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Some aspects of current State of Knowledge on Triassic series on both sides of the Central Atlantic Margin / *Quelques aspects de l'état des connaissances des séries triasiques de part et d'autre de la Marge Atlantique*

Paleobotanical and palynological evidence for the age of the Matzitzi Formation, Mexico

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Abstract. This study addresses some of the stratigraphical problems of the Matzitzi Formation of Puebla and Oaxaca States in Mexico. The age assignment for this unit is controversial although most researchers today accept a Leonardian age (Kungurian, 279.3–272.3 Ma) based on the presence of the gigantopterid *Lonesomia mexicana* Weber. However, after re-examination of the holotype and two paratypes, the absence of diagnostic taxonomic characters prevents the assignment of this fossil type species to the gigantopterid group. Excluding the presence of gigantopterids in this formation, the macroflora seems to be Permian in age. Samples were collected for palynological analysis to determine the age of the formation. Studied palynological assemblages seem to be reworked and are represented by 18 fossil taxa assigned to the following genera: *Calamospora*, *Deltoidospora*, *Densosporites*, *Granulatisporites*, *Laevigatosporites*, *Latipulvinites*, *Lophotriletes*, *Platysaccus*, *Punctatosporites*, *Raistrickia*, *Schopfpollenites*, *Thymospora*, *Triquitrites*, *Verrucosisporites*, and *Vesicaspora*. Described palynomorphs are likely Late Pennsylvanian according to the presence of *Latipulvinites kosankii* and *Thymospora thiessenii*. The biostratigraphic and geochronologic age disparities should be solved in the future.

Keywords. Paleobotany, Palynology, Matzitzi Formation, *Lonesomia mexicana*, Mexico.

1. Introduction

The Paleozoic Matzitzi Formation is the most important continental unit from Mexico due to its diverse and abundant fossil flora, and because

it is a key to understanding the terminal stages of Pangea amalgamation in southern Mexico [Ortega-Gutiérrez, 1992].

Southern Mexico was subjected to large-scale thrusting, reactivation of preexisting structures, metamorphism and magmatism that occurred at different depths during burial and exhumation

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throughout the late Paleozoic and early Mesozoic [Elías-Herrera *et al.*, 2007]. The Matzitzi Formation was affected by the Caltepec fault, a dextral transpressional fault, which is one of the best examples of this main structure with multiple reactivation episodes in Mexico [Ortega-Gutiérrez *et al.*, 2018]. It represents the tectonic contact between the Acatlán crystalline Complex (Cambrian-Ordovician boundary to the latest Devonian) and Mesoproterozoic Oaxacan Complex, delimiting the Mixteco and Zapoteco terranes [Elías-Herrera *et al.*, 2007, Ortega-Gutiérrez *et al.*, 2018]. Whether accretion of the Acatlán and Oaxacan complexes took place during the Devonian or the Cretaceous is still a matter of debate [Elías-Herrera *et al.*, 2007, García-Duarte, 1999, González-Hervert *et al.*, 1984, Ramírez-Espinosa, 1984, Sedlock *et al.*, 1993, Yañez *et al.*, 1991].

The Matzitzi Formation is a post-collisional unit, overlying the amalgamation of the metamorphic Acatlán and Oaxacan complexes, and is also an important lithostratigraphic unit for understanding the western end termination of Pangea amalgamation [Elías-Herrera *et al.*, 2007, 2011, García-Duarte, 1999, Hernández-Láscares, 2000].

The age of the Matzitzi Formation has been variously estimated as Pennsylvanian-Permian based on floral content [Magallón-Puebla, 1991, Silva-Pineda, 1970, Weber, 1997, Weber *et al.*, 1987] to Permian, Triassic and Jurassic based on geological data [Bedoya *et al.*, 2020, Burckhardt, 1930, Calderón-García, 1956, Elías-Herrera *et al.*, 2011, Erben, 1956, Hernández-Láscares, 2000, Mülleried, 1933a,b, 1934]. On the basis of its rich macrofossil plant assemblage, this deposit has been considered as Pennsylvanian [Hernández-Láscares, 2000, Silva-Pineda, 1970] or Permian [Magallón-Puebla, 1991, Velasco-Hernández and Lucero-Arellano, 1996, Weber, 1997, Weber *et al.*, 1987]. However, the Matzitzi Formation is now widely accepted as Leonardian (Kungurian, latest early Permian) [Weber, 1997, Weber and Cevallos-Ferriz, 1994], on the basis of the presence of the giantopterid *Lonesomia mexicana*. Giantopterids are believed to have first appeared in North American in the Leonardian (Kungurian, latest early Permian) and this age assignment was based mainly by correlation to their appearance in Texas [Weber, 1997]. Giantopterids are a poorly defined group of uncertain botanical affinity characterized by their distinctive megaphyll leaves with marked

reticular venation [Glasspool *et al.*, 2004], Permian-Triassic in age [Wang, 2010]. According to Weber [1997] Leonardian age was also supported by *Sigillaria ichthyolepis-brardii* group, *Pterophyllum*, *Rhipidopsis* or *Ginkgoites* sp., cf. *Sphenophyllum* ex gr. *thonii*, *Sphenophyllum* sp., *Taeniopteris* cf. *multi-nervis*, which extend since the Late Carboniferous to the early Permian and *Fasciapteris* known in China since the Permian. However, these fossil genera have a wider stratigraphic range.

Assigning a Permian age to the Matzitzi Formation based on the presence of giantopterids is problematic for two reasons: (1) lack of defining traits, (2) vague stratigraphic range. First, many paleobotanists exclude fossils attributed to giantopterids from Mexico because of the absence of defining characters (Booi *et al.*, 2009, DiMichele *et al.*, 2011b, among others). Many works on giantopterids indicate that the venation pattern is an important trait to include a fossil plant within this group [Booi *et al.*, 2009, Koidzumi, 1936, Liu and Yao, 2002, Mamay, 1988, Ricardi-Branco, 2008, Seyfullah *et al.*, 2014]. Weber [1997] created a new genus of giantopterids, *Lonesomia*, because it was difficult to observe its venation pattern, possibly due to trichomes obscuring the surface. Today the only published giantopterid from the Matzitzi Formation are three samples of *Lonesomia mexicana* (holotype and two paratypes), which corresponds to a new genus and species within this group by Weber [1997]. Second, the stratigraphic range of giantopterids in North America is unclear, but it may extend into the middle Permian in the United States of America [DiMichele *et al.*, 2011b]. Moreover, we do not know whether giantopterid-bearing beds in the United States [DiMichele *et al.*, 2000, 2001, 2004a, 2011b] are synchronous with the Matzitzi Formation.

Palynology is an important biostratigraphic tool for continental deposits. There are no formally published palynological studies from the Matzitzi Formation. There is only one palynological report corresponding to the Matzitzi Formation from an abstract that indicates a Pennsylvanian age in the Río Hondo section [Di Pasquo and Hernández-Láscares, 2013].

To provide a better estimate of the deposition age of this formation, in this study we re-examine the holotype and paratypes of *Lonesomia mexicana* Weber and discuss the macroflora content and palynological assemblages from the Matzitzi Formation

of Puebla and Oaxaca States in Mexico.

2. Geological setting

The Matzitzi Formation crops out in the southern part of Puebla State (Figure 1). The Oaxacan and Acatlán Complexes appear unconformably underlying this unit or in fault contact with the Matzitzi Formation in the Los Reyes Metzontla area, being the crystalline basement of the region [Centeno-García *et al.*, 2009]. The latter is unconformably overlain in Caltepec-Metzontla area by Mesozoic red beds (conglomerates and quartz-feldspathic sandstones) [Centeno-García *et al.*, 2009] informally named as Red Conglomerate Unit [González-Hervert *et al.*, 1984], Caltepec red conglomerate [Hernández-Láscares, 2000] and Metzontla Formation [García-Duarte, 1999] (Figure 2).

Aguilera and Ordoñez [1896] were the first to informally describe the Matzitzi Formation, based on studies of localities between Los Reyes Metzontla and San Luis Atolotitlán. Flores [1909] also studied this formation and collected some fossil plants that were the basis for a comprehensive work of the fossil plants from this formation [Silva-Pineda, 1970]. This formation was informally described in a field-work guide by Calderón-García [1956] as a 600 m thick sequence of sandstones intercalated by dark shales with abundant fossil plants and occasionally containing conglomerate and coal seams. Later Centeno-García *et al.* [2009] described the formation as a clastic succession mainly dominated by sandstones intercalated by shales, carbonaceous mudstone, conglomeratic sandstone, and conglomerate (Figure 3A). They also reported coarse massive conglomerate strata near the locality of Los Reyes Metzontla containing metamorphic clasts from the Oaxacan Complex. This continental deposit has been interpreted as an anastomosing fluvial system with six facies associations described along the road connecting Los Reyes Metzontla and Coatepec localities [Centeno-García *et al.*, 2009]. Described facies by these authors include: (1) alluvial and fluvial channel fill (probably debris flows), (2) probably transverse bedforms, conglomeratic bars and channel fill, (3) sandy channel fill, longitudinal bedforms and/or sandy point bars, with scarce paleosols, (4) mostly sandy channel fill eroded by small currents (scour hollows) which may be the result of crevasse splays

in some cases, (5) floodplains and/or crevasse splays, and (6) small swamps associated with the river system or floodplains.

The felsic Atolotitlán Tuff of volcanic-arc origin, exposed in San Luis Atolotitlán, is believed to correspond to the Matzitzi Formation [Centeno-García *et al.*, 2009, Elías-Herrera *et al.*, 2011] (Figure 2). This volcanic unit has been dated by U-Pb method (240 ± 3 Ma) as Middle Triassic [Bedoya, 2018, Elías-Herrera *et al.*, 2011] (Figure 2).

It is important to note that a comprehensive stratotype for the Matzitzi Formation has not been established due to incomplete depositional sequence and tectonically separated deposition from this unit has not been correlated yet. The lack of continuous exposures together with the presence of thrusting and faulting makes it difficult to define a single continuous section of even a composite stratotype, due to difficulty to correlate among sections. The Matzitzi Formation has been dated by its relative stratigraphic position between younger and older deposits (Figure 3A) as formally described by Elías-Herrera *et al.* [2005, 2011]. This deposit lies in different fault blocks, so the outcrops in many cases appear isolated as it is very difficult to correlate strata. Also, modern vegetation obscures bedrock in the studied area. For this reason, it is difficult to locate the stratigraphic levels of the palynological samples from the nearby areas of Los Reyes Metzontla and San Luis Atolotitlán localities (labelled as MATZ samples) within the synthetic stratigraphic column. Only the Río Hondo section presents a stratigraphic continuity, with some minor faulting, and the palynological samples labelled as MATZ RH could be stratigraphically located (Figure 3B). This latter deposit consists of sandstones and siltstones and shales with floral remains (Figure 3B).

The Matzitzi Formation has been much studied for its rich well-preserved macrofloras [Carrillo and Martínez-Hernández, 1981, Flores-Barragan *et al.*, 2019a,b, Silva-Pineda, 1970, Silva-Pineda *et al.*, 2003, Velasco-Hernández and Lucero-Arellano, 1996, Velasco-de León *et al.*, 2015, Weber, 1997, Weber and Cevallos-Ferriz, 1994, Weber *et al.*, 1989]. Most of the macroflora determinations correspond to professional and Master dissertations [Flores-Barragan, 2018, Galván-Mendoza, 2000, Hernández-Láscares, 2000, Magallón-Puebla, 1991, Rincón-Pérez, 2010, Valdés-Vergara, 2017]. Based on these studies the

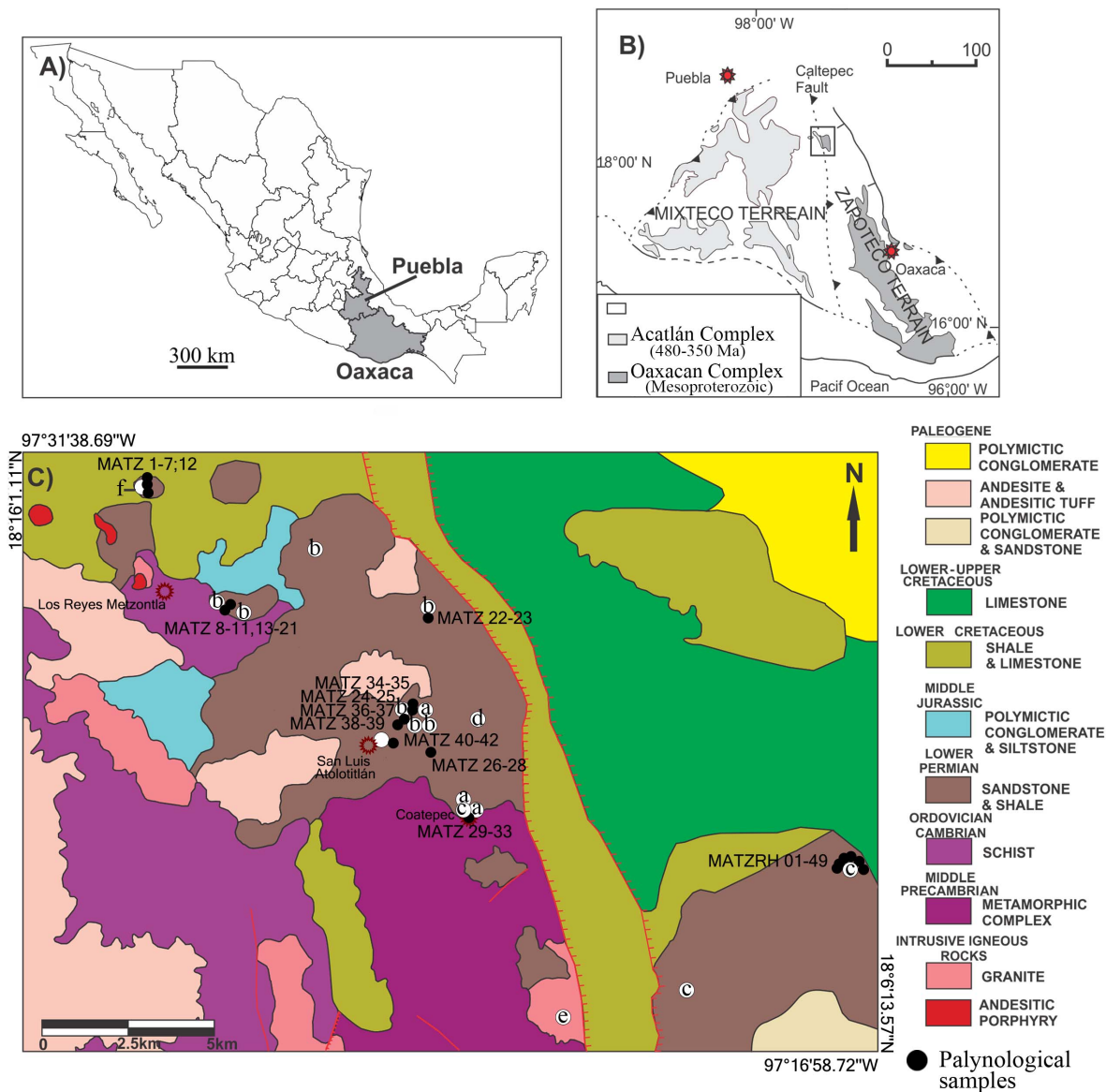


Figure 1. Geographic location, geological setting, and sample location of the studied area. (A) Geographic location of the study area in Mexico. (B) Regional geological setting of the studied area (modified from Elías-Herrera *et al.*, 2005). (C) Detailed geological setting of the studied area. Black circles indicate collected palynological samples (MATZ samples from the nearby areas of Los Reyes Metzontla and San Luis Atolotitlán localities; MATZ RH samples from the Río Hondo section). The location of previously studied biostratigraphic and geochronologic data are indicated by white circles and a letter: fossil plants (a: locations of Weber, 1997; b: Magallón-Puebla, 1991; c: Valdés-Vergara, 2017; Flores-Barragan, 2018); geochronological isotope dating (d: Atolotitlán tuff, Elías-Herrera *et al.*, 2011; e: Cozahuico Granite, Elías-Herrera *et al.*, 2005; f: Bedoya, 2018). *Lonesomia* bearing strata are indicated by the letter a within a white circle, northeast of San Luis Atolotitlán locality.

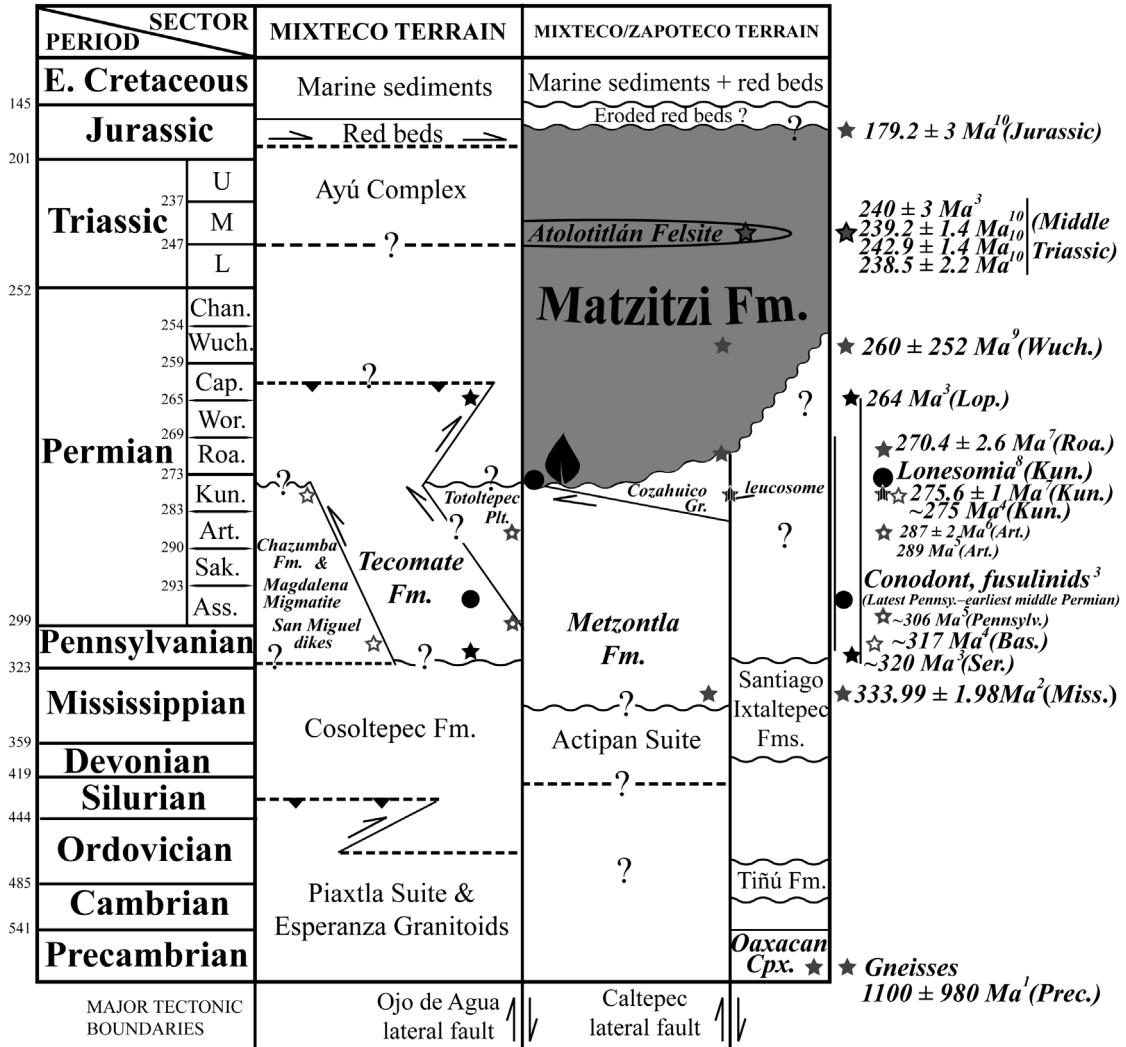


Figure 2. Correlation chart with stratigraphic units present in the studied area and adjacent States. Biostratigraphic and chronostratigraphic data are included. ¹Oaxacan Complex: 1100 ± 980 Ma (Precambrian) [Solari et al., 2003]; ²Metzontla Formation: 333.99 ± 1.98 Ma (Mississippian) [Elías-Herrera et al., 2011]; ³Tecomate Formation: Latest Pennsylvanian–earliest Middle Permian (conodont, fusulinids), ~320–264 Ma [Keppie et al., 2004]; ⁴Chazumba Suite: ~317–275 Ma [Talavera-Mendoza et al., 2005]; ⁵Totoltepec Pluton: ~306–289 Ma [Kirsch et al., 2012]; ⁶Totoltepec Pluton: 287 ± 2 Ma (Artinskian) [Yañez et al., 1991]; ⁷Anatectic leucosome (275.6 ± 1 Ma); Cozahuico Granite: 270.4 ± 2.6 Ma (Roadian); Matzitzí Formation: 240 ± 3 Ma (Atolotitlán Felsite, Middle Triassic) [Elías-Herrera et al., 2007, 2011]; ⁸Matzitzí Formation: Kungurian (Leonardian) on the basis of the presence of the giantopterid *Lonesomia mexicana* [Weber, 1997]; ⁹relative position of the Matzitzí Formation: 260 ± 252 Ma (Wuchiapingian) [Elías-Herrera et al., 2019]; ¹⁰Matzitzí Formation: 238.5 ± 2.2, 239.2 ± 1.4, 242.9 ± 1.4 Ma (Atolotitlán Felsite, Middle Triassic), 179.2 ± 1.98 Ma (Jurassic) [Bedoya et al., 2020]. Cpx.: Complex; Fm.: Formation; Gr.: Granite; Plt.: Pluton; Ass.: Asselian; Sak.: Sakmarian; Art.: Artinskian; Kun.: Kungurian; Roa.: Roadian; Wor.: Wordian; Cap.: Capitanian; Wuch.: Wuchiapingian; Chan.: Changhsingian; L: Lower; M: Middle; U: Upper; E: Early; Prec.: Precambrian; Miss.: Mississippian; Ser.: Serpukhovian; Bas.: Bashkirian; Pennsylv.: Pennsylvanian; Lop.: Lopingian.

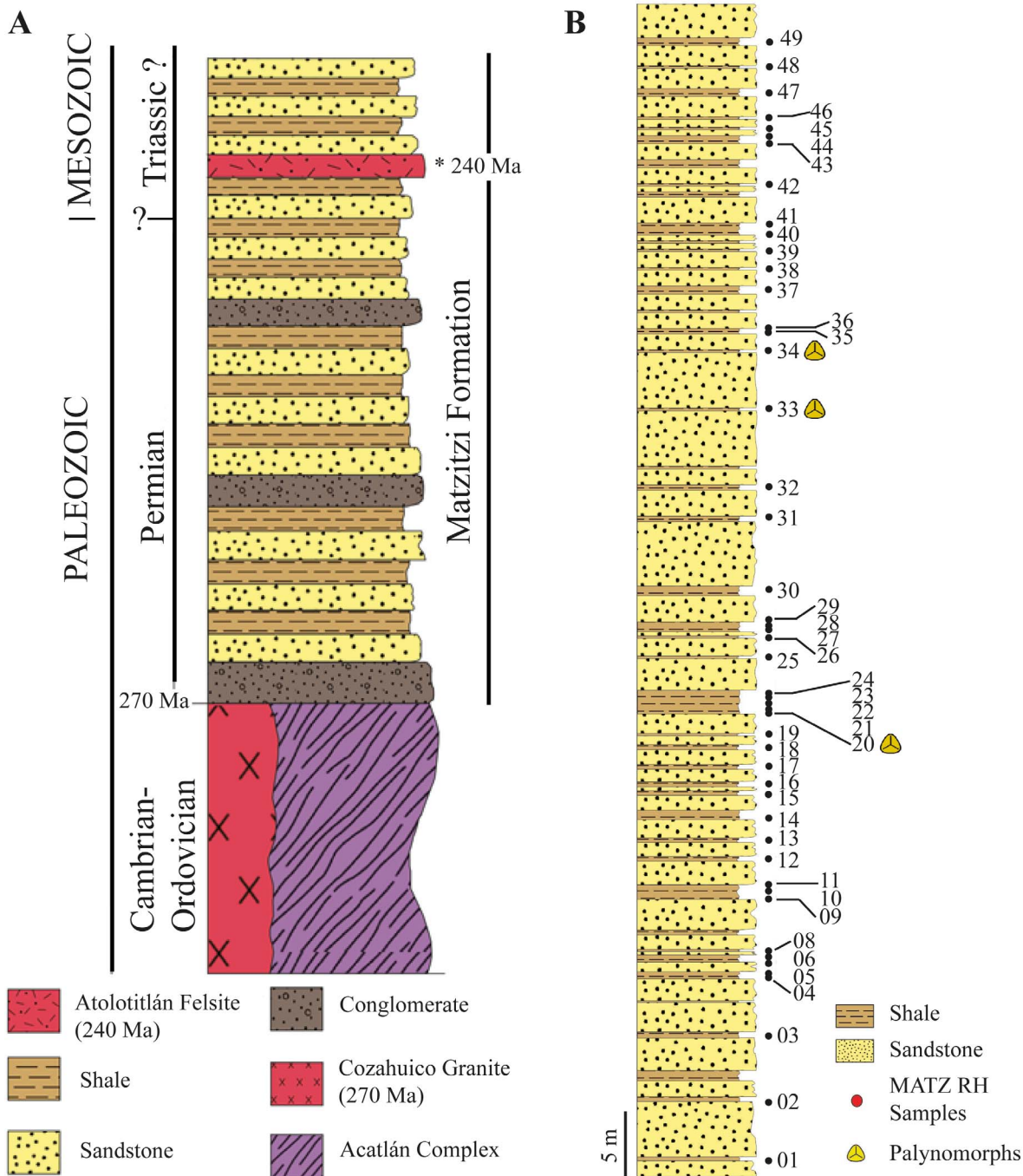


Figure 3. Stratigraphy of the Matzitzi Formation. (A) Synthetic stratigraphic column of the Matzitzi Formation based on Elías-Herrera *et al.* [2005, 2011]. (B) Stratigraphic column for the Río Hondo Section indicating the stratigraphic position of the 49 collected samples.

macroflora is represented by calamitaleans, lepidodendraleans, gigantopterids, ginkgoales, glossopterids and fossil genera including: *Annularia*, *Asolanus*, *Bjuvia*, *Comia*, *Fascipteris*, indeterminate Cycadophyte, *Holcospermum*, *Lesleya*, *Macrotaeniopteris*, *Mexiglossa*, *Neuropteris*, *Pecopteris*, *Plumsteadia*, *Pseudoctenis*, cf. *Psymphyllum*, *Pterophyllum*, *Schizoneura*, *Sphenophyllum*, *Sphenopteris*, *Taeniopteris*, *Trigonocarpus*, and *Velascoa*.

3. Material and methods

For macroflora studies, images taken by a Nikon D5600 camera were later processed with Photoshop CS6. The re-examined holotype (IGM-PB-1027-1059) and two paratypes (IGM-PB-1027-1058, IGM-PB-1027-1060) of *Lonesomia mexicana* deposited in the National Paleontological Collection at the Instituto de Geología of the Universidad Nacional Autónoma de México (UNAM) were re-studied and re-photographed under a fluorescence stereo microscope (Zeiss AX10 Zoom V16) and were analyzed using Zen Pro software. These three specimens belong to the locality 1027 described by Weber [1997] as Escurridero in the Barranca Xoconoxtitla about 0.5 km northeast of San Luis Atolotitlán in the Puebla State (18° 11' 36" N, 97° 24' 46" W).

Ninety-one palynological samples were collected from two main areas: nearby Los Reyes Metzontla and San Luis Atolotitlán localities (42 samples) labelled as MATZ located in the state of Puebla and also from the Río Hondo area located in the Mexican Federal Highway 135D connecting Tehuacán and Oaxaca (49 samples) labelled as MATZ RH (Figures 1, 2). None of the palynological sampling localities corresponds to formerly reported macroflora sites except for the Río Hondo section. We also sampled a *Lonesomia mexicana* holotype-containing a piece of rock but lacking palynomorphs. We used standard palynological methods [Batten, 1999, Erdtman, 1960] for palynomorph extraction, using HCl and HF acid digestions followed by Schulze's solution. For palynomorph concentration, we used a 5-micron nylon mesh. Four slides for each stratigraphic level were prepared using Loctite® 349.

We classified and photographed palynomorphs under light microscopy (Olympus BH2, Axio Imager A2m, and Leica DM 2000 LED-equipped by Nikon

Coolpix 990, AxioCam Icc5 and Leica ICC50 W cameras respectively). The sample and slide numbers are followed by England Finder® coordinates. All figured specimens are housed at the Paleontology Collection of the Estación Regional del Noroeste (ERNO-UX0016 to ERNO-UX0027), Instituto de Geología, UNAM, in Hermosillo, Sonora, Mexico.

4. Results

4.1. Macroflora

The abundant and well-preserved fossil flora from the Matzitz Formation appears as impression and compression forms. These fossils are autochthonous, parautochthonous, and allochthonous in terms of transportation. Most of the previously studied plant-bearing localities correspond to facies associated with floodplain and/or crevasse splay deposits in anastomosing river system [Centeno-García *et al.*, 2009]. Pieces of evidence supporting the autochthonous nature of fossil plants are the in situ *Calamites* trunks near San Luis Atolotitlán municipality [Carrillo and Martínez-Hernández, 1981] and numerous paleosols associated to these fossiliferous strata from San Francisco Xochiltepec locality [Weber, 2007]. Many paleosols from the Matzitz Formation and in situ undetermined stumps (possibly of Filicophyta affinity) are also present [Centeno-García *et al.*, 2009, Weber and Cevallos-Ferriz, 1994]. However, most of the flora assemblages are associated to planar or cross-bedding stratification [Centeno-García *et al.*, 2009] corresponding to parautochthonous material. The well-preserved material, the large leaves in connection with the axis, and their disposition parallel to the stratification are an indication of short transport before burial. Lepidodendraleans and calamitalean in most cases are possibly allochthonous (except for in situ autochthonous specimens), and in few cases parautochthonous, as they appear fragmentary associated to channel deposits.

In the Río Hondo section, the plant-bearing strata are scarce and they also present parautochthonous and allochthonous material. Most of the fossil flora from this section is parautochthonous; however, lepidodendraleans and calamitalean appear fragmentary in most cases associated with channel deposits that possibly are parautochthonous-allochthonous (parautochthonous in the case of *Stigmaria*).

We re-examined the holotype and two paratypes of the fossil plant *Lonesomia mexicana* Weber 1997 to determine its affinity to the gigantopterid group. They are poorly preserved as impressions. It is noteworthy that cuticles are not preserved within the flora remains contained in the Matzitzi Formation. As described by Weber [1997] these specimens are characterized by having: “leaf simple, symmetrical, sessile or with very short petiole, blade elliptic to lanceolate, lamina leathery, arched between midrib and margin, base rounded, tip rounded or retuse, margin entire, lamina reaching about 5 cm in width and over 20 cm in length (length/width ratio about 5). Petiole to 5 mm in width. Midrib straight, to 3 mm wide at lamina base, narrowing to the tip. Venation of at least three orders, secondaries intersected at the midrib at 75°–80°, tertiaries intersected on these at about 45°”.

Only the primary and secondary veins are distinguished in the paratypes (IGM-PB-1027-1058 and IGM-PB-1027-1060) (Figure 4). The tertiary veins only can be observed in the holotype (IGM-PB-1027-1059), and they are not clearly defined (Figure 5A–C). Zen Pro software was used to determine the intersection angles between venation orders in the holotype (Figure 5C). The measured angles differ slightly with Weber’s description: secondary veins extend from the midrib at an angle of around 62°–65° (Weber reported 75°–80°) and an angle of 29°–34° at the intersection of the secondaries at the midrib and tertiaries (Weber reported around 45°). The use of a fluorescence stereo zoom microscope (Zeiss Discovery V8) did not help determine third-order or higher venation patterns, which are only visible in a small area of the holotype leaf (Figure 5D). For this reason, until more specimens are found, it will be risky to classify *Lonesomia mexicana* as a gigantopterid.

4.2. Microflora

From 91 collected palynological samples of the Matzitzi Formation, only five samples produced scarce and poorly preserved palynomorphs with a total of 18 fossil taxa identified (Figures 6, 7, Tables 1 and 2). Three samples (MATZ 27, MATZ RH 33, and MATZ RH 34) produced less than 10 palynomorphs per stratigraphic level, and only two (MATZ 1 and MATZ RH 20) have more abundance with less than 50 palynomorphs for each stratigraphic level.

Most of the studied palynomorphs from San Luis Atolotitlán, Los Reyes Metzontla (MATZ), and Río Hondo areas (MATZ RH) have a wide stratigraphic range and almost all identified genera indicate a Late Carboniferous–early Permian age. The palynological assemblages correspond to wetland microflora genera as *Calamospora* (Equisetales including calamitaceans, Sphenophyllales and Noeggerathiales), *Deltoideospora*, *Granulatisporites*, *Lophotriletes*, *Triquitrites* and *Raistrickia* (herbaceous fern spores), *Laevigatosporites* (Sphenophyllales and Marattiales), *Punctatosporites* and *Thymospora* (Marattiales), *Schopfipollenites* (Medullosales) and *Vesicaspora* (Peltaspermales). All of the identified spores are typical of Late Pennsylvanian palynofloras elsewhere, but the presence of *Thymospora thiessenii* and *Latipulvinites kosankii* could restrict the age of MATZ RH 20 stratigraphic level of Río Hondo deposit to the Middle-Late Pennsylvanian [e.g. Peppers, 1964, 1985, Ravn, 1979, 1986]. On the one hand, *Latipulvinites kosankii* Peppers 1964 (Figure 6G) is restricted to the Pennsylvanian of Illinois, Kentucky, Texas, and England [Peppers, 1964, Stone, 1969, Ravn, 1979, Turner, 1991]. On the other hand, *Thymospora thiessenii* (Kosanke) Wilson and Venkatachala, 1963 (Figure 6J) known from the Bolsovian–Westphalian boundary (Westphalian C–D) in Europe and the United States of America to the Stephanian C, that is to say, Middle-Late Pennsylvanian [Clendening, 1972, Hower *et al.*, 1983, Jerzykiewicz, 1987, Kosanke, 1984, Lesnikowska and Willard, 1997, Peppers, 1985, Playford and Dino, 2005, Vozárová, 1998, Waters *et al.*, 2011]. This latter fossil species has also been reported from MATZ 27 stratigraphic level from the San Luis Atolotitlán area.

Even though most of the taxa extend into the early Permian, they are gradually supplanted by Permian forms, such as taeniates, which are completely absent in these assemblages. The lack of Permian pollen and spores does not determine that they were not present during the deposition of the Matzitzi Formation because they may not have been preserved or restricted to other paleoenvironmental conditions. So, we could confidently conclude that the palynological assemblages at the Río Hondo section (MATZ RH 20) and MATZ 27 are likely Pennsylvanian, possibly earliest Permian.

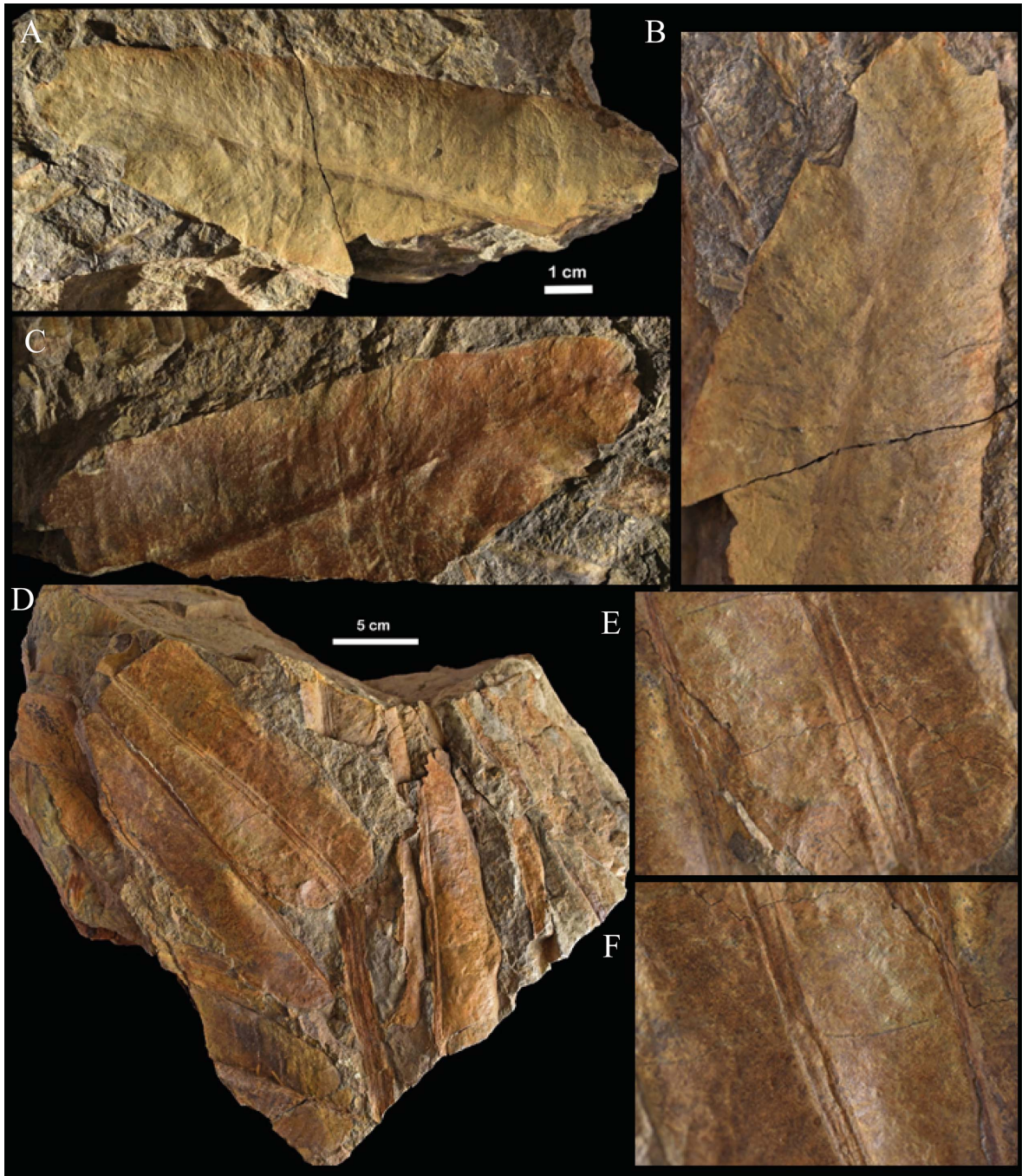


Figure 4. *Lonesomia mexicana* paratypes IGM-PB-1027-1058 and IGM-PB-1027-1060 (A–C). (A) Part and counterpart of the paratype IGM-PB-1027-1060. (B) Detail of the paratype IGM-PB-1027-1060 lacking preserved venation above the second order. (D) Paratype IGM-PB-1027-1058. (E,F) A detail of the leaf belonging to the paratype IGM-PB-1027-1058 which lacks venation above the second order.

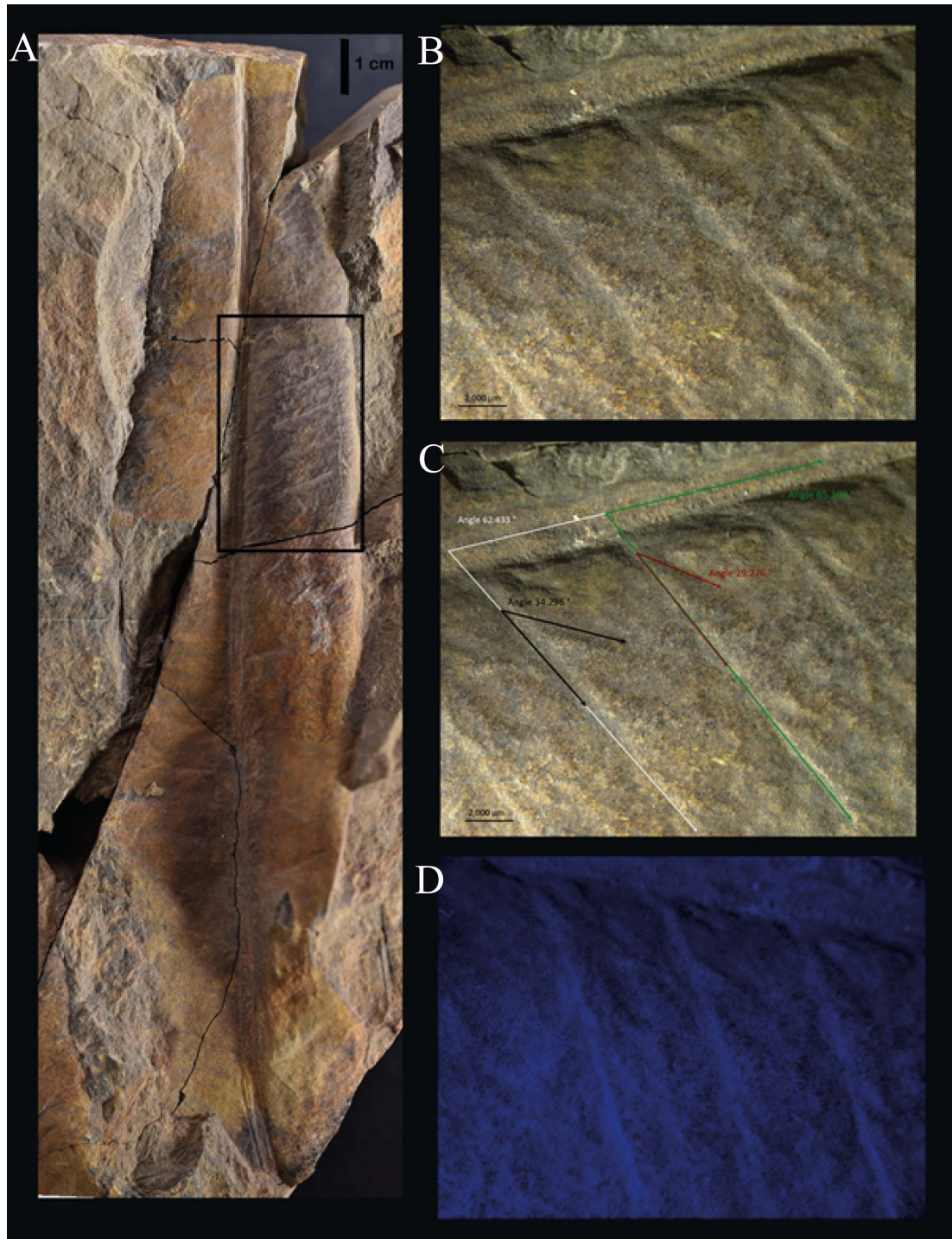


Figure 5. (A) *Lonesomia mexicana* IGM-PB-1027-1059 holotype. (B) Detail of an area of the leaf (indicated by a black square) used for the character description under white light. (C) Image taken using the Zen Pro programme indicating the second and third order venation angles. (D) Image under ultraviolet light that demonstrates the difficulty for determining third order venation pattern.

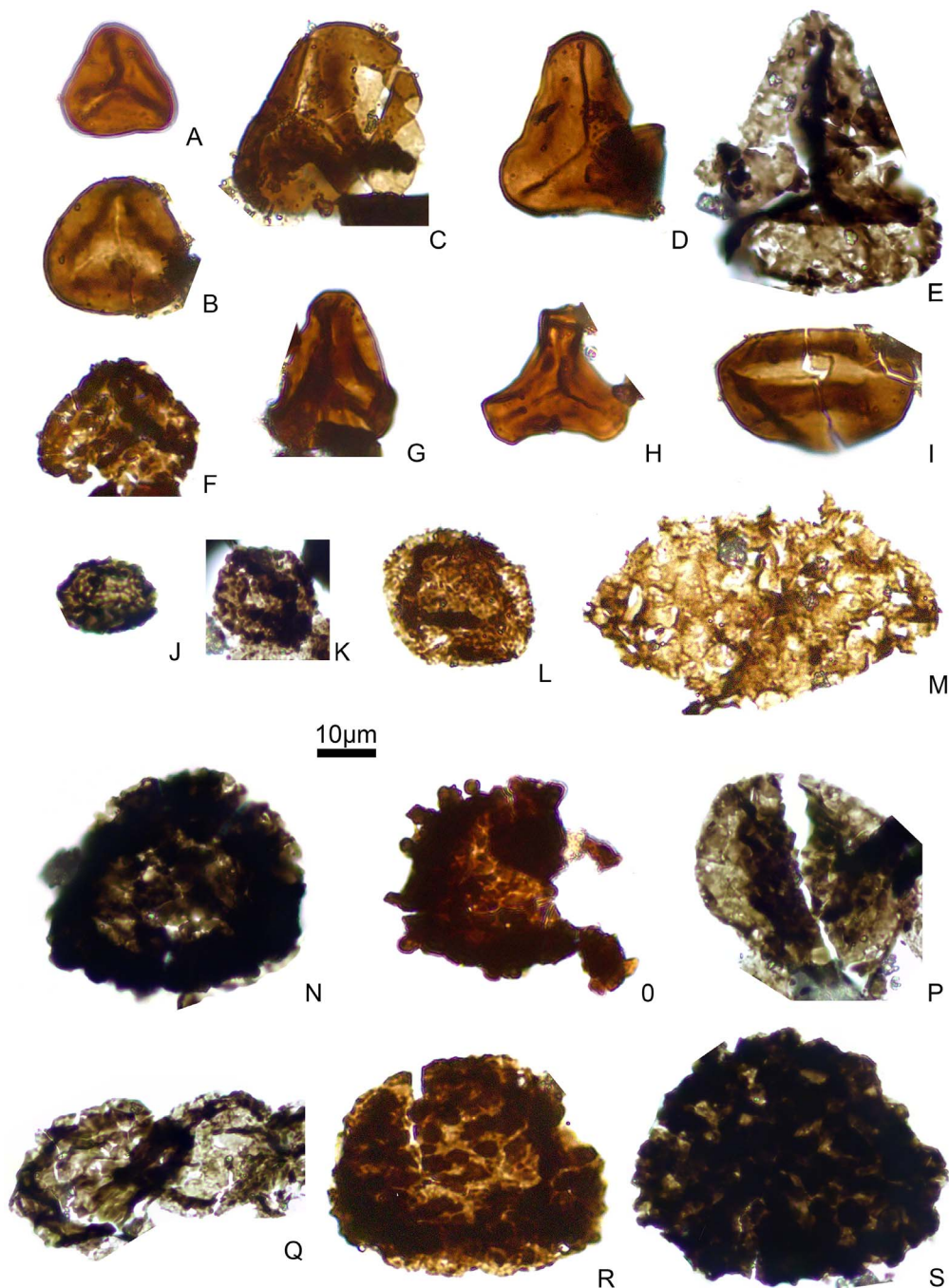


Figure 6. Palynomorphs from the Matzitzi Formation from San Francisco Xochiltepec, Santiago Coatepec, San Luis Atolotitlán, Los Reyes Metzontla and Río Hondo areas, Mexico. (A) *Deltoidospora gracilis* (Imgrund) Ravn, 1986, EF: MATZ 1_4_4_U322. (B) *Deltoidospora levis* (Kosanke) Ravn, 1986 EF: MATZ 1_2_4_S520. (C) *Deltoidospora priddyi* (Berry) McGregor, 1973, EF: MATZ 1_3_4 D464. (D) *Deltoidospora adnata* (Kosanke) McLean, 1993, EF: MATZ 1_3_4 U301. (E) *Deltoidospora sphaerotriangula* (Loose) Ravn, 1986, EF: MATZ RH 20_2_4_T431. (F) *Granulatisporites* sp., EF: MATZ RH 34_3_4_V321.

Figure 6 (cont.). (G) *Latipulvinites kosankii* Peppers, 1964, EF: MATZ 1_4_4_C432. (H) *Triquitrites* sp., EF: MATZ 1_4_4_S310. (I) *Laevigatosporites medius* Kosanke, 1950, EF: MATZ 1_2_4_X681. (J) *Thymospora thiesseii* (Kosanke) Wilson and Venkatachala, 1963, EF: MATZ RH 20_2_4_S384. (K) *Punctatosporites minutus* (Ibrahim) Alpern and Doubinger, 1973, EF: MATZ RH 20_2_4_X430. (L) *Punctatosporites punctatus* Ibrahim, 1933, EF: MATZ RH 34_2_4_Q474. (M) *Laevigatosporites minor* Loose, 1934, EF: MATZ RH 20_2_4_P551. (N) *Densosporites* sp., EF: MATZ RH 20_4_4_R324 (O) *Raistrickia saetosa* (Loose) Schopf *et al.*, 1944, EF: MATZ RH 34_4_4_O574. (P) *Vesicaspora cf. wilsonii* (Schemel) Wilson and Venkatachala, 1963, EF: MATZ RH 20_4_4_M394. (Q) *Platysaccus* sp., EF: MATZ RH 20_2_4_P352. (R) *Verrucosisporites* sp. Type 1, EF: MATZ RH 20_3_4_C490. (S) *Verrucosisporites* sp. Type 2, EF: MATZ RH 20_1_4_Q290. EF: England Finder[®] coordinates. Scale bar: 10 μ m.

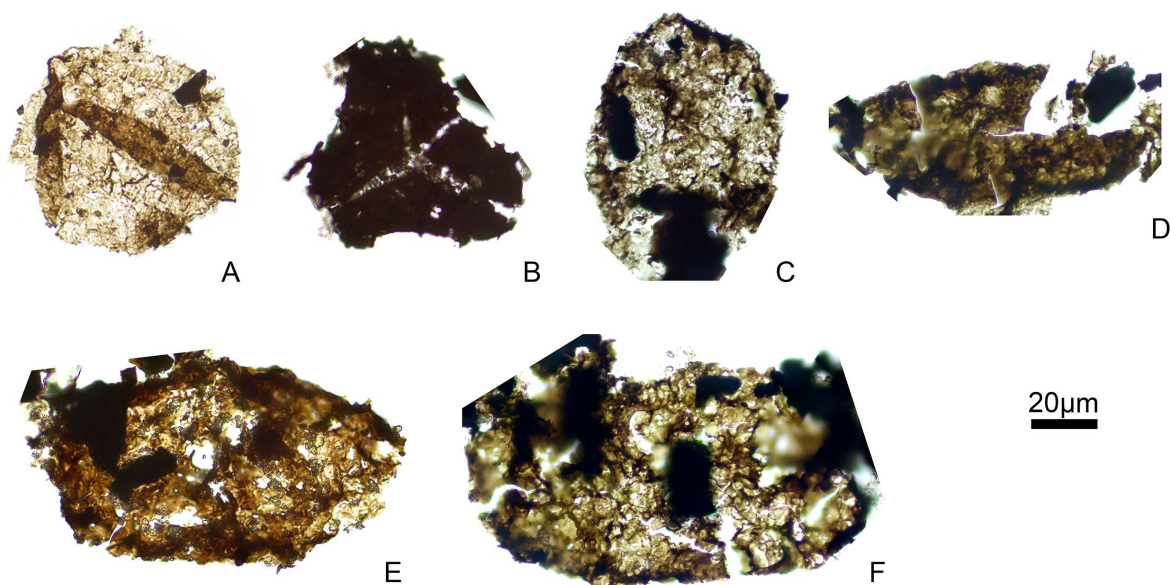


Figure 7. Palynomorphs from the Matzitzi Formation from San Francisco Xochiltepec, Santiago Coatepec, San Luis Atlotitlán, Los Reyes Metzontla, and Río Hondo areas, Mexico. (A) *Calamospora* sp., EF: MATZ RH 20_1_4_N353. (B) *Lophotriletes* sp., EF: MATZ 27_1_4_Y560. (C) *Schopfipollenites ellipsoides* (Ibrahim) Potonié and Kremp, 1954, EF: MATZ RH 20_2_4_Y380. (D) *Laevigatosporites vulgaris* (Ibrahim) Ibrahim, 1933, EF: MATZ RH 20_4_4_O340. (E) *Laevigatosporites maximus* (Loose) Potonié and Kremp, 1956, EF: MATZ RH 33_2_4_S522. (F) *Laevigatosporites maximus* (Loose) Potonié and Kremp, 1956, EF: MATZ RH 20_2_4_W312. EF: England Finder[®] coordinates. Scale bar: 20 μ m.

5. Discussion

The palynomorphs seem to be reworked, especially given the poor condition of the preservation and the very low amount of grains, contrary to the parautochthonous fossil plants. Hence, it is impossible to correlate micro and macroflora. As stated by Silva-Pineda [1970] and Weber [1997] it seems that the Matzitzi Formation contains typical Late Pennsylvanian and early Permian macroflora.

In Euramerican areas, based on macroflora and palynological studies, it has been observed that the initial flora adapted to humid conditions in the tropics during the Late Mississippian (Namurian) was replaced by the Pennsylvanian wetland flora dominated by lycopsids, ferns, and primitive seed plants [DiMichele *et al.*, 2006, Pfefferkorn *et al.*, 2000]. During the Late Pennsylvanian, when aridity increased but alternated with wetter periods, floras rich in conifers, peltasperms, and other seed plants began

Table 1. Observed pollen and spores from studied palynomorph-containing samples

Genera/Levels	MATZ 1	MATZ 27	MATZ RH 20	MATZ RH 33	MATZ RH 34
<i>Calamospora</i> sp.			1		
<i>Deltoidospora gracilis</i>	1				
<i>Deltoidospora levis</i>	3				
<i>Deltoidospora priddyi</i>	7				
<i>Deltoidospora adnata</i>	16	1			
<i>Deltoidospora sphaerotriangula</i>			2		
<i>Deltoidospora</i> sp.		2	2		
<i>Densosporites</i> sp.			1		
<i>Granulatisporites</i> sp.			1		1
<i>Laevigatosporites medius</i>	7	1	1		3
<i>Laevigatosporites minor</i>			2		
<i>Laevigatosporites maximus</i>			1	1	
<i>Laevigatosporites vulgaris</i>			1		
<i>Latipulvinites kosankii</i>			2		1
<i>Lophotriletes</i> sp.		1		1	
<i>Platysaccus</i> sp.			1		
<i>Punctatosporites minutus</i>		4	2		
<i>Punctatosporites punctatus</i>					4
<i>Raistrickia saetosa</i>					1
<i>Schopfipollenites ellipsoides</i>			1		
<i>Thymospora thiessenii</i>		1	1		
<i>Triquitrites</i> sp.	3				
<i>Verrucosisporites</i> sp. Type 1			2		1
<i>Verrucosisporites</i> sp. Type 2			1		1
<i>Vesicaspora</i> cf. <i>wilsonii</i>			1		
Total	37	10	23	2	12

to appear while the species that dominated the Pennsylvanian wetlands declined [DiMichele *et al.*, 2004b]. In the Euramerican Province, the transition from the Pennsylvanian to the Permian encompassed a gradual global environmental change from ever-wet during the Pennsylvanian to a drier Permian [e.g. DiMichele *et al.*, 2004a, 2008, Michel *et al.*, 2015, Tabor and Poulsen, 2008]. During this change, considerable tectonic activity in the tropics is recorded. These phenomena, may have combined to affect both local and regional microclimates and depositional environments [DiMichele *et al.*, 2004a]. A replacement of hygrophytic by mesophytic and mesoxerophytic flora that tolerate seasonally dry climate is observed. Also, xeric floras can be found intercalated with vegetation typical of very wet conditions, even at the scale of individual outcrops [Broutin *et al.*, 1990, DiMichele and Aronson, 1992, DiMichele

et al., 2004b, 2019, Kerp and Fichter, 1985]. It seems that climatic conditions maintained along wetland corridors since Middle Pennsylvanian to Artinskian, possibly fringing the channels surrounded by plants adapted to a drier condition under a seasonal climate as reported for the Appalachians, New Mexico, Texas and Utah [DiMichele *et al.*, 2011a]. It is also significant that the transition from wetter-to-drier climates during Pennsylvanian–Cisuralian range is different depending on the paleogeographic location; being earlier in New Mexico (Middle Pennsylvanian), and later in Texas–Appalachians (Late Pennsylvanian) and Utah (Permian) [DiMichele *et al.*, 2011a] so it is worth expecting a diachronic disappearance of typically Carboniferous flora adapted to wetlands in drier conditions in Euramerica.

In the Euramerican Province (including Mexico and the U.S.A.), the more common small spores

Table 2. Collected samples and their coordinates. Outlined in grey colour indicate palynomorph-containing stratigraphic levels

Samples	Coordinates	Samples	Coordinates
	MATZ		MATZ RH
MATZ 1	18° 15' 11.8" N, 97° 29' 42.6" W	MATZ RH 1	18° 09' 09.3" N, 97° 18' 2.8" W
MATZ 2	18° 15' 11.6" N, 97° 29' 42.7" W	MATZ RH 2	18° 09' 09.4" N, 97° 18' 3.0" W
MATZ 3	18° 15' 11.3" N, 97° 29' 42.5" W	MATZ RH 3	18° 09' 09.5" N, 97° 18' 3.2" W
MATZ 4	18° 15' 11.3" N, 97° 29' 42.5" W	MATZ RH 4	18° 09' 09.7" N, 97° 18' 4.0" W
MATZ 5	18° 15' 11.3" N, 97° 29' 42.5" W	MATZ RH 5	18° 09' 09.7" N, 97° 18' 4.0" W
MATZ 6	18° 15' 11.3" N, 97° 29' 42.6" W	MATZ RH 6	18° 09' 09.8" N, 97° 18' 4.3" W
MATZ 7	18° 15' 11.3" N, 97° 29' 42.6" W	MATZ RH 7	18° 09' 09.8" N, 97° 18' 4.3" W
MATZ 8	18° 13' 20.4" N, 97° 28' 22.5" W	MATZ RH 8	18° 09' 09.8" N, 97° 18' 4.3" W
MATZ 9	18° 13' 21.0" N, 97° 28' 22.3" W	MATZ RH 9	18° 09' 10.1" N, 97° 18' 4.9" W
MATZ 10	18° 13' 21.0" N, 97° 28' 22.3" W	MATZ RH 10	18° 09' 10.1" N, 97° 18' 4.9" W
MATZ 11	18° 13' 21.0" N, 97° 28' 22.3" W	MATZ RH 11	18° 09' 10.4" N, 97° 18' 5.2" W
MATZ 12	18° 15' 11.3" N, 97° 29' 42.6" W	MATZ RH 12	18° 09' 10.9" N, 97° 18' 5.8" W
MATZ 13	18° 13' 16.1" N, 97° 28' 13.1" W	MATZ RH 13	18° 09' 11.0" N, 97° 18' 6.1" W
MATZ 14	18° 13' 16.1" N, 97° 28' 13.1" W	MATZ RH 14	18° 09' 11.2" N, 97° 18' 6.3" W
MATZ 15	18° 13' 16.1" N, 97° 28' 13.1" W	MATZ RH 15	18° 09' 11.5" N, 97° 18' 6.8" W
MATZ 16	18° 13' 16.1" N, 97° 28' 13.1" W	MATZ RH 16	18° 09' 11.5" N, 97° 18' 6.8" W
MATZ 17	18° 13' 16.0" N, 97° 28' 12.6" W	MATZ RH 17	18° 09' 11.7" N, 97° 18' 7.3" W
MATZ 18	18° 13' 16.0" N, 97° 28' 12.6" W	MATZ RH 18	18° 09' 12.1" N, 97° 18' 8.2" W
MATZ 19	18° 13' 24.1" N, 97° 28' 09.4" W	MATZ RH 19	18° 09' 12.4" N, 97° 18' 8.8" W
MATZ 20	18° 13' 24.1" N, 97° 28' 09.4" W	MATZ RH 20	18° 09' 12.6" N, 97° 18' 9.2" W
MATZ 21	18° 13' 24.1" N, 97° 28' 09.4" W	MATZ RH 21	18° 09' 12.6" N, 97° 18' 9.2" W
MATZ 22	18° 13' 04.3" N, 97° 24' 53.4" W	MATZ RH 22	18° 09' 12.6" N, 97° 18' 9.2" W
MATZ 23	18° 13' 04.3" N, 97° 24' 53.4" W	MATZ RH 23	18° 09' 12.6" N, 97° 18' 9.2" W
MATZ 24	18° 11' 39.0" N, 97° 25' 00.2" W	MATZ RH 24	18° 09' 12.6" N, 97° 18' 9.2" W
MATZ 25	18° 11' 39.0" N, 97° 25' 00.2" W	MATZ RH 25	18° 09' 12.8" N, 97° 18' 9.6" W
MATZ 26	18° 11' 07.8" N, 97° 24' 38.9" W	MATZ RH 26	18° 09' 12.9" N, 97° 18' 9.9" W
MATZ 27	18° 11' 07.8" N, 97° 24' 38.9" W	MATZ RH 27	18° 09' 13.1" N, 97° 18' 10.1" W
MATZ 28	18° 11' 07.8" N, 97° 24' 38.9" W	MATZ RH 28	18° 09' 13.1" N, 97° 18' 10.1" W
MATZ 29	18° 09' 59.5" N, 97° 23' 53.6" W	MATZ RH 29	18° 09' 13.1" N, 97° 18' 10.1" W
MATZ 30	18° 09' 59.5" N, 97° 23' 53.6" W	MATZ RH 30	18° 09' 13.4" N, 97° 18' 10.7" W
MATZ 31	18° 09' 59.5" N, 97° 23' 53.6" W	MATZ RH 31	18° 09' 13.8" N, 97° 18' 11.9" W
MATZ 32	18° 09' 59.5" N, 97° 23' 53.6" W	MATZ RH 32	18° 09' 14.0" N, 97° 18' 12.3" W
MATZ 33	18° 09' 59.5" N, 97° 23' 53.6" W	MATZ RH 33	18° 09' 14.3" N, 97° 18' 13.6" W
MATZ 34	18° 11' 41.7" N, 97° 24' 59.2" W	MATZ RH 34	18° 09' 14.3" N, 97° 18' 14.3" W
MATZ 35	18° 11' 41.7" N, 97° 24' 59.2" W	MATZ RH 35	18° 09' 14.0" N, 97° 18' 14.6" W
MATZ 36	18° 11' 36.2" N, 97° 25' 03.1" W	MATZ RH 36	18° 09' 14.0" N, 97° 18' 14.6" W
MATZ 37	18° 11' 36.2" N, 97° 25' 03.1" W	MATZ RH 37	18° 09' 13.6" N, 97° 18' 15.0" W
MATZ 38	18° 11' 33.1" N, 97° 25' 08.6" W	MATZ RH 38	18° 09' 13.7" N, 97° 18' 15.4" W
MATZ 39	18° 11' 33.1" N, 97° 25' 08.6" W	MATZ RH 39	18° 09' 13.4" N, 97° 18' 16.1" W
MATZ 40	18° 11' 14.5" N, 97° 25' 18.2" W	MATZ RH 40	18° 09' 13.4" N, 97° 18' 16.3" W
MATZ 41	18° 11' 14.5" N, 97° 25' 18.2" W	MATZ RH 41	18° 09' 13.2" N, 97° 18' 16.5" W
MATZ 42	18° 11' 14.5" N, 97° 25' 18.2" W	MATZ RH 42	18° 09' 12.7" N, 97° 18' 17.5" W

(continued on next page)

Table 2. (continued)

Samples	Coordinates
MATZ RH	
MATZ RH 43	18° 09' 11.9" N, 97° 18' 18.6" W
MATZ RH 44	18° 09' 11.9" N, 97° 18' 18.6" W
MATZ RH 45	18° 09' 11.7" N, 97° 18' 18.8" W
MATZ RH 46	18° 09' 11.5" N, 97° 18' 18.9" W
MATZ RH 47	18° 09' 10.6" N, 97° 18' 19.4" W
MATZ RH 48	18° 09' 09.9" N, 97° 18' 19.8" W
MATZ RH 49	18° 09' 09.3" N, 97° 18' 20.0" W

found in Late Pennsylvanian coals include Marattialean spores (*Thymospora* spp., *Punctatisporites minutus*, *Punctatosporites* spp., *Cyclogranisporites* spp., *Laevigatosporites minimus*, *Laevigatosporites medius*, *Laevigatosporites ovatus*), as well as such herbaceous fern taxa as *Lophotriletes*, *Raistrickia*, *Triquitrites* and *Deltoidospora* [DiMichele *et al.*, 2018, Eble *et al.*, 2013]. *Verrucosiporites* also occur, but much less frequently [Eble *et al.*, 2013]. These taxa are typical of the uppermost Pennsylvanian coal from the Bursum Formation, New Mexico, including significant amounts of *Vesicaspora* [DiMichele *et al.*, 2016] and coal of similar age described from north-central Texas [Looy and Hotton, 2014].

There is also evidence of calamitaleans, reported from macrofossil remains [DiMichele *et al.*, 2016] in the Bursum Formation (Carrizo Arroyo, New Mexico, U.S.A.). Therefore, Marattialeans and calamitaleans were the most important wetland plant groups throughout western Pangea during the Late Pennsylvanian and well into the early Permian, reflecting their tolerance of soil moisture fluctuation and also their dispersal capacities [DiMichele *et al.*, 2016].

In the eastern part of Euramerican Province (Western Europe), palynological assemblages display a broadly similar pattern [e.g. Clayton *et al.*, 1977, Juncal *et al.*, 2019]. The wetland microflora (marattialean spores and herbaceous fern taxa) and pollen of *Calamites* and *Cordaites* are dominant.

The only two studies [Rincón-Pérez, 2010, Valdés-Vergara, 2017] based on macrofloral content from the Río Hondo section, representing the most complete and continuous stratigraphic section for the Matzitzi Formation, show different abundance data due to methodological procedure: the first author

without considering their stratigraphic level and the second author indicating it. The main flora representatives in this locality seem to be Filicophyta, Lycophyta and Spermatophyta and less abundant is Equisetophyta (calamitalean). The macroflora composition changes depending on its stratigraphic range [Valdés-Vergara, 2017] due to differences in the depositional environment. Both studies agree that Marattiales (*Pecopteris* spp.) and lepidodendrales (*Sigillaria*) are well-represented in the macroflora assemblage. Based on macroflora remains from the Río Hondo section [Rincón-Pérez, 2010, Valdés-Vergara, 2017] an early Permian age is suggested for the Matzitzi Formation. Four key taxa ranging from late Carboniferous to early Permian age have been described. *Sigillaria brardii-ichthyolepis* group is present in the Río Hondo section [Valdés-Vergara, 2017, Weber, 1997], which is also common in the Matzitzi Formation [Weber, 1997], and it ranges from the Late Pennsylvanian [Remy and Remy, 1977] to early Permian in USA [Blake and Gillespie, 2011]. *Taeniopteris multinervis* is known from the Late Pennsylvanian-early Permian in the USA [Remy and Remy, 1975] and medullosalean seed *Trigonocarpus* extend from Late Mississippian to early Permian [Cleal and Thomas, 2019]. *Holcospermum* is a common element from the Carboniferous but some reports have described it from the early Permian in Germany [Barthel, 2016] and Kansas [McKinley, 1966]. Moreover, the fossil genus *Comia* is known since the Permian [Mamay *et al.*, 2009, Weber, 1997] and it occurs in North America (Texas and Oklahoma) in the early Permian (Artinskian, Cisuralian) [Mamay *et al.*, 2009], restricting the age of the Matzitzi Formation in this locality to a probable age not older than the Artinskian. In consequence,

the macroflora from the Río Hondo section would likely correspond to the Artinskian–Kungurian. This would support the idea of reworked palynomorphs. Reports of *Pseudoctenis* from the Matzitzi Formation at Río Hondo and Camino sites [Valdés-Vergara, 2017] remain inconclusive due to the poor preservation of described specimens and lack of cuticle information. *Pseudoctenis* is known since the late Permian [Blomenkemper *et al.*, 2018, Schweitzer, 1986] and it is an important component during the Mesozoic, especially in the uppermost Triassic and Jurassic [Taylor *et al.*, 2009]. This fossil genus has been described from early and middle Permian deposits in India [Maheshwari and Bajpai, 2001], however, it has not been figured. If confirmed the occurrence of *Pseudoctenis* in the Matzitzi Formation, this fossil genus would extend its stratigraphic range up to the lower Permian.

Other fossil flora genera from the Matzitzi Formation known since the early Permian from other localities are *Fascipteris* [Magallón-Puebla, 1991] and *Bjuvia* [Velasco-de León *et al.*, 2015]. Magallón-Puebla [1991], also noted that although a new species of *Pecopteris* might be present in this formation, it should have more Permian than Carboniferous affinities. Likewise, using the macroflora, a Permian age seems more likely for the Matzitzi Formation.

The fossil plants exhibit fragmentary preservation, breakup during collection, and obscured plant characters, that make much of the material unidentifiable. This is the case of *Lonesomia mexicana* that does not allow the identification of the venation pattern above the second order. In the long run, the identification of plant fossils of the Matzitzi Formation is greatly reduced due to the poor preservation of key diagnostic characters, their fragmented nature, and in some cases their very low abundance in the fossil record. This is especially problematic for specimens with glossopterid affinity. For example, a specimen initially described as *Glossopteris* was finally identified as *Sphenophyllum* *ex gr. thonii* [Weber, 1997]. There are also examples of misidentified specimens such as *Fascipteris* *sp. cf. F. hallei* [Magallón-Puebla, 1991] which was initially described as *Neuropteris jugosa* by Silva-Pineda [1970] and *Schizoneura gondwanensis* [Flores-Barragan, 2018] that was initially described as *Annularia* *sp.* by Velasco-de León *et al.* [2015]. These complications indicate that more studies are

required for a comprehensive determination of the macroflora remains from the Matzitzi Formation, including consideration of their stratigraphic level and locality.

The available geochronological data for the Matzitzi Formation differs from our results (Figure 2). On the one hand, the Oaxacan Complex exposed southeast of San Luis Atolotitlán consists of quartzfeldspathic and garnet gneisses in granulite facies that are Grenvillian in age (1.1–0.98 Ga) [Keppie and Ortega-Gutiérrez, 1999, Solari *et al.*, 2003]. On the other hand, the Acatlán Complex appears as highly deformed and metamorphosed green schists to the west of Los Reyes Metzontla and southeast of La Compañía (Puebla) whose age is poorly understood [Keppie *et al.*, 2004]. The youngest units belonging to the Acatlán Complex (in chronological order: Tecamate Formation, Totoltepec stock, and San Miguel intrusions) are less deformed and metamorphosed compared to the oldest units of this complex [Yañez *et al.*, 1991]. The Tecamate Formation has been considered the Latest Pennsylvanian–earliest middle Permian in age based on U–Pb SHRIMP dating (~320–264 Ma) and conodont and fusulinid content [Keppie *et al.*, 2004]. One of the youngest units of the Acatlán Complex is the Chazumba Suite: the maximum depositional age of the Magdalena Formation is ~317 Ma, and the maximum depositional age of the overlying Chazumba Formation is ~275 Ma [Talavera-Mendoza *et al.*, 2005]. The youngest unit of the Acatlán Complex, the San Miguel intrusive has interpreted with two distinct emplacement ages based on Rb–Sb dating indicating two thermal events in the Late Triassic–Early Jurassic (Rhaetian–Hettangian; 207 ± 9 Ma) and Middle Jurassic (Aalenian; 173 ± 0.3 Ma) [Ruiz-Castellanos, 1979]. The Magdalena migmatite also corresponding to one of the youngest units of the Acatlán Complex, is concordant with this Middle Jurassic age (Aalenian–Bajocian; 170 ± 2 Ma) by U–Pb method [Powell *et al.*, 1999]. The amalgamation of the Acatlán and Oaxacan complexes apparently took place in the early Permian represented by the foliated Totoltepec pluton (287 ± 2 Ma; ~306–289 Ma) dated by U–Pb method in zircons [Kirsch *et al.*, 2012, Yañez *et al.*, 1991] and the anatectic leucosome (275.6 ± 1 Ma) and the syntectonic milonitized intrusive Cozahuico Granite (Kungurian–Roadian, 270.4 ± 2.6 Ma) dated by SHRIMP method [Elías-Herrera *et al.*, 2007]. The

Cozahuico Granite has been interpreted as one of the oldest and deepest tectono-magmatic-metamorphic activity in the fault zone related to the oblique collision between Oaxacan and Acatlán complexes [Elías-Herrera and Ortega-Gutiérrez, 2002, Elías-Herrera *et al.*, 2007]. In an abstract, Elías-Herrera *et al.* [2019] indicates an age not older than the Lopingian (260–252 Ma) for the Matzitzi Formation based on its relative stratigraphic position over deposits affected by the Caltepeense Orogeny. However, it is unclear whether deposition of the Matzitzi Formation and this latter orogeny is contemporaneous or post-depositional. The Atolotitlán Tuff corresponding to this formation is reported as Middle Triassic (240 ± 3 Ma: Elías-Herrera *et al.*, 2011; $239.2 \pm 1.4/242.9 \pm 1.4/238.5 \pm 2.2$ Ma: Bedoya, 2018). However, the geochronology of the Caltepeense Orogeny and the Atolotitlán Tuff awaits formal publication. Moreover, the age of the Matzitzi Formation is a vexing matter by the Middle Jurassic maximum depositional age (177 Ma) for a sampled sandstone [Bedoya, 2018].

In summary, based on its relative stratigraphic position, the non-metamorphosed Matzitzi Formation has been placed overlying the metamorphosed units such as the Cozahuico Granite and the Acatlán Complex. Geochronological data indicate that the depositional age of the Matzitzi Formation should be not older than 270 Ma (earliest Roadian, middle Permian) corresponding to the underlying Cozahuico Granite and not older than Latest Pennsylvanian–earliest middle Permian (Tecomate Formation, Acatlán Complex), leading some geologists to think that the Matzitzi Formation is younger than the Roadian. Nevertheless, the Tecomate Formation has not been reported in direct contact with the Matzitzi Formation. Moreover, the macroflora remains indicate an Artinskian–Kungurian maximum age (e.g. Río Hondo section), so the deposition of the Matzitzi Formation was possibly contemporaneous, at least in part, to the Caltepeense Orogeny and the emplacement of the Cozahuico Granite. The Atolotitlán Tuff corresponding to the Matzitzi Formation has been reported as Middle Triassic, and this formation also contains Jurassic deposits. Besides, the depositional setting and controls of deposition of the Matzitzi Formation and its geologic contacts with other metamorphosed rocks are still poorly understood. There is a great need for work to do to understand the geological

contact between different geological units and also to disentangle the geological setting and evolution of the area.

Three important aspects should be clarified. First, the possibility that the Matzitzi Formation may include different chronostratigraphic units from the early Permian (or from the early middle Permian in the case of palynomorph reworking) to at least Middle Triassic or even younger (Jurassic) that may all record the same sedimentary environment must be considered. Also, a more comprehensive stratigraphic and sedimentologic work should be done. To achieve it, a re-examination of the already studied fossil flora controlling its stratigraphic level and geographical location is required. Besides, it is important to understand the evolution from Late Carboniferous wet conditions to drier conditions during the early Permian in Mexico. It has been proved a diachronous climatic change in the USA depending the locality so it is not worth expecting a diachronous appearance of certain macroflora and microflora key taxa. Second, it is important to control the correlation of the strata of the Matzitzi Formation, and third, a more comprehensive study of the geologic contact with underlying metamorphosed rocks is needed.

6. Conclusion

A more comprehensive study of the Matzitzi Formation is necessary to define its stratotype; not yet formally defined. Also, the biostratigraphic and geochronologic age disparities need to be resolved to improve stratigraphic correlation among disparate outcrops of the Matzitzi Formation. From those outcrops, it seems that the most continuous and complete stratigraphic section of this formation corresponds to the Río Hondo section. The fundamental problem of the Matzitzi Formation is that it may represent more than a single package of rocks with a similar depositional environment. The palynological assemblages presented in this study indicate most likely Late Pennsylvanian in the Río Hondo section. However, palynomorphs were possibly reworked and re-deposited in rock along with the Permian parautochthonous macroflora from this formation. If palynomorphs are reworked, their source would correspond to the erosion of Middle-Upper Pennsylvanian continental deposits. The re-study of

the holotype and paratypes of the gigantopterid fossil plant species *Lonesomia mexicana*, a key specimen for Kungurian age assignment, showed the lack of diagnostic characters to place them within the gigantopterids. Although these fossil plant specimens have a huge lamina, they do not have the reticulate venation that characterizes gigantopterids. The paratypes only showed primary and secondary veins whilst the holotype also presents a tertiary vein in a small area of the lamina due to the poor preservation of these specimens. Macroflora described from the early Permian Matzitzi Formation suggests wetland corridors possibly fringing the channels associated with anastomosing river systems related to a gradual global environmental change from everwet during the Late Pennsylvanian to a drier early Permian. This study suggests that maybe the deposition of the Matzitzi Formation possibly was contemporaneous, at least in part, to the Caltepeense Orogeny and the emplacement of the Cozahuico Granite.

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