# GEOLOGY OF THE AHUACHAPAN-CHIPILAPA, EL SALVADOR C.A. GEOTHERMAL ZONE

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## ABSTRACT

The caldera Concepcion de Ataco in the region of Ahuachapan-Chipilapa represents part of the southern, Plio-Quaternary volcanic belt of Salvador, which forms one of the borders of the Central Graben 17 $km^3$ of alkaline lavas were emitted above a basaltic-andesitic basement and older agglomerates, forming the volcanos Cuyanausul, Apaneca and Empalizada, which preceeded the evacuation of 70 $km^3$ of silicic pyroclastics The pyroclastic sequence is formed by breccias, surges, and ignimbrites Flows occupy the major part with a lateral distribution of 271 $km^2$ The most distal pumice and ash fall deposits are distributed over an area of 484 $km^2$ The release of this material caused a caldera collapse with a dimension of 5 km x 3.5 **kin.** The river Asisno-Sisiniapa carves its bed into this depression

The caldera collapse was reactivated at its NE-tlank by a new evacuation, emitting pyroclastics with limited distribution. The pyroclastics correspond to laminated tuff ("Zebra Tuff") or brown tuff

Dome injections of dacitic to andesitic composition partly border the collapses and the internal parts of the caldera The magmatism shows characteristics of a calcalkaline series, formed by an active continental margin The age varies between Middle Pleistocene and Holocene

Three craters of phreatic explosion type. which are mapped in the east of the caldera structure, released debris locally This activity corresponds to a postmagmatic hydrothermal phase. representing the first superficial occurrence of the emplacement of an active hydrothermal system in this region

## INTRODUCTION

El Salvador is one of the countries of Central America that depends on geothermal energy for power generation The southern volcanic belt represents the principal target of exploration. with major geothermal zones, hot springs, hot wells. fumaroles and exposures of hydrothermal activities (Meyer-Abich, 1953) The increased interest in geothermal energy has been the result of its proven economic advantage over all other alternative energy sources (Campos. 1988)

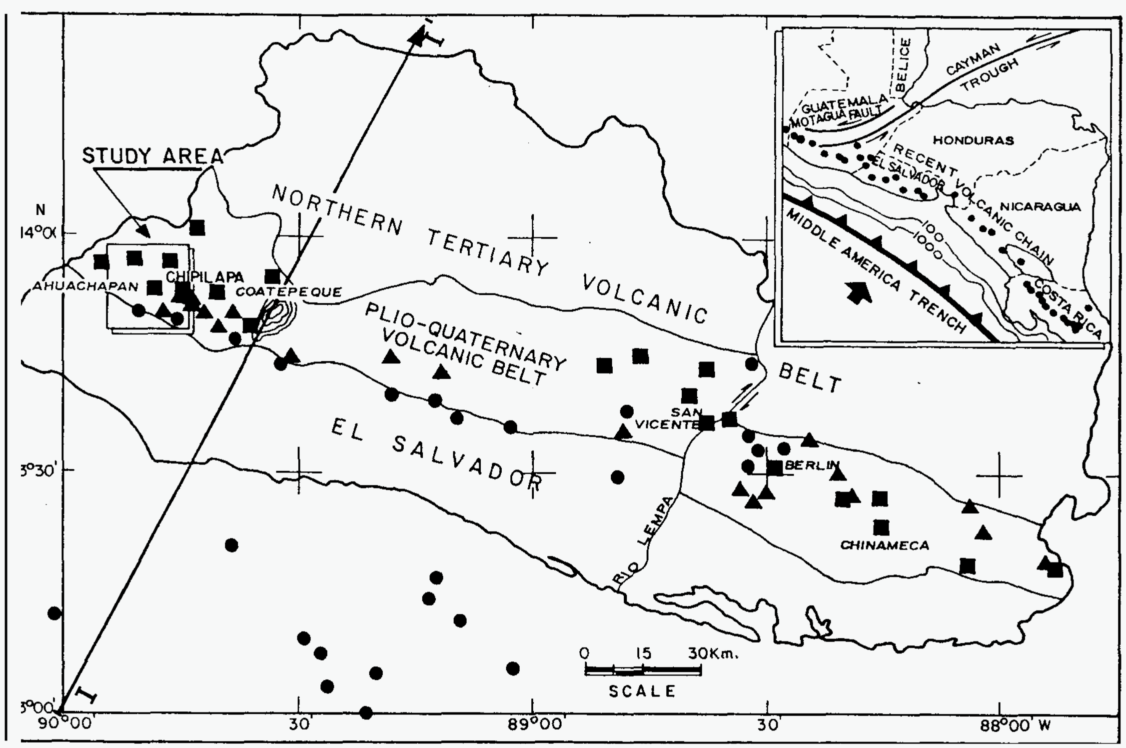


**Fig. 1:** Localisation of the studied area with symbols (filled circle seismic epicenters, tilled triangles. Quaternary volcanos, filled squares thermal springs and geothermal fields)

This paper merges responses fi-om the Comisión Ejecutiva del Rio Lempa (CEL) to understand the volcanic mecanisms which arc related to heat sources. Also, it illuminates the geologic pattern which determines the distribution of the actual hydrothermal fluids in the zones of Ahuachapan and Chipilapa The study of the stratigraphy and the structural behaviour is the main subject of this work

The Ahuachapan - Chipilapa geothermal field is located 80 **kin** west of San Salvador and 15 **kin** froin the border to Guatemala, close to the city of Ahuachapan and Atiquizaya - Turin **(Fig. 1)** The studied zone covers an area of 200 $km^2$ and comprises parts ofthe counties of Santa Ana, Ahuachapán and Sonsonate

## RESIJLTS

### I. Volcanic Stratigraphy

The local basement covers the area south of Concepción de Ataco and the total area of the Sierra de Tacuba Its lithology consists of interlayers of andesitic-basaltic lavas and breccias with the same coinposition The age ofthe andesites is 7 37 ± 0 73 M a Towards the north, the Bálsamo Forination fills the Central Graben with tuffs, agglomerates and ancient pyroclastics (Jonsson, 1970; Electroconsult, 1082)

### 1.1. Pre caldera volcanism

The three volcanos Cuyanausul, Apaneca, and Einpalizada were inapped **(Fig.2)** The first one consists of an alternating sequence of lava, scoria of andesitic to basaltic coinposition. corresponding to a stratovolcano of strombolian type. whose age ranges from 1 3 ± 0 3 to 1 7 ± 0.3 M a Common features are cutoffs by faults Domes and zones of hydrothermal activity affected the northern flank, producing advanced clay mineralization The fumaroles of El Tortugero discharge primary vapour Low resistivitiec ai-e related to the graben with the same name. which is an important aim for deep drilling in the area of Chipilapa Apaneca is a volcano of the same type as Cuyanausul, but is not affected by hydrothermalism and tectonics. Its basalt flows include plagioclase phenocrysts and pyroxenes which arc intercalated with scoria The volcano Empalizada consists of olivine-basalt lava and scoria with an age of 0 7 ± 0 14 M a Its original form is destroyed by a caldcra collapse. marked by the bed of Rio Asino On the other hand, tlie river bed is covered by pyroclastic products of the Caldera Concepción de Ataco The magmatism, previous to tlie forination of the caldera, has a calc-alkaline chemical composition and :jected magma was estimated to comprise 17 $km^3$ (González et al , 1991)

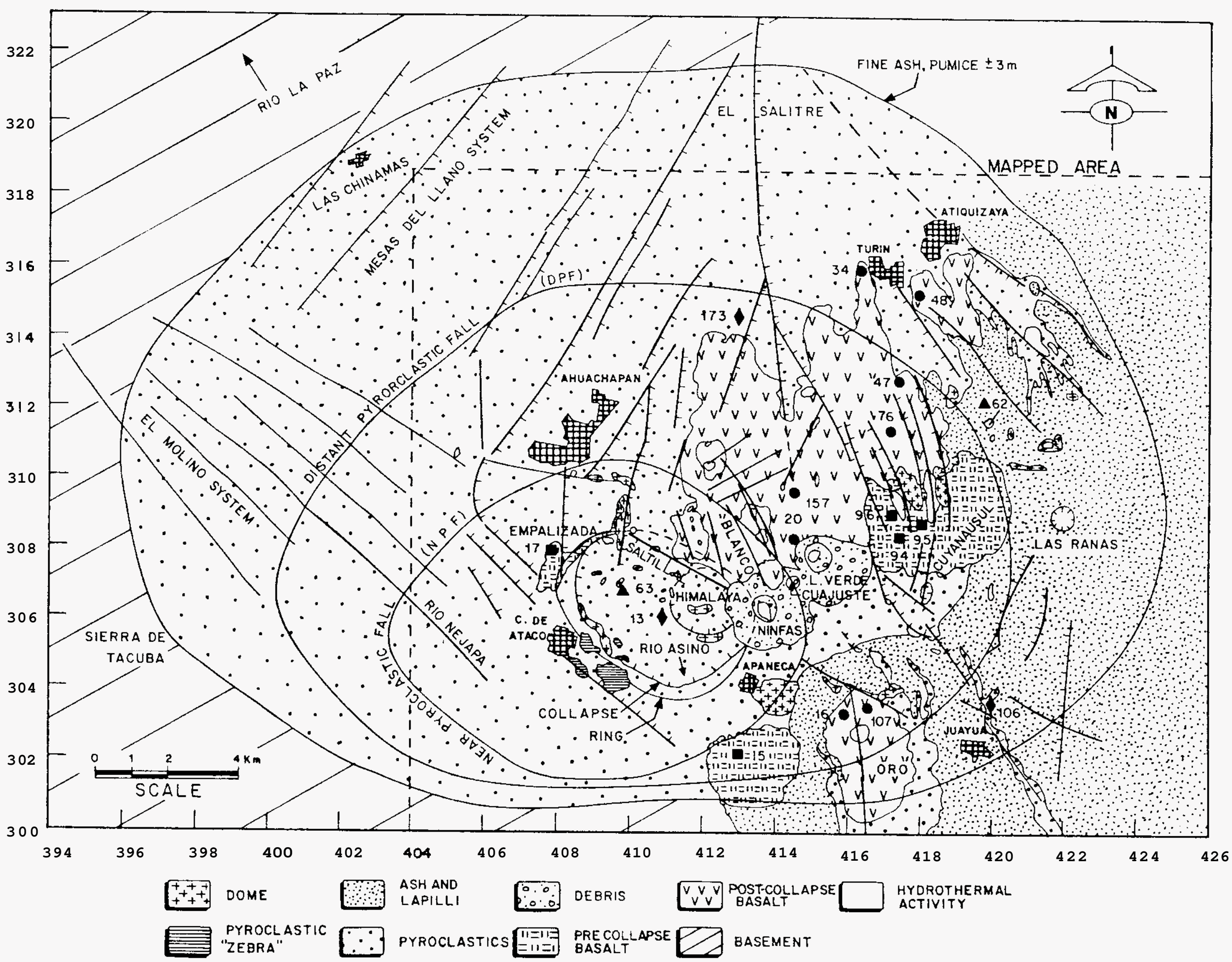


**Fig. 2:** Geological scheme of the geothermal zones at Ahuachapán-Chipilapa, El Salvador C A

### 1.2. Caldera volcanism

Morphological features and the interpretation of satellite images show up clearly the Meseta Concepcion de Ataco-Apaneca. which forins a hydrological subbasin governed by the river Asino-Sisiniapa **(Fig. 2)** The diameter ofthe oval alignment (6 x 4 kin) corresponds to the major caldera collapse

The complete stratigraphic column, which crops out between the river Nejapa (Rio Nejapa) and Meseta de Ataco-Apaneca. is shown in **Fig. 3** It is characterized by a sequence of pyroclastic products. which represents the different petrological phases of an explosive caldera event, defined by González et al (1991). Towards the base of the pyroclastic column. breccias with fragments of the volcano Empalizada, surge deposits. ignimbrites with a thickness of about 20 m and textures of "fiamme" and veiy abundant pyroclastic flows were observed The pyroclastic tlows are covered by pumice and ash fall deposits The thickest section was found inside the ring caldera with variatons between 640 m and 350 m

Petrological and geochemical studies indicate a dacitic-rhyolitic composition with calc-alkaline tendencies and forination temperatures of approximately 650°C ± 50°C for the evacuation moment of the pyroclastic material Petrophysical data (Tor-res. 1991) gives a total density of 0 3780 g/cm$^3$ for the pumice and an average value of 1 98 g/cm$^3$ for the flows.

The lithological scheme of **Fig. 3** represents the distribution of the pyroclastics. The flows cover an area of 231 km$^2$ and the distal pumice an area of 484 km$^2$ with the annotations *of* the indicated thickness The total volume of the pyroclastic inaterial released by the caldera comprises approximately 70 km$^3$

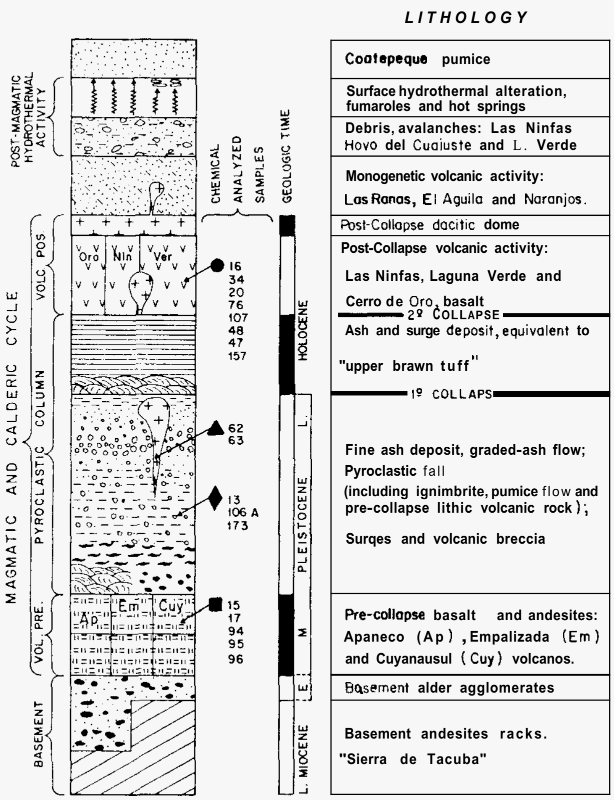


**Fig.** *3:* Stratigraphic column of the studied zone

The determination of rocks sealed by the hydrothermal system is one of the questions to he answered with the help of the reported data. The pyroclastic inaterial, which covers an andesitic-basaltic basement (in which the geothermal deposit of Ahuachapán is located), is considered to be the sealing rock of the hydrothermal system Its largest thickness is observed in Ahuachapan, whereas 80 m are not exceeded in Chipilapan

Paleomagnetism and fission-track measurement confirm that the caldera released its silicic products within the period from Middle to Late Pleistocene Numerous rock samples were taken from the ignimbrites for studies of reinanent paleomagnetism. which shows normal polarity for the paleomagnetic Brunhes event (Urrutia et al , 1991). Fission-tracks in volcanic glass of the pyroclastics give an age of 16,884 ± 4. I93 years

The extreme NE ofthe caldera was reworked by the formation of a nested caldera. which released "Zebra Tuff" or brown tuff These new pyroclastics products have an approximate thickness of 25 m and their spatial distribution is limited.

### 1.3. Post caldera volcanism

The volcanos Cerro de Oro, Las Ninfas, and Laguna Verde closed the magmatic cycle related to the calderic evolution of the region The volcanic exposures consist of effusive lavas intercalated with scoria. Petrological and geochemical studies define a basaltic composition with calcalkaline characteristics Numerous domes surround the calderic collapse and the principle mapped faults **(Fig. 1)**. The volume of the magma released is 6 5 km$^3$, and surface rocks show an average total density of 2.41 g/cm$^3$ No K-Ar ages were achieved, because the rocks are very recent Also. the abundance of Ar is below the detection limit of the method of 100,000 years

The fluid lavas, which were emitted by the volcanos Las Ninfas and Laguna Verde at their final stage, extend broadly up to the valley, which forins the Central Graben They occupy an area of approximately 39 km$^2$ with a variable thickness between 80 m and 120 m Their extension towards the west is limited by the lateral contact with pyroclastics, in which the river Los Ausoles carves its bed The front of the lava, covered partly by pumice of the Coatepeque event, can he observed at the crossing of the Turin-Ahuachapan road

The detrital avalanches from Hoyo del Cuajuste-Las Ninfas-Laguna Verde correspond to fragmentary deposits which crown the upper parts of the volcanos Laguna Verde and Las Ninfas Mapped from Gonzalez et al. (1991) they represent products from phreatic explosions covering an area or 2 km$^2$, with a volume less than 0 3 km$^3$

Hydrothermal activity **(Fig. 1)** has exposed zones of sui-face alteration, generally associated with fumaroles The inineralogy is characterized by clay mineralization, which retlects an acid medium with temperatures close to 100°C, indicating the occurrence of hydrothermal fluids The field relation between principal structures and the emplacement of geothermal sites is direct evidence for the importance of secondary permeability in a volcanic medium by means of ascending tluid mecanisms in zones with major structural debility

## 2. Tectonics and Structural Geology

From the tectonic point *of* view, El Salvador belongs to the Caribean Plate, which is subducted by the Cocos Plate in the Pacific Ocean at an angle of about 40" **(Fig.** 1) The tectonic processes produced recent volcanic fringes, seismic activity and active hydrotherinal systems.

Four structural system can he detected in the geothermal fields of Ahuachapan and Chipilapa The NE-SW called Mesas del Llano with tilted blocks to the SE and alinost vertical planes (83° to 89°) **(Fig. 2)** The NW-SE system or El Molino system affects the local andesitic basement of the Sierra de Tacuba and the NE-SW system The N-S system. which is the youngest. has regional characteristics and is related to faulting of the Ipala Graben The fourth one is the semicircular Cuyanausul system with a NNW-SSE tendency.

The distended tectonics, based on deformation tensors, impress secondary permeability of geothermal interest for the zone. whei-e the N-S and NNW-SSE directed systems represent the most active ones.

### 3. Relation between Volcanism and Geothermal Activity

The calderic and magmatic evolution of Concepcihn de Atacao was initiated with the emplacement of the basaltic-andesitic monuments of Cuyanausul, Apaneca and Empalizada A magma chamber was settled within igneous basement. Its shallow crustal level allowed the first alkaline effusions at approximately 0 7 ± 0 61 M.a A repose time. which occurred around 0 5 ± 0 1 M.a., permitted magmatic differentiation by the accumulation of silicic material at the roof of the chamber This is demonstrated by the release of 70 $km^3$ of pyroclastic products distributed within an area of 484 $km^2$ According to its characteristics of lithology, grain size and texture. the pyroclastic materials can be classified as proximal, distal and fall deposits The material accumulated towards the roof of the chamber must have been within a temperature range of 650 ± 50 C° The evacuation followed the "Zebra" event The emission of pyroclastic material provoked a collapse of the caldera, which had an elliptic form of 6 x 4 kin The collapsed area is bounded by the carving of the river Asino. The collapse event has been dated within the Late Pleistocene. A deep injection of new magma fed the installed chamber at an estimated depth of 9 kin and occupied at least the underlying area of the originating volcanic exposures It is estimated that the chamber has actually minimum temperatures of 900°C The ultimate effusions were forming the Cerro de Oro, Las Ninfas and Laguna Verde, and domes, which intruded into faults and into the calderic collapse The young magmatic chamber has an age of less than 100,000 years and delivers heat to the underground

The explosion craters of Las Ninfas, Hoyo del Cuajuste and Laguna Verde originated fragmentary products They show the primary evidence for the beginning emplacement of an active postmagmatic hydrothermal system in the region The deep hydrodynamic processes are shown at the surface between hydrothermal exposures and alteration zones For its spatial distribution, a natural discharge can be suggested for the geothermal deposit from the south of the volcanic chain towards the river Agua Caliente

Systematic studies of radon (Balcazar & Gonzalez, 1992) in Chipilapa suggest that detected anomalies are controlled by structural events, which characterize tlie zone The highest anomaly values were encountered at places of natural discharge and at fault intersections (La Labor zone), which is typical for the natural evolution of a hydrothennal sytem Low resistivity values were detected with the same spatial distribution as those shown by the radon method. It is pointed out. that the actual geothermal tluids have temperatures around 50°C, which are less than those detected from studies of fluid inclusions

## CONCLUSIONS

The volcanic products of the Caldera de Concepción de Ataco. which form part of the southern Plio-Quaternary volcanic belt of Salvador, belong to the calc-alkaline series The pre caldera volcanos of Cuyanausul, Apaneca and Einpalizada emitted I7 $km^3$ of basaltic to basaltic-andesitic lava froin Lower to Middle Pleistocene The subsequent evacuation of pyroclasic products. which include breccias. surges. ignimbrites and tlows at the bottom of the sequence. caused the principal collapse of the Caldera de Concepcion de Ataco. Pumice and ash deposits of the upper sequence are locally distributed. whereby tlie blasted material comprises a volume of 70 $km^3$, the flows and distal pumices an area of 23 1 $km^2$ and 484 $km^2$, respectively

The post caldera phase is characterized by a new evacuation at tlie northeastern flank of the caldera, emitting pyroclastic products of limited distribution. also called "zebra pyroclastics" or "brown tuff" Dome injections of dacitic to andesitic composition partly surround the collapses and the internal parts of the caldera

## ACKNOWLEDGEMENTS

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