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Digital Geologic Cartography and Geochronologic Database of the Trans-Mexican Volcanic Belt and Adjoining Areas☆

Cartografía Geológica Digital y Base de Datos Geocronológica del Cinturón Volcánico Transmexicano y Áreas Contiguas

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Abstract

We present the first interactive digital geologic map of the Trans-Mexican Volcanic Belt (TMVB). The area covered by the cartography span 10° of Longitude (106°- 96° W) and 2°45′ of Latitude (19°-21°45′ N). The geology has been compiled in ArcGIS through an interpretation of all the information available in the literature and integrated with our own geologic mapping. Published maps were digitized from printed copies; when possible, the location of features with clear morphological expression was corrected using digital elevation models within the GIS. The map includes 36 geologic units, faults, volcanic vents, and calderas. The informal geologic units used in the compilation are chronostratigraphic and lithologic and were designed to emphasize the main volcanic episodes that make up this volcanic province. The age assignment for each unit has been cross-checked with a geochronologic database that includes 2009 ages, which can be displayed on the map with access to their attributes. Lithology of each polygon has been also checked against a large geochemical database compiled from the literature.

Keywords: Central Mexico; Trans-Mexican Volcanic Belt; Digital geologic map

Resumen

En este trabajo se presenta el primer mapa geológico digital interactivo de la Faja Volcánica Transmexicana (FVTM). El área cubierta por la cartografía geológica abarca 10° de longitud (106°- 96° W) y 2°45′ de latitud (19°-21°45′ N). La geología ha sido compilada en ArcGIS a través de una interpretación de toda la información disponible en la literatura e integrada con nuestra propia cartografía geológica. Los mapas publicados fueron digitalizados a partir de copias impresas; cuando fue posible se corrigió la ubicación de los rasgos con una clara expresión morfológica utilizando modelos de elevación digital en el SIG. El mapa incluye 36 unidades geológicas, fallas, chimeneas volcánicas y calderas. Las unidades geológicas informales utilizadas son cronoestratigráficas y litológicas y están diseñadas para destacar los principales episodios volcánicos que conforman el cinturón volcánico. La asignación de la edad para cada unidad ha sido cotejada con una base de datos geocronológicos que incluye 2009 edades. La clasificación litológica de cada polígono ha sido comparada por consistencia con una base de datos geoquímicos recopilados de la literatura.

Palabras clave: México central; Faja Volcánica Trans-Mexicana; Mapa geológico digital

1. Introduction

The Trans-Mexican Volcanic Belt (TMVB) is the largest Neogene volcanic arc in North America with an area of 160,000 km^2 and a length of almost 1000 km between Latitude 18°30′ and 21°30′ N in central Mexico. The irregular plateau formed by this geologic province hosts an important part of the population and industrial and agricultural activity of Mexico. Furthermore, its formation in the past 20 m.y. had a significant impact

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on climate and the evolution of biodiversity (e.g., Mastretta-Yanez et al., 2015). The TMVB displays several peculiarities when compared with most volcanic arcs, such as the arc-transversal orientation of the main stratovolcanoes, the large compositional variation of its products, the young age of the two plates subducting in front of the arc, and the absence of seismicity associated with them beneath the arc (Ferrari et al., 2012). Because of these peculiarities, over the past 40 years the TMVB has been the focus of hundreds of studies. Geologic maps have been published for the major active stratovolcanoes and some volcanic fields or for some discrete regions (Gastil et al., 1979; Demant, 1981; Pasquaré et al., 1991; Mooser et al., 1996; Carrasco et al., 1997; Ferrari et al., 2000, 2005; García-Palomo et al., 2002a, 2002b; Cortés et al., 2010; Gómez-Tuena et al., 2007; Rodríguez-Elizarrarás, 2005; Macías, 2007; Guilbauld et al., 2012; Gómez-Vasconcelos et al., 2015). However, a geologic map spanning the whole province was needed to disentangle the evolution of this volcanic province and better constrain its genesis. Here we present the first digital geologic map of the TMVB and adjoining areas of its heterogeneous basement. The area covered by the map is comprised between Longitude 106° and 96°W and Latitude 19° and 21°45′N. An earlier version of the map was published in static format (PDF figure in conventional papers) in Gómez-Tuena et al. (2007) and in Ferrari et al. (2012), to which the reader is referred for a comprehensive review of the geophysics of the Mexico subduction system and the geologic and petrologic evolution of the TMVB.

2. Methods

The geology presented in the map has been compiled over the past 18 years by the authors with the collaboration of several graduate and undergraduate students (see the Acknowledgements section for a complete list). The first step in the process was to define a general stratigraphy at the provincial level. We defined 36 informal geologic units, 25 of which belong to the TMVB proper, whereas the rest are part of the Sierra Madre Occidental and older basement terranes. The definition of this regional stratigraphy was based on chronostratigraphic and lithologic criteria and was supported by an extensive database that was first presented in Ferrari et al. (1999) and updated continuously since then by the second author. In this work, we include 2009 isotopic ages covering the area of the map, which were compiled from the literature and publicly available thesis. This information can be consulted in the interactive version of the map. Lithology of each polygon has been also checked against a large geochemical database compiled from the literature and partly published in Gomez-Tuena et al. (2007). Subsequently, existing regional geologic maps and our unpublished cartography has been reinterpreted according to the regional stratigraphy established in the previous stage. In most cases this implied grouping two or more original units into a single unit characterized by similar lithology and age range. We also compiled faults, volcanic vents, and calderas. The regional geologic maps used in the compilation were generally at 1:50,000 to 1:100,000 scale. Once georeferenced, the maps were digitized with different versions of ESRI GIS software (initially ArcView and later ArcInfo). During the digitization, the lithological classification and age assignment for each unit was cross-checked for consistency with geochronologic and geochemical databases. Digitization of paper copies and the intrinsic limitations of pre-GPS era geologic mapping introduced some spatial error, particularly in the case of features like volcanic vents and fault scarps. The location of these features has been therefore refined in the GIS using a digital elevation model as a guide. The map was eventually imported into ArcGIS to correct minor errors and for final rendering.
The main sources of the initial cartographic information were as follows (Fig. 1):

- Western TMVB: Ferrari et al. (2000), original 1:250,000 and 1:50,000 scale sheets provided by the authors.
- San Pedro-Ceboruco area, Nay.: Ferrari et al. (2003), original 1:50,000 scale sheets provided by the authors.
- Colima volcanic complex: Cortés et al. (2010), published map at 1:50,000 scale.
- Jilotlán region. Jal.: Colima 1:250,000 scale map of Servicio Geológico Méxicano by Rosas Elguera et al. (2000).
- Central TMVB: Pasquaré et al. (1991), original 1:100,000 and 1:50,000 scale sheets provided by the authors.
- Sierra de Guanajuato and Querétaro area: Alaniz et al. (2001), original shapefiles provided by the authors.
- Eastern TMVB: Mooser et al. (1996), published sheets at 1:100,000 scale.
- Nevado de Toluca area: García-Palomo et al. (2002a), published map at 1:100,000 scale.
- Valle de Bravo and Zitácuaro areas: geologic maps in Blatter et al. (2001).
- Apan area, Hidalgo: geologic map in García-Palomo et al. (2002b).
- Zimapán area, Hidalgo: Carrillo-Martínez (2000), published map at 1:100,000 scale.
- Cerro Grande and surroundings, Puebla: Carrasco-Núñez et al. (1997), published map at 1:100,000 scale.
- Easternmost TMVB: Ferrari et al. (2005), original 1:50,000 scale sheets provided by the authors.

In some cases, information of the original maps was updated according to field data and unpublished mapping by Ferrari and Orozco, which also served as a base for areas not covered by the above maps.

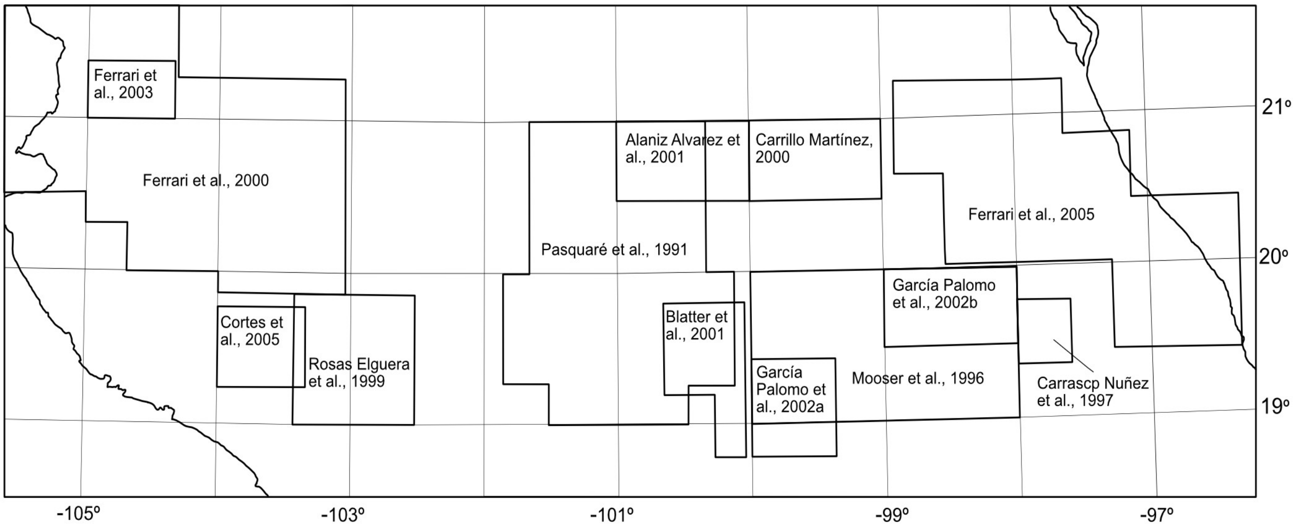

Figure 1. Main sources of the initial cartographic information
Figura 1. Principales fuentes de la información cartográfica inicial.

3. Map units

All geologic units used in the map are informal and were established with the aim of correlating volcanic episodes throughout the TMVB. They can be divided in to two broad groups: a) rocks that precede the onset of the TMVB, and 2) rocks belonging to the TMVB volcanic activity and associated continental sedimentary basins. The TMVB group can be further subdivided according to the four volcanic episodes described in Ferrari et al. (2012). Rocks pre-dating the TMVB belong to the Sierra Madre Occidental, the Laramide arc, the Sierra Madre Oriental and the Guerrero terrane. Table 1 (see Appendix A) summarizes each map unit under this scheme. See Plate 1 for a PDF version of the map.

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Geologic map of the Trans-Mexican Volcanic Belt

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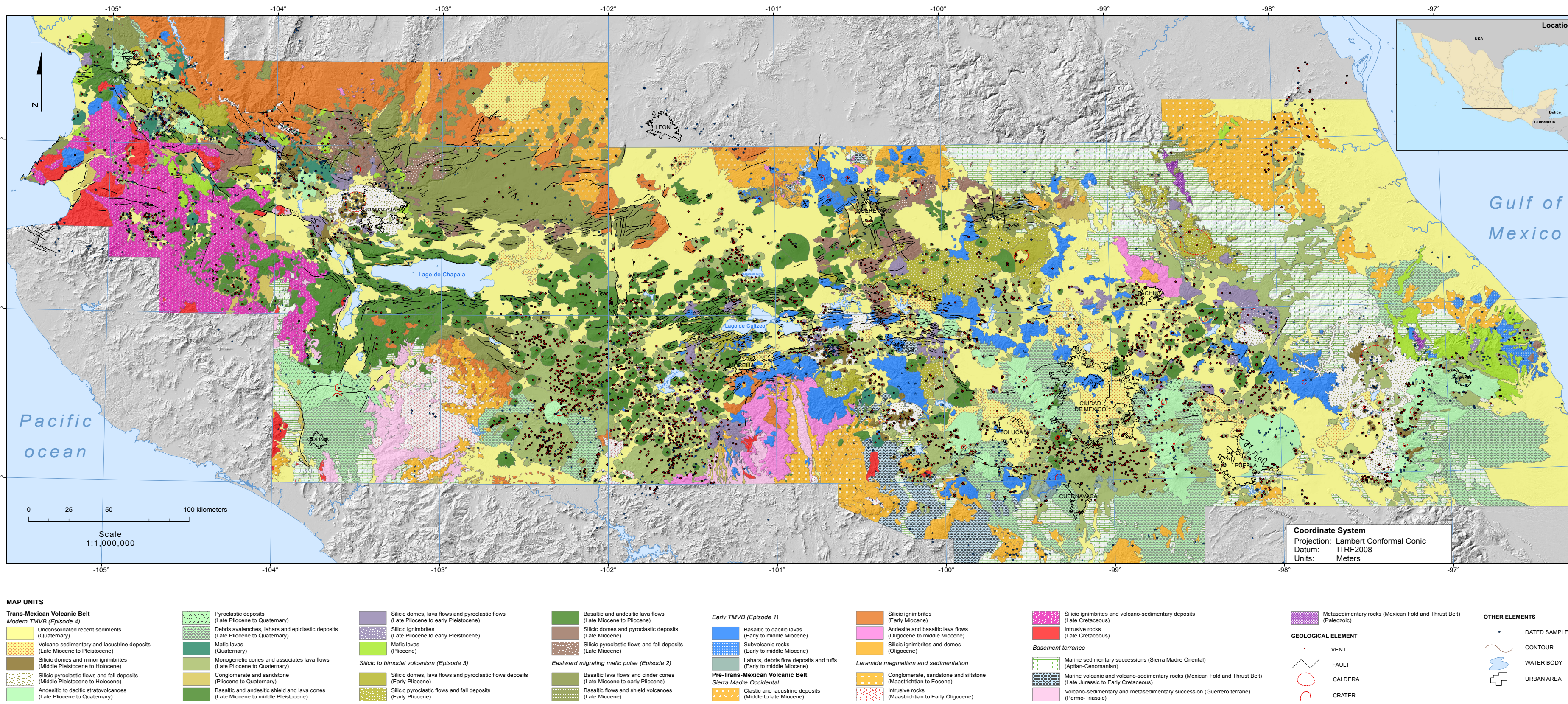

Plate1: Geologic map of the Trans-Mexican Volcanic Belt
Lámina 1. Mapa geologico del Cinturón Volcánico TransMexicano

Appendix A. Table 1. Description of maps units (Tabla 1. Descripción de las unidades del mapa)

Map unit	Age	Description
	Trans-Mexican Volcanic Belt	
Modern TMVB (Episode 4)		
Unconsolidated recent sediments	Quaternary	Uppermost, recent alluvial and lacustrine deposits, mostly undergoing sedimentation.
Volcano-sedimentary and lacustrine deposits	Late Miocene to Pleistocene	Volcano-sedimentary and lacustrine deposits filling basins bounded by tectonic or volcanic structures. In some cases, under active erosion.
Silicic domes and minor ignimbrites	Middle Pleistocene to Holocene	Effusive rhyolitic volcanism and related pyroclastic deposits, associated to calderas (La Primavera, Los Humeros) or part of fault controlled dome clusters (Tequila area).
Silicic pyroclastic flows and fall deposits	Middle Pleistocene to Holocene	Large volume rhyolitic ignimbrites associated to caldera forming eruptions (La Primavera, Los Azufres, Zitácuaro, Acoculco, Los Humeros, La Cumbre).
Andesitic to dacitic stratovolcanoes	Late Pliocene to Quaternary	Main stratovolcanoes of the TMVB formed by alternating effusive and explosive volcanic activity with subduction-related character. From W to E they include: San Juan, Sangangüey, Tepetiltic, Ceboruco, Tequila, Tancítaro, Temascalcingo, Jocotitlán, San Antonio, Nevado de Toluca, Popocatépetl, Iztaccíhuatl, Telapón, Malinche, Pico de Orizaba, and Cofre de Perote volcanoes, as well as the Colima and Sierra de Las Cruces volcanic complexes.
Pyroclastic deposits	Late Pliocene to Quaternary	Pyroclastic flows and fall deposits associated to major explosive eruptions of the main stratovolcanoes of the TMVB.
Debris avalanches, lahars and epiclastic deposits	Late Pliocene to Quaternary	Mass-wasting deposits associated to major explosive eruptions of the main stratovolcanoes of the TMVB.
Mafic lavas	Quaternary	Fissure-fed basaltic lava plateaus and small cinder cones associated with extensional fault systems; mostly with intraplate affinity and located in the western and eastern parts of the TMVB.
Monogenetic cones and associates lava flows	Late Pliocene to Quaternary	Cinder cones and lavas flows mostly with subduction-related character, which may be associated to extensional fault systems. Sometimes forming large fields such as the Michocán-Guanajuato and Chichinautzin volcanic fields.
Conglomerate and sandstone	Pliocene to Quaternary	Clastic sedimentary deposits filling tectonic basins, mostly in the western TMVB.
Basaltic and andesitic shield and lava cones	Late Miocene to middle Pleistocene	Polygenetic volcanoes with dominant effusive activity and subduction-related character. Mostly in the Michoacán-Guanajuato and Apan volcanic fields.
Silicic domes, lava flows and pyroclastic flows	Late Pliocene to early Pleistocene	Effusive rhyolitic volcanism and associated pyroclastic deposits (W TMVB, Michoacán-Guanajuato VF, Villa Madero, Los Azufres, Apan, Tulancingo, Las Navajas).
Silicic ignimbrites	Late Pliocene to early Pleistocene	Large volume explosive volcanism associated to caldera-forming eruptions (Acoculco).
Mafic lavas	Pliocene	Fissure-fed basaltic lavas and small lava cones in part associated with normal faults, mostly with intraplate affinity and located in the western and eastern parts of the TMVB.
Silicic to bimodal volcanism (Episode 3)		
Silicic domes, lava flows and pyroclastic flows deposits	Early Pliocene	Effusive rhyolitic volcanism and associated low-volume pyroclastic deposits. In the western TMVB these rocks are not associated with calderas.
Silicic pyroclastic flows and fall deposits	Early Pliocene	Large volume ignimbrites often from caldera-forming eruptions (Ciudad Hidalgo, Amealco, Huichapan, Carbonera).
Basaltic and andesitic lava flows	Late Miocene to Pliocene	Fissure-fed lava flows, cinder cones and mid-sized lava cones with dominantly subduction-related character. Mostly in the western and central TMVB.

Silicic domes and pyroclastic deposits	Late Miocene	Effusive rhyolitic volcanism and associated low volume pyroclastic deposits. Chiefly located in the Guadalajara and Querétaro regions.
Silicic pyroclastic flows and fall deposits	Late Miocene	Large volume ignimbrites sometimes from caldera forming eruption (Amazcala).
Eastward migrating mafic pulse (Episode 2)		
Basaltic lava flows and cinder cones	Late Miocene to early Pliocene	Mafic lava flows and cinder cones with intraplate affinity of the north-eastern TMVB.
Basaltic flows and shield volcanoes	Late Miocene	Fissure fed mafic lava flows and small shield volcanoes showing migration from W to E (NW of Tepic, San Cristobal, Altos de Jalisco, Cotija region, Querétaro-Pathé region).
Early TMVB (Episode 1)		
Basaltic to dacitic lavas	Early to middle Miocene	Dominantly intermediate lava cones and stratovolcanoes with associated pyroclastic deposits, mostly with subduction-related character.
Subvolcanic rocks	Early to middle Miocene	Gabbroic to granodioritic plutons, mostly in the eastern TMVB. Often with adakitic character.
Lahars, debris flow deposits and tuffs	Early to middle Miocene	Volcaniclastic and epiclastic deposits located at the front of the TMVB south of Mexico City and Toluca (Tepoztlán formation).
	Pre-Trans-Mexican Volcanic Belt	
Sierra Madre Occidental		
Clastic and lacustrine deposits	Middle to late Miocene	Conglomerate, sandstone and lacustrine deposits filling large basins, mostly north of the TMVB (e.g. Teocaltiche, San Juan de los Lagos).
Silicic ignimbrites	Early Miocene	Large volume ash flow deposits of the second pulse of silicic volcanism of the Sierra Madre Occidental. They are found also south of the TMVB in the Cotija and Mil Cumbres regions.
Andesite and basaltic lava flows	Oligocene to middle Miocene	Mafic lava flows capping or intercalated in the upper part of the SMO ignimbrite, often showing an intraplate affinity. Basaltic and andesitic lava flows in the Tzitzio-Mil Cumbres and Pachuca-Real del Monte regions.
Silicic ignimbrites and domes	Oligocene	Large volume ash flow deposits and rhyolitic domes of the first pulse of silicic volcanism of the Sierra Madre Occidental. Located north and south of the eastern TMVB.
Laramide magmatism and sedimentation		
Conglomerate, sandstone and siltstone	Maastrichtian to Eocene	Clastic continental deposits. South of the TMVB they correspond to red beds of the Cutzamala Formation.
Intrusive rocks	Maastrichtian to Early Oligocene	Granitic to dioritic rocks of the Jilotlán and La Huacana plutons.
Silicic ignimbrites and volcano-sedimentary deposits	Late Cretaceous	Ash flow deposits, andesitic lava flows and breccias within the Jalisco Block.
Intrusive rocks	Late Cretaceous	Granite, granodiorite and diorite of the Puerto Vallarta batholith.
Basement terranes		
Marine sedimentary successions (Sierra Madre Oriental)	Aptian-Cenomanian	Limestone, argillite, slate and sandstone. In the Tejupilco area they show intercalation of pillow lavas.
Marine volcanic and volcano-sedimentary rocks (Mexican Fold and Thrust Belt)	Late Jurassic to Early Cretaceous	Sandstone, shales and minor limestone interbedded with volcanic rocks. Mostly exposed in the Sierra de Los Cuarzos.
Volcano-sedimentary and metasedimentary succession (Guerrero terrane)	Permo-Triassic	Low to medium grade metamorphic succession of the Guerrero terrane mostly exposed in the Tejupilco and Tzitzio anticlinorium (correlative with the Arteaga Complex).
Metasedimentary rocks (Mexican Fold and Thrust Belt)	Paleozoic	Meta-sandstone and -shales of the Huayacocotla anticline.

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