REVISTA MEXICANA DE CIENCIAS GEOLÓGICAS v. 39, núm. 2, 2022, p. 128-141

La Unión Monzogranite: geochronology and significance of the Jurassic arc in the Sula Terrane, Guatemala

Francis Emanuel Salguero-Díaz[1,*], Luigi A. Solari[2], Osmín J. Vásquez[1], Ricardo Enrique Milián de la Cruz[1], and Carlos Ortega-Obregón[2]

[1] *Universidad de San Carlos de Guatemala, Centro Universitario del Norte. Carrera de Geología, Finca Sachamach, km 210, ruta Las Verapaces, Cobán Alta Verapaz, Guatemala.*
[2] *Centro de Geociencias, Universidad Nacional Autónoma de México, Campus Juriquilla, Querétaro, Qro., 76230 Mexico.*
** geo_salguero@outlook.com*

ABSTRACT

La Unión pluton (LUP) belongs to the metamorphic and igneous Sula Terrane (ST) of Central Guatemala, limited to the north by the Motagua fault (MF) and to the south by the Jocotán-Chamelecón fault system (J-CH-FS). The basement of the ST is characterized by the high-grade metamorphic rocks belonging to the Las Ovejas Complex and the extensive low-grade San Diego phyllite, the latter in tectonic contact with LUP. A combination of field data, petrographic and geochemical analyses as well as geochronologic dating by U-Pb method, allow to classify LUP as a monzogranite with an age of 170 Ma (average of two dated samples), characterized by high-K calcalkaline and peraluminous affinity and with a REE pattern typical of a continental magmatic arc. Some trace-elements behavior and a comparison of similar-age units found elsewhere in eastern, central and southern Mexico, allow to associate its formation to the lithospheric thinning and extension that occurred during the breakup of Pangea and the opening of the Gulf of Mexico.

Key words: La Unión pluton; Las Ovejas Complex; San Diego Phyllite; Guatemala; Geochronology.

RESUMEN

El Plutón La Unión (LUP) intrusiona al Terreno Sula (TS) en el centro de Guatemala. Este terreno tectono-estratigráfico se encuentra limitado por la falla del Motagua (MF) al norte y, al sur, por la falla Jocotán-Chamelecón (J-CH-FS). Gran parte de este terreno posee un desarrollo metamórfico e ígneo, caracterizado por la presencia de rocas metamórficas de alto grado que forman parte del Complejo Las Ovejas (LOC) al norte, agrupadas como meta-ígneas u ortogneises por algunos autores y, al sur por rocas metamórficas de bajo grado correspondientes a la Filita San Diego con la cual se relaciona mediante un contacto tectónico. Datos de campo, análisis petrográficos, geoquímicos y geocronológicos por el método U-Pb permiten definir a este plutón como Monzogranito La Unión con una edad de ca. 170 Ma (promedio de 2 muestras datadas) y con características de un granitoide calcoalcalino alto en K, peraluminoso, con patrón de REE típico de un arco magmático continental. El comportamiento de algunos elementos traza y la comparación con rocas ígneas de edad similar presentes en el este, centro y sur de México, permite asociar su formación a un proceso de fusión parcial, asociado con el adelgazamiento cortical que ocurrió durante la ruptura de Pangea y la apertura del Golfo de México.

Palabras clave: Plutón La Unión; Complejo Las Ovejas; Filita San Diego; Guatemala; Geocronología; magmatismo continental jurásico.

INTRODUCTION

The geology of Guatemala is key to recognize geodynamic processes associated to plate tectonics, because it occupies a notable position along the plate boundary between North America and Caribbean plates, which are in tectonic contact along the transcurrent Polochic-Motagua Fault System (PMFS) (Donnelly *et al*., 1990, and references therein) (Figure 1a). While the classic studies somehow simplify the tectonic assemblage mostly as the contact of two blocks (Maya Block to the north and Chortís block to the south of the Motagua Fault, respectively, *e.g.*, McBirney, 1963; Burkart *et al*., 1973; Dengo, 1985), more focused studies reveal the existence of several fault bounded crustal blocks, possibly allochthonous between them, characterized by distinct geological features, which can be considered as suspect terranes (*e.g.*, Ortega-Gutiérrez *et al*., 2007; Ratschbacher *et al*., 2009; Torres de León *et al*., 2012; Solari *et al*., 2013) (Figure 1b). As those authors stress, each of the aforementioned crustal blocks is characterized by its different nature, which makes it different from the adjacent one in terms of age, metamorphic evolution, igneous and sedimentary content. All these peculiarities, which will be briefly synthesized in the forthcoming paragraphs, are in turn affected by the sinistral movement, ductile and brittle shearing associated with the evolution of the PMFS during Cenozoic (Ratschbacher *et al*., 2009; Pindell and Kennan, 2009). The focus on some of those elements contained in such deformed blocks can shed light on possible correlations that predate the Cenozoic shearing. That's especially true for plutonic rocks, which are present in several localities and that span a large amount of geologic time, from Paleozoic (*e.g.*, Solari *et al*., 2013), to Mesozoic (*e.g.*, Clemons and Long, 1971; Ratschbacher *et al*., 2009; Torres de León *et al*., 2012), to Cenozoic (*e.g.*, Ratschbacher *et al*., 2009). In this view, we are presenting some new data belonging to the La Unión pluton (LUP) one of the plutons cropping out in the Sula Terrane, intended to characterize its geologic features, age and geochemistry, as well as to allow comparisons with other similar igneous bodies.

Salguero-Díaz, F.E., Solari, L.A., Vásquez, O.J., Milián de la Cruz, R.E., Ortega-Obregón, C., 2022, La Unión Monzogranite: geochronology and significance of the Jurassic arc in the Sula Terrane, Guatemala: Revista Mexicana de Ciencias Geológicas, v. 39, núm. 2, p. 128-141.

DOI: http://dx.doi.org/10.22201/cgeo.20072902e.2022.2.1675

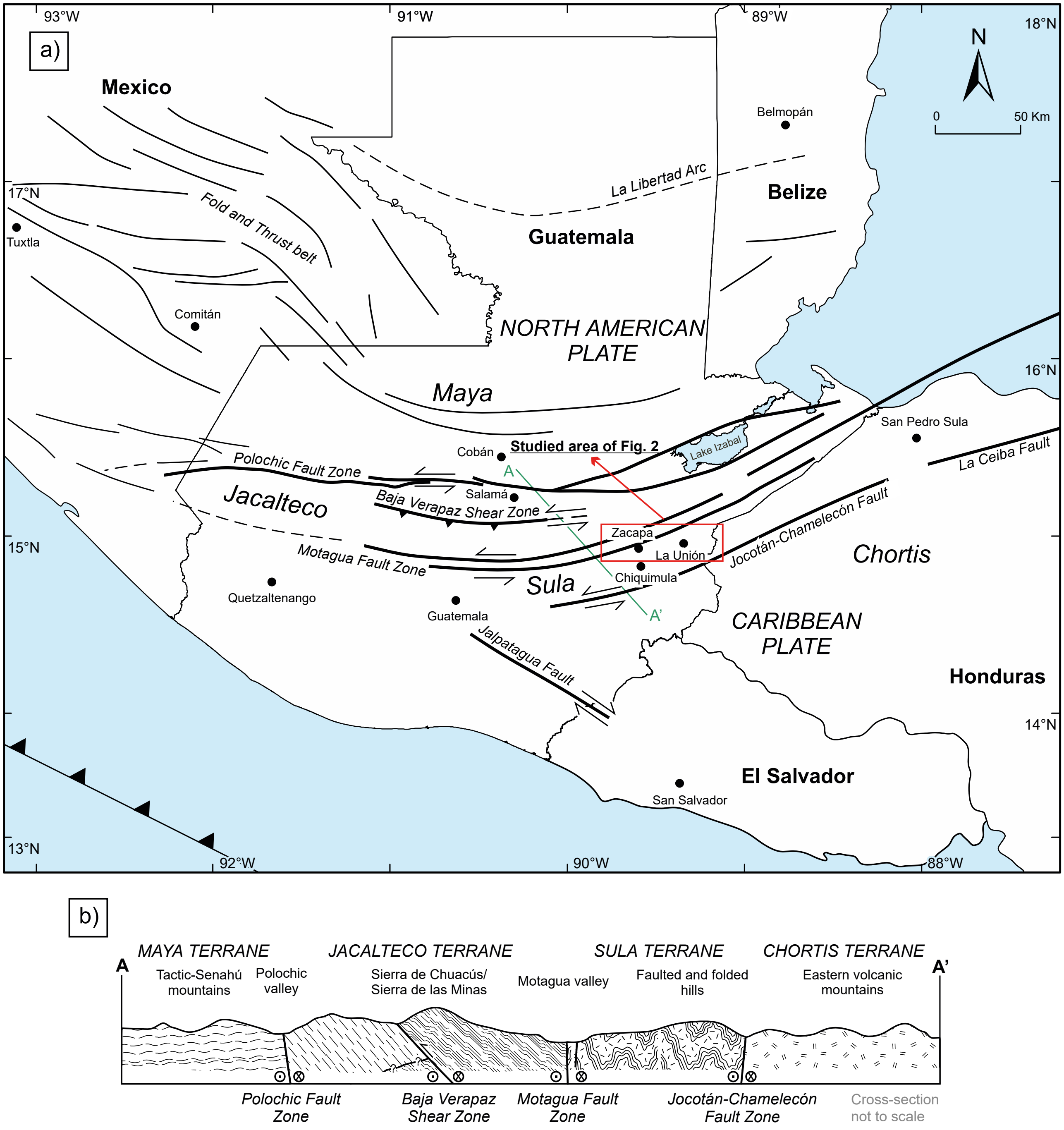

Figure 1. Geodynamic framework of central America and Guatemala, reporting localities, principal features, and a section with a sketch of proposed terrane subdivision.

GEOLOGIC SETTING

Moving from North America (north) to the Caribbean plate (south) along an hypothetic section, across Guatemala, one will cross all the suspect terranes (as in the definition of Ortega-Gutiérrez *et al.*, 2007) or, most precisely, due to the lack of precise age information in several of those, fault blocks (Figure 1b). From north to south, thus, the fault blocks that represent the geological subdivision of Guatemala, are the Maya block, the Achi block, the Jacalteco block, the Motagua block, the Sula block, the Yoro block and the Chortís block. The Maya block is made up of local Precambrian rocks (Guichicovi Complex in southern Mexico, Weber and Kohler, 1999, and several outcrops in the El Triunfo Complex, Weber *et al.*, 2018, 2020) that, together with Neoproterozoic low to medium-grade metasediments are intruded by abundant Ordovician to Mississippian and Permian igneous rocks (Weber *et al.*, 2007; Estrada-Carmona *et al.*, 2012; Ramírez-Fernández *et al.*, 2021). The Achí terrane was originally interpreted by Ortega-Gutiérrez *et al.* (2007) as a separate crustal block, characterized by the Rabinal Granite suite intruding Neoproterozoic sediments (*e.g.*, Ortega-Obregón *et al.*, 2008; Solari *et al.*, 2013). The studies in the El Triunfo Complex allow to interpret the Achi Terrane as the eastward continuation of the same sequence, thus pertaining to the Maya Block. Farther south, in

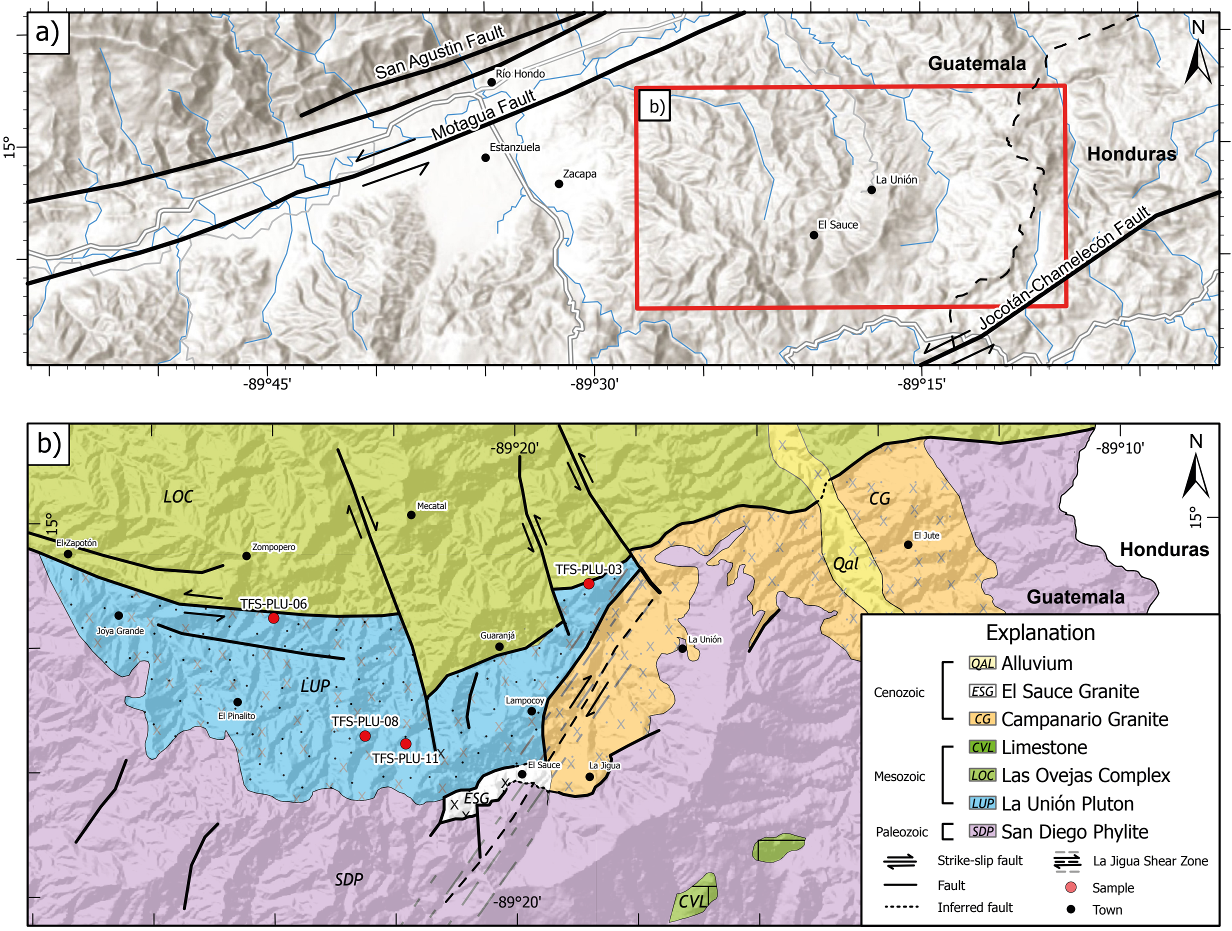

Figure 2. Location of the study area. a) Map of eastern Guatemala with the principal tectonic structures. The inset represents the location of the generalized geologic map b) with location of the La Unión Pluton and analyzed samples.

tectonic contact along the Baja Verapaz Shear Zone (Ortega-Obregón *et al.*, 2008), the Jacalteco terrane is mostly made up by the Chuacús Complex, containing Precambrian to Triassic metamorphic protoliths, and affected by *ca.* 218 Ma decompression melting and migmatization and Late Cretaceous high-pressure metamorphism (Ortega-Gutiérrez *et al.*, 2004; Ratschbacher *et al.*, 2009; Solari *et al.*, 2011; Martens *et al.*, 2012; Maldonado *et al.*, 2018). South of the Motagua fault the Sula terrane is a completely different entity, made up almost entirely by the Las Ovejas Complex (Torres de León *et al.*, 2012), characterized by medium to high-grade metasediments (Paleozoic to Jurassic protolith ages) metamorphosed under high temperature-low pressure during the Oligocene, and associated with Jurassic to Cretaceous plutons, with or without deformation (*e.g.*, Ratschbacher *et al.*, 2009). The Las Ovejas Complex was earlier seen as representative of the basement of the Chortís Block, since the studies of Bosc (1971) and Schwartz (1976) and the description of similar rocks in the Sierra de Omoa in Honduras (Horne *et al.*, 1976). In fault contact with the Las Ovejas metasediments, the San Diego phyllite follows farther south. This unit, initially reported by Lawrence (1975) was studied by Torres de León *et al.* (2012) who demonstrated that its U-Pb detrital zircon content cannot be considered as the source of the Las Ovejas protoliths. Since the San Diego phyllite is older than Las Ovejas Complex, to which is in fault contact, has a lower metamorphic grade and possible correlative in the Cacaguapa schists on Honduras and northwerstern Nicaragua (Martens *et al.*, 2007, and references therein) our interpretation is that it is the best candidate to be considered as the true basement of the Chortís block of Central America. Being positive that more studies are needed to clarify the significance of Proterozoic rocks in Honduras (*e.g.*, Manton, 1996) and thus the true existence of Yoro terrane as proposed by Ortega-Gutiérrez *et al.* (2007). Although it is not part of the current study, it is worth to mention that both Jacalteco and Sula terranes are variably overthrust by mafic to ultramafic units, belonging to the Motagua terrane of Ortega-Gutiérrez *et al.* (2007) that groups all the different ophiolitic nappes cropping out in central Guatemala (Beccaluva *et al.*, 1995; Brueckner *et al.*, 2009; Flores *et al.*, 2013).

LUP is one of the igneous bodies cropping out in the Sula Terrane, thus south of the Motagua, and north of the Jocotán-Chamelecón, faults (Figure 2). The lack of detailed studies induced some previous authors (*e.g.*, Ratschbacher *et al.*, 2009) to correlate LUP with the adjacent Chiquimula Pluton. The latter is a Late Cretaceous granite to granodiorite batholith, for which Ar/Ar in biotite yielded 90±10 Ma (Ratschbacher *et al.*, 2009) and U-Pb LA-ICPMS zircon dating yielded 91±1 Ma (Torres de León, 2016).

The field geology and mapping reveal that LUP has sheared and intrusive contacts along its northern and southern limits, respectively (Figure 2b); however, in some areas of the pluton, the original texture of the rock is still preserved (Figure 3a and 3b). Its northern limit with the adjacent orthogneisses is in fact a ductile shear zone, in which the original granite (probably a portion of the same LUP) is foliated, sheared, and metamorphosed after its emplacement (Figure 3c and 3d). Locally, in Lampocoy town (La Unión, Zacapa) it is possible to observe how the original igneous texture shows top-to-the-W shearing, indicated by deformed quartz ribbons (Figure 3d). The contact with the northern Las Ovejas metasediments and metaigneous rocks is also affected by deformation: although its kinematics is unclear because overprinted by the late, sinistral shearing along the Motagua Fault system, the presence of faults in the host rock just near the contact (Figure 3e) suggests a compressional regime, so probably a thrust of the host rock over LUP.

The Río La Jigua Shear Zone, a subsidiary branch of the Motagua-Jocotán-Chamelecón fault system, is also intensely shearing most of LUP intrusion, producing greenschist facies mylonite, also with top-to-the-W shearing (mapped in Figure 2b). LUP southern limit with the San Diego phyllite is also affected by brittle and ductile faulting. This contact is better observable farther to W, where the *ca.* 34 Ma Campanario monzongranite (Salguero-Díaz, 2016) is overthrusted by the San Diego phyllite along a brittle fault (Figure 3f). The presence of

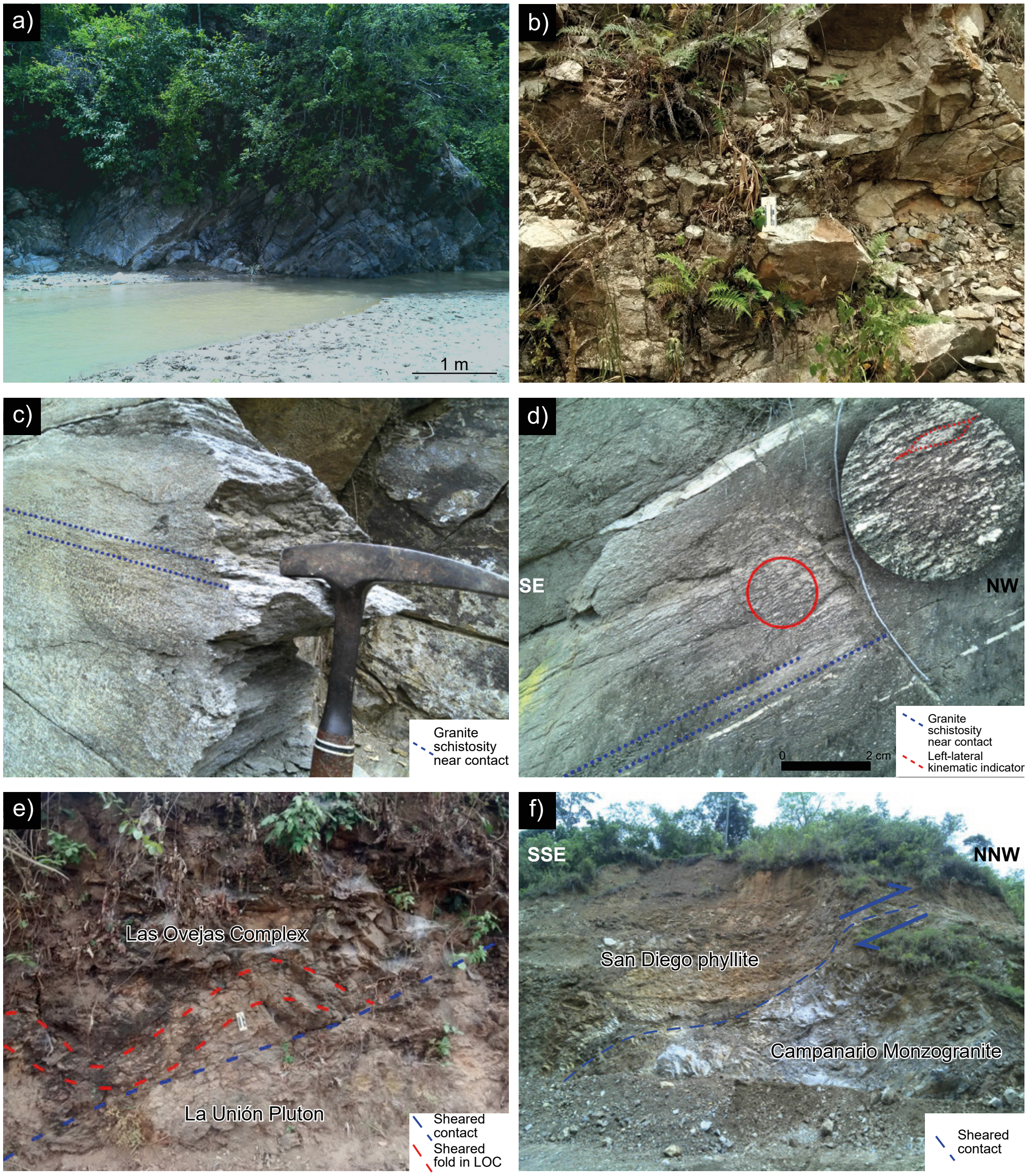

Figure 3. Field pictures. a) and b): Outcrop photographs of the La Unión Pluton near El Pinalito and Joya Grande towns, respectively. c) Schistosity as observed in La Unión Pluton near its tectonic contact with the Las Ovejas Complex rocks south of El Zapotón. d) Left-lateral, top-to-the-NW ductile kinematic indicators in the La Unión Pluton near Lampocoy. e) Shear contact between Las Ovejas Complex metasediments and La Unión Pluton. f) Another sheared contact, in this case of San Diego phyllite near Guaranjá, overthrusting the *ca.* 34 Ma Campanario monzogranite (Salguero-Díaz, 2016) near La Jigua. The presence of granitic dikes (one is visible in the left portion of the picture, just above the sheared contact) probably indicates that the original contact was intrusive and, then, affected by deformation.

small granitic dikes into the phyllite, however, suggests that the original contact is in fact intrusive, and later affected by faulting (see detail in the left portion of Figure 3f).

METHODS

Geochemistry

Four representative samples (sample coordinates in Table 1) of LUP were analysed by X-ray fluorescence for major elements at LANGEM, Instituto de Geología, Universidad Nacional Autónoma de México (UNAM), following the methodology reported by Lozano-Santacruz and Bernal (2005). Precision and accuracy of the X-ray fluorescence technique are generally better than ± 5 % for major elements. The same, selected samples were employed for the determination of rare-earth as well as trace elements at the Laboratorio de Estudios Isotópicos (LEI), Centro de Geociencias, UNAM, by ICP-MS, according to the methodology reported by Mori *et al.* (2007). The ICP-MS method indicates a precision and accuracy of < 5–10 %.

Geochronology

Two samples of granite were chosen for U-Pb dating. They were crushed and the zircon grains separated with conventional techniques, terminating by handpicking under binocular microscope. U-Pb analyses were conducted by laser ablation inductively-coupled plasma mass spectrometry (LA-ICPMS) at Laboratorio de Estudios Isotópicos, UNAM, using a Resonetics M050 (now, Applied Spectra) 193 nm excimer laser workstation, coupled to a Thermo ICap Qc quadrupole mass spectrometer, according to the methods reported by Solari *et al.* (2018). A 23 µm spot was employed during this study for all the zircon U-Pb analyses, alternating unknown zircon crystals with several standards. The standard zircon 91500 was employed as external reference zircon (*ca.* 1062 Ma, Wiedenbeck *et al.*, 1995), whereas Plešovice standard zircon acted as secondary (control) standard (*ca.* 337 Ma, Sláma *et al.*, 2008). Together with those isotopes employed for U-Pb ratios and age calculation (Pb's, Th, U) other isotopes were monitored for trace element concentrations (Si, Ti, Y, Nb, REE, Hf). The NIST 610 glass was measured and employed as an external standard for trace element concentration calculations, using ^{29}Si as an internal (stoichiometric) standard element. Initial Pb correction was not performed, because the ^{204}Pb signal is swamped by the isobar ^{204}Hg present in the ICP carrier gas. Data were carefully filtered, using the cutoff discordance criteria of +30 % / -5 %. Raw data were reduced offline using Iolite 4 software (Paton *et al.*, 2011), including all the error calculations and propagation, and employing the VizualAge data reduction scheme of Petrus and Kamber (2012). The secondary Plešovice standard zircon yielded a mean ^{206}Pb/^{238}U age of 339.4 ± 1.7 Ma, in agreement with its accepted age. All the data were plotted employing the free software IsoplotR (Vermeesch, 2018).

Table 1. Sample coordinates of the samples studied for geochronology and geochemistry. Datum: WGS84.

Sample	Latitud (N)	Longitud (W)	Analysis
TFS-PLU-03	14°58'58.8"	89°18'46.8"	Geochemistry
TFS-PLU-06	14°58'29.9"	89°24'00.0"	Geochronology and geochemistry
TFS-PLU-08	14°56'45.5"	89°22'30.0"	Geochemistry
TFS-PLU-11	14°56'38.4"	89°21'46.7"	Geochronology and geochemistry

RESULTS

Four samples from La Unión Pluton were analyzed. Under the microscope, samples have an inequigranular to phaneritic texture that becomes equigranular in some samples.

Quartz crystals are mainly subhedral to anhedral and range from 24 % to 35 % in all samples (Figure 4a and 4b). Plagioclase range from

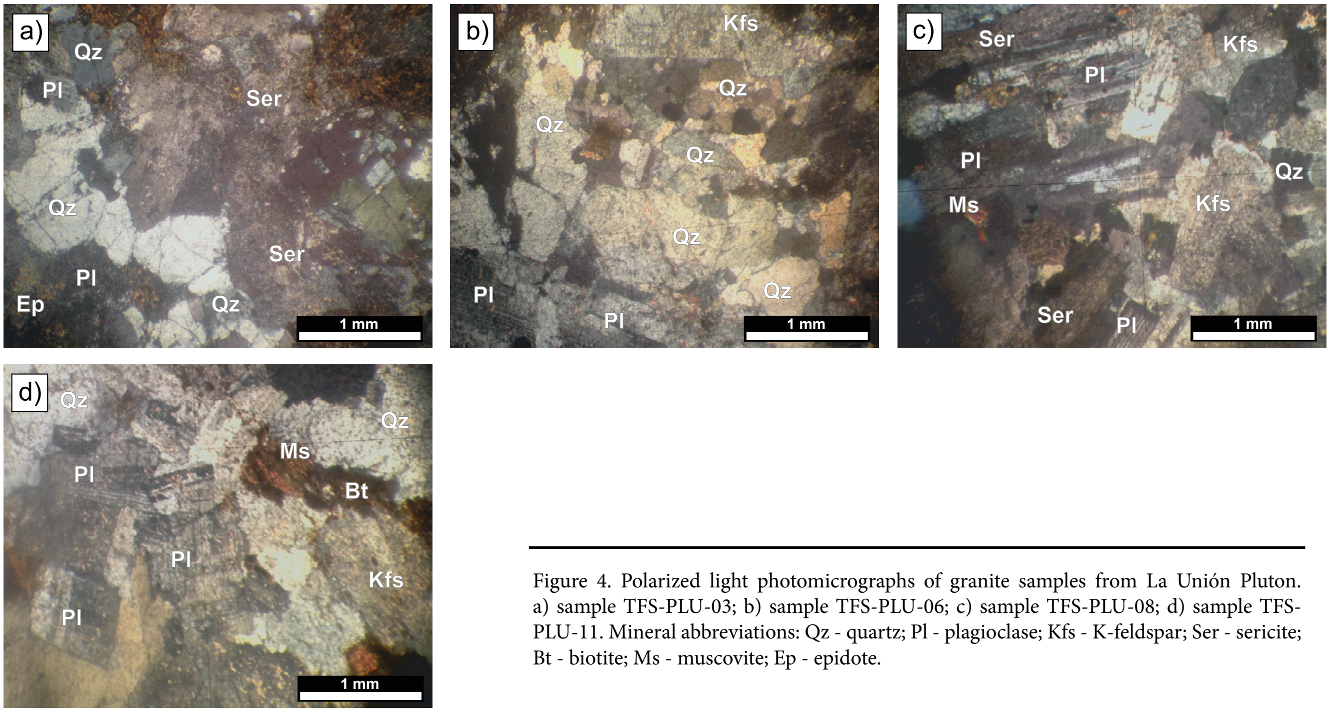

Figure 4. Polarized light photomicrographs of granite samples from La Unión Pluton. a) sample TFS-PLU-03; b) sample TFS-PLU-06; c) sample TFS-PLU-08; d) sample TFS-PLU-11. Mineral abbreviations: Qz - quartz; Pl - plagioclase; Kfs - K-feldspar; Ser - sericite; Bt - biotite; Ms - muscovite; Ep - epidote.

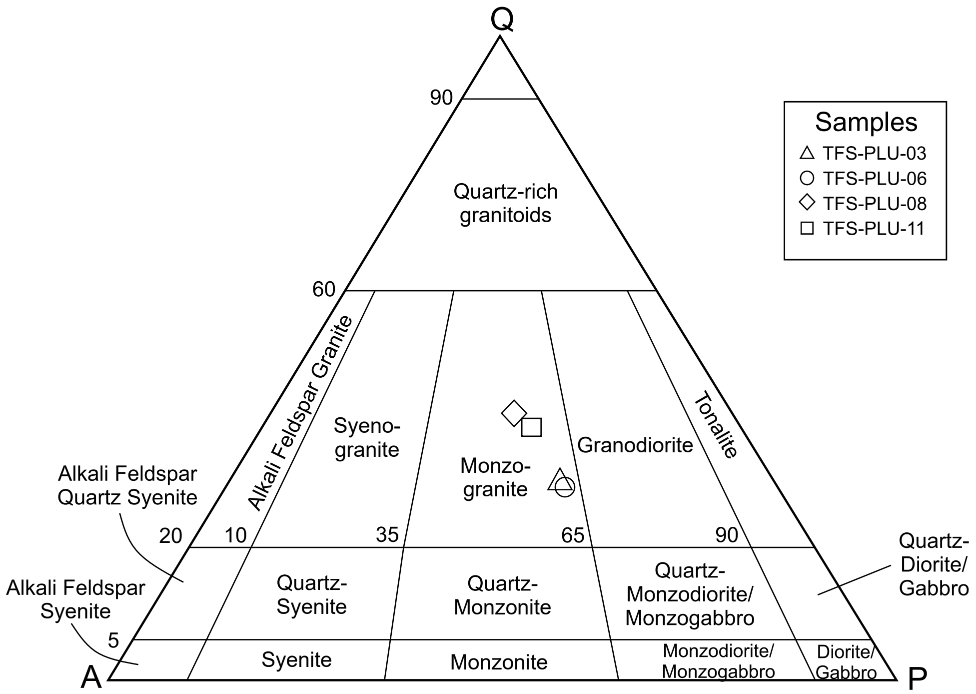

Figure 5. Modal classification for granite samples from La Unión Pluton. Q – quartz, A – K-feldspar, P – plagioclase.

25–33 %. The crystals are anhedral-euhedral and present twin deformation (Figure 4c and 4d). This mineral phase is often altered to sericite and replaced by epidote. The K-feldspar are partially altered to sericite (Figure 4c). The crystals are subhedral to anhedral and, Their content ranges from 21 % to 24 % in all samples. Biotite is an abundant phase with content ranging from 5 % to 16 % (Figure 4d). The crystals are commonly replaced by chlorite. Muscovite crystals range from 4–8 %. Epidote is present as an accessory mineral with less than 2 %. Other accessory minerals include zircon, apatite, and opaque.

Based on the mineralogical modal content of quartz, alkali feldspar, and plagioclase, we classify the La Union Pluton as a monzogranite (Figure 5) according to the Le Maitre *et al.* (2002) classification.

Geochronology

The two rock samples selected for geochronology contain prismatic zircon crystals, with elongation up to 4:1 ratio, well-developed bipyramidal terminations and without any sign of corrosion and/or resorption. Under cathodoluminescence they show a clear igneous zoning, the presence of some tiny inclusions represented by apatite and quartz (Figure 6).

For each sample, 30 grains were analyzed. After discordance filtering, 27 (TFS-PLU-06) and 25 grains (TFS-PLU-11) were considered useful for age interpretation. The sample TFS-PLU-06 yielded a concordia age of 170.4±0.9 Ma (MSWD=1.3, Figure 7a and Table S1 of the supplementary material), whereas the sample TFS-PLU-11 a concordia age of 169.4±0.95 Ma (MSWD=1.4, Figure 7b). Both ages are virtually the same, within the analytical errors. Thanks to the zircon shape and the igneous oscillatory zoning observed under cathodoluminescence, we can interpret the obtained ages as indicative of the LUP crystallization.

Geochemistry

Four samples from LUP were analyzed by major and trace element geochemistry. Samples have SiO_2 values between 70–75 wt%., whereas

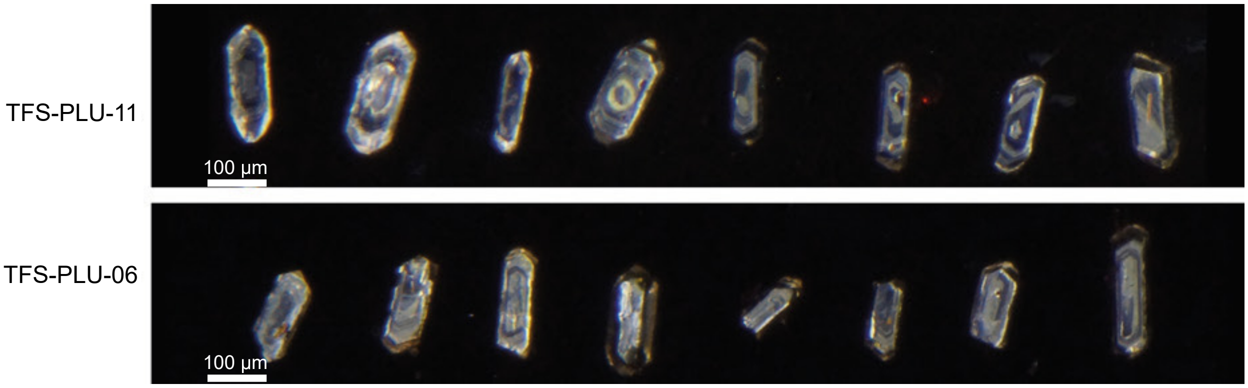

Figure 6. Cathodoluminescence images of some of the dated zircon grains. Note the bypiramidal morphology, as well as the igneous zoning developed around xenocrystic cores.

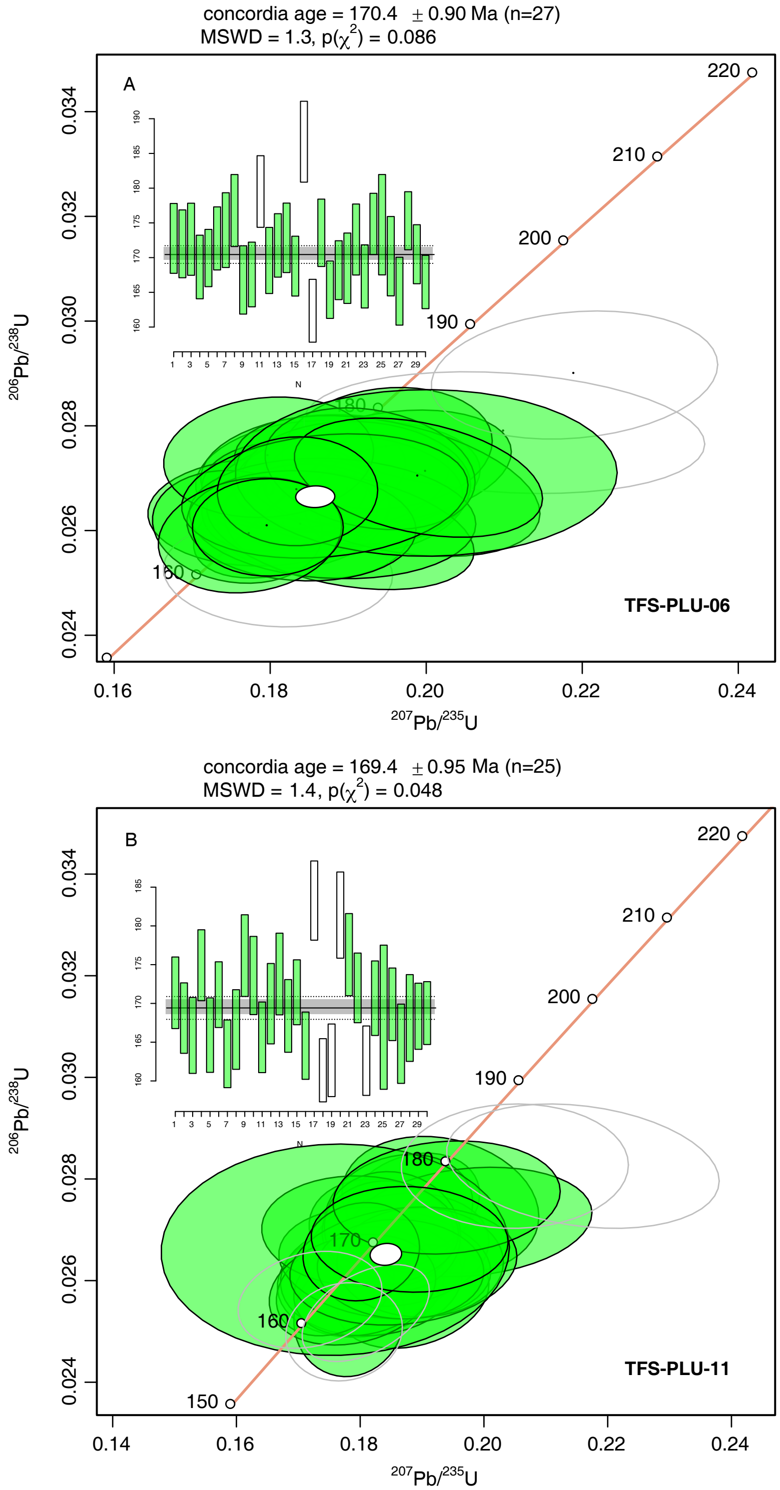

Figure 7. U-Pb concordia and mean age diagrams for the two dated samples belonging to the La Unión Pluton, Guatemala.

Al_2O_3, Na_2O and K_2O ranging between 12–15 %, 3–5 %, and 4–6 % respectively (Table 2). The SiO_2 *vs.* Na_2O+K_2O biplot (Middlemost, 1994) classify the samples in the Granite field due to their high SiO_2 content (Figure 8a). Within the SiO_2 *vs.* K_2O diagram (Figure 8b), most samples are classified on the High-K Calc-alkaline series, and only sample TFS-PLU-06 plot near the boundary of the Shoshonitic series. On the A/CNK *vs.*A/NK plot (Shand, 1943), samples are classified as peraluminous granites (Figure 8c) with a strong I-type character according to the K_2O *vs.*Na_2O diagram of Chappell and White (1974) (Figure 8d).

The chondrite-normalized REE patterns (Figure 9a) show moderately enriched Light Rare Earth Elements (LREE), when compared with Heavy Rare Earth Elements (HREE), with $(La/Yb)_n$ ranging between *ca.* 5 and 10 with variably Eu anomalies, positive for sample TFS-PLU-08,

Table 2. Major and trace-REE determined elements in studied samples.

Sample	TFS-PLU-03	TFS-PLU-06	TFS-PLU-08	TFS-PLU-11
SiO_2 (wt%)	73.45	70.88	74.28	70.08
TiO_2	0.25	0.44	0.22	0.44
Al_2O_3	12.58	14.11	13.56	13.62
F_2O_3t	2.77	2.97	1.99	3.57
MnO	0.09	0.19	0.05	0.11
MgO	1.03	1.12	0.85	0.89
CaO	1.12	1.43	1.56	2.01
Na_2O	3.44	4.11	4.02	4.76
K_2O	4.71	5.07	4.12	4.71
P_2O_5	0.09	0.13	0.55	0.11
LOI	0.58	0.44	0.14	0.54
Sum	100.11	100.89	101.34	100.84
Li (ppm)	30	46	33	22
Be	3	2	2	2
B	6	10	5	9
Sc	7	8	8	9
Rb	126	105	89	132
Cs	5	6	4	5
Ba	577	545	1816	291
Sr	189	182	303	109
Ga	17	17	18	18
Ta	1.10	0.85	0.77	0.98
Nb	11	11	10	11
Zr	149	169	159	171
Y	27	22	13	24
Cr	25	22	24	23
Ni	11	9	10	10
Co	8	9	6	6
V	42	39	34	39
Cu	3	5	2	4
Zn	46	51	21	16
Mo	0.39	0.31	0.46	0.90
Sn	11	3.2	2.9	3.7
Sb	0.18	0.10	0.10	0.19
La	28	8	8	23
Ce	55	16	15	48
Pr	6.48	2.11	1.89	5.85
Nd	23.39	9.35	8.16	21.98
Sm	4.85	2.72	2.18	4.77
Eu	1.01	0.98	1.15	0.74
Gd	4.63	3.12	2.34	4.45
Tb	0.74	0.54	0.38	0.70
Dy	4.56	3.58	2.32	4.20
Ho	0.92	0.75	0.46	0.83
Er	2.62	2.13	1.25	2.33
Yb	2.59	2.20	1.43	2.32
Lu	0.39	0.33	0.22	0.35
Hf	3.94	4.38	4.08	4.44
W	1.68	0.49	0.35	0.59
Pb	15	15	10	10
Th	10	4	0.7	9
U	2.8	1.4	1.4	2.4

the size of which correlate with Al_2O_3 contents, suggesting accumulation of plagioclase in this rock, and negative to absent in the remainder samples, suggesting feldspar crystallization. The concave downward shape of heavy REE for the sample TFS-PLU-08 is characteristic of the garnet role in its evolution. The mantle normalized trace element patterns of all the rocks (Figure 9b) show depletion in Nb and Ti in three out of four samples, typical of subduction-related or crustally-derived magmas, while the remainder has positive anomalies of Eu, Sr, Ba, Ti, consistent with the accumulation of plagioclase and some Ti-rich phase (possibly, Ti-rich biotite). A volcanic arc tectonic setting is also indicated by the Rb *vs.* Y+Nb plot (Figure 10a). According to chemical classification of Batchelor and Bowden (1985) the rocks range from syn-collisional to late-orogenic (Figure 10b).

DISCUSSION

Provenance of the LUP granitic magmas: subduction or rift processes?

This study provides some constraints on the Mesozoic magmatism in present Central America. While sheared and metamorphosed orthogneisses of Middle Jurassic age were previously reported, north of the studied area, by Torres de León *et al.* (2012), LUP is the first characterization of a mostly undeformed and unmetamorphosed Jurassic monzogranite in this portion of central Guatemala. Middle Jurassic ages from an orthogneiss with granitic protolith was previously reported by Ratschbacher *et al.* (2009) in central east of Guatemala. Rastchbacher *et al.* (2009) also reported Middle Jurassic ages of granites in central-western Guatemala (Sacapulas granite) and directly south of the Jocotán-Chamelecón fault near Chamelecón town in Honduras.

LUP chemical characterization suggests that the parental magmas originating LUP are high-K, mostly calc-alkaline, magmas which are either typical of subduction processes or related to partial melting of continental rock with arc-like signature.

While in northwestern Mexico the Jurassic continental magmatism is seen as the southern continuation of the Cordilleran system (see Martini and Ortega-Gutierrez, 2018, for a complete synthesis), in northeastern, central and southern Mexico Jurassic magmatism belonging to the Nazas Igneous Province (NIP) has been recently reinterpreted as crustally derived by partial melting of continental rocks during the extensional tectonics that accompanied the opening of the Gulf of Mexico, based upon a strict reinterpretation of its geochemical character (Parolari *et al.*, 2022). The model proposed by Parolari *et al.* (2022) also applies to isolated Jurassic rocks of southwestern Mexico, such as: (a) a Middle Jurassic pluton with an age of 165 Ma reported by Guerrero-García *et al.* (1978) from the Acapulco – Tierra Colorada transect of the Xolapa Complex; (b) a ~158 Ma orthogneiss reported by Ducea *et al.* (2004) from north of Puerto Escondido; and (c) the Early Jurassic Tizapa metagranite (186.5 ± 7.4 Ma, lower intercept of discordant data) in the eastern Guerrero Terrane, Teloloapan subterrane (Elías-Herrera *et al.* 2000); (d) Jurassic, two-mica granites exposed E of the Puerto Vallarta batholith (Valencia *et al.*, 2013; Schaaf *et al.*, 2020). In southern Mexico a migmatization event is known in the eastern Acatlán complex (Magdalena migmatite, 175±3 and 171±1 Ma) and associated with a thermal unroofing during the breakup of Pangea (Keppie *et al.*, 2004), thus it can be clearly ascribed to the same extensional event. In this view, a characterization of LUP magmas is needed, under the same geochemical parameters that compare, for instance, a compatible element, such as Sr, enriched in arc magmas, ratioed to Nb, a variably, but generally depleted element in subduction-related magmas, which obtained Sr/Nb ratio can be compared to other two incompatible elements such as Rb and Nd, whose ratio is very low (<1) in intraplate basalts. Doing so and compare the studied ratios

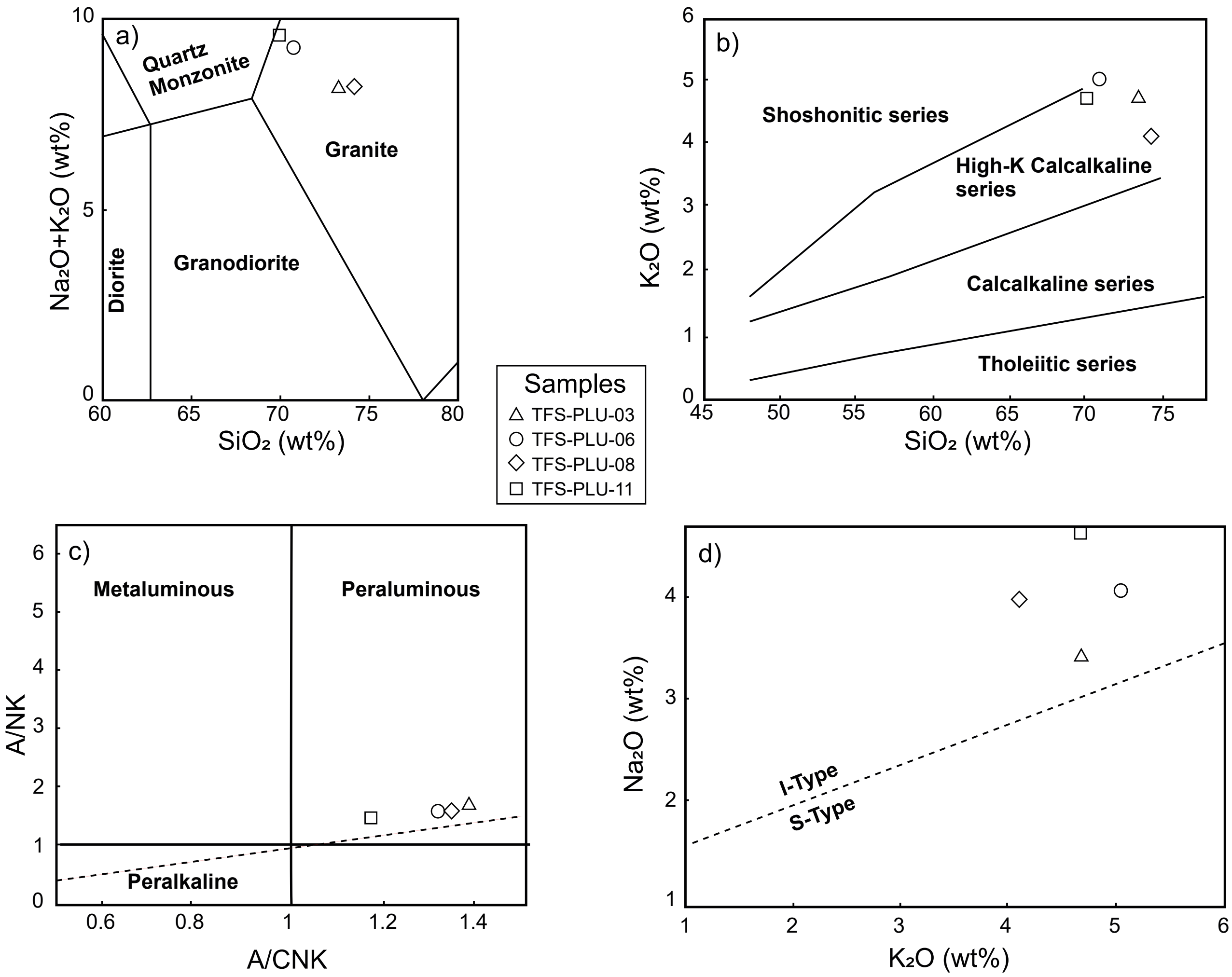

Figure 8. Geochemical classification of the studied granites. a) SiO_2 *vs.* Na_2O+K_2O discrimination diagram (Middlemost, 1994); b) Peccerillo and Taylor (1976) discrimination diagram. c) A/CNK *vs.* A/NK diagram of Shand (1943) for metaluminous *vs.* peraluminous discrimination. d) K_2O *vs.* Na_2O diagram for discrimination between I-type and S-type granites. After Chappell and White (1974).

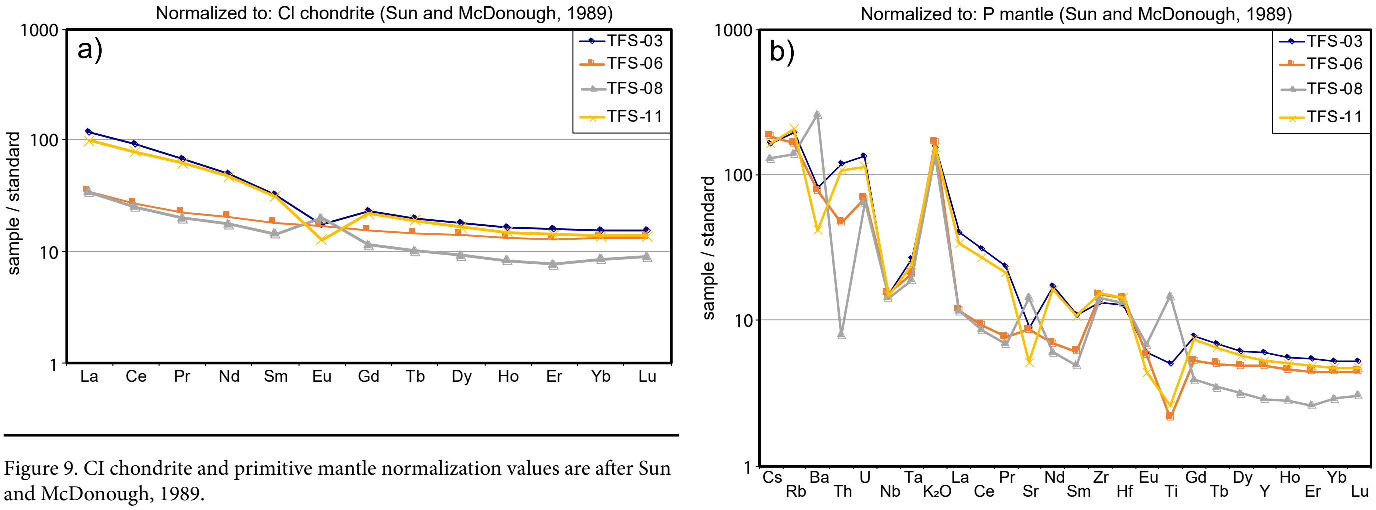

Figure 9. CI chondrite and primitive mantle normalization values are after Sun and McDonough, 1989.

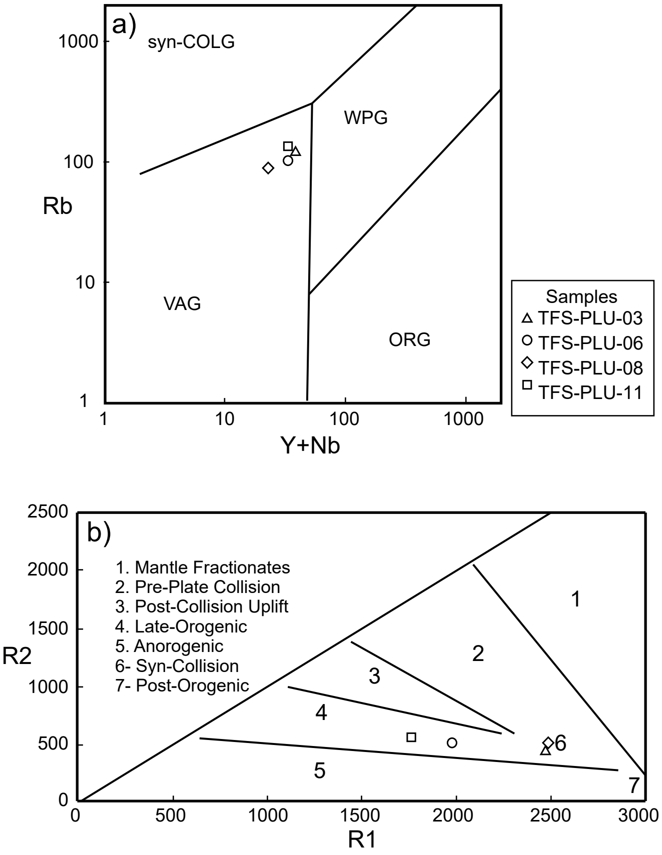

Figure 10. Tectonic discrimination diagrams for the studied samples. a) Rb *vs.* Y+Nb diagram, after Pearce *et al.*, 1984. b) R1-R2 discrimination diagram of Batchelor and Bowden (1985). R1 equals 4Si-11(Na+K)-2(Fe+Ti), whereas R2 is equal to 6Ca+2Mg+Al. All cations are expressed as millications per 100 g.

for LUP samples with a database of modern (Trans Mexican Volcanic Belt) and Mesozoic (Alisitos and NW) arcs in Mexico, as well as to the NIP Jurassic samples reported by Parolari *et al.* (2022), it is possible to observe that LUP samples fit with the NIP ones, being equally depleted in Sr, high in Rb and with low, but variable, Nb contents (Figure 11).

Tectonic implications

South of the Sula terrane, in Central America, there aren't any reports of Jurassic magmatic rocks. In Northern South America, Colombia is characterized by a vast Mesozoic magmatic arc (*e.g.*, Bayona *et al.*, 2020). Few localities, however, show Middle Jurassic magmatism, being mostly of Early Jurassic or even Late Triassic time (López-Isaza and Zuluaga, 2020). Practically, the Middle Jurassic igneous rocks are limited to the northern sector of Colombia, in the Alta Guajira and Serranía de Perijá (La Quinta Formation, Serranía de Perijá, 167±3 Ma, Dasch, 1982, Maze, 1984; Siapaná Granodiorite 167±9.4 Ma, Cardona *et al.*, 2006; San Lucas Massif batholiths, 193–162 Ma, Cuadros *et al.*, 2014; Segovia diorite, Upper Jurassic, Leal-Mejía, 2011; González *et al.*, 2015a and 2015b; Segovia vulcanites of 165.5±2.1 Ma, González *et al.*, 2015b; La Malena volcanics, 163.5±0.95 to 183.2±3 Ma, González *et al.*, 2015c). Such rocks in northern Colombia are interpreted as belonging to subduction-related processes (*e.g.*, López-Isaza and Zuluaga, 2020).

While the obtained ages sit the LUP magmatism in the Middle Jurassic, two regimes contributed to the generation of this magmatism for this time span: 1) the magmatism related to the subduction of the Farallon and Cocos plates, which were active at least since the beginning of Mesozoic, as the widespread magmatism since the Early Jurassic testifies (*e.g.*, Spikings *et al.*, 2015; Martini and Ortega-Gutiérrez, 2018, and Figure 12); together with 2) the extensional processes that produced several rift basins associated to the onset of the Gulf of Mexico opening (*e.g.*, Engebretson *et al.*, 1985; Pindell and Kennan, 2009; Martini and Ortega-Gutiérrez, 2018; Parolari *et al.*, 2022, and references therein), the breakup of Pangea (*e.g.*, Martini *et al.*, 2022) with the relative migration of Gondwana toward SE and the formation of several NS and WNW-oriented lateral faults in southern Mexico (#1 to 5 in Figure 12, see also Zepeda-Martínez *et al.*, 2021). The NS-trending lateral faults are subparallel to the Tamaulipas-Chiapas Transform zone, which corresponds to the main trace of the Yucatán displacement during the opening of the Gulf of Mexico (Figure 12). Several of those faults imply a complex history of WNW-ESE displacements during the thinning of the lithosphere caused by the Pangea breakup. Such processes, and the existence of that fault system, was previously envisaged by several authors (*e.g.*, Anderson and Schmidt, 1983; Pindell and Kennan, 2009) and recently documented in southern Mexico by Zepeda-Martínez *et al.* (2021), who concluded that southern Mexico migrated from a more westward position during the Jurassic, toward ESE thanks to the action of such fault system (Figure 12). In this model it is envisaged that at least some of the magmatic arc previously emplaced into the continental crust, including LUP, suffered the same displacement toward ESE. Some remnant portion of this arc is represented by those plutons found in NW South America (La Guajira, Perijá, Mérida in Figure 12) was displaced toward SE during the Late Jurassic to Early Cretaceous by a continuous separation mechanism in which Gondwana reached its actual position.

CONCLUSIONS

La Unión Pluton is a Bajocian (170 Ma), high-K calc-alkaline and peraluminous pluton intruding the Sula Terrane of Central Guatemala. It is interpreted as the (currently known) southernmost magmatic witness of the melting of continental sediments, during the process of

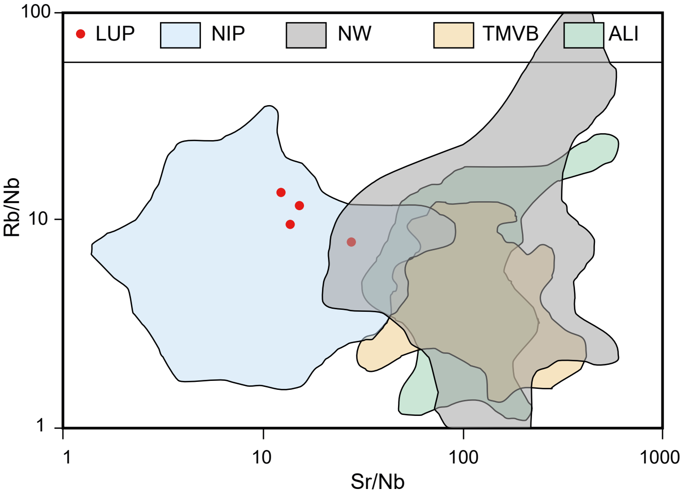

Figure 11. Rb/Nb *vs.* Sr/Nb ratios of LUP samples, compared with the same ratios in continental arc, subduction-related rocks (TMVB: Trans-Mexican Volcanic Belt; Ali: Alisitos; NW: northwestern Mexico) and continental magmas interpreted as sedimentary partial melts (NIP: Nazas Igneous Province). Comparison data taken from Parolari *et al.* (2022) and references therein.

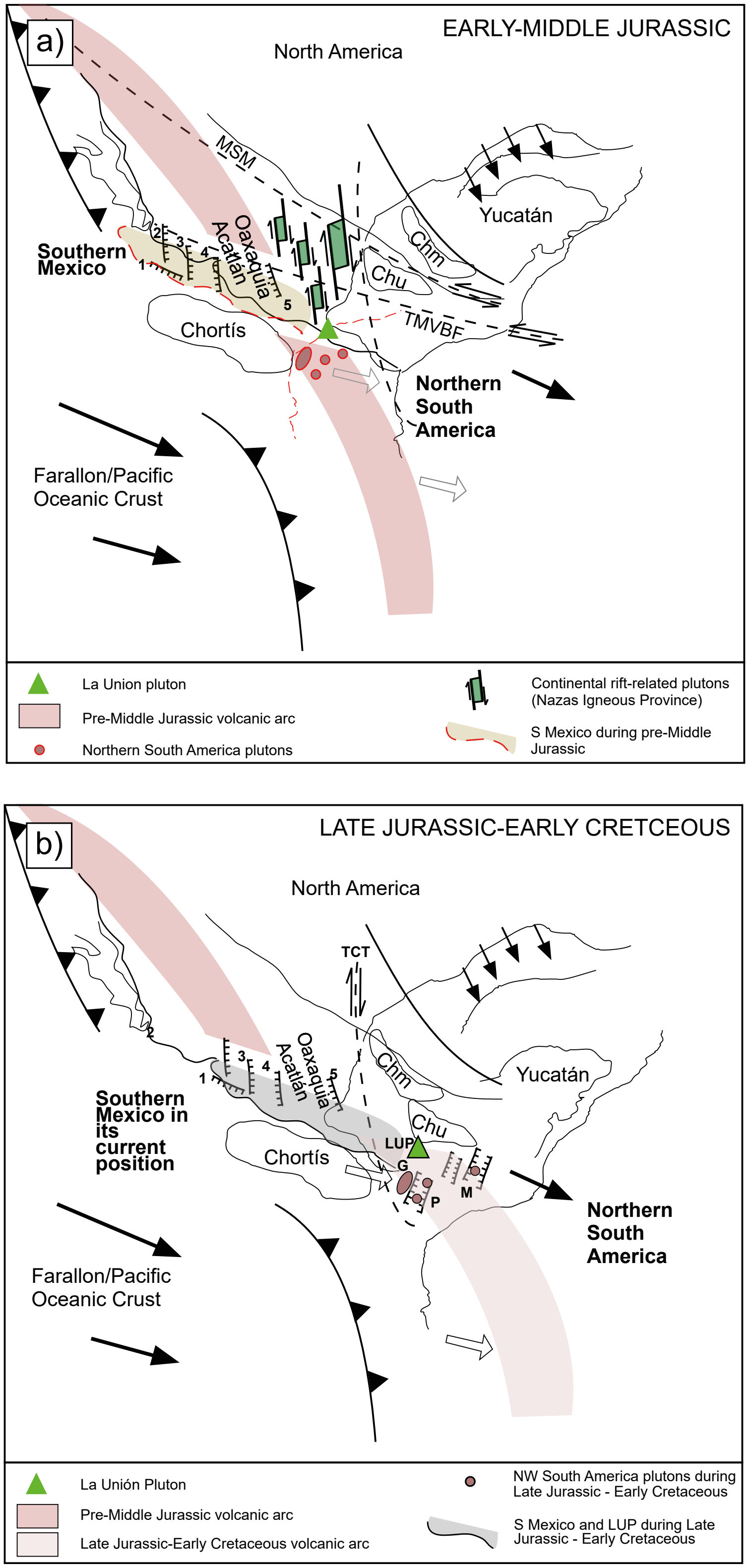

Figure 12. Proposed tectonic cartoon ranging from the a) Early-Middle Jurassic to b) Late Jurassic – Early Cretaceous. MSM: Mojave-Sonora megashear; TMVBF: Trans-Mexican Volcanic Belt Fault (Gastil and Jensky, 1973); TCT: Tamaulipas-Chiapas Transform Fault; Chm: Chiapas Massif; Chu: Chuacús Metamorphic Complex; G: La Guajira batholith; P: Perijá batholith; M: Mérida (from Bayona *et al.*, 2020); 1-5: Salado River, Texcalapa, El Sabino, Caltepec and Oaxaca NNW-trending faults in southern Mexico (Zepeda-Martínez *et al.*, 2021). Modified from Keppie *et al.* (2004); Pindell and Kennan (2009); Bayona *et al.* (2020); Martini and Ortega-Gutiérrez (2018); Zepeda-Martínez *et al.* (2021). LUP: La Unión Pluton (this paper). Bordered in red: envisaged position of some of the elements discussed in the text (southern Mexico), as well as some of the Middle Jurassic discussed plutons; in black, their position relative to the Middle Jurassic volcanic arc, after the displacement related to the action of the WNW-ESE major faults.

crustal thinning that accompanied the initial stages of Pangea breakup. Such process is represented, in Mexico, by the Nazas Igneous Province (*e.g.*, Parolari *et al*., 2022) whose emplacement accompanied the breakup of Pangea and opening of the Gulf of Mexico.

SUPPLEMENTARY MATERIAL

Table S1 can be downloaded at the website of this Journal, <www.rmcg.unam.mx>, in the preview of the abstract of this article.

ACKNOWLEDGEMENTS

Ofelia Pérez-Arvizu is thanked for her help during geochemical determinations. This paper is a contribution to the UNAM PAPIIT-DGAPA IN101520 and CONACyT Ciencia de Frontera #7351 grants to LAS. R. Milian de la Cruz acknowledges the Consejo Nacional de Ciencia y Tecnología, México, for a "Ayudante de Investigador Nacional" scholarship during the writing of this work.

Ing. Fernando Moterroso Rey is also thanked for his help in analyzing and interpreting stereoscopic images of the studied area. Sergio Alfonso Ibarra Winter is also thanked for his help during field work.

REFERENCES

Anderson, T.H., Schmidt, V.A., 1983, A model of the evolution of Middle America and the Gulf of Mexico–Caribbean Sea region during Mesozoic time: Geological Society of America Bulletin, 94, 941-966, https://doi.org/10.1130/0016-7606(1983)94<941:TEOMAA>2.0.CO;2

Anderson, T.H., Rodríguez-Castañeda, J.L., Silver, L.T., 2005, Jurassic rocks in Sonora, Mexico—relations to the Mojave-Sonora megashear and its inferred northwestward extension, *in* Anderson, T.H., McKee, J.W., Steiner, M.B. (eds.), The Mojave-Sonora megashear hypothesis—development, assessment, and alternatives: Geological Society of America Special Paper, 393, 51-95.

Batchelor, R.A., Bowden, P., 1985, Petrogenetic interpretation of granitic rock series using multicationic parameters: Chemical Geology, 48, 43-55.

Bayona, G., Bustamante, C., Nova, G., Salazar-Franco, A.M., 2020, Jurassic Evolution of the Northwestern Corner of Gondwana: Present Knowledge and Future Challenges in Studying Colombian Jurassic Rocks, *in* Gómez, J., Pinilla-Pachon, A.O. (eds.), The Geology of Colombia, Volume 2, Mesozoic: Bogotá, Colombia, Servicio Geológico Colombiano, Publicaciones Geológicas Especiales 36, 171-207, https://doi.org/10.32685/pub.esp.36.2019.05

Beccaluva, L., Bellia. S., Coltorti, M., Dengo, G., Giunta,G., Mendez, J., Romero, J., Siena, F., 1995, The northwestern border of the Caribbean Plate in Guatemala: New geological and petrological data on the Motagua ophiolitic belt: Ophioliti, 20, 1-15.

Bosc, E.A., 1971, Geology of the San Agustín Acasaguastlán Quadrangle and Northeastern Part of El Progreso Quadrangle: Houston, Texas, Rice University, PhD Thesis, 131 pp.

Brueckner, H., Lallemant, H., Sisson, V., Harlow, G., Hemming, S., Martens, U., Tsujimori, T., Sorensen, S., 2009, Metamorphic reworking of a high pressure–low temperature mélange along the Motagua fault, Guatemala: A record of Neocomian and Maastrichtian transpressional tectonics: Earth and Planetary Science Letters, 284, 228-235, https://dx.doi.org/10.1016/j.epsl.2009.04.032

Burkart, B., Clemons, R.E., Crane, D.C., 1973, Mesozoic and Cenozoic Stratigraphy of Southeastern Guatemala: American Association of Petroleum Geologists Bulletin, 57(1), 63-73.

Cardona, A., Cordani, U.G., MacDonald, W.D., 2006, Tectonic correlations of pre–Mesozoic crust from the northern termination of the Colombian Andes, Caribbean region: Journal of South American Earth Sciences, 21(4), 337-354, https://doi. org/10.1016/j.jsames.2006.07.009

Chappell, B.W., White, A.J.R., 1974, Two contrasting granite types: Pacific Geology, 8, 173-174.

Clemons, R., Long, L., 1971, Petrologic and Rb-Sr Isotopic Study of the Chiquimula Pluton, Southeastern Guatemala: Geological Society of America Bulletin, 82(10), 2729-2740, https://dx.doi.org/10.1130/0016-7606(1971)82[2729:pariso]2.0.co;2

Cuadros, F.A., Botelho, N.F., Ordóñez–Carmona, O., Matteini, M., 2014, Mesoproterozoic crust in the San Lucas Range (Colombia): An insight into the crustal evolution of the northern Andes: Precambrian Research, 245, 186-206. https://doi. org/10.1016/j.precamres.2014.02.010

Dasch, L.E., 1982, U–Pb geochronology of the Sierra de Perijá, Venezuela: Cleveland, USA, Case Western Reserve University, Master Thesis, 183 pp.

Dengo, G., 1985, Mid America: Tectonic Setting for the Pacific Margin from Southern Mexico to Northwestern Colombia: The Ocean Basins and Margins https://dx.doi.org/10.1007/978-1-4613-2351-8_4

Donnelly, T.W., Horne, G.S., Finch, R.C., López-Ramos, E., 1990, Northern Central America: the Maya and Chortis blocks, *in* Dengo, G., Case, J. (eds.), The Caribbean Region. Geology of North America: Geological Society of America, H, 37-76.

Ducea, M.N., Gehrels, G.E., Shoemaker, S., Ruiz, J. Valencia, V. A., 2004, Geologic evolution of the Xolapa Complex, southern Mexico: Evidence from U-Pb zircon geochronology: Geological Society of America, Bulletin, 116, 1016-1025.

Elías-Herrera, M., Sánchez-Zavala, J., Macías-Romo, C., 2000, Geologic and geochronologic data from the Guerrero terrane in the Tejupilco area, southern Mexico: new constraints on its tectonic interpretation: Journal of South American Earth Sciences, 13, 355-376.

Engebretson, D., Cox, A. Gordon, G., 1985, Relative plate motions between oceanic and continental plates in the Pacific basin: Geological Society of America Special Paper, 206, 1-64.

Estrada-Carmona, J., Weber, B., Martens, U., López-Martínez, M., 2012, Petrogenesis of Ordovician magmatic rocks in the southern Chiapas Massif Complex: relations with the early Palaeozoic magmatic belts of northwestern Gondwana: International Geology Review, 54, 1918-1943, doi:10.1080/00206814.2012.685553

Flores, K., Martens, U., Harlow, G., Brueckner, H., Pearson, N., 2013, Jadeitite formed during subduction: In situ zircon geochronology constraints from two different tectonic events within the Guatemala Suture Zone: Earth and Planetary Science Letters, 371-372, 67-81, https://dx.doi.org/10.1016/j.epsl.2013.04.015

Gastil, R.G., Jensky, W.A., 1973, Evidence for strike-slip displacement beneath the Trans- Mexican Volcanic Belt: San Andreas Fault Symposium, Stanford, California, Stanford University Publications in the Geological Sciences, 171-180.

González, H., Maya, M., García, J.F., Gómez, J.P., Palacio, A.F. Vélez, W., 2015a, Memoria explicativa: Plancha 84 Los Canelos, scale 1:100000: Medellín, Colombia, Servicio Geológico Colombiano, 147 pp.

González, H., Maya, M., García, J.F., Camacho, J.A., Gómez, J.P., Cardona, O.D., Palacio, A.F., Vélez, W., 2015b, Memoria explicativa: Plancha 94 El Bagre. Scale 1:100000: Medellín, Colombia, Servicio Geológico Colombiano, 196 pp.

González, H., Maya, M., Tabares, L.F., Montoya, A., Palacio, A.F., Sánchez, C., Barajas, A., Vélez, W., 2015c, Memoria explicativa: Plancha 118 San Francisco. Scale 1:100000: Medellín, Colombia, Servicio Geológico Colombiano, 220 pp.

Guerrero-García, J., Silver, L., Anderson, T., 1978, Estudios geocronológicos en el Complejo Xolapa: Boletín de la Sociedad Geológica Mexicana, 39, 22-23.

Horne, G.S., Clark, G.S., Pushkar, P., 1976, Pre-Cretaceous rocks of northwestern Honduras: basement terrane in Sierra de Omoa: American Association of Petroleum Geologists Bulletin, 60, 4, 566-583.

Keppie, J., Nance, R., Dostal, J., Ortega-Rivera, A., Miller. B.V., Fox, D., Muise, J., Powell, J.T., Mumma, S.A., Lee, J.K.W., 2004, Event Superposed on a Paleozoic Geological Record in the Acatlán Complex of Southern Mexico: Hotspot Activity During the Breakup of Pangea: Gondwana Research, 7, 239-260.

Lawrence, D.P., 1975, Petrology and structural geology of the Sanarate–El Progreso area, Guatemala: Binghamton, New York, State University of

New York, Ph. D. thesis, 255 pp.

Le Maitre, R.W. (ed.), Streckeisen, A.L., Zanettin, B.A., Le Bas, M.J., Bonin, B., Bateman, P., Bellieni, G., Dudek, A., Efremova, S., Kepper, J., Lameyre, J., Sabine, P.A., Schmid, R., Sorensen, H., Woolley, A.R., 2002, Igneous rocks; A classification and glossary of terms: recommendations of the International Union of Geological Science Subcommission on the Systematics of Igneous Rocks: Cambridge, Cambridge University Press, 256 pp.

Leal-Mejía, H. 2011, Phanerozoic gold metallogeny in the Colombian Andes: A tectono– magmatic approach: Barcelona, Universitat de Barcelona, PhD thesis, 989 pp.

López-Isaza, J.A., Zuluaga, C.A., 2020, Late Triassic to Jurassic magmatism in Colombia: Implications for the evolution of the northern margin of South America, *in* Gómez, J., Pinilla– Pachon, A.O. (eds.), The Geology of Colombia, Volume 2 Mesozoic: Bogotá, Colombia, Servicio Geológico Colombiano, Publicaciones Geológicas Especiales 36, 77-116, https://doi. org/10.32685/pub.esp.36.2019.03

Lozano-Santacruz, R., Bernal, J., 2005, Characterization of a new set of eight geochemical reference materials for XRF major and trace element analysis: Revista Mexicana de Ciencias Geológicas, 22(3), 329-344.

Maldonado, R., Ortega-Gutiérrez, F., Ortíz-Joya, G.A., 2018, Subduction of Proterozoic to Late Triassic continental basement in the Guatemala suture zone: A petrological and geochronological study of high-pressure metagranitoids from the Chuacús complex: Lithos, 308-309, 83-103, doi:10.1016/j.lithos.2018.02.030

Manton, W.I., 1996, The Grenville of Honduras: Geological Society of America Abstracts with Programs, 28, 7, A-493.

Martens, U., Ortega-Obregón, C., Estrada, J., Valle, M., 2007, Metamorphism and metamorphic rocks, *in* Bundschuh, J., Alvarado, G.E. (eds.), Central America: Geology, Resources and Hazards: The Netherlands, Taylor and Francis, 489-526.

Martens, U., Brueckner, H., Mattinson, C., Liou, J., 2012, Timing of eclogite-facies metamorphism of the Chuacús Complex, Central Guatemala: Record of Late Cretaceous continental subduction of North America's sialic basement: Lithos, 146-147, 1-10.

Martini, M., Ortega-Gutiérrez, F., 2018, Tectono-stratigraphic evolution of eastern Mexico during the break-up of Pangea: A review: Earth Science Reviews, 183, 38-55, doi:10.1016/j.earscirev.2016.06.013

Martini, M., Anaya-Guarneros, J.A., Solari, L.A., Bedoya-Mejía, A., Zepeda-Martínez, M., Villanueva-Amadoz, U., 2021, The Matzitzi Formation in southern Mexico: A record of the final assembly of Pangea or of its breakup initiation along inherited suture belts?: Basin Research, 34(2), 727-747, https://doi.org/10.1111/bre.12638

Maze, W.B., 1984, Jurassic La Quinta Formation in the Sierra de Perija, northwestern Venezuela: Geology and tectonic environment of red beds and volcanic rocks, *in* Bonini, W.E., Hargreaves, R.B., Shagam, R. (eds.), The Caribbean-South America plate boundary and regional tectonics: Geological Society of America Memoir, 263-282.

McBirney, A.R., 1963, Geology of a part of the central Guatemala Cordillera: University of California, Publications in Geological Sciences, 38, 172-242.

Middlemost, E.A., 1994, Naming materials in the magma/igneous rock system: Earth Science Reviews, 37, 215-224.

Mori, L., Gómez-Tuena, A., Cai, Y., Goldstein, S., 2007, Effects of prolonged flat subduction on the Miocene magmatic record of the central Trans-Mexican Volcanic Belt: Chemical Geology, 244(3-4), 452-473, http://doi.org/10.1016/j.chemgeo.2007.07.002

Ortega-Gutiérrez, F. Solari, L., Solé, J., Martens, U., Gómez-Tuena, A., Morán-Ical, S., Reyes-Salas, M., Ortega-Obregón, C., 2004, Polyphase, High-Temperature Eclogite-Facies Metamorphism in the Chuacús Complex, Central Guatemala: Petrology, Geochronology, and tectonic Implications: International Geology Review, 46, 445-470.

Ortega-Gutiérrez, F., Solari, L.A., Ortega-Obregón, C., Elías-Herrera, M., Martens, U., Morán-Icál, S., Chiquín, M., Keppie, J.D., Torres de León, R., Schaaf, P., 2007, The Maya-Chortís Boundary: A Tectonostratigraphic Approach: International Geology Review, 49, 996-1024, doi:10.2747/0020-6814.49.11.996

Ortega-Obregón, C., Solari, L., Keppie, J.D., Ortega-Gutiérrez, F., Solé, J., Morán-Ical, S., 2008, Middle-Late Ordovician magmatism and Late Cretaceous collision in the southern Maya block, Rabinal-Salamá area, central Guatemala: Implications for North America–Caribbean plate tectonics: Geological Society of America Bulletin, 120, 556. doi:10.1130/b26238.1

Ortega-Obregón, C., Abdullin, F., Solari, L., Schaaf, P. Solís-Pichardo, G., 2019, Apatite U-Pb dating at UNAM laboratories: analytical protocols and examples of its application: Revista Mexicana de Ciencias Geológicas, 36, 27-37.

Parolari M., Martini M., Gómez-Tuena A., Ortega-Gutiérrez F., Errázuriz-Henao C., Cavazos-Tovar J.G., 2022, The petrogenesis of Early–Middle Jurassic magmatism in southern and central Mexico and its role during the break-up of Western Pangaea: Geological Magazine, 159, 873-892 https://doi.org/10.1017/S0016756822000061

Paton, C., Woodhead, J.D., Hellstrom, J.C., Hergt, J.M., Greig, A., 2010, Improved laser ablation U-Pb zircon geochronology through robust downhole fractionation correction: Geochemistry Geophysics Geosystems 11, Q0AA06.

Paton, C., Hellstrom, J., Paul, B., Woodhead, J., Hergt, J., 2011, Iolite: freeware for the visualisation and processing of mass spectrometric data: Journal of Analytic Atomic Spectrometry, 26, 2508-2518. doi:10.1039/c1ja10172b

Pearce, J.A., Harris, N.B.W., Tindle, A.G., 1984, Trace element discrimination diagrams for the tectonic interpretation of granitic rocks: Journal of Petrology, 25, 956-983.

Peccerillo, A., Taylor, S.R., 1976, Geochemistry of Eocene calc-alkaline volcanic rocks from the Kastamonu area, Northern Turkey: Contribution to Mineralogy and Petrology, 58, 63-81, doi.org/10.1007/BF00384745

Petrus, J.A., Kamber, B.S., 2012, VizualAge: a novel approach to laser ablation ICP-MS U– Pb geochronology data reduction: Geostandards and Geoanalytical Research, 36, 247-270, doi:10.1111/j.1751-908X.2012.00158.x

Pindell, J., Kennan, L., 2009, Tectonic evolution of the Gulf of Mexico, Caribbean and northern South America in the mantle reference frame: an update: Geological Society London Special Publications 328(1), 1-55, https://dx.doi.org/10.1144/sp328.1

Pindell, J., Maresch, W., Martens, U., Stanek, K., 2012, The Greater Antillean Arc: Early Cretaceous origin and proposed relationship to Central American subduction melanges: implications for models of Caribbean evolution: International Geology Review, 54(2), 131-143, https://dx.doi.org/10.1080/00206814.2010.510008

Ramírez-Fernández, J.A., Alemán-Gallardo, E.A., Cruz-Castillo, D., Velasco-Tapia, F., Jenchen, U., Becchio, R., León-Barragán, L.D., Casas-Peña, J.M., 2021, Early Mississippian precollisional, peri-Gondwanan volcanic arc in NE-Mexico: Aserradero Rhyolite from Ciudad Victoria, Tamaulipas: International Journal of Earth Sciences, 1-29, doi:10.1007/s00531-021-01992-3

Ratschbacher, L., Franz, L., Min, M., Bachmann, R., Martens, U., Stanek, K., Stubner, K., Nelson, B.K., Herrmann, U., Weber, B., López-Martinez, M., Jonckheere, R., Sperner, B., Tichomirowa, M., McWilliams, M.O., Gordon, M., Meschede, M., Bock, P., 2009, The North American-Caribbean Plate boundary in Mexico-Guatemala-Honduras, *in* James, K.H., Lorente, M.A., Pindell, J.L. (eds.) Origin and Evolution of the Caribbean Region: Geological Society London Special Publications, 328, 219-293, doi:10.1144/sp328.11

Salguero-Díaz, F.E., 2016, Petrografía, Geoquímica y Geocronología del Plutón La Unión en los municipios de La Unión y Gualán, Zacapa, Guatemala: Guatemala, Centro Universitario del Norte, Universidad de San Carlos, Honor Thesis, 140 pp.

Schaaf, P., Díaz-López, F., Gutiérrez-Aguilar, F., Solís-Pichardo, G., Hernández-Treviño, T., Arrieta-García, G., Solari, L., Ortega-Obregón, C., 2020, Geochronology and geochemistry of the Puerto Vallarta igneous and metamorphic complex and its relation to Cordilleran arc magmatism in northwestern Mexico: Lithos, 352-353, 105248, doi: 10.1016/j.lithos.2019.105248

Schwartz, D.P., 1976, Geology of the Zacapa Quadrangle and vicinity, Guatemala, Central America: Binghamton, New York, State University of New York, Binghamton, PhD Thesis, 191 pp.

Shand, S.J., 1943, Eruptive rocks. Their genesis, composition, classification and their relation to ore deposits, with a chapter on meteorites: New York, USA, Wiley & Sons, 488 pp.

Sláma, J., Košler, J., Condon, D., Crowley, J., Gerdes, A., Hanchar, J., Horstwood, M., Morris, G., Nasdala, L., Norberg, N., Schaltegger, U., Schoene, B., Tubrett, M., Whitehouse, M.J., 2008, Plešovice zircon—a new natural reference material for U–Pb and Hf isotopic microanalysis: Chemical Geology, 249, 1-35, doi:10.1016/j.chemgeo.2007.11.005

Solari, L., Gómez-Tuena, A., Bernal, J., Pérez-Arvizu, O., Tanner, M., 2010, U-Pb Zircon Geochronology with an Integrated LA-ICP-MS Microanalytical Workstation: Achievements in Precision and Accuracy: Geostandards and Geoanalytical Research, 34(1), 5-18.

Solari, L.A., Gómez-Tuena, A., Ortega-Gutiérrez, F., Ortega-Obregón, C., 2011, The Chuacús Metamorphic Complex, central Guatemala: geochronological and geochemical constraints on its Paleozoic-Mesozoic evolution: Geologica Acta, 9, 329-350.

Solari, L.A., Garcia-Casco, A., Martens, U., Lee, J.K.W., Ortega-Rivera, A., 2013, Late Cretaceous subduction of the continental basement of the Maya block (Rabinal Granite, central Guatemala): Tectonic implications for the geodynamic evolution of Central America: Geological Society of America Bulletin, 125, 625-639.

Solari, L.A., González-León, C. M., Ortega-Obregón, C., Valencia-Moreno, M., Rascón- Heimpel, M. A., 2018, The Proterozoic of NW Mexico revisited: U–Pb geochronology and Hf isotopes of Sonoran rocks and their tectonic implications: International Journal of Earth Sciences, 37, 1-17, http://doi.org/10.1007/s00531-017-1517-2

Spikings, R., Cochrane, R., Villagomez, D., van der lelia, R., Vallejo, C., Winkler, W., Beate, B., 2015, The geological history of northwestern South America: from Pangaea to the early collision of the Caribbean Large Igneous Province (290–75Ma): Gondwana Research, 27, 95-139.

Sun, S.S., McDonough, W.F., 1989, Chemical and isotopic systematics of oceanic basalts– implications for mantle composition and processes, *in* Saunders, A.D., Norry, M.J. (eds.), Magmatism in the ocean basins: London, The Geological Society, Special Publication, 42, 313-345.

Torres de León, R., 2016, Caracterización Geológica y Geocronológica de Unidades Metamórficas e Intrusivas de la Región Centro-Oeste de la Cuenca del Río Motagua, Sureste de Guatemala, Centroamérica: Implicaciones en las Conexiones Sur de México - Bloque Chortis: Mexico, City, Mexico, Posgrado en Ciencias de la Tierra, Universidad Nacional Autónoma de México, Instituto de Geología, PhD Thesis, 243 pp.

Torres de León, R., Solari, L.A., Ortega-Gutiérrez, F., Martens, U., 2012, The Chortis Block-- southwestern Mexico connections: U-Pb zircon geochronology constraints: American Journal of Science, 312, 288-313, doi:10.2475/03.2012.02

Valencia, V.A., Righter, K., Rosas-Elguera, J., López-Martínez, M., Grove, M., 2013, The age and composition of the pre-Cenozoic basement of the Jalisco Block: implications for and relation to the Guerrero composite terrane: Contributions to Mineralogy and Petrology, 166, 801-824.

Vermeesch, P., 2018, IsoplotR: a free and open toolbox for geochronology: Geoscience Frontiers, 9, 1479-1493. doi:10.1016/j.gsf.2018.04.001

Weber, B., Kohler, H., 1999, Sm-Nd, Rb-Sr and U-Pb geochronology of a Grenville Terrane in Southern Mexico: origin and geologic history of the Guichicovi Complex: Precambrian Research, 96, 245-262.

Weber, B., Iriondo, A., Premo, W. R., Hecht, L. Schaaf, P., 2007, New insights into the history and origin of the southern Maya block, SE México: U–Pb–SHRIMP zircon geochronology from metamorphic rocks of the Chiapas massif: International Journal of Earth Sciences, 96, 253-269.

Weber, B., Cameron, K.L., Osorio, M., Schaaf, P., 2010, A Late Permian Tectonothermal Event in Grenville Crust of the Southern Maya Terrane: U-Pb Zircon Ages from the Chiapas Massif, Southeastern Mexico: International Geology Review, 47, 509-529, doi:10.2747/0020-6814.47.5.509

Weber, B., González-Guzmán, R., Manjarrez-Juárez, R., Cisneros de León, A., Martens, U., Solari, L., Hecht, L., Valencia, V., 2018, Late Mesoproterozoic to Early Paleozoic history of metamorphic basement from the southeastern Chiapas Massif Complex, Mexico, and implications for the evolution of NW Gondwana: Lithos, 300-301, 177-199, doi:10.1016/j.lithos.2017.12.009

Weber, B., Schmitt, A.K., Cisneros de León, A., González-Guzmán, R., Gerdes, A., 2020, Neoproterozoic extension and the Central Iapetus Magmatic Province in southern Mexico – new U-Pb ages, Hf-O isotopes and trace element data of zircon from the Chiapas Massif Complex: Gondwana Research, 88, 1-20, doi:10.1016/j.gr.2020.06.022

Wiedenbeck, M., Allé, P., Corfu, F., Griffin, W.L., Meier, M., Oberli, F., Von Quadt, A., Roddick, J., Spiegel, W., 1995, Three natural zircon standards for U-Th-Pb, Lu-Hf, trace element and REE analyses: Geostandard Newsletters, 19, 1-23.

Zepeda-Martínez, M., Martini, M., Solari, L.A. Mendoza-Rosales, C.C., 2021, Reconstructing the tectono-sedimentary evolution of the Early– Middle Jurassic Tlaxiaco Basin in southern Mexico: New insights into the crustal attenuation history of southern North America during Pangea breakup: Geosphere, 17, doi:10.1130/ges02309.1

Manuscript received: december 8, 2021
Corrected manuscript received: february 24, 2022
Manuscript accepted: march 3, 2022