Volcanic geology of the easternmost sector of the Trans-Mexican Volcanic Belt, Mexico

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Abstract
This work presents the volcanic geology of the easternmost sector of the Trans-Mexican Volcanic Belt, including the Serdán-Oriental basin and Cofre de Perote-Citlaltépetl volcanic range, two contrasting Quaternary volcanic fields. The first comprises dominant monogenetic volcanism of bimodal composition including isolated rhyolitic domes and tuff rings, basaltic andesite maar volcanoes, cinder and lava cones, and an active caldera complex (Los Humeros). The second is dominated by large composite polygenetic volcanoes of andesitic-dacitic composition, including the shield-like compound Cofre de Perote volcano, La Gloria and Las Cumbres complexes, and the active Citlaltépetl stratovolcano. Mapping units include a pre-volcanic basement made of metamorphic (Paleozoic), and sedimentary (Jurassic-Cretaceous); intrusive (Miocene) rocks; multiple basaltic-andesitic lava flows and rhyolitic domes; volcaniclastic sequences (debris avalanches and lahars; and pyroclastic deposits (block-and-ash flows, ignimbrites, fallbacks, and surges) (Miocene-Holocene). This map provides a comprehensive view of the highly diverse volcanism, which may reference for future research work.

1. Introduction
The easternmost sector of the Trans-Mexican Volcanic Belt (TMVB) is a large natural volcanic laboratory made of two contrasting volcanic areas, the Serdán-Oriental basin (SOB) and the Cofre de Perote-Citlaltépetl volcanic range (CPCVR) (Figure 1). Both areas host a large diversity of volcanic landforms formed by intense and highly variable volcanism since the Miocene (10.5-8.9Ma), in terms of eruptive style and composition (effusive to explosive and magmatic to phreatomagmatic and basaltic to rhyolitic). As a result, volcanoes range from small monogenetic (cinder and lava cones, domes, maars, tuff rings, and small shields) to large polygenetic volcanic landforms (stratovolcanoes, compound volcanoes, calderas, and dome complexes), formed by a broad range of deposit types including lava flows, domes, volcaniclastic sequences (debris avalanches and lahars), and pyroclastic deposits (ignimbrites, fallbacks, block-and-ash flows, and surges). The relatively young age and climatological conditions of these areas permit the preservation of the original volcanic landforms, making this sector an exceptional volcanic region.

The SOB is a broad closed basin (2,300 m.a.s.l.), hosting isolated basaltic andesite cinder and lava cones, maar volcanoes, small to medium-sized rhyolitic domes and tuff-rings, pyroclastic sequences, and an active caldera (Los Humeros). In contrast, the CPCVR comprises two andesitic-dacitic composite volcanoes (Citlaltépetl, or Pico de Orizaba, and Cofre de Perote) and two volcanic complexes (La Gloria, Las Cumbres) (Figure 2a), which form a pronounced physiographic boundary between the SOB and the Gulf of México Coastal Plain (GMCP) (Figure 1), with a nearly 1 km relief height. Continuous degradation and sedimentation processes associated with these large and unstable volcanic ranges have promoted repeated sector collapses toward the GMCP (Carrasco-Núñez et al., 2006).

This work presents the volcanic geology of this sector in a regional map and cross-sections, showing the distribution, chronostratigraphy, and composition of the main volcanic units, which may serve as an important reference for future work in this region.

2. Methodology
2.1. Field methods and data compilation
Cartographic work consisted of the digital mapping of an extensive fieldwork database (>150 sites with stratigraphic and structural descriptions) into a 154 × 119 km area by using GIS software. Geographical data
from each site were recorded using a handheld GPS in UTM coordinates under the WGS84 datum. Representative samples were selected for further petrographic and geochemical characterization (61 new analyses from 550 compiled: data source available in the repository). Also, 104 isotopic ages obtained by different dating methods were compiled into the map (references and dating methods are cited in the main map), leading to identifying distinct lithostratigraphic units and constructing the regional chronostratigraphy.

2.2. Map compilation

Geologic maps and Google Earth satellite images were compiled and plotted over a 15 × 15 m resolution digital elevation model (DEM) provided by the Mexican Elevation Continuum source (CEM3.0), and by using the ArcGIS software. Compiled geologic maps include the Los Humeros volcanic complex (LHVC) (Carrasco-Núñez et al., 2017a), Cofre de Perote (Carrasco-Núñez et al., 2010), Citlaltépetl (Carrasco-Núñez, 2000; Carrasco-Núñez & Ban, 1994), Cerro Grande volcano and surroundings (Carrasco-Núñez et al., 1997), Las Cumbres complex (Rodríguez, 2005), Naolinco-Chiconquiaco (Ferrari et al., 2005), and several 1:50,000 (Zacatlán, Teziutlán, Altotonga, Misantla, Mexcaltepec, Xonacatlán, Perote, Xalapa, Guadalupe Victoria, and Coatepec) and 1:250,000 scale geologic maps (Orizaba and Veracruz) published by the Mexican Geological Survey (SGM, 1996; 1997; 2001; 2002; 2007a; 2010a; 2010b; 2011a: 2011b; 2011c; 2012).

Furthermore, in addition to our regional analysis, lithological contacts and volcano-structural features were redefined by imagery analyses of the geological maps and regional structural works by Fitz-Díaz et al. (2018) and Norini et al. (2019).

2.3. Integration of the lithostratigraphic framework and map construction

Mapping volcanic geology is always a challenging work due to the complex nature of volcanic systems,
which commonly records facies variations, overlapping eruptive styles, and temporal changes (Németh & Palmer, 2019). Mapping is even more complicated when mapping on a regional scale because of the large diversity of volcanic landforms, eruptive products, compositions, and spatio-temporal variations, which is the case in this work. To solve this, we constructed a regional lithostratigraphic framework based on the lithology, eruptive style, origin, and stratigraphic relations. For this, we integrated field and chronological data along with the cartographic database. This approach allowed us to combine, in some cases, individual rock units into single lithostratigraphic units. In the cases where the lithostratigraphic units include rocks from multiple volcanoes or vents, and to summarize their description and facilitate their identification in the map, we preferred to use general descriptions (as a Group) based on the dominant composition, age, and type of volcanic product (e.g. andesitic lavas, rhyolitic domes, ignimbrites) rather than assigning formal names. A stratotype locality was assigned in individual lithostratigraphic units from a particular vent source, and volcanic facies were featured following Németh and Palmer (2019).

By following this methodology, and after careful analysis, a comprehensive regional lithostratigraphic column was constructed comprising 36 lithostratigraphic units. For practical purposes, and due to space limitations, the descriptions of the lithostratigraphic units presented are deliberately summarized. However, the reader is referred to the cited bibliography for additional information.
3. Volcanic stratigraphy

3.1. Pre-volcanic basement

Pz.- Paleozoic metamorphic and granitic basement

The regional basement is formed by a Paleozoic (131-246 Ma, K/Ar, Yáñez-García & García-Durán, 1982) crystalline complex of greenschists, pillowed meta-basalt, meta-andesitic basalts, granodiorites and granites grouped as the Teziutlán Massif (Vinegra-Osorio, 1965), located westward of Teziutlán city and in Las Minas region.

J.- Jurassic shale and limestone

The regional basement is overlain by a Jurassic sedimentary sequence, which mostly corresponds to highly-deformed shales and limestones forming the Sierra Madre Oriental (SMO) province (Vinegra-Osorio, 1965), also referred as the Mexican fold and thrust belt (Fitz-Diaz et al., 2018). Outcrops are limited northwest of LHVC and in the Las Minas region.

K.- Cretaceous limestone

This unit corresponds to the Cretaceous SMO sequence, composed of clayey limestones with flint intercalations that laterally grades to reef facies (Vinegra-Osorio, 1965). Outcrops are widespread and are unconformably overlain by the Cenozoic volcanism (Figure 2a).

3.2. Tertiary magmatism (T)

Tig/Tidg.- Intrusive rocks

Tig. This unit includes granite-granodiorite-diorite rocks dated at 15.12 ± 0.64 Ma near Tepeyahualco town (U/Pb, Carrasco-Núñez et al., 2017b) that cut Cretaceous limestones. This age is consistent with the previously reported dating range from 14.5 ± 7–31 ± 3.7 Ma (K/Ar, Yáñez-García & García-Durán, 1982). Several outcrops of this unit are exposed in the Tlaxco range and Las Minas valley.

Tidg.- This unit comprises dloritic and gabbroic intrusions with pervasive alteration to chlorite (Cantagrel & Robin, 1979), ranging from 10.9 ± 0.8 Ma to 15.6 ± 0.5 (40Ar/39Ar; Ferrari et al., 2005). Outcrops are located to the west and more extensively to the northeast of Xalapa city.

TCg.- Cerro Grande andesitic-dacitic lava flows and breccias

This unit belongs to the Cerro Grande (CG) volcano. It comprises low-silica, pyroxene-bearing andesitic to hornblende-bearing dacitic lava flows and breccias (ignimbrites), with K/Ar ages ranging from 11 ± 0.6–8.9 ± 0.4 Ma (Carrasco-Núñez et al., 1997). This unit was dated near the locality of Cuyoaco at 10.5 ± 0.7 Ma (K/Ar) and correlates with the Alseseca andesite (Yáñez-García & García-Durán, 1982). Stratotype: 6 km southwest of Cuyoaco town.

Tvs.- Nocayoco-Ixtacamaxtitlán volcano-sedimentary sequence (CG)

This is a stratified sequence composed by volcanic conglomerates and lacustrine layers, interbedded with brecciated block-and-ash-flow, and pumice-rich fallout and surge deposits (Carrasco-Núñez et al., 1997), dated at 9.2 ± 0.3 Ma (K/Ar, Gómez-Tuena & Carrasco-Núñez, 2000). The sequence corresponds to medial-to-distal ring plain facies (Németh & Palmer, 2019) from the explosive destruction of Cerro Grande (CG) volcano. Stratotype: 4 km southeast of Ixtacamaxtitlán town.

3.3. Tertiary (Neogene)-Early Pleistocene volcanism

Tab.-Teziutlán-Chiconquiaco andesite to basalt lava flows Group

This unit is composed of massive, porphyritic, two-pyroxene-bearing andesite and minor olivine-bearing basalt lava flows, with reported 40Ar/39Ar ages ranging from 1.46 ± 0.31–2.61 ± 0.43 Ma (Carrasco-Núñez et al., 2017b), and K/Ar dates from 1.55 ± 0.1 Ma (Ferriz & Mahood, 1984) to 3.5–5.0 Ma (K/Ar, Yáñez-García & García-Durán, 1982). This unit is contemporaneous with the alkaline-trending basaltic-andesitic volcanism of the Chiconquiaco plateau dated between 1.97 ± 0.04–6.93 ± 0.16 Ma (K/Ar, Ferrari et al., 2005), and the rocks exposed eastward of Xalapa city with K/Ar ages ranging from 1.57–1.9 Ma (Cantagrel & Robin, 1979). This volcanism seems to be associated with dominant fissure activity with scarce volcanic edifices.

3.4. Quaternary volcanism (Q)

3.4.1. Middle-Early Pleistocene

Qa3.- Andesitic, trachyandesitic and dacitic lava flows and domes Group (Cofre de Perote, La Gloria).

Trachyandesitic lava flows and andesitic-trachyandesitic dacies are associated with the early activity of the Cofre de Perote shield-like compound volcano, forming medial facies in a stratovolcano-dominated system (Németh & Palmer, 2019) around the main volcano edifice. A 40Ar/39Ar age is reported in 0.51 ± 0.06 Ma (Carrasco-Núñez et al., 2010), which is consistent with the K/Ar age range of 0.47 ± 0.2 Ma to 1.3 ± 0.12 Ma of Cantagrel and Robin (1979). These lavas correlate with those derived from La Gloria complex (LGC) at its central edifice and eastern distal facies, where lavas intercalate with volcaniclastic deposits (ring plain).

Qr4.- Rhyolitic domes (LHVC)

This unit consists of high-silica, flow-banded, porphyritic rhyolitic domes (Carrasco-Núñez et al., 2017b). 40Ar/39Ar ages range from 485 ± 2.2–693 ±
1.7 ka, representing Los Humeros pre-caldera activity (Carrasco-Núñez et al., 2018). A K/Ar age of 470 ± 40 ka (Ferriz & Mahood, 1984) is also reported for this unit. Stratotype: Oyameles western scarp of LHVC.

3.4.2. Middle Pleistocene

Qb2.- Basaltic and basaltic andesitic lava flows Group (CG, Coatepec, SOB) This is a widespread unit comprising massive basaltic lava flows, autobrecias, and scoria deposits, derived from small scoria and lava cones. Lavas around CG have been dated at 490 ± 70 ka (K/Ar, Carrasco-Núñez et al., 1997), and those around Coatepec range from 250 ± 30 ka (Rodríguez et al., 2010) to 260 ± 30 ka (40Ar/39Ar; Carrasco-Núñez et al., 2010). Isolated and small cone clusters are widely distributed along the SOB; one has an age of 190 ± 20 ka (40Ar/39Ar; Carrasco-Núñez & Riggs, 2008).

Qa2.- Andesitic and dacitic lava flows Group (Citlaltépetl, Cofre de Perote, Las Cumbres, Sierra Negra) This unit includes a succession of massive andesitic to dacitic lava flows and associated breccias. For Citlaltépetl stratovolcano (medial facies), two-pyroxene-bearing andesites and amphibole-bearing dacites formed during the initial effusive stage (Torrecillas), ranging from 290 ± 5 ka (K/Ar, Carrasco-Núñez, 2000) to 340 ± 50 ka (K/Ar, Höskuldsson, 1992). For the Cofre de Perote compound-volcano (proximal facies), massive, two-pyroxene-bearing andesitic-trachytic to dacitic lava flows erupted between 307 ± 35–400 ± 30 ka (40Ar/39Ar; Carrasco-Núñez et al., 2010), representing its second (intermediate) stage. Amphibole-bearing andesites feature Las Cumbres Complex (LCC; central edifice), dated at 365 ± 15 ka (40Ar/39Ar, Rodríguez, 2005). Although there are not reported ages for the andesite-dacite lava flows from Sierra Negra volcano (central edifice), Carrasco-Núñez (2000) proposes they may be contemporaneous with this unit.

Qtrav.- Puente Nacional travertine deposits Late Pliocene-Pleistocene travertine deposits are located to the southeast of Xalapa city and Citlaltépetl volcano and around Acatzingo town. These are characterized by recrystallized and massive textures (SGM, 2010b). Stratotype: Puente Nacional (40 km southeast of Xalapa city, north of San José Chipila).

Qvs.- Coastal plain volcanioclastic sequence This unit includes volcanioclastic deposits formed by diluted debris avalanches, lahars, and fluviatile events. Even when the sources remain unknown, these are interpreted to derive from either LGC or LCC, or both (see section C-C in the map). This sequence represents ring plain distal facies from the CPCVR.

Qtr3.- Rhyolitic domes Group (LHVC, Las Águilas, Cerro Pizarro, Citlaltépetl) This unit includes flow-banded, spherulite-bearing, obsidian-rich rhyolitic domes, regarded as part of the Los Humeros pre-caldera stage, dated between 155.7 ± 4.9–350 ± 17 ka (K/Ar and U/Th - Ferriz & Mahood, 1984; Carrasco-Núñez et al., 2017a; 2018). This unit also comprises Las Águilas dome, the early activity Cerro Pizarro polygenetic obsidian-bearing dome system with a central cryptodome facies (Figure 3c) of 220 ± 60–65 ± 10 ka (40Ar/39Ar; Carrasco-Núñez & Riggs, 2008), and several domes outcropping between Citlaltépetl and Las Cumbres volcanoes, where an amphibole-bearing rhyolitic dome was dated in 350 ± 60 ka (K/Ar, Höskuldsson, 1992).

Qlda.- Jamapa debris avalanche (Citlaltépetl) This unit consists of a highly altered, heterolithic, and massive avalanche deposit derived by a sector collapse of the Torrecillas edifice at Citlaltépetl volcano. It shows a hummocky topography and transitional downstream changes to flat distal laharc facies (Carrasco-Núñez et al., 2006); occurred between 0.29 (Torrecillas rocks) and 0.21 Ma (Espolón de Oro rocks-younger stage) (Carrasco-Núñez, 2000). Stratotype: northern Huatusco town with numerous exposures along the Jamapa river.

Qal1.- Andesitic and dacitic lava flows Group (Citlaltépetl, Cofre de Perote, SOB) This unit comprises porphyritic two-pyroxene andesitic and amphibole-bearing dacitic lava flows ranging from 90 ± 53 ka (K/Ar, Höskuldsson, 1992) to 210 ± 40 ka (K/Ar, Carrasco-Núñez, 2000). It is associated with the construction of the Espolón de Oro paleocone (second stage: central edifice) at Citlaltépetl stratovolcano and to other andesites in a dome situated between Citlaltépetl and LCC (Sillatepec), which include distal avalanche facies (Rodríguez, 2005). This unit includes highly-jointed, trachyte-dacite lava flows and breccias associated with the last Cofre de Perote summit activity (central edifice) between 200 ± 100–254 ± 10 Ka (K/Ar and 40Ar/39Ar; Carrasco-Núñez et al., 2010).

QXig.- Xáltipan Ignimbrite (LHVC) This is a pumice-rich, rhyolitic pyroclastic sequence composed of two flow units bounded by a basal and an intercalated thin pumice fallout layer. This unit’s recent cartographic and stratigraphic studies reveal that this ignimbrite formed during a continuous, multi-phase eruption, with ca. 290 km³ of DRE ejected magma (Cavazos-Alvarez & Carrasco-Núñez, 2019; 2020), ranking this eruption as the largest in the TMVB. A previous K/Ar date provided an age of 460 ka (K-Ar, Ferriz & Mahood, 1984); however, combined 40Ar/39Ar and U/Th dating provided an age of 164 ± 4.2 ka (Carrasco-Núñez et al., 2018). This unit is related to the formation of the ca. 17 km-diameter Los Humeros caldera. A stratotype locality is referred adjacent to the
Xáltipan town (northern LHVC). Nevertheless, the complete stratigraphy of this unit can be better assessed by following the two stratotype sections described in Cavazos and Carrasco-Núñez (2020) since this is a composite, facies-variating ignimbrite (from proximal outflow sheet to distal valley-pond; outcrops are all around Los Humeros caldera).

3.4.3. Late Pleistocene
QFt.- Faby Tuff (LHVC)

The Faby Tuff is a thick, paleosol-bounded, rhyodacitic pumice fallout succession derived from Plinian eruptions widely dispersed to the southeast sector of the Los Humeros caldera (proximal facies) (Ferriz & Mahood, 1984; Willcox, 2011). This unit is dated at 70 ± 23 ka ($^{40}$Ar/$^{39}$Ar; Carrasco-Núñez et al., 2018). Stratotype: El Frijol quarry, 20 km west of Perote city.

QZig.- Zaragoza Ignimbrite (LHVC)
This ignimbrite records the second caldera-forming eruption at Los Humeros that formed the nested Los Potreros caldera (Ferriz & Mahood, 1984; Willcox, 2011) at 69 ± 16 ka (40Ar/39Ar; Carrasco-Núñez et al., 2010). This ignimbrite was emplaced radially as an outflow sheet composed of an intraplinian massive ignimbrite bounded by two fallout layers. It is characterized by a double compositional zonation (rhyodacite-andesite-rhyodacite) (Carrasco-Núñez & Branney, 2005). Stratotype: 5 km west of Cerro Pizarro summit.

Qr2/Qd2.- Rhyolitic and dacitic domes (LHVC, Cerro Pinto, Las Cumbres, Citlaltepetl)

Qr2.- Rhyolitic domes (LHVC, Cerro Pinto). This unit includes flow-banded and porphyritic rhyolitic domes outcropping at Los Humeros caldera. These domes were dated at 44.8 ± 1.7 ka and 50.7 ± 6 ka (U/Th and 40Ar/39Ar; Carrasco-Núñez et al., 2017a). This unit includes the Cerro Pinto rhyolitic tuff ring-dome complex (Figure 3a), dated at 62 ± 8 ka (40Ar/39Ar; Zimmer et al., 2010); however, a recent 14C dating reveals a younger age of 22.5 ka (Chédeville et al., 2019).

Qd2.- Dacitic domes (LCC, Citlaltepetl). This unit represents a summit dacitic plug dome at the Las Cumbres complex, with a minimum age of 40 ka (14C; Rodríguez, 2005). Some peripheral amphibole-bearing dacitic domes with associated syn-eruptive pyroclastic flows, forming localized block-and-ash fans, are exposed to the west of Citlaltepetl crater, overlying 90 ka old lavas (Carrasco-Núñez, 2000). However, some are younger than 23 ka (Rodríguez, 2005).

Qba-b.- Basaltic andesites and basalts Group (Cofre de Perote- Naolinco, Eastern LCC-LGC)

This unit consists of lava flows from the northeastern vent cluster of the Cofre de Perote and the Naolinco volcanic field, with an age range of 40–43 ka (14C; Siebert & Carrasco-Núñez, 2002). This unit also includes some small scoria and lava cones located east of LCC-LGC.

Qquet.- Quetzalapa Pumice

This unit consists of high-silica, biotite-bearing, widespread-dispersed, Plinian pumice fallout deposits derived from a vent located westward of LCC, dated at 23 ka (14C; Rodríguez et al., 2002). Stratotype: 10 km west of Las Cumbres summit.

QTI/QLCa/QCvc.- Volcaniclastic deposits Group

QTI.- Teteltzingo lahar. It is a massive mixture of pebbles-boulders supported by a yellow-brown clayey matrix. It represents an avalanche-induced lahar (post-eruptive, channelized distal facies) derived by a sector collapse of hydrothermally altered rocks from the ancient Citlaltepetl volcano, showing no significant transformations downstream (Carrasco-Núñez et al., 1993). 14C dating yielded an age of 16.5 ka (Carrasco-Núñez et al., 2006). Stratotype: 1 km east of Teteltzingo town, crossing Jamapa river.

QLCa.- Las Cumbres debris avalanche. It consists of poorly-sorted, heterolithic, altered boulders with jigsaw-fractures and imbricated blocks and clayey minerals (Carrasco-Núñez et al., 2006; Rodríguez, 2005). It was formed by the sector collapse of Las Cumbres volcano and transformed downstream to debris flow and fluviatile facies. 14C dating provides a minimum age of 40 ka (Rodríguez, 2005). Stratotype: 12 km northeast from Las Cumbres summit.

QCvc.- Cofre Perote volcanoclastic deposits. This unit includes two different deposits derived from sector collapses of the Cofre de Perote compound volcano (Carrasco-Núñez et al., 2006; 2010). Los Pescados debris flow deposit consists of a massive and heterolithic mixture of boulders and jigsaw-fractured blocks supported by a silt-rich matrix, dated at 44 ka (14C). Stratotype: Los Pescados river, next Jalcumulco town. Also, it includes the Xico debris-avalanche deposit dated between 11–13 ka (14C), which is composed of heterolithic, boulder-to-gravel-sized lithic clasts within a sand-silty matrix, showing hummocky topography. Downstream transformation to fluviatile deposits is observed in both deposits at the distal facies. Stratotype: 2 km northwest of Xico town.

3.4.4. Holocene

Qta-b.- Trachyandesitic to basaltic andesite maars and lavas Group

This unit groups basaltic andesite maar volcanoes and isolated scoria and lava cones. They have a widespread distribution within the SOB. The maar volcanoes record periodic fluctuations in the water-magma interactions, resulting in diverse sizes and shapes of their craters. Some depict ellipsoidal-shaped forms with aligned scoria and spatter cones, such as Aljojuca (14C: 4.1 ± 0.03–2.8 ± 0.03 ka, De León-Barragán et al., 2020, p. 5.5 ka, Bhattacharya et al., 2015, p. 2.6 ± 0.08 ka, Chédeville et al., 2020) (Figure 2b) and Tecuitlapa (14C: 8.9 ± 0.13 ka, Chédeville et al., 2020) (Figure 2d), or show an irregular elongated shape such as Atexcac (Carrasco-Núñez et al., 2007) (Figure 3e), dated at 8.3 ± 0.9–5.1 ± 0.1 ka (14C; Chédeville et al., 2020), Quechulac, La Preciosa, Xalapazco tuff cone (Abrams & Siebe, 1994), and others. These features indicate structurally-controlled phreatomagmatic conditions with temporal migration of the explosion locus (Ort & Carrasco-Núñez, 2009). The largest maar in the SOB has a quasi-circular shape: Alchichica (14C: 11.2 ± 0.05; Chédeville et al., 2020, p. 40Ar/39Ar: 14–6 ka, Chako-Tchamabé et al., 2020) (Figure 3d). This unit also includes several vent clusters and fissure lava flows.
located to the south of Serdán town and west of La Gloria Complex, such as El Brujo lava shield, $^{14}$C dated at 7.5 ± 0.06–6.8 ± 0.1 ka (Chédeville et al., 2019). Besides, the post-caldera trachyandesitic and basaltic andesite lava flows from LHVC, exposed within and along the caldera rim, resulted in a maximum age of 8.9 ± 0.03 ka (14C; Carrasco-Núñez et al., 2017a). They overlie a pyroclastic sequence dated at 7.4 ka and therefore is even younger than this age.

**QCig.- Citlaltépetl Ignimbrite**

This unit is a radially distributed sequence of massive pumice and scoria-rich pyroclastic flow (ignimbrite) deposits dated between 9–8.5 ka. ($^{14}$C; Carrasco-Núñez & Rose, 1995). These deposits are interbedded with ash and lapilli fallout (Plinian) layers, referred to as the Citlaltépetl Pumice (Rossotti & Carrasco-Núñez, 2004) Stratotype: near Loma Grande village, 14 km south of Citlaltépetl crater.

**QMp.- Malinche pyroclastic sequence.** This unit includes a sequence of massive ash-flow deposits dated in 7.43 ± 0.2 ka ($^{14}$C; Castro-Govea & Siebe, 2007), forming ring plain facies. This sequence overlays older lavas at the northeast flank of La Malinche stratovolcano (outside the map).

**Qt1/Qd1/Qr1.- High-silica (trachyte-dacite-rhyolite) eruptive products Group**

**Qt1.- Los Humeros trachyte.** This unit comprises two pyroxene porphyritic trachytic lava flows located within and south of Los Humeros caldera. A maximum $^{14}$C age of 2.8 ± 0.03 ka is reported by Carrasco-Núñez et al. (2017a). Stratotype: Los Pajaros vent near the southern caldera rim.

**Qd1.-Chichimeco dacitic domes (Citlaltépetl).** This unit represents a fresh-looking dome complex located northeast of the Citlaltépetl crater, composed of amphibole-bearing dacites overlying the 8.6 ± 0.09 ka Citlaltépetl ignimbrite ($^{14}$C; Carrasco-Núñez, 2000). Stratotype: Chichimeco dome complex, 5 km northeast from Citlaltépetl’s summit.

**Qr1.- Derrumbadas rhyolitic domes.** This unit comprises Las Derrumbadas twin rhyolitic domes and its associated debris-avalanches and lahar facies (Figure 2c) surrounding the main domes (Siebe et al., 1995), depicted with shade marks in the map. A U/Th age of 4.7 ± 1.3/–1.2 ka is reported by Bernal et al. (2014), which is consistent with a maximum age range of 4.3 ± 0.1–0.86 ± 0.07 ka ($^{14}$C; Chédeville et al., 2019). This unit includes the rhyolitic Tepexitl circular tuff ring (Austin-Erickson et al., 2011) dated at 6.25 ± 0.05 ka ($^{14}$C, Chédeville et al., 2019), and also a small dome-tuff cone northward Las Cumbres summit dated at 5.8 ± 0.6 ka ($^{14}$C; Rodríguez, 2005).

**Qb1.- Olivine-bearing basaltic lava flows Group (LHVC, LGC, northern Xalapa)**

This unit includes vesicular aa, and pahoehoe lava flows from different sources. At LHVC, it appears within and outside the caldera, such as the Texcual flow dated at 3.8 ± 0.13 ka ($^{14}$C; Carrasco-Núñez et al., 2017a); at the northern La Gloria complex, this unit is dated between 5.6 ± 0.06–1.9 ± 0.8 ka ($^{14}$C; Rodríguez, 2005); at the northeast of Xalapa city, it includes the Coacotzintla lava and El Volcancillo volcano, dated at 2.9 ± 0.5 ka and 0.9 ± 0.05 ka, respectively ($^{14}$C; Siebert & Carrasco-Núñez, 2002).

**Qd-Citlaltépetl dacitic lavas.** This unit (Qd1) comprises blocky and levee-sided, amphibole-pyroxyene-bearing dacitic-andesites lavas mainly erupted in historical times from the Citlaltépetl summit crater (Mosser et al., 1958). Stratotype: Citlaltépetl-Sierra Negra divide.

**Qp.- Undifferentiated pyroclastic and alluvial deposits**

This unit includes pyroclastic deposits of different sources, reworked pumice deposits, and soil layers.

### 4. Summary and concluding remarks

The geologic cartography of the SOB and CPCVR records the highly diverse Quaternary volcanism of the easternmost sector of the TMVB. The SOB is featured by monogenetic bimodal volcanism comprising basaltic andesite maar volcanoes (e.g. Alchichica, Aljolouca, Atexcac, Tecuitlapa, Preciosa), cinder and lava cones (e.g. El Brujo), large isolated rhyolitic domes (e.g. Cerro Pizarro, Las Derrumbadas), tuff rings (e.g. Cerro Pinto, Tepexitl), and the active Los Humeros volcanic complex, the largest caldera in the TMVB. In contrast, the CPCVR comprises large andesitic-dacitic polygenetic volcanoes, including the shield-like compound Cofre de Perote volcano, La Gloria and Las Cumbres complexes, and the active Citlaltépetl (Pico de Orizaba) stratovolcano, with subordinate monogenetic volcanism.

The map and cross-sections show the spatio-temporal distribution of the volcanism and its relationship with the structural framework. The most recent volcanism is everywhere, so no systematic variations across the volcanic arc are observed through the entire easternmost sector of the TMVB. This work may serve as a useful reference for further studies, not only for volcanological purposes but also for petrology, geophysics, hydrogeology, geothermal exploration, and even volcanic hazards, as this is regarded as an active volcanic area.

### Software

Geo-referencing and digitization of map elements was made using ESRI© ArcGIS 10.2. The final map layout and pictures were produced using CorelDRAW X7.
Geolocation information

The map presented in this work has the shape of a box delimited by the coordinates $-98.000^\circ$E – $-96.777^\circ$E, $18.735^\circ$N – $18.808^\circ$N (WGS84 datum).

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Disclosure statement

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Data availability statement

The data that support the findings of this study are available from the corresponding author, [GCN], upon reasonable request.

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