1. Introduction

Geomorphological cartography in volcanic areas has been a very useful tool, for example, in obtaining data on geological hazards (Siebe & Macías, 2006; Thouret, 2010), in the analysis of erosion (Baumann, Bonadonna, Cuomo, Moscariello, & Manzella, 2018), as well as, relating geoforms to areas with geothermal potential (Dermawan, Hamka, Malik, Sianipar, & Ramadhan, 2016). Which are the three main topics related to the volcanic complex Las Derrumbadas.

Las Derrumbadas (LDR) is located east of the central part of the state of Puebla, Mexico, a little more than 100 km away from the state’s capital city of Puebla. It stretches over 285 km² with a length of 18 and 16 km wide, approximately. Features average heights between 2300 and 3500 masl. It is delimited in the polygon 19°12′41″ to 19°22′18″ N and 97°32′52″ to 97°23′29″ W (Figure 1).

The study area is defined by two large geological domains (Figure 1). The first one is related to the Sierra Madre Oriental (SMO) and the second is the Mexican Volcanic Belt (MVB). The SMO is made up of units of marine origin from the Upper Jurassic to the Upper Cretaceous formed by carbonate and deformed terrigenous sequences with NW–SE orientation folds and mounts and NE–SW direction overfalls, all the Laramide orogeny of the Cretaceous boundary. Later have intrusive Tertiary events, both are covered by the magmatic processes of the MVB, an event that is established with a preferential direction EW and whose geological evolution begins in the middle Miocene, forming stratovolcanoes and lava cones with ages that vary between ~13 and 10 Ma. Among these devices are the Cerro Grande stratovolcano in Puebla (Carrasco-Núñez, Gómez-Tuena, & Laura, 1997; Gómez-Tuena & Carrasco-Núñez, 2000). The volcanism of the eastern portion of the MVB experiences an hiatus that extends from the late Miocene to the early Pliocene. Volcanism is reestablished at ~3.7 Ma with the location of some medium polygenetic centers of the Apan volcanic field, located northwest of Las Derrumbadas (Gómez-Tuena, Orozco-Ésquível, & Ferrari, 2005; Palomo, Macías, Tolson, Valdez, & Mora, 2002). However, most of the volcanism in the eastern sector of the MVB takes place during the Quaternary. Thus, mafic volcanism is concentrated in the monogenetic cones of the fields of the Sierra de Chichinautzin (Martín del Pozzo, 1982; Siebe, Rodríguez-Lara, Schaaf, & Abrams, 2004) and Apan (Palomo et al., 2002); and in the region of Pico de Orizaba and Cofre de Perote (Siebert & Carrasco-Núñez, 2002). The most evolved products are found in Acoculco Caldera (Verma, 2001), Los Humeros (Ferriz & Mahood, 1984; Verma, 2000), the Las Cumbres silicic center (Rodríguez, Siebe, Komorowski, & Abrams, 2002) and domes of Las Derrumbadas and Cerro Pizarro (Riggs & Carrasco-Nunez, 2004). Further to the east is the La Malinche volcano and the – N–S alignment of the Pico de Orizaba-Cofre de Perote (Carrasco-Núñez & Ban, 1994). Apparently, all the stratovolcanoes of this part of the MVB have ages less than one Ma (Gómez-Tuena et al., 2005). In the region, geothermal potential studies...
are abundant (Alvarez & Yutsis, 2017; Arzate, Corbo-Camargo, Carrasco-Núñez, Hernández, & Yutsis, 2018; Romero-Ríos, 1985; Siebe & Verma, 1988), and they have an interest in the LDR (Palacios-Hartweg & García-Velázquez, 1981; Yáñez & García, 1982).

In this work, we will present a detailed geomorphological mapping of LDR Pleistocene–Holocene volcanism and observe the evolution of the endogenous and exogenous processes that over time have carved an area of recent volcanic activity and, therefore, obtain a relationship between the geoforms, the volcanic danger and its possible geothermal potential. Other articles on the area published hitherto did not include a geomorphological study or a detailed morphological map (Campos-Enriquez & Garduño-Monroy, 1987; Capra, Macías, Scott, Abrams, & Garduño-Monroy, 2002; Siebe & Verma, 1988). This paper presents the geomorphological mapping of LDR, supported with dates \(^{40}\text{Ar}/^{39}\text{Ar}\) and with the interpretation of morphometric models.

2. Methodology

2.1. Inputs and information processing

The inputs and information processing used to prepare the map are summarized in Tables 1 and 2.

2.2. Geomorphological map

Polygons were traced according to the patterns visible in the morphometric models. The ruggedness model (Jenness, 2004) was one of the inputs that best highlighted the geological structures, undistinguishable with other models. The interpretation was made according to Hobson (1967, 1972). In this model, if...
the terrain is even, the vector sum will be high and the dispersion low (0.61546–0.99001), which means smooth or homogeneous topographies. In the case of rough terrain, with orientation and slope changes, the vector sum will be low and the dispersion high (0.009991–0.38455), corresponding to more complex or rugged topography zones. A total of 573 polygons were drawn with ArcMap in shapefile format. The average on-screen digitalization scale was 1:15,000.

The objective of the classification of the legend was to discriminate units that allowed to recognize the geomorphological products of the volcanic activity of the units resulting from slope erosion processes, so the landforms were identified according to the next hierarchical level. The first level distinguishes between the two major processes forming the relief: endogenous and exogenous. For the endogenous forms, the second level its lithological origin, the third level the formation process and fourth level its type of morphology. In the second level the exogenous landforms are its geomorphological product and in third level its type of morphology. Which are distinctive products of the LDR.

In order to have a short key that is easy to read, the keys of the units are composed of two elements. The first element is the acronym (En) if it corresponds to endogenous landform and (Ex) if it corresponds to exogenous landform. The second element is a consecutive numbering (1–29) according to the sequence of the legend and being a reference the sections on the map.

The cartographic work was complemented with the following stages: (1) field work and the recognition of the zone and the units and collection of samples (2) laboratory analysis of petrographic, geochemical studies (Trujillo Hernandez, 2019) and (3) dating samples. The $^{40}\text{Ar}/^{39}\text{Ar}$ datings presented in this paper were obtained in the laboratories of the Department of Geology and Geophysics at the University of Alaska. The last step was achieved in 2017 and included the verification of the map’s units.

## 3 Results

### 3.1. Products of sedimentary endogenous processes (sedimentary features)

Limestone deformed units (En1) Eight units of Cretaceous limestone crop out in the zone. Three of the units (at the bottom of the map) present a morphology with homogenous slope ranks from 20° to 45°, reaching 53° in some zones. Its drainage pattern is angular dominated by structural features. Their geometry is mostly concave and convex linked to the folds. These units reach 2750 masl. Other units are irregular, located in the inferior zones of the En2, and near the Atexcac pyroclastic ring, they reach 3200 masl and slopes of 45°. Their drainage pattern tends to be subparallel. These rocks were raised by the growth of the North Dome, as seen in the integrated profile on the main map.

### 3.2. Collapse (volcanic features)

Deposits resulting from the first phase of destruction or collapse (En2 and En3) of the Las Derrumbadas domes are included in this category (Capra et al., 2002; Siebe et al., 1995). These have been classified as follows, according to their morphology:

**Hummocks (En2 and En3).** Hummocks or mounds (Figure 2) are part of the topography of the three units of avalanche deposits; their total size is 9.46 km². Their composition is heterolithic, as it is a mix of blocks and substratum sediments. Possibly it is about two different events and origins (Stage 0
Hummocks and Debris avalanches deposits and Stage one Hummocks and Debris avalanches deposits).

The highest hummocks (En2) are in zone W, with up to 2480 masl (Figure 2). Until now its origin is uncertain, but they appear to have a radial order and to be oriented towards their possible source, apparently in the same zone where the unit En12 is currently located.

In unit En3, the hummocks are more dispersed. Almost all of them are the same size and their point of origin is not clear. In zone S (En3) they form a clear flow structure, are of different sizes and mainly concentrated in the frontal part of the flow. The hummocks of zone SE (En3) are very particular: they are elongated and all of them oriented in the same direction.

Debris Avalanche deposits (En4 and En5). A total of two deposits were identified in this group. The first (En5) is located W of the North dome and extends over 26 km²; it presents a very irregular geometry but nonetheless reveals the direction of the flow towards the W. Its heterolithologic composition includes up to 2 m-large andesite blocks with puzzle structures, blocks of lacustrine sequences, and pyroclastic and limestone surges. It was named Avalanche Zero because there is no evidence of its source.

The apparent deposit direction and lithology of the two remaining units (En4) link them with the volume of the collapsed SE sector of the En12. Together they cover an area of more than 7 km² forming part of the old destructive phase of the unit En12.

### 3.3. Extrusive bodies (volcanic features)

**Old domes (En6).** The Colorado dome, west of the central domes, and dated 169 ± 158 ka by ⁴⁰Ar/³⁹Ar method, is part of the zone’s old volcanism. It was classified as andesite with the presence of hornblende-bearing and calc-alkaline xenoliths. It extends over 0.39 km² with a maximum height of 2563 masl. It is half-moon-shaped, open towards the SW, with slopes graded 10–45°, reaching more than 45° at the highest parts. Its flanks are mostly even, with some concave sections, and a convex summit. The drainage is diffuse and little developed, with a tendency to flow towards the SW in a sub-parallel manner.

**Tuff rings (En7).** Three structures were identified in the zone, located in the south and southwestern sectors. Tepexitl when 1km-in-diameter circular geometry and its maximum height of 2470 masl was dated 29.1 ± 3.5 ka (Ross, Núñez, & Hayman, 2017). Its external slopes remain under 20°, with a radial drainage system, whereas inside they reach 30° with radial centripetal drainage. The second structure is called Tlanelolli (meaning mixed in Náhuatl), located SW of the map, stretching over 1.62 km² with 2750 masl; its geometry is irregular, forming a small volcanic complex. Its slopes vary between 10° and 45°, its drainage system is barely developed but complex due to the combination of volcanic structures. The third structure is called Centlacometztli (half-moon in Náhuatl), located 6 km W of the Tepexitl ring. It covers an area of barely 0.17 km² and remains under 2400 masl. Its slopes are
graded from 0° to 20°, and its geometry is that of a half-moon, open towards the SW.

**Maars (En8).** The Atexcac crater is the only maar in the study area. It has an interior lake and was dated 330 ± 80 ka using the 40Ar/39Ar method (Carrasco-Núñez, Ort, & Romero, 2007). Its geometry is elliptical, its major axis (1.27 km) oriented NE, is cut at its northern part by a cinder cone. Its slopes are gentle at the external flanks (0–20°), and in the internal slopes, which are flat with concave sectors, its present dips of 30 to >45°, and a more developed drainage system (Figure 3). The difference in length between the internal and external slopes is of 156 m, the external being the deepest.

**Cinder cones (En9).** This classification is composed of five cinder cones. The first (I) in the NNE sector, cutting the Atexcac crater at its northern part. This cone is barely visible because it is also covered by the maar products. Its lavas are dated 330 ± 80 ka using the 40Ar/39Ar method (Carrasco-Núñez et al., 2007). Cone II has located 1 km towards the NW of the En2, covering 0.18 km² with radial and not very dense drainage system. Two more (III and IV) stand SW of the En3. Both are of andesitic-basaltic composition. Cone III stretches over 0.36 km² with a crater of associated lava flows on its top. Cone IV, of barely 0.02 km², also has a small crater and a lava flow at its summit. It has been dated 101 ± 25 ka. Cone V is located E of the En13, extending over 0.23 km² with a lava flow of trachyandesite composition, dated 65 ± 17 ka.

**Pyroclastic cones (En10).** Located NE of the En2 a cone of andesitic-basaltic composition dated 117 ± 91 ka with a crater on its summit, open towards the SE. The drainage pattern of its slopes is radial sub-parallel. It is noteworthy that an andesite dike oriented N60 was identified within this structure, the only case in the zone.

**Lava flows (En11).** The lava flows of the zone cover a total of 8.15 km² and are the result of a few cinder cones. Chemically speaking, the different lava bodies range from basalt (1076 ± 33 ka) and basaltic andesite (101 ± 25 ka) to trachyandesite (65 ± 17 ka). The structure of the flows varies, some are massive without visible structure and others present AA structure or blocks. One of the flows has been considered spatter due to its amalgamated blocks structure.

**North Dome (En12).** Rhyolitic composition dome of 10 ± 3 ka (40Ar/39Ar), of containing crystals of biotite, hornblende and garnet crystals exclusive to this unit. It covers an area of 12.54 km² with a maximum height of 3434 masl. Its form is classic dome, with slopes from 10° at the foothills to 64° in the higher parts. The entire dome presents many variations between concave, composed and convex areas generated by intense hydrothermalism, followed by a high degree of hydraulic erosion. This is reflected in a large web of reddish gullies, up to 40 m deep and interconnected. The primary drainage network presents a well-developed radial parallel and radial sub-parallel pattern. A striking characteristic of the North Dome is a large, horseshoe-shaped collapse scar, opening in SE direction. A smaller resurgence dome developed inside (En15). The avalanche deposits located south and east of this dome (Figure 4) are related to this large collapse amphitheater (En4).

**South Dome (En13).** Of rhyolitic composition, it was aged 6 ± 4 ka (40Ar/39Ar). This dome has a maximum height of 3481 masl. It’s dome classic, with slopes of 10° at the base and up to 45° on the higher sides, with some sectors above the 45°. Drainage is radial parallel; the bend of its surface is complex, the combination of concave, composed and convex surfaces is limited to certain areas, which correspond to the presence of collapsed sectors of the dome, where also the density of gully erosion is higher (Figure 5). These collapse sectors have been related to the instability of the
dome’s slopes because of hydrothermal alteration (Capra et al., 2002).

It is important to mention that the volume calculated for the North and South domes, together with the resurgent domes, is of approximately 12.71 km$^3$. Clearly, the central domes, the twins, have an almost identical cylindric shaped morphology, whereas the resurgent domes are lower, and their slopes less pronounced.

_Torta dome (En14)._ This structure is named Torta, because of its flat-topped and roughly circular shape (Silva, Self, Francis, Drake, & Carlos, 1994), with a visible eruptive vent, composed of andesitic and on the surface, it looks like an AA type lava. It is located E of the main domes, and morphologically positioned as the youngest, since it is not covered by pyroclastic material. It stretches over an area of 0.48 km$^2$ with a maximum height of 2500 masl; the highest part of the dome is flat and related to its gentle slopes (0–10°). These are convex at the shoulder and concave at the foothill, the latter presenting dips between 20° and 45°.

_Resurgent Domes (En15, En16 and En17)._ Three resurgent domes were identified. North resurgent dome (En15), of 7 ± 4 ka and rhyolitic composition, located in the collapse amphitheater of the En12,
approximately 1.26 km$^2$ large and 3179 masl high. Geometrically, it can be considered a classic dome. Its drainage pattern is radial subparallel, and its dips range between 20° and 45°. The bend of its surface is not very complex. The Ex-hacienda dome (En16) is of rhyolitic composition, aged 7 ± 3 ka, located SW of the En3, and extends over 0.64 km$^2$; it forms a counterslope with the En3. Its primary drainage is not developed and presents a radial pattern. Its slopes present sectors varying from 10° to 45°, the bend being fairly regular and flat, excepting small, convex areas. Finally, the resurgent south dome (En17), of rhyolitic composition and 2 ± 5 ka, is located at the northern part of the South Dome, stretching over 1.89 km$^2$. It has a prominent geometry, presenting steep and homogenous dips up to 45°; its slopes are gentle except for the summit and the collapse crest, which are convex. In the inner part of the collapse, the surface is mainly concave, and presents radial sub-parallel drainage pattern.

### 3.4. Exogenic landform

**Gravitational slope movement** (Ex18, Ex19 and Ex20). Collapse scars are an important characteristic of the En13. Three important traces have been identified (parabolas). Apparently, the collapse crowns do not present any tectonic or structural alignment, but these events share morphological and lithological characteristics that give evidence of their similar genesis, like the geometry of the collapse, the form of the deposits and zones of severe erosion. Among their morphometric attributes, they present semi-circular forms, from the right to the left flank in the sliding surface, a maximum breadth between 0.76 and 1.34 km, and its slopes remaining between 30 and 45°, up to 45–64° in steeper zones.

The associated sedimentary deposits appear as tongues, with very regular and homogenous topography, except for the proximal parts of the deposits of Ex19 and Ex20, which can present hummock-type mounds of up to 20 m in height. This characteristic was only perceived in the field (Figure 6). The deposits (Ex18, Ex19 and Ex20, respectively) present a maximum length of 4.17, 4.09 and 2.04 km. According to the general slope model, the slope remains homogeneous within 10°, except for the edges of the deposits, which have slopes from 10° to 30°.

These deposits present grey-colored massive and chaotic structures with sub-angular clasts. They are monolithologic, with fragments of rhyolitic rock and a matrix of medium-sized silt. One of the striking characteristics of these deposits are the *vari colori* fragments, which are chunks of rhyolitic rock altered by reddish coloration. In some of the hummocks of deposit Ex19, we also found that the matrix presented kaolin-type alteration material (Figure 7).

**Fluvial/Alluvial deposits – Piedmont** (Ex21 to Ex27). These have been classified according to their distance from the foothills of the North and South domes respectively in proximal, intermediate and distal. This

![Figure 6](image_url)

*Figure 6. Photography of the arrangement of hummocks towards the zone near collapse Ex19.*
classification also refers to their time of deposit, the distal being the oldest and the proximal more recent. They are practically constituted of sediments and clasts dragged from the gullies of the domes by fluvial agents. Some of the proximal deposits present alluvial fan geometry and were therefore distinguished with the symbol of alluvial cones.

In this cartography, we identified a unit composed of limestone breccia (Ex27) of approximately 0.06 km². It is located W of the North Dome, near one of the limestone bodies. Its composition is monolithological, formed by blocks of limestone of up to 1.5 m and smaller fragments of the same rock as part of the cementitious material.

Reworked Deposits (Ex28 and Ex29). Lahars and pyroclastic deposits (Ex28) are the largest unit. With 120 km², its geometry is irregular due to the nature of the deposits. Topographically, the zone presents a very gentle slope (0–10°); it is composed of multiple lahar and pyroclastic deposits, mostly coming from nearby pyroclastic domes and volcanic bodies. It is important to note that the flat zones around the domes correspond to antique fluvio-lacustrine deposits. Alluvial deposits (Ex29) are the alluvial deposits that surround the LDR.

4. Conclusions

The geomorphological map of LDR is composed of twenty-nine units. Seven are volcanic domes, three are avalanche deposits and six are foothill deposits. The diversity of landforms allowed to define both endogenic and exogenic processes. This resulted in a map showing features of volcanic origin such as slope erosion processes. The morphology of the volcanic domes is highlighted, and in the collapse of their slopes, the relationship with geothermal activity indicates that this factor conditioned the formation of hummock-type deposits. The ages found for the entire complex ranged from 1509 to 2 ka. The use of the ⁴⁰Ar/³⁹Ar method was believed to be correct if the ages would be greater, but the results indicate ages of 170–6 ka. In some samples the error ranges were close to the established age, however, it was decided to use them as an indicator in the evolution of LDR, which helped to classify and sort the morphological units and sections on the map.

Avalanche Zero presents the characteristic chaotic morphology of these forms, like large heterolithological hummocks, with gullies oriented perpendicularly to the direction of the flow, which allow to suggest that the area of the North Dome is its source of origin.
Clearly, the morphological study carried out in the Las Derrumbadas domes confirms its Holocene age, verified with datings and confirming that the hydrothermal processes contributed to the exogenic processes.

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Software

The software used (Table 2) was Global Mapper 9 to Contour generation. ESRI ArcGIS 10.2 was used to digitize, process and classify morphometric maps and edit the geomorphological map.

Disclosure statement

No potential conflict of interest was reported by the authors.

References

Alvarez, R., & Yutsis, V. V. (2017). Potential fields modeling of the Serdán Oriental Basin, Eastern Mexico. Journal of South American Earth Sciences, 80, 375–388. doi:10.1016/j.james.2017.10.003
Arzate, J., Corbo-Camargo, F., Carrasco-Núñez, G., Hernández, J., & Yutsis, V. (2018). The Los Humeros (Mexico) geothermal field model deduced from new geophysical and geological data. Geothermics, 71, 200–211. doi:10.1016/j.geothermics.2017.09.009
Baumann, V., Bonadonna, C., Cuomo, S., Moscariello, M., & Manzella, I. (2018). Slope stability models for rainfall-induced lahars during long-lasting eruptions. Journal of Volcanology and Geothermal Research, 359, 78–94.
Campos-Enriquez, J., & Garduño-Monroy, V. H. (1987). The shallow structure of Los Humeros and Las Derrumbadas geothermal fields, Mexico. Geothermics, 16(5-6), 539–554. doi:10.1016/0375-6505(87)90038-1
Capra, L., Macias, J. L., Scott, K. M., Abrams, M., & Garduño-Monroy, V. H. (2002). Debris avalanches and debris flows transformed from collapses in the Trans-Mexican Volcanic Belt, Mexico–behavior, and implications for hazard assessment. Journal of Volcanology and Geothermal Research, 113(1-2), 81–110. doi:10.1016/S0377-0273(01)00025-9
Carrasco-Núñez, G., & Ban, M. (1994). Geologic map and structure sections of the Citlaltépetl volcano summit area, Mexico, with summary of the geology of the Citlaltépetl volcano summit area. UNAM, Instituto de Geología.
Carrasco-Núñez, G., Gómez-Tuena, A., & Laura, L. V. (1997). Geologic map of Cerro Grande volcano and surrounding area, Central Mexico.
Carrasco-Núñez, G., Ort, M. H., & Romero, C. (2007). Evolution and hydrological conditions of a maar volcano (Atexcac crater, Eastern Mexico). Journal of Volcanology and Geothermal Research, 159(1–3), 179–197. doi:10.1016/j.jvolgeores.2006.07.001
Dermawan, F. A., Hamka, H., Malik, R. T. A., Sianipar, J. Y., & Ramadhan, Q. S. (2016). Volcanostratigraphic study in constructing volcano chronology and its implication for geothermal resource estimation; Case Study Mount Sawal, West Java. In IOP conference series: Earth and environmental science (Vol. 42, No. 1, p. 012027). IOP.
Ferriz, H., & Mahood, G. A. (1984). Eruption rates and compositional trends at Los Humeros volcanic center, Puebla, Mexico. Journal of Geophysical Research, 89(B10), 8511–8524. doi:10.1029/JB089iB10p08511
Gómez-Tuena, A., & Carrasco-Núñez, G. (2000). Cerro Grande volcano: The evolution of a Miocene stratocone in the early Trans-Mexican Volcanic Belt. Tectonophysics, 318(1–4), 249–280. doi:10.1016/S0040-1951(99)00314-5
Gómez-Tuena, A., Orozco-Esquível, M., & Ferrari, L. (2005). Petrogenesis ignea de la faja volcánica transmexicana. Boletín de la Sociedad Geológica Mexicana, 57(3), 227–283. doi:10.18268/bsgm2005v57n3a2
Hobson, R. D. (1967). FORTRAN IV programs to determine surface roughness in topography for the CDC 3400 computer. University of Kansas.
Hobson, R. D. (1972). Surface roughness in topography: Quantitative approach, in spatial analysis in geomorphology. New York: Harper and Row.
Jenness, J. S. (2004). Calculating landscape surface area from digital elevation models. Wildlife Society Bulletin, 32(3), 829–839.
Julia, F., Vladimir, L., Sergey, R., & David, Z. (2014). Effects of hydrothermal alterations on physical and mechanical properties of rocks in the Kuril–Kamchatka island arc. Engineering Geology, 183, 80–95.
Martin del Pozzo, A. L. (1982). Monogenetic vulcanism in sierra Chichinautzin, Mexico. Mexico: Bulletin of Volcanology, 45(1), 9–24.
Mitchell, T. M., Smith, S. A., Anders, M. H., Di Toro, G., Nielsen, S., Cavallo, A., & Beard, A. D. (2015). Catastrophic emplacement of giant landslides aided by thermal decomposition: Heart Mountain, Wyoming. Earth and Planetary Science Letters, 411, 199–207.
Moore, I. D., Grayson, R. B., & Landson, A. R. (1991). Digital terrain modelling: A review of hydrological, geomorphological, and biological applications. Hydrological Processes, 5, 3–30. doi:10.1002/hyp.3360050103
Palacios-Hartweg, L. H., & García-Velázquez, H. (1981). Rhyolite pumice deposits in the Early Pleistocene rhyolite deposit in the eastern Trans-Mexican Volcanic Belt. Journal of Volcanology and Geothermal Research, 15(1–2), 133–150.
Romero-Ríos, F. (1985). Exploración en la zona geotérmica de Las Derrumbadas, Pue. Informe 37/85 para la Comisión Federal de Electricidad. Departamento de exploración.

Ross, P. S., Núñez, G. C., & Hayman, P. (2017). Felsic maar-diatreme volcanoes: A review. Bulletin of Volcanology, 79(2), 20.

Siebe, C., Macias, J. L., Abrams, M., Rodriguez, S., Castro, R., & Delgado, H. (1995). Quaternary explosive volcanism and pyroclastic deposits in east central Mexico: Implications for future hazards. In Guidebook of geological excursions: in conjunction with the Annual Meeting of the Geological Society of America, New Orleans, Louisiana, November 6-9, 1995 (pp. 1-48). Louisiana State University. Basin Research Institute. Center for Coastal Energy & Environmental Resources, Baton Rouge, Louisiana, United States.

Siebe, C., & Macías, J. L. (2006). Volcanic hazards in the Mexico city metropolitan area from eruptions at Popocatépetl, Nevado de Toluca, and Jocotitlán stratovolcanoes and monogenetic scoria cones in the Sierra Chichinautzin volcanic field. Special Papers-Geological Society of America, 402, 253.

Siebe, C. P., & Verma, S. (1988). Major element geochemistry and tectonic setting of Las Derrumbadas Rhyolitic Domes, Puebla, Mexico. Chemie Der Erde – Geochemistry, 48 (1988), 177–189.

Siebe, C., Rodríguez-Lara, V., Schaaf, P., & Abrams, M. (2004). Radiocarbon ages of Holocene Pelado, Guespalapa, and Chichinautzin scoria cones, south of Mexico city: Implications for archaeology and future hazards. Bulletin of Volcanology, 66(3), 203–225.

Siebert, L., & Carrasco-Núñez, G. (2002). Late-Pleistocene to precolumbian behind-the-arc mafic volcanism in the eastern Mexican Volcanic Belt; implications for future hazards. Journal of Volcanology and Geothermal Research, 115(1-2), 179–205. doi:10.1016/S0377-0273(01)00316-X

Silva, S. D., Self, S., Francis, P. W., Drake, R. E., & Carlos, R. R. (1994). Effusive silicic volcanism in the central Andes: The Chao dacite and other young lavas of the Altiplano-Puna Volcanic Complex. Journal of Geophysical Research: Solid Earth, 99(B9), 17805–17825.

Strahler, A. N. (1952). Hypsometric (area-altitude) analysis of erosional topography. Geological Society of America Bulletin, 63(11), 1117–1142.

Thouret, J. C. (2010). Volcanic hazards and risks: A geomorphological perspective. In I. A. Ayala & A. Goudie (Eds.), Geomorphological hazards and disaster prevention (pp. 13–32). Cambridge: Cambridge University Press.

Trujillo Hernandez, N. (2019). Petrography of Las Derrumbadas volcanic complex. Unpublished manuscript. Morelia: Universidad Michoacana de San Nicolás de Hidalgo – CEMIEGEO.

Verma, S. P. (2000). Geochemical evidence for a lithospheric source for magmas from Los Humeros caldera, Puebla, Mexico. Chemical Geology, 164(1–2), 35–60. doi:10.1016/S0009-2541(99)00138-2

Verma, S. P. (2001). Geochemical evidence for a lithospheric source for magmas from Acoculco caldera, eastern Mexican Volcanic belt. International Geology Review, 43 (1), 31–51.

Yáñez, G. C., & García, D. S. (1982). Exploración de la región geotérmica Los Humeros – Las Derrumbadas, estados de Puebla y Veracruz. Comisión Federal de Electricidad.