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# Pennsylvanian fusulinids and calcareous algae from Sonora (northwestern Mexico), and their biostratigraphic and palaeobiogeographic implications

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**Abstract**

Pennsylvanian carbonates are widespread in Sonora (Mexico) and contain a diverse biota of foraminifers and calcareous algae. Detailed studies here are devoted to the outcrops of the Sierra Agua Verde and Cerro El Tule. The Late Atokan (early Late Moscovian part), Desmoinesian (= late Late Moscovian) and Missourian (= Kasimovian) stages are especially rich in fusulinids and algae. The principal zones of fusulinids of Wilde encountered are A3, DS1 and MC1–2. New data are given about the genera *Fusulinella, Parawedekindellina, Zellerella, Komia* and *Paraepimastopora*, in order to establish migrations or vicariances between Mexico and Palaeotethys. ***To cite this article: C. Gomez-Espinosa et al., C. R. Palevol 7 (2008).***


**Résumé**

**Fusulines et algues calcaires du Pennsylvanien de l'État de Sonora (Nord-Ouest du Mexique) ; implications biostratigraphiques et paléobiogéographiques.** Les carbonates du Pennsylvanien de l'État de Sonora (Mexique) sont riches en fusulines et algues calcaires dans la Sierra Agua Verde et le Cerro El Tule. L'Atokien supérieur et le Desmoinésien (tous deux équivalents du Moscovien supérieur) et le Missourien (=Kassimovien) sont les étages les mieux caractérisés, avec les biozones A3, DS1 et MC1–2 de l'échelle de fusulines de Wilde. Des informations complémentaires sur les genres *Fusulinella*, *Parawedekindellina*, *Zellerella*, *Komia* et *Paraepimastopora* permettent de discuter si ces peuplements résultent de migrations ou de vicariances. ***Pour citer cet article : C. Gomez-Espinosa et al., C. R. Palevol 7 (2008).***


*Keywords:* Foraminifers; Algae; Biostratigraphy; Palaeobiogeography; Pennsylvanian; Sonora; Mexico

*Mots clés :* Foraminifères ; Algues ; Biostratigraphie ; Paléobiogéographie ; Pennsylvanien ; Sonora ; Mexique

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## Version française abrégée

Les échantillons de calcaires recueillis en février 2003, 2004 et 2005, dans l'État de Sonora au Mexique, ont livré des microfaciès de *wackestones* et de *packstones* bioclastiques à fusulinidés, petits foraminifères et algues.

Les séries examinées les premières ont été celles de la Sierra Agua Verde, colline où le Mississippien (= Carbonifère inférieur) affleure [30], et où le Pennsylvanien comporte du Morrowien et de l'Atokien inférieur, que nous attribuons à la zone A2 de Wilde [36]. Au Cerro El Tule, seules quelques fusulines pennsylvaniennes avaient été mentionnées, sans être illustrées [7] ; *Triticites ventricosus* avait permis d'identifier le Virgilien [7].

L'assemblage de l'Atokien supérieur A3 de Sierra Agua Verde est identique à celui de la partie supérieure du calcaire de Marble Falls, dans le Texas central [10]. Il se compose d'*Eugonophyllum* ? sp., *Kamaena* ? sp., *Zidella* ( ?) sp., *Komia abundans*, *Pachysphaerina pachysphaerica*, *Eotuberitina reitlingerae*, *Insolentitheca horrida*, *Endothyra* ex gr. *bowmani*, *Globivalvulina bulloides*, *Climacammina* ex gr. *moelleri*, *Deckerella* sp., *Mediocris breviscula*, *Eostaffella grozdilovae*, *Millerella* sp., *Pseudostaffella* sp. (rare), *Staffella powwowensis*, *Eoschubertella texana*, *Fusulinella llanoensis*, *F.* aff. *llanoensis*, *Zellerella* sp. 1, *Calcivertella* sp., *Baryshnikovia* sp. et *Syzrania* sp. Les bancs à fusulines atokiennes sont interstratifiés dans des niveaux bioconstruits à *Chaetetes* [1,2,30] ou bioaccumulés à crinoïdes [3] (Fig. 2).

L'association du Desmoinésien inférieur DS1 du Cerro El Tule comporte de rares *Komia abundans*, *Endothyra* sp., *Bradyina* spp., *Polytaxis* sp., *Climacammina moelleri*, *Globivalvulina* sp., *Eoschubertella* sp, *Wedekindellina euthysepta*, *Beedeina leei*, *B. euryteines* et *B.* cf. *novamexicana*.

Enfin, le Missourien du Cerro El Tule contient de très abondants *Triticites canyonensis* et de rares *T. springvillensis*, *Paraepimastopora kansasensis*, *Bradyina* sp., *Polytaxis* sp. et *Globivalvulina bulloides*. *Triticites canyonensis* date plutôt les biozones MC1 et MC 2 [37].

Les fusulines supramoscoviennes (Atokien–Desmoinésien), *Fusulinella llanoensis*, *Beedeina leei*, *B. euryteines* et *Wedekindellina euthysepta*, sont les formes habituelles du Sud des États-Unis [4,7,10,23,24,28]. En Sonora, de multiples transitions morphologiques, entre *Fusulinella llanoensis* et son écophène probable *F. thompsoni*, s'observent, ce qui confirme la synonymie proposée au Texas [10]. La découverte la plus importante est celle de *Zellerella* sp. 1 (Fig. 3.2), dont l'apparition dans l'Atokien supérieur du Sonora précède l'acmé desmoinésienne dans les Big Hatchet Mountains du Nouveau Mexique [37]. Le genre *Zellerella*, quoique décrit depuis peu [37], a une indéniable valeur paléobiogéographique et phylogénétique, car il apparaît très proche morphologiquement du genre *Parawedekindelllina* de l'Oural. Les vraies *Wedekindellina* des États-Unis d'Amérique, qui se développent à partir du Desmoinésien [36,37], sont peut-être à distinguer génériquement de leurs contemporaines de Russie. Par ailleurs, une autre espèce nord-américaine, *Wedekindellina matura*, est considérée par certains auteurs comme une *Nipperella*, autre genre voisin [37], tandis que des « *Wedelindellina* » assez similaires à celles du sud des États-Unis, comme « *W.* » *pseudomatura* [20,24] et « *W* » *praematura* [3,6], apparaissent aussi proches de *Parawedekindellina* que de *Zellerella*. On est donc conduit à penser que l'on pourrait préciser la limite biostratigraphique Atokien-Desmoinésien grâce à de possibles lignées, soit migrantes, soit vicariantes : (a) *Zellerella-Wedekindellina* sensu stricto ; (b) *Nipperella-Wedekindellina* sensu 2 ; (c) *Parawedekindellina-Wedekindellina* sensu 3.

Les fusulines missouriennes du Sonora appartiennent au groupe I de Wilde [36] décrit au Nouveau Mexique et partiellement connu dans d'autres états des États-Unis.

L'algue problématique *Komia* est assez représentative de l'Atokien de Sierra Agua Verde. La répartition de ce genre, dont l'attribution a oscillé entre algues rouges et microstromatoporoïdes, fait l'objet de controverses ; elle est particulièrement abondante dans le Desmoinésien des États-Unis [36], mais s'y observe dès l'Atokien [9]. Cela semble être l'inverse dans le Sonora. Par ailleurs, si *Komia* a été signalée dans le Bashkirien, et même dès le Viséen [16], c'est probablement à cause de confusions avec *Foliophycus*, *Efluegelia* ou *Chuvashovia*. Enfin, dans les populations de *Komia* que nous avons étudiées, les caractères de *Pseudokomia* se rencontrent chez plusieurs individus, ce qui nous incite à penser que ces deux taxons sont synonymes.

La dasycladale *Paraepimastopora* a été diversement définie [13,25]. Selon nos observations, elle se compose (a) d'une grande cellule centrale, entourée (b) d'un manchon calcaire percé de nombreux pores polygonaux à l'emplacement de latérales parallèles, prismatiques et aspondyles, et (c) d'intusannulations obliques bien développées [12,13] ; sa répartition stratigraphique s'étend du Viséen supérieur [5] au Permien [15].

Les associations d'algues et de fusulines du Sonora, similaires à celles du Sud des États-Unis (Tableau 2), les complètent par la découverte d'une espèce précoce


Fig. 1. Location maps of the studied outcrops in Sonora State (northwestern Mexico).
Fig. 1. Cartes de localisation des affleurements étudiés dans l'État de Sonora (Nord-Ouest du Mexique).

de *Zellerella*. Il conviendrait de préciser efficacement ses différences morphologiques avec l'élément ouralien *Parawedekindellina*. Cette distinction est d'autant plus importante que des migrations de microfaunes sont prouvées dans le Permien mexicain et guatémaltèque [32]. En ce qui concerne la paléogéographie locale, les associations étant semblables dans les deux grands domaines géodynamiques du Sonora, le craton Nord-Américain et le « terrane » Caborca [8,27], ceux-ci ne sont donc pas encore individualisés au Carbonifère–Permien. Il y a aussi liaison des plates-formes continentales, entre le Sonora et le « terrane » Mixteco, au Missourien, à cause de la présence conjointe de certaines espèces de *Triticites*, malgré l'intercalation de bassins remplis de flyschs. Cette continuité s'étend à la bordure périgondwanienne de l'Amérique du Sud [1–3] (Fig. 4).

## 1. Introduction

The Sierra Agua Verde and Cerro El Tule in the Sonora State, northwestern Mexico (Figs. 1 and 2), were sampled by our team in February 2003, 2004 and 2005. The Pennsylvanian carbonates are composed of bioclastic wackestones and packstones with fusulinids, smaller foraminifers and calcareous algae. In the Sierra Agua Verde, the Mississippian (Early Carboniferous) and the Early Pennsylvanian (Morrowan = Early Bashkirian), as well as the Early Atokan (= *Profusulinella* zone = zone A2 of Wilde [36] = Late Bashkirian–Early Moscovian) were found (Table 1). In Cerro El Tule, only few Pennsylvanian fusulinids have been mentioned, but never illustrated [7]. Its Virgilian deposits were dated based on the occurrence of *Triticites ventricosus* [7].

The aim of this paper is to describe the Pennsylvanian fossil assemblages, with emphasis on the calcareous algae and foraminifers, and the carbonate depositional environments of the strata. Other goals are to confirm the palaeobiogeographical affinities with the southwestern United States, and document the possible migrations or vicariances from the Urals and Southeast Asia that have been previously proposed in Mexico (Patlanoaya) and Guatemala [32–34].

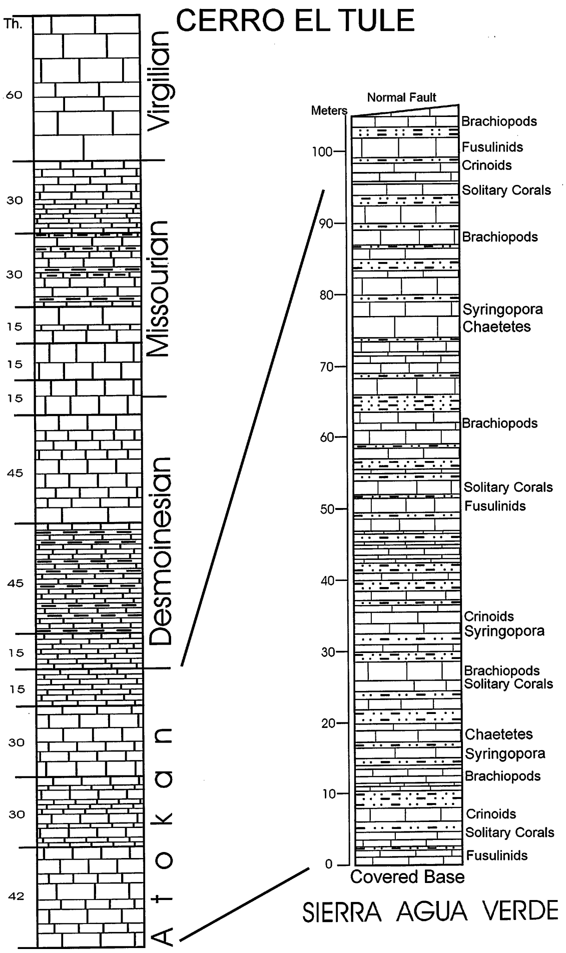


Fig. 2. Scheme of the lithostratigraphic section. 0, 50, 100 = thickness (in metres).

Fig. 2. Coupe lithostratigraphique synthétique. 0, 50, 100 = épaisseur (en mètres).

## 2. Previous work

The Pennsylvanian carbonates and their microfaunal and microfloral assemblages are rather poorly studied in Sonora [14,19,26,34]. Few fossiliferous outcrops are known. The Pennsylvanian of the other Mexican States is even more poorly known [34]. The Pennsylvanian limestones previously studied in Sonora and Chihuahua are parts of the Horquilla Formation, with outcrops located near the American border [31] in the Sierra de Palomas (Chihuahua) and Cerro El Tule (Sonora) [7]. The Sierra Agua Verde was also studied up to the Early Atokan [18,30]. In this locality, the Pennsylvanian section is denominated La Joya Formation [18], which is coeval to unit 4 of Sierra Santa Teresa [29]. The fusulinids are mentioned in a few publications [7,14,19], but are very rarely illustrated [31,38]. In the USA, the Pennsylvanian subsystem is divided into five stages (Table 1): Morrowan, Atokan, Desmoinesian, Missourian, and Virgilian. The approximate correlations with global stages are as follows: Morrowan = Early Bashkirian, Atokan = Late Bashkirian to Early Late Moscovian (Podolskian); Desmoinesian = late Late Moscovian (Myachkovian); Missourian = Kasimovian; Virgilian = Gzhelian. Wilde [36] recognized 16 zones of fusulinids in the Permian Basin of the southwestern USA (Table 1). Pennsylvanian calcareous algae are poorly known in Mexico, but have been well studied further north in North America (e.g., [9,16]).

## 3. Biostratigraphy

Late Atokan (A3) assemblages of the Sierra Agua Verde (location of the section in [17]) are similar to those of the upper part of the Marble Falls Limestone [10] of central Texas. They contain: *Eugonophyllum*? sp., *Kamaena*? sp., *Zidella*? sp., *Komia abundans*, *Pachysphaerina pachysphaerica*, *Eotuberitina reitlingerae*, *Insolentitheca horrida*, *Endothyra* ex gr. *bowmani*, *Globivalvulina bulloides*, *Climacammina* ex gr. *moelleri*, *Deckerella* sp., *Mediocris breviscula*, *Eostaffella grozdilovae*, *Millerella* sp., *Pseudostaffella* sp. (rare), *Staffella powwowensis*, *Eoschubertella texana*, *Fusulinella llanoensis*, *F.* aff. *llanoensis*, *Zellerella* sp. 1, *Calcivertella* sp, *Baryshnikovia* sp., and *Syzrania* sp. Beds with Atokan fusulinids are intercalated with bioconstructions of *Chaetetes*, which have been previously cited from this outcrop [30], and are being re-investigated by our team [1,2].

The Early Desmoinesian (DS1) limestone from Cerro El Tule contains rare *Komia abundans*, *Endothyra* sp., *Bradyina* spp., *Polytaxis* sp., *Climacammina moelleri*, *Globivalvulina* sp., *Eoschubertella* sp, *Wedekindellina euthysepta*, *Beedeina leei*, *B. euryteines*, and *B.* cf. *novamexicana*.

The Missourian of Cerro El Tule is very rich in representatives of *Triticites canyonensis*, but the associated biota is poorly diversified, consisting of only *Triticites springvillensis*, *Bradyina* sp., *Polytaxis* sp., *Globivalvulina bulloides*, and *Paraepimastopora kansasensis*. This Missourian assemblage corresponds probably to biozone MC 1 or MC 2 [36], characterized by two out of the seven species of group I of Wilde, 2006 [37].

## 4. Micropaleontology

Generally, the Pennsylvanian fusulinids of Sonora are well-known species of the southern USA: e.g., *Fusulinella llanoensis*, *Beedeina leei*, *B. euryteines* and

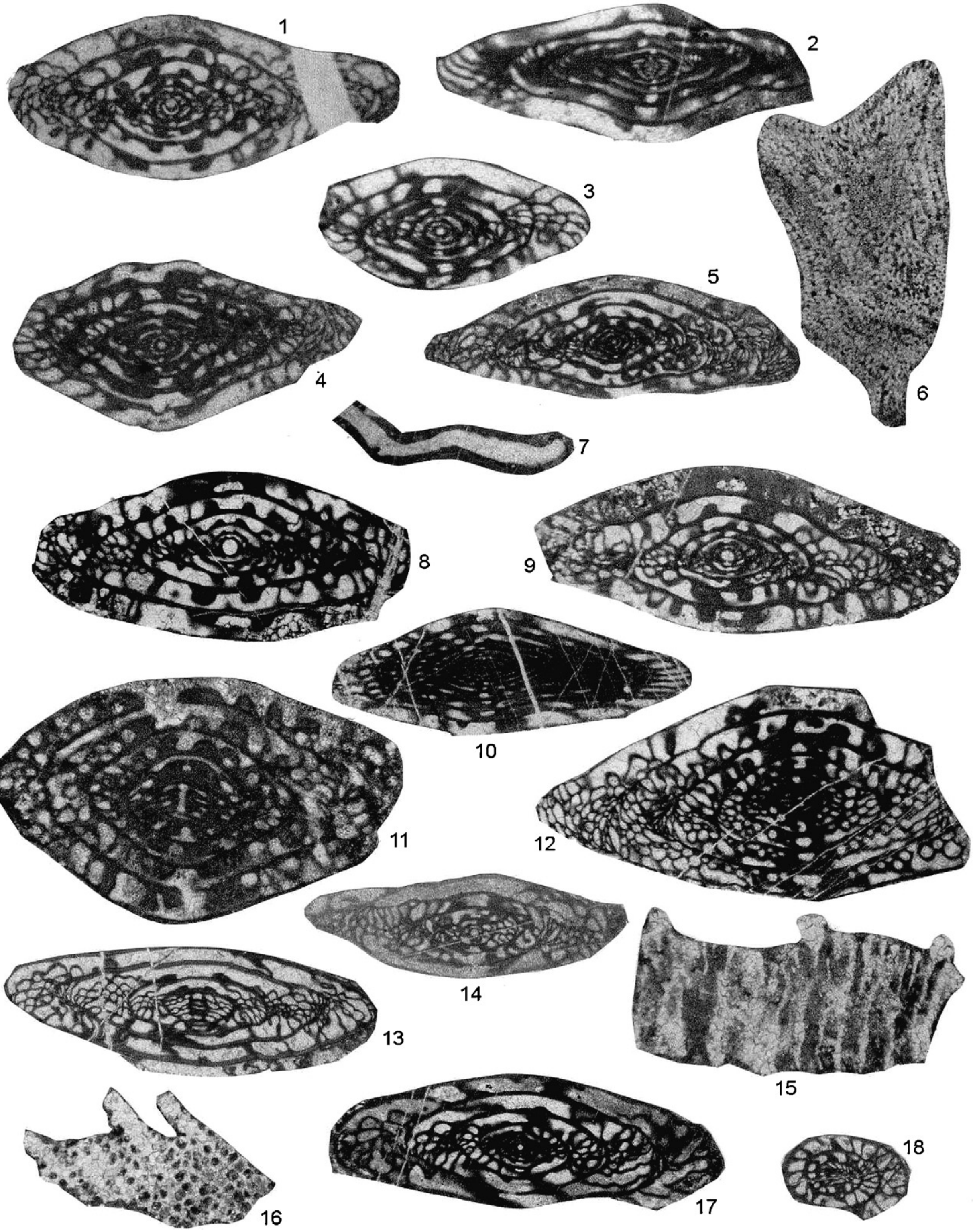


Fig. 3. Fusulinids and algae from the Pennsylvanian of Sonora. (**1, 3–4**) *Fusulinella llanoensis* (Thomas) (= *F. thompsoni* Skinner and Wilde). Three axial sections. Atokan A3, Sierra Agua Verde. **1.** Sample SAV 1, ×20. **3.** Sample SAV 6 (1), ×25. **4.** Sample SAV 7. ×20. (**2**) *Zellerella* sp. 1. Axial section, Atokan As3, Sierra Agua Verde, ×25. (**5**) *Fusulinella* aff. *llanoensis* (Thomas). Axial section, sample SAV 6 (1), Atokan A3, Sierra Agua

Table 1
Chronostratigraphic and biostratigraphic (fusulinids) scales of the Pennsylvanian, and biozones identified in Sonora (Mexico)
Tableau 1
Échelles chronostratigraphiques and biostratigraphiques (fusulines) du Pennsylvanien et biozones identifiées dans l'État de Sonora (Mexique)

| International stages | | North American stages | Zones of fusulinids of Wilde (1990) | Zones discovered in Sonora |
|---|---|---|---|---|
| PENNSYLVANIAN | GZHELIAN | VIRGILIAN | VC 3 | |
| | | | VC 2 | |
| | | | VC1 | |
| | KASIMOVIAN | MISSOURIAN | MC 4 | |
| | | | MC 3 | |
| | | | MC 2 | MC 1/2 |
| | | | MC 1 | |
| | LATE MOSCOVIAN (Myachkovian) | DESMOINESIAN | DS 5 | |
| | | | DS 4 | |
| | | | DS 3 | |
| | | | DS 2 | |
| | | | DS 1 | DS 1 |
| | LATE MOSCOVIAN (Podolskian) | LATE ATOKAN | A 4 | |
| | | | A 3 | A 3 |
| | EARLY MOSCOVIAN | EARLY ATOKAN | A 2 | |
| | LATE BASHKIRIAN | | A 1 | |
| | EARLY BASHKIRIAN | MORROWAN | M 2 | |
| | | | M 1 | |

*Wedekindellina euthysepta* (e.g., [4,6,10,23,24,28]). The most notable difference in the Mexican fauna is the presence of the recently described genus *Zellerella* [37] in the Late Atokan of Sonora (Fig. 3.2); i.e., prior to its appearance in the Desmoinesian of New Mexico. That confirms the opinion of Wilde [37] that *Zellerella* is the ancestor of the Desmoinesian *Wedekindellina euthysepta*. However, some atypical *Wedekindellina* of the USA, such as *W. praematura* [6] and *W. pseudomatura* [24] probably belong to *Zellerella*, and *W. matura* itself has been assigned by some authors to the genus *Nipperella*. In northern Urals, two genera are quoted: *Parawedekindellina* and *Wedekindellina* [22]. Consequently, in order to characterize more accurately the Atokan–Desmoinesian (i.e. the Podolskian–Myachkovian) boundary in North Amer-

Verde, ×12.5. (**6**) *Komia abundans* Korde. Longitudinal section relatively similar to a *Pseudokomia*, because of the irregular central part, sample SAV 7, Atokan A3, Sierra Agua Verde, ×25. (**7**) Phylloid alga *Eugonophyllum* ? sp. Longitudinal section, sample M.SAV.03.4, Atokan A3, Sierra Agua Verde, ×8. (**8, 9**) *Beedeina leei* (Skinner). Two axial sections, sample ST 1, Desmoinesian DS1, Cerro El Tule, ×20. (**10**) *Wedekindellina euthysepta* (Henbest). Axial section, sample ST 2 (2), Desmoinesian DS1, Cerro El Tule, ×20. (**11**) *Beedeina* cf. *novamexicana* (Needham), subaxial section, sample ST 2, Desmoinesian DS1, Cerro El Tule, ×25. (**12**) *Beedeina euryteines* (Thompson), axial section, sample ST 2, Desmoinesian DS1. Cerro El Tule, × 16. (**13–14, 17–18**) *Triticites canyonensis* Wilde. **13.** Subaxial section, sample ST 4, Missourian MC1–2, Cerro El Tule, × 16. **14.** Axial section, sample ST 5 (2), Missourian MC1–2, Cerro El Tule, × 16. **17.** Subaxial section, sample ST 5 (2), Missourian MC1–2, Cerro El Tule, × 16. **18.** Subtransverse section, sample ST 4, Missourian MC1–2, Cerro El Tule, × 16. (**15–16**) *Paraepimastopora kansasensis* (Johnson). **15.** Longitudinal section, sample ST 5, Missourian MC1–2, Cerro El Tule, × 25. **16.** Transverse section, sample ST 5 (2), Missourian MC1–2, Cerro El Tule, ×16.

Fig. 3. Fusulines et algues du Pennsylvanien de Sonora. (**1, 3–4**) *Fusulinella llanoensis* (Thomas) (= *Fusulinella thompsoni* Skinner et Wilde). Trois sections axiales. Atokien A3, Sierra Agua Verde. **1.** Échantillon SAV 1, ×20. **3.** Échantillon SAV 6 (1), ×25. **4.** Echantillon SAV 7, Atokien A3, Sierra Agua Verde, ×20. (**2**) *Zellerella* sp. 1. Section axiale, échantillon SAV 2 (2), Atokien A3, Sierra Agua Verde, ×25. (**5**) *Fusulinella* aff. *llanoensis* (Thomas). Section axiale, échantillon SAV 6 (1), Atokien A3, Sierra Agua Verde, ×12,5. (**6**) *Komia abundans* Korde. Section longitudinale atypique évoquant une *Pseudokomia*, à cause de sa partie centrale irrégulière, échantillon SAV 7, Atokien A3, Sierra Agua Verde, ×25. (**7**) Algue phylloïde *Eugonophyllum* ? sp. Section longitudinale, échantillon M.SAV.03.4, Atokien A3, Sierra Agua Verde, ×8. (**8, 9**) *Beedeina leei* (Skinner). Deux sections axiales, échantillon ST 1, Desmoinésien DS1, Cerro El Tule, ×20. (**10**) *Wedekindellina euthysepta* (Henbest). Section axiale, échantillon ST 2 (2), Desmoinésien DS1, Cerro El Tule, ×20. (**11**) *Beedeina* cf. *novamexicana* (Needham), section subaxiale, échantillon ST 2, Desmoinésien DS1, Cerro El Tule, ×25. (**12**) *Beedeina euryteines* (Thompson), section axiale, échantillon ST 2, Desmoinésien DS1, Cerro El Tule, ×16. (**13–14, 17–18**) *Triticites canyonensis* Wilde. **13.** Section subaxiale, échantillon ST 4, Missourien MC1–2, Cerro El Tule, ×16. **14.** Section axiale, échantillon ST 5 (2), Missourien MC1–2, Cerro El Tule, ×16. **17.** Section subaxiale, échantillon ST 5 (2), Missourien MC1–2, Cerro El Tule, ×16. **18.** Section subtransverse, échantillon ST 4, Missourien MC1–2, Cerro El Tule, ×16. (**15–16**) *Paraepimastopora kansasensis* (Johnson). **15.** Section longitudinale, échantillon ST 5, Missourien MC1–2, Cerro El Tule, ×25. **16.** Section transverse, échantillon ST 5 (2), Missourien MC1–2, Cerro El Tule, ×16.

Table 2
Geographical distribution in the USA of the fusulinids and algae identified in Sonora (Mexico)
Tableau 2
Répartition géographique aux États-Unis des fusulines et algues identifiées en Sonora (Mexique)

| | SONORA | TEXAS | NEW MEXICO | ARIZONA | MID CONTINENT |
|---|---|---|---|---|---|
| *Fusulinella llanoensis* | ● | ● | | | |
| *Zellerella* sp. | ● | | ● | | |
| *Wedekindellina euthysepta* | ● | ● | ● | ● | ● |
| *Beedeina leei* | ● | ● | ● | ● | ● |
| *Beedeina novamexicana* | ● | ● | ● | ● | ● |
| *Beedeina euryteines* | ● | ● | ● | ● | ● |
| *Komia abundans* | ● | ● | ● | | ● |
| *Paraepimastopora kansasensis* | ● | | ● | | ● |

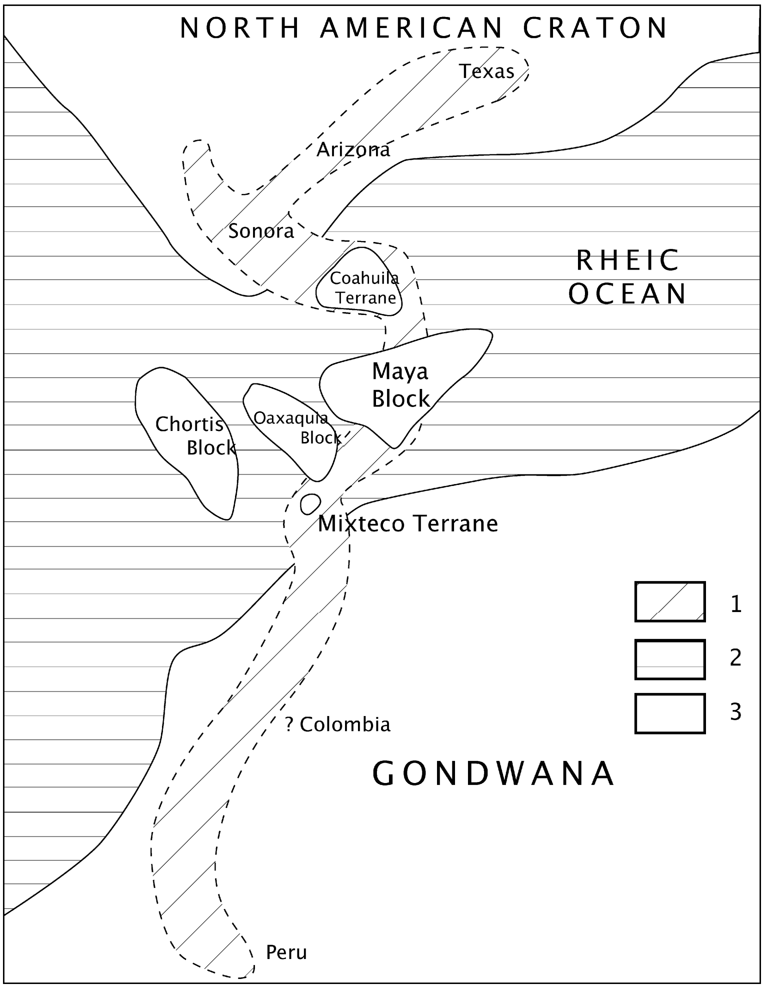


Fig. 4. Palaeogeographic reconstruction showing the connections between Sonora, the North American Craton (Arizona, Texas) and the Perigondwanan South American Domain, via several Mexican terranes: Coahuila, Maya, Oaxaquia and Mixteco. 1 = carbonate platforms; 2 = flysch basins; 3 = mainlands and islands (after [1–3]).
Fig. 4. Reconstitution paléogéographique indiquant une possible connexion entre le Sonora, le craton Nord-Américain (Arizona, Texas) et le domaine périgondwanien Sud-Américain via différents « terranes » mexicains : Coahuila, Maya, Oaxaquia, and Mixteco. 1 = plates-formes carbonatées ; 2 = bassins à flyschs ; 3 = îles et continents (d'après [1–3]).

ica and the northern Urals, the following hypothetical generic phylogeny might be used: (a) *Zellerella*-typical *Wedekindellina*; (b) *Nipperella*-atypical North American *Wedekindellina*; (c) *Parawedekindellina*-atypical Russian '*Wedekindellina*' If we have only two genera, *Wedekindellina* and its ancestor, migrations are necessary. In case of three lineages, vicariances are the explanation.

It should also be noted that transitional stages in our material confirm, as previously suggested in Texas [10], that *Fusulinella llanoensis* is synonym of *F. thompsoni* (Fig. 3.1, 3.3 and 3.4).

The Late Atokan smaller foraminifers of the Sierra Agua Verde correspond exactly to the assemblages of Marble Falls, Texas [11]. Two calcareous algae have a particular importance. First, the dasyclad *Paraepimastopora*, which has been diversely defined [13,25], but is distinguished by a large axial cell, parallel prismatic aspondyl laterals, and oblique intusannulations [12,13] (Fig. 3.15–16). Its stratigraphical distribution is from the Late Visean [5] to the Permian [15]. Second, the alga *incertae sedis Komia*, which has been assigned to the red algae or the microstromatoporoidean, is uncommon in the Atokan of the USA, and is generally considered as Desmoinesian in age [36], but, in Sonora, it is more common in the Atokan [9]. Previous citations of *Komia* in the Early Bashkirian, and even the Visean [13], are probably due to confusions with *Foliophycus*, *Efluegelia* or *Chuvashovia*. Finally, we illustrate here (Fig. 3.6) some specimens of *Komia* that look like *Pseudokomia* by the irregularity of the central skeleton, and we suggest that the genera are synonyms.

The Desmoinesian and Missourian fusulinids of Sonora are well-known endemic North-American taxa (Table 2).

## 5. Palaeobiogeography

The Sonoran Pennsylvanian fusulinids, algae, smaller foraminifers and chaetetids have clean palaeobiogeographical affinities with biota from Arizona, New Mexico, Texas, and California, similar to the Permian ([20,21]; see also [11] and [35]) (Table 2). An exception should be the lineage *Zellerella*–*Wedekindellina* compared with that of *Parawedekindellina*–Russian *Wedekindellina*. A possible connection between Mexico and the Urals and/or Palaeo-Tethys was previously observed by our team [32–34], but it remains difficult to explain geodynamically.

The regional geodynamic problem in Sonora is simpler, because the assemblages are similar in the two domains of Sonora: Craton and Caborca Terranes [8,27]. These two domains apparently were not separated during the Carboniferous–Permian. The continuity with the Mixteco Terrane during Missourian times is evidenced by the presence of *Triticites* of group I, although the two domains were separated by basins filled by flysch deposits (Fig. 4).

These data confirm the previous palaeobiogeographical reconstructions of our team [32–34]. The North American Craton is separated from the Gondwana of South America by a remnant of the Rheic Ocean, where there are some separated tectonostratigraphic terranes with carbonate platforms, such as Mixteco and Oaxaquia, while many basins with flysch are developed in the intermediary parts of Mexico [1–3] (Fig. 4).

## 6. Conclusions

1. Pennsylvanian carbonates from Sonora (Mexico) in Sierra Agua Verde and Cerro El Tule contain different assemblages of carbonate microfossils.
2. The Wilde zones A3, DS1 and MC1–2 of Wilde are well developed.
3. The Late Atokan *Fusulinella* belong to *F. llanoensis* and correlate the outcrops to Texas.
4. A newly encountered form in Mexico and in the Atokan in general, *Zellerella* sp. 1, is phylogenetically and palaeobiogeographically interesting. They seem to be morphologically similar to the Russian genus *Parawedekindellina*. The interpretation of this discovery is difficult, either a migration or a vicariance; i.e. the presence or absence of a palaeobiogeographic connection with the Uralian Province.
5. Desmoinesian fusulinids are represented by three species of the genus *Beedeina* and a species of *Wedekindellina*. They are all well-known species in the USA, but are essentially unknown in the Tethys.
6. The calcareous alga *Komia* is abundant in the Atokan of Sonora, unlike in the USA, where its acme is Desmoinesian in age.
7. *Paraepimastopora kansasensis* is reported from Sonora at Cerro El Tule, for the first time.
8. The Mexican Pennsylvanian palaeogeography is composed of only one domain in Sonora, more or less related to the Oaxaquia and Mixteco terranes.

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