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STRATIGRAPHY AND CORRELATION OF THE LOWER PERMIAN HUECO GROUP IN THE SOUTHERN SAN ANDRES MOUNTAINS, DOÑA ANA COUNTY, NEW MEXICO

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ABSTRACT.— At Little Wells in the southern San Andres Mountains a complete and well exposed section of the Lower Permian Hueco Group is ~ 517 m thick and conformably overlies the Panther Seep Formation and is conformably overlain by the Abo Formation. The Hueco Group strata here are assigned to three formations (ascending order): (1) Shalem Colony Formation, 119-m thick, mostly shale and relatively thick ledges of wackestone that are characteristically cherty and coarse grained; (2) Community Pit Formation, 140-m thick, mostly shale and thin ledges of wackestone and lime mudstone that lack chert and are typically orange or yellow in color; and (3) Robledo Mountains Formation, 258-m thick, mostly shale with intercalated thin beds of red-bed sandstone and wackestone limestone. Microfossils from these Hueco Group strata include calcareous algae, non-fusulinacean and fusulinacean foraminifers and ostracods; macroinvertebrate fossils are mostly brachiopods and gastropods. Tetrapod footprints and the conifer *Walchia* are common fossils in the Robledo Mountains Formation. Correlation of the Hueco Group section at Little Wells across the Rio Grande rift to the Robledo Mountains is relatively straightforward and indicates continuity of Early Permian lithofacies across the western Orogrande basin.

INTRODUCTION

Lower Permian strata of the Hueco Group (Formation) are well exposed throughout the San Andres Mountains in Socorro, Sierra and Doña Ana Counties, New Mexico (Fig. 1). These strata thicken from north to south through the mountain range more than threefold and are, in part, laterally equivalent to the Abo Formation. Much of what we know of these strata is based on the classic work of Kottlowski et al. (1956). Here, we add to this work by describing and correlating an excellent section of the Hueco Group exposed at Little Wells, in the southern San Andres Mountains (Fig. 1).

PREVIOUS STUDIES

Lee (1909, p. 29-30, fig.7) first described Permian strata in the "San Andreas [sic] Mountains" in the northern part of the range at Rhodes Ranch (T145, R2E), but he recognized no Hueco Group strata in this section. Baker (1920, p. 110) also did not use the term Hueco in the San Andres Mountains, but noted that in the southern part of the range the Abo "consists of medium-bedded brown and greenish brown sandstone interbedded with fossilferous limestones" and is "about 1000 ft thick."

Darton (1928, p. 189, p. 40) included Hueco strata in the San Andres Mountains in the Magdalena Group, as "the uppermost portion [which] consists of alternations of limestone and reddish sandy shale which are overlain by Abo sandstone." Dunham (1935, p. 166) also regarded Hueco strata in the San Andres Mountains as part of the "Magdalena Series." Needham (1937, p. 13, 33, 43-45) reported the fusulinaceans *Triticites ventricosus* (Meek) and *T. rhodesi* new species from his locality 22, "along Rhodes Canyon." He identified the stratum of these fossils as "upper black limestones of the Magdalena formation, 400 to 500 feet below the Abo red beds" (p. 44), so it is likely in the Hueco Group.

In a cross section, Thompson (1942, p. 2) first recognized the "Lower Hueco limestone" from Ash Canyon in the southern part of the range through Rhodes Canyon in the northern part of the range. North of that point, Thompson indicated that the Hueco grades laterally into the Abo and Bruton formations.

Thompson (1954, fig. 5) republished his cross section and described two sections of the "Hueco limestone" in the San Andres Mountains: at Rhodes Canyon (fig. 6) and Ash Canyon (fig. 7). Thompson also described Hueco fusulinaceans from these sections, including the new species *Schwagerina andresensis, Pseudoschwagerina rhodesi* and *P. needhami*, all indicative of a Wolfcampian age.

Road logs and articles in the New Mexico Geological Society Sixth Field Conference Guidebook (Anonymous, 1955; Kottlowski, 1955; Kottlowski et al., 1955) reiterated the observations of Thompson (1942, 1954) regarding the Hueco in the San Andres Mountains, but added no new data. Kottlowski et al. (1956) did present new data, based on measured sections of the "Hueco Formation" at Rhodes Canyon, Hembrillo Canyon, Ash Canyon and near Love Ranch. Their observations regarding the Hueco are most of the current knowledge of the unit in the San Andres Mountains, and subsequent publications (e.g., Kottlowski, 1963; Jordan, 1975; Mack and James, 1986; Kottlowski and LeMone, 1994; Lucas et al., 1998) are based largely on their work.

An exception is Bachman and Myers (1969), who mapped the Hueco in the Bear Peak area in the southern part of the range and interpreted the intertonguing of the Abo and Hueco formations (their fig. 5). Thus, in the Bear Peak area, they identified lower and upper tongues of the Hueco separated by a lower tongue of the Abo Formation (Fig. 3). According to Bachman and Myers (1969, pl. 1), this lower Abo tongue pinches out just south of Little Wells at the boundary of T19S and T20S.

Seager (1981) divided the Hueco Formation in the southern San Andres Mountains into three informal members that he also recognized in the Doña Ana and Robledo Mountains to the west:

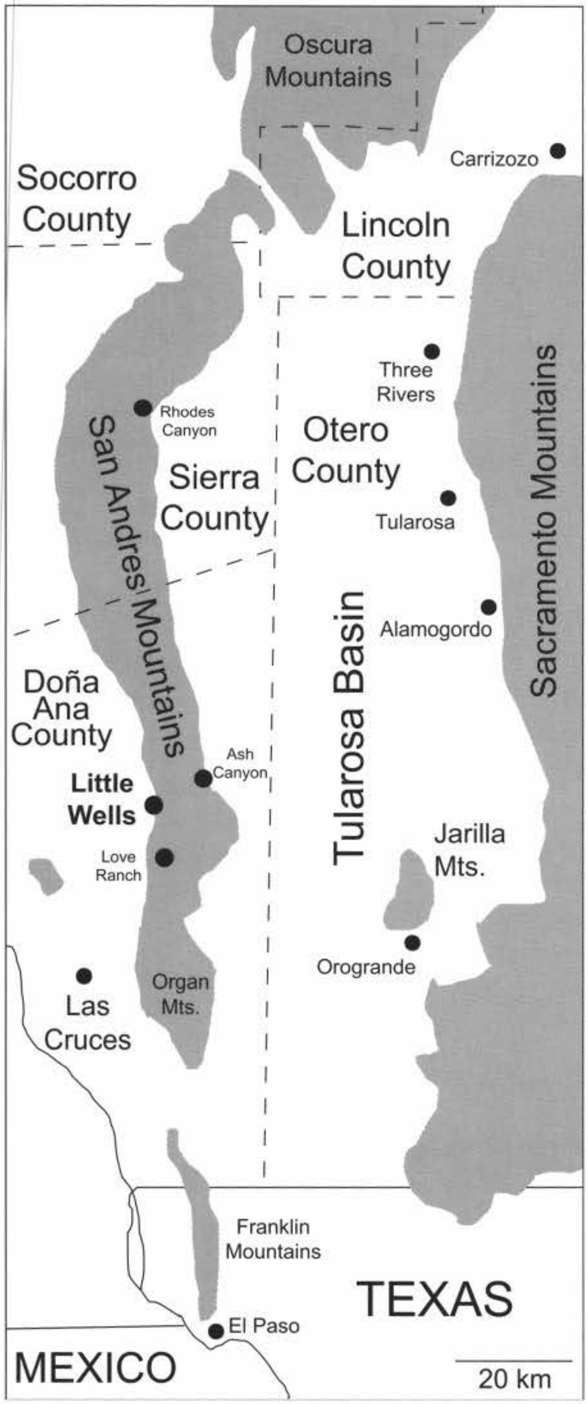


FIGURE 1. Index map of San Andres Mountains showing location of Hueco Group section at Little Wells and some other locations mentioned in the text.

LOCATION

We base our interpretation of the Hueco Group in the southern San Andres Mountains primarily on an excellent, previously undescribed section near Little Wells, in the N 1/2 sec. 31, T 19S, R 4 E, Doña Ana County (Figs. 1-2). This outcrop, along the western front of the range about 4.4 km WSW of the mouth of Ash Canyon, is in the area mapped by Bachman and Myers (1969) and well exposes a complete and fossiliferous section of the Hueco Group about 517 m thick.

LITHOSTRATIGRAPHY

We agree with Seager (1981) that Hueco Group stratigraphy in the southern San Andres Mountains is very similar to that in the Doña Ana and Robledo Mountains to the west. Therefore, in the southern San Andres Mountains, we apply the formal nomenclature of the Hueco Group introduced in the Robledo Mountains by Lucas et al. (1995a, 1998) (Fig. 3). In this nomenclature, the lower unit of the Hueco is the Shalem Colony Formation, and the middle unit is the Community Pit Formation. The "intertongued Abo-Hueco" and "Abo-Hueco member" of previous workers is the Robledo Mountains Formation. The base of Bachman and Myer's (1969) "lower tongue of the Abo Formation" is the base of the Robledo Mountains Formation. Therefore, their "lower Abo tongue" and their "upper Hueco tongue" are equivalent to the Robledo Mountains Formation. The uppermost unit of the Hueco Group in the Robledo Mountains, the Apache Dam Formation, is not present in the southern San Andres Mountains. Instead, the Abo Formation overlies the Robledo Mountains Formation in the San Andres Mountains.

Kottlowski et al. (1956, p. 49-53, 121-123, fig. 9) described a section of the Hueco Group near Love Ranch in the southern San Andres Mountains. This section, mostly in sec. 17, T20S, R4E, is only about 6-7 km SSE of the Little Wells section. We have examined Kottlowski et al.'s Love Ranch section of the Hueco, and it lower and middle members and "intertonguing Abo-Hueco" (Fig. 3). Mack and James (1986) employed this stratigraphy (they referred to the upper member as "Abo-Hueco member"), and Seager et al. (1987) mapped it in the southern San Andres Mountains as far north as Hembrillo Pass.

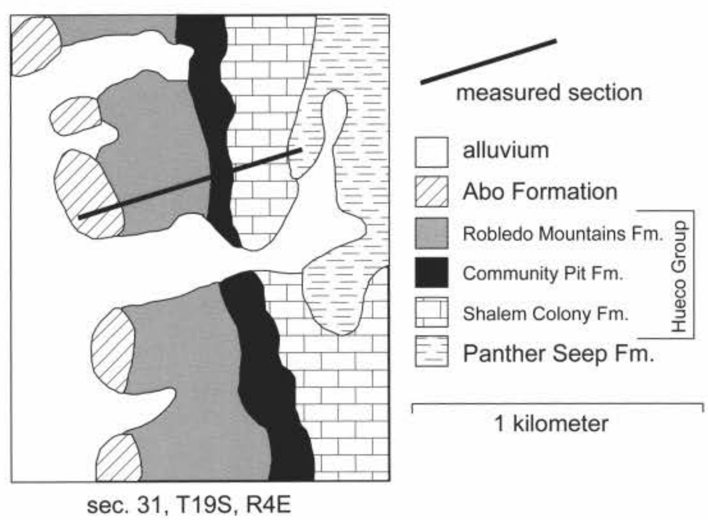


FIGURE 2. Geologic map of the Little Wells section.

Kottlowski et al. (1956)	Bachman and Myers (1969)	Seager (1981)	this paper	
Abo Formation	Abo Formation	Abo Formation	Abo Formation	
Hueco Formation	upper tongue of Hueco Fm.	Abo-Hueco	HUECO GROUP	Robledo Mountains Formation
	lower tongue of Abo Formation	middle Hueco Limestone		
	lower tongue of Hueco Formation			Community Pit Formation
		lower Hueco Limestone		Shalem Colony Formation
Panther Seep Fm.	Panther Seep Fm.	Panther Seep Fm.	Panther Seep Fm.	

FIGURE 3. Comparison of previous stratigraphic nomenclature of the Hueco Group in the southern San Andres Mountains with that advocated in this paper.

is poorly exposed relative to the Little Wells section. The 413-m Love Ranch section can, nevertheless, be assigned to the Shalem Colony (units L14-L19 of Kottlowski et al., about 61 m thick), Community Pit (units L20-L50, about 198 m thick) and Robledo Mountains (units L52-L77, about 152 m thick) formations.

Seager (1981, p. 31-32, fig. 32, sheet 3) stated that the Hueco Limestone ranges from 434 to 579 m thick in the San Andres Mountains and central Organ Mountains. His lower member of the Hueco is characterized by cherty, sandy, algal and oolitic limestones and clearly is the same unit we term Shalem Colony Formation. The base of Seager's middle member of the Hueco is a "bright orange" lime mudstone, and the overlying ~152-m thick unit is mostly thin limestones and shale. Seager (1981, p. 32) chose the base of his "intertonguing Abo-Hueco member" at the "base of the lowest shale-siltstone unit of the Abo that is at least 10-20 ft thick." This means that his middle member not only is equivalent to our Community Pit Formation, but it includes strata of the lower part of the Robledo Mountains Formation (Fig. 3).

Subdivisions of the Hueco are readily mapped in the southern San Andres Mountains (e.g., Fig. 2; Bachman and Myers, 1969; Seager et al., 1987), and the term Hueco is used as a unit of group rank at its type section in the Hueco Mountains of west Texas, and elsewhere (Lucas et al., 1998). Therefore, we use the term Hueco Group in the southern San Andres Mountains, and regard its subdivisions, which are readily mappable at 1:24,000 scale, as formations.

The Hueco Group section at Little Wells (Fig. 4) has a total thickness of 517 m and we divide it into three formations (ascending order): Shalem Colony, Community Pit and Robledo Mountains formations. The Shalem Colony Formation is 119 m thick and rests with apparent conformity on the underlying Panther Seep Formation. Most of the Shalem Colony Formation is covered slopes of shale (44% of the measured section) and relatively thick (2-11 m) ledges of wackestone (35% of the measured section). Cherty limestones are characteristic of the unit, as are coarse-grained limestones, such as skeletal sandstones, grainstones and rudites. Lime mudstone (10% of the measured section) is a minor lithotype. The topographic expression of the Shalem Colony Formation also is characteristic—it forms a prominent topographic ridge between slope-forming strata of the underlying Panther Seep and overlying Community Pit formations. The Shalem Colony-Panther Seep contact is between olive gray slope-forming shale and thin grainstone of the upper Panther Seep, and cliff-forming, phylloid algal biohermal limestones at the base of the Shalem Colony Formation. The Shalem Colony-Community Pit formations contact is between a thick ledge of Shalem Colony lime wackestone, and slope-forming shale and thin (<1 m) ledges of grayish orange wackestone and lime mudstone of the Community Pit Formation. The changes in color, lithotype and topographic expression between the Panther Seep, Shalem Colony and Community Pit formations allow their formational contacts to be readily mapped (Fig. 2).

At Little Wells, the Community Pit Formation is 140 m thick and is mostly covered shale slopes (67% of the measured section) and relatively thin ledges (mostly <1 m) of wackestone (15%), lime mudstone (9%), and grainstone (7%). Limestones of the

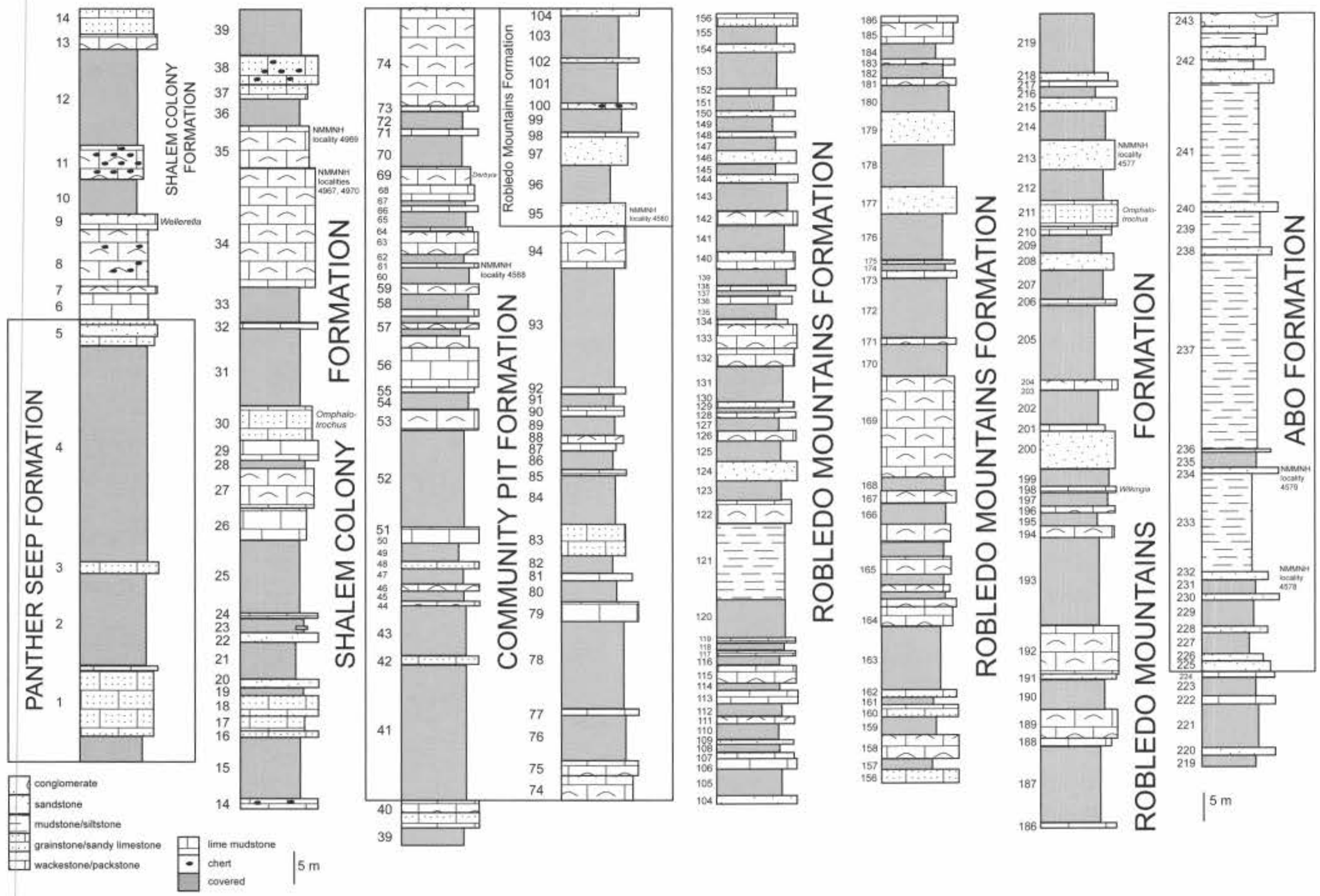


FIGURE 4. Measured stratigraphic section of the Hueco Group at Little Wells. See Appendix for descriptions of numbered lithologic units.

Community Pit Formation are distinguished from those of the Shalem Colony Formation primarily by thinner beds, lack of chert, abundant gastropods and orange, yellow and brown coloration. The Community Pit Formation crops out as a slope/valley, and its upper contact is readily mapped at the red-bed sandstone that marks the base of the overlying Robledo Mountains Formation.

Most of the thickness of the Hueco Group at Little Wells is composed of the 258-m thick Robledo Mountains Formation. The majority of this unit (66% of the measured section) is slope-forming covered intervals underlain by shale, mudstone or siltstone. Beds of red shale and siltstone are common in the lower and middle parts of the formation. Ledge-forming units usually are thin (<1 m thick) beds of red-bed sandstone (10% of the measured section) and lime wackestone (16% of the section) and minor beds of yellowish lime mudstone (2%), grainstone (<1%) and crinoidal conglomerate (<1%). The Robledo Mountains Formation is a slope and valley former, and its contact with the overlying Abo Formation is at the top of the stratigraphically highest marine limestone of the Robledo Mountains Formation.

Overlying the Robledo Mountains Formation at Little Wells are about 80 m of well exposed siliciclastic red beds of the Abo Formation. Most of the Abo is mudstone and siltstone slopes, largely covered (92% of the section). Sandstone beds, almost all less than 1 m thick, are about 6% of the section, and there is a single bed of conglomerate. The total thickness of the Abo Formation at Little Wells is estimated at ~114 m (Bachman and Myers, 1969).

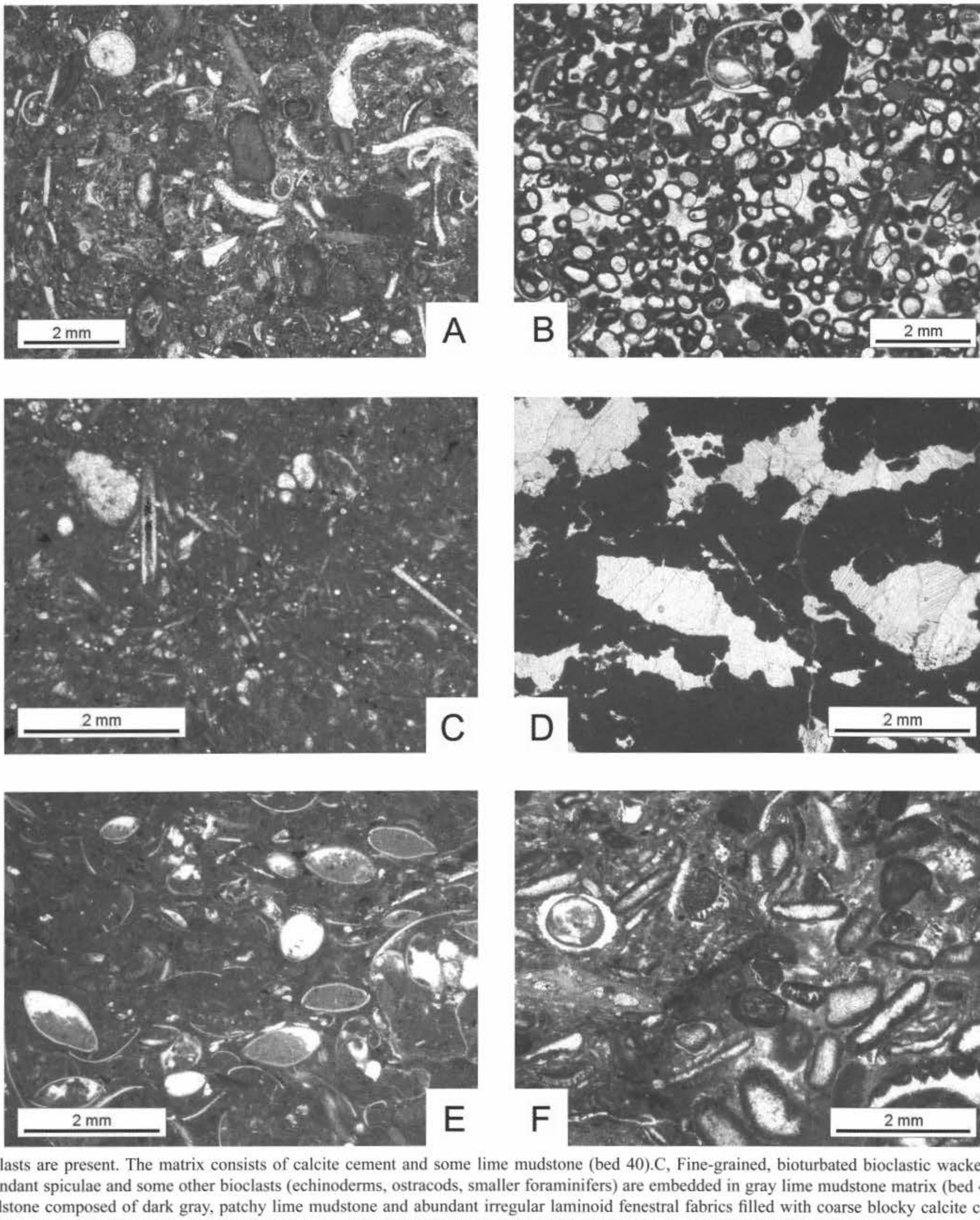
MICROFACIES AND SEDIMENTARY ENVIRONMENTS

Microfacies

We prepared and stuidied petrographic thin sections of 19 beds in the Little Wells section (Figs. 5-6). They well represent characteristic microfacies of the Hueco Group, and can be described as follows:

1. Panther Seep Formation top, bed 5: Sandstone, indistinctly laminated, crossbedded (partly), mostly 0.2–0.5 mm detrital quartz (mono- and polycrystalline) grains, abundant detrital feldspar grains (mostly altered), some detrital micas, carbonate

FIGURE 5. Thin section photographs showing microfacies types of the Hueco Group at Little Wells. A, Bioclastic wackestone composed of recrystallized lime mudstone matrix and abundant bioclasts (shell debris, bryozoans, echinoderms, ostracods, smaller foraminifers, *Tubiphytes*, rarely *Epimastopora*) (bed 35). B, Oolitic grainstone, moderately sorted, composed of abundant ooids, mostly with completely recrystallized nuclei and thin, lime mudstone cortices. A few (continued on next page)



bioclasts are present. The matrix consists of calcite cement and some lime mudstone (bed 40).C, Fine-grained, bioturbated bioclastic wackestone. Abundant spiculae and some other bioclasts (echinoderms, ostracods, smaller foraminifers) are embedded in gray lime mudstone matrix (bed 46).D, Mudstone composed of dark gray, patchy lime mudstone and abundant irregular laminoid fenestral fabrics filled with coarse blocky calcite cement (bed 64). E, Bioclastic wackestone, bioturbated, containing abundant ostracods which are floating in the lime mudstone matrix. Some ostracods display well developed geopetal structures (bed 111). F, Algal wackestone composed of abundant broken fragments of recrystallized calcareous algae (*Epimastopora, ?Eugonophyllum*), subordinate shell debris, echinoderms, bryozoans, ostracods and some smaller foraminifers. Most algal plates are encrusted by cyanobacteria (lime mudstone envelopes). Some lime mudstone intraclasts and peloids are present. Matrix is mostly patchy, dark gray lime mudstone, rarely calcite cement (bed 198).

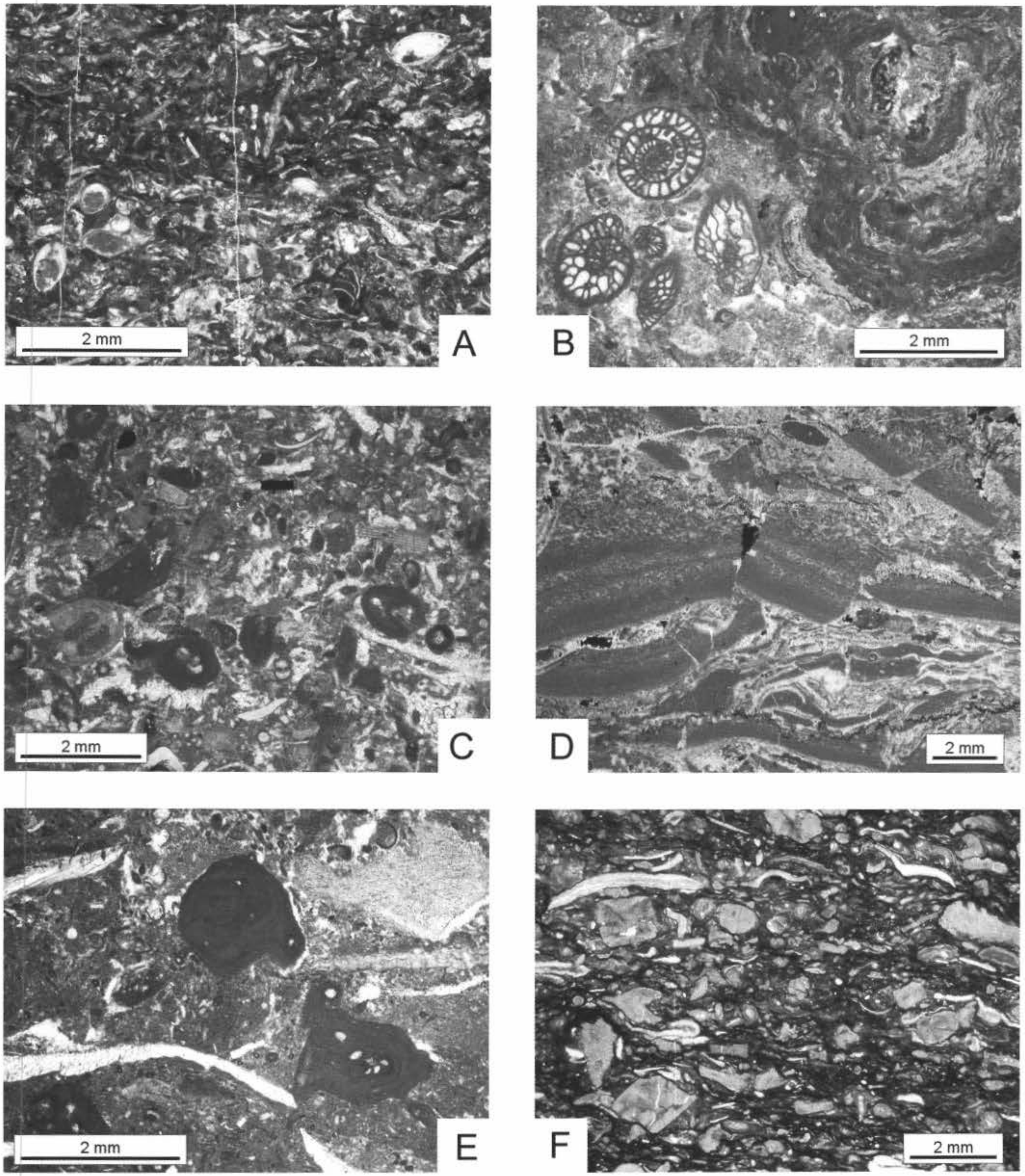


FIGURE 6. Thin section photomicrographs showing microfacies types of the Panther Seep Formation and Hueco Group at Little Wells. A, Bioclastic wackestone/packstone. Most bioclasts are ostracod shells, subordinately some other recrystallized shell faragments and smaller foraminifers are present. The rock also contains abundant peloids and some larger lime mudstone intraclasts. The matrix is dominantly lime mudstone (bed 94).B, Bioclastic wackestone composed of pellime mudstone matrix, fusulinacean tests and some other bioclasts, and small oncoids up to 2 cm in diameter (upper right), composed of a small nucleus (recrystallized bioclast), encrusted by algae (*Claracrusta*) and cyanobacteria (bed 43).C, Bioclastic wackestone/packstone formed of abundant bioclasts (recrystallized shell debris, echinoderms, bryozoans, ostracods, smaller foraminifers, recrystallized phylloid algae, and *Tubiphytes*), lime mudstone matrix and some calcite cement (sample bed 11). D, Gray lime mudstone to pellime mudstone laminae, 1- 2 mm thick, broken in situ. Between the laminae there is litho- and bioclastic wackestone/grainstone. Matrix is lime mudstone, pellime mudstone (continued on next page)

clasts (lime mudstone, dark brown); a few bioclasts (ostracods and some larger shell fragments) are present; rock cemented by calcite, some dark gray lime mudstone matrix is present.

2. Shalem Colony Formation base, bed 6 (Fig. 6D): lime mudstone-pellime mudstone laminites, gray, laminae 1 – 2 mm thick, broken *in situ* (?subaerially exposed); between these broken laminae there is litho-bioclastic wackestone/grainstone. Bioclasts are diverse shell fragments, bryozoans, echinoderms, rarely calcareous algae, *Tubiphytes*, and smaller foraminifers (*Diplosphaerina, Tetrataxis* and others). Peloids and larger lime mudstone lithoclasts (intraclasts) are present. Many bioclasts display thin lime mudstone envelopes. Matrix is lime mudstone/pellime mudstone and calcite cement.

3. Shalem Colony Formation, bed 9 (Fig. 6E): Bioclastic wackestone, gray, strongly bioturbated, nonlaminated, patchy gray lime mudstone, locally pellime mudstone matrix, containing some larger and many smaller bioclasts. Larger bioclasts: diverse shell fragments (bivalves, brachiopods); smaller bioclasts: echinoderms, bryozoans, ostracods, shell fragments, abundant smaller foraminifers (*Diplosphaerina, Tuberitina, ?Earlandia*, calcivertellids, *Climacammina* and others).

4. Shalem Colony Formation, bed 11 (Figs. 6C, F): Bioclastic wackestone/packstone, poorly sorted, nonlaminated, slightly recrystallized. Matrix is lime mudstone and some calcite cement, containing abundant bioclasts, more or less densely packed: diverse shell fragments, echinoderms, bryozoans, ostracods, *Tubiphytes*, smaller foraminifers (*Diplosphaerina, Endothyra, Climacammina*, calcitornellids), and ?recrystallized phylloid algal fragments. The upper part of the thin section is crinoidal packstone composed of densely packed crinoid stem fragments, subordinate shell fragments, bryozoans, trilobite fragments, rare ostracods, phylloid algal fragments, and smaller foraminifers (*Tetrataxis*). Dark gray lime mudstone matrix. Some bioclasts aligned parallel to the bedding plane.

5. Shalem Colony Formation, bed 20: Sandstone, moderately sorted, nonlaminated, carbonate cemented, angular-subangular, siliciclastic with some carbonate grains; abundant quartz (mostly monocrystalline quartz, some polycrystalline quartz), subordinate detrital feldspars (altered), gray to brownish-gray lime mudstone clasts, rare shell fragments, cemented by finer-grained calcite.

6. Shalem Colony Formation, bed 28: Siltstone, reddish, laminated, synsedimentary deformation structures (or bioturbation?), crossbedded. The siltstone is composed mostly of carbonate grains, stained by Fe-hydroxides

and calcite cement (bed 6). E, Bioclastic wackestone, coarse grained, bioturbated, composed of patchy lime mudstone and pellime mudstone groundmass containing some larger and many small bioclasts (diverse shell fragments, echinoderms, bryozoans, ostracods, smaller foraminifers and *Tubiphytes*) (bed 9). F, Crinoidal packstone composed of densely packed crinoid stem fragments, subordinate shell fragments, bryozoans, trilobite fragments, rarely ostracods, algal fragments and smaller foraminifers. The matrix is dark gray lime mudstone. Many bioclasts are aligned parallel to the bedding (bed 11).

7. Shalem Colony Formation, bed 34 (Fig. 6B): Bioclastic wackestone/bindstone; bioturbated pellime mudstone matrix (lime mudstone containing abundant small dark gray peloids), strongly bioturbated, nonlaminated. In the matrix relatively few bioclasts: fusulinaceans, shell fragments, ostracods, echinoderms, bryozoans, smaller foraminifers (*Diplosphaerina, Deckerella, Tetrataxis, Syzrania, ?Spireitlina*), rare *Efluegelia* and *?Tubiphytes*. Large bioclasts (crinoids, bryozoans) encrusted by algae (*Claracrusta*) and cyanobacteria forming oncoids up to 2 cm long.

8. Shalem Colony Formation, bed 35 (Fig. 5A): Bioclastic wackestone, nonlaminated, poorly sorted, slightly recrystallized, composed of recrystallized gray lime mudstone matrix and abundant smaller and some larger bioclasts: diverse shell fragments, bryozoans, echinoderms, ostracods, smaller foraminifers (*Diplosphaerina, Tetrataxis, Globivalvulina, Calcitornella, ?Nodosinelloides* and others) and *Tubiphytes*. A few fusulinaceans, rare corals and algae (*Epimastopora*) are present, as are a few oncoid grains.

9. Shalem Colony Formation, bed 35/1: Bioclastic wackestone, nonlaminated, poorly sorted, quite densely packed, slightly recrystallized, composed of gray lime mudstone matrix and abundant, mostly small bioclasts: diverse shell fragments, recrystallized ?phylloid algal fragments, echinoderms, gastropods, ostracods, bryozoans, fusulinaceans, smaller foraminifers, (*Diplosphaerina, Tetrataxis, Globivalvulina, Deckerella*), and rare *Tubiphytes* and *Epimastopora*. Some bioclasts are encrusted by lime mudstone algae/cyanobacteria to form small oncoid grains. Some calcite cement is present

10. Shalem Colony Formation top, bed 40 (Fig. 5B): Ooid grainstone, moderately to poorly sorted, nonlaminated, poorly washed, containing calcite cement and some lime mudstone matrix. Abundant ooids, mostly with completely recrystallized nuclei and mostly thin, in most cases micritized cortices. Shell fragments, recrystallized phylloid algal fragments, ostracods, echinoderms, gastropods, a few small foraminifers and some lime mudstone lithoclasts (intraclasts) are present. Small patches contain larger amounts of lime mudstone matrix with some ooids floating in the matrix. Lime mudstone matrix is predominant, with remaining pore space filled by sparry calcite cement.

11. Community Pit Formation, bed 43: siltstone, brownish, laminated, mixed siliciclastic-carbonate, no fossils.

12. Community Pit Formation, bed 44: bioclastic wackestone, fine-grained, moderately to well sorted, partly laminated, in part bioturbated, composed of lime mudstone matrix and abundant small bioclasts, including small shell debris, ostracods, smaller foraminifers (mostly calcivertellids, some *Globivalvulina*) and sponge spicules. Bioturbated areas contain more calcite cement

13. Community Pit Formation, bed 46 (Fig. 5C): bioclastic wackestone, fine-grained, gray, bioturbated, nonlaminated, composed of abundant small bioclasts imbedded in dark gray lime mudstone matrix. Abundant sponge spicules and small shell fragments (mostly ostracods), with subordinate echinoderms and smaller foraminifers (*Globivalvulina*, also *Syzrania* and others), and locally small amounts of calcite cement (areas of stronger bioturbation).

14. Community Pit Formation, bed 64 (Fig. 5D): lime mudstone, dark gray-brownish, patchy lime mudstone sediment,

nonlaminated, containing some small lime mudstone lithoclasts, abundant "laminoid fenestral fabrics" filled with coarse blocky calcite cement, no fossils (shallow restricted environment).

15. Community Pit Formation top, bed 94 (Fig. 6A): bioclastic wackestone/packstone; nonlaminated, bioturbated, locally densely packed bioclasts and some lime mudstone lithoclasts imbedded in gray lime mudstone matrix and some calcite cement; slightly recrystallized. Bioclasts are mostly ostracods and small gastropods, and some other bioclasts (recrystallized shell fragments) and a few small foraminifers are present. The rock contains abundant small peloids and some larger lime mudstone lithoclasts (intraclasts).

16. Robledo Mountains Formation, bed 111 (Fig. 5E): bioclastic wackestone, nonlaminated, bioturbated, dark gray lime mudstone matrix containing abundant ostracods, subordinate small gastropods and shell fragments (bivalves), rarely *Spirorbis.* From many ostracods both valves are preserved, the interior is filled with lime mudstone and calcite cement forming prominent geopetal fabrics. A few calcivertellid foraminifers are present. Matrix consists of lime mudstone-pellime mudstone.

17. Robledo Mountains Formation, bed 144: siltstone/fine-grained sandstone; small-scale crossbedding (ripples), locally showing dewatering structures, reddish-brown, mixed siliciclastic-carbonate.

18. Robledo Mountains Formation, bed 198 (Fig. 5F): algal fragment wackestone/packstone, nonlaminated, bioturbated, moderately sorted, containing abundant broken fragments of calcareous algae—*Epimastopora* and recrystallized phylloid algae (?*Eugonophyllum*)—subordinate diverse shell fragments, echinoderms, bryozoans, ostracods, rarely smaller foraminifers (mostly calcivertellids, *Diplosphaerina, Globivalvulina*), gastropods. Most algal fragments are microbially encrusted, forming "coated grains" (lime mudstone envelopes). Small lime mudstone grains (peloids) are present. Matrix consists of patchy, dark gray lime mudstone and some calcite cement.

19. Abo Formation, bed 243: carbonate conglomerate, fine-grained, composed of gray, lime mudstone, massive, nonlaminated carbonate clasts, nonfossiliferous; many carbonate clasts contain septarian fissures filled with calcite cement (reworked caliche). Carbonate clasts are imbedded in brownish-gray silty carbonate matrix. A few carbonate clasts display weathered rims.

Interpretation

The dominant microfacies of the Shalem Colony Formation (beds 9, 11, 33 and 35) and Robledo Mountains Formation (bed 198) are bioclastic and algal wackestone containing fragments of diverse biota and a dark gray lime mudstone matrix, and frequently displaying bioturbation. This microfacies refers to the standard microfacies type (SMF) 9 of Wilson (1975), interpreted to indicate conditions that are shallow, open marine and below wave base. The presence of brachiopods, echinoderms, crinoids, bryozoans and diverse smaller foraminifers indicates normal marine salinity. The occurrence of phylloid and dasycladacean algae (*Epimastopora*) points to deposition within the photic zone. According to Johnson (1961), Konishi and Wray (1961), Toomey and Winland (1973), Toomey (1976) and Roylance (1990), phylloid, and probably also dasycladacean, algae are believed to have grown in shallow water with a maximum depth of about 30 m. The abundance of muddy bioclastic wackestone/packstone, diverse biota, and irregular, frequently wavy bedding is regarded as typical of shelf sediments (Wilson and Jordan, 1983).

Ooid grainstones (Shalem Colony Formation, bed 40) and bioclastic packstones (Robledo Mountains Formation, bed 198), referred to SMF-Type 15 and 10 of Wilson (1975), are rare. Ooid grainstones are indicative of high-energy shoal environments, and bioclastic packstones most likely formed in shallow water with open circulation at or just below the wave base.

Unfossiliferous mudstone (SMF-Type 23) and laminated pelletal mudstone, interbedded with litho- and bioclastic wackestone/packstone (SMF-Type 19), are two microfacies that are regarded as characteristic of a shallow marine, restricted carbonate environment (Wilson, 1975; Enos, 1983). The latter occurs at the base of the Shalem Colony Formation (bed 6) and suggests a restricted shallow marine environment, probably intertidal with periodic subaerial exposure. Bioclastic wackestones containing oncoid grains (SMF-Type 22) are also typical of shallow, low-energy shelf environments.

The bioclastic wackestones of the Community Pit Formation (beds 44, 46 and 94) and the lower part of the Robledo Mountains Formation (bed 111) contain a low diversity fauna (abundance of ostracods), abundant peloids and a pellime mudstone matrix, and show evidence of strong bioturbation, correspond to SMF-Type 19. This microfacies is indicative of a restricted, low energy, shallow marine shelf environment.

Siltstones and sandstones of the Panther Seep (bed 5), Shalem Colony (beds 20 and 28) and Community Pit (bed 43) formations are clastic sediments with a mixed siliciclastic/carbonate composition that rarely contain bioclasts. They indicate deposition in a shallow marine, high-energy (current ripples, crossbedding) environment (?tidal currents; small tidal channels).

The carbonate conglomerate of the Abo Formation (bed 243) consists of reworked carbonate clasts of subaerially exposed carbonate grains (weathered rims) and caliche carbonates. It lacks fossils, and probably was deposited subaerially.

Summing up, most of the microfacies types and the biota in the limestones characteristic of the Shalem Colony Formation (and some of those in the Robledo Mountains Formation) indicate deposition in an open shelf environment with normal marine salinity, in the photic zone, just below or near the wave base. Deposits of high energy shoal environments are recognized within the Community Pit Formation, but many limestones of this formation are composed of microfacies that indicate deposition in a restricted, low-energy shallow marine shelf environment.

In comparison, limestones of the Shalem Colony Formation in the Robledo Mountains (sections A and B near Robledo Peak: Krainer et al., 2000) are also composed mostly of bioclastic wackestone but differ in having: (1) higher diversity of microfacies types and biota; (2) high-energy deposits (grainstones) are more abundant, particularly in section B; (3) calcareous algae (phylloid algae, *Epimastopora, Archaeolithoporella, Archaeo-*

lithophyllum lamellosum) are more abundant, forming algal wackestones, packstones and boundstones, and locally algal mounds; and (4) presence of fusulinaceans, locally forming fusulinaceans packstones. Fusulinaceans are relatively rare in the Little Wells section.

In general, the limestones of Shalem Colony Formation at Robledo Peak were also deposited in a shallow shelf environment of open circulation and normal marine salinity, rarely in a restricted shallow shelf environment. The differences listed above may be explained by somewhat shallower water conditions and slightly increased circulation at Robledo Peak

Although only a limited number of samples from the Robledo Mountains Formation has been investigated in thin section at Little Wells, the limestones seem to be very similar to those of the Robledo Mountains Formation in the Robledo Mountains described by Krainer and Lucas (1995). At both localities, bioclastic wackestones seem to be the dominant microfacies.

PALEONTOLOGY

Microfossils

We did not make a systematic effort to collect or study microfossils from the Hueco Group section at Little Wells. Ostracods are common in many beds, and Bachman and Myers (1969) listed taxa from one bed, but presented no specific data on its stratigraphic level in the Hueco section. Fusulinaceans are common in units 33-35 of the Shalem Colony Formation but have not been identified. Thin sections we prepared (see above) include the following microfossils:

1. Bed 6: Foraminifers: *Diplosphaerina, Globivalvulina, Tetrataxis; Tubiphytes* (problematicum)
2. Bed 9: Foraminifers: *Diplosphaerina, Tuberitina, Calcivertella, Deckerella, Endothyra, Tetrataxis* Algae: *Koivaella Tubiphytes* (problematicum)
3. Bed 11: Foraminifers: *Deckerella, Endothyra, Eotuberitina, Calcitornella; Tubiphytes* (problematicum)
4. Bed 33: Foraminifers: *?Pseudoschwagerina, Diplosphaerina, Deckerella, Tetrataxis, Syzrania.* Algae: *Claracrusta, Efluegelia*
5. Bed 35: Foraminifers: *Deckerella, Tetrataxis, Diplosphaerina, Globivalvulina, Calcitornella* Algae: *Epimastopora, Nankinella*
6. Bed 35a: Foraminifers: *Globivalvulina, Nodosinelloides, Tetrataxis; Tubiphytes* (problematicum)
7. Bed 40: Foraminifers: *Asselodiscus*
8. Bed 44: Foraminifers: *Nodosinelloides, Globivalvulina, Calcivertella*
9. Bed 46: Foraminifers: *Geinitzina, Globivalvulina, Syzrania*
10. Bed 111: *Spirorbis* (serpulid)
11. Bed 198: Foraminifers: *Globivalvulina, Pseudoreichelina, Calcivertella, Diplosphaerina.* Algae: *Epimastopora*.

Macroinvertebrate Fossils

Marine macroinvertebrate fossils are present in numerous beds in the Little Wells Hueco section, up to bed 211 (see taxa listed in the appendix), but typically are fragmented, severely weathered, and difficult to extract from limestones. We made several small collections, and describe them here.

Shalem Colony Formation, Bed 34

Bed 34 is a thick, massive, dark gray, cherty limestone (Fig. 4). The upper meter is densely packed with a fauna of small *Wellerella*-like brachiopods and a few larger specimens of *Composita* (NMMNH locality 4970). The limestone is relatively soft where weathered, and crumbles around the brachiopods, the volume of which exceeds that of the surrounding matrix. Aside from these brachiopods, no other invertebrates were observed in this fauna.

Identification of small, plicate, *Wellerella*-like rhychonellids from the late Paleozoic is complicated by the fact that Cooper and Grant (l976) described dozens of Permian species within numerous genera, distributed among three families, that externally resemble *Wellerella, sensu lato*. They stated (p. l95l) that identification "of *Wellerella* at present is difficult and....if the interior cannot be satisfactorily established it is impossible to put a correct generic name to a species," and noted the high degree of external homeomorphy among numerous genera. Here, we describe the external morphology of the species present in unit 34, but as the internal features were not observed our identification must be regarded as tentative.

***Pontisia* aff. *P. wolfcampensis* Cooper & Grant**—These specimens (Fig. 7A-P) are small, no greater than l0 mm in width, with the width/length ratio typically between l.00 and l.l0 on the largest specimens (width = 8-l0 mm). The brachial valve is strongly inflated, with the pedicle valve less so, producing an articulated thickness/length ratio ranging from 0.80 to l.00. The surface of the brachial valve is strongly but evenly convex, especially at the anterior margin. The lateral slopes of the brachial valve are steep or nearly vertical in some specimens. The fold of the brachial valve is only slightly raised, and usually includes three strong, sharp-crested plicae that begin about 30-40% of the distance from the hingeline to the anterior valve margin. The central plica may be a little depressed and slightly smaller than the others. On most specimens two (occasionally three) smaller plicae are present laterally on each side of the fold. The median anterior portion of the commissure is strongly and rather narrowly raised adjacent to the fold.

The pedicle valve has a short, sharp, triangular beak that projects significantly beyond the hingeline, and this contains a small oval foramen. The sulcus of the pedicle valve is shallow, and typically contains two wide, relatively low plicae, with an additional prominent plica bordering each side of the sulcus. Two additional smaller plicae are present laterally on each side of the sulcus. A few specimens have four plicae on the fold and three on the sulcus (e.g., Fig. 7M-P).

Specimens that are about 6.5 to 8.5 mm wide (Figs. 7E-J) tend to have less inflated brachial valves and a thickness/length ratio of 0.60 to 0.70, but otherwise are closely similar to the larger specimens. Immature individuals (width = 5-6 mm; Figs.7K-L) have relatively low valves and appear considerably more compressed (thickness/length = 0.40-0.55) than the larger specimens. Cooper and Grant (l976) documented similar ontogenetic changes for numerous *Wellerella*-like species from the West Texas Permian.

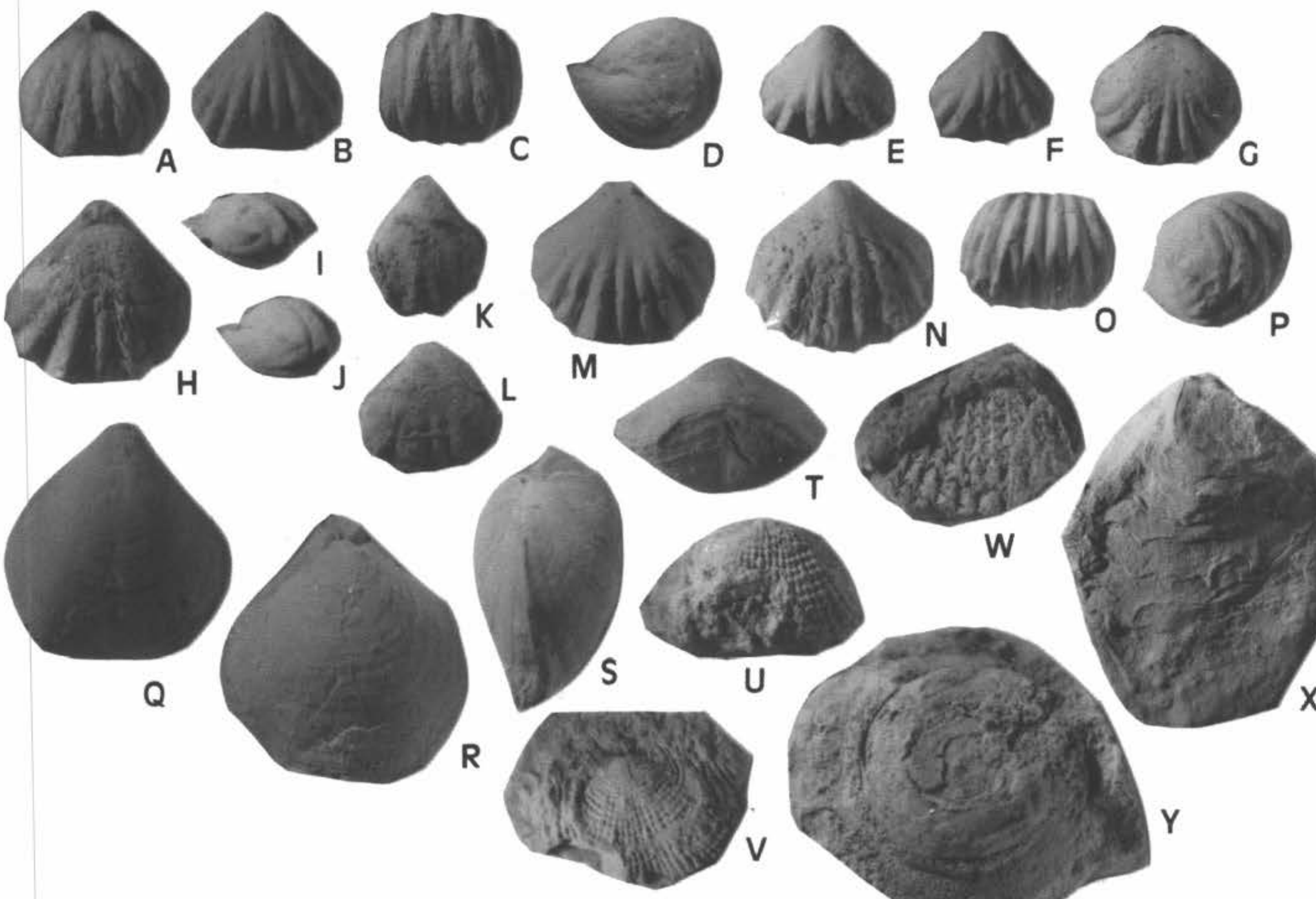


FIGURE 7. Invertebrate fossils from the Hueco Group, Little Wells section. Figures A-T are from bed 34 (NMMNH locality 4970); figures U-Y are from bed 189 (NMMNH locality 4971). A-P, *Pontisia* aff. *P. wolfcampensis* Cooper and Grant. A-D, brachial, pedicle, front, and side views of a gerontic specimen, P-35236, x2.25; E, pedicle valve, smaller specimen, P-35238, x2.25; F, H, pedicle valve, x2.25, and brachial valve, x 3.25, P-35242; G, brachial valve, P-35239, x2.25; I, side view, smaller specimen with less inflated brachial valve, P-35240; J, side view, smaller specimen, P-35241, x2.25; K, pedicle valve, juvenile specimen, P-35243, x3; L, pedicle valve, slightly larger juvenile specimen, P-35244, x3.0; M-P, brachial, pedicle, front, and side views of a gerontic specimen with 4 fold plicae and 3 sulcus plicae, P-35245. Q-T, *Composita* aff. *C. discina* Cooper and Grant, pedicle valve, x 1.67, brachial view, x 1.75, side view (pedicle beak is broken), x 1.75, and front view, x 1.67, P-35234. U, V, *Reticulatia* sp. U, pedicle valve of a small specimen in matrix, P-35231, x1; V, brachial valve of a small specimen in matrix, P-35230, x 1. W, *Acanthopecten* sp., fragment of left valve in matrix, P-35229, x 1.5. X, *Septimyalina burmai* Newell, fragment of left valve in matrix, P-35233, x 1; Y, *Omphalotrochus* sp., oblique dorsal view of a weathered shell, P-35228, x1.

Taxa that are externally similar to the Little Wells taxon include species in several genera (e.g., *Tautosia podistra* Cooper & Grant, *Phrenophoria ventricosa* Cooper & Grant, *Anteridocus gongylus* Cooper & Grant, *Wellerella nitidula* Cooper & Grant, several species of *Pontisia*), which are differentiated mainly or entirely on internal features. Most of these taxa, with the exception of *Pontisia*, are Leonardian and/or Guadalupian in age, and Cooper and Grant (1976) reported no species of *Tautosia*, *Phrenophoria*, *Anteridocus*, or *Wellerella* from the lower Wolfcampian of West Texas, although *T. podistra* is known from upper Wolfcampian strata. On the other hand, numerous species of *Pontisia* are known from lower Wolfcampian strata, and the specimens from the lower Hueco of the Little Wells section very likely belong to this genus.

In valve shape and proportions, strongly but evenly convex brachial valve, plicae number and prominence and overall size, the Little Wells specimens most closely resemble *Pontisia wolfcampensis* Cooper & Grant and *P. parva* Cooper & Grant, both from the Neal Ranch Formation of West Texas. However, both of these species display a median groove in the anterior portions of the plicae of the fold and sulcus, a feature that is lacking on the sharp-crested plicae of the Little Wells specimens. The plicae morphology of the Little Wells specimens is more similar to that of other species of *Pontisia,* but these specimens differ in other features. Compared with the Little Wells specimens, *P. franklinensis* Cooper & Grant has a more widely triangular shell; *P. costata* Cooper & Grant has a less inflated brachial valve and four or five plicae on the lateral flanks of the valves; and *P. magnicostata* Cooper & Grant attains a much larger size, and its plicae develop much earlier in growth. *Pontisia kingi* Cooper & Grant, from the Neal Ranch Formation, is similar to the Little Wells specimens in most features, but attains a larger size, the brachial valve is not so inflated, and the thickness/length ratio is typically smaller than on Little Wells specimens of equivalent size. The Little Wells specimens also closely resemble smaller individuals of *P. stehlii stehlii* Cooper & Grant (1976, see especially pl. 517, figs. 21-25, 38-43), but that subspecies is confined to considerably younger (Leonardian-Guadalupian) strata. The Little Wells specimens may represent an undescribed species of *Pontisia*; we refer to this taxon here as *P.* aff. *P. wolfcampensis.* Kues (1995) described probable conspecific specimens as *P.* aff. *P. wolfcampensis* from higher in the Hueco Group (Robledo Mountains Formation) of the Robledo Mountains.

***Composita* aff. *C. discina* Cooper & Grant**—Specimens of *Composita* are much less common than *Pontisia* aff. *P. wolfcampensis* at locality L-4970, but are represented by both juvenile (length about 6 mm) and mature specimens. The best preserved mature specimen (Fig. 7Q-T) is 20.3 mm long, 18.2 mm wide, and has an articulated thickness of 11.8 mm. Both valves are moderately convex, the pedicle valve more so than the brachial, and the greatest width is about at midlength. The pedicle and brachial beaks are narrower and longer than is typical of most Early Permian species of *Composita*. A shallow, wide sulcus and very low fold are restricted to the anterior margins of the valves. Growth lines are widely spaced and relatively strong. Juvenile specimens have slightly more inflated valves and lack the fold and sulcus but are otherwise similar to mature individuals.

Species of *Composita* typically display high intraspecific variability, and some Early Permian species described by Cooper and Grant (1976) were separated on the basis of rather subtle differences. The few specimens from locality L-4970 do not allow adequate definition of intraspecific variability. Of the lower Wolfcampian species described by Cooper and Grant (1976) from West Texas, *C. cracens* Cooper & Grant differs from the Little Wells species in having a relatively wider shell, a higher, narrower commissural fold, and a shorter, wider pedicle beak. *Composita mexicana* (Hall) is parasulcate, with a wider pedicle beak, and *C. strongyle* Cooper & Grant has a shell that is typically wider than long, and a short, blunt pedicle beak. The Little Wells specimens most closely resemble some specimens of *C. discina* Cooper & Grant (e.g., a paratype, their pl. 656, figs. 11-15), a relatively small species that occurs in the upper Gaptank, Lenox Hills and Skinner Ranch formations. General valve shape, low fold and narrow pedicle and brachial beaks are also features in common with *C. crassa* Cooper & Grant, but that species occurs in Leonardian strata and attains a considerably larger size (up to 33 mm long).

Community Pit Formation, bed 61

Bed 61 , a thin, medium-gray, hard limestone, locally contains high concentrations of small gastropods (NMMNH locality 4568). The shells are coarsely recrystallized, often filled with sparry calcite, and severely weathered, producing steinkerns lacking any trace of original ornamentation and precluding definite identification. Two taxa appear to be present. One is relatively high spired, with inflated whorls and deeply indented sutures, and attains a height of approximately 20 mm. The second is smaller, narrower, and more highly spired, with inflated whorls and a sharp periphery and deep sutures. Probably these are steinkerns of *Goniasma*, a common genus in Lower Permian strata of New Mexico. Indeterminate small shell fragments are the only other fossils observed in this unit. The abundance of gastropods and their low diversity, and apparent absence of other invertebrate groups suggest a shallow, possibly somewhat hypersaline environment.

Robledo Mountains Formation, bed 189

Bed 189, a massive, medium-gray limestone, yields a mixed fauna dominated by molluscs and productoid brachiopods (NMMNH locality 4971). Locally, diverse concentrations of small gastropods similar to those of bed 61 are present, but isolated specimens of other taxa were collected as float from the slope beneath bed 189. One incomplete, weathered specimen of *Omphalotrochus* sp., about 40 mm wide (Fig. 7Y), reflects the common occurrence of this distinctive gastropod in the Hueco Group of New Mexico (e.g., Yochelson, 1966). *Omphalotrochus* was also observed in beds 30, 88, and 211 of the Little Wells section. Indeterminate bellerophontid gastropod steinkerns are also present. Bivalves include fragments of *Aviculopinna* and *Acanthopecten* (Fig. 7W), and large, incomplete valves of *Septimyalina burmai* Newell (Fig. 7X), a common early Wolfcampian species in New Mexico. Fragments of productoids, probably *Reticulatia* (Fig. 7U-V), and of *Derbyia* sp. and *Meekella* sp., represent the brachiopods in this assemblage. Sparse fenestrate bryozoans and crinoid columnals are also present. These taxa indicate a normal marine environment, probably relatively close to the shoreline.

The sparse macroinvertebrate data from the Little Wells section do little more than underscore the well-established Wolfcampian age of the Hueco Group based on fusulinaceans. The gastropod *Omphalotrochus* is a reliable indicator of Wolfcampian strata (Yochelson, 1966), and the two brachiopod taxa identified in bed 34 of the Shalem Colony Formation are most closely related to taxa of Wolfcampian age in West Texas. The presence of the foraminifers *Geinitzia* in bed 46 and *Pseudoreichelina* in bed 198 are also indicative of a Wolfcampian age.

Fossil Plants and Tetrapod Footprints

Strata of the Robledo Mountains and Abo formations contain sparse fossil plants and abundant tetrapod footprints. These fossils come from four horizons:

1. Bed 95 contains poorly preserved impressions of the conifer *Walchia* and abundant footprints of small amphibians *(Batrachichnus:* Fig. 8) at NMMNH locality 4580.
2. Bed 213 yields footprints of *Batrachichnus* and a procolophonomorph (*Dromopus:* Fig. 8) at NMMNH locality 4577.
3. Bed 232 yields footprints of *Batrachichnus, Dromopus* and a small pelycosaur (*Gilmoreichnus?*) at NMMNH locality 4578.
4. Bed 234 yields impression of *Walchia* (Fig. 8) and footprints of *Batrachichnus, Dromopus, Gilmoreichnus* (Fig. 8) and of a large pelycosaur (*Dimetropus*?: Fig, 8) at NMMNH locality 4579. This is the richest footprint assemblage in the section.

The association of *Walchia* and tetrapod footprints assigned to *Batrachichnus, Dromopus, Gilmoreichnus* and *Dimetropus* is characteristic of the Robledo Mountains Formation in the

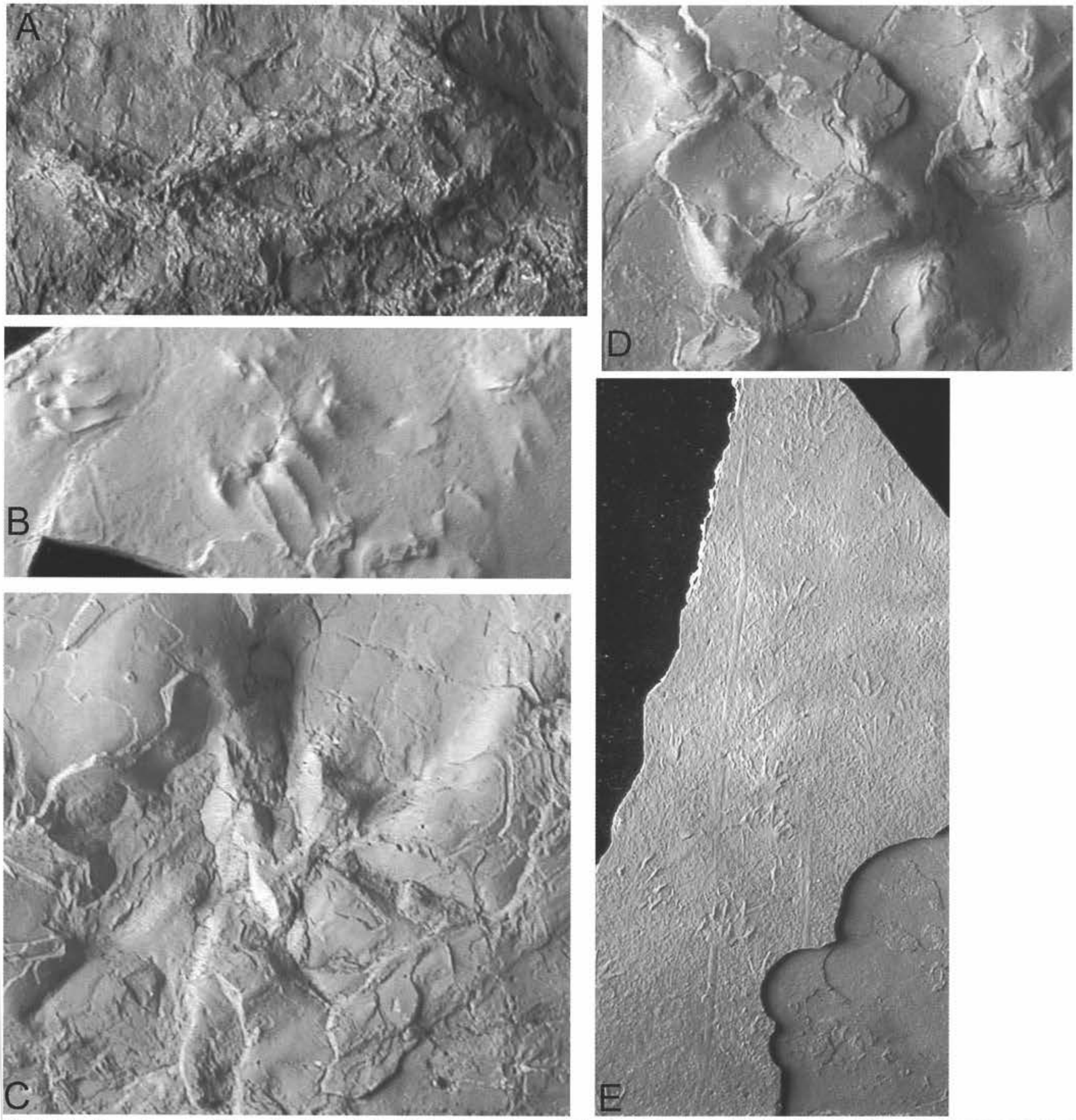


FIGURE 8. *Walchia* and tetrapod footprints from the Robledo Mountains and Abo formations at Little Wells. A, *Walchia*, NMMNH P-35213 from locality 4579. B, *Gilmoreichnus*, NMMNH P-35218 from locality 4579. C, *Dimetropus*?, NMMNH P-35220 from locality 4579. D, *Batrachichnus*, NMMNH P-35224 from locality 4577. E, *Batrachichnus*, NMMNH P-35212 from locality 4580. All x ~1.3

Robledo Mountains of Doña Ana County, west of the Rio Grande (Lucas et al., 1995a; Hunt et al., 1995).

CORRELATION

The Hueco Group section exposed at Little Wells in the San Andres Mountains can be correlated to Hueco Group sections exposed in other parts of New Mexico and West Texas, where Lower Permian strata also deposited in the Orogrande basin are exposed (Fig. 9). In the Doña Ana Mountains to the northwest, Seager et al. (1976), Mack et al. (1988) and Lucas et al. (1995b) described the Hueco section as: (1) lower Hueco, about 128 m of algal biomicrudite, shaly limestone and lime mudstone; (2) middle Hueco, about 76 m of biolime mudstone and lime mudstone; (3) gastropod-bearing member, about 122 m of gastropod-rich limestone; and (4) Abo Formation (Seager et al., 1976; Mack

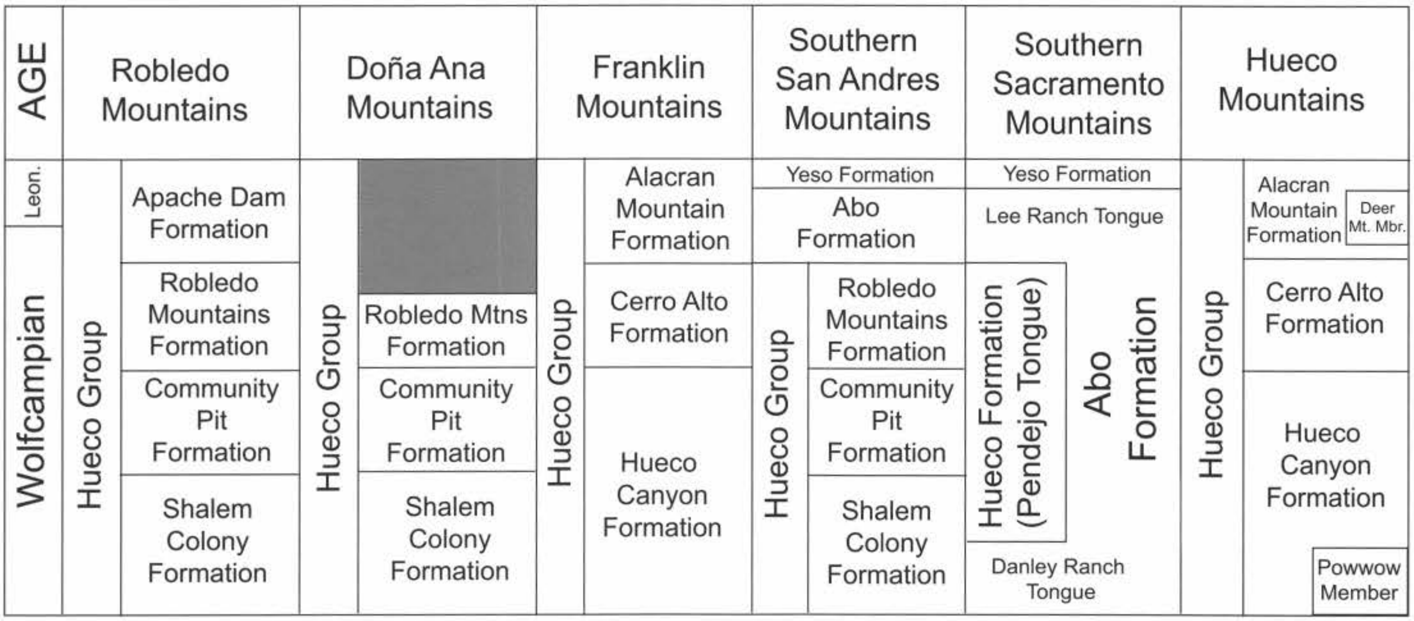


FIGURE 9. Correlation chart of Hueco Group strata across the Orogrande basin.

et al., 1988) or Robledo Mountains Member (Lucas et al., 1995b), about 81 m of calcareous shale, packstone and red-bed sandstone and siltstone. This unit (and the rest of the upper Hueco) is incomplete in the Doña Ana Mountains due to erosion.

Clearly, the term Robledo Mountains Formation can be readily extended into the Doña Ana Mountains (Lucas et al., 1995b, 1998) (Fig. 9). Direct extension of the underlying Shalem Colony and Community Pit formations from the Robledo Mountains into the Doña Ana Mountains also is straightforward. As Seager et al. (1976, fig. 6) indicate, what is now called the Community Pit Formation in the Robledo Mountains is probably equivalent to the upper part of the lower–middle Hueco and the gastropod-bearing member in the Doña Ana Mountains.

To the south, in the Franklin Mountains, the Hueco Group section (Fig. 9) is about 640 m thick and has been divided into the Hueco Canyon, Cerro Alto and Alacran Mountain formations (Williams, 1966; Jordan and Wilson, 1971). This is the same stratigraphic nomenclature used in the Hueco Mountains farther east, where the type Hueco Group section is about 488 m thick (Williams, 1963; Jordan, 1975), though in the Hueco Mountains the Hueco Canyon Formation contains basal red-bed siliciclastics (Powwow Member) not present in the Franklin Mountains. Key to correlation of these sections to the southern San Andres Mountains Hueco strata is the fact that the Cerro Alto Formation contains a late Wolfcampian fusulinacean assemblage (Williams, 1963), and this supports correlation to the late Wolfcampian Robledo Mountains Formation (Jordan, 1971, 1975). The Shalem Colony and Community Pit formations are thus broadly correlative to the Hueco Canyon Formation (Fig. 9). However, the paleontological and lithostratigraphic basis for these latter correlations is not definitive.

In the southern Sacramento Mountains, the Hueco Formation is a tongue (Pendejo Tongue of Pray, 1961) about 190 m thick between two red-bed tongues of Abo Formation (Bachman and Hayes, 1958; Otté, 1959; Pray, 1961). The lower Abo Tongue is the Danley Ranch Tongue, whereas the upper Abo Tongue is the Lee Ranch Tongue, both units named by Bachman and Hayes (1958). Otté (1959), Pray (1961) and Williams (1963) correlated the Pendejo Tongue in the southern Sacramento Mountains to the Hueco Canyon, Cerro Alto and Alacran Mountain (lower part) formations in the Hueco Mountains. This indicates that the Pendejo Tongue correlates to the Shalem Colony, Community Pit and Robledo Mountains formations to the west (Fig. 9).

Bachman and Hayes (1958) correlated the Lee Ranch Tongue of the Abo Formation with the lower part of the Yeso Formation. They did so because the Lee Ranch Tongue contains an assemblage of the *Supaia* paleoflora ("Zone"), which Read and Mamay (1964) identified as a Leonardian paleoflora. However, as Hunt (1983) demonstrated, some localities of the *Supaia* paleoflora are of Wolfcampian age; the distribution of the paleoflora is more facies- and taphofacies-controlled than temporally significant. Therefore, the correlation of Williams (1963) and Jordan (1971, 1975) of the Lee Ranch Tongue and the redbeds of the Alacran Mountain Formation in the Hueco Mountains is plausible. This means the Lee Ranch Tongue is correlative to at least part of the Apache Dam Formation in the Robledo Mountains (Fig. 9).

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APPENDIX—DESCRIPTION OF MEASURED SECTION

Section of the Hueco Group at Little Wells (N"2 sec. 31. T195, R4E), measured by Spencer G. Lucas and Barry S. Kues, Oct 12-14, 2000. Section begins at UTM 13,352870E, 3609374N and ends at UTM 13,352148E, 3609280N (NAD27). Dips are: Units 1-48 = 49° to S60° W, Units 49-94 = 84° to S80°W, Units 95-243 = 76° to S80° W.

unit lithology **thickness (m)**

Abo Formation:

243 Sandstone and conglomerate; sandstone is grayish orange (10YR7/4) fresh, weathers moderate brown (5YR4/4), fine to medium grained, not calcareous, subarkose; conglomerate is composed of pale reddish brown (10R5/4) angular clasts of limestone up to 3 cm in diameter, through cross-bedded; conglomerateoccurs in lenses; unit forms a cuesta. **1.2**

242 Mudstone and siltstone; pale reddish brown (10R5/4); not calcareous; siltstone forms ledges in mudstone slope. **5.7**

241 Mudstone; pale reddish brown (10R5/4); largely a covered slope. **12.0**

240 Sandstone; dark reddish brown (10R3/4); very fine grained; not calcareous; climbing ripples. **0.7**

239 Mudstone; same color and lithology as unit 241. **4.0**

238 Sandstone; same color and lithology as unit 240. **0.8**

237 Mudstone; same color and lithology as unit 241; mostly covered slope. **19.0**

236 Sandstone; same color and lithology as unit 240. **0.2**

235 Covered slope. **1.6**

234 Sandstone; same color and lithology as unit 240; contains tetrapod footprints (NMMNH locality 4579). **0.3**

233 Covered slope; appears to be mudstone like unit 241. **10.8**

232 Sandstone; same color and lithology as unit 240; contains tetrapod footprints (NMMNH locality 4578). **0.7**

231 Covered slope. **15.0**

230 Sandstone; same color and lythology as unit 240. **0.3**

229 Covered slope. **3.0**

228 Sandstone; same color and lithology as unit 240; ripple laminations. **0.2**

227 Covered slope. **2.9**

226 Sandstone; same color and lithology as unit 240. **0.2**

225 Sandstone; grayish red (10R4/2); very fine grained; sub-arkose; calcareous; ripple laminated. **1.5**

Hueco Group:

Robledo Mountains Formation:

224 Limestone; light brownish gray (5YR6/1); weathers grayish orange (10YR7/4); algal lime mudstone; wavy laminae. **0.2**

223 Covered slope. **2.0**

222 Limestone; same color and lithology as unit 224. **0.3**

221 Covered slope. **4.3**

220 Sandstone; grayish red (10R4/2); very fine grained; sub-arkose; calcareous; climbing ripples. **0.8**

219 Covered slope. **6.7**

218 Sandstone; light olive gray (5Y5/2); very fine grained; subarkose; ripple laminated. **0.3**

217 Limestone; medium light gray (N6); weathers grayish orange (10YR7/4); lime mudstone. **0.3**

216 Covered slope. **1.2**

215 Sandstone; grayish red (10R4/2); very fine grained; sub-arkose; climbing ripples. **1.0**

214 Covered slope. **3.2**

213 Sandstone; pale red (10R6/2) and pale reddish brown (10R5/4); very fine grained; subarkose; ripple laminated; tetrapod footprints (NMMNH locality 4577). **2.9**

212 Covered slope. **3.5**

211 Limestone; medium gray (N5); rudite at base, grainstone above that; some brachiopods and gastropods (including *Omphalotrochus*). **2.1**

210 Limestone; same color and lithology as unit 217. **1.1**

209 Covered slope. **2.2**

208 Sandstone; grayish red (10R4/2); fine grained; subarkose; ripple laminated; not calcareous. **1.6**

207 Covered slope. **2.8**

206 Limestone; same color and lithology as unit 217. **0.3**

205 Covered slope. **8.3**

204 Limestone; pale yellowish brown (10YR6/2); weathers very pale orange (10YR8/2); algal lime mudstone; wavy laminae. **0.2**

203 Limestone; medium gray (N5); weathers light gray (N7); gastropod and algal wackestone. **0.4**

202 Covered slope. **3.5**

201 Limestone; brownish gray (5YR4/1); weathers very pale orange (10YR8/2); lime mudstone. **0.1**

200 Sandstone; pale brown (5YR5/2); very fine grained; subarkose; slightly calcareous; climbing ripples. **4.4**

199 Covered slope. **1.8**

198 Limestone; medium gray (N5); nodular wackestone; ostracods and *Wilkingia*. **0.2**

197 Covered slope. **1.2**

196 Limestone; same color and lithology as unit 203. **0.8**

195 Covered slope. **1.9**

194 Limestone; medium dark gray (N4); weathers medium gray (N5); algal wackestone; gastropods. **0.8**

193 Covered slope. **9.0**

192 Limestone; medium gray (N5); algal and gastropod wackestone; thick bedded. **5.1**

191 Sandstone; pale brown (5YR5/2); very fine grained; quartzose; slightly calcareous; ripple laminated. **0.1**

190 Covered slope. **3.5**

189 Limestone; medium dark gray (N4); wackestone; brachiopods and scaphopods. **2.8**

188 Limestone; brownish gray (5YR4/1); weathers very pale orange (10YR8/2); lime mudstone. **0.5**

187 Covered slope. **7.3**

186 Limestone; same color and lithology as unit 188. **0.2**

185 Limestone; medium dark gray (N4); weathers light gray (N7); ostracodal wackestone; medium bedded. **2.3**

184 Covered slope. **2.1**

183 Limestone; same color and lithology as unit 185. **0.1**

182 Covered slope. **1.4**

181 Limestone; same color and lithology as unit 185. **0.4**

180 Covered slope. **3.1**

179 Sandstone; pale yellowish brown (10YR6/2); very fine grained; subarkose; calcareous; ripple laminated. **2.9**

178 Covered slope. **4.2**

177 Sandstone; same color and lithology as unit 179. **3.0**

176 Covered slope. **5.0**

175 Limestone; medium gray (N5); weathers light olive gray (5Y5/2); bioclastic wackestone. **0.2**

174 Covered slope. **0.7**

173 Limestone; same color and lithology as unit 175. **0.5**

172 Covered slope. **6.2**

171 Limestone; medium gray (N5); weathers medium light gray (N6); nodular wackestone; myalinid bivalves,gastropods, brachiopods, bryozoans. **0.2**

170 Covered slope. **3.5**

169 Limestone; medium gray (N5); weathers light olive gray (5Y6/1); wackestone; algae, gastropods, brachiopods. **10.0**

168 Covered slope. **1.7**

167 Limestone; medium gray (N5); weathers light olive gray (5Y6/1); gastropod (bellerophontid) wackestone. **0.9**

166 Covered slope. **2.2**

165 Limestone and shale in 0.3-0.6-m-thick interbeds; limestone is same color and lithology as unit 169; shale is covered. **8.5**

164 Limestone; same color and lithology as unit 169. **1.6**

163 Covered slope. **1.7**

162 Limestone; medium dark gray (N4); weathers light olive gray (5Y6/1); crinoidal conglomerate. **0.6**

161 Covered slope. **0.8**

160 Limestone; same color and lithology as unit 162. **0.9**

159 Covered slope. **2.2**

158 Limestone; same color and lithology as unit 169. **2.1**

157 Covered slope. **1.2**

156 Limestone; medium dark gray (N4); weathers light olive gray (5Y6/1); rudite and grainstone. **1.4**

155 Covered slope. **1.6**

154 Sandstone; light brown (5YR6/4); very fine to fine grained; subarkose; ripple laminated. **0.6**

153 Covered slope. **4.4**

152 Limestone; very pale orange (10YR8/2) to pale yellowish brown (10YR6/2); mudstone. **0.2**

151 Covered slope. **2.1**

150 Sandstone; yellowish gray (5Y7/2); very fine grained; quartzose; ripple laminated. **0.1**

149 Covered slope. **2.0**

148 Sandstone; same color and lithology as unit 150. **0.2**

147 Covered slope. **1.1**

146 Sandstone; same color and lithology as unit 150. **1.8**

145 Covered slope. **1.2**

144 Sandstone; same color and lithology as unit 150. **0.6**

143 Covered slope. **3.0**

142 Limestone; medium dark gray (N4); wackestone; ostracods, brachiopods, gastropods. **1.4**

141 Covered slope. **2.8**

140 Limestone; same color and lithology as unit 142. **1.7**

139 Covered slope. **2.3**

138 Limestone; medium dark gray (N4); weathers yellowish gray (5Y7/2); algal mudstone; wavy laminae. **0.2**

137 Covered slope. **1.4**

136 Limestone; medium dark gray (N6); weathers light olive gray (5Y6/1); mudstone; thin bedded. **0.7**

135 Covered slope. **1.6**

134 Limestone; medium light gray (N6); weathers yellowish gray (5Y7/2); ostracodal wackestone. **0.5**

133 Limestone; medium dark gray (N4); nodular wackestone. **2.4**

132 Limestone; medium dark gray (N4); weathers light gray (5Y6/1); ostracod and gastropod wackestone. **1.5**

131 Covered slope. **4.4**

130 Limestone; same color and lithology as unit 134. **0.4**

129 Covered slope. **0.9**

128 Limestone; same color and lithology as unit 134. **0.4**

127 Covered slope. **1.4**

126 Limestone; medium gray (N5); weathers yellowish gray (5Y7/2); wackestone; algae, gastropods, brachiopods. **0.5**

125 Covered slope. **2.3**

124 Sandstone; yellowish gray (5Y7/2); very fine grained; quartzose; ripple laminated. **1.5**

123 Covered slope. **2.2**

122 Limestone; same color and lithology as unit 126. **2.4**

121 Siltstone and mudstone; pale reddish brown (10R5/4); not calcareous. **7.7**

120 Covered slope. **4.2**

119 Limestone; medium light gray (N6); weathers very pale orange (10YR8/2); mudstone. **0.2**

118 Covered slope. **1.0**

117 Limestone; medium gray (N5); weathers yellowish gray (5Y7/2); ostracodal wackestone. **0.4**

116 Covered slope. **1.0**

115 Limestone; medium light gray (N6); weathers yellowish gray (5Y7/2); ostracodal wackestone. **1.5**

114 Covered slope. **1.0**

113 Limestone; same color and lithology as unit 119. **1.2**

112 Covered slope. **1.5**

111 Limestone; same color and lithology as unit 115; gastropods. **0.3**

110 Covered slope. **2.1**

109 Sandstone; grayish red (10R4/2); fine to medium grained; arkosic; not calcareous; ripple laminations and herringbone crossbeds. **0.2**

108 Covered slope. **0.8**

107 Limestone; medium gray (N5); weathers medium light gray (N6); grainstone. **0.7**

106 Limestone; same color and lithology as unit 119. **0.7**

105 Covered slope. **2.9**

104 Sandstone; same color and lithology as unit 109. **0.2**

103 Covered slope; red mudstone? **4.6**

102 Sandstone; same color and lithology as unit 109. **0.2**

101 Covered slope. **4.3**

100 Limestone; light gray (N7) with moderate yellowish brown (10YR5/4) chert; algal mudstone. **0.3**

99 Covered slope. **2.6**

98 Limestone; medium gray (N5); weathers very pale orange (10YR8/2); nodular wackestone. **0.2**

97 Sandstone; same color and lithology as unit 109. **2.7**

96 Covered slope; red mudstone? **4.0**

95 Sandstone; pale reddish brown (10R5/4); fine grained; arkosic; not calcareous; ripple laminations; contains *Walchia* impressions and tetrapod footprints (NMMNH locality 4580). **2.2**

Community Pit Formation:

94 Limestone; medium dark gray (N4); wackestone; bioturbated; thick bedded. **4.3**

93 Shale; light olive gray (5Y6/1); calcareous; slope. **12.0**

92 Limestone; pale yellowish brown (10YR6/2); weathers very pale orange (10YR8/2); algal mudstone. **0.3**

91 Covered slope. **1.7**

90 Limestone; medium gray (N5); weathers medium light gray (N6); grainstone. **0.7**

89 Covered slope. **2.5**

88 Limestone; medium gray (N5); weathers light gray (N7) and grayish orange (10YR7/4); nodular bioclastic wackestone. **0.5**

87 Limestone; same color and lithology as unit 92. **0.6**

86 Covered slope. **2.1**

85 Limestone; medium gray (N5); weathers grayish orange (10YR7/4); mudstone. **0.2**

84 Covered slope. **5.2**

83 Limestone; medium dark gray (N4); grainstone; thick bedded. **3.3**

82 Covered slope. **2.1**

81 Limestone; same color and lithology as unit 83. **0.3**

80 Covered slope. **2.0**

79 Limestone; same color and lithology as unit 85. **2.1**

78 Covered slope. **9.0**

77 Limestone; medium dark gray (N4); weathers light brownish gray (5YR6/1); grainstone. **0.3**

76 Covered slope. **5.0**

75 Limestone; medium light gray (N6); weathers light gray (N7); wackestone; gastropods. **1.4**

74 Limestone; medium dark gray (N4); gastropod wackestone with some rudite lenses; medium bedded. **9.4**

73 Limestone; medium light gray (N6); weathers yellowish gray (5Y7/2); algal mudstone. **0.4**

72 Covered slope. **1.8**

71 Limestone; same color and lithology as unit 73. **0.5**

70 Covered slope. **3.0**

69 Limestone; medium dark gray (N4); weathers light brownish gray (5YR6/1); wackestone; algae, gastropods, sponges, productoids, *Derbyia, Aviculopinna.* **2.2**

68 Limestone; same color and lithology as unit 73. **1.6**

67 Covered slope. **1.1**

66 Limestone; same color and lithology as unit 85. **0.3**

65 Covered slope. **1.3**

64 Limestone; same color and lithology as unit 73. **0.2**

63 Limestone; medium dark gray (N4); weathers pale yellowish brown (10YR6/2); wackestone; algae and some gastropods; thick bedded. **2.7**

62 Covered slope. **0.7**

61 Limestone; medium gray (N5); gastropod wackestone; NMMNH locality 4568. **0.3**

60 Covered slope. **1.5**

59 Limestone; medium dark gray (N4); algal wackestone; brachiopods, gastropods. **1.1**

58 Covered slope. **7.8**

57 Limestone; medium dark gray (N4); weathers light olive gray (5Y6/1); gastropod wackestone (with bellerophontids); medium bedded with some shale breaks. 3.6

56 Limestone; light gray (N7); and very pale orange (10YR8/2); nodular mudstone. **4.0**

55 Limestone; medium dark gray (N4); grainstone. **0.6**

54 Covered slope. **1.6**

53 Limestone; medium gray (N5); weathers light gray (N7); wackestone; some gastropods. **2.4**

52 Covered slope. **9.8**

51 Limestone; medium gray (N5); weathers medium light gray (N6); mudstone. **0.2**

50 Limestone; yellowish gray (5Y8/1); algal mudstone. **1.1**

49 Covered slope. **1.7**

48 Limestone; medium dark gray (N4); weathers light brownish gray (5YR6/1); grainstone and algal mudstone. **0.6**

47 Covered slope. **2.1**

46 Limestone; medium gray (N4) and grayish orange (10YR7/4); algal mudstone and bioclastic wackestone; wavy laminations. **0.4**

45 Covered slope. **1.1**

44 Limestone; same color and lithology as unit 46. **0.3**

43 Covered slope; some siltstone lenses. **4.7**

42 Limestone; medium gray (N5); weathers grayish orange (10YR7/4); calcarenite. **1.5**

41 Covered slope. **12.5**

Shalem Colony Formation:

40 Limestone; medium dark gray (N4); weathers light olive gray (5Y6/1); grainstone at base grading up to wackestone with large brachiopods and bellerophontid gastropods; thick bedded. **3.6**

39 Covered slope. **4.6**

38 Limestone; medium gray (N5); grainstone; some chert nodules; thick bedded. **3.0**

37 Limestone; medium gray (N5); grainstone; rare chert; thick bedded. **1.5**

36 Covered slope. **2.5**

35 Limestone; medium dark gray (N4); nodular wackestone; thick bedded; fusulinaceans, bryozoans, brachiopods at top of unit (NMMNH locality 4969). **4.3**

34 Limestone; medium gray (N5); weathers light olive gray (5Y6/1); wackestone; cherty; finely laminated; upper 1 m has brachiopods, mostly *Composita* and *Pontisia* at NMMNH locality 4970 and fusulinaceans at NMMH locality 4967. **11.3**

33 Covered slope. **5.0**

32 Limestone; medium dark gray (N4); mudstone. **0.2**

31 Covered slope. **8.0**

30 Limestone; light olive gray (5Y6/1); cherty grainstone; some lenses of algal wackestone with gastropods *(Omphalotrochus).* **3.0**

29 Limestone; same color and lithology as unit 32. **2.0**

28 Covered slope; some siltstone lenses. **1.0**

27 Limestone; medium gray (N5); weathers light gray (N7); wackestone; medium bedded; top of ridge. **3.9**

26 Limestone; medium gray (N5); algal mudstone; forms a massive cuesta at the top of the ridge. **3.3**

25 Covered slope. **8.0**

24 Limestone; medium dark gray (N4); wackestone; algae, brachiopods, gastropods. **0.4**

23 Covered slope with a lens of algal limestone that is medium light gray (N6) and weathers grayish orange (10YR7/4). **1.1**

22 Carbonate sandstone; yellowish gray (5Y8/1); skeletal (carbonate) grains; medium grained; herringbone crossbeds. **0.9**

21 Covered slope. **4.0**

20 Sandstone; same color and lithology as unit 22. **0.3**

19 Covered slope. **1.1**

18 Limestone; medium gray (N5) and light brownish gray (5YR6/1); rudite lenses in grainstone; trough crossbeds. **1.8**

17 Limestone; medium gray (N5); grainstone; thinly laminated. **1.7**

16 Limestone; medium gray (N5); weathers pale brown (5YR5/2); calcarenite; thin bedded, trough crossbeds. **0.8**

15 Covered slope. **6.3**

14 Limestone; medium dark gray (N4); grainstone; slightly cherty; massive. **1.8**

13 Limestone; medium dark gray (N4); weathers very pale orange (10YR8/2); algal wackestone; thin bedded and somewhat nodular; some lenses have echinoid and gastropod debris. **2.0**

12 Covered slope. **9.7**

11 Limestone; medium gray (N5) with moderate brown (5YR4/4) chert; very cherty; wackestone; algae, corals, brachiopods, crinoids; some lenses of crinoidal conglomerate; medium bedded. **3.5**

10 Covered slope. **3.3**

9 Limestone; medium gray (N5); wackestone; algae, bellerophontid gastropods, rugose corals, *Wellerella*, crinoids; medium bedded. **1.7**

8 Limestone; light gray (N7); some chert; wackestone; algae, brachiopods. **6.5**

7 Limestone; medium gray (N5); weathers yellowish gray (5Y7/2); wackestone with crinoidal conglomerate lenses. **0.4**

6 Limestone; medium light gray (N6); algal mudstone; units 6-8 form a bioherm cliff that thins to the north. **2.3**

Madera Group:

Panther Seep Formation:

5 Limestone and sandstone; light olive gray (5Y6/1), weathers pale yellowish brown (10YR6/2); arkosic; thick bedded. **2.1**

4 Covered slope. **22.0**

3 Limestone; same color and lithology as unit 5. **1.3**

2 Covered slope with thinly laminated medium gray (N5) to yellowish gray (5Y8/1) lime mudstone at base. **9.8**

1 Limestone; olive gray (5Y4/1); grainstone; thinly bedded, ripple laminations and herringbone crossbeds. 6.5