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The Tulancingo-Acoculco Caldera Complex, Puebla, Mexico: The geology and geophysics as key data for a geothermal energy prospect.

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ABSTRACT

Acoculco (Puebla) is a potential site for geothermal energy and has been studied since the 1980s by Comisión Federal de Electricidad (CFE) Mexican agency. Previous studies indicate that Acoculco is an elliptical-shaped caldera, with 18 by 15 km in diameter, nested within the 32 km in diameter Tulancingo caldera (López-Hernández et al., 2009). Our stratigraphic and structural work suggests a new geological model for this complex; there is a Tulancingo caldera, but it is graben type, as defined in Aguirre-Díaz (2008), linked to regional fault systems in the area. This interpretation agrees with geophysical studies and with the information from two deep wells (2000 m) in the central part of the complex. The Tulancingo-Acoculco caldera complex started activity at about 2.7 Ma and finished it at about 0.8 Ma, with four caldera collapses associated to pumice fallouts and ignimbrite-forming eruptions, with emplacement of lava domes in between and at the end. The youngest rocks are scoria cones and related mafic lavas as young as Pleistocene and probably Holocene, which are aligned to the fault trends. Geothermal heat in the zone is apparently related to this mafic volcanism controlled by the regional fault systems. Assuming the existence of a post-collapse remnant of the subcaldera silicic magma body, heat in this body may have been preserved by continuous inputs of mafic magma that fed the scoria cones. But it is more probable a direct link with the mafic Pleistocene volcanism for the heat source. This hypothesis would explain the heat anomaly just beneath the Acoculco dome complex, where there is magmatic cold gas emissions and temperatures > 250°C at 2000 m depth, and also would explain the aligned hot springs and hot water wells observed along the SE and NE borders of the Tulancingo graben caldera. Financed by GEMex grant 268074 SENER-CONACyT

1. INTRODUCTION

The Tulancingo-Acoculco Volcanic Complex (TAVC) is located at the eastern sector of the Mexican Volcanic Belt (MVB) province (fig. 1). It is one of several caldera complexes within the belt. The MVB is a continental margin volcanic arc related to subduction of the Cocos-River oceanic plates beneath North American plate (Aguirre-Díaz et al. 1998; Pardo and Suárez, 1994). Some of these calderas are geothermic energy sites in production or potential sites for developing a geothermal energy plants, including Ceboruco, La Primavera, Azufres, Acoculco, and Los Humeros.

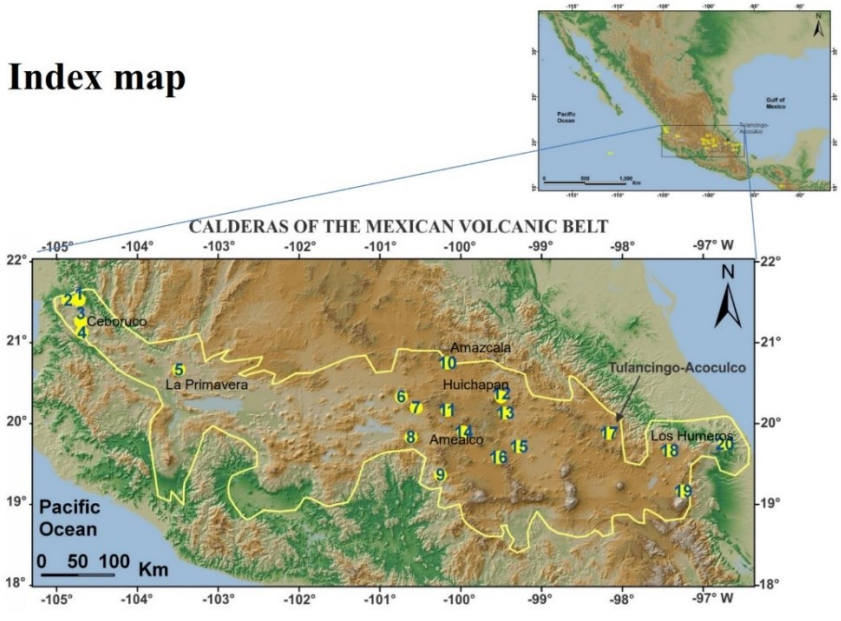

Figure 1: Index map of Tulancingo-Acoculco Volcanic Complex at the eastern portion of the Mexican Volcanic Belt, showing the location calderas including those with geothermal energy plants (La Primavera, Azufres, Los Humeros).

Acoculco site has been studied since the decade of 1980s by the Comisión Federal de Electricidad (CFE) due to its potential for geothermal energy. Two deep boreholes (2000 m) were done in the center of what it is interpreted as a caldera, named Acoculco (López-Hernández et al., 2009; Avellán et al., 2020). Results on these boreholes indicate a sealed, impermeable system but with enough heat (over 250°C) for considering for a geothermal power plant. Thus, in past years, this area has been studied in detail for confirming this goal; among these new projects is the GEMex consortium 2017-2021 entitled "Mexico-Europe cooperation for research on Enhanced Geothermal Systems and Superhot Geothermal Systems", through the SENER-CONACYT grant No. 268074. According to previous and GEMex new data, Acoculco would be a candidate for an Enhanced Geothermal System, due to the lack of permeability. However, this is based mostly on the data from the two deep boreholes, which represent a very localized area, practically a point of the area under study. In this work, our group is working on a larger region, even beyond the limits of the Acoculco caldera, in order to get a better knowledge of the two main volcanic structures of the TAVC, the Tulancingo caldera and the nested Acoculco caldera. Geologic work on a more regional scale indicates 1) There is a large caldera, Tulancingo, which is graben type in the way Aguirre-Díaz (2008) define them, 2) Acoculco is apparently not a caldera but a lava dome complex and resurgence feature, and 3) Actual heat in the area is apparently related to the last volcanic event, the mafic volcanism that formed scoria cones controlled by the regional faults.

2. THE TULANCINGO CALDERA: GEOLOGY AND STRUCTURE

The Tulancingo-Acoculco caldera complex was defined by López-Hernández (2009) and López-Hernández et al. (2009) as a nested caldera complex, with a semicircular larger and older caldera named Tulancingo (32 km; 2.7 Ma) and a younger, smaller, semicircular caldera named Acoculco (18x15 km, 1.7-0.8 Ma). Younger volcanism in the form of scoria cones continued until at least 0.24 Ma. Recent works by Avellán et al. (2019, 2020) support the existence of the Acoculco caldera and their new ages mostly confirm those of López-Hernández et al. (2009), also providing even younger ages for the last volcanic events of mafic scoria cones. The geology of TAVC based upon the work of López-Hernández (2009) is shown in Figure 2.

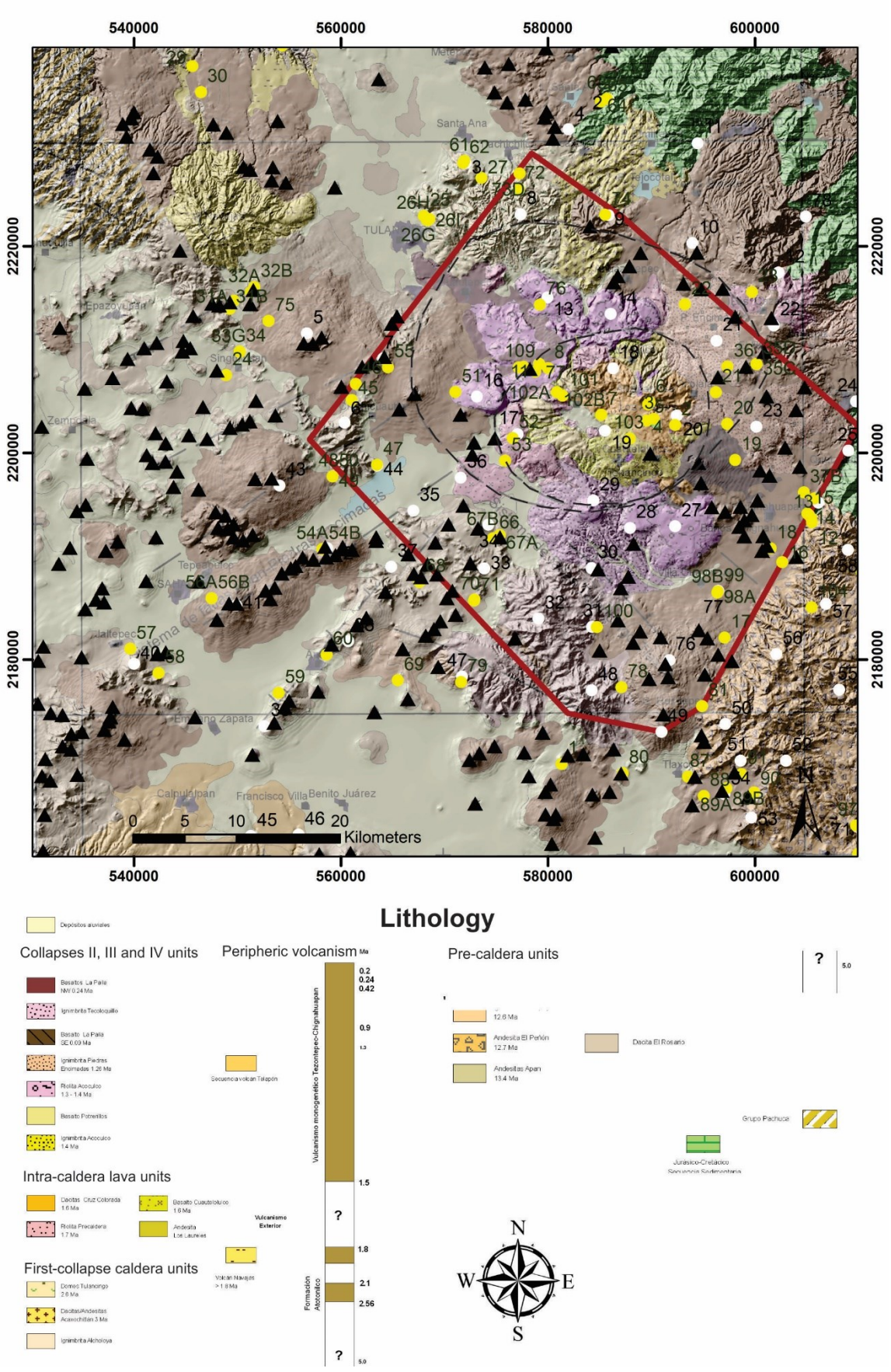

Figure 2: Geologic map of the Tulancingo-Acoculco Volcanic Complex and surrounding area, showing the outline of the Tulancingo caldera (red line), the originally proposed semicircular nested calderas by López-Hernández et al. (2009; (dashed black lines), with Tulancingo as the larger one and Acoculco as the smaller one, and the Pleistocene scoria cones (black triangles). Also indicated are sampling/data sites (yellow and white dots). Modified from López-Hernández (2009).

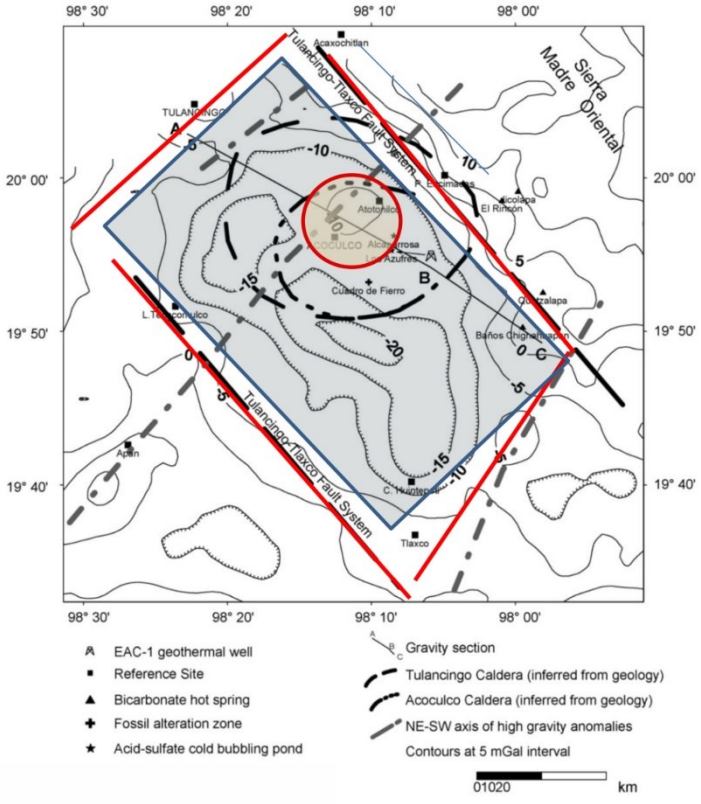

Figure 3: Residual Bouger gravity anomaly for the TAVC (reference density 2.4 gr/cm^3) showing main fault regional faults (black dashed and dash-point straight lines), Tulancingo caldera outline (red line), and originally proposed semicircular caldera outlines for Tulancingo and Acoculco calderas. Note that the negative anomaly marking the graben-type caldera for Tulancingo and a positive anomaly for the area of Acoculco caldera. Modified from López-Hernández et al. (2009).

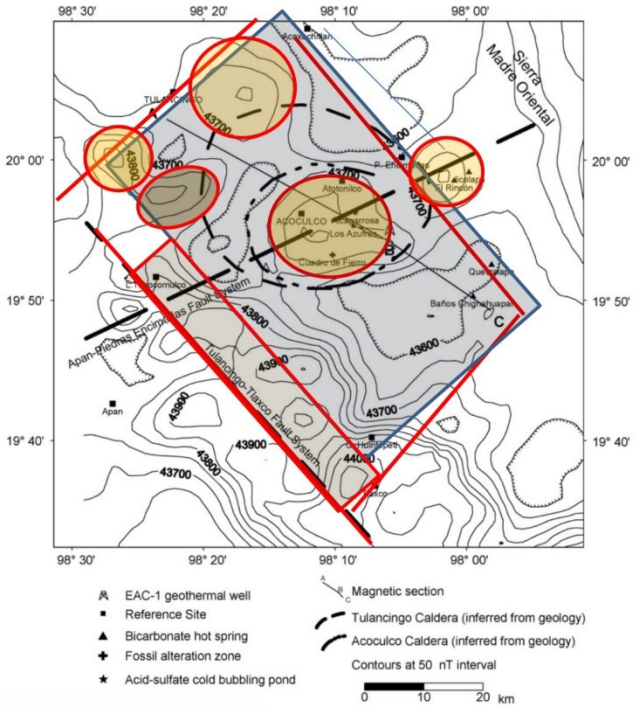

Figure 4: Total magnetic field reduced to the pole for the TAVC, showing a negative anomaly for the Tulancingo graben caldera, and positive anomalies for dome complexes at the caldera margin and at Acoculco caldera area. Modified from López-Hernández et al (2009).

Tulancingo graben caldera is also evident in the morphology (fig. 5). Digital elevation model of the area shows a rectangular shape structure with sharp scarps and lineaments that coincide with graben caldera borders. It is clearer in the eastern and southern margin, but geology and geophysics confirm the rectangular shape of this caldera.

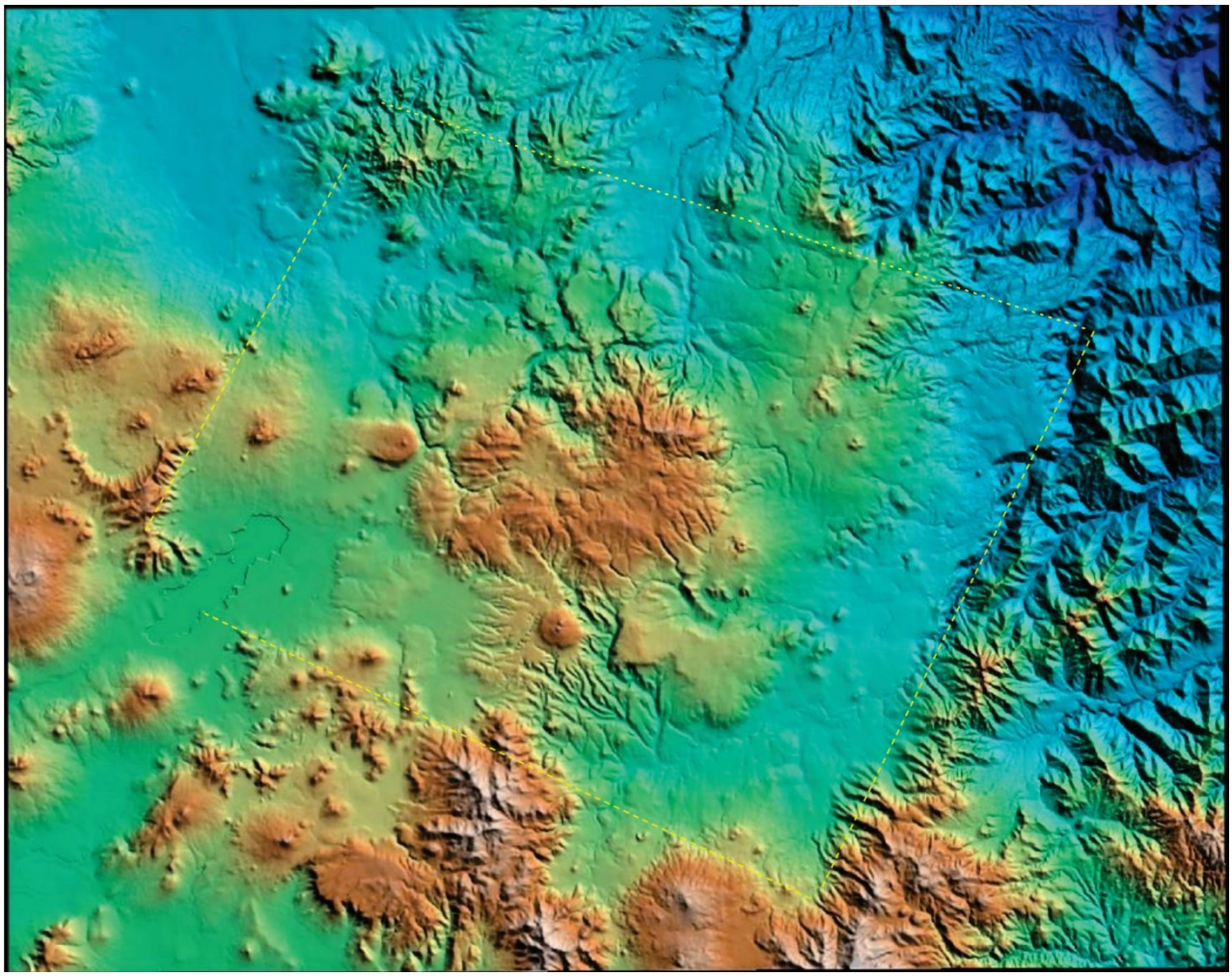

Figure 5: Digital elevation model for the TACV area. Yellow dashed line marks the Tulancingo graben caldera outline. At the central part is the Acoculco dome complex.

The vents for the Tulancingo graben caldera products were mainly the major faults that border the caldera, but also intra-caldera faults connected to the subcaldera magma chamber. These intra-caldera faults are related to the crustal blocks that collapsed during caldera formation (fig. 6).

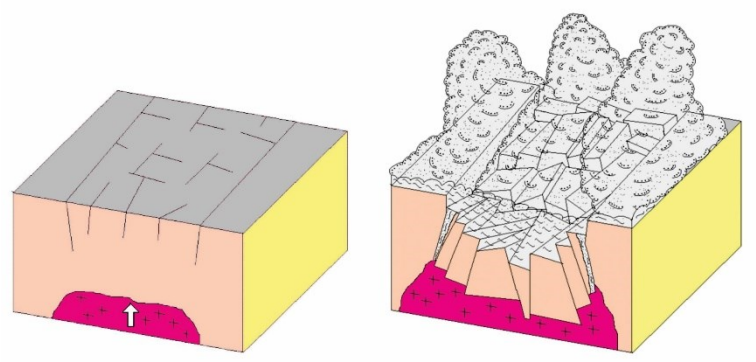

Figure 6: Conceptual model for a graben type caldera collapse and climactic explosive eruption (ignimbrite-forming eruption) with a piece-meal style of collapse, following the classification of Aguirre-Díaz (2008).

3. VOLCANIC PHASES OF TAVC

Our geologic-stratigraphic results, documented with geochronologic data from López-Hernández et al. (2009), indicate that TACV had several volcanic phases, with the most important ones those that formed ignimbrites and post-ignimbrite lava domes. Each ignimbrite-forming phase was related to a collapse of the Tulancingo caldera. Stratigraphic record indicates 4 major ignimbrites and thus, four collapses. First collapse occurred at 2.7 Ma, which formed the graben caldera and the Tulancingo ignimbrite (fig. 7 and 9). This was followed by the emplacement of post-collapse rim domes represented by the Tulancingo Rim Domes (fig. 8 and 9). At about 1.6 Ma, a cluster of lava domes were emplaced at the central portion of Tulancingo caldera together with a resurgence event, forming the Acoculco lava dome complex (fig. 9). At about 1.4 Ma a second collapse of Tulancingo caldera formed the Piedras Encimadas ignimbrite and some post-collapse domes (fig. 9). Then, at about 1.1 Ma a third collapse formed the Atexca Ignimbrite with some post-collapse domes. At about 0.8 Ma there was the last collapse of Tulancingo caldera that was related to the emplacement of La Gloria Ignimbrite (former Tecoloquillo Ignimbrite) and a few post-collapse lava domes. The last volcanic events in the area are several mafic scoria cones and related lavas with ages of 0.24 Ma and younger (fig. 9). Only a few of the have been dated, but their age range could well be Pleistocene-Holocene. The scoria cones are aligned with the regional faults, so it is common to observe them with NN or ENE trends (fig. 2). New Ar-Ar ages from samples collected by us are in progress in order to revise and actualize the ages used here, in combination with those reported by Avellán et al. (2020.

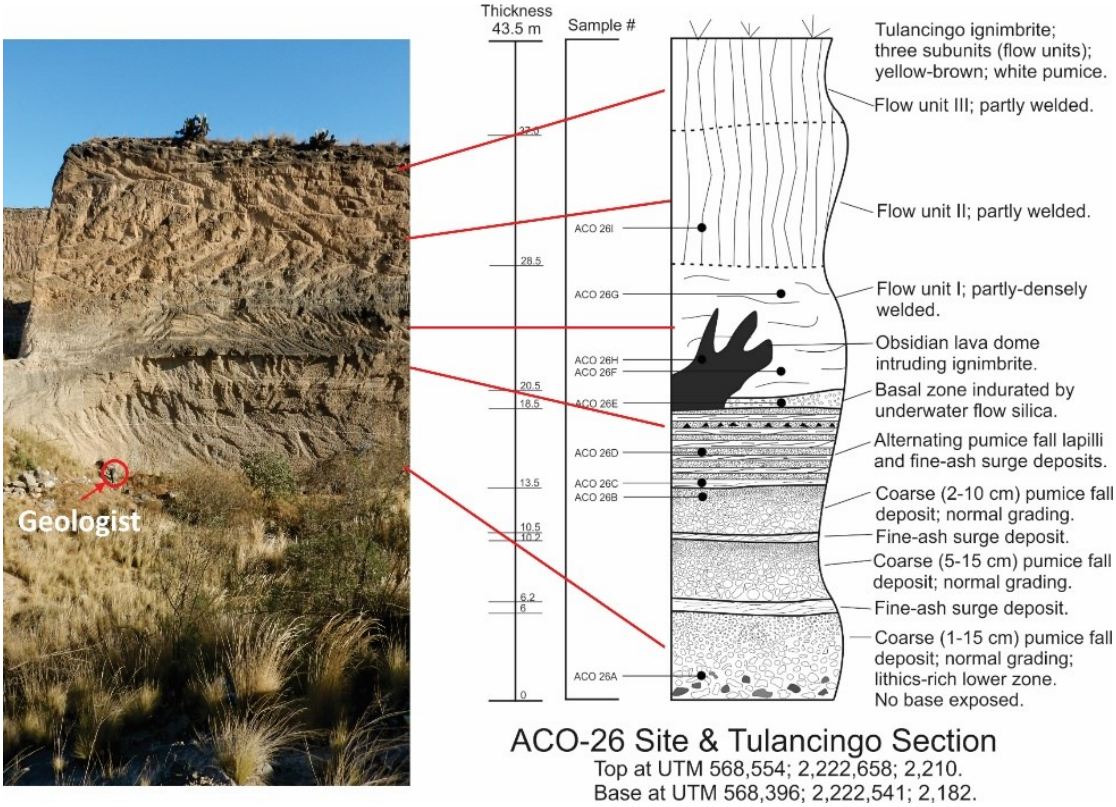

Figure 7: Type section of Tulancingo Ignimbrite. It overlies a pumice fall deposits (pre-collapse stage), and a series of lithic-rich PDC deposits (caldera onset stage). The ignimbrite is formed by three continuous pyroclastic flow units (collapse stage).

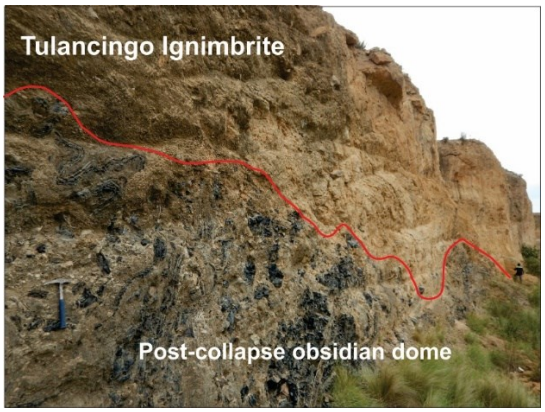

Figure 8: Post-collapse obsidian lavas intruding Tulancingo Ignimbrite at Type Section site. It represents the post-collapse lava domes after ignimbrite formation.

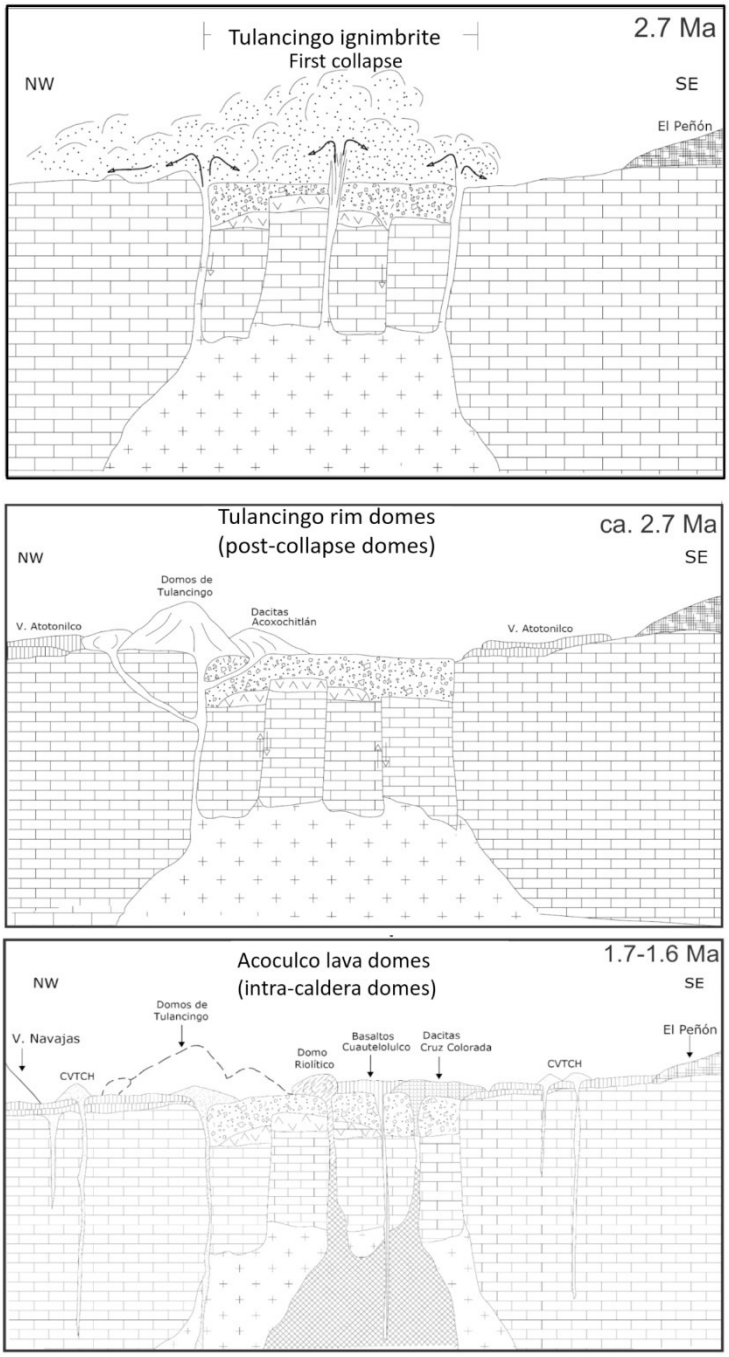

Figure 9: Volcanic phases of the TAVC. Modified after López-Hernández (2009).

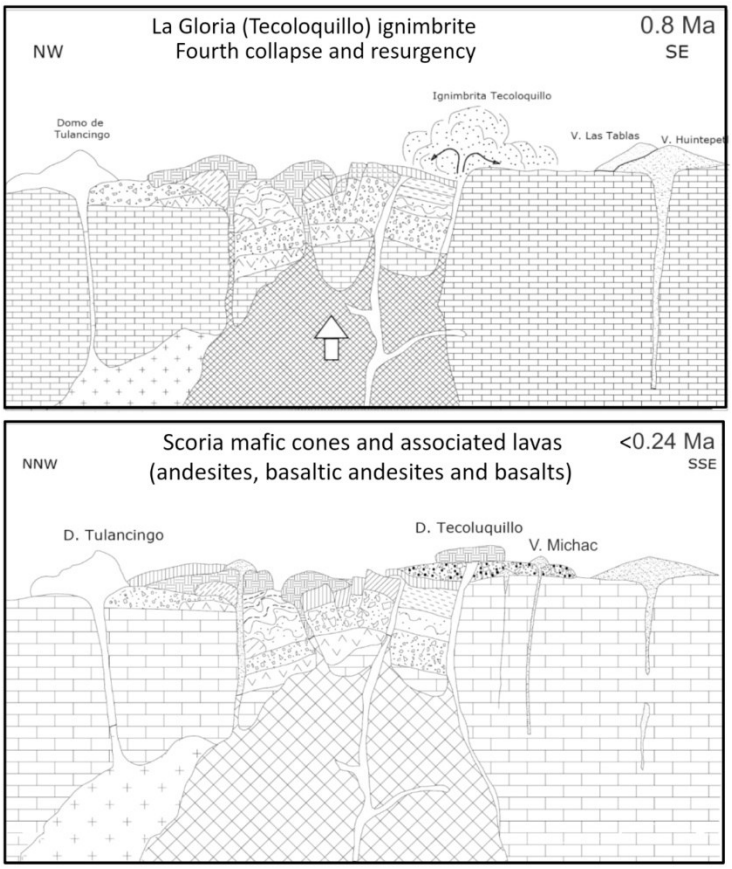

Figure 9 continued: Volcanic phases of the TAVC. Modified after López-Hernández (2009).

4. CONCLUSIONS

The Tulancingo caldera is a graben type caldera with 4 possible collapses, each one producing an ignimbrite, at 2.7 Ma, 1.4 Ma, 1.1 Ma and 0.8 Ma.

The caldera is rectangular and controlled by NE and NW regional fault systems.

Tulancingo ignimbrite was the main (most voluminous); no volume estimates yet, but surely over 100 km^3.

Gravity and magnetic studies confirm the rectangular shape and size of the caldera, with about 45 km by 35 km.

Source of geothermal heat in the area is still unknown; but probably is related to the <0.24 ka mafic scoria cones magmatism and not to a subcaldera silicic magma chamber.

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