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FACIES, MICROFOSSILS (SMALLER FORAMINIFERS, CALCAREOUS ALGAE) AND BIOSTRATIGRAPHY OF THE HUECO GROUP, DOÑA ANA MOUNTAINS, SOUTHERN NEW MEXICO, USA

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Abstract. The Lower Permian Hueco Group of the Doña Ana Mountains (south-central New Mexico, USA) is studied in three sections (A, B, C) located east of Leasburg, Doña Ana County. Regionally, the Hueco Group has been subdivided into four formations termed Shalem Colony, Community Pit, Robledo Mountains and Apache Dam formations; the lower three are exposed in the Doña Ana Mountains. The succession shows a shallowing upward trend from dominantly shallow, open marine conditions (Shalem Colony Fm) to increasingly restricted marine environments (Community Pit Fm) and siliciclastic influx (Robledo Mountains Formation). Sedimentation, particularly siliciclastic influx, was mainly controlled by reactivation of basement uplifts during the last pulses of the Ancestral Rocky Mountains deformation. The microfossils and microfacies of the two first formations are studied in detail here. The Shalem Colony Formation can be divided into a lower biozone with *Triticites pinguis*, which is Newwellian (latest Pennsylvanian, early Wolfcampian) in age, and an upper division characterized by the first occurrence of *Geinitzina*, and lower-middle Asselian (late early Wolfcampian) in age. By comparison with the subdivisions of the Carnic Alps (Austria), the Community Pit Formation is characterized as Sakmarian (middle Wolfcampian) in age due to the first occurrence of the genus *Pseudovermiporella*, and its probable complete phylogeny from *Hedraites*. The late Asselian is restricted to the uppermost part of the Shalem Colony and lowermost part of the Community Pit Formation. Due to the occurrence of *Pseudoreichelina* the Robledo Mountains Formation is dated as Artinskian (late Wolfcampian). Some bioconstructions of *Archaeolithophyllum* are emphasized, as well as some species of foraminifers-globivalvulinids, Miliolata and Nodosariata.

Riassunto. Il Gruppo Hueco delle Doña Ana Mountains (centro-sud New Mexico, USA), di età permiana inferiore, è stato studiato in tre sezioni (A, B, C), situate ad E di Leasburg, Contea di Doña Ana. Il Gruppo Hueco è stato suddiviso su base regionale in quattro formazioni chiamate in ordine ascendente Shalem Colony, Community Pit, Robledo Mountains e Apache Dam. Le tre formazioni più antiche affiorano nelle Doña Ana Mountains. La successione mostra una tendenza alla diminuzione della profondità da prevalenti condizioni marine di acqua basse, ma aperte, (Shalem Colony Fm.) ad ambienti marini confinati (Community Pit Fm.) sino a una importante apporto di silicoclasti (Robledo Mountains Formation). La sedimentazione, e in particolare gli apporti silicoclastici, furono soprattutto controllati da sollevamenti del basamento durante gli ultimi episodi della deformazione denominata Ancestral Rocky Mountains. Sono qui studiati in dettaglio i microfossili e le microfacies delle due formazioni più antiche. La Shalem Colony Formation può essere suddivisa in una biozona inferiore con *Triticites pinguis*, di età Newwelliana (Pennsylvaniano sommitale, Wolfcampiano inferiore). La biozona superiore è caratterizzata dalla prima presenza di *Geinitzina*, ed è di età asseliana inferiore-media (tardo Wolfcampiano inferiore). Confrontando questa successione con le suddivisioni delle Alpi Carniche, la Community Pit Formation viene attribuita al Sakmariano (Wolfcampiano medio) sulla base del primo rinvenimento del genere *Pseudovermiporella*, di cui si ha la probabile completa filogenesi da *Hedraites*. L'Asseliano superiore è limitato alla parte sommitale della Fm. Shalem Colony ed a quella basale della Fm. Community Pit. In base alla presenza di *Pseudoreichelina*, la Formazione Robledo Mountains viene datata come Artinskiano (tardo Wolfcampiano). Vengono poste in particolare evidenza alcune biocostruzioni di *Archaeolithophyllum*, così come alcune specie di foraminiferi appartenenti ai globivalvulinidi, Miliolata e Nodosariata.

Introduction

The Doña Ana Mountains are a westward-tilted fault block located on the eastern margin of the Rio Grande rift, just about 5 km northeast of the Robledo

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Mountains, Doña Ana County, southern New Mexico. The oldest rocks exposed in the Doña Ana Mountains have long been assigned to the Lower Permian Hueco Group (Kottlowski 1960; Seager et al. 1976; Mack et al. 2003), though recent study (Krainer et al. 2005) and the fossils documented here indicate that uppermost Pennsylvanian strata are present in the Doña Ana Mountains.

In this paper we describe the facies and microfossils, particularly smaller foraminifers, calcareous algae and some problematic microfossils, and discuss the depositional environment and biostratigraphy of the Hueco Group in the Doña Ana Mountains.

We studied three sections (A, B, C) in the Doña Ana Mountains that are located east of Leasburg, Doña Ana County. These sections overlap and thus form a composite section of the entire Hueco Group exposed in the Doña Ana Mountains. Location of the studied sections is shown on Fig. 1.

Stratigraphy

Due to the fact that the stratigraphic nomenclature of Hueco strata ("Hueco Formation") in the Robledo Mountains was not consistent with the nomenclature of the Hueco Group used in the Hueco and Franklin Mountains to the southeast, Lucas et al. (1998) presented a new formal nomenclature that is consistent with the regional stratigraphic nomenclature of the Hueco Group. Thus, Lucas et al. (1998) elevated the local Hueco Formation to group status and divided the Hueco Group into four formal formations, which they termed (in ascending order) Shalem Colony, Community Pit, Robledo Mountains and Apache Dam formations (Fig. 2). Krainer et al. (2005) applied the nomenclature of Lucas et al. (1998) to the Hueco strata of the Doña Ana Mountains.

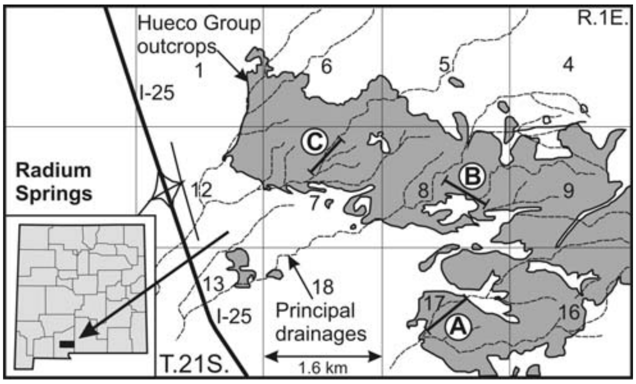
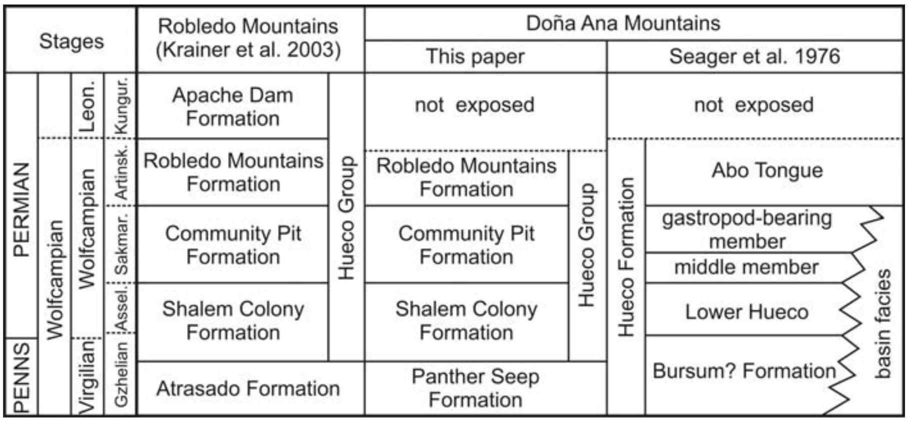


Fig. 1 - Map showing the locations of the studied sections (A, B and C) in the Doña Ana Mountains, New Mexico, USA.

Some fusulinids have been reported from the Shalem Colony Formation of the Robledo Mountains by Wahlman & King (2002). From the upper part of the Shalem Colony Formation in the Doña Ana Mountains, Seager et al. (1976) noted the occurrence of *Schwagerina* and *Pseudoschwagerina* (identified by W.E. King). Fossils, particularly conodonts from the Robledo Mountains Formation, indicate a late Wolfcampian age, and the Apache Dam Formation is probably of earliest Leonardian age, although age-diagnostic fossils have not been reported so far (Lucas et al. 1995a, 1998).

Krainer et al. (2000, 2003) demonstrated that in the Robledo Mountains the "Bursum Formation" of Thompson (1954), which is dated as "Bursumian" (latest Pennsylvanian) by Wahlman & King (2002), is an equivalent of the lower part of the Shalem Colony Formation of Lucas et al. (1998). Lucas et al. (2000) demonstrated that the fusulinid fauna of the Bursum type section indicates an early Wolfcampian age. This is also indicated by the smaller foraminifers of the "Bursum Formation" = Shalem Colony Formation of the Robledo Mountains (Krainer et al. 2003). Thus, the Hueco Group in Doña Ana County, New Mexico can be dated as Wolfcampian to earliest Leonardian (Fig. 2). In the Doña Ana Mountains the Shalem Colony, Community Pit and lower part of the Robledo Mountains Formation are exposed. The upper part of the Robledo Mountains Formation and the Apache Dam Formation have been removed tectonically by faulting along the local eastern margin of the Rio Grande rift.

We identified the strata below the Hueco Group as Panther Seep Formation because these strata differ



Stages				Robledo Mountains (Krainer et al. 2003)		Doña Ana Mountains				
						This paper		Seager et al. 1976		
PERMIAN		Leon.	Kungur.	Apache Dam Formation	Hueco Group	not exposed		not exposed		
	Wolfcampian	Wolfcampian	Artinsk.	Robledo Mountains Formation		Robledo Mountains Formation	Hueco Group	Hueco Formation	Abo Tongue	
			Sakmar.	Community Pit Formation		Community Pit Formation			gastropod-bearing member middle member	basin facies
			Assel.	Shalem Colony Formation		Shalem Colony Formation			Lower Hueco	
PENNS		Virgilian	Gzhelian	Atrasado Formation		Panther Seep Formation			Bursum? Formation	

Fig. 2 - Stratigraphic nomenclature of the Hueco Group (after Lucas et al. 1998).

significantly in lithology from the Bursum and Laborcita formations. Indeed, lithologies of the strata below the Hueco Group in the Doña Ana Mountains are very similar to those of the Panther Seep Formation as described by Kottlowski et al. (1956) in the nearby San Andres Mountains and by Lucas & Krainer (2002) in the Jarilla Mountains. The Panther Seep Formation has been mapped from Mockingbird Gap to the southern end of the San Andres Mountains, and to the northern end of the Franklin Mountains (Kottlowski et al. 1956; Kues 2001; Lucas et al. 2002). The recognition of the Panther Seep Formation in the Doña Ana Mountains therefore only extends its distribution about 30 km to the west.

Facies Description of the Hueco Group, Doña Ana Mountains

Shalem Colony Formation

At the type locality in the Robledo Mountains, the Shalem Colony Formation measures 106 m, but is incomplete. According to Jordan (1971), the total thickness at the type locality is about 183 m.

The Shalem Colony Formation in the studied section A overlies the Panther Seep Formation and measures 63.3 m (Fig. 3). A detailed description is presented by Krainer et al. (2005).

Within the Shalem Colony Formation the following facies types are distinguished:

Limestone conglomerate

A poorly exposed, thin limestone conglomerate resting on nodular limestone is present in the upper part of the section. Due to poor exposure no details could be obtained, so the depositional history – marine or non-marine – is unknown.

Shale with limestone nodules

Also in the upper part of the Shalem Colony Formation in the studied section a poorly exposed interval occurs below the limestone conglomerate that consists of limestone nodules embedded in a matrix of shale. This horizon may be of pedogenic origin.

Shale facies

The intercalated shale intervals and covered slopes are 0.5-5.1 m thick. We assume that all covered slope intervals between the limestones represent shale. The exposed shale is gray and locally contains brachiopods as in the upper part of unit 104 and limestone nodules as in the upper part of unit 89. We interpret the shale intervals to be of shallow marine origin.

Limestone facies with a low-diverse fossil assemblage

This facies is rare and appears as a 0.4 m thick laminated gray limestone in the lower part of the Sha-

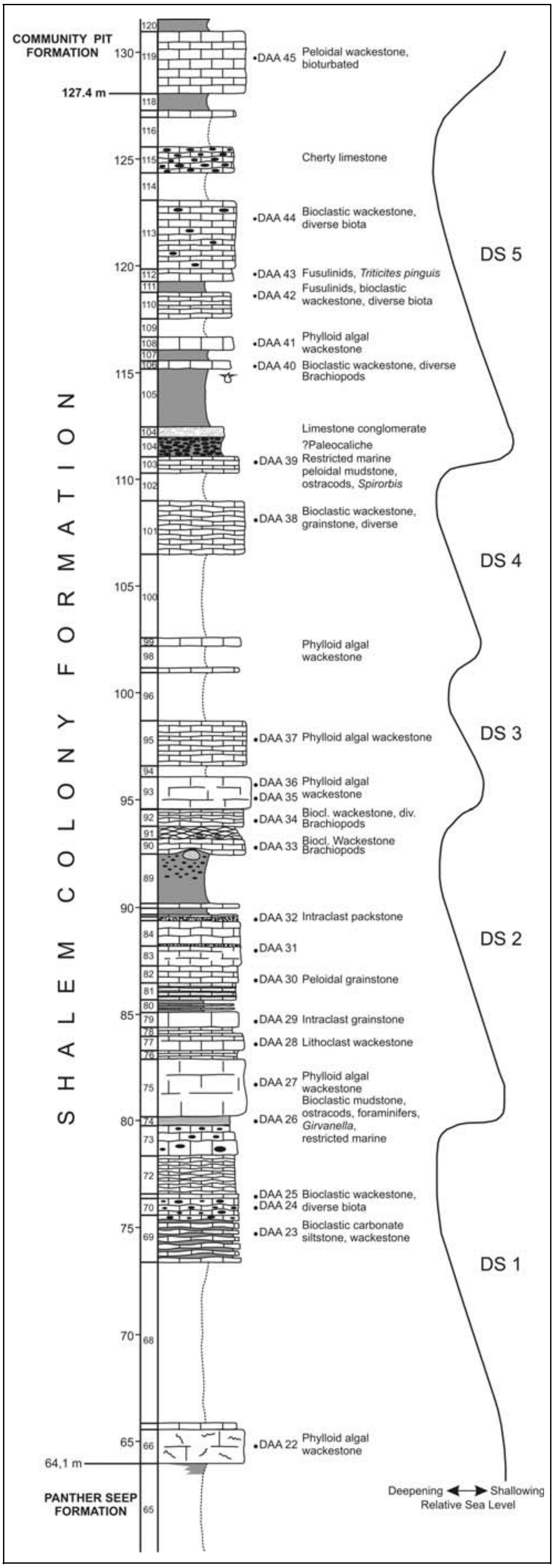


Fig. 3 - Measured stratigraphic section through the Shalem Colony Formation (section A). Thickness in m. Location see Fig. 1.

lem Colony Formation and a 0.8 m thick, indistinctly bedded and indistinctly laminated gray limestone in the upper part. The lower limestone consists of indistinctly laminated bioclastic mudstone containing ostracods. Intercalated is a 1 cm thick layer of foraminiferal wackestone to packstone composed of abundant tubular foraminifers (*Calcitornella/Calcivertella*), many ostracods, shell fragments, rare gastropods and *Girvanella*.

The upper restricted limestone is an indistinctly laminated, locally bioturbated mudstone to peloidal mudstone containing a few ostracods and *Spirorbis*. This facies, with its low-diversity fossil assemblage, is interpreted as a low-energy, shallow restricted platform facies similar to the low energy, shallow restricted platform facies of the Pennsylvanian Paradox Formation (Grammer et al. 1996).

Limestone facies with a diverse fossil assemblage

This is the most common limestone facies of the Shalem Colony Formation and occurs as gray to dark gray, thin- to medium-bedded limestone intervals up to 2.5 m thick. Subordinately, individual limestone beds up to 0.4 m thick occur. Bedding is mostly wavy to nodular, and rarely even. Locally, shale partings or thicker shale intervals occur between individual limestone beds within the limestone intervals.

The typical microfacies is bioturbated, bioclastic wackestone containing a diverse normal marine fossil assemblage of echinoderms (mostly crinoids), brachiopods, bivalves, gastropods, bryozoans, smaller foraminifers, ostracods, *Tubiphytes*, rare dasycladacean algae (*Epimastopora*), fusulinids (*Triticites*), corals and trilobites. The matrix consists of micrite and peloidal micrite. Most of the fossils are broken but lack abrasion. In bioclastic wackestone the skeletons locally display micritic envelopes and are encrusted by cyanobacteria (*Girvanella*) and sessile foraminifers forming small oncoids.

Subordinate are intraclast wackestone and packstone, which occur as thin layers within the bioclastic wackestone facies.

Intraclast wackestone to packstone is poorly washed and poorly sorted, indistinctly laminated and contains some micritic matrix. Most common are peloids and micritized ooids. The fossil assemblage includes shell debris, echinoderms, ostracods and algal fragments.

Intraclast grainstone is poorly sorted, nonlaminated and composed of abundant micritic intraclasts, subordinately of peloids and ooids. Fossils such as shell fragments, echinoderms, bryozoans and smaller foraminifers are present (Pl. 1, fig. 1).

Peloidal grainstone is nonlaminated and contains ostracods and other small skeletons.

Intercalated are also two thin, fine-grained intraclast conglomerates composed of gray micritic intraclasts embedded in a matrix of intraclast wackestone to packstone containing a low-diversity fauna.

This facies, which is commonly characterized by a diverse, normal marine fossil assemblage, is similar to the diverse, low to moderate energy, open platform facies described from the Pennsylvanian Paradox Formation by Grammer et al. (1996). We interpret this facies to have been deposited in a low to moderate energy, open marine platform environment with normal salinity. Rare short periods of higher energy caused deposition of thin layers of grainstone and intraclast conglomerate.

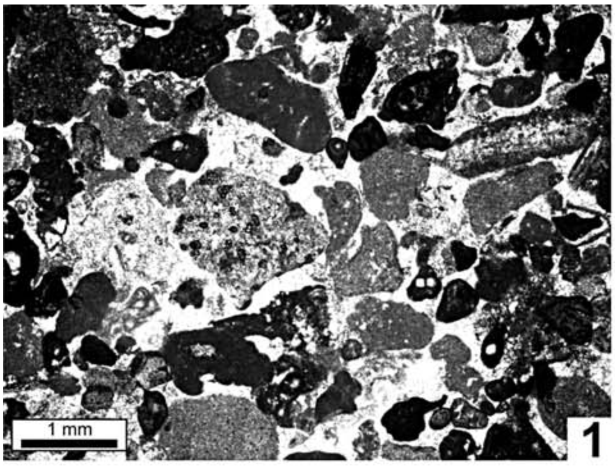
Cherty limestone facies

Cherty limestone is present in the lower and upper part of the studied section and occurs as 0.8- to

PLATE 1

Thin section photographs of microfacies types from limestones of the Hueco Group in the Doña Ana Mountains.

Fig. 1	- Intraclast grainstone composed of abundant gray micritic intraclasts, subordinate are ooids and peloids. Few fossil fragments are also present such as shell fragments, echinoderms and bryozoans. Sample DAA 29, Shalem Colony Formation.
Fig. 2	- Bioclastic wackestone, fine-grained and recrystallized, containing ostracods, smaller foraminifers and recrystallized spicules. Sample DAA 26, Shalem Colony Formation.
Fig. 3	- Phylloid algal wackestone containing completely recrystallized phylloid algae and rare other fossils particularly ostracods and smaller foraminifers. Sample DAA 22, Shalem Colony Formation.
Fig. 4	- Bioclastic wackestone containing a diverse fossil assemblage of shell fragments, bryozoans, smaller foraminifers, echinoderms, gastropods, ostracods and few intraclasts in micritic matrix. Many skeletons are encrusted by cyanobacteria (*Girvanella*). Sample DAA 53, Community Pit Formation.
Fig. 5	- Bioclastic wackestone, fine-grained and bioturbated, containing abundant tubular foraminifers (*Calcivertella* and *Calcitornella*), few other small foraminifers, ostracods, small gastropods and other shell fragments. Sample DAA 48, Community Pit Formation.
Fig. 6	- Ostracod wackestone, bioturbated, containing a low diverse assemblage dominated by ostracods and rare smaller foraminifers and mollusk fragments. Sample DAC 10, Robledo Mountains Formation.
Fig. 7	- Bioclastic wackestone containing a diverse fossil assemblage of mollusk fragments, ostracods, echinoderms, smaller foraminifers, rare bryozoans and echinoderms in micritic matrix. Sample DAC 11, Robledo Mountains Formation.
Fig. 8	- Grainstone containing abundant recrystallized mollusk fragments, ostracods, echinoderms, smaller foraminifers, rare calcareous algae and bryozoans, micritic intraclasts, few peloids and calcite cement. Sample DAC 12, Robledo Mountains Formation.



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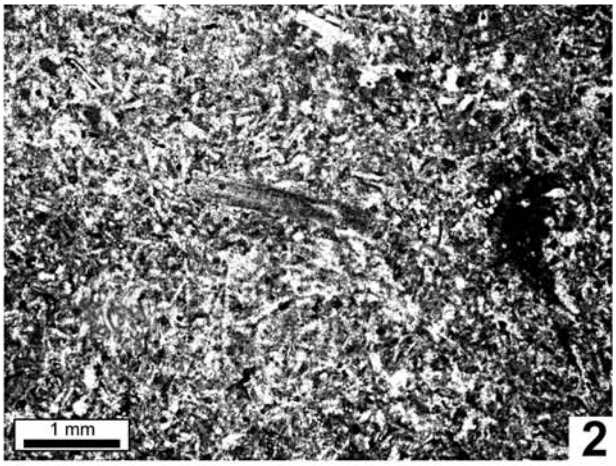

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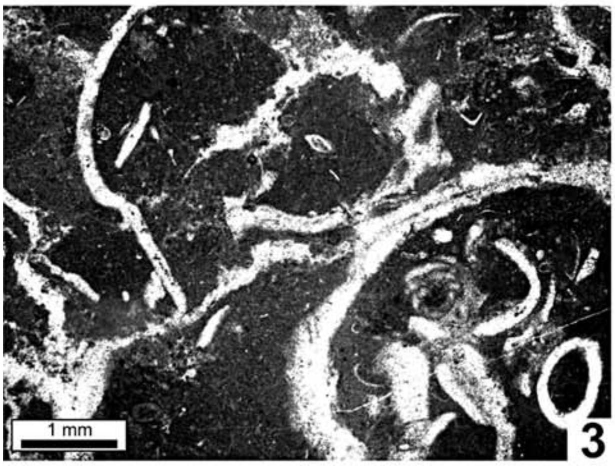

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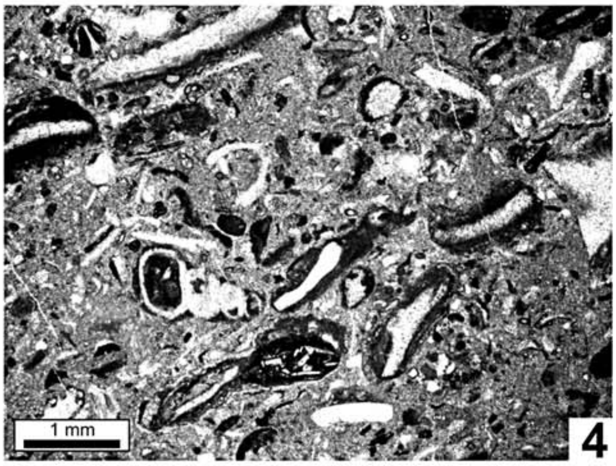

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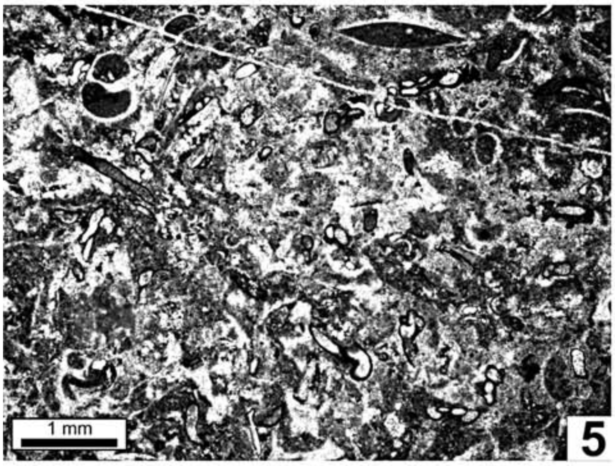

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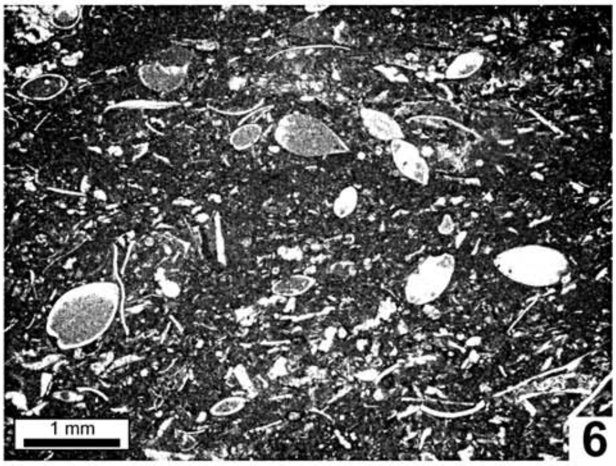

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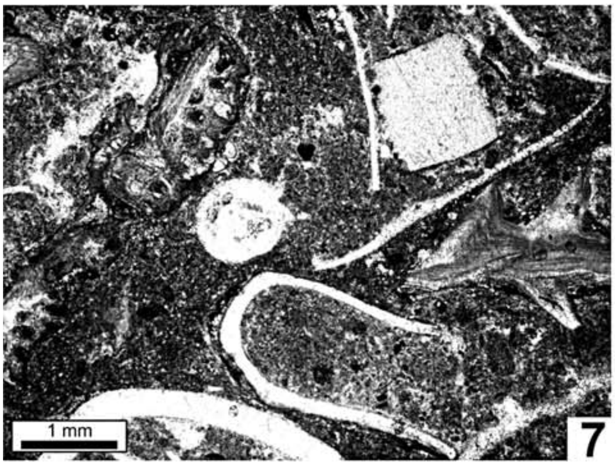

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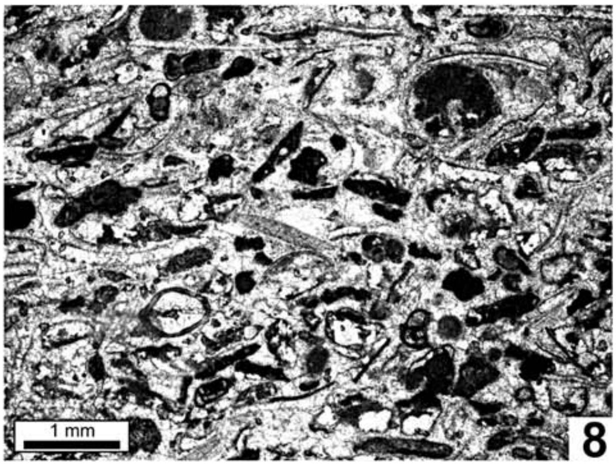

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3.2-m-thick intervals of wavy to nodular bedded, dark gray limestone containing black chert nodules and silicified fossils such as brachiopods, gastropods, crinoids and corals. The microfacies consists of bioclastic wackestone containing a diverse fossil assemblage similar to that of the diverse limestone facies. Additionally, bioturbated bioclastic carbonate siltstone is present containing recrystallized, calcified sponge spicules and ostracods (Pl. 1, fig. 2). This facies, with its typical muddy texture and normal marine fossil assemblage, is interpreted to have been deposited in a low energy, open marine environment below the storm wave base, in a slightly deeper environment than the diverse limestone facies.

Phylloid algal limestone facies

This facies occurs as 0.6 to 2.7 m thick, massive to indistinctly bedded limestone intervals. The typical microfacies is phylloid algal wackestone composed of abundant, completely recrystallized fragments of phylloid algae, some dasycladacean algae (*Epimastopora*) embedded in micritic, locally pelmicritic, matrix that contains a relatively low-diversity fauna composed of shell fragments, echinoderms, bryozoans, smaller foraminifers and ostracods (Pl. 1, fig. 3). Due to complete recrystallization, identification of the phylloid algae is not possible, but most probably it is *Ivanovia*. This codiacean green alga is the most abundant type of phylloid algae in the Yucca Mound Complex of the Holder Formation in the Sacramento Mountains (Wilson 1975; Toomey et al. 1977; Bowsher 1986) and in the Paradox Basin (Pray & Wray 1963; Grammer et al. 1996). But it may also be a phylloid alga related to the genus *Anchicodium,* which is the primary mound-building organism of the Scorpion Mound Complex of the Laborcita Formation (lower Wolfcampian) in the Sacramento Mountains (Cys & Mazullo 1977; Mazullo & Cys 1979; Shinn et al. 1983; Bowsher 1986). *Ivanovia* is thought to have grown in warm, shallow marine settings with low tidal influence at depths of 1 to 10 m (Wray 1968; Toomey et al. 1977).

The phylloid algal limestone forms biostromes; typical mounds (bioherms) composed of algal bafflestones containing phylloid algae in growth position are absent. The phylloid algal wackestone indicates that the algal thalli toppled in-situ or have been transported over short distances by current and/or by wave action in shallow water of depths up to about 10 m.

Within the Shalem Colony Formation, five indistinctly-developed, deepening upward cycles (depositional sequences) are recognized (DS 1 – 5; Fig. 3). Relative sea-level lowstands are represented by phylloid algal limestone and at the base of depositional sequence 2 by a thin interval of laminated limestone composed of bioclastic mudstone containing a restricted fauna. Phylloid algae are believed to have lived in water depths not greater than about 30 m (e.g. Heckel & Cocke 1969; Roylance 1990; Toomey 1976; Toomey & Winland 1973). The base of the uppermost depositional sequence is formed by a restricted marine peloidal mudstone. Relative sea-level highstands are documented by nodular and wavy bedded, partly cherty limestones, which are mostly composed of bioclastic wackestone with a diverse fossil assemblage. The highstand of depositional sequence 2 is probably represented by gray shale, which in the upper part contains limestone nodules. Limestones that formed during relative sea-level highstands were deposited in water depths of a few tens of meters in a low-energy shelf environment below storm wave base. Differences in water depths between lowstands and highstands were within a few tens of meters.

Community Pit Formation

The Community Pit Formation is 59 m thick at the type section in the Robledo Mountains (Lucas et al. 1998), which is nearly complete. Jordan (1971) estimated a total thickness of 61 m.

In the Doña Ana Mountains, the Community Pit Formation measures 107.6 m at section A (Fig. 4), and 156.2 m at section B (see fig. 5 in Krainer et al. 2005), where the base is not exposed. The basal 12.6 m of section C are assigned to the uppermost part of the Community Pit Formation.

At section A the succession is composed of alternating covered intervals (shale) and limestone.

Covered intervals (shale facies)

At section A, shale/covered intervals are 0.5 to 5.1 m thick and constitute about 67% of the total thickness of the section. Shale is rarely exposed and appears as brownish and reddish marly shale in the uppermost part of the section. We assume that the covered intervals that occur throughout the section represent shale and marly shale intervals. At section B shale intervals (mostly covered) constitute about 69%, intercalated siltstone/fine sandstone 9% and limestone 22% of the total thickness. Covered slope/shale units are up to 11.8 m thick. Shale is mostly greenish in color.

Siltstone - fine sandstone facies

This facies is only present at section B and occurs as 0.1 to 4.3 m thick units of reddish to greenish siltstone and fine-grained sandstone. The composition is mixed carbonate-siliciclastic with up to about 50% detrital quartz grains. Typical sedimentary structures are small-scale current ripples and horizontal lamination. Rarely, mudcracks are observed.

Limestone facies

Limestone intervals are 0.1-2.9 m thick, mostly 0.2-1 m at section A and 0.1-1.4 m thick at section B. Thin limestone intervals mostly consist of one limestone bed. Thicker limestone intervals are indistinctly

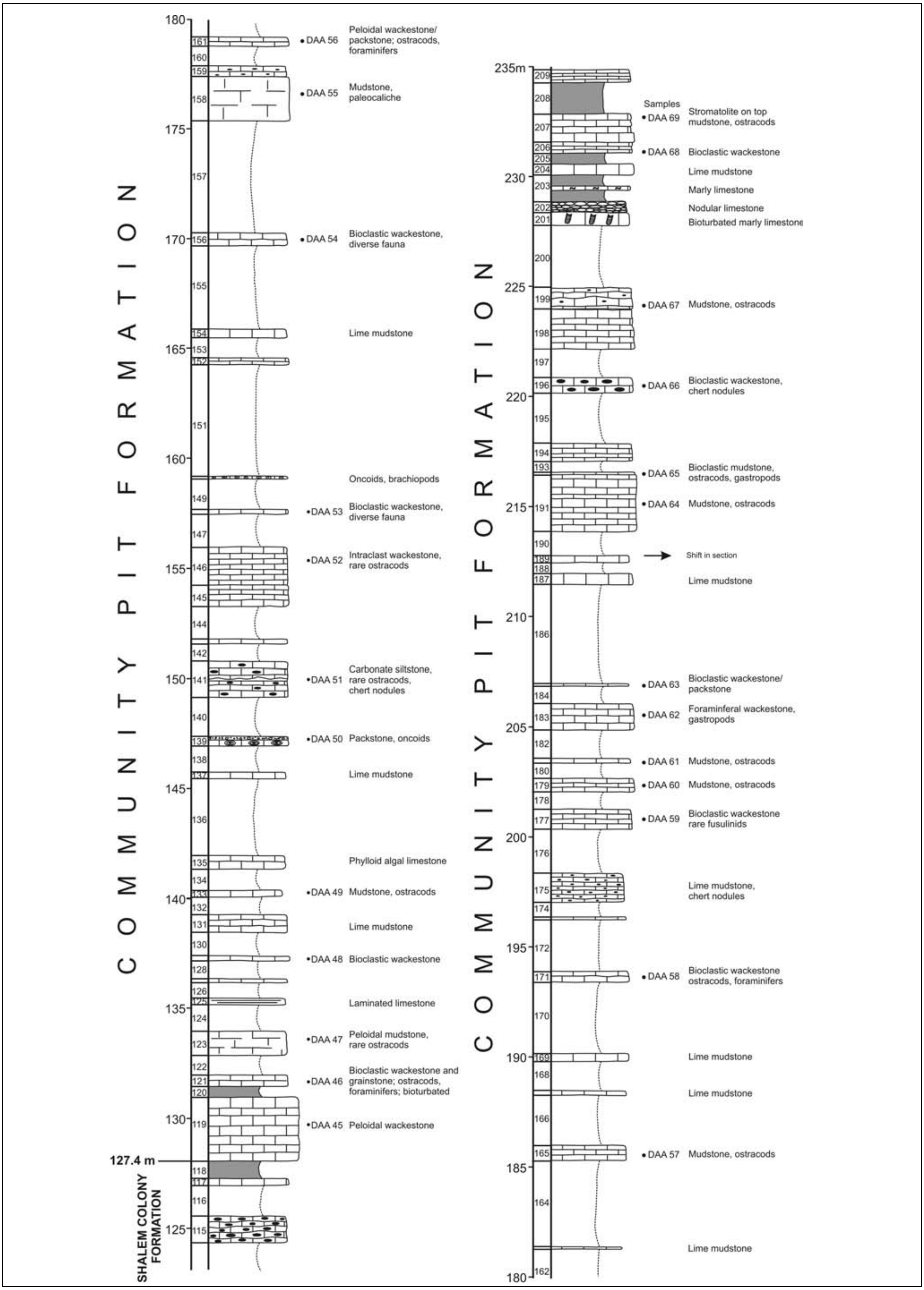

Fig. 4 - Measured stratigraphic section through the Community Pit Formation (section A). Location see Fig. 1.

to well bedded, mostly with even bedding planes. Limestone with wavy bedding and nodular limestone are rare. Bed thickness ranges from 10 to 30 cm, and only rarely are individual limestone beds thicker. Limestone is gray to dark gray and micritic throughout the section.

Based on microfacies analysis most limestones belong to the limestone facies with a restricted fossil assemblage, which is composed of the following microfacies types:

1. Nonlaminated, bioturbated peloidal wackestone containing a low diversity fauna of ostracods, smaller foraminifers, rare *Spirorbis* and other small skeletons.

2. Laminated mudstone, locally bioturbated, containing few ostracods, locally also a few smaller foraminifers, small gastropods and recrystallized spicules. This mudstone may be peloidal.

Other microfacies types include nonlaminated ostracod mudstone and intraclast wackestone. In the middle of the section a nonlaminated peloidal mudstone is exposed that displays circumgranular cracks around peloidal grains and shrinkage fissures. We interpret this mudstone as a paleocaliche formed during subaerial exposure.

The low diversity fauna composed of ostracods and smaller foraminifers (dominantly the tubular foraminifers *Calcivertella* and *Calcitornella*, subordinately *Globivalvulina*, and *Earlandia*, and rare *Nodosinelloides* and *Geinitzina*) and muddy texture point to deposition in a very shallow, low-energy restricted environment.

The limestone facies with a diverse fossil assemblage is mainly composed of bioclastic wackestone, which is commonly nonlaminated, bioturbated and fine-grained. The wackestone contains a diverse fauna composed of smaller foraminifers (locally abundant calcivertellids; *Calcivertella, Cornuspira, Earlandia, Eotuberitina, Geinitzina, Globivalvulina, Nankinella-Pseudoreichelina, Nodosinelloides, Pseudovermiporella*), ostracods, small gastropods, diverse shell fragments, bryozoans, echinoderms, algae (*Epimastopora*), rare *Spirorbis* and very rare fusulinid fragments (*Schwagerina*). Peloids and small detrital quartz grains are present in some beds. Locally abundant mollusk shell fragments and dark gray micritic intraclasts are present (Pl. 1, fig. 4).

Subordinate microfacies types of the diverse limestone facies include bioclastic packstone and foraminiferal wackestone. The fauna is composed of abundant broken shell fragments, tubular foraminfers, subordinate ostracods, echinoderms, bryozoans and small gastropods (Pl. 1, fig. 5). Many peloids and few detrital quartz grains are present, too. Many skeletons display micritic envelopes, and some are encrusted by cyanobacteria. The foraminiferal wackestone contains abundant calcivertellid foraminifers and *Globivalvulina*, rare other foraminifers such as *Geinitzina*, ostracods and small recrystallized skeletons. Rare are limestone beds that contain cm-size oncoids and brachiopods. At section B rare peloidal grainstone and crinoidal wackestone/packstone containing a diverse fauna occur. In the upper part of section C, a 0.3 m thick limestone bed containing small phylloid algal mounds is present. The algal mounds are dome-shaped and composed of crusts formed of *Archaeolithophyllum lamellosum*, *Girvanella* and rare encrusting foraminifers and bryozoans. Laterally, these small mounds grade into bioclastic mudstone. Limestone is locally bioturbated, and rarely laminated. Gastropods are present throughout the section, but more abundant in the upper part (from unit 64 upwards).

This facies is characterized by a diverse normal marine fossil assemblage and muddy texture and is interpreted to have been deposited in a low energy, open marine platform environment with normal salinity. Lithotypes indicating higher energy conditions are very rare. This facies is similar to the normal marine facies of the Shalem Colony Formation, although the fossil assemblage is less diverse.

Cherty limestone facies

This facies is mainly composed of bioclastic wackestone with a low-diversity fauna of smaller foraminifers, ostracods and other recrystallized small skeletons. Intercalated is a thin layer of carbonate siltstone containing a few detrital quartz grains and displaying small-scale ripples. This type contains ostracods and a few recrystallized skeletons.

This facies is similar to the cherty limestone facies of the Shalem Colony Formation but has a less diverse fauna and is also interpreted to have formed in a low energy, open marine environment, probably under slightly deeper conditions than the diverse limestone facies.

Considerable differences exist between sections A and B of the Community Pit Formation. At section B, which is located about 1.5 km north of section A, shale intervals are thicker, and the section also contains siltstone-fine-grained sandstone intervals that are absent in section A. The gastropods, which are abundant in the limestones of section B, particularly in the upper part, are rare to absent in section A. The phylloid algal mound facies of section A is absent in section B, where only one thin interval with small mounds is present in the upper part. Limestones of a shallow, open marine platform environment are more common in section A, and the restricted limestone facies dominates section B, which is also characterized by coarser siliciclastic influx. These differences indicate that sediments of section B were deposited in a more proximal, nearshore environment than section A.

The limestones of the Community Pit Formation of both sections (Fig. 4) were deposited during periods of marine flooding (sea-level highstands) allowing carbonate production on the shallow inner shelf. Carbonate production was repeatedly interrupted by increased influx of siliciclastic sediment during periods of lowered sea-level. Siliciclastic sediments and limestones alternate in an irregular pattern, so a cyclic pattern is not obvious.

Robledo Mountains Formation

The type section of the Robledo Mountains Formation is 125.4 m thick (Lucas et al. 1998). In the Doña Ana Mountains, the Community Pit Formation at section C (Fig. 5) is overlain by a 57.9 m thick sequence of the Robledo Mountains Formation, which is composed of partly covered shale intervals (62.2%) with intercalated siltstone/sandstone (15.5%) and limestone (22.3%). A complete section of the Robledo Mountains Formation is not exposed. The Robledo Mountains Formation is equivalent to the Robledo Mountains Member of Lucas et al. (1995a, b), Krainer & Lucas (1995), the Abo Tongue of Seager et al. (1976), Abo Member of Mack (2007) and Abo Formation of Mack et al. (1988).

The Robledo Mountains Formation in the Doña Ana Mountains is composed of the following facies:

Sandstone - siltstone facies

Sandstone-siltstone intervals are up to 4 m thick and composed of different lithofacies that are colored red to brown.

a) Sandstone is fine-grained, displays trough crossbedding, erosive bases and typical channel geometry. Upward, the sandstone grades into ripple laminated fine-grained sandstone to siltstone.

b) Siltstone intervals display different types of ripple cross lamination and horizontal lamination. Rarely, desiccation cracks are observed.

c) Red mudstone is intercalated between sandstone and siltstone.

From the red beds at the base of the section, Lucas et al. (1995b) reported vertebrate bones and teeth (F 5) and fossil plants (F 4). From a coarse siltstone interval in the middle of the section they reported tetrapod footprints (F 3), and from fine-grained sandstone and mudstone in the upper part (F1 and F 2) tetrapod footprints and fossil plants.

We interpret the thicker, crossbedded sandstone as fluvial channel fill. The thin crossbedded and ripple laminated sandstone-siltstone beds probably represent crevasse splay deposits, and intercalated mudstone overbank deposits. Thicker, ripple laminated intervals may have been deposited in a tidal flat or deltaic environment.

Shale facies

Shale intervals mostly are covered or poorly exposed. Shale is greenish and dark gray in the lower part,

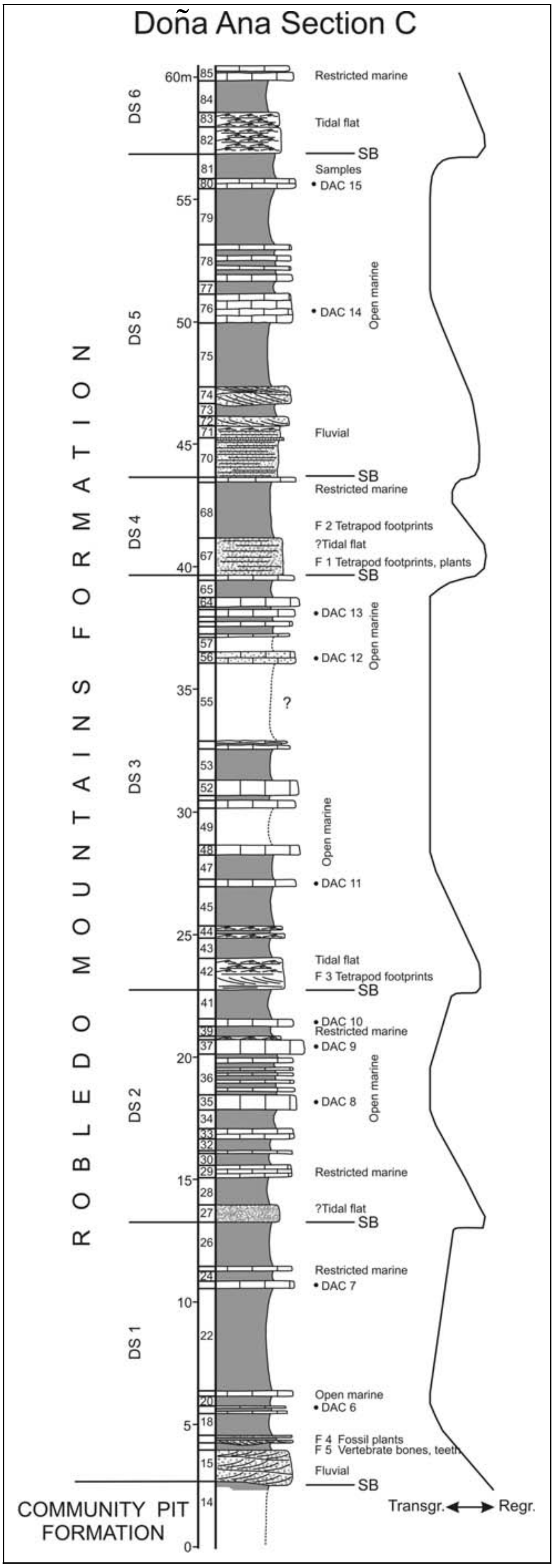

Fig. 5 - Measured stratigraphic section through the Robledo Mountains Formation (section C). Location see Fig. 1.

and greenish and red in the upper part. Red shale occurs particularly in the clastic sequence in the upper part. Shale units are up to 4.2 m thick, mostly < 1.5 m.

Green and dark gray shale is interpreted as marine, and according to Mack (2007) this shale was deposited in the lower shoreface. Red shale associated with red sandstone and siltstone is interpreted as overbank deposits.

Limestone facies

Intercalated limestone commonly occurs as one limestone bed 0.1-0.8, mostly 0.2-0.4 m thick. Evenly bedded limestone intervals up to 1.4 m thick are rare. Cherty limestone is absent. Limestone is dark gray, micritic and bioturbated. Individual limestone beds contain large gastropods and crinoid fragments.

The restricted limestone facies consists of wackestone, packstone and mudstone, with a low diversity fossil assemblage of ostracods and tubular foraminifers (*Calcivertella*), rare other foraminifers such as *Globivalvulina, Nankinella* and *Pseudoreichelina*, rare *Spirorbis*, small mollusk shell fragments and cyanobacteria (Pl. 1, fig. 6). This muddy, low diversity microfacies indicates deposition in a restricted, very shallow low-energy platform environment, probably with increased salinity.

The typical microfacies of the diverse limestone facies is bioclastic wackestone containing a diverse fossil assemblage including mollusc shell fragments, ostracods, smaller foraminifers (*Calcivertella, Earlandia, Eotuberitina, Geinitzina, Globivalvulina, Nankinella, Nodosinelloides, Pseudoreichelina, Pseudovermiporella, Syzrania*), echinoderms, rare fragments of dasycladacean algae (*Epimastopora*), rare *Efluegelia* and calcisponges (Pl. 1, fig. 7). Rarely, grainstone containing a similar fossil assemblage (Pl. 1, fig. 8) and crinoidal packstone occur. Some beds contain gastropods. Near the base of the formation two coquina layers are developed.

The diverse limestone facies is very similar to that of the Community Pit Formation of section C. Texture and the diverse fossil assemblage indicate deposition in an open marine shallow platform setting under mostly low-energy conditions, except for the grainstone and coquina layers, which indicate short periods of turbulent conditions.

According to Mack (2007), the Abo Member (=Robledo Mountains Formation) in the Doña Ana Mountains is approximately 100 m thick and composed of 16-18 fourth order sequences 3-15 m thick, and fifth-order cycles of m-cm scale interbeds of shallow-marine limestone and shale-siltstone. He interprets these cycles to be primarily related to glacio-eustatic sea-level fluctuations caused by the Gondwana glaciation.

The fourth-order sequences start with a fluvial facies, grading into estuarine, lower shoreface shale-siltstone, shallow-marine limestone and peritidal dolomicrite (Mack 2007). However, we did not observe the estuarine facies and the peritidal dolomicrite in the Doña Ana Mountains.

Within the Robledo Mountains Formation (section C) we observed six depositional sequences bounded by sequence boundaries that are drawn at the bases of the clastic intervals (Fig. 5). The clastic sediments are overlain by shallow marine shale with intercalated, restricted to open marine limestone intercalated with shale. The clastic intervals represent periods of relative sea-level lowstands and increased siliciclastic influx. The limestone facies formed during periods when the platform was flooded and under restricted to open marine circulation, and the inter- to subtidal carbonate factory was established producing limestones with a restricted to diverse fossil assemblage. Limestone production was repeatedly interrupted by deposition of shale intervals.

Isbell et al. (2003) pointed out that within Lower Permian (Asselian-Sakmarian) sedimentary successions an abrupt change from glacial to postglacial deposits is recognized, indicating the rapid melting of substantial ice masses during this period. This also indicates that only until this time the waxing and waning of the massive Gondwana ice sheet of Glacial Episode III produced sea-level changes that resulted in the formation of cyclothems. During the Artinskian, i.e., during deposition of the Robledo Mountains Formation, considerable glacioeustatic sea-level changes responsible for the formation of cycles most likely did not occur. Increased siliciclastic influx and sedimentation rates may also reduce accommodation space and thus cause relative sea-level lowstands on the shelf.

We thus interpret the increased siliciclastic influx of "Abo red beds" onto the Hueco shelf to be caused by increased tectonic activity in the hinterland, resulting in increased siliciclastic influx into the Orogrande basin during the Artinskian.

Microfossils

Cyanobacteria

Crusts of *Girvanella* intercalated with bindstones of *Archaeolithophyllum lamellosum* Wray, 1964 are present in the upper part of the Community Pit Formation of section A (Pl. 2, figs 2, 4-5). *Koivaella* was also observed (Pl. 3, figs 8-9, 12). As indicated by Senowbari-Daryan & Flügel (1993), some consortia between *Tubiphytes* and *Koivaella* (*sic* the genus *Rigidicaulis* of these authors) seem to occur in the Shalem Colony Formation (Pl. 3, fig. 7). *Tubiphytes* is itself a consortium between a *Palaeonubecularia* foraminifer and possible cyanobacteria (Vachard & Krainer 2001b; Vachard et al. 2002; Kabanov 2003; Gaillot & Vachard in Gaillot 2006). *Tubiphytes* is a perfectly valid name (Gaillot &

Vachard in Gaillot 2006). True *Tubiphytes obscurus* Maslov, 1956 (Pl. 3, fig. 3) also are present.

Green algae

Epimastopora ex gr. *likana* Kochansky & Herak, 1960 (Pl. 4, fig.16) and *E.* ex gr. *alpina* Kochansky & Herak, 1960 (Pl. 4, figs. 15, 17-18) are characterized by the shapes of their laterals. *E. likana* is cylindrical at each end and inflated in the center; *E. alpina* is subrectangular, and may have a small peduncle at the base (Pl. 4, fig. 18). *Epimastopora* is a perfectly valid name (Gaillot & Vachard in Gaillot 2006). An indeterminate epimastoporellacean is present (Pl. 4, fig. 14), but some laterals seem to be ramified (Pl. 4, fig. 14, right).

Red algae

Crusts of *Archaeolithophyllum lamellosum* built some micro-reefs in the Community Pit Formation of section B. These complex assemblages of *Archaeolithophyllum*, *Girvanella* and *Hedraites* are relatively different from the traditional type of construction of self-encrusting thalli of *A. lamellosum* or are only separated by a fine dark crust without individualized trichomes of girvanellaceans (e.g. Toomey 1969; Flügel & Flügel-Kahler 1980; Wahlman 1988; Skompski 1996; Forke et al. 1998; Krainer et al. 2003), eventually forming some rhodolites (Toomey 1985; Vachard et al. 2000).

Algospongia

These microproblematica are only represented by rare *Claracrusta* and *Efluegelia.* These well-adapted genera are known from the late Viséan to latest Permian (Vachard unpublished data). They were previously reported from New Mexico (Toomey et al. 1977; Krainer et al. 2003).

Smaller Foraminifera: Tuberitinidae

Some Tuberitinidae, which are unquestionably Protista, might belong to another phylum than Foraminifera. A *Tuberitina collosa* Reitlinger, 1950 is illustrated as a good representative of this group.

Biseriamminoidea

Three groups of globivalvulinids, morphologically similar, differ only by the microstructure of the wall: *G.* ex gr. *bulloides* (Brady, 1876) with a homogenous dark wall (Pl. 5, fig. 15); *G.* ex gr. *mosquensis* Reitlinger, 1950 with a two-layered wall (Pl. 4, figs. 6-7); and *G.* cf. *apiciformis* Zolotova in Zolotova & Baryshnikov, 1980 with a thicker, brownish wall (Pl. 4, figs. 5; Pl. 5, figs. 15, 17-20). This kind of wall is not considered as a generic characteristic (Vachard et al. 2006). Globivalvulinids occur in all Hueco Group formations in the Doña Ana Mountains, particularly in the restricted limestone facies.

Other Fusulinata

These fusulinaceans belong to the tolerant superfamily Staffelloidea, with *Staffella* and *Nankinella* (Pl. 4, figs. 4, 8-10, 13). Some forms at the top of the Community Pit Formation represent *Pseudoreichelina* (Pl. 4, figs. 9-10), characteristic of the Artinskian in the Robledo Mountains (Krainer et al. 2003). Rare *Triticites pinguis* Dunbar & Skinner, 1937 were found in our samples, indicating the Newwellian («Bursumian») age of the upper part of the Shalem Colony Formation, correlative of the earliest Wolfcampian *sensu* Wilde (2006, p. 12). A small *Schwagerina* was observed in the middle of the Community Pit Formation at section A.

Attached Miliolata (Nubecularioidea)

The Calcivertellidae *Calcivertella* (Pl. 5, fig. 10); *Calcitornella* (Pl. 5, fig. 12); *Orthovertella* sp. (Pl. 5, fig. 16); *Hedraites plummerae* Henbest, 1963; *Hedraites*? sp. (Pl. 5, fig. 14); and *Pseudovermiporella* sp. 1 and sp. 2 were identified in our collections. As indicated above, a biological part of *Tubiphytes* is related to this group.

Free Miliolata (Hemigordiidae)

Some representatives of this group are *Hemigordius* cf. *discoideus* (Brazhnikova & Potievska, 1948) (Pl. 4, figs 11-12) and *Midiella*? n. sp. (Pl. 4, figs 1-3), already reported from the Robledo Mountains Formation by Krainer et al. (2003, pl. 27, fig. 34) under the name *Hemigordius* sp. 4.

Nodosariata

Many species of *Nodosinelloides* are present, particularly in the diverse limestone facies, subordinately in the restricted limestone facies: *N. netschajewi* (Cherdyntsev, 1914) (Pl. 5, figs 1, 4; Pl. 6, fig. 25); *N.* cf. *pinardae* Groves & Wahlman, 1997 (Pl. 5, fig. 3; Pl. 6, figs 13, 18); *N. longa* (Lipina, 1949) (Pl. 5, figs 5-6; Pl. 6, figs 23); and *N. longissima* (Suleimanov, 1949) (Pl. 6, fig 24, 26-27). The most significant species is *N. longissima.* If compared with smaller *Nodosinelloides*, this species appears with numerous chambers and an omega-shaped base (i.e., with angulatus and nodosity stage compared with the archaediscoids). Contrary to some authors (Groves & Wahlman 1997; Pinard & Mamet 1998; Groves 2000), we think that the Russian species exist and can be distinguished. Other Nodosariata are *Protonodosaria rauserae* Gerke, 1959 (Pl. 6, fig. 19), *Frondicularia* cf. *turae* (Baryshnikov in Baryshnikov et al. 1982) (Pl. 5, fig. 7; Pl. 6, fig. 28) and *Pachyphloia* ? sp. (Pl. 5, fig. 8; Pl. 6, fig. 20). *Geinitzina* is represented by three taxa: true *Geinitzina postcarbonica* Spandel, 1901 (Pl. 6, figs 1-6, 8, 11-12, 14-16, 17, 21, 22), *G.* aff. *postcarbonica* (Pl. 6, fig. 10) and *G.* sp. 2 (Pl. 6, figs 7-9).

Discussion

Wilson & Jordan (1983) described the Hueco limestone as an example of an open shelf marine carbonate facies. Wahlman & King (2002) interpret the lower Hueco member (= Shalem Colony Formation) as deposits of a predominantly offshore, normal marine, shallow shelf environment with a shallowing upward trend from normal marine shelf in the lower part to mostly restricted shallow water inner shelf facies in the upper part. Krainer et al. (2003) listed a number of features from the Shalem Colony Formation of the Robledo Mountains that are diagnostic of an open, well-oxygenated shelf environment with mostly normal marine salinity. A similar, dominantly open marine shelf facies is developed in the Jarilla Mountains (Lucas & Krainer 2002). In the Community Pit Formation the restricted marine facies is more abundant, and there is also some coarse clastic influx, indicating a general shallowing. This shallowing is also observed in the Robledo and Jarilla Mountains (Lucas & Krainer 2002). The shallowing trend culminated in the Robledo Mountains Formation, which contains several horizons of coarser siliciclastics ("Abo red beds") partly deposited in a nonmarine environment.

In New Mexico sedimentation during the Pennsylvanian and Early Permian was strongly influenced by Ancestral Rocky Mountains deformation events. During the Wolfcampian, sedimentation occurred under increasingly arid climatic conditions. Reactivation of Precambrian basement resulted in the deposition of dominantly nonmarine red beds (Cutler Group, Abo Formation and equivalent successions) in northern and central New Mexico. Huge amounts of siliciclastic sediments were transported from the basement uplifts (Uncompahgre, Sierra Grande, Peñasco, Zuni, Joyita and Pedernal uplifts) into the adjacent basins. In central New Mexico, transport direction was mainly towards the south, where at the northern margin of the Orogrande basin the nonmarine Abo red beds interfinger with the shallow marine carbonates and shales of the Hueco Group. In south-central New Mexico, active uplift and rapid subsidence of the Orogrande basin resulted in the deposition of a thick and complex succession of nonmarine and marine sediments during the Early Permian (summary in Kues & Giles 2004; Raatz 2002). The shallowing trend within the Hueco Group results from progradation of the nonmarine Abo red beds towards the south.

In the McLeod Hills, which are located about 50 km NNW of the Doña Ana Mountains, the Wolfcampian is almost completely represented by nonmarine Abo red beds with only a thin horizon of marine sediments. Towards the south (Robledo and Doña Ana Mountains) the Abo red beds interfingers with marine strata of the Hueco Group. The "Abo tongue" (Robledo Mountains Formation) formed during increased siliciclastic influx from the reactivated basement uplifts towards the Orogrande basin.

There is, for example, evidence of tectonic activity in the northern Sacramento Mountains during the early Wolfcampian that strongly influenced sedimentation of the Laborcita Formation on the eastern shelf of the Orogrande Basin (Kottlowski 1963; Otté 1959; Pray 1961). The time-equivalent Shalem Colony Formation of the Robledo and Doña Ana Mountains, which was deposited on the western to northwestern shelf of the Orogrande basin, indicates much less tectonic influence.

Dickinson & Lawton (2003) pointed out that during the Ancestral Rocky Mountain deformation times of peak subsidence are compatible with the inference that the most active deformation migrated from northeast towards southwest (Orogrande and Pedregosa Basin). Peak subsidence and thus tectonic activity in the Orogrande basin occurred during the Virgilian and Wolfcampian (Dickinson & Lawton 2003, fig. 4).

The chronostratigraphic problem related to the interpretation and correlation of the "Bursumian" (Newwellian)-Wolfcampian with the Russian stages (Orenburgian etc.) and the Permo-Carboniferous boundary has been discussed by Krainer et al. (2003). In the Robledo Mountains the Shalem Colony Formation is dated as upper "Bursumian" (Newwellian = Orenburgian) to Asselian. From the Robledo Mountains Formation, Krainer et al. (2003) reported a typical Sakmarian assemblage with *Geinitzina* and *Pseudovermiporella* from section A, early Artinskian in section C indicated by *Pseudoreichelina*, and probably late Artinskian in section B.

Four elements are useful for the biostratigraphy of the Doña Ana Hueco Group sections: *Triticites*, *Geinitzina*, *Hedraites* and *Pseudovermiporella*. Also, the absence of *Pseudovidalina* Sosnina, 1978 (= *Raphconilia* Brenckle & Wahlman, 1992) is noticeable. The other fossils have little importance in the studied interval because they have a long temporal range in the Late Pennsylvanian-early Cisuralian (Kasimovian-Sakmarian distribution).

SYSTEM		STAGE	FORMATION	PROPOSED BIOZONE
PERMIAN	WOLFCAMPIAN	ARTINSKIAN	ROBLEDO MOUNTAINS FORMATION	*PSEUDOREICHELINA* ZONE
		SAKMARIAN LATE ASSELIAN	COMMUNITY PIT FORMATION	*PSEUDOVERMIPORELLA* ZONE
		EARLY - MIDDLE ASSELIAN	SHALEM COLONY FORMATION	*GEINITZINA* ZONE
PENNSYLVANIAN		LATE VIRGILIAN (NEWWELLIAN)		*TRITICITES PINGUIS* ZONE

Fig. 6 - Proposed biostratigraphy of the Shalem Colony, Community Pit and Robeldo Mountains Formation (Hueco Group) in the Doña Ana Mountains.

The upper Shalem Colony Formation in the Doña Ana Mountains is characterized by the presence of *Triticites pinguis*. This species, according to Wilde (2006), is considered earliest Wolfcampian in age. In other words, it can be considered as Newwellian ("Bursumian") in age, i.e., latest Pennsylvanian. As it is coeval with the presence of *Geinitzina*, another marker of the Permian, it is really earliest Permian in age. Concordantly, it is normal to record the absence of *Pseudovidalina,* which is relatively common in the Gzhelian, Orenburgian and/or "Bursumian" (Henderson et al. 1995; Pinard & Mamet 1998; Vachard & Krainer 2001a; Krainer et al. 2003). Many smaller foraminifers are common to the interval late Moscovian-late Sakmarian: Biseriamminoidea, Miliolata, and *Nodosinelloides* spp., as well as the epimastoporellaceans, *Efluegelia* and *Claracrusta*. They do not provide more information here.

The LO (lowest occurrence) of *Geinitzina* in the Shalem Colony Formation indicates that the middle and upper parts of this formation are Permian. This conclusion about the FAD (first appearance datum) of *Geinitzina* was discussed in several publications by Groves (Groves & Wahlman 1997; Groves & Boardman 1999; Groves 2000, 2002). The other species are less significant. *N. netschajewi* is Gzhelian-Kungurian (Groves & Wahlman 1997), *N. pinardae* is Asselian-Sakmarian (Groves & Wahlman 1997) and generally Sakmarian (Pinard & Mamet 1998; Vachard & Krainer 2001b), *N. longa* is Gzhelian-Sakmarian according to Pinard & Mamet (1998) and Vachard & Krainer (2001a), but seems to be abundant only since the late Asselian (Rauzer-Chernousova 1949). *N. longissima* is Orenburgian-Sakmarian (Lipina 1949; Vachard & Krainer 2001a-b; Krainer et al. 2003); its unquestionable presence in northern Spain (see Cózar et al. 2007, fig. 7f under the name *Nodosinelloides*? sp.) necessitates a revision of the Kasimovian age assigned to the series. *Protonodosaria rauserae* is Gzhelian to late Artinskian (Groves & Wahlman 1997), *Frondicularia* cf. *turae* is Sakmarian-Artinskian (Baryshnikov et al. 1982; Vachard & Krainer 2001b), and *Pachyphloia* appears at the base of the Permian (Groves & Wahlman 1997). *Geinitzina postcarbonica* published records are all Permian. *G.* aff. *postcarbonica* is not especially well documented in the literature, or it may correspond to a local variation of *G. multicamerata* Lipina, 1949, known in the Sakmarian of the Carnic Alps (Vachard & Krainer 2001b), and *G.* sp. 2 might be similar to *Geinitzina* sp. A of Groves & Wahlman (1997) from the late Sakmarian of the Barents Sea (Norway).

The Community Pit Formation corresponds more or less to the Sakmarian stage and may include at its base the late Asselian, due to the transition from *Hedraites* to *Pseudovermiporella*. We (Vachard & Krainer 2001b) have demonstrated that in the Carnic Alps, the first *Pseudovermiporella* appear in the Sakmarian, and are questionably associated with *Pseudovermiporella*? cf. *graiferi* (Baryshnikov in Baryshnikov et al. 1982) as early as the late Asselian. This latter species might be congeneric with *Hedraites*? sp. 2 found in this study. Consequently, deposition of the Community Pit Formation began in the late Asselian, but it is mainly Sakmarian in age. Correlatively, the overlying formation can be characterized as early Artinskian in age, due to the presence of *Pseudoreichelina* Leven, 1970. This genus is very useful since it is cosmopolitan, known from the Americas (from Guatemala to Nevada) and Palaeotethys. In Palaeotethys its age was clearly established (Leven 1970; Vachard 1980; Baryshnikov et al. 1982; Ueno 1992; Vachard et al. 1997; Krainer et al. 2003) as early Artinskian (Figs 6, 7).

There is still some discrepancy in the biostratigraphic range of the Robledo Mountains Formation, which in the Robledo Mountains contains Sakmarian and Artinskian assemblages (Krainer et al. 2003), whereas in the Doña Ana Mountains only Artinskian elements seem to be present, and the Sakmarian is represented by the Community Pit Formation (see Fig. 6).

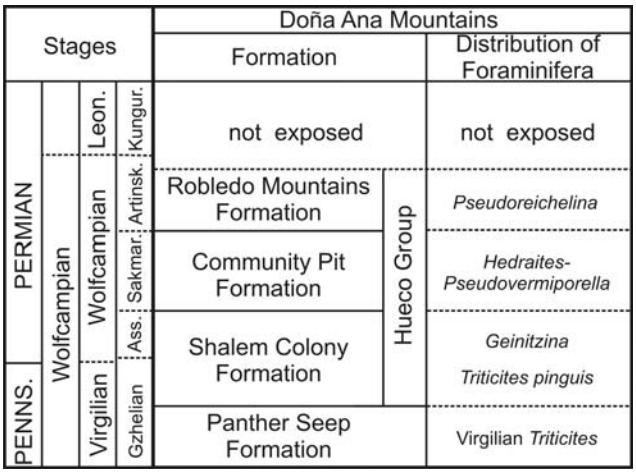

Fig. 7 - Stratigraphy and age of the Hueco Group in the Doña Ana Mountains and distribution of biostratigraphically important foraminifers.

Conclusions

The Hueco Group in the Doña Ana Mountains in south-central New Mexico is divided into Shalem Colony, Community Pit and Robledo Mountains formations; the Apache Dam Formation is not exposed. The Shalem Colony Formation is characterized by limestones of a shallow, open marine shelf environment with a diverse marine fossil assemblage, and intercalated marine shale. Five indistinctly developed, deepening-upward cycles are recognized. The Community Pit Formation is composed of alternating limestone and marine shale. Limestones of a restricted shallow marine environment are more abundant, and there is also some coarser siliciclastic influx, indicating a general shallowing. The overlying Robledo Mountains Formation is a mixed siliciclastic-carbonate succession composed of nonmarine and shallow marine siliciclastic sediments, marine shale and open to restricted marine limestone, which are arranged in cycles. We assume that these cycles are tectonically induced, resulting from reactivation of basement uplifts during the last events of the Ancestral Rocky Mountains deformation and periodically increased siliciclastic influx into the Orogrande basin.

The middle part of the Shalem Colony Formation is characterized by the appearance of *Geinitzina*, more or less correlative with the Carboniferous/Permian boundary. The upper part of the Shalem Colony Formation is characterized by the first acme of *Geinitzina* and the occurrence of *Triticites pinguis*, indicating a Permian age. The fusulinid-bearing horizon in the upper part of the Shalem Colony Formation contains different species of *Triticites*; the identification of *Pseudoschwagerina* by Seager et al. (1976) cannot be supported. The Community Pit Formation, characterized by the first occurrence of the genus *Pseudovermiporella*, and its probable complete phylogeny from *Hedraites*, corresponds more or less to the Sakmarian stage and may include at its base the late Asselian. Correlatively, the overlying Robledo Mountains Formation is early Artinskian in age, due to the presence of *Pseudoreichelina*.

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PLATE 2

Figs 1-6 - *Archaeolithophyllum lamellosum* Wray, 1964. Fig. 1 - Typical bindstone. Community Pit Fm. Sample DAB10a-1, x 20. Fig. 2 - Longitudinal sections with *Girvanella* sp. Community Pit Fm. Sample DAB10a-2, x 33. Fig. 3 - Longitudinal sections with *Girvanella* sp. Community Pit Fm. Sample DAB10a-3, x 28. Fig. 4 - Longitudinal sections with *Girvanella* sp. and *Hedraites plummerae* Henbest, 1963 (silicified). Community Pit Fm. Sample DAB10a-4, x 60. Fig. 5 - Longitudinal sections with domal stromatolites. Community Pit Fm. Sample DAB10b-2, x 12. Fig. 6 - Longitudinal sections with *Hedraites* ? n. sp. Community Pit Fm. Sample DAB10b-1, x 28

PLATE 3

Figs. 1, 5, 6 - *Pseudovermiporella* sp. 1 (silicified). Fig. 1 - Longitudinal section. Community Pit Fm. Sample DAB10b-4, x 30. Fig. 5 - Longitudinal section. Community Pit Fm. Sample DAB10b-5, x 22.5. 4. Fig. 6 - Transverse section. Community Pit Fm. Sample DAB4-4, x 67.

Fig 2 - *Productus* spine with a cyanobacterial (girvanellacean crust). Community Pit Fm. Sample DAC5-3, x 24.

Fig. 3 - *Tubiphytes obscurus* Maslov, 1956. Transverse section. Shalem Colony Fm. Sample DAA42-1, x 14.

Fig. 4 - Crinoid (longitudinal section) with complex crust composed of *Spirorbis* sp. (left, top), cyanobacteria (dark) and *Claracrusta catenoides* (Homann, 1972) emend. Vachard, 1980 (yellowish layers). Community Pit Fm. Sample DAA 53-4, x10.5.

Fig. 7 - *Tubiphytes ("Rigidicaulis")* sp. Longitudinal section. Shalem Colony Fm. Sample DAA38-2, x 23.

Figs. 8-9, 12 - *Koivaella permiensis* Chuvashov, 1974. Various sections. Shalem Colony Fm. Fig. 8 - DAA38-3, x 49. Fig. 9 - DAA38-6, x 67. Fig. 12 - DAA38-5, x 60.

Fig. 10 - *Efluegelia johnsoni* (Flügel, 1966) emend. Vachard in Massa & Vachard, 1979. Community Pit Fm. Sample DAC5-6, x 18.

Fig. 11 - *Pseudovermiporella* sp. 2. Community Pit Fm. Sample DAB13-1, 38.

PLATE 4

Figs. 1-3 - *Midiella*? n. sp. Fig. 1 - Community Pit Fm. Sample DAC3-7, x 75. Fig. 2 - Community Pit Fm. Sample DAC3-2, x 110. Fig. 3 - Community Pit Fm. Sample DAB13-6, x 80.

Fig. 4 - *Nankinella* sp. with truncated lateral sides. Community Pit Fm. Sample DAA54-2, x 30.

Fig. 5 - *Globivalvulina* cf. *apiciformis* Zolotova in Zolotova & Baryshnikov, 1980. Subtransverse section. Community Pit Fm. Sample DAB14-5, x 50.

Fig. 6 - *Globivalvulina* ex gr. *mosquensis* Reitinger, 1950. Axial section. Community Pit Fm. Sample DAC1-7, x 150.

Fig. 7 - *Globivalvulina* ex gr. *mosquensis* Reitinger, 1950. Subtransverse section. Community Pit Fm. Sample DAC1-7, x 135.

Fig. 8 - *Staffella* sp. Recrystallized and abraded axial section. Shalem Colony. Sample DAA 33-3, x 50.

Fig. 9 - *Nankinella* transitional to *Pseudoreichelina* sp. Transverse section. Community Pit Fm. Sample DAC2-6, x 50.

Fig. 10 - *Nankinella* transitional to *Pseudoreichelina* sp. Transverse section. Community Pit Fm. Sample DAC3-10, x 50.

Figs. 11-12 - *Hemigordius* cf. *discoideus* (Brazhnikova & Potievska, 1948). Fig. 11 - Community Pit Fm. Sample DAB7-5, x 150. Fig. 12 - *Hemigordius* cf. *discoideus* (Brazhnikova & Potievska, 1948). Community Pit Fm. Sample DAB7-2, x 100.

Fig. 13 - *Nankinella* or *Staffella*. Shalem Colony Fm. Sample DAA 33-4, x 50.

Fig. 14 - *Epimastopora alpina* Kochansky-Devidé & Herak, 1960. Community Pit Fm. Sample DAC1-4, x 90.

Fig. 15 - *Paraepimastopora*? sp. Shalem Colony Fm., Sample DAA40-1, x 40.

Fig. 16 - *Epimastopora likana* Kochansky-Devidé & Herak, 1960. Shalem Colony Fm. DAA29-5, x 70.

Fig. 17 - *Epimastopora* spp. Community Pit Fm. Sample DAB13-7, x 35.

Fig. 18 - *Epimastopora fluegeli* Kulik, 1978. Community Pit Fm. Sample DAC2-3, x 80.

PLATE 5

Figs. 1, 4 - *Nodosinelloides netchajewi* (Cherdyntsev, 1914). Fig. 1 - Axial section. Community Pit Fm. Sample DAA50-1, x 180. Fig. 4 - Community Pit Fm. Sample DAB6-1, x 205.

Figs. 2, 5-6 - *Nodosinelloides longa* (Lipina, 1949). Fig. 2 - Axial section. Community Pit Fm. Sample DAC5-4, x 200. Fig. 5 - Axial section. Community Pit Fm. Sample DAC3-6, x 130. Fig. 6 - Axial section. Community Pit Fm. Sample DAC3-6, x 195.

Fig. 3 - *Nodosinelloides pinardae* Groves & Wahlman, 1997. Subaxial section. Community Pit Fm. Sample DAA59-3, x 200.

Fig. 7 - *Frondicularia* cf. *turae* Baryshnikov in Baryshnikov et al. 1982. Axial section. Community Pit Fm. Sample DAB 14-1, x 145.

Fig. 8 - *Pachyphloia*? sp. Frontal subaxial section. Community Pit Fm. DAB7-3, x 240.

Fig. 9 - *Tuberitina collosa* Reitlinger, 1950. Axial section. Shalem Colony Fm. Sample DAA25-2, x 70.

Fig. 10 - *Calcivertella* cf. *vaga* Reitlinger, 1950. Subaxial section. Community Pit Fm. Sample DAA46-1, x 45.

Fig. 11 - *Triticites pinguis* Dunbar & Skinner, 1937. Subaxial section. Shalem Colony Fm. Sample DAA 43-1, x 18.

Fig. 12, 14 - *Calcitornella* cf. *latimerensis* (Galloway & Harlton, 1928). Fig. 12 - Axial section. Community Pit Fm. Sample D1AA47-2, x 80. Fig. 14 - *Pseudovermiporella* cf. sp. 2. Community Pit Fm. Sample DAA62-1, x 120.

Fig. 13 - *Hedraites* cf. *plummerae* Henbest, 1963. Transverse section. Community Pit Fm. Sample DAA53-3, x 105.

Fig. 15 - *Globivalvulina* ex gr. *bulloides* (Brady, 1876). Community Pit Fm. Sample DAA66-1, x 100.

Fig. 16 - *Orthovertella* cf. *protae* Cushman and Waters, 1928. Subtransverse section. Community Pit Fm. Sample DAA47-1, x 105.

Fig. 17-20 - *Globivalvulina* cf. *apiciformis* Zolotova in Zolotova & Baryshnikov, 1980. Fig. 17 - Transverse section. Community Pit Fm. Sample DAA59-4, x 105. Fig. 18 - Subtransverse section. Community Pit Fm. Sample DAC2-5, x 130. Fig. 19 - Community Pit Fm. Sample DAB5-3, x 90. Fig. 20 - Community Pit Fm. Sample DAB5-2, x 70.

PLATE 6

Figs. 1-6, 8, 11-12, 14-16, 17, 21, 22 - *Geinitzina postcarbonica* Spandel, 1901. Fig. 1 - Transverse section. Shalem Colony Fm. Sample DAA 36-1, x 170. Fig. 2 - Oblique section Community Pit Fm. Sample DAB5-1, x 100. Fig. 3 - Subaxial section. Shalem Colony Fm. Sample DAA38-1, x 80. Fig. 4 - Oblique section. Community Pit Fm. Sample DAB5-1, x 100. Fig. 5 - Transverse section. Shalem Colony Fm. Sample DAA38-7, x 120. Fig. 6 - Transverse section. Community Pit Fm. Sample DAC5-2, x 150. Fig. 8 - Subaxial section. Community Pit Fm. Sample DAB6-2, x 150. Fig. 11 - Sagittal axial section. Community Pit Fm. Sample DAB7-4, x 200. Fig. 12 - Oblique section. Community Pit Fm. Sample DAA50-2, x 160. Fig. 14 - Sagittal axial section. Community Pit Fm. Sample DAC5-5, x 200. Fig. 15 - Subaxial section. Community Pit Fm. Sample DAB7-6, x 175. Fig. 16 - Subaxial section. Community Pit Fm. Sample DAB6-4, x 155. Fig. 17 - Frontal subaxial section. Community Pit Fm. Sample DAC3-11, x 110. Fig. 21 - Frontal subaxial section. Community Pit Fm. Fm. Sample DAC2-5, x 125. Fig. 22 - Frontal axial section. Community Pit Fm. Sample DAA50-3, x 170. Identification for figs 17, 21 and 22 is doubtful.

Figs. 7, 9 - *Geinitzina* sp. 2. Fig. 7 - Oblique section. Community Pit Fm. Sample DAB9-6, x 70. Fig. 9 - Sagittal axial section. Community Pit Fm. Sample DAB14-3, x 120.

Fig. 10 - *Geinitzina* aff. *postcarbonica.* Sagittal axial section. Community Pit Fm. Sample DAC3-8, x 75.

Figs. 13, 18 - *Nodosinelloides pinardae* Groves & Wahlman, 1997. Fig. 13 - Subaxial section. Community Pit Fm. Sample DAB6-3, x 165. Fig. 18 - Subaxial section. Community Pit Fm. Sample DAB13-2, x 230.

Fig. 19 - *Protonodosaria rauserae* Gerke, 1959. Subaxial section Community Pit Fm. Sample DAB14-4, x 80.

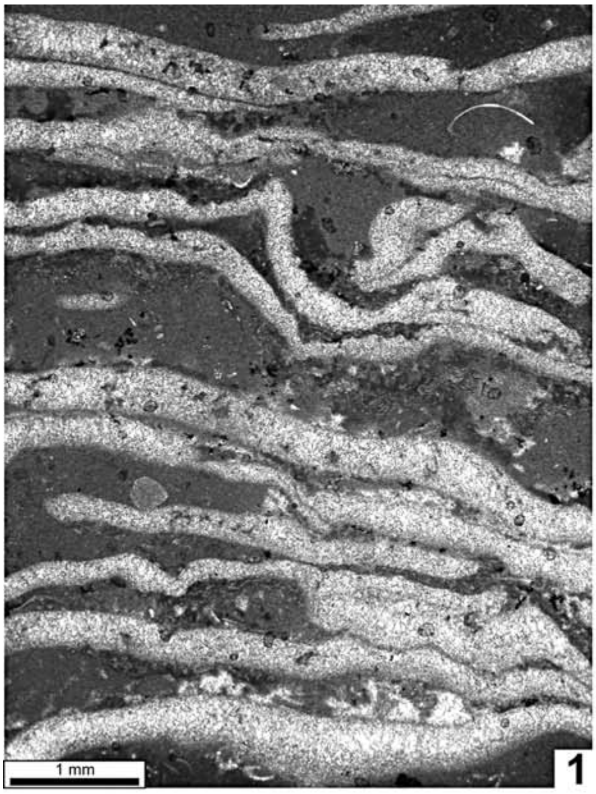
Fig. 20 - *Pachyphloia*? sp. Oblique section. Community Pit Fm. Sample DAC3-1, x 220.

Fig. 23 - *Nodosinellodes longa* (Lipina, 1949). Community Pit Fm. Sample DAA62-2, x 125.

Figs. 24, 26-27 - *Nodosinelloides longissima* (Suleimanov, 1949). Three longitudinal sections. Fig. 24 - Community Pit Fm. Sample DAB7-1, x 130. Fig. 26 - Shalem Colony Fm. Sample DAA42-3, x 80. Fig. 27 - Shalem Colony Fm. Sample DAA41-1, x 65.

Fig. 25 - *Nodosinelloides netschajewi* (Cherdyntsev, 1914). Longitudinal section. Community Pit Fm. Sample DAB6-5, x 140.

Fig. 28 - *Frondicularia* cf. *turae* Baryshnikov in Baryshnikov et al. 1982. Frontal axial section. Community Pit Fm. Sample DAB14-2, x 160.



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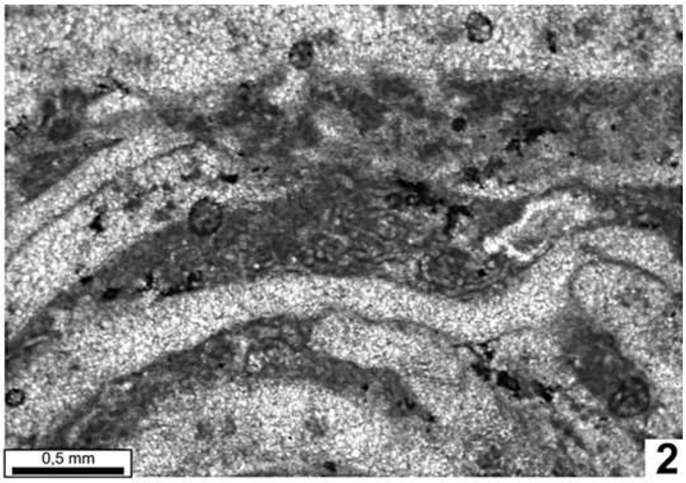

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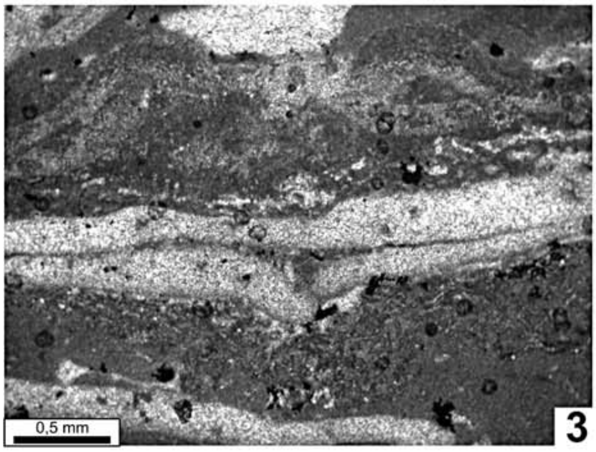

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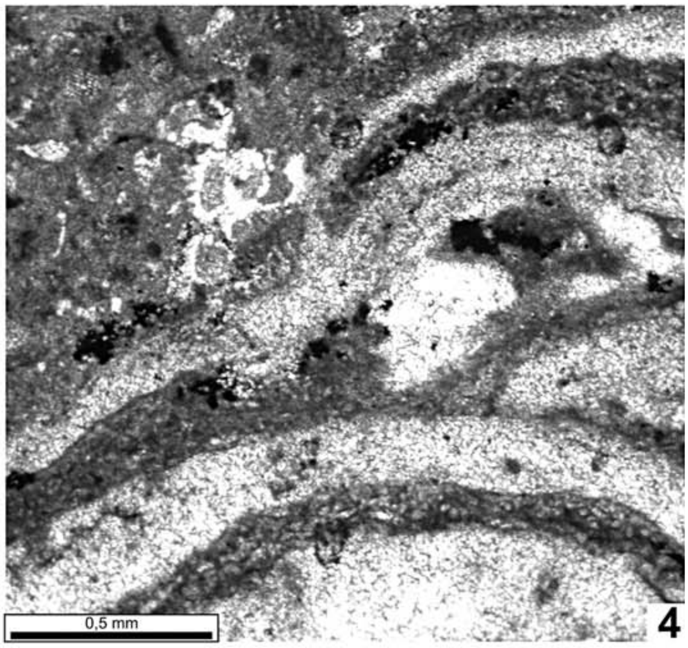

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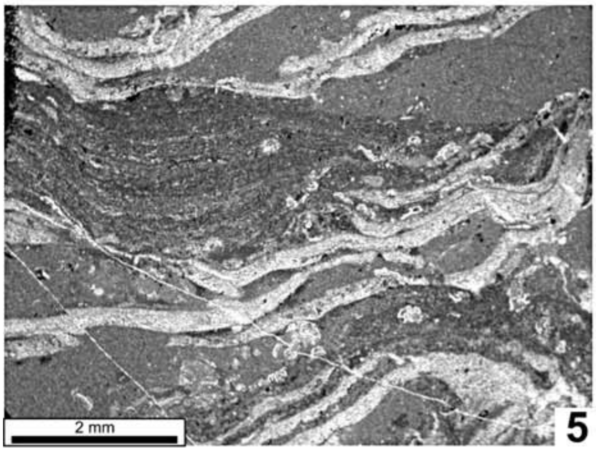

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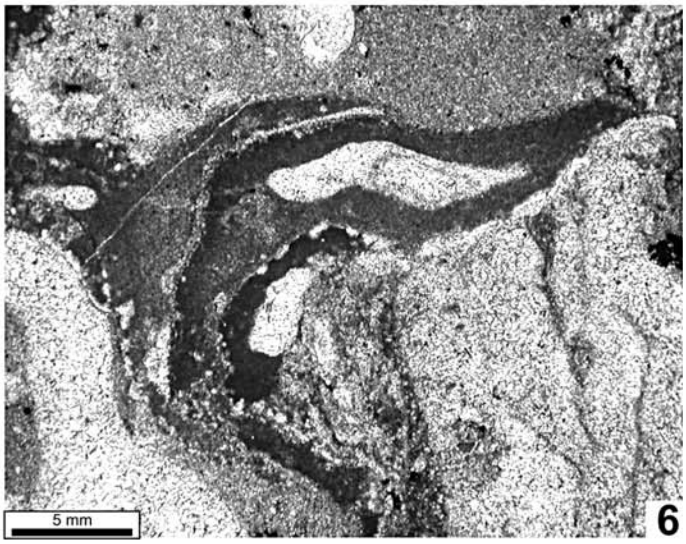

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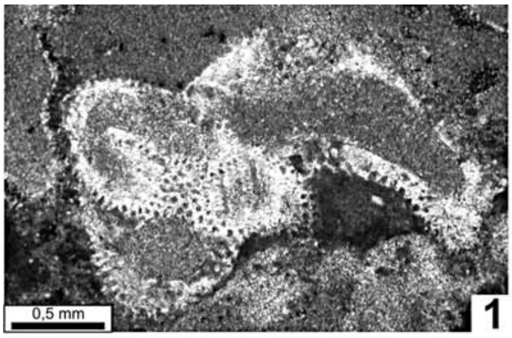
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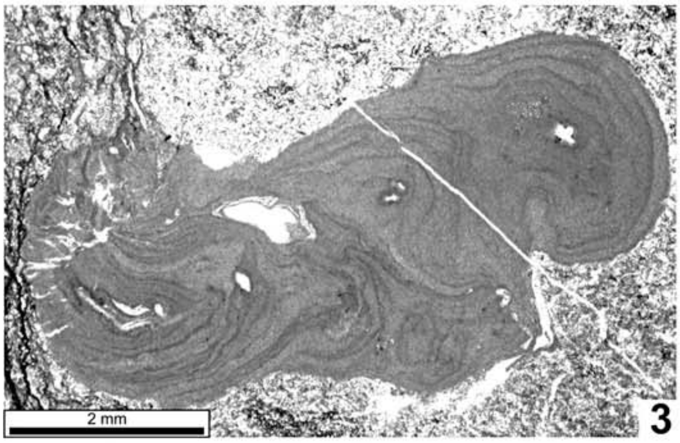
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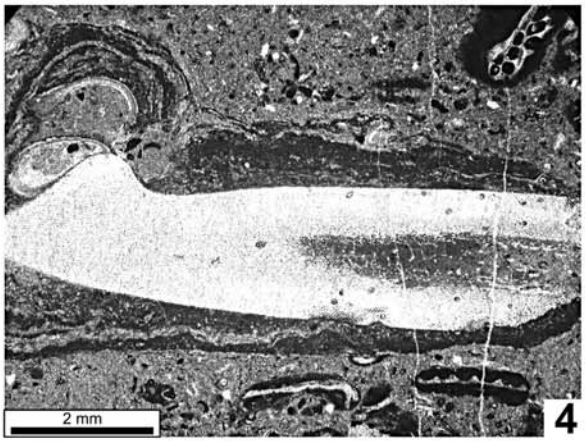
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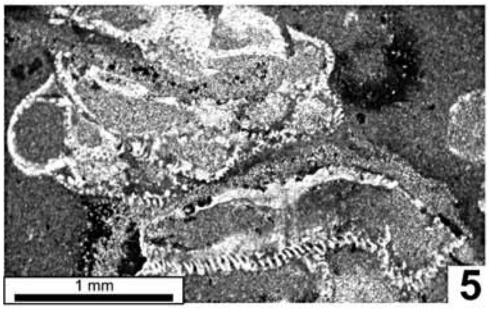
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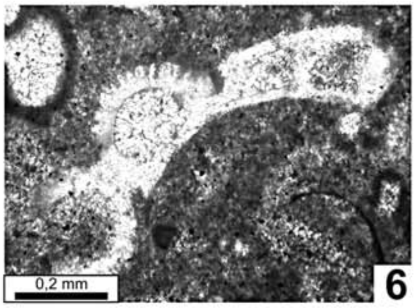
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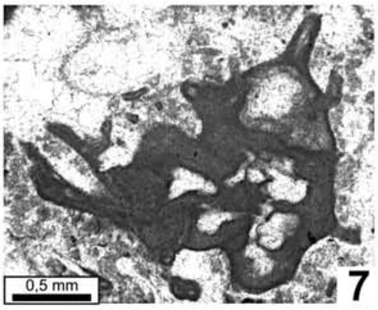
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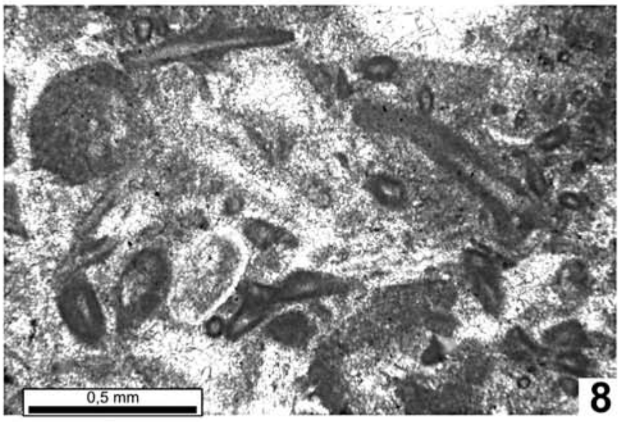
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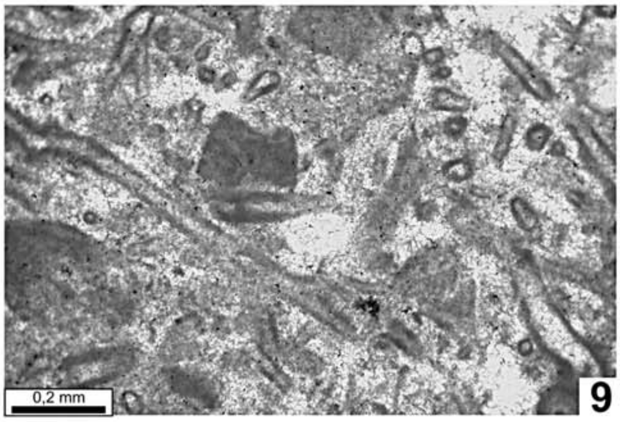
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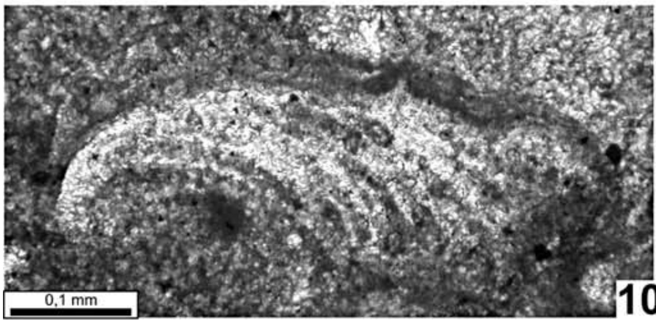
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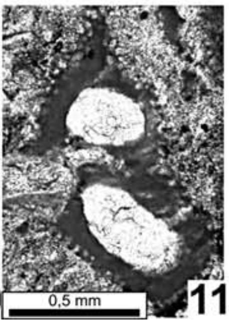
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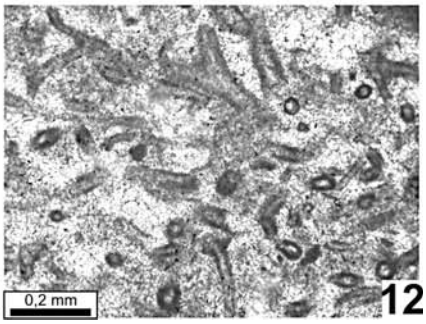
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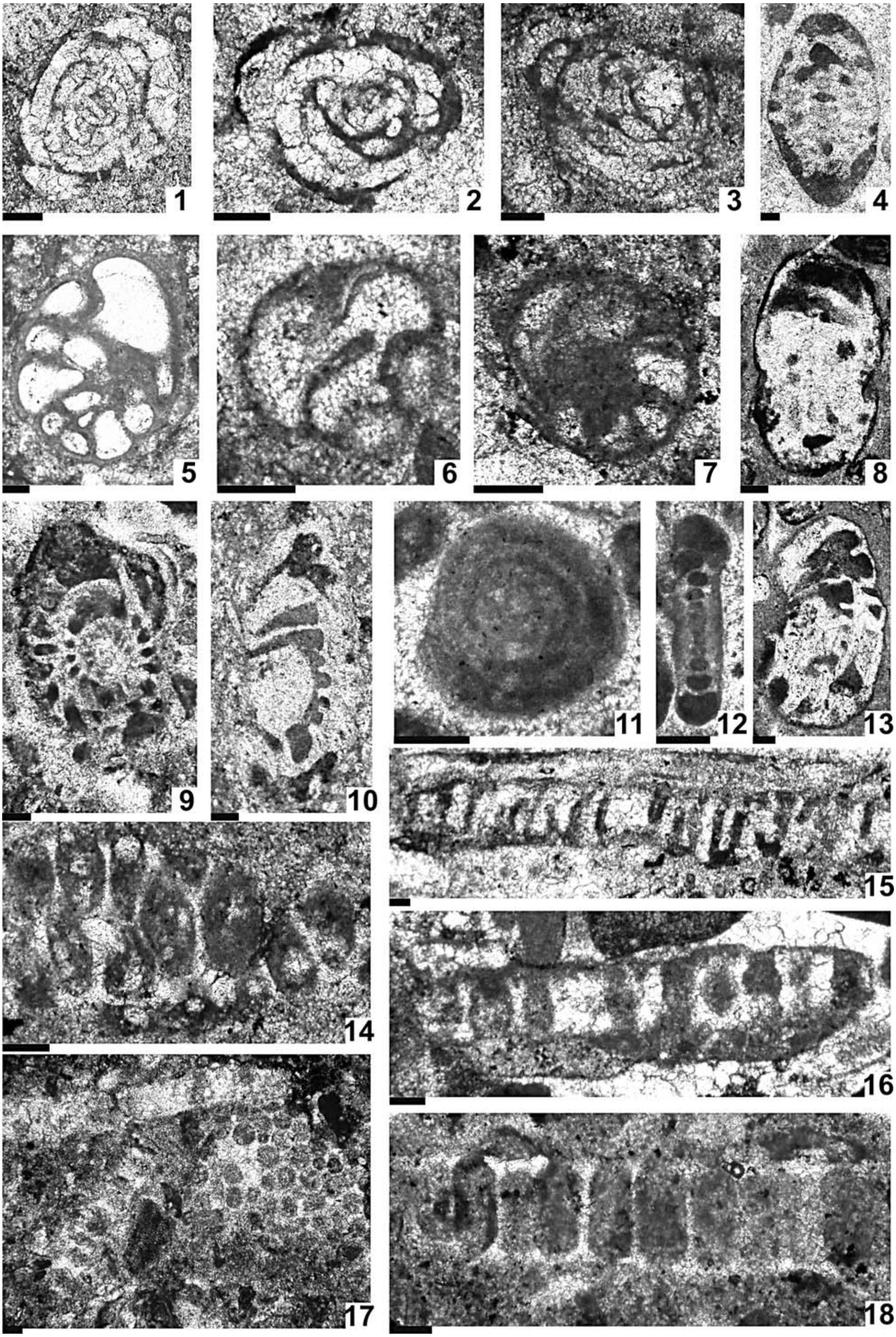

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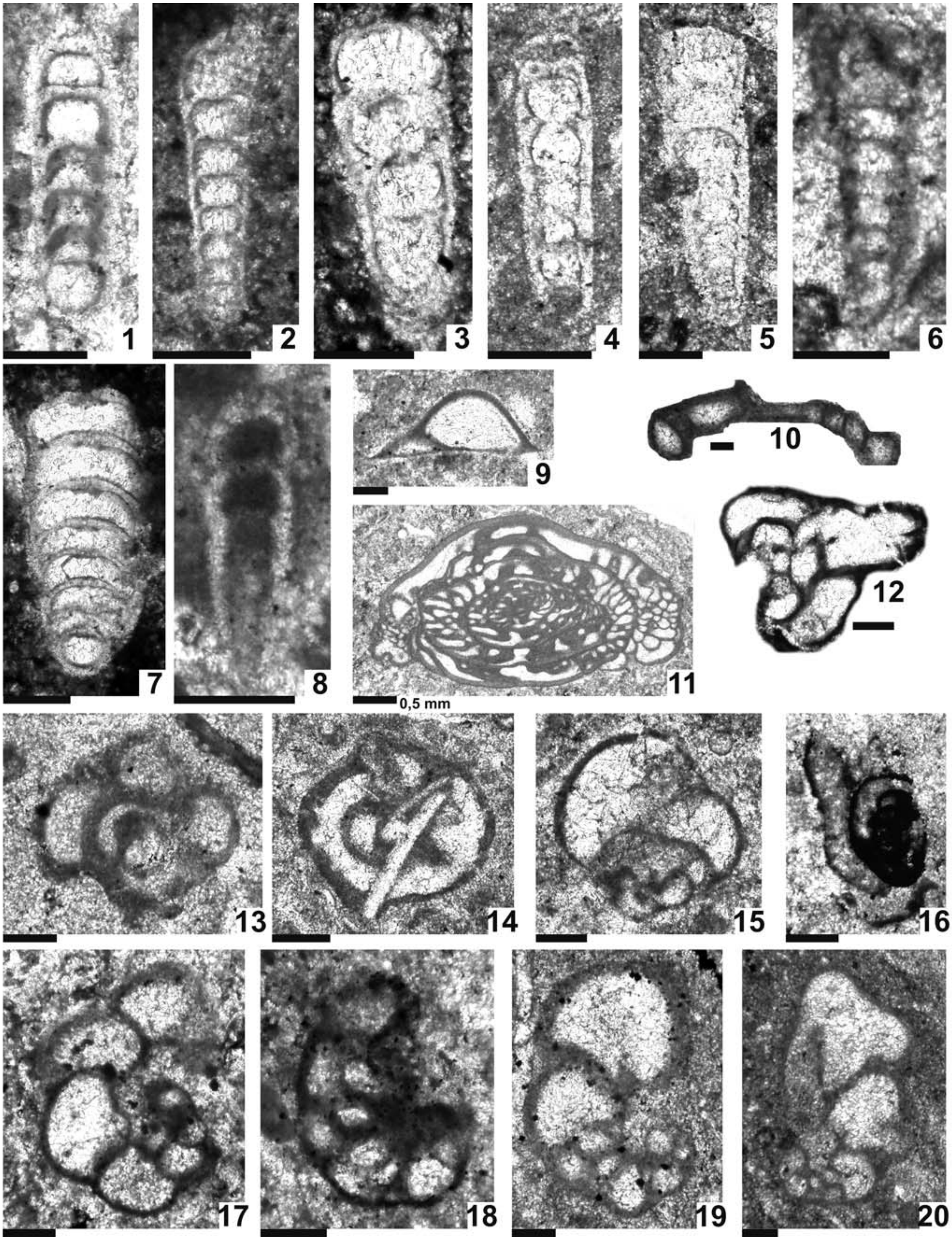

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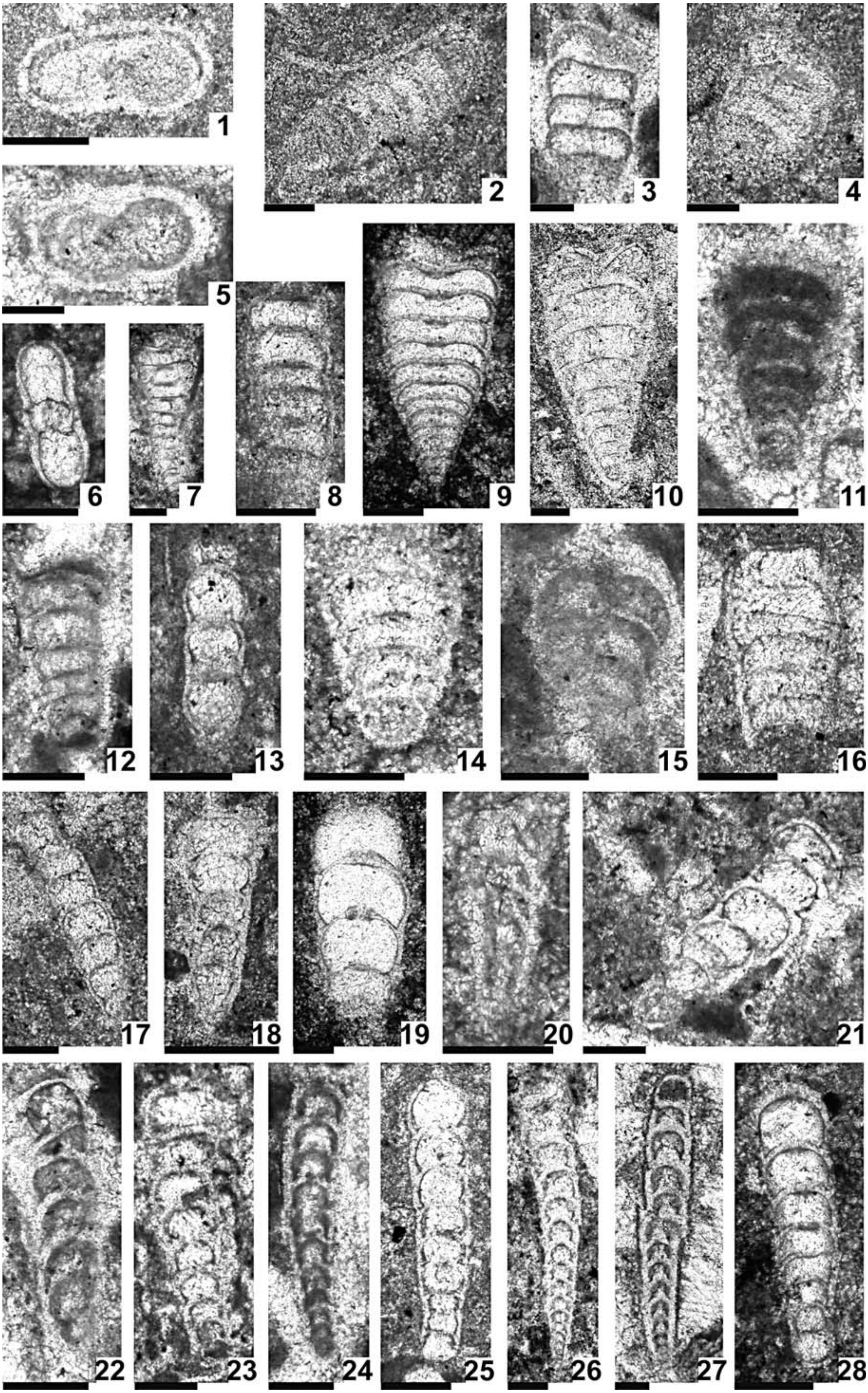

PLATE 6

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