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Calpionellid biostratigraphy, U-Pb geochronology and microfacies of the Upper Jurassic-Lower Cretaceous Pimienta Formation (Tamazunchale, San Luis Potosí, central-eastern Mexico)

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Abstract

Detailed sampling of a stratigraphic section corresponding to the La Pimienta Formation in the state of San Luis Potosí allows the determination of the upper Tithonian *Crassicollaria* Zone (Remanei, Brevis and Colomi Subzones). The presence of *Praetintinnopsella andrusovi* Borza and chitinoidellids in the *Crassicollaria* Zone, was interpreted as the result of sedimentary reworking as due to fact that these taxa have not been reported in such a high stratigraphic position. Nonetheless additional work is needed in order to establish a clear relationship. The U-Pb date for a bentonite bed that underlies rocks of the Elliptica Subzone is 139.1 ± 2.6 Ma (late Berriasian-early Valanginian). These new data suggest a different age range for the Elliptica Subzone in Mexico as compared with coeval sections in the Mediterranean Tethys.

Keywords: Calpionellids, microfacies, Upper Jurassic-Lower Cretaceous, central-eastern Mexico.

Resumen

El muestreo detallado de una sección estratigráfica de la Formación Pimienta en el estado de San Luis Potosí permitió el reconocimiento de la Zona de Crassicollaria del Tithoniano superior (Subzonas Remanie, Brevis y Colomi). La presencia de Praetintinnopsella andrusovi Borza y chitinoidélidos en facies pertenecientes a la Zona de Crassicollaria se interpreta como resultado de retrabajo pues el rango estratigráfico de estos taxones no ha sido reportado con anterioridad abarcando estas biozonas. Sin embargo se necesitan trabajos adicionales para esclarecer su verdadera relación. Análisis geocronológicos de U-Pb realizados en una capa de bentonita que subyace a la Subzona Elliptica (Zona Calpionella) indicaron edades de 139.1 ± 2.6 Ma correspondientes al Berriasiano tardío-Valanginiano temprano. Estos nuevos datos sugieren un rango de edad diferente para la Subzona de Elliptica en México comparado con secciones similares en el Este del Tethys.

Palabras clave: Calpionélidos, microfacies, Jurásico Superior-Cretácico Inferior, centro-este de México.

1. Introduction

The study of calpionellids in Mexico and especially late Tithonian calpionellids has been controversial. Locally, Tithonian sediments mainly contain radiolarian and are associated with large amounts of siliciclastics. These special conditions produced some differences with respect to coeval facies further east in Tethys where micritic limestones favor the preservation of abundant calcareous microplankton (calpionellids, dinoflagellates and nannofossils).

Adatte *et al*. (1996) argued that in northern Mexico, markers or species of the *Chitinoidella* and *Crassicollaria* Zones were absent. The authors explained this phenomenon by inferring the isolation of Mexico from the rest of the Tethys and paleoclimatological conditions. Nonetheless, in central Mexico Adatte *et al*. (1996) reported the presence of the genus *Chitinoidella* and *Saccocoma* sp. in the Guapote and Tehepican profiles. These finds at outcrops confirmed the results from oil exploration cores (Lugo, 1975) and demonstrate the presence of Tithonian calpionellids in Mexico.

Adatte *et al*. (1996) concluded that the influence of the Tethys on central-eastern Mexico during the Tithonian was sporadic, with short-lived incursions and no permanent connection.

Different opinions on the topic can be found in the literature (Cantú-Chapa, 1967, 1989; Adatte *et al*., 1992; Stinnesbeck *et al*., 1993; Eguiluz *et al*., 2012; López-Martínez *et al*., 2013). However, the controversy persists and is still far from resolution.

Furthermore, the age of calpionellid biozones in Mexico has not been determined with precision due to the scarcity of ammonites and other biostratigraphical markers in the studied sections. Thus, correlation of calpionellid biozones is still tentative. Main calpionellid bioevents have been recognized in Mexican sections and correlated approximately with coeval sections in the rest of the Tethys. Nonetheless, successions of calpionellids are not strictly identical to those defined in Europe and North Africa. Thus the question of the real span of calpionellid species and their biozones in Mexico is still under debate.

Calpionellid bioevents, U-Pb geochronology and facies in the Tamazunchale section shed new light on calpionellid distribution in central-eastern Mexico. Our results show for the first time the occurrence of *Praetintinnopsella andrusovi* Borza in western Tethys as well as a more complete standard *Crassicollaria* Zone with its subzones. Furthermore, U-Pb dates on bentonites in the Elliptica subzone allow us to present new information on the age of that biozone in western Tethys.

2. Material and methods

2.1 Biostratigraphy

Due to the poor preservation and scarcity of calpionellids in Mexican sections (Cantú-Chapa, 1989; Adatte *et al*., 1994; Eguiluz *et al*., 2012; López-Martínez *et al*., 2013), in this work it was necessary to use a methodology based on detailed sampling and observation of microfacies, so as to improve on previous biostratigraphical results.

Detailed bed -by- bed sampling and a grid observation of at least two thin sections (of different orientation) of beds and interbeds were carried out. Ninety-two samples were collected from thirty-two beds and thin sections were studied under LEICA DM 2500 and Olympus Bx 60 microscopes.

Generally accepted calpionellid zonations proposed from different Tethyan areas have been considered; and the standard calpionellid zones and subzones *sensu* Reháková and Michalík (1997) have been adopted.

2.2. U-Pb geochronology

In order to constrain the succession in an absolute chronostratigraphic framework, zircons separated from one felsic tuff layer were dated by laser ablation inductively-coupled plasma mass spectrometry (LA-ICPMS) at the Isotopic Studies Laboratory of the Centro de Geociencias, UNAM. Mineral separation was carried out using the standard methodology (Morton, 1985) at the mineral separation facility of the Instituto de Geología, UNAM. Zircons were observed and imaged under cathodoluminescence (CL) using an ELM3R luminoscope connected to a digital camera. Individual zircon ages were obtained with a Thermo Neptune Plus Multi Collector-ICPMS coupled to a Resonetics Resolution M050 excimer laser workstation. Details of the analytic methodology can be found in Solari *et al*. (2010). Tera-Wasserburg (1972) concordia and weighted mean diagrams were obtained using Isoplot v. 3.06 (Ludwig, 2004). Plots were constructed using the $^{206}Pb/^{238}U$ age for zircons younger than 1.0 Ga, whereas $^{207}Pb/^{206}Pb$ ages were preferred for grains older than 1 Ga. As a statistical rejection criterion, 30 % normal and 5 % reverse discordancy was chosen (Harris *et al*., 2004; Gehrels, 2011), and none of these zircons are included in the plots or discussion below. Details on the analytical results of the analyzed samples are given in Table 1.

3. Geological setting

The section studied is located in central-eastern Mexico at the border between the states of Hidalgo and San Luis Potosí near the towns of Chapulhuacán and Tamazunchale. The section is located at 21°10'3.11"N and 98°54'49.99"W and consists of 50 m of thin limestone-bentonite intercalations (Figure 1). Geologically it forms part of the Mexican Fold-Thrust Belt (Eguiluz *et al*., 2000) and is next to the western part of the Tampico-Misantla Basin.

The geological units of the aforementioned belt start with continental facies related to the opening of the Gulf

Table 1. U-Pb geochronological results for the dated tuff sample.

FELSIC TUFF: TMZ 19

				CORRECTED RATIOS							CORRECTED AGES (Ma)									
	U (ppm)	Th (ppm)	Th/U	$^{207}Pb/^{206}Pb$	±2σ abs	$^{207}Pb/^{235}U$	±2σ abs	$^{206}Pb/^{238}U$	±2σ abs	Rho	$^{206}Pb/^{238}U$	±2σ	$^{207}Pb/^{235}U$	±2σ	$^{207}Pb/^{206}Pb$	±2σ	Best age (Ma)	±2σ	Disc %	$^{207}Pb/^{235}U$ error %
_31	**685**	**314**	**0.458394**	**0.087**	**0.019**	**0.239**	**0.066**	**0.01996**	**0.00072**	**0.77619**	**127.4**	**4.5**	**217**	**44**	**1350**	**230**	**127.4**	**4.5**	**41.2903**	**27.62**
_4	704	371	0.526989	0.0503	0.0029	0.15	0.01	0.02112	0.00038	0.27579	134.7	2.4	142.1	8.8	210	120	134.7	2.4	5.2076	6.67
_17	**240**	**167**	**0.695833**	**0.0639**	**0.0048**	**0.184**	**0.019**	**0.02126**	**0.00039**	**0.63943**	**135.6**	**2.4**	**172**	**16**	**750**	**140**	**135.6**	**2.4**	**21.1628**	**10.33**
_8	1097	1086	0.989973	0.0522	0.0027	0.1536	0.0086	0.02128	0.00036	0.61099	135.7	2.3	145	7.6	290	120	135.7	2.3	6.41379	5.6
_5	**260**	**285**	**1.096154**	**0.076**	**0.0068**	**0.229**	**0.021**	**0.0213**	**0.0004**	**0.51371**	**135.9**	**2.5**	**209**	**16**	**1080**	**140**	**135.9**	**2.5**	**34.9761**	**9.17**
_24	253	112	0.442688	0.0608	0.0051	0.177	0.013	0.02152	0.00037	0.5641	137.3	2.3	166	11	630	140	137.3	2.3	17.28916	7.34
_33	**886**	**539**	**0.608352**	**0.0739**	**0.009**	**0.221**	**0.029**	**0.02166**	**0.00051**	**0.88581**	**138.2**	**3.2**	**203**	**22**	**1040**	**170**	**138.2**	**3.2**	**31.9212**	**13.12**
_18	**336**	**247**	**0.735119**	**0.069**	**0.024**	**0.209**	**0.086**	**0.02171**	**0.00083**	**0.33535**	**138.4**	**5.2**	**192**	**55**	**900**	**310**	**138.4**	**5.2**	**27.9167**	**41.15**
_25	331	175	0.528701	0.0501	0.0032	0.149	0.011	0.02181	0.00036	0.034479	139.1	2.3	141.1	9.7	190	140	139.1	2.3	1.417434	7.38
_14	1242	1523	1.226248	0.065	0.0034	0.196	0.012	0.02186	0.00038	0.51789	139.4	2.4	181	10	770	110	139.4	2.4	22.9834	6.12
_9	522	218	0.417625	0.0499	0.0026	0.15	0.01	0.02191	0.00036	0.39025	139.7	2.3	141.6	8.7	160	130	139.7	2.3	1.34181	6.67
_34	2198	715	0.325296	0.0489	0.0023	0.1471	0.0092	0.02193	0.00037	0.89049	139.8	2.3	139.3	8.1	140	110	139.8	2.3	-0.3589	6.25
_12	**130**	**63**	**0.484615**	**0.0813**	**0.0093**	**0.254**	**0.03**	**0.02221**	**0.00049**	**0.84417**	**141.6**	**3.1**	**230**	**23**	**1240**	**190**	**141.6**	**3.1**	**38.4348**	**11.81**
_36	**140**	**92**	**0.657143**	**0.0887**	**0.0073**	**0.274**	**0.026**	**0.0224**	**0.00043**	**0.1187**	**142.8**	**2.7**	**246**	**20**	**1380**	**120**	**142.8**	**2.7**	**41.9512**	**9.49**
_6	309	134	0.433657	0.0492	0.0037	0.152	0.011	0.02242	0.00036	0.84837	142.9	2.3	143.3	9.4	140	150	142.9	2.3	0.27913	7.24
_13	**358**	**456**	**1.273743**	**0.077**	**0.034**	**0.25**	**0.16**	**0.0229**	**0.0015**	**0.84263**	**146.2**	**9.6**	**227**	**87**	**1120**	**310**	**146.2**	**9.6**	**35.5947**	**64**
_30	**96**	**56**	**0.583333**	**0.097**	**0.015**	**0.306**	**0.052**	**0.02308**	**0.00056**	**0.40946**	**147.1**	**3.5**	**276**	**34**	**1550**	**170**	**147.1**	**3.5**	**46.7029**	**16.99**
_27	1479	1731	1.170385	0.0692	0.0051	0.217	0.015	0.02312	0.00051	0.12641	147.3	3.2	200	12	900	130	147.3	3.2	26.35	6.91
_15	**494**	**812**	**1.643725**	**0.0827**	**0.0063**	**0.267**	**0.022**	**0.02311**	**0.0004**	**0.051161**	**147.3**	**2.5**	**240**	**17**	**1260**	**120**	**147.3**	**2.5**	**38.625**	**8.24**
_22	**234**	**173**	**0.739316**	**0.101**	**0.01**	**0.324**	**0.032**	**0.02342**	**0.00049**	**0.62103**	**149.3**	**3.1**	**285**	**23**	**1630**	**150**	**149.3**	**3.1**	**47.61404**	**9.88**
_38	**95**	**50**	**0.526316**	**0.095**	**0.017**	**0.512**	**0.062**	**0.0385**	**0.0013**	**0.59313**	**243.7**	**8.3**	**419**	**36**	**1530**	**190**	**243.7**	**8.3**	**41.8377**	**12.11**
_11	650	238	0.366154	0.0615	0.0034	0.414	0.032	0.04904	0.00094	0.78457	308.6	5.7	351	22	660	110	308.6	5.7	12.0798	7.73
_23	599	193	0.322204	0.0722	0.0034	0.58	0.046	0.0604	0.0032	0.072449	378	19	464	28	990	110	378	19	18.53448	7.93

of Mexico (Salvador, 1991; Stern and Dickinson, 2010), which evolve to shallow marine facies that gradually change to a thick open marine carbonate-siliciclastic unit. The whole sequence is capped with regressive fore-deep turbiditic facies.

The present work focuses on a section in the Pimienta Formation, in the upper part of the open marine carbonate-siliclastic unit (Figure 2).

This formation was defined by Heim (1940) as "well stratified limestones with black chert intercalations". Sutter (1990) estimated its thickness at more than 300 m. Frequent green bentonitic layers are documented in the upper part of the formation (Bondelos, 1956).

Bonet (1956) on the basis of calpionellid content and Cantú-Chapa (1971) on the base of ammonites estimated the relative age of this formation as Late Jurassic to early Berriasian.

4. Results

4.1. Calpionellid Biostratigraphy

Observed fine-grained sediments of the Tamazunchale section contain predominantly pelagic microfossils (radiolarians and calpionellids). The succession of calpionellids in the section allows us to identify calpionellid zones and subzones as follows:

4.1.1. Crassicollaria Zone, Remanei Subzone. Samples: TMZ 2-6

The interval is defined by the first occurrence (FO) of *Tintinnopsella remanei* (Borza) in microfacies dominated by *Crassicollaria intermedia* Durand-Delga (Reháková and Michalík, 1997). The calpionellid association in the studied section is composed of *Chitinoidella* cf. *elongata* (Pop) (Figure 3 A, B), *Tintinnopsella remanei* (Borza), (Figure 3 C, D), *Crassicollaria* sp. (Figure 3 E) and *Calpionella alpina* Lorenz (Figure 3 F). *Crassicollaria intermedia* Durand-Delga was not observed.

The microfacies of this interval are characterized by wackestone-packstone of calcified radiolarians with less abundant calpionellids. Intervals with stratiform black cherts or chert nodules are frequent.

4.1.2. Crassicollaria Zone, Brevis Subzone. Samples: TMZ 7-10

The Brevis Subzone (*sensu* Reháková and Michalík, 1997) is the part of the *Crassicollaria* Zone that is characterized by a diverse and abundant calpionellid association. It corresponds to the Intermedia Subzone of Remane (1986) or Massutiniana Subzone of Lakova (1993). In the Tamazunchale section, the subzone is characterized by a poor calpionellid association composed of *Calpionella alpina* Lorenz (Figure 3 G), *Crassicollaria* sp. (Figure 3 E), *Crassicollaria massutiniana* Colom (Figure 3 H), *Tintinnopsella carpathica* (Murgeanu and Filipescu) (Figure 3 I) and *Praetintinnopsella andrusovi* Borza (Figure 3 J). Due to the scarcity of calpionellids and the missing species normally found in the Intermedia Subzone (*sensu* Remane, 1986), the presence of *Crassicollaria massutiniana* Colom instead leads us to consider the interval to be the Brevis Subzone.

The microfacies of this interval are wackestones to packstones in which calcified radiolarians are dominant.

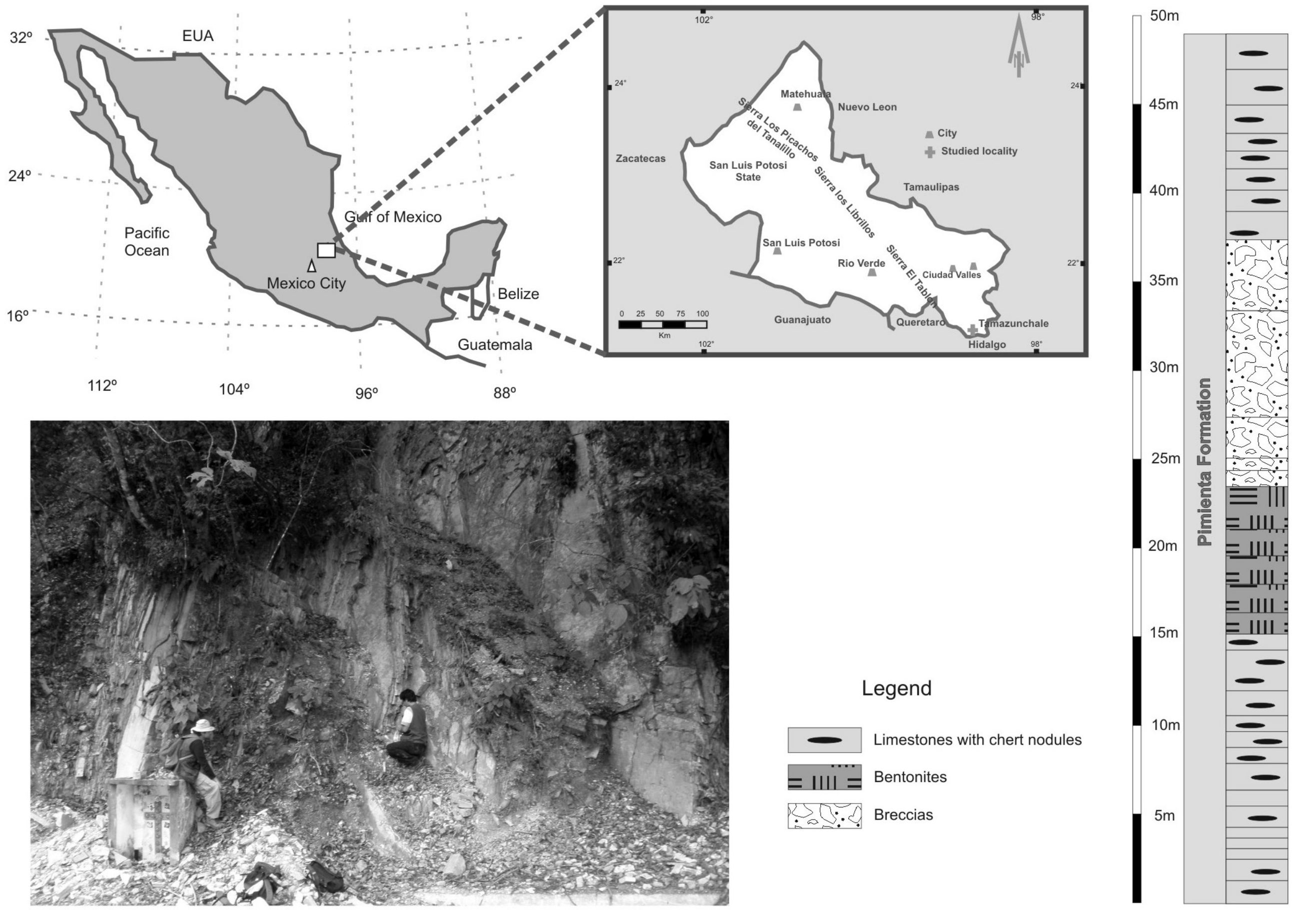

Figure 1. Location of the Tamazunchale section

4.1.3. Crassicollaria Zone, Colomi Subzone. Samples: TMZ 11-19.1

The subzone was defined by Pop (1994) by the FO of *Crassicollaria colomi* Doben. In the studied section *Crassicollaria colomi* Doben (Figure 3 K) appears in sample TMZ 11 accompanied by *Crassicollaria* sp. (Figure 3 E), *Crassicollaria parvula* Remane (Figure 3 L), *Calpionella alpina* Lorenz (Figure 4 A), *Chitinoidella boneti* Doben (Figure 4 B), *Praetintinnopsella andrusovi* Borza (Figure 4 C, D), *Tintinnopsella carpathica* (Murgeanu and Filipescu) (Figure 4 E), *Tintinnopsella subacuta* Colom (Figure 4 F) and deformed tintinnopsellid loricas (Figure 4 G). A form with an unusual crassicollarian lorica with distinct double collar was noted (Figure 4 H), a feature interpreted as probably the product of bacteria induced mineralization.

An interval with the deformed calpionellids in the *Crassicollaria* Zone was documented by Borza (unpublished data) and Reháková (2000) and this coincided with the decline of crassicollarians and extinction of most *Crassicollaria* species near the Jurassic/Cretaceous boundary.

It is noteworthy, that *Chitinoidella* and *Praetintinnopsella andrusovi* Borza have never occurred so high in the *Crassicollaria* Zone. Chitinoidellids often persist in the *Praetintinnopsella* Zone, but have never been documented in any normal succession in the *Crassicollaria* Zone. Similar chaotic distribution of stratigraphically important microfossils was documented in Remanei Subzone in France by Wimbledon *et al*. (2013). We can also interpret this as the result of sedimentary reworking. Nonetheless, it is an important finding because it indicates the presence of calpionellid biomarkers of the *Chitinoidella* Zone and the *Praetintinnopsella* Zones and, therefore, the certain communication of the Tampico-Misantla basin with the rest of the Tethys during the late Tithonian.

The finding of *Tintinnopsella subacuta* Colom in the *Crassicollaria* Zone is another unexpected result. This species is reported from Berriasian strata but has never been reported in the Tithonian. Additional studies are necessary to clarify the total range of this species in Mexican sections.

This subzone can be divided into two main parts according to microfacies.

The first one, TMZ 11-15, comprises wackestones to packstones dominated by radiolarians with scarce calpionellids.

The second one, TMZ 16-19.1, is composed of

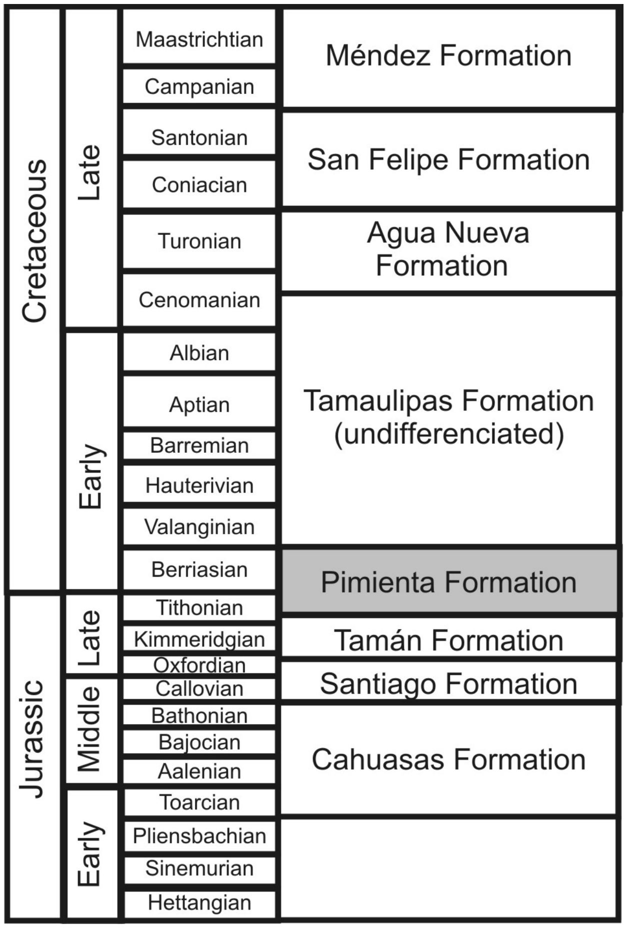

Figure 2. Jurassic and Cretaceous formations of the studied area. Studied interval is in gray.

bentonites and intercalations of radiolarian wackestone-packstone. The bentonites are green-gray in color and well stratified (Figure 4 I). Their tabular bed form and parallel stratification, and their assumed sedimentation in deep-water conditions, point to a free fall volcanic ash. In thin section it is possible to observe some altered volcanic glass, micas, quartz and plagioclases (Figure 4 J).

4.1.4. Erosional and breccias beds. Samples: TMZ 20-22

An abrupt change in microfacies is seen in sample TMZ 20. The bentonites and radiolarian wackestones-packstones are suddenly replaced by thick breccias of around twelve meters (Figure 5 A, B).

The breccias are either mud supported or subordinately clast supported; clasts differ in shape and size. In thin section, zones with sparitic matrix (Figure 5 C, D) alternating with more micritic matrix can be observed.

Clasts are mainly made up of micrite grains, peloids, benthic foraminifers, algae fragments (Figure 5 E), mollusk debris and other shallow water derived bioclasts like fragments of the ulvophycean algae *Lithocodium agregatum* Elliott (Figure 5 F).

4.1.5. Calpionella Zone. Elliptica Subzone. Samples: TMZ 23-32

The Elliptica Subzone was defined by Catalano and Ligouri (1971) by the FO of *Calpionella elliptica* Cadish. In the studied section the calpionellid association was determined in the breccia matrix and is composed of *Calpionella elliptica* Cadish (Figure 6 A), *Calpionella alpina* Lorenz (Figure 6 B), *Remaniella colomi* Doben (Figure 6 C), *Remaniella ferasini* Catalano (Figure 6 D) and *Tintinnopsella longa* Colom (Figure 6 E) and frequent radiolarian (Figure 6 F). In the Mediterranean Tethys and central Europe the species *Tintinnopsella longa* appears usually in the uppermost part of the Elliptica Subzone. Therefore, Pop (1997) proposed the Longa Subzone as the last subzone of the *Calpionella* Zone. The biomarkers of the higher *Calpionellopsis* and *Calpionellites* zones have not been identified in the Tamazunchale section.

4.2. U-Pb geochronology

The analyzed tuff sample (TMZ 19) yielded colorless and amber-colored euhedral zircon grains ranging from 30 to 200 μm in size. Scarce dark brown, metamict zircons were also observed but not considered for isotopic analysis. CL images show the predominance of concentric oscillatory and sector zoning that are typical of magmatic zircons (Connelly, 2001; Corfu *et al*., 2003). Th/U ratios are > 0.1 for all analyzed grains, supporting a magmatic origin for these zircons (Rubatto, 2002). Given the small dimension of most grains and the recurrent apatite and opaque inclusions, only 11 grains gave ages that vary from 134.7 to 378.0 Ma (Figure 7 A). Nine grains yielded concordant to slightly discordant ages that define a $^{206}Pb/^{238}U$ weighted mean of 139.1 ± 2.6 Ma (Figure 7 B). This age is interpreted as reflecting the time of emplacement of the analyzed felsic tuff. Two grains yielded discordant ages of 308.6 and 378.0 Ma (Figure 7 A) that we interpret due to mixing with xenocrystic cores inherited from Paleozoic or older rocks assimilated during the Lower Cretaceous volcanic event.

5. Discussion

The distribution of calpionellids in the Tamazunchale section does not prove the zonal scheme that is known from many Tethyan sections (Figure 8). Also, the biological components present reflect different environmental conditions. While calpionellids (mainly crassicollarians) dominated in late Tithonian microfacies in the European and North African Tethyan regions, radiolarians reflecting upwelling and rich nutrient conditions, prevailed in the westernmost Tethyan areas.

In spite of the scarcity of calpionellids, more detailed sampling has made possible the establishment of a more complete division of the late Tihonian *Crassicollaria* Zone.

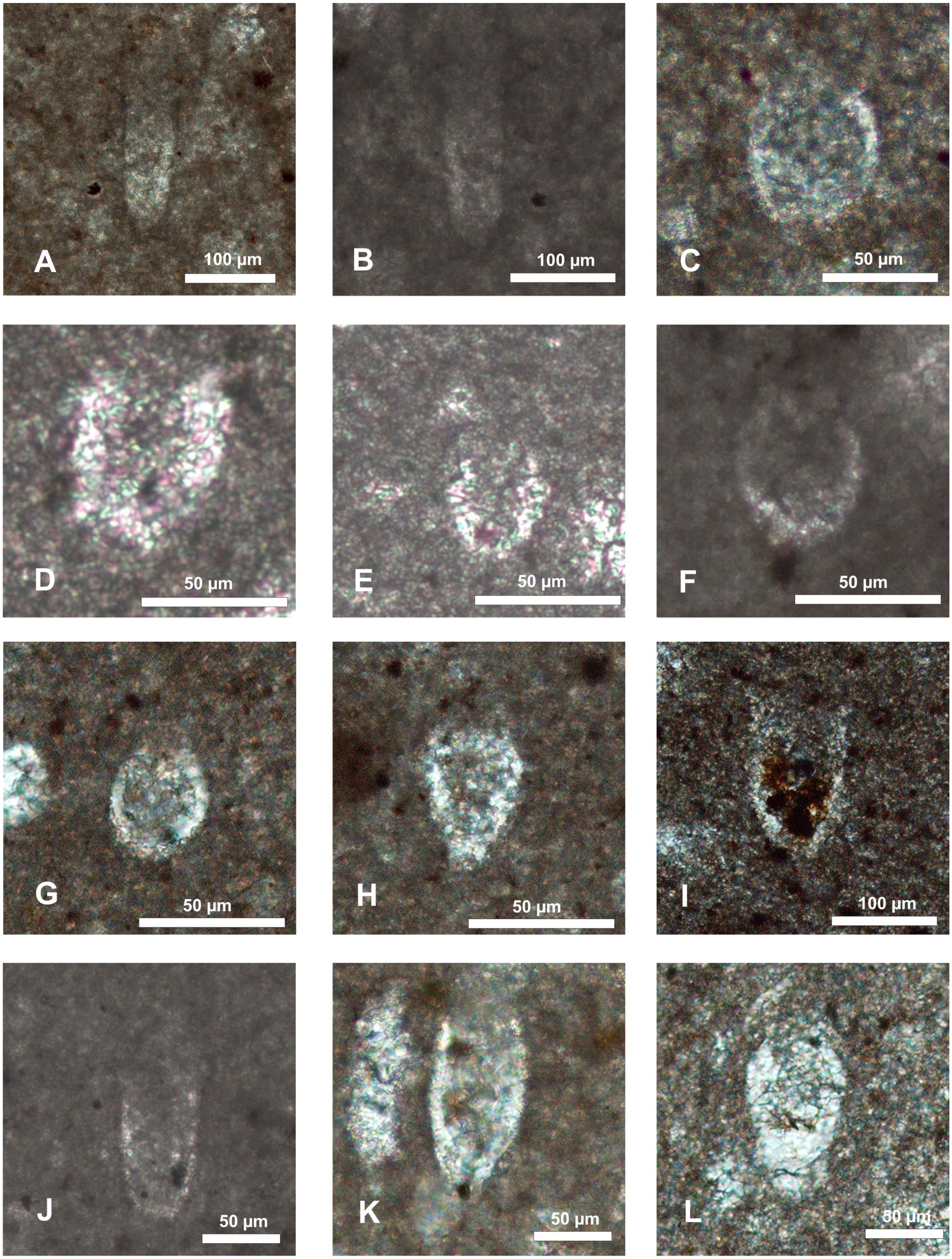

Figure 3. Calpionellids of the *Crassicollaria* Zone. A, B: *Chitinoidella* cf. *elongata* (Pop). Sample TMZ 2.0. C, D: *Tintinnopsella remanei* (Borza). Sample TMZ 2. E: *Crassicollaria* sp. Sample TMZ 2.1. F: *Calpionella alpina* Lorenz. Sample TMZ 3.2. G: *Calpionella alpina* Lorenz. Sample TMZ 10.0. H: *Crassicollaria massutiniana* Colom. Sample TMZ 8. I: *Tintinnopsella carpathica* (Murgeanu and Filipescu). Sample TMZ 8. J: *Praetintinnopsella andrusovi* Borza. Sample TMZ 9. K: *Crassicollaria colomi* Doben. Sample TMZ 11. L: *Crassicollaria parvula* Remane. Sample TMZ 11.

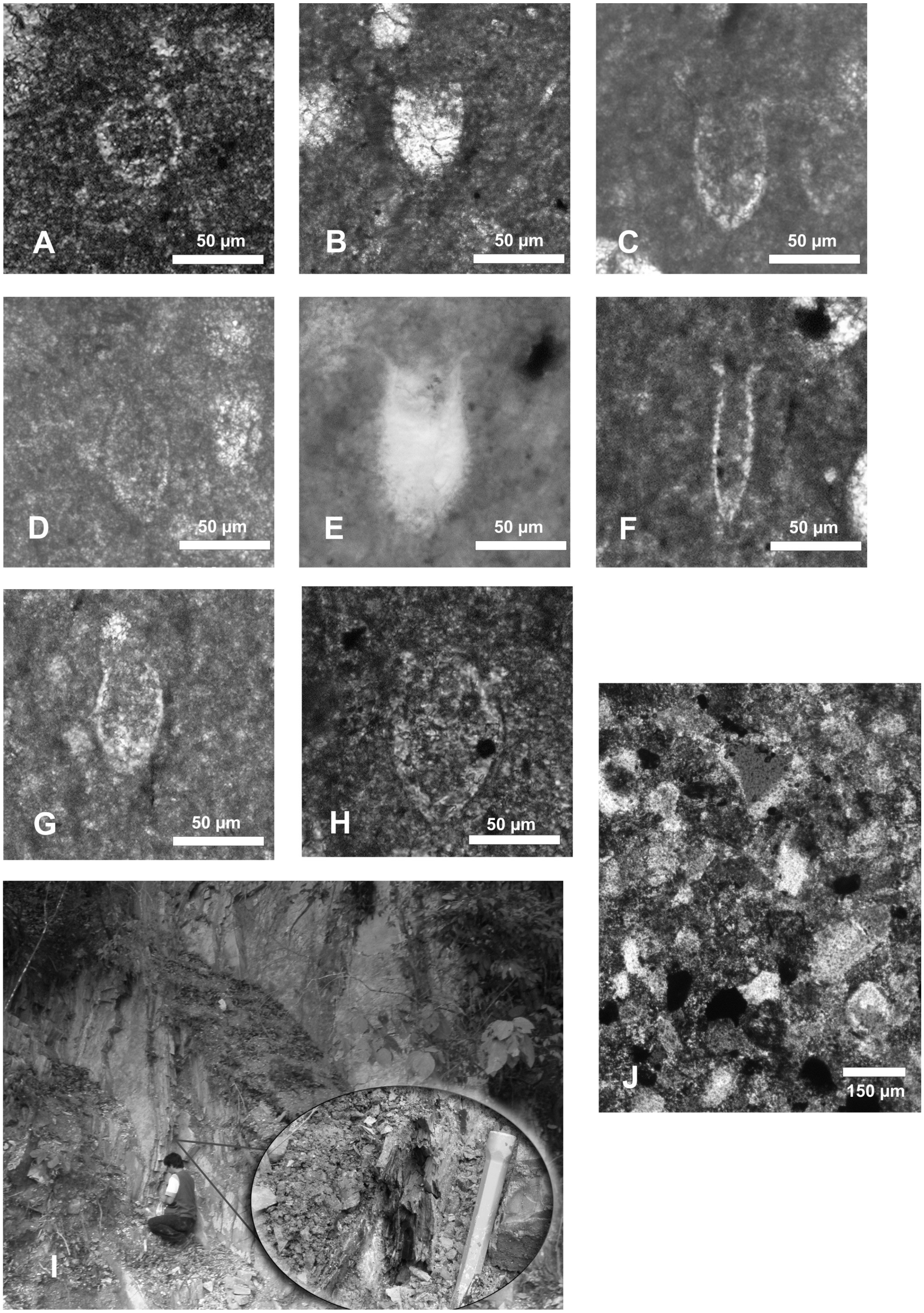

Figure 4: Calpionellids and facies of the *Crassicollaria* Zone. A: *Calpionella alpina* Lorenz. Sample TMZ 12. B: *Chitinoidella boneti* Doben. Sample TMZ 12. C, D: *Praetintinnopsella andrusovi* Borza. Sample TMZ 12. E: *Tintinnopsella carpathica* (Murgeanu and Filipescu). Sample TMZ 13.1. F: *Tintinnopsella subacuta Colom*. Sample TMZ 13. G: Deformed tintinnopsellid loricas. Sample TMZ 17. H: Unusual crassicollarian lorica with distinct double collar may be due to bacterial mineralization. I: Outcrop of the Tamazunchale section showing the bentonite layers. J: Bentonite in thin section. Some altered micas, volcanic glass, quartz and plagioclases.

Thus, the zone can be divided into the same subzones (Remanei, Brevis and Colomi Subzones) as those described for Tethyan areas farther east. This fact indicates a constant arrival of calpionellids to Mexican regions through a permanent connection with the main part of Tethys.

The presence of *Chitinoidella boneti* Doben and *Praetintinnopsella andrusovi* Borza in the Brevis subzone is considered to be the result of reworking, but this type of mixing has never been reported at a stratigraphic level as high as the Brevis Subzone. This is interpreted as the result of an agitated water regime reworking sediments that persisted until the Colomi Subzone in this area.

The *Crassicollaria* Zone terminated with signs of active regional volcanism reflected by intervals with bentonites. The change in sea water temperature and high input of nutrients could have lead to large scale mortality of oligotrophic organisms (among them also calpionellids). Volcanic activity is reflected by deposition of bentonites

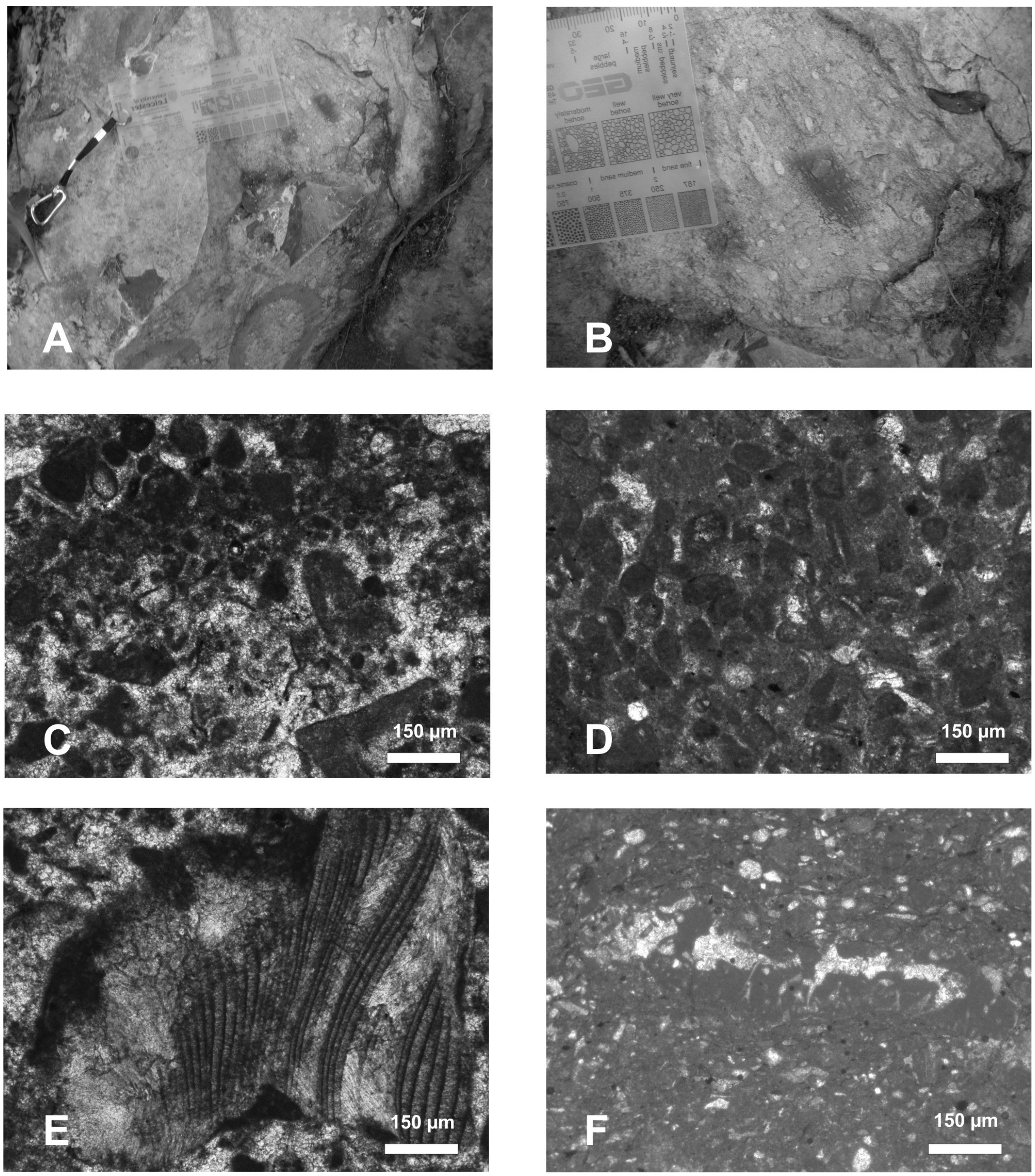

Figure 5: Main features of breccias beds in outcrop and in thin section. A, B: Features of the brecciated limestone in outcrop. Sample TMZ 20. C, D: Thin section view of sample TMZ 20. Breccias are mainly composed of peloids, micritic grains and fossil fragments. The matrix varies from sparitic to micritic in different areas. E: Frequent red algae fragments appear in the entire breccia interval. Sample TMZ 23. F: Ulvophycean algae *Lithocodium agregatum* Elliott. Sample TMZ 23.

in which the last bed (TMZ 19) shows a geochronological age of 139.1 ± 2.6 Ma. According to Gradstein *et al*., 2012 (International Stratigraphic Chart) this age corresponds to approximately to the Berriasian – Valanginian boundary.

The bentonites are covered by thick breccia beds also containing bioclasts derived from shallow water suggesting erosion that accompanied sea-level fall.

More or less coeval breccias beds have been identified in some Tethyan sections (Borza *et al*., 1980; Reháková, 2000; Benzaggagh, 2011; Eguiluz *et al*., 2012). In the western Carpathians Reháková (2000) and Michalík (2007) described a similar event as the "Nozdrovice Breccia".

In the lowermost samples from the breccia bed (Samples TMZ 20, 21, 22) it has not been possible to find any biostratigraphical marker. However, within the matrix of sample TMZ 23 calpionellids start to appear again. It is

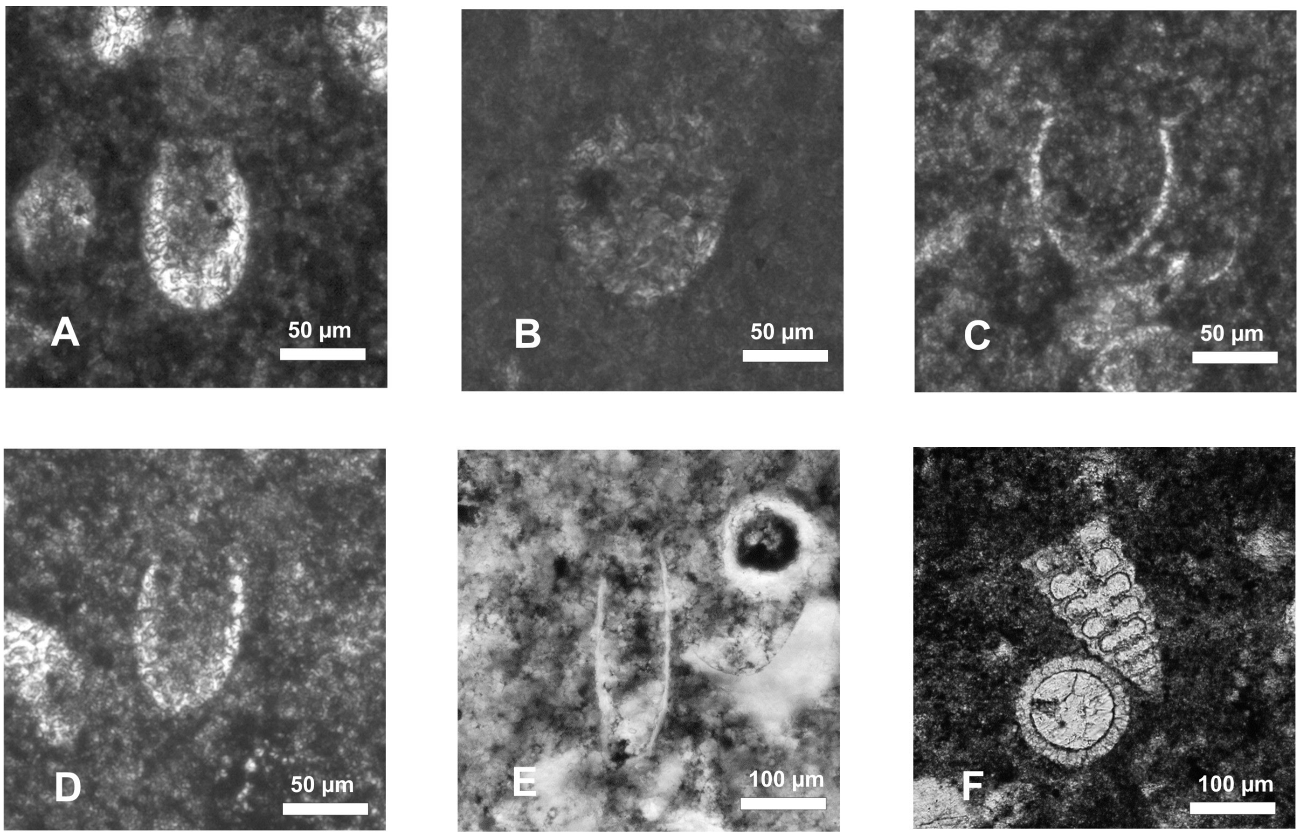

Figure 6. Microfossils of the Elliptica Subzone. A: *Calpionella elliptica* Cadish. Sample TMZ 24. B: *Calpionella alpina* Lorenz. Sample TMZ 24.2. C: *Remaniella colomi* Doben. Sample TMZ 30. D: *Remaniella ferasini* Catalano. Sample TMZ 28. E: *Tintinnopsella longa* Colom. Sample TMZ 31. F: Some well preserved radiolarian.

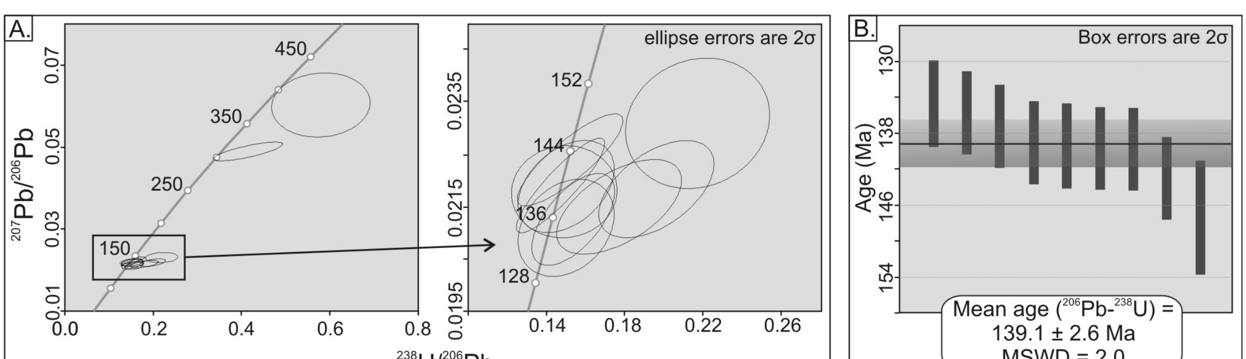

Figure 7. A: Tera-Wasserburg (1972) and B: weighted mean diagrams for the dated tuff sample TMZ 19. Plots were constructed using the $^{206}Pb/^{238}U$ age for zircons younger than 1.0 Ga, whereas $^{207}Pb/^{206}Pb$ ages were preferred for grains older than 1.0 Ga. As a statistical rejection criterion, 10 % normal and 5 % reverse discordancy was chosen (Harris *et al*., 2004; Gehrels, 2011), and none of these zircons are included in the plots or discussion below.

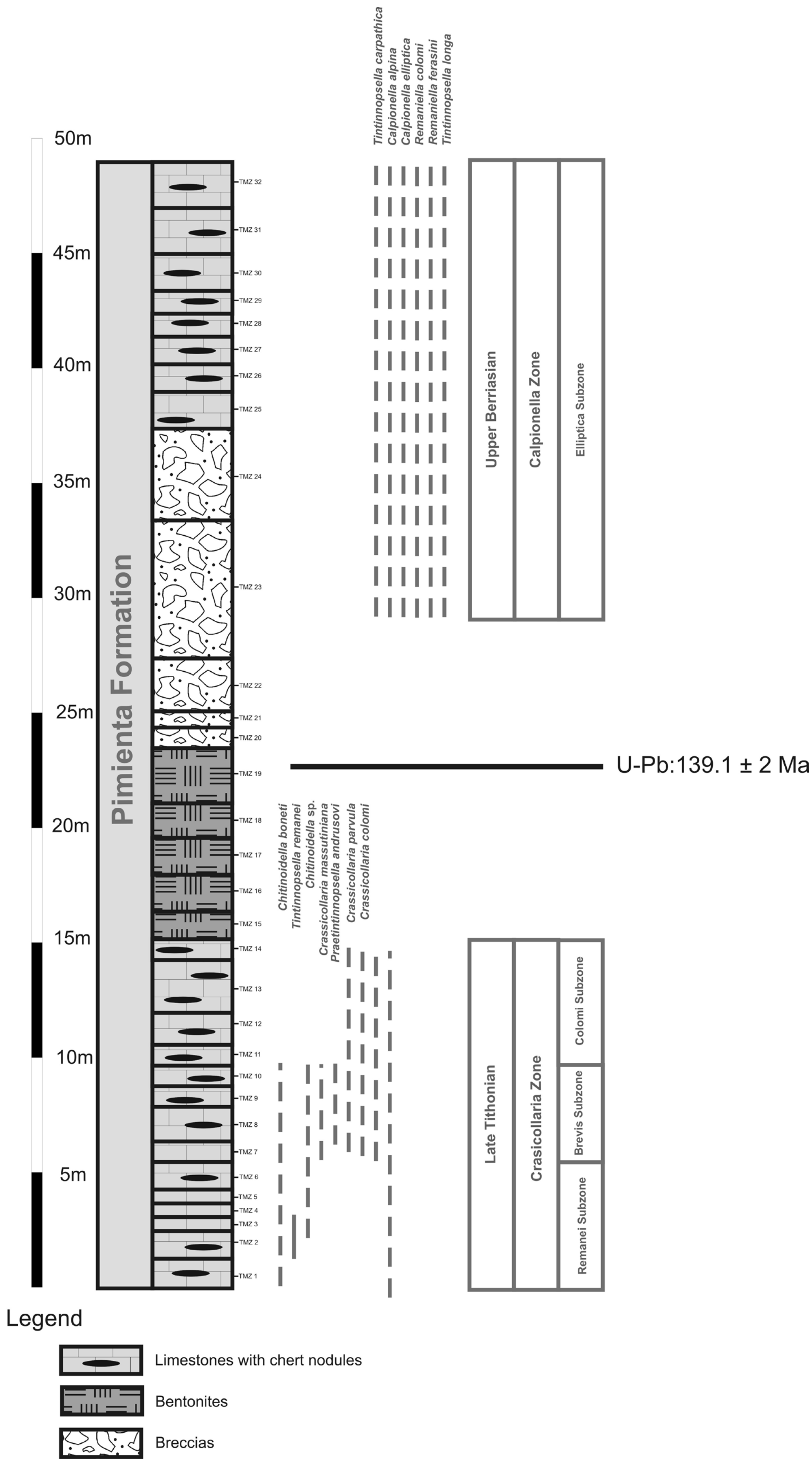

Figure 8. Calpionellid biozonation, bioevents and U-Pb age of the Tamazunchale section.

possible to construct a calpionellid biozonation that starts in the Elliptica subzone but the Alpina and Ferasini Subzones are missing. A similar situation was reported in northern Mexico by Eguiluz *et al*. (2012).

The Elliptica Subzone was defined by several authors as middle Berriasian (see Figure 2). Nonetheless, the unexpected appearance of the Elliptica Subzone five meters above the last bentonite layer, dated at 139.1 ± 2.6 Ma, suggests that the Elliptica subzone in Mexico is younger and at least late Berriasian. This new discovery points to different ranges for calpionellid biozones in Mexico, and offers new opportunities for the calibration of calpionellids bioevents in the main part of Tethys. More work is required to make regional correlations with calpionellids calibrated with U-Pb geochronology.

Upward, the section continues into the Elliptica Subzone but is then covered by soil and vegetation, which prevents more sampling for the moment.

6. Conclusion

The Tamazunchale section contains rocks dating from the late Tithonian to the late Berriasian (*Crassicollaria* Zone to Elliptica subzone). The *Crassicollaria* Zone was divided into the Remanei, Brevis and Colomi subzones. Microfossils corresponding to the *Chitinoidella* Zone and *Praetintinnopsella* point to a direct and continuous connection of this Mexican region with European Tethys during late Tithonian times.

The last bentonite bed dated at 139.1 ± 2.6 Ma suggests a different vertical distribution of calpionellids biozones in Mexico compared with the Mediterranean Tethys. Further work is necessary and desirable to clarify this point in different regions of Mexico.

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