Received: 23 Nov. 2021, **Accepted:** 8 Apr. 2022
Published online: 30 June 2022
DOI: https://doi.org/10.22201/igg.25940694e.2022.1.90 **Volume:** 6, **Issue:** 1, **Pages:** 1-7

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Geological map of the distribution of igneous Cenozoic rocks in central Tampico-Misantla Basin☆

Mapa geológico de la distribución de rocas ígneas cenozoicas en la porción central de la Cuenca Tampico-Misantla

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Abstract

We present a geological map that shows the distribution of Cenozoic igneous rocks in the central portion of the Tampico-Misantla Basin in eastern Mexico at 1:350,000 scale. This map covers an area of ~25000 km^2, including part of the States of Veracruz, Hidalgo and Puebla in Mexico. It was made as background information for the geophysical exploration of the CONACYT Fronteras de la Ciencia project 1787 "Un acercamiento a los Yacimientos no Convencionales a partir de Métodos Electromagnéticos de exploración". This map resulted from the compilation of cartographic and geochronological (28 K-Ar isotopic ages) information from available literature, complemented and improved with photogeology and regional reconnaissance tours along several roads that cross the region. Main Cenozoic units were recognized during fieldwork. Particular emphasis was placed on identifying igneous rocks, especially intrusive bodies, as this was one of the main goals of the CONACYT Project, by using geophysical methods, and characterizing the geometry of the basin. The map is now available to the community interested in the Cenozoic evolution of east-central Mexico. Besides that, it will be the basis of the research that the group is carrying out in the Eastern Mexican Alkaline Province and the eastern Sierra Madre Oriental Cenozoic magmatism.

Keywords: Tampico-Misantla Basin map, Cenozoic, Igneous Rocks

Resumen

Se presenta un mapa geológico que muestra la distribución de rocas ígneas cenozoicas en la parte central de la Cuenca Tampico-Misantla en escala 1:350,000. Este cubre un área aproximada de ~25000 km^2 y comprende parte de los estados de Veracruz, Hidalgo y Puebla, México. Como parte de la colaboración dentro del proyecto "Un acercamiento a los Yacimientos No Convencionales a partir de Métodos Electromagnéticos de exploración" (CONACYT Fronteras de la Ciencia 1787) se compiló el presente mapa geológico regional, con el objetivo de funcionar como base para el trabajo de exploración geofísica. Se compiló el mapa geológico a partir de la información cartográfica y geocronológica (28 edades isotópicas K-Ar) disponible en la literatura que posteriormente fue complementada con trabajo de fotointerpretación y transectos geológicos a través de las vías de comunicación que atraviesan el área. Durante el trabajo de campo, se identificaron las principales unidades litológicas cenozoicas en la zona, y se puso especial énfasis en la identificación de las rocas ígneas, como derrames e intrusiones, esto debido a que el principal objetivo del proyecto CONACYT fue el de identificar mediante métodos geofísicos las intrusiones en la región. Este mapa se pone a disposición de la comunidad interesada en la evolución cenozoica de la porción oriente-central de México, además de que será base de la investigación que realiza el grupo de trabajo sobre la Provincia Alcalina Oriental Mexicana y el magmatismo cenozoico del este de la Sierra Madre Oriental.

Palabras clave: Mapa Cuenca Tampico-Misantla, Cenozoico, Rocas ígneas

1. Introduction

The study area is located in the physiographic province of the northern Gulf Coastal Plain. It comprises part of the Tampico-Misantla Basin, a productive hydrocarbon basin since the earliest 1900s (Rueda-Gaxiola, 2003; Juárez-Arriaga et al., 2019a), in the vicinity with the Mexican Fold and Trust Belt (MFTB) (Fitz-Díaz et al., 2018) to the west, and with the Trans-Mexican Volcanic Belt to the south-southwest (Figure 1). The Tampico-Misantla Basin is a foreland basin that belongs to a major system named the Mexican Foreland Basin (MFB) (Juárez-Arriaga et al., 2019a), developed along the eastern front of the MFTB, and extends from Chihuahua city in northern Mexico, to Jesus Carranza, in Veracruz, south of the present map area, reaching an extension of c. 1700 km (Davison et al., 2020). The stratigraphic record of the Tampico-Misantla Basin comprises continental to marine sedimentary rocks from Permian to Mesozoic age, uncomformable overlied by marine Cenozoic detrital sediments (Segerstrom, 1962; Fries Jr and Rincón-Orta, 1965; López-Ramos, 1982; Cantú-Chapa, 1985; Ortega-Gutiérrez et al., 2018; Davison et al., 2020). Pre-Cenozoic units were folded during the development of the MFTB (Fitz-Díaz et al., 2018) and subsequently exhumed, weathered, and partially eroded during the Cenozoic, becoming the main sediment source of the Tampico-Misantla Basin (Juárez-Arriaga et al., 2019a). Late Miocene and Quaternary mafic lava flows partially cover the Cenozoic sedimentary units (Cantagrel and Robin, 1979; Ferrari et al., 2005). Isolated outcrops of Oligo-Miocene gabbros and granodiorites are reported in the region (Cantagrel and Robin, 1979; López-Reyes et al., 1997; Moreira-Rivera et al., 1997; Maldonado-Lee et al., 2004a; Ferrari et al., 2005). Such Cenozoic igneous rocks are considered as part of Eastern Mexican Alkaline Province (EMAP), which is an NNW trending belt of alkaline volcanic fields that border the Gulf of Mexico from Texas, in the USA, to southern Veracruz (Cantagrel and Robin, 1979; Ferrari et al., 2005). The EMAP was initially interpreted as the result of gulf-parallel extensional faulting that migrated from north to south since the Oligocene to Quaternary (Cantagrel and Robin, 1979). Later studies proposed that this magmatism resulted from the tearing and detachment of part of a slab subducted from western Mexico, triggering mantle melting. The ascent of these magmas would be controlled and facilitated by pre-existing basement structures of Late Jurassic origin (Ferrari et al., 2005).

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2. Methods

Our map is a compilation and integration of previous works, including: (a) portions of 1:250,000 scale geologic maps of the Servicio Geológico Mexicano (SGM) completely covering the area (Ciudad Valles, F14-8; Tamiahua, F14-9; Pachuca, F14-11; Poza Rica, F14-12); (b) 1:50,000 scale SGM maps covering the western and southwestern parts of the area; and (c) two maps published by Ferrari et al. (2005) covering the Tlanchinol – Álamo and Tulancingo – Poza Rica areas (Figure 2). The pre-Cenozoic rocks were grouped as Permian – Cretaceous sediments, except for the Precambrian Huiznopala Gneiss as Metamorphic Basement. The lithostratigraphic nomenclature of the Cenozoic sedimentary units was adopted after Servicio Geológico Mexicano maps, which is based on early twentieth-century literature and supported by micropaleontological fossil determinations. Geochronological available data consists of twenty-eight K-Ar isotopic datings from the mafic lava flows (Cantagrel and Robin, 1979; Ferrari et al., 2005). The cartographic and geochronological data were georeferenced and digitalized using an open-source QGIS Geographic Information System. The geological contacts were verified using Google Earth satellite images and digital elevation models generated using continental relief data from the Instituto Nacional de Estadística y Geografía at 1:10,000 scale (INEGI). The compiled map was later verified and corrected when necessary by field observations during regional reconnaissance tours along federal highways and secondary roads (Figure 2). Structural data and rock samples were collected during fieldwork to verify field observations and for future research.

3. Regional Geology

According to previous works (Fries Jr and Rincón-Orta, 1965; López-Ramos, 1982; Ortega-Gutiérrez et al., 2018; Coombs et al., 2020), the basement of the Tampico-Misantla Basin comprises igneous and metamorphic rocks of the Precambrian to Triassic: (a) the Proterozoic Huiznopala Gneiss to the northwest in the region of Tulancingo and Molango, (b) early Paleozoic schists in the Poza Rica area and (c) Triassic granitic rocks in the southwest. The only known basement rocks cropping out in the map area are the Huiznopala Gneiss (Ortega-Gutiérrez et al., 2018) [Metamorphic basement (Gns), with "pEgn" symbol in the map]. The rest mentioned basement units had been identified through PEMEX drill cores.

Permian to Cretaceous age sediments overlies the crystalline basement discordantly [Permian-Cretaceous Sediments, with "PzMzs" symbol in the map]. Late Triassic continental red beds were deposited over tectonic depressions during the breakup of western Equatorial Pangea (Davison et al., 2020). This sequence is represented in the area by the Guacamaya (Early Permian), Huizachal (Late Triassic-Early Jurassic), Huayacocotla (Early Jurassic), and Cahuasas (Middle Jurassic) formations (Carrillo-Bravo, 1965; Rueda-Gaxiola, 2003). The Early Permian Guacamaya Formation consists of thin to medium thickness strata of black shales wich alternates with sandstones and conglomerates, and limestones horizons have been reported in some localities (Buitrón-Sánchez et al., 2017). Huizachal Formation, known as a redbeds succession, consists of shales, sandstone and conglomerate of Late Triassic to Early Jurassic Age (Carrillo-Bravo, 1965; Rueda-Gaxiola, 2003; Barboza-Gudiño et al., 2010). Early Jurassic conglomerates covered by sandstones and shales are grouped in the Huayacocotla Formation (Carrillo-Bravo, 1965; Rueda-Gaxiola, 2003). The Middle Jurassic Cahuasas Formation also consists of red sandstones, conglomerate and shale (Carrillo-Bravo, 1965).

Sandstones, shales, and carbonates units of marine environment dominated the deposition since Late Jurassic times, as Trancas, Santiago, Tamán, Chipoco and Pimienta formations (Segerstrom, 1962; Carrillo-Bravo, 1982). Las Trancas Formation is a black, thinly bedded shale with sandstone and mudstone concretions, interbedded with graywacke (Segerstrom, 1962). The Santiago Formation consists of dark and calcareous shales interbedded with thinly bedded limestone (Carrillo-Bravo, 1982). In turn, the Late Jurassic Tamán Formation consists of an interbedded sequence of black limestone and black shales (Cantú-Chapa, 1985). The Chipoco Formation comprises dark gray mudstones and grainstones interbedded with calcareous shale (Carrillo-Bravo, 1982). The Late

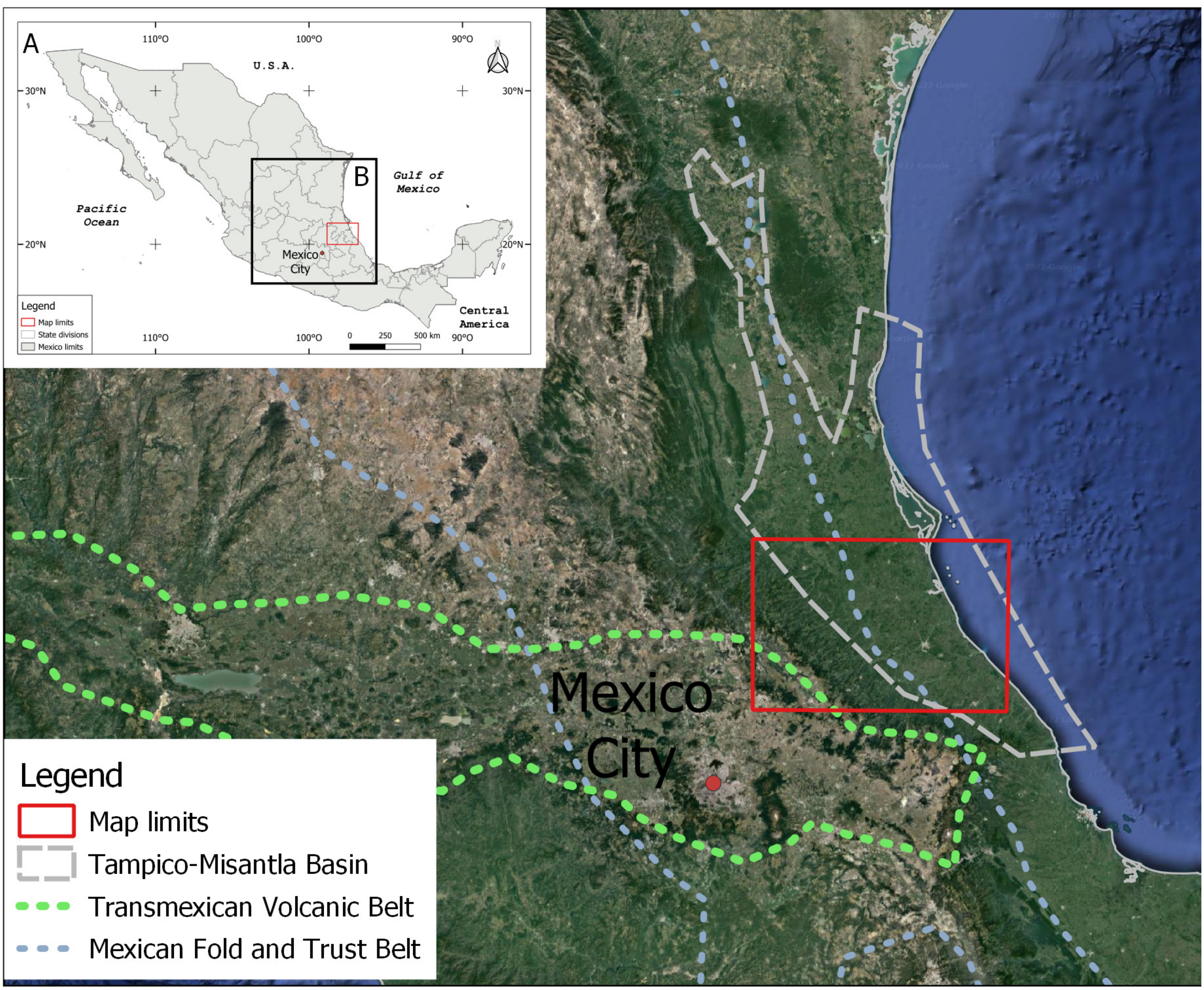

Figure 1: A. Location of map area. B. Location of the Google Satellite extract in the figure. Main provinces are shown. In red the location of present map, in gray Tampico-Misantla Basin, in pale blue the Mexican Fold and Trust Belt, and in light green the Trans-Mexican Volcanic Belt (modified after CNH, 2015; Ferrari et al., 2018; Fitz-Díaz et al., 2018). / Figura 1: A. Ubicación del área del presente mapa. B. Ubicación del extracto de la imagen de Google Earth que se muestra en la figura. Se presentan las principales provincias. El recuadro rojo señala la ubicación de este mapa geológico, en gris la Cuenca Tampico-Misantla, en azul claro el Cinturón de Pliegues y Cabalgaduras Mexicano, y en verde claro la Faja Volcánica Transmexicana (Modificado de CNH, 2015; Ferrari et al., 2018; Fitz-Díaz et al., 2018).

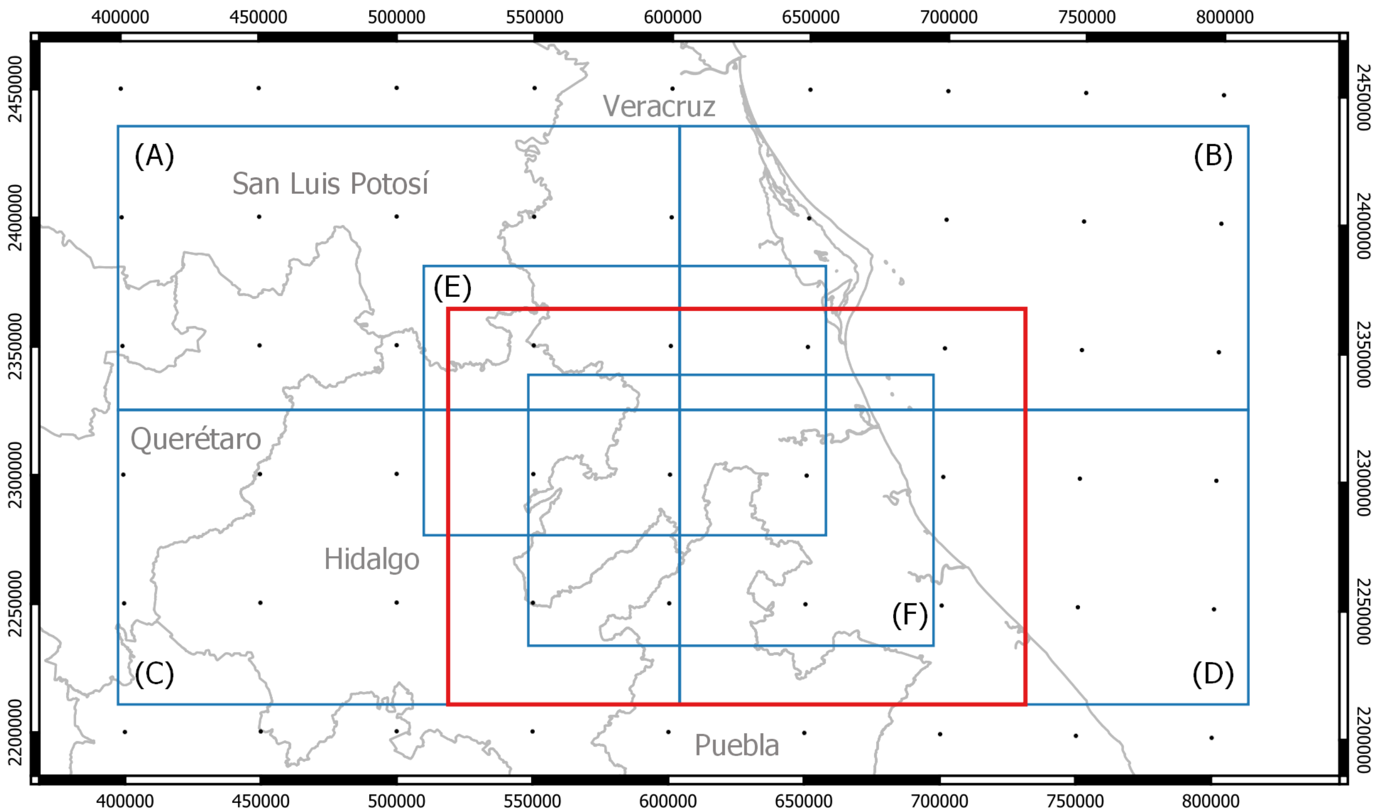

Figure 2: Distribution of previously published maps comprising portions of present map. A) Servicio Geológico Mexicano Ciudad Valles (F14-8) 1:250,000 scale map. B) Servicio Geológico Mexicano Tamiahua (F14-9) 1:250,000 scale map. C) Servicio Geológico Mexicano Pachuca (F14-11) 1:250,000 scale map. D) Servicio Geológico Mexicano Poza Rica (F14-12) 1:250,000 scale map. E) Gelogical map of Tlanchinol-Alamo area, from Figure 3 of Ferrari et al. (2005). F) Gelogical map of Tulancingo-Poza Rica area, from Figure 4 of Ferrari et al. (2005). / Figura 2: Distribución de mapas publicados previamente que abarcan parte del área del mapa del presente trabajo. A) Mapa Ciudad Valles (F14-8) escala 1:250,000, Servicio Geológico Mexicano. B) Mapa Tamiahua (F14-9) escala 1:250,000, Servicio Geológico Mexicano. C) Mapa Pachuca (F14-11) escala 1:250,000, Servicio Geológico Mexicano. D) Mapa Poza Rica (F14-12) escala 1:250,000, Servicio Geológico Mexicano. E) Mapa geológico del área de Tlanchinol-Álamo, tomado de la Figura 3 de Ferrari et al. (2005). F) Mapa geológico del área Tulancingo-Poza Rica, de la Figura 4 de Ferrari et al. (2005).

Jurassic-Early Cretacic Pimienta Formation consists of fine grained dark limestone interbedded with clayey limestone, calcareous shales and shales rich in organic matter (Cantú-Chapa, 1985). The Santuario, Tamabra, El Abra and Tamaulipas formations represent Early Cretaceous calcareous units and carbonate platforms. Santuario Formation comprises dark gray limestone, calcarenite, phyllitic shale and greywacke (Segerstrom, 1962). Tamabra, El Abra and Tamaulipas consists of limestones, interbedded with calcareous breccia in Tamabra Formation, thick bedded limestone in El Abra Formation, and limestone with chert lenses in Tamaulipas Formation. The input of detrital sediment from the ancestral Sierra Madre through the basin is represented by the Late Cretaceous, deep-marine Soyatal, Agua Nueva, San Felipe and Méndez formations (Segerstrom, 1962; Carrillo-Bravo, 1971). The Soyatal Formation consists of medium to thin-bedded dark gray limestone interbedded with shales (Segerstrom, 1962). Agua Nueva Formation comprises a succession of thin-bedded dark gray clayey limestone interbedded with shales with thin beds or lenses of black chert (Carrillo-Bravo, 1971). The San Felipe Formation has been defined as alternating limestone and shale of Conacian to Lower Santonian age, with altered volcanic ash interbedded with laminated limestone (Velasco-Tapia et al., 2016). Mendez Formation has been described as shale (Aguayo-Camargo et al., 2018) and marl (Segerstrom, 1962), being its main lithology.

The Mesozoic succession was folded and trusted during Late Cretaceous to Paleogene contractional Mexican Orogeny responsible for the MFTB and MFB (Eguiluz-de Antuñano et al., 2000; Fitz-Díaz et al., 2018; Juárez-Arriaga et al., 2019b). It was under this episode that the Paleocene – Eocene Chicontepec Formation was deposited (Carrillo-Bravo, 1971; Eguiluz-de Antuñano et al., 2000; Fitz-Díaz et al., 2018; Juárez-Arriaga et al., 2019b). The Chicontepec Formation consist of calcareous and siliciclastic turbidites deposited from the Paleocene to the early Eocene in a submarine canyon generated by the intense erosion of the underlying Cretaceous and Upper Jurassic succession (Busch and Govela, 1978) [Chicontepec Formation (Ss-Sh), with "Pec" symbol in the map]. Overlying the canyon-fill deposits of the Chicontepec Formation, the deposition of terrigenous sediments continued during the late

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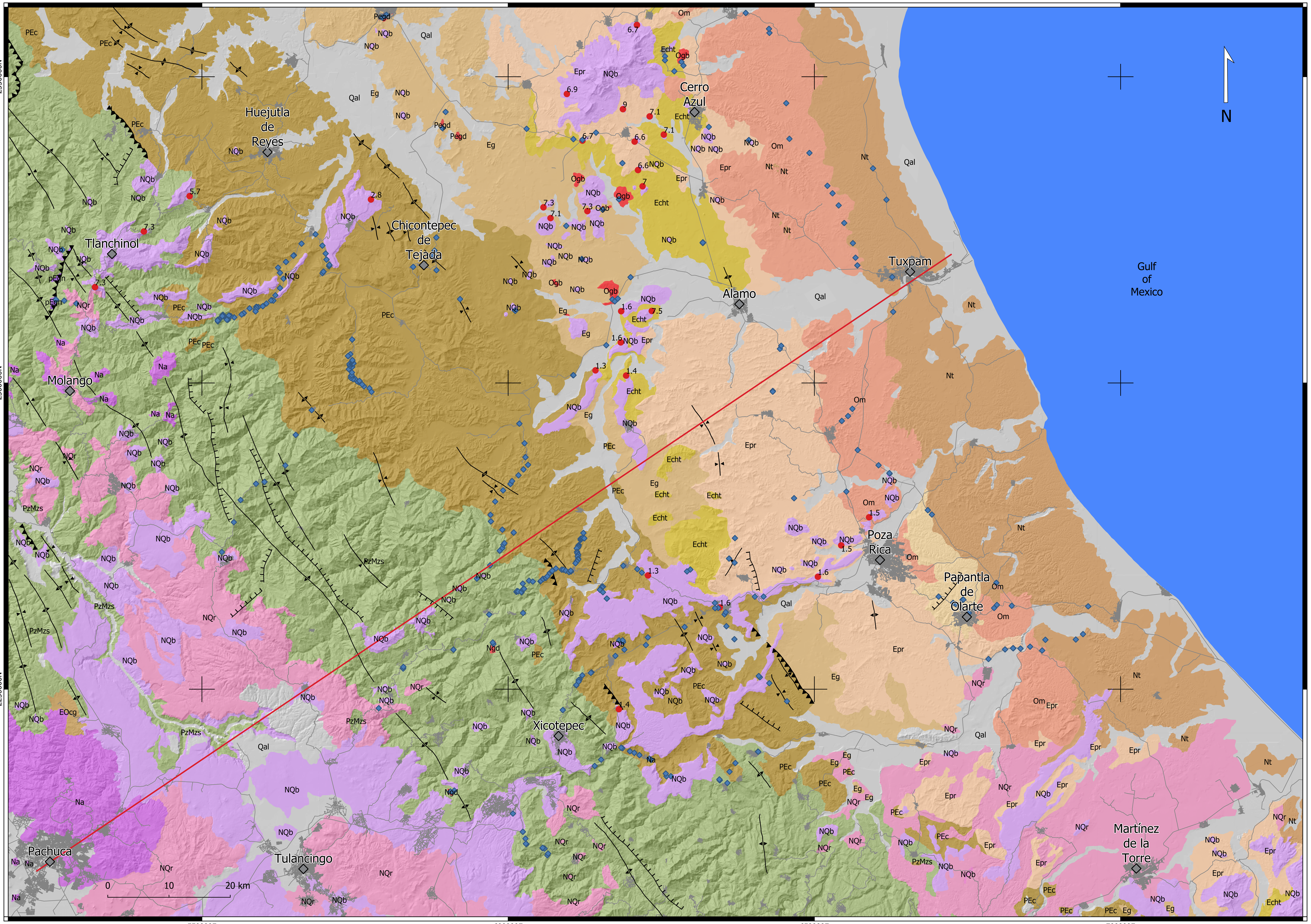


Legend

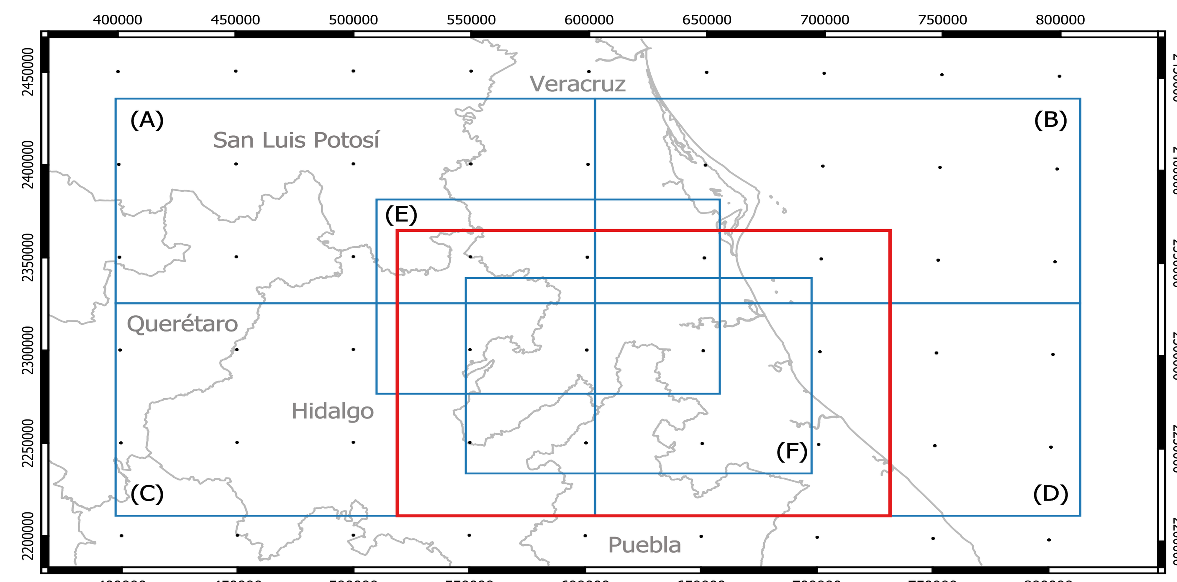
CENOZOIC	QUATERNARY	PLEISTOCENE
	NEOGENE	PLIOCENE
		MIOCENE
	PALEOGENE	OLIGOCENE
		EOCENE
		PALEOCENE
MESOZOIC PALEOZOIC		
PRECAMBRIAN		

- Qal Alluvial Deposits
- NQr Rhyolite
- Nqd Granodiorite
- NQb Basalt
- Na Andesite
- Nt Tuxpan Formation (Ss-Cgl)
- Ne Escolin Formation (Cgl-Ss)
- Oqb Gabbro
- Pegd Granodiorite
- Om Meson Formation (Ss-Sltst)
- EOcg Continental Conglomerate
- Epr Palma Real Formation (Ss-Sh)
- Echt Chapopote-Tantoyuca Formation (Ml-Sh)
- Eg Guayabal Formation (Sh-Ss)
- PEc Chicontepec Formation (Ss-Sh)
- PzMzs Permian-Cretaceous Sediments
- pEgn Metamorphic Basement (Gns)

- Reverse Fault
- Normal Fault
- Synclinal Fold
- Anticlinal Fold
- K-Ar Ages (Ferrari et al., 2005)
- Verification Points
- Main Cities
- Federal Highways
- Pachuca-Tuxpan Cross Section

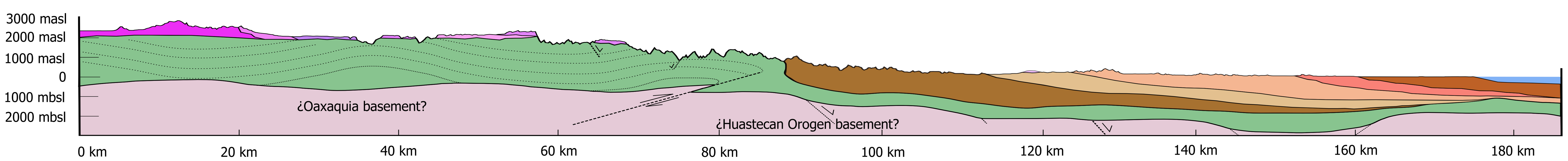
Scale 1:350000 WGS 84 / UTM 14N

Fieldwork was funded by CONACYT Fronteras de la Ciencia Grant to Fernando Corbo-Camargo, project #1787 "Un acercamiento a los Yacimientos no Convencionales a partir de Métodos Electromagnéticos de exploración".



(A) Ciudad Valles 1:250000 SGM map, (B) Tamiahua 1:250000 SGM map, (C) Pachuca 1:250000 map, (D) Poza Rica 1:250000 map, (E) Fig. 3, Ferrari et al. (2005), (F) Fig. 4 Ferrari et al. (2005). Map limits in red.

Pachuca - Tuxpam schematic cross section



Modified after: Segerstrom (1962); López-Ramos (1972); Alzaga-Ruíz et al. (2009); Aguayo-Camargo et al. (2018); Fitz-Díaz et al. (2018); JuárezArriaga et al. (2019); Ávila-Vargas et al. (2022).

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Eocene to Oligocene named as Guayabal, Chapopote-Tantoyuca, Palma Real and Mesón formations. The Guayabal Formation is described as grayish blue shale interbedded with thin layers of clayer and calcareous fine-grained sandstones (PEMEX, 1988) [Guayabal Formation (Sh-Ss), with "Eg" symbol in the map]. Chapopote-Tantoyuca Formation consists of a sequence of calcareous shale and gray greenish color sandy shale of upper Eocene age (Alzaga-Ruíz et al., 2009) [Chapopote-Tantoyuca Formation (Ml-Sh), with "Echt" symbol in the map].

The Oligocene Palma Real Formation comprises interbeds of sand and shale with greenish colour, and isolated conglomerates (Alzaga-Ruíz et al., 2009) [Palma Real Formation (Ss-Sh), "Epr" symbol in the map]. Meson Formation consists of sandy shales and marl of grayish blue color interbedded with fine to medium grained calcareous sandstone of late Oligocene-early Miocene age (Camacho-Angulo, 1987) [Meson Formation (Sh-Ss), "Om" symbol in the map]. Meanwhile, southwest of the basin continental conditions and sedimentation are evidenced by reported Eocene to Oligocene polymictic conglomerates (López-Reyes et al., 1997) [Continental Conglomerate, "EOcg" symbol in the map]. During the Miocene, the basin was filled by medium to coarse-grained sediments corresponding to the Escolin and Tuxpan formations, representing the last sedimentary deposits in the canyon. The Escolin Formation has been described as a succession comprised of a conglomerate in the top, with calcareous and conglomeratic sandstones and shales to the base (Carrillo-Martínez, 1960) [Escolin Formation (Cgl-Ss), "Ne" symbol in the map]. Tuxpan Formation comprises beds of sandstones, sandy limestone and shale of early-middle Miocene age (Camacho-Angulo, 1987) [Tuxpan Formation (Ss-Sh), "Nt" symbol in the map].

The sedimentary succession of the basin is intruded by a series of medium-sized granodiorites-diorites (Moreira-Rivera et al., 1997) and diorites-gabbros according to Maldonado-Lee et al. (2004a, 2004b). Diorites-granodiorites and diorites-gabbros are assigned to the Eocene [Granodiorite, "Pegd" symbol in map] and Oligocene [Gabbro, "Ogb" symbol in map], respectively, by the authors previously mentioned, although there is no geochronological data on those intrusions in the map area. Middle Miocene intrusive bodies have been reported south of the area (Cantagrel and Robin, 1979; Ferrari et al., 2005) [Granodiorite, "Ngd" symbol in map], while Paleocene-Eocene plutonic rocks are reported to the west (Sutter, 1984).

As seen in the map, late Miocene to Pleistocene lava flows partially cover the sedimentary marine successions [Basalt, "NQb" symbol in the map]. Several massive lava flows are exposed at the northwest part of the study region, between Tlanchinol and Huejutla de Reyes. Twenty-two basaltic flows deposited during four activity phases were identified by Robin and Bobier (1975) around Tlanchinol. Six samples were dated later by Cantagrel and Robin (1979) and Ferrari et al. (2005), reporting K-Ar ages from 7.4 Ma to 5.7 Ma between them (red circles in map). According to Ferrari et al. (2005), these are aphyric to microporphyritic lavas with olivine and pyroxene phenocrysts, ranging in composition from alkali basalt to hawaiite. The same authors report that these basaltic flows are deeply eroded and partly covered by early Pliocene silicic ash and pumice flow deposits ("rhyolite" in the map). They become more abundant in the southwestern margin of the study region. Also exposed are 2-10 m thick, aphyric to microphhorphyritic lava flows compositionally ranging from basanite to hawaiite in the Cerro Azul area. They mostly cover the Palma Real and Guayabal formations. Ferrari et al. (2005) dated three samples which yielded K-Ar ages ranging from 6.9 to 6.6 Ma. Large tens-of-meters-thick "mesas" covering the Chicontepec Formation yield a K-Ar age of 2.82 Ma (Ferrari et al., 2005) to the northwest of Chicontepec de Tejada. Finally, to the southeast of the study region, porphiritic basalt and hawaiites with olivine and clinopyroxene phenocrysts described by Ferrari et al. (2005) covers the Palma Real and Meson formations around the Poza Rica area. These authors reported K-Ar ages between 1.64 and 1.31 Ma. To the south and southwest of the area, Neogene to Quaternary andesitic lava flows [Andesite, "Na" symbol in the map] and silicic lavas and pyroclasts [Rhyolite, "NQr" symbol in the map] are reported (López-Reyes et al., 1997; Ferrari et al., 2005).

4. Conclusions

We present the first digital geological map focused on the distribution of the volcanic rocks and intrusive bodies cropping out in the central Tampico-Misantla Basin. Apart from the works of Cantagrel and Robin (1979) and Ferrari et al. (2005), most of the previous studies in the region focused on the stratigraphy of the Sierra Madre Oriental and Tampico-Misantla Basin, and the history and style of deformation in the Mexican Fold and Thrust Belt. By contrast the magmatic activity that affected the region received scarce attention. Few isotopic geochronological and geochemical data are available for volcanic centers, while the geochronology, thermochronology, and geochemistry of most intrusive bodies remains unknown. Our digital map provides a valuable work tool for the region and contributes to a better understanding of the Cenozoic geological evolution of eastern Mexico.

Funding

Fieldwork was funded by CONACYT Fronteras de la Ciencia no. 1787 Grant to Fernando Corbo-Camargo.

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This article accompanies the following material:

Static map: 10.22201/igg.25940694e.2022.1.90.199
Interactive map: 10.22201/igg.25940694e.2022.1.90.200