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Mexico Quaternary Fault Database☆

Base de datos de fallas cuaternarias de México

Gonzalo Cid Villegas[a], Carlos Mendoza[b], Luca Ferrari[b]

[a] *Posgrado en Ciencias de la Tierra, Centro de Geociencias, Universidad Nacional Autónoma de México, Campus Juriquilla, Apartado Postal 1-742, Querétaro, Qro., 76001, México.*
[b] *Centro de Geociencias, Universidad Nacional Autónoma de México, Campus Juriquilla, Apartado Postal 1-742, Querétaro, Qro., 76001, México.*

Abstract

We present a Geographic Information System (GIS) database that synthesizes information on the geometry, the sense of movement and the last displacement on known Quaternary faults in Mexico. Faults are classified according to the age of the last known geologic displacement and the quantity and quality of the information available. Class A faults have documented displacement in the Holocene; Class B faults have Pleistocene displacement with possible reactivation in the Holocene; and Class C faults have a last known displacement in the Pleistocene. The database includes the fault name, the type of fault, the fault geometry, the fault length, the evidence for displacement, the slip rate, the recurrence interval, and the size of the most recent earthquake associated with each fault. The database compiles Quaternary fault information for Mexico that can be readily updated as more geologic data become available.

Keywords: Quaternary fault; database; Mexico.

Resumen

Se presenta una base de datos en un Sistema de Información Geográfica (SIG) que sintetiza información sobre la geometría, el sentido de movimiento y el último desplazamiento de fallas cuaternarias en México. Las fallas se clasifican como Tipo A con desplazamiento en el Holoceno; Tipo B con desplazamiento en el Pleistoceno y posible reactivación en el Holoceno; y Tipo C, estructuras con último desplazamiento en el Pleistoceno. La base de datos incluye el nombre de la falla, el tipo de falla, la geometría y longitud de la falla, la evidencia geológica del desplazamiento, la taza de deslizamiento, el intervalo de recurrencia, y el tamaño del sismo más reciente asociado a la falla. La base de datos recopila información de fallas cuaternarias en México que se puede actualizar fácilmente con la disponibilidad de datos adicionales.

Palabras clave: Fallas cuaternarias; base de datos; México.

1. Introduction

Mexico is located in a region of high seismic activity due to the interaction of the Pacific, Rivera, Cocos, North America, and Caribbean plates. The majority of the seismicity is concentrated along the Cocos-North America and Rivera-North America subduction margins and along the transform boundary between the Pacific and North America plates. However, crustal earthquakes of large magnitude (M 6 to 7) have been associated with pre-existing continental geologic faults. These include, for example, the 3 May 1887 M 7.4 Bavispe, Sonora earthquake that produced a mapped surface rupture of more than 80 km with an average displacement of 3 m and the 19 November 1912 M 7 Acambay earthquake that produced surface cracks along the Acambay-Tixmadeje and Pastores faults in central Mexico.

Several studies have documented Quaternary faulting along the TransMexican Volcanic Belt (TMVB), the Baja California peninsula, the Polochic-Motagua fault region, and the state of Sonora that provide valuable information on the geometry and seismic history of the faults, their slip rate, and the earthquake

**E-mail address:* gcvillegas@geociencias.unam.mx

recurrence interval. The documentation, however, has generally been of a local nature, and no single repository currently exists that compiles Quaternary fault information for Mexico. The objective of this work is to present an updated database that identifies potentially-active fault information in the country, based on an unpublished compilation initiated more than a decade ago by the Working Group for Quaternary Faults of Mexico (WGQFM) in the framework of the International Lithosphere Program Task Group II-2 "Major Active Faults of the World". Fault data from a preliminary WGQFM report are digitized and updated to prepare a contemporary database of continental structures in Mexico that characterizes the geometry, the sense of motion, and the most recent surface displacement of known Quaternary faults. The digital format used allows an efficient update of the database as more geologic information become available. This compilation was initiated as part of an M.Sc. thesis project at the Centro de Geociencias of the Universidad Nacional Autónoma de México.

2. Documentation of quaternary faults

The documentation of Quaternary faults involved 1) the review and compilation of geologic information obtained from published articles, theses, books, and maps available from several sources, including government institutes, research centers and universities; 2) the classification of documented faults based on the most recent known surface displacement and the quantity and quality of the information available; 3) the preparation of a database that includes specific parameters and observations that characterize each fault; and 4) the transfer of fault-trace information to a Geographic Information System (GIS) format. A complete list of data sources consulted or used in the preparation of the database are presented in the References.

Our classification of documented faults incorporates the use of various observational criteria that help determine the age of the most recent displacement along the fault. These criteria are 1) instrumental and historical seismicity where known epicenters, as well as available aftershock patterns or focal mechanisms, identify the location of earthquakes associated with the fault, 2) paleoseismic evidence that identifies large $M > 5.5$ prehistoric earthquakes based on observed buried deformational features, 3) structural, lithologic and geochronologic features that identify the geometry and sense of motion on the fault and allow the development of spatio-temporal relations that place bounds on the fault age and location.

Faults are placed into one of three categories: 1) Class A Holocene faults characterized by conclusive evidence of displacement in the last 11,700 years based on instrumental and/or historical seismicity, paleoseismic observations, GPS measurements and structural, lithologic, and geochronologic constraints; 2) Class B Pleistocene faults with possible Holocene displacement identified from historical earthquake locations and geomorphologic, structural, lithologic and geochronologic observations; and 3) Class C Pleistocene faults identified on the basis of structural, geomorphologic, lithologic and geochronologic considerations.

Several informational fields are used to document each fault. These include 1) the name of the fault; 2) the type of fault and sense of motion, if known; 3) the fault strike, expressed by its directional quadrant (N, E, S, or W); 4) the dip angle in degrees and the dip direction expressed by its directional quadrant; 5) the length of the fault, in km; 6) the available evidence for fault activity; 7) the date, magnitude, and maximum displacement of the last known seismic event associated with the fault; 8) the slip rate on the fault, in mm per year; 9) the recurrence interval of the fault, in thousands of years; 10) the reference from where the fault information was obtained; and 11) other relevant observations, such as the type of lithology cut by the fault or the presence or absence of microseismicity.

3. Fault database

The database contains 150 Quaternary faults (Plate 1) of which 28 are Class A (Holocene), 21 are Class B (possibly-Holocene), and 101 are Class C (Pleistocene). Class A and Class B faults are listed in Tables 1 and 2, respectively, together with the principal geologic parameters identified for each of the structures. A total of 25 faults are documented in the Baja California peninsula (Figure 1), including 19 Holocene (Class A) faults in the northern portion of the peninsula within the Vallecitos-San Miguel, Agua Blanca, Cerro Prieto-Imperial, Laguna Salada and Sierra Juárez-San Pedro Mártir fault systems. The other six faults are possibly-Holocenic (Class B) and are located in the southern part of the peninsula. A total of 42 structures are documented in northern Mexico (Figure 2a) in the southern part of the Basin and Range province within the states of Chihuahua, Sonora and Durango. Four of these have known Holocene faulting (Class A) and one has possible Holocene displacement (Class B). The structures consist of normal faults that are distributed within the Bavispe, the Camargo Volcanic Field, the Durango Volcanic Field, and the northern Chihuahua regions. A total of 80 Quaternary structures are documented along the TMVB (Figure 2b) in central Mexico. Faults are grouped into five geographic areas that include the Acambay-Graben, the Tenango, the Chapala-Tula, the Tepic-Zacoalco, and the Aljibes-Mezquital regions. Most of the faults show a preferential E-W orientation except for the Tepic-Zacoalco fault system, which is oriented NW-SE. Holocene (Class A) faults are located in the Acambay-Graben and Tenango regions. The Tepic-Zacoalco and Aljibes-Mezquital regions contain several Class B possibly-Holocene faults. Only one fault structure has been documented in southern Mexico: the left-lateral, strike-slip Class B (possibly-Holocenic) Concordia fault in the state of Chiapas.

4. Conclusion

This study presents a compilation of Quaternary fault information for Mexico through the development of a GIS database

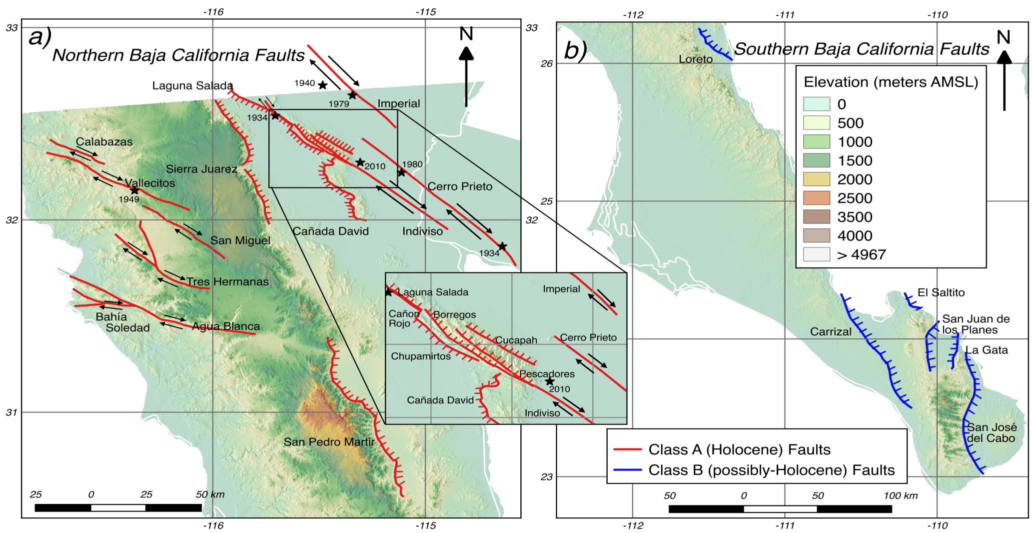

Figure 1: Fault systems in Baja California. a) Class A faults within the Vallecitos-San Miguel, Agua Blanca, Cerro Prieto-Imperial, Laguna Salada and Sierra Juarez-San Pedro Martir fault systems. Inset shows central portion of Laguna Salada fault system. b) Class B faults in southern Baja California including the Loreto, Carrizal, El Saltito, San Juan de los Planes, La Gata and San Jose del Cabo faults. Stars indicate known crustal earthquakes that may be associated with Quaternary faulting.

Figura 1. Sistemas de falla en la península de Baja California. a) Fallas Tipo A de los sistemas de falla Vallecitos-San Miguel, Agua Blanca, Cerro Prieto-Imperial, Laguna Salada y Sierra Juárez-San Pedro Mártir. El recuadro muestra la parte central del sistema de fallas de Laguna Salada. b) Fallas Tipo B en el sur de Baja California incluyendo las fallas Loreto, Carrizal, El Saltito, San Juan de los Planes, La Gata y San José del Cabo. Las estrellas muestran sismos corticales posiblemente asociados a fallas cuaternarias.

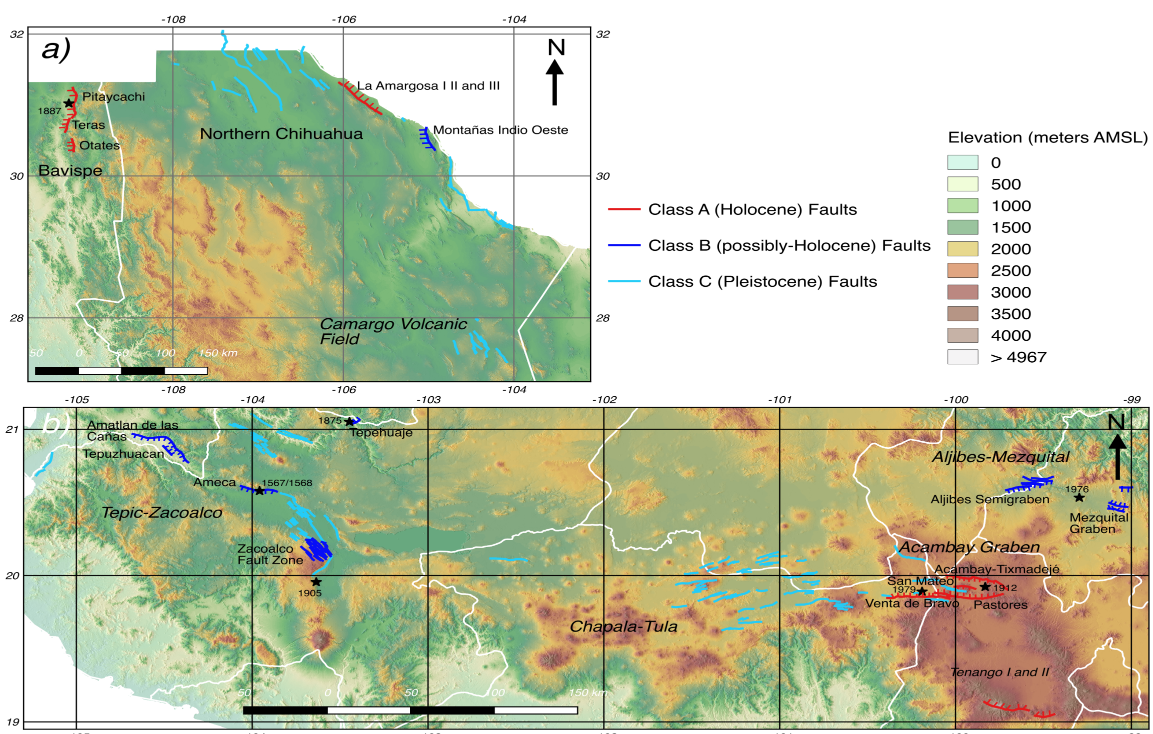

Figure 2: a) Northern Mexico fault systems including the Class A faults of Pitaycachi, Teras and Otates near Bavispe, and La Amargosa in northern Chihuahua. b) Fault systems of the TransMexican Volcanic Belt including the Class A faults in the Acambay and Tenango regions. Stars indicate known crustal earthquakes that may be associated with Quaternary faulting.

Figura 2. a) Sistemas de falla en el norte de México incluyendo las fallas Tipo A de Pitaycachi, Teras y Otates en Bavispe, y La Amargosa, en el norte de Chihuahua. b) Sistemas de falla de la Faja Volcanica TransMexicana incluyendo las fallas Tipo A en las zonas de Acambay y Tenango. Las estrellas muestran sismos corticales posiblemente asociados a fallas cuaternarias.

Table 1: Class A (Holocene) Faults / Tabla 1. Fallas Clase A (Holoceno)

Fault System and Fault Type	Fault Name	Orientation, Dip	Length (Km)	Slip Rate (mm/yr)	Recurrence Interval (Kyr)	Principal Reference*
Baja California						
Vallecitos-San Miguel, Right Lateral Strike Slip	San Miguel	NW, 90°	52	1	-	1
	Calabazas	NW, 90°	31	1	-	1
	Vallecitos	NW, 90°	82	1	-	1
	Tres Hermanas I	NW, 90°	59	1	-	1
	Tres Hermanas II	NW, 90°	28	1	-	1
Agua Blanca, Right Lateral Strike Slip	Agua Blanca	WNW, 90°	103	4	0.2	1
	Maximitos	NW, 90°	34	4	0.2	1
	Bahía Soledad	W, 90°	15	4	0.2	1
Cerro Prieto-Imperial, Right Lateral Strike Slip	Cerro Prieto	NW, 90°	108	50	-	1
	Imperial	NW, 90°	65	40	0.7	1
Laguna Salada, Right Lateral Strike Slip, Normal Component	Laguna Salada	NW, 60° SW	42	1	-	1
	Cañon Rojo	NE, 60° NW	3	1	-	1
	Chupamirtos	NW, SW	22	-	-	1
	Cucapah	NW, NE	22	1	-	1
	Pescaderos	NW, NE	24	1	-	1
	Borregos	NNW, NE	38	1	-	1
	Indiviso	NW, 70° SW	61	-	-	2
	Paso Inferior-Superior	NW, NE	19	-	-	2
Sierra Juárez-San Pedro Martir, Normal	Sierra Juárez I	NNW, ENE	43	-	-	3
	Sierra Juárez II	NNW, ENE	34	-	-	3
	San Pedro Martir	NNW, ENE	111	-	-	3
Northern Mexico						
Bavispe, Normal	Pitaycachi	N, 74° W	44	0.015	27	4
	Teras	N, 74° W	21	0.07	26	4
	Otates	N, 74° W	19	0.06	37	4
Northern Chihuahua,Normal	Amargosa I	NW, 70°NE	56	0.75	30	5
	Amargosa II	NW, 70°NE	6	0.75	30	5
	Amargosa III	NW, 70°NE	3	0.75	30	5
Central Mexico						
Acambay Graben, Normal	Pastores Este	E-W, 65° N	33	0.03	12.5	6
	Pastores Oeste	E-W, 65° N	11	0.12	12.5	7
	Acambay-Tixmadejé	E-W, 80° S	42	0.17	3.6	8
	Venta de Bravo	W-E, 68° N	38	0.2	-	9
	San Mateo	E-W, S	13	0.055	12	10
Tenango, Left lateral Strike Slip, Normal Component	Tenango I	E-W, 35° N	30	0.4	-	11
	Tenango II	E-W, 35° N	12	0.4	-	11

* Principal References / Referencias principales: 1 Cruz-Castillo, 2002; 2 Fletcher et al., 2014; 3 Diaz-Torres et al., 2012; 4 Suter & Contreras, 2002; 5 Collins & Raney, 1993; 6 Langridge et al., 2013; 7 Ortuño et al., 2012; 8 Langridge et al., 2000; 9 Suter et al., 1992; 10 Sunye-Puchol et al., 2015; 11 Norini et al., 2006

that incorporates vectorized fault traces. The data fields used to describe each structure allow the synthesis of information on the geometry, kinematics and known displacement on the fault. A total of 150 faults have been documented, of which 28 exhibit Holocene displacement, 21 are possibly-Holocenic, and 101 are identified as having most recent displacement in the Pleistocene.

Quaternary fault information for Mexico has generally been limited due to the fact that geologic studies of surface faulting have generally been concentrated in areas where large, infrequent earthquakes have occurred. Also, modern seismic and geodetic instrumentation has historically been deployed near the plate boundaries, away from the continental interior. Furthermore, paleoseismic techniques, which are of great utility in identifying Holocene displacement along existing geologic faults, have only been recently applied in Mexico. The availability of a complete Quaternary fault database would be of great benefit in the calculation of the probabilistic seismic hazard. These surface-faulting sources have generally been excluded in the preparation of national seismic-hazard maps in Mexico, despite their obvious effect on the hazard expected for inland areas characterized by seismogenic structures capable of producing large earthquakes. The exclusion has been due primarily to a scarcity of complete and reliable active-fault information. The GIS format of the current database, however, is expected to allow a timely update of fault information as more data become available.

5. Software

Open-source GRASS GIS v. 6.4 (https://grass.osgeo.org/) and Quantum GIS v. 2.12.1 (http://www.qgis.org/) software were used in the construction of the fault database.

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Table 2. Class B (possibly-Holocene) Faults / Tabla 2. Fallas Clase B (posiblemente Holoceno)

Region	Fault Name	Fault Type	Orientation, Dip	Length (Km)	Slip Rate (mm/yr)	Principal Reference*
Baja California						
	San Juan de los Planes	Normal	NNE, 72° E	42	0.63	1
	El Saltito	Normal	NW, NE	17	0.8	1
	La Gata	Normal	N, W	29	0.63	1
	San Jose del Cabo	Normal	N, E	102	0.65	1
	Loreto	Normal	N, E	35	0.06	2
	El Carrizal	Normal	NW, NE	101	0.25	3
Northern Mexico						
	Montañas Indio Oeste	Normal	N, 70° SW	50	0.2	4
Central Mexico						
	S. Zacoalco Fault zone	Normal	NW, 65° SW	2 - 14	0.2	5
	Amatlan de las Cañas	Normal	E, 60° S	44	0.75	6
	Tepuzhuacan	Normal	NW, 60° NE	8	0.64	6
	Ameca	Normal	WNW, 70° S	23	0.2	6
	Tepehuaje	Normal	SW, 79° NW	8	0.2	7
	Aljibes Mediograben A	Normal	W, 45° S	13	0.07	8
	Aljibes Mediograben B	Normal	W, 65° S	18	0.07	8
	Aljibes Mediograben C	Normal	W, 70° S	13	0.07	8
	Aljibes Mediograben D	Normal	W, 75° S	11	0.07	8
	Aljibes Mediograben E	Normal	W, S	15	0.07	8
	Cerro el Fraile	Normal	W, 80° S	7	0.2	8
	Reservorio Debodhe	Normal	W, 65° N	11	0.2	8
	Cerro Guadril	Normal	W, 70° N	9	0.2	8
Southern Mexico						
	Concordia	Left Lateral Strike Slip	NW-SE, 90°	101	-	9

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Quaternary Faults Mexico

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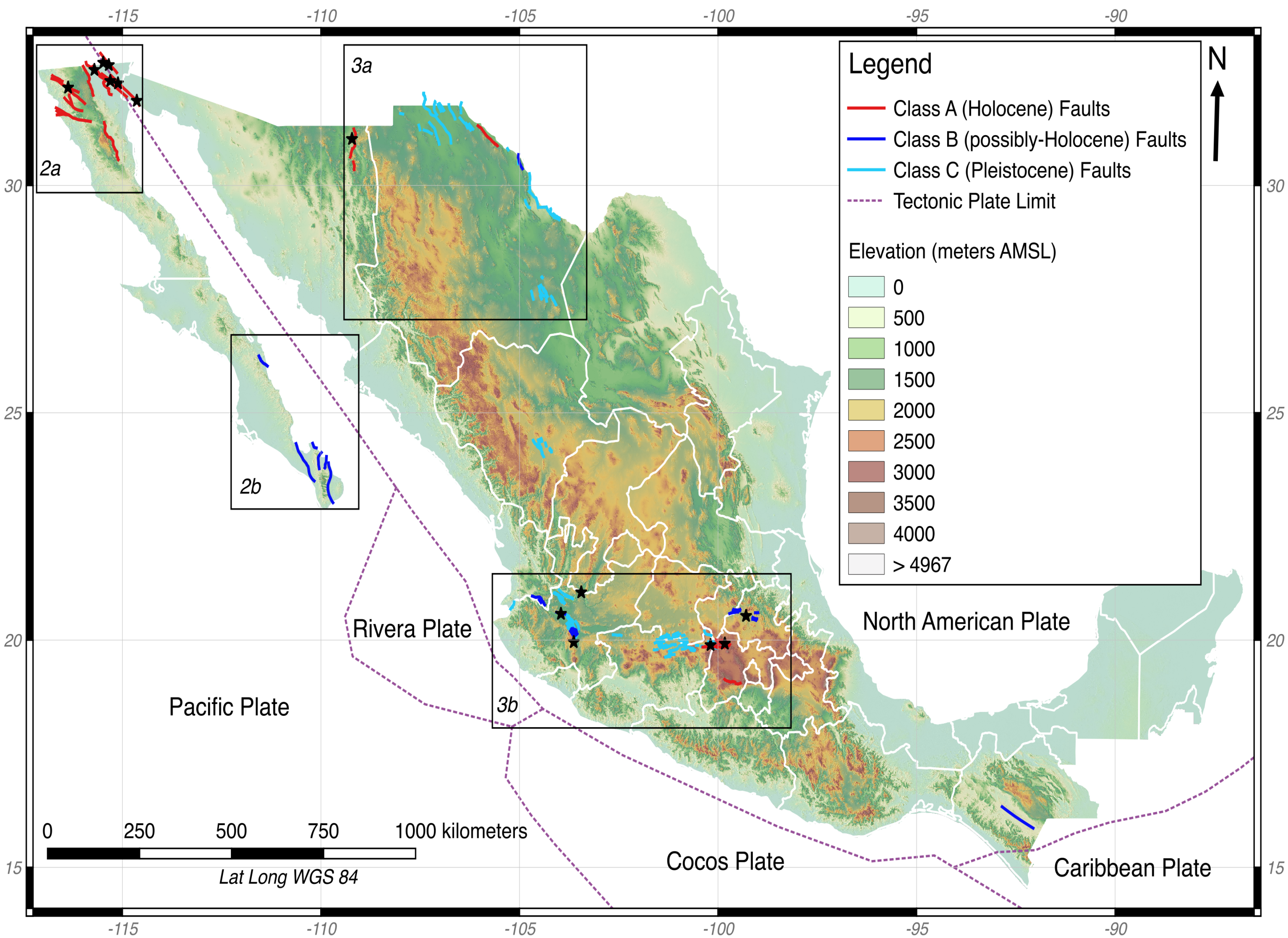

Plate 1. Quaternary faults included in the GIS database
Lámina 1. Fallas cuaternarias incluídas en la base de datos del Sistema de Información Geográfica.

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