This block was named the Atapasco Ignimbrite after the village. Deformed glass shards show no signs of hydratation and/or devitrification (see Fig. 4). On the NE rim of the Cinotepeque Range (NW of Aguilares), a second block of Basal Ignimbrites occurs, called the Delicias Ignimbrite. Stripes or fine laminae of grey and pink or violet colours are typical for these rocks. They are even more compacted and completely devitrified.

Two types of devitrification and secondary modification processes were observed within these originally glass-rich ignimbrites: a) the crystallization of chalcedony spherulites; and b) the recrystalization of silica-rich glass into microcrystalline quartz. These two processes are closely associated (see microphotograph on Fig. 5).

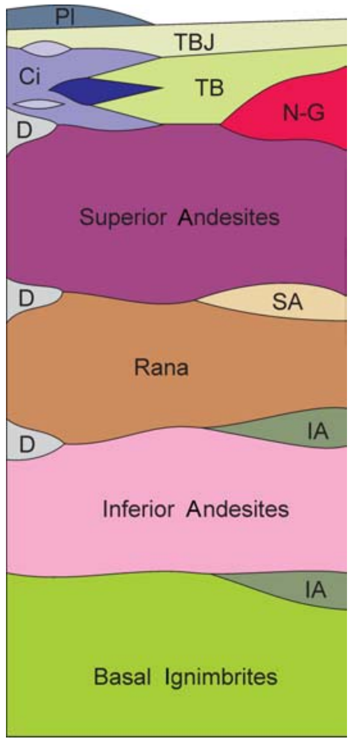
Basal Ignimbrites occur in tectonic relics or in erosional windows. Their original extent and source vents are unknown. They may represent the initial phase of Cenozoic volcanism in El Salvador, which created a basement of younger volcanic products. Stratigraphic comparison with other Central American ignimbrite phases remains unclear, which is why radiometric data are needed.

At some locations slightly welded pumiceous pyroclastic flow deposits, or dacitic Plinian fall-out tuffs, were observed beneath the Inferior Andesites or beneath the Rana flows (Fig. 15). These are believed to be ancient products of the Quaternary Ilopango or Coatepeque Calderas or the ?Pliocene Chilamatal Caldera. Lack of data on these ancient pumiceous deposits and bad exposure prevents these rocks from being more clearly distinguished, and the matching of individual deposits to their respective sources.

Paleobotanical findings from some silicic and intermediate pyroclastic deposits north and east of Guazapa probably correspond to the Chalatenango Formation (dated as Upper Miocene, Kvaček in Hradecký et al. 2004).

Extensive effusions of andesitic lavas represent a significant proportion of the Cinotepeque basement. Sheet effusions were divided into two groups, which differ in stratigraphic position and chemical composition. A similar subdivision was used during the 2003 studies in eastern El Salvador, and is reliably anchored in the Neogene volcanic stratigraphy of Central Nicaragua (Hradecký et al. 2003, 2004). Both of these individual groups comprise thick and laterally wide spread sheet-like lava fields. The older andesites, designated as "inferior" are of more acidic, andesitic s.s. composition. The Inferior Andesites were covered by thick younger volcanics and currently occur in tectonically or erosionally exposed margins of the Cinotepeque Block.

Figure 3. Stratigraphic column of the Cinotepeque Range based on field observations (no borehole data are available). The stratigraphic scheme is not in scale (maximum thickness of the Rana deposits in the Cinotepeque Range reaches 100 m, as does the thickness of the Superior Andesites, whereas thicknesses of young basaltic edifices vary from several meters to tens of metres). Thicknesses of Inferior Andesites, Ilopango antiguo or Basal Ignimbrites remain unknown. Colours correspond to the geological map on the Fig 2. Pl – lavas and scorias of El Playón – Grandes Bloques system, Ci – products of the Cinotepeque monogenic cones system, TBJ – tuffs and epiclastic material of Tierra Blanca Joven, TB – pyroclastic flow and fall-out deposits of Tierra Blanca



Andesitic agglomeratic "block and ash" pyroclastic flows, called the Rana deposits, were probably produced from the Texistepeque Caldera, which is located 6 km north of Santa Ana city. These deposits consist of moderately welded, poorly sorted andesitic agglomerates. Juvenile vesiculated andesitic fragments mostly of 8–12 cm across (sometimes up to 30 cm) are enclosed within a matrix of ash and small-scale lithics. The brown-violet colour corresponds well to the intermediate composition of this material. Weathering of these deposits produces surfaces that are reminiscent of the skin of toad (rana = toad in Spanish). Characteristic "warts" of more resistant andesitic fragments were exposed by small-scale selective removal of finer matrix. Rock fragments can be concentrated in the basal flow units (Fig. 14). On many outcrops, deposits of associated ground-surge and ash-cloud-surge were observed (see Fig. 6). The Rana deposits consist of multiple flow units from a series of eruptions. Short interruptions in activity of the Texistepeque Caldera were documented by thin intercalations of fluvial sediments or local thin lava flows between the individual flow units of the entire sequence. The complete thickness of the Rana sequence reaches about 100 m in the region of Cinotepeque Range. Agglomerates often built up vertical rock walls (Fig. 7). In some localities these steeply dipping cliffs were unstable and prone to collapse, and thus debris flows were triggered.

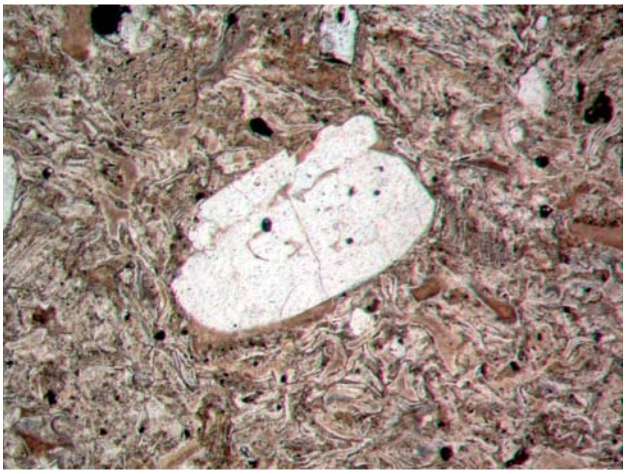


Figure 4. Microphotograph of the Atapasco Ignimbrite. Note the deformed glass-shards curving around rigid phenocrysts. Real size of the picture is 1.6 mm.

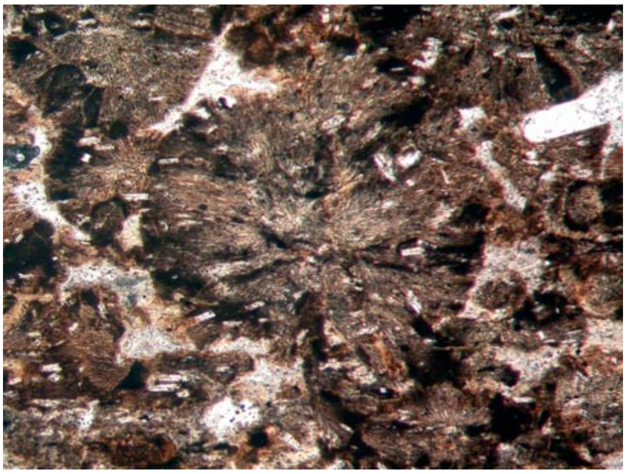


Figure 5. Microphotograph of the Delicias Ignimbrite. Two types of devitrification (spherulites and micro-quartz) alternate in very small distances. Real size of the picture is 3 mm.

Figure 6. Block of the Rana deposits – well developed ash-cloud surge structure and coarse units. Real scale of the block being showed is 0.8 x 1.2 m. (Photo by Petr Hradecký)

Similar phenomena can be seen also in the marginal parts of deeply eroded Texistepeque Caldera.

Younger lava sheets of basaltic to basaltic andesite composition covered the Rana pyroclastic flows. They are designated the Superior Andesites by the present authors because of their stratigraphic position. Their spatial extent and degree of weathering are quite similar to those of the inferior andesites, which sometimes complicates discriminating between them. However, they are easily distinguished at outcrops that show their relations to the Rana deposits (the Inferior Andesites underlying the Rana deposits, while the Superior Andesites overlie the Rana). Such local observations had to be applied also to the rest of the area.

Lavas of the Superior Andesites were produced from numerous sources. Later volcanic and tectonic activity destroyed the original sources or vents. Effusions of these more basic lavas began when extensional activity in the BVF environment occurred in this region. The decompressional melting of an uplifted mantle slab is demonstrated by the chemical composition of these lavas (discussed below). The Superior Andesites in central El Salvador are the oldest rocks showing the BVF character. Future radiometric dating will define the time span during which the extension and mantle slab emplacement started.

The youngest, freshest, and morphologically most distinctive volcanic forms in the Cinotepeque Range are the ?Upper Pleistocene to Holocene monogenic cones. They were subdivided into two groups according to their geotectonic position, composition, and magmatic affinity.

A NW-SE trending fault is located on the SW margin of the Cinotepeque Range, west of Quezaltepeque city and south of San Juan Opico (fault *b* in Fig. 2). This fault runs southeastward to the center of the San Salvador Volcano. Several scoria cones and maars located on this fault erupted with a more differentiated magma (basaltic andesite) than became current in the cases of such monogenic cones. Their chemical composition (sample No. 81 in this paper, see also Sofield 1998) corresponds to that of the lavas of the San Salvador Volcano. This magmatic system, known as the Cerro El Playón–Grandes Bloques System, is therefore related to the magma chamber of San Salvador. Magmatism associated with this fault is still active. The last strombolian eruptions associated with lava effusions (Cerro El Playón) occurred in the years 1575 and 1658. This system differs in more differentiated composition and melt origin (flux melting at subduction zone, discussed below) from the Cinotepeque System.

Monogenic cones of the Cinotepeque System are located on several N-S and NW-SE trending faults. This relatively young local volcanism of primitive magma is represented in several types of volcanic forms. Aside from common cinder cones and maars, some smaller shield volcanoes and lava cones were also observed. The direction of this system of faults is oblique to the Salvadorian part of the Central American Trench, and they are of extensional character (Baratoux in Hradecký et al. 2004). The chemistry of the lavas and scorias of the Cinotepeque System shows the origin of their magmas by decompressional melting in the BVF environment. There is no report on the historical activity of the cones of the Cinotepeque

Range, but their well-preserved shape and the freshness of their scoria should indicate a very young (probably Holocene) age. Unfortunately, no carbonized wood to be used for ^{14}C dating was found within deposits of these volcanoes. The southern parts of the Cinotepeque Range are often covered by distal fall-outs of the last Ilopango eruption.

Volcanism

As the origin and composition of the magmas erupted in the Cinotepeque were changing during the history of this region, the eruption style likewise varied. After voluminous, silicic, explosive activity from large calderas, the effusion of the inferior andesites took place. The sources of the Basal Ignimbrites and the Inferior Andesites are no longer preserved.

The newly described Rana volcanic sequence may have been produced by multiple eruptions of the Texistepeque Caldera. The character of these pyroclastic flows suggests that they resulted from lava dome explosions or the over boiling of gas-rich magma from andesitic-caldera faults.

The effusive activity of the Superior Andesites was probably similar to that of the inferior ones. Basic to intermediate lavas (basalt to basaltic andesite) accumulated to thicknesses of several tens to one hundred metres.

Small-scale local forms represent volcanism of the last eruptive episode of the Cinotepque Range. Common cinder cones are accompanied by several maars, some smaller shield volcanoes, and by lava cones. In some cases, selective erosion has exposed one dyke and two isometric compact vent fillings. Successions of phreatomagmatic and Strombolian/Hawaiian activity were observed at many of these occurrences. A list of the individual younger volcanic forms (some of them newly observed) is presented in Table 1.

Five well-preserved maar structures have been documented, another three represent erosional remnants. Phreatomagmatic activity is evinced in the base surge deposits, and some bigger fragments of fall origin are preserved with bomb-sags structures (Fig. 9). Most of maar structures are situated in the southern part of the studied area.

Several cinder cones have been located in the area, some of which are situated close to the maar craters and represent the continued dry activity of the magma chambers. Some cones are associated with small lava flows. Both scoria and lava show the primitive basaltic composition. Several forms of lava without pyroclastic deposits were documented in the area. In the geological map in Fig. 2, we have tried to differentiate between the lavas of the lava cones and those associated with scoria cones, according to the differences in activity style. The term "lava cone" is used for the smaller-scale effusive vents of slightly higher viscosity lavas that do not create flat shields, but elevated volcanic edifices of conical form. Their higher viscosity was probably due to lower temperature and higher degree of crystallinity, as the chemical composition is very similar to the lavas of the cinder cones and shield volcano. Usage of this term distinguishes these forms and their activity from the more explosive activity of cinder cones and the lower viscosity of lavas erupted from shield volcanoes. Lava cones are current in the Guazapa Block, but scarce in the Cinotepeque area. Their lavas have a basaltic to basaltic andesite composition.

Figure 7. High cliffs of Rana pyroclastic flow deposits on the NE margin of the Cinotepeque Range. (Photo by Vladislav Rapprich)

Figure 8. Cinotepeque scoria cone. Prominent, fresh-looking volcanic body. (Photo by Petr Hradecký)

In the Cinotepeque area one shield volcano was identified, named Ojo del Agua (points 50, 52). It is probably of the same age as the young monogenic volcanic forms around it. Its lavas are less viscous compared with those of the cinder cones. Most of the lavas flowed northwards. The volcano is situated on the fault that delimits the regional Central Graben (fault *b* in Fig. 2). The fault was reactivated after the volcanic activity, and cut the volcanic edifice into two parts. The southern part subsided some 50 metres.

In some cases erosion has destroyed the original volcanic surfaces, and only vent-filling rock remained from the former volcano. Such a case was documented as a point 431 at the small hill of Cantón Segura (467 m a.s.l.), which is situated 6 km SW of Aguilares. Its vent consists of massive basalt. Another small vent-filling body lies in Caserio Los Anzora (482 m a.s.l.), 7 km west of Aguilares, with the associated small lava flow (point 432). Loma Chata, which is at a low elevation 5 km SE of San Pablo Tacachico, is a dyke surrounded by an old volcanic edifice. In the south, the youngest TBJ ashes cover most of these monogenic forms.

Table 1. List of young monogenic volcanic forms of the Cerro El Playón–Grandes Bloques (“P-GB” in table) and the Cinotepeque (“CINO” in table) systems. CC – cinder cone, LC – lava cone, SV – shield volcano, p. – documentation point.

Name	Type	System	Location	Description
Loma Caldera	maar	P-GB	S of small volcano Laguna Caldera	ring of maar deposits, partly covered by strombolian scoria of Laguna Caldera
Caldera Escondida (Sofield 1998)	maar	P-GB?	1 km SE of Cerro Las Viboras	greater part of maar structure is covered by Las Flores lava
Pueblo Viejo (Hradecký et al. 2004)	maar	P-GB?	W of Pueblo Viejo village (p. 87 in Hradecký et al. 2004), 5 km W of Quezaltepeque	base surge and fall-out deposits were documented in the relic of maar. Maar has been destroyed by the Sucio river and its tributaries and partly buried by lavas of El Playón (1658) and La Primavera.
Lava Caldera (Sofield 1998)	maar	??	2.5 km WNW of Quetzaltepeque (p. 71 in Hradecký et al. 2004)	most of the structure is filled by El Playón lavas. Small scoria cone rests in the bottom of the crater.
Quetzaltepeque	maar	??	W limits of town of Quetzaltepeque	tuff ring is composed of basaltic surge and falls with fragments up to 2–5–20 cm in diameter
La Tabla (Hradecký et al. 2004)	maar + CC	CINO	5 km E of Quetzaltepeque (p. 24, 67 and 68 in Hradecký et al. 2004)	surge and fall deposits are mostly covered by the TBJ Ilopango ashes. Continuing explosive activity formed small Cerro La Tabla scoria cone in N limits of maar crater.
Acelhuate (Hradecký et al. 2004 and Wiesemann et al. 1978)	maar	CINO	7.5 km ENE of Quetzaltepeque (p. 62 and 407 in Hradecký et al. 2004)	structure is cut by the Acelhuate River. This maar is situated upon the N-S trending fault. Faulting caused the lithologic differences in W and E crater walls.
La Esperanza (Hradecký et al. 2004)	maar	CINO	1.5 km SW of Aguilares (p. 502 in Hradecký et al. 2004)	two relics of former maar structure: one of them crops out beneath the Cerro Chino scorias, another forms the half ring elevation in the S. Badly sorted fall deposits reveal the bomb-sag structures. W part of the maar is covered by lavas of Cerro Las Tunas volcano and by colluvial deposits.
Laguna Caldera	CC	P-GB	3 km S of San Juan Opico (p. and analyses 23 and 74 in Sofield 1998)	cone built after the phreatic activity of the volcano which destroyed the Joya de Cerén Mayan settlement
Laguna Ciega (Sofield 1998)	CC	P-GB	0.5 km SE of Laguna Caldera (p. and analyses 67 in Sofield 1998)	small cinder cone
Las Viboras (Sofield 1998)	CC	P-GB?	1.5 km E of Laguna Caldera (p. 89 in Hradecký et al. 2004)	small cinder cone
El Pollo (Hradecký et al. 2004)	CC	??	3 km WNW of Quetzaltepeque (p. 86 in Hradecký et al. 2004)	low scoria cone inside the Lava Caldera maar
Buenos Aires (Hradecký et al. 2004)	CC	CINO	2.5 km NE of Quetzaltepeque (p. 21 in Hradecký et al. 2004)	scoria cone located upon the elevated tectonic block composed of superior andesite
Mulunga (Hradecký et al. 2004)	CC	CINO	5 km ENE of Quetzaltepeque (p. 25 in Hradecký et al. 2004)	small cinder cone situated on the NW-SE trending fault
Cerro Redondo (Hradecký et al. 2004)	CC	CINO	1 km S of Tutultepeque, 6 km SSW of Aguilares (p. 11 in Hradecký et al. 2004)	cinder cone with basaltic lava erupted to south
Cerro Segura (Hradecký et al. 2004)	CC	CINO	5 km SW of Aguilares (p. 499 in Hradecký et al. 2004)	deposits of Strombolian and Hawaiian activity were accompanied by lava effusion. The cone is cut by dextral fault NE-SW which was also a conduit of volcanic eruption.
Santa Rita (Hradecký et al. 2004)	CC	CINO	4 km WSW of Aguilares (p. 406 in Hradecký et al. 2004)	cinder cone and basaltic lava flow
Cerro Chino	CC	CINO	1.2 km W of Aguilares (p. 416, 417 and 419 in Hradecký et al. 2004)	one of the largest cinder cones in the area with 1.2 km^2 of area covered by edifice
San Augustín (Hradecký et al. 2004)	CC	CINO	6 km SE of San Pablo Tacachico (p. 386 in Hradecký et al. 2004)	cinder cone with associated basaltic lava flow (point 387)
Cerro Cinotepeque	CC	CINO	6 km NW of Aguilares (p. 404 in Hradecký et al. 2004)	cone with very fresh morphology almost without vegetation. Crater is well preserved, opened towards the W. Long lava flow (p. 436) reaches up to 4 km of distance from the cone and covers wide area. Another, small flow was produced towards the S.
Santa Rosa (Hradecký et al. 2004)	CC	CINO	1.5 km NE of San Matias, 5 km E of San Juan Opico (p. 411 in Hradecký et al. 2004)	relic of cinder cone, destroyed by erosion, situated in the Santa Rosa village. It is situated upon the NW-SE trending normal fault; part NE of cone down-tilted several tens of meters. This faulting started the cone destruction.

Table 1, continued

Name	Type	System	Location	Description
Las Tunas (Hradecký et al. 2004)	LC	CINO	3 km SW of Aguilares	cone formed of basaltic lavas
Picado (Hradecký et al. 2004)	LC	CINO	5 km SW of Aguilares	cone formed of basaltic lavas
Los Dos Cerros (Hradecký et al. 2004)	LC	CINO	6 km NE of San Pablo Tacachico	cone formed of basaltic lavas
Ojo del Agua (Hradecký et al. 2004)	SV	CINO	4 km NE of Quetzaltepeque (p. 50 and 52 in Hradecký et al. 2004)	shield volcano cut by N marginal fault of Central Graben

Chemical composition and magma origin

The results of major element and selected trace element analyses are presented in Table 2. Classification was based on comparison of the TAS diagram (Le Bas et al. 1986 – see Fig. 10) with the Nb/Y–Zr/TiO_2 diagram (Winchester and Floyd 1977 – see Fig. 11). The application of these two diagrams was necessary due to content of water in the samples of pyroclastic materials. A wide spectrum of compositions is shown in these diagrams. The oldest rock, represented by the Atapasco Basal Ignimbrite, is of rhyodacitic or rhyolitic composition, in agreement with macroscopic and microscopic observations.

Samples of the Rana pyroclastic flow deposits have been affected by weathering (total water content is over 17 %), and are strongly depleted in alkalis (see Fig. 10). This is why the Nb/Y–Zr/TiO_2 diagram was also used to classify this rock. This diagram showing the proportions of immobile elements confirmed the andesitic composition deduced from the TAS diagram and macroscopic observations.

The difference between the Inferior and Superior Andesites is very similar to that between equivalent rocks in eastern El Salvador. Similarly, in the Conchagua Peninsula and in central El Salvador the Inferior Andesites are more evolved and silicic than the Superior ones (see Fig. 10 for comparison with rocks from eastern El Salvador).

The most basic rocks are represented in lavas and scorias of young monogenic cones. We draw the attention to the relatively wide compositional range of the magmas of these monogenic cones, where no differentiation could be made. The lavas of Cerro El Playón have a more evolved composition (basaltic andesite) in comparison to the Cinotepeque System. This can be explained by a possible connection between the cones of the Cerro El Playón–Grandes Bloques System and the more evolved magmatic system of San Salvador Volcano. On the other hand, the products of the Cinotepeque System are of a more primitive character (see Fig. 10).

Walker et al. (2000) presented numerous diagrams to demonstrate differences between VF and BVF volcanites, of which their MgO-Nb and MgO-Ba/La diagrams are of the most value. In their other diagrams, the distinction between both defined groups is unclear, while their main discriminating factor, "distance from volcanic front", is doubtful. In the MgO–Nb and MgO–Ba/La diagrams (Figs 12 and 13) two clusters of data are distinctive. High MgO/high Nb values characterize rocks of BVF, whereas low MgO/low Nb values characterize rocks of VF in the MgO–Nb diagram. In the MgO–Ba/La diagram, high MgO values are accompanied with low Ba/La in the case of BVF volcanics, whereas high Ba/La values accompany the low MgO values in the VF volcanics. The clustering of values and their interpretation are the same in these two diagrams.

Figure 9. Balistic deposits of phreato-magmatic eruption with bomb-sag structures beneath larger fragments. Maar Rio La Esperanza 1.5 km SW of Aguilares. (Photo by Vladislav Rapprich)

Analyses of the Inferior Andesites, Rana deposits, Basal Ignimbrites, and lava 1575 from Cerro El Playón cluster in the field of VF volcanics. Therefore, it can be supposed that the magmas of all these sequences were produced by flux melting at a subduction zone. Concerning Cerro El Playón lava 1575, our analyses evince a connection with the magmatic system of the San Salvador Volcano, and a distinction of the Cerro El Playón–Grandes Bloques System from the Cinotepeque System.

BVF rocks are characterized by higher MgO and Nb, and lower Ba/La values, which can be interpreted as a result of decompressional melting in the BVF environment (Walker et al. 2000). Two samples of BVF in the VF cluster (one of lavas of Cinotepeque System, and one sample of the Superior Andesites from eastern El Salvador) could be wrongly classified in the field.

Discussion

Field work together with laboratory investigation from the area of the Cinotepeque Range allow the volcanostratigraphic comparison of central El Salvador with that of eastern El Salvador. The main point deduced from this compa-

Table 2. Chemical analyses of the volcanic rocks of Cinotepeque range.

Sample Sequence	1	41	81	336	416	427	432	436	438	521	617
oxides (wt.%)	Inferior Andes.	Cinot. sys.	Playón 1575	Basal Ignim.	Cinot. sys.	Cinot. sys.	Cinot. sys.	Cinot. sys.	Cinot. sys.	Super. Andes.	Rana
SiO_2	58.03	52.81	55.48	67.76	49.68	53.7	52.85	51.04	51.33	52.38	49.51
TiO_2	0.78	1.02	1.31	0.55	0.92	0.99	0.97	1.13	1.08	0.92	1.1
Al_2O_3	17.41	17.32	15.1	14.56	17.38	19.19	17.03	17.82	17.66	17	19.82
Fe_2O_3	4.17	3.1	4.17	2.06	4.34	7.14	3.52	2.4	3.72	3.18	7.92
FeO	1.52	5.86	6.96	0.57	5.48	1.27	4.97	6.57	5.12	5.15	0.03
MgO	1.91	4.86	2.95	0.47	6.45	1.72	5.71	5.99	5.93	5.64	1.02
MnO	0.133	0.181	0.273	0.106	0.199	0.178	0.178	0.191	0.175	0.168	0.107
CaO	6.03	8.3	6.9	1.68	10.22	7.57	8.54	9.28	8.62	8.88	1.43
Na_2O	4.03	3.26	3.91	3.97	2.68	3.87	3.31	3.36	3.48	3.24	0.77
K_2O	1.6	1.45	1.75	4.01	0.68	1.52	1.3	1.07	1.21	1.26	0.72
P_2O_5	0.244	0.388	0.338	0.084	0.189	0.24	0.275	0.27	0.314	0.282	0.044
H_2O^+	2.38	0.9	0.31	3.32	0.84	1.3	0.67	0.44	0.42	0.95	8.96
H_2O^-	1.3	0.22	0.08	0.43	0.26	0.68	0.31	0.21	0.22	0.47	8.11
Total	99.54	99.67	99,53	99,57	99,32	99,37	99,63	99,77	99,28	99,52	99,54
Minor and trace elements (ppm)											
Cr	3	72	9	*	149	6	112	71	107	109	179
Ni	*	32	*	6	56	5	42	35	44	36	50
Cu	17	59	127	7	79	47	80	80	50	73	105
Zn	81	85	116	70	76	70	82	70	73	79	95
As	6	4	6	8	4	4	3	6	5	5	6
Rb	45	32	50	95	25	44	31	26	28	29	39
Sr	437	506	346	179	473	492	425	534	507	450	133
Zr	165	185	162	251	65	138	160	128	157	162	145
Nb	3	6	2	5	3	4	7	9	7	6	5
Pb	5	5	9	7		3	9	*	*	2	*
Y	22.3	38.7	37.6	50.8	20	46.8	37.1	19.4	21.5	21.5	29.6
La	12	20.5	11.5	24.5	7.1	20.9	16.9	10.5	13.3	14.4	17.4
Ba	689.7	600.1	707.6	1316.7	358.3	886.7	519.5	376.2	447.9	1289.8	824

Inferior Andes. – Inferior Andesites, Cinot. sys. – lavas and scorias of monogenic cones of the Cinotepeque system, Basal Ignim. – Basal Ignimbrites, Super. Andes. – Superior Andesites, * – not detected.

rison is that not all the earlier and/or newly defined volcanostratigraphic units can be applied regionally. On the other hand, some stratigraphic units are of regional validity. The ages could be estimated by stratigraphic relationships and the correlation of ages known from of the generally similar sequences in Nicaragua and/or Honduras. Radiometric data are needed for the better determination of the volcanostratigraphy of El Salvador.

In the development of the Cinotepeque Range, BVF volcanism played an important role. The composition of the BVF volcanics is similar to the basalts of volcanologically identical areas in Guatemala and Honduras described by Walker et al. (2000). The hypothesis of decompressional melting of a mantle slab emplaced in the space vacated after the breaking-off of a subducted slab is also accepted for the case of central El Salvador. The break-off of a subducted slab was well documented in lower crust/mantle tomography of Central America published by Rogers et al. (2002). As shown above, this petrogenic process can be applied for some older sequences as well. Magmas of the Superior Andesites were produced also by decompressional melting in the BVF environment. Moreover, the Superior Andesites are widely distributed in El Salvador behind the active volcanic chain, thus extensional stress and decompressional melting took place, and perhaps still occurs, along entire El Salvador. Because the exact age of the Superior Andesites remains unknown, it is impossible to say when the processes of decompressional melting in the Salvadorian part of BVF zone began.

Conclusion

Rock composition and stratigraphy of the Cinotepeque Range is comparable with those of eastern El Salvador

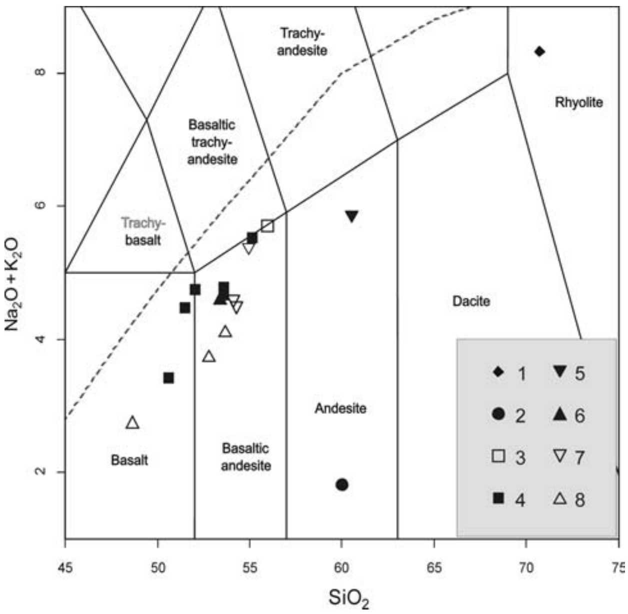


Figure 10. Detail of TAS diagram (Le Bas et al. 1986) with rocks of Cinotepeque Range. For comparison data of Inferior and Superior Andesites from Conchagua Peninsula (E part of El Salvador – from Hradecký et al. 2003) were also plotted in this diagram.
Key: 1 – Basal Ignimbrite, 2 – Rana, 3 – Cerro El Playón lava from 1575, 4 – products of monogenic cones of the Cinotepeque system, 5 – Inferior Andesites, 6 – Superior Andesites, 7 – Inferior Andesites from eastern El Salvador (data from Hradecký et al. 2003), 8 – Superior Andesite from eastern El Salvador (data from Hradecký et al. 2003). Loss of alkalies and thus abnormal position of Rana (solid circle) in the TAS diagram was caused by weathering of clastic and porous Rana material. For this reason Winchester and Floyd diagram (see Fig. 11) is more relevant.

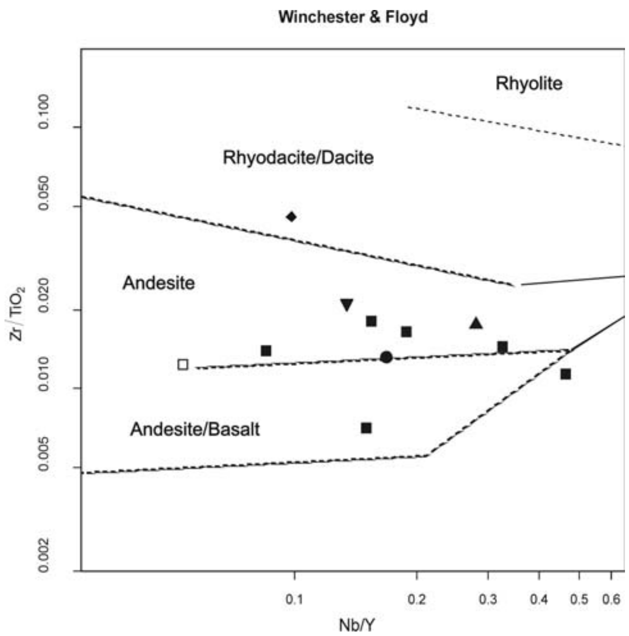


Figure 11. Detail of Nb/Y–Zr/TiO_2 diagram (Winchester and Floyd 1977) of the rocks of Cinotepeque Range. Andesites of eastern El Salvador are not plotted in this diagram. Used symbols correspond to the Fig. 10.

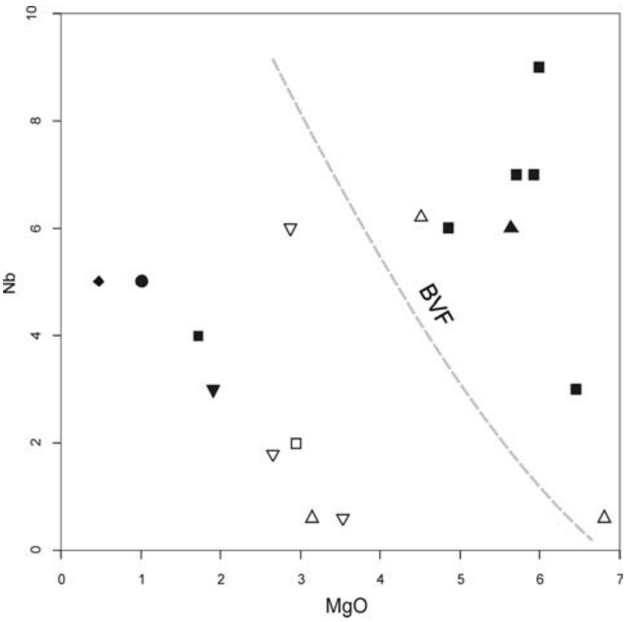


Figure 12. MgO–Nb diagram (after Walker et al. 2000) with plotted analyses of rocks from Cinotepeque Range. Used symbols correspond to the previous Figs. Grey curve deliminates volcanics of the BVF from volcanics of the VF.

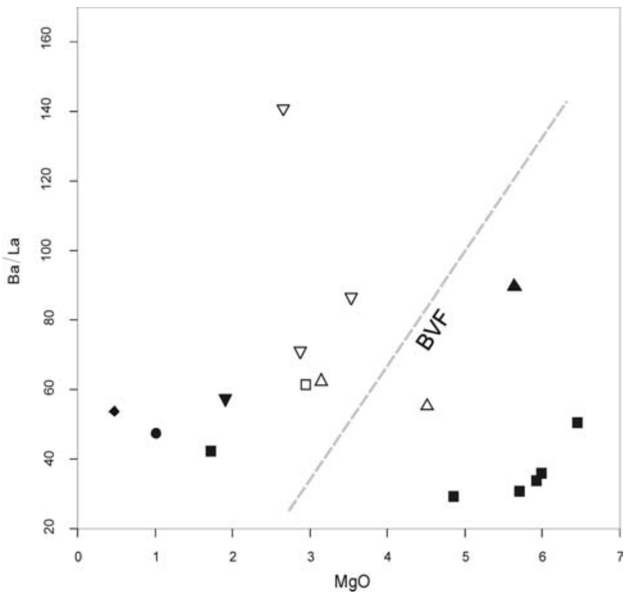


Figure 13. MgO–Ba/La diagram (after Walker et al. 2000) with plotted analyses of rocks from Cinotepeque Range. Used symbols correspond to the previous Figs. Grey curve deliminates volcanics of the BVF from volcanics of the VF.

(Hradecký et al. 2003). The Basal Ignimbrites are of similar appearance and composition in the two areas. They possibly represent connected stratigraphic formations exposed in different parts of El Salvador. The presence of the Inferior and Superior Andesites shows another similarity between eastern and central El Salvador. In both areas, the older Inferior Andesites are of more differentiated character than the Superior ones. The main difference between the two areas is the presence of the San Alejo silicic complex of yet unknown source, which separates both andesitic suites in eastern El Salvador (Hradecký et al. 2003), whereas in central and NW El Salvador the two andesitic suites are separated by the Rana pyroclastic flow deposits. The origin of the magma of the

Figure 14. Fallen blocks of Rana agglomerate flow near Aguilares show flow units with concentration of big rock fragments at the base. (Photo by Petr Hradecký)

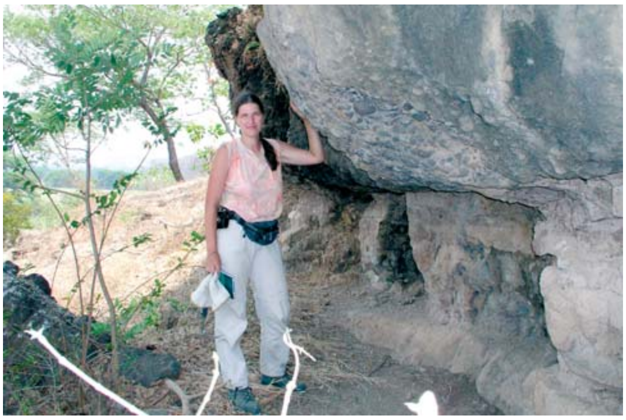


Figure 15. Coarse basal unit of Rana deposits rests upon Old Coatepeque silicic ignimbrite. (Photo by Petr Hradecký)

Superior Andesites differs from that of the Inferior ones in the two areas. The magma of Inferior Andesites was produced by flux melting, whereas the magma of the Superior ones originated by decompressional melting in the BVF environment.

Younger monogenic volcanic forms were subdivided into two systems, which differ in magma origin. The Cerro El Playón–Grandes Bloques System is situated on a NW-SE trending fault that continues to the San Salvador Volcano. The more evolved character of the magmas erupted in this system, and the VF petrochemical characteristics, lead us to interpret it as a system of adventive cones associated with the magma chamber of the San Salvador Volcano. On the other hand, magmas that belong to the Cinotepeque system are of primitive character and were produced by decompressional melting in the BVF environment.

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