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\textsuperscript{3} of alkaline lavas were emitted above a basaltic-andesitic basement and older agglomerates, forming the volcanos Cuyanausul, Apaneca and Empalizada, which preceded the evacuation of 70 km\textsuperscript{3} of siliceous pyroclastics. The pyroclastic sequence is formed by breccias, surges, and ignimbrites. Flows occupy the major part with a lateral distribution of 271 km\textsuperscript{2}. The most distal pumice and ash fall deposits are distributed over an area of 484 km\textsuperscript{2}. The release of this material caused a caldera collapse with a dimension of 5 km x 3.5 km. The river Asisno-Sisiniapa carves its bed into this depression. The caldera collapse was reactivated at its NE-flank 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-Aisich, 1953). The increased interest in geothermal energy has been the result of its proven economic advantage over all other alternative energy sources (Campos, 1988).
This paper merges responses from the Comision Ejecutiva del Rio Lempa (CEL) to understand the volcanic mechanisms which are 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 Chililapa. The study of stratigraphy and the structural behavior is the main subject of this work.

The Ahuachapan-Chililapa geothermal field is located 80 km west of San Salvador and 15 km from the border to Guatemala close to the city of Ahuachapan and Atiquizaya -Turín (Fig. 1). The studied zone covers an area of 200 km² and comprises parts of the counties of Santa Ana, Ahuachapan, and Sonsonate.

**RESULTS**

1. 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 composition. The age of the andesites is 7.37 ± 0.73 Ma. Towards the north, the Balsamo formation fills the Central Graben with tuffs, agglomerates, and ancient pyroclastics (Jonsson, 1970; Electroconsult, 1982).

1.1. Pre caldera volcanism

The three volcanos Cuyanauis, Apaneca, and Eimpalizada were mapped (Fig. 2). The first one consists of an alternating sequence of lava, scoria of andesitic to basaltic composition, corresponding to a stratovolcano of Strombolian type. Its age ranges from 13.1 ± 0.3 to 17 ± 0.3 Ma. Common features are cut-offs by faults. Domes and zones of hydrothermal activity affected the northern flank, producing advanced clay mineralization and fumaroles of El Tortugero discharge primary vapor. Low resistivity is related to the graben with the same name. This is an important aim for deep drilling in the area of Chililapa. Apaneca is a volcano of the same type as Cuyanauis, but it is not affected by hydrothermalism and tectonics. Its basalt flows include plagioclase phenocrysts and pyroxenes which are intercalated with scoria. The volcano Empalizada consists of olivine-basalt lava and scoria with an age of 0.7 ± 0.14 Ma. Its original form is destroyed by a caldera collapse, marked by the bed of Rio Asino. On the other hand, the river bed is covered by pyroclastic products of the Caldera Concepcion de Ataco. The magnatism, previous to the formation of the caldera, has a calc-alkaline chemical composition and injected magma was estimated to comprise 17 km³ (González et al., 1991).

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**Fig. 2:** Geological scheme of the geothermal zones at Ahuachapan-Chililapa, 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 forms a hydrological sub-basin governed by the river Asino-Sisimaipa (Fig. 2) The diameter of the oval alignment (6 x 4 km) 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 "hâme" and very abundant pyroclastic flows were observed. The pyroclastic flows are covered by pumice and ash fall deposits. The thickest section was found inside the ring caldera with variations between 640 m and 350 m. Petrological and geochemical studies indicate a dacitic-rhyolitic composition with calc-alkaline tendencies and formation temperatures of approximately 650°C ± 50°C for the evacuation moment of the pyroclastic material. Petrophysical data (Torres, 1991) gives a total density of 0.3780 g/cm³ for the pumice and an average value of 1.98 g/cm³ for the flows. The lithological scheme of Fig. 3 represents the distribution of the pyroclastics. The flows cover an area of 231 km² and the distal pumice an area of 484 km² with the annotations of the indicated thickness. The total volume of the pyroclastic material released by the caldera comprises approximately 70 km³.

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 reinstant paleomagnetism, which shows normal polarity for the paleomagnetic Brunhes event (Uruttia et al., 1991). Fission-tracks in volcanic glass of the pyroclastics give an age of 16,884 ± 4,193 years. The extreme NE of the caldera was reworked by the formation of a nested caldera, which released "Zebra Tuft" or brown tuft. 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 km³, and surface rocks show an average total density of 2.41 g/cm³. 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 forms the Central Graben. They occupy an area of approximately 39 km² 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 be observed at the crossing of the Turner-Ahuachapan road.

The detrital avalanches from Hoyo del Cuajute-Las Ninfas-Laguna Verde correspond to fragmentary deposits which crown the upper parts of the volcanos Laguna Verde and Las Ninfas. Mapped from González et al. (1991) they represent products from phreato-fragmented explosions covering an area of 2 km², with a volume less than 0.3 km³. Hydrothermal activity (Fig. 1) has exposed zones of sulfide alteration, generally associated with fumaroles. The inerogeneity is characterized by clay mineralization, which reflects 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 fluid mechanisms in 20 × 10⁶ with major structural deformity.

2. Tectonics and Structural Geology

From the tectonic point of view, El Salvador belongs to the Caribbean 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 hydrothermal systems. Four structural systems can be detected in the geothermal fields of Ahuachapan and Chichapal. The NE-SW called Mesas del Llano with tilted blocks to the SE and almost vertical planes (83° to 89°) (Fig. 2) The NW-SE system or El Molino system affects the local andesitic basement of the Sierra de Tancapa and the NE-SW system. The N-S system, which is the youngest, has regional characteristics and is related to faulting of the Ipa Graven. The fourth one is the semicircular Cuayanasul system with an NNW-SSE tendency. The distended tectonics, based on deformation tensors, impress secondary permeability of geothermal interest for the zone. Where 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 Concepción de Ataco 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 ± 0.1 Ma. The repose time, which occurred around 0.5 ± 0.1 Ma., permitted magmatic differentiation by the accumulation of silicic material at the roof of the chamber. This is demonstrated by the release of 70 km³ of pyroclastic products distributed within an area of 484 km². 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 ejection of pyroclastic material provoked a collapse of the caldera, which had an elliptic form of 6 x 4 km. 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 km 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 Cuarto 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 the 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 hydrothermal system. 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 fluids have temperatures around 50°C, which are lower 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 Pleistocene volcanic belt of Salvador, belong to the calc-alkaline series. The pre caldera volcanos of Cuyanausul, Apaneca and Empalizada emitted 17 km³ of basaltic to basaltic-andesitic lava from Lower to Middle Pleistocene. The subsequent evacuation of pyroclastic products, which include breccias, surges, ignimbrites and flows at the bottom of the sequence, caused the principal collapse of the Caldera de Concepción de Ataco. Pumice and ash deposits of the upper sequence are locally distributed, whereby the blasted material comprises a volume of 70 km³, the flood and distal pumices an area of 231 km² and 484 km², respectively.

The post caldera phase is characterized by a new evacuation at the northeastern flank of the caldera, emitting pyroclastic products of limited distribution. Also called "Zebra pyroclastics" or "Brown Tuff". Dome injections of dacite to andesite composition partly surround the collapses and the internal parts of the caldera.

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