Progress report on correlation of nonmarine and marine Lower Permian strata, New Mexico, USA

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Introduction

In the southwestern USA, the state of New Mexico preserves a paleoenvironmental transect of Upper Carboniferous-Lower Permian strata from entirely nonmarine siliciclastic red beds in the northern part of the state, to mixed marine-nonmarine strata in the central part of the state to wholly marine strata in the southern part of the state (Fig. 1). This transect provides a remarkable and probably unique opportunity to correlate nonmarine and marine biostratigraphic data of the Lower Permian and, in particular, across the Carboniferous-Permian boundary.

The upper Paleozoic strata in New Mexico were deposited in equatorial western Pangea during the Ancestral Rocky Mountain (ARM) orogeny, so they range from synorogenic alluvial red beds to marine carbonates. The Hueco seaway, in southern New Mexico, was a western and northwestern extension of the famous Permian basin of West Texas. Here we present a progress report on the cross correlation of nonmarine and marine biostratigraphy across the depositional transect from ARM alluvial plains in northern New Mexico to Hueco seafloors in southern New Mexico.

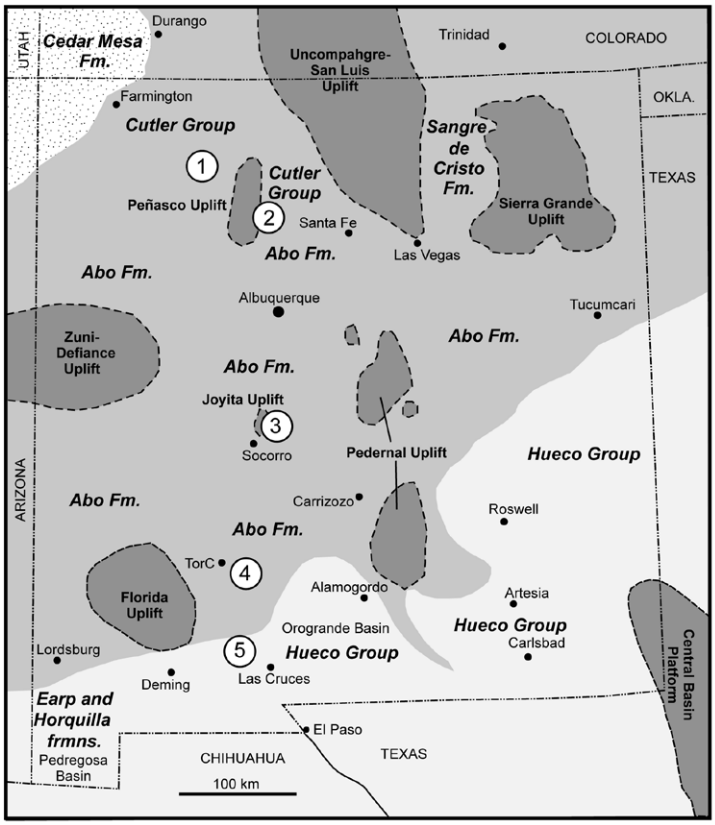

Fig. 1. Paleogeographic map of New Mexico during part of the Early Permian (~Wolfcampian) (after Kues and Giles, 2004). The numbers in circles locate the columns in the correlation chart in Figure 2.

Lower Permian of Central New Mexico

The older nonmarine Lower Permian strata in New Mexico encompass siliciclastic red beds of the Cutler Group, Sangre de Cristo and Abo formations and the Robledo Mountains Formation, a red-bed tongue of the upper part of the Abo Formation intercalated with Hueco Group strata in south-central New Mexico (Fig. 2) (Lucas et al., 2013e; Voigt et al., 2013). Other red-bed tongues of the Abo Formation are intercalated with the Hueco Group to the southeast, in the Sacramento Mountains of southeastern New Mexico, and in the Franklin Mountains of western Texas (Bachman and Hayes, 1958; Pray, 1961; Williams, 1963; Lucas et al., 2011c, 2014; Lucas 2014). The base of the Abo Formation correlates to the middle Wolfcampian (Nealian) Powwow Conglomerate at the Hueco Group base (Pray, 1961; Williams, 1963; Lucas et al., 2011a), and records a pulse of the ARM orogeny, the Dugout orogeny of Ross and Ross (1987). The red-bed strata yield well-known fossil assemblages of plants, tetrapod bones, vertebrate footprints and arthropod traces, as well as a few arthropod body fossils. The tetrapod footprint record is the most extensive record of Early Permian age known (Lucas and Heckert, 1995; Minter and Braddy, 2009; Lucas et al., 2011b; Voigt and Lucas, 2015).

At the base of the Permian section, and locally transgressing the Carboniferous-Permian boundary (= Wolfcampian base: Lucas, 2013a, c), is the mixed marine-nonmarine Bursum Formation. The marine biostratigraphy from Bursum carbonate beds can be directly related to tetrapod and blattid (cockroach) biostratigraphy from the intercalated nonmarine strata (see, especially, articles in Lucas and Zeigler, 2004, as well as Lucas et al., 2013c and Schneider et al., 2013). Thus, fusulinid and conodont biostratigraphy of the Bursum Formation demonstrate that it is diachronous, older (Virgilian or Virgilian/Wolfcampian) north of Socorro and younger (Wolfcampian) to the south, and that its base and/or top are unconformable in many sections (e. g., Lucas et al., 2000, 2009, 2013c; Krainer and Lucas, 2013).

The oldest Lower Permian marine strata of southern New Mexico belong to the Hueco Group and are mostly shallow marine platform carbonates (Fig. 2). They have well-studied fusulinid and brachiopod records (e. g., Thompson, 1954; Simpson, 1984; Kues, 1995; Lucas et al., 2000, 2015; Wahlman and King, 2002), a few ammonoid records (Miller and Parizek, 1948; Kues, 1995), and recent studies have developed an extensive understanding of other microfossil records, particularly of non-fusulinid foraminifers and algae (Krainer et al., 2003, 2009, 2015; Lucas et al., 2015). The

most significant result for correlation to the nonmarine section is identification of the Leonardian/Artinskian age of the Robledo Mountains Formation (Fig. 3). This indicates that the base of the Leonardian is in the upper part of the Abo lithosome (below strata correlative to the Robledo Mountains Formation) to the north (Fig. 2).

Broadly overlying all of these older Permian strata is the Yeso Group, a complex array of shallow marine, sabkha, arid coastal plain and eolian strata that extend across much of New Mexico (Fig. 2) (Lucas et al., 2013b). To the northwest, the lower part of the Yeso Group is the DeChelly Sandstone, which was deposited by an erg that covered the Four Corners region. To the southeast, Yeso strata are laterally equivalent to marine strata of the Victorio Peak and Bone Spring formations in the Permian basin. In between, across most of central New Mexico, Yeso strata are composed of gypsum, siltstone, fine sandstone and thin dolomite beds that represent deposition in brine pools, sabkhas, tidal flats and eolian sand sheets on a vast coastal plain to the northwest of the Permian basin (Mack and Dinterman, 2002). Yeso strata have long been regarded as largely unfossiliferous or, at least, devoid of biostratigraphically useful fossils. However, during the last decade we have discovered tetrapod footprint and plant assemblages in the lower part of the Yeso strata (Arroyo de Alamillo Formation: Lucas et al., 2013b), and marine interbeds stratigraphically high in the Yeso Group (Los Vallos Formation) locally yield extensive microfossil assemblages (Vachard et al., 2013, 2015), though fusulinids remain undiscovered.

In central New Mexico, the Glorieta Sandstone overlies the Yeso Group and is homotaxial to the Coconino Sandstone of northern Arizona and the San Angelo Formation in the Midland basin of Texas (Fig. 2) (Lucas, 2004; Lucas et al., 2013a). Glorieta strata are mostly of eolian origin (Mack and Bauer, 2014), and the Coconino yields a well known ichnofauna, whereas the youngest Permian tetrapod body fossils from North America (Littlecrotonian LVF of

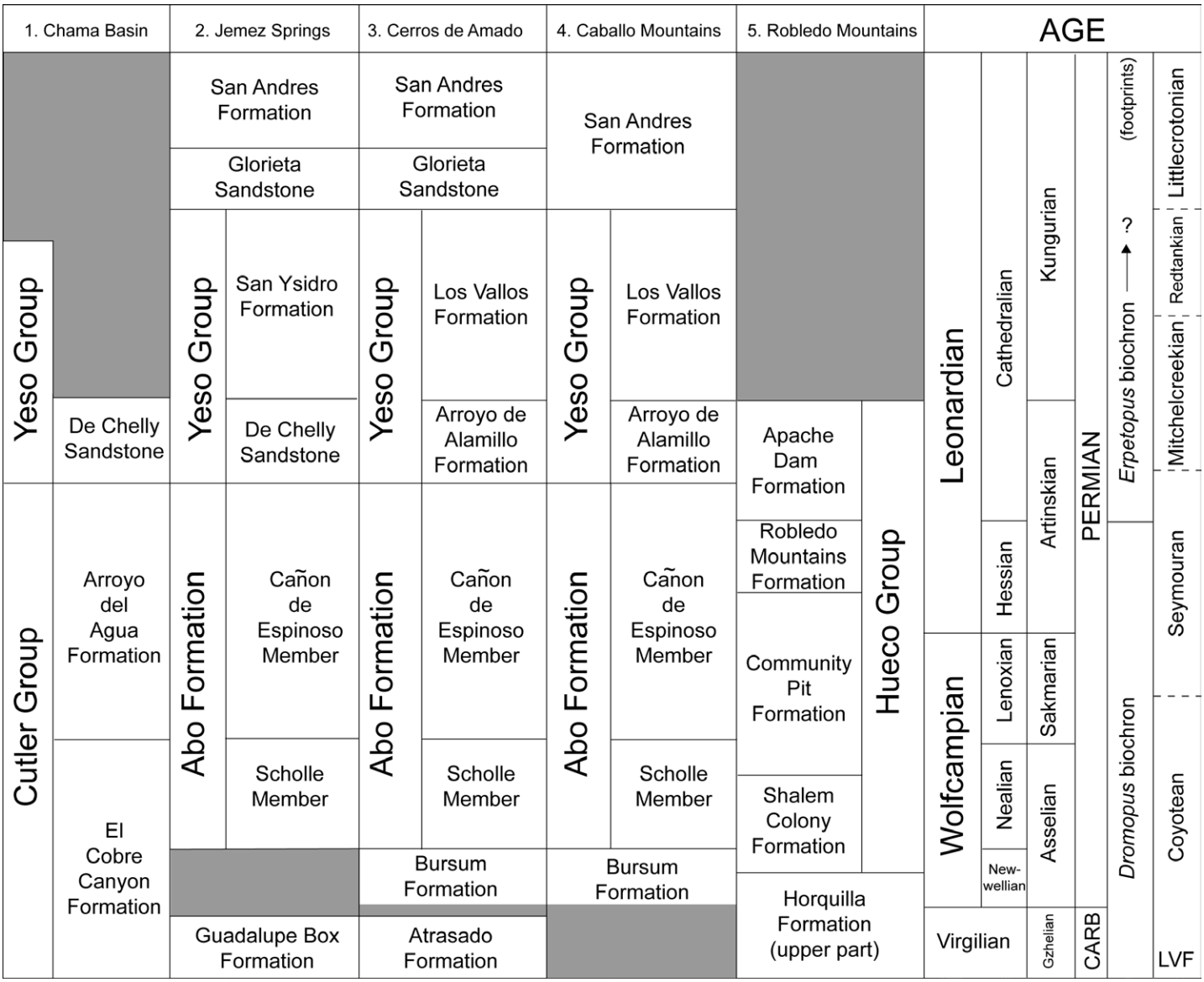

Fig. 2. Correlation of non-marine and marine strata from north to south across central New Mexico. See Figure 1 for location of columns. Modified from Lucas et al. (2013e).

Lucas, 2006) are from the San Angelo Formation in Texas and its Oklahoma equivalents, the Flowerpot and Chickasha formations (Olson, 1962; Lucas, 2004). No biostratigraphically useful fossils have been recovered from the Glorieta Sandstone in New Mexico. But, these homotaxial eolian and fluvial units are overlain by late Leonardian strata—the lower parts of the Kaibab Formation in Arizona, San Andres Formation in New Mexico-West Texas and the Blaine Formation in north-central Texas-Oklahoma (Lucas,

ZONATION	FORMATIONS		Thickness (m)	BIOMARKERS (and representative samples)		REGIONAL STAGES	INTERNATIONAL STAGES
Zone 15	SAN ANDRES FORMATION			*Olgaorlovella davydovi* *Tubiphytes epimonellaeformis* *Geinitzina indepressa*	LEONARDIAN	CATHEDRALIAN	LATE KUNGURIAN
Zone 14				*Hemigordiellina* spp.			MIDDLE KUNGURIAN
Zone 13	GLORIETA SANDSTONE			barren of foraminifers			
Zone 12	YESO GROUP			*Frondicularia* aff. *turae*			EARLY KUNGURIAN
Zone 11				*Ellesmerella rara* *Nestellorella* ? sp.			
Zone 10				*Globivalvulina novamexicana* *Orthovertellopsis protaeformis* *Glomomidiella infrapermica*			
Zone 9	HUECO GROUP	Apache Dam Formation					LATE ARTINSKIAN
Zone 8		Robledo Mountains Formation	53	*Pseudoreichelina* sp. *Geinitzina* sp. 2 (?*multicamerata*)		HESSIAN	MIDDLE ARTINSKIAN
Zone 7		Community Pit Formation	10	*Praeneodiscus* sp. *Globivalvulina novamexicana* *Globivalvulina praegraeca* DAB 13 + DAB 14/DAC 1-DAC 5			EARLY ARTINSKIAN
Zone 6			20	*Pseudovermiporella* sp. DAB 10 - DAB 12	WOLFCAMPIAN	LENOXIAN	LATEST SAKMARIAN
Zone 5			50	*Pachyphloia*? sp. *Geinitzina postcarbonica* *Nodosinelloides longissima* DAB 7 - DAB 9			LATE SAKMARIAN
Zone 4			7	*Nodosinelloides pinardae* *Globivalvulina parapiciformis* *Geinitzina postcarbonica* DAA 59 - DAA 69/DAB 2 - DAB 6			EARLY SAKMARIAN
Zone 3			50	*Hedraites* sp. DAA 53 - DAA 58		NEALIAN	LATE ASSELIAN
Zone 2			20	*Geinitzina postcarbonica* *Nodosinelloides netschajewi* DAA 45 - DAA 52			MIDDLE ASSELIAN
Zone 1		Shalem Colony Formation	65	*Leptotriticites* sp. (DAA 43) *Nodosinelloides longissima* *Tubiphytes* sp., *Geinitzina* sp. (DAA 38) *Pseudovidalina* sp., *Pseudoschwagerina* sp. DAA 42		Newwellian	EARLY ASSELIAN

Fig. 3. Foraminiferal biozonation of the marine Lower Permian of southern New Mexico (modified from Lucas et al., 2015 and Vachard et al., 2015). The column for thicknesses is for the Robledo Mountains section in southern New Mexico.

2004; Vachard et al., 2015).

Marine strata of the San Andres Formation in central New Mexico yield numerous fossils, traditionally brachiopods and cephalopods (e.g., Kottlowski et al., 1956; Krainer et al., 2012), and more recently nonfusulinid foraminifers and algae (Vachard et al., 2013, 2015) that indicate the San Andres Formation is of late Leonardian age (Fig. 3). Note that to the southeast, toward the Permian basin, younger strata of the San Andres Formation are preserved that are of Roadian age (Kerans et al., 1993), but the central New Mexico San Andres Formation appears to be a less temporally extensive unit that represents only late Leonardian time (Brose et al., 2013; Vachard et al., 2013, 2015).

The Artesia Formation encompasses the youngest Permian strata across central New Mexico (e. g., Tait et al., 1962; Kelley, 1972; Lucas and Hayden, 1991; Lucas, 2013b). These are siliciclastic red beds, dolomites and gypsum that were deposited on the vast shelf behind the great Guadalupian reefs that fringed the northwestern end of the Permian basin. In central New Mexico, the Artesia Formation is a thin clastic wedge that lacks age diagnostic fossils but is equivalent to the Grayburg and Queen formations basinward. Thus, Artesia Formation strata in central New Mexico (from San Miguel to Socorro counties) are Wordian based on stratigraphic position and basinward age determinations of correlative strata (Lucas, 2013b).

Biostratigraphy, Biochronology and Chronostratigraphy

Recent micropaleontological work in the Hueco and Yeso groups and San Andres Formation (Lucas et al., 2011a, c, 2015; Krainer et al., 2003, 2009, 2015; Vachard et al., 2013, 2015), combined with earlier work, have allowed us to construct a biozonation of these strata that can be correlated to the standard global chronostratigraphic scale (Fig. 3). This correlation places the Leonardian base in the Hueco Group.

The nonmarine red beds yield fossil vertebrate assemblages that are part of a succession of biochronological units (LVFs: land-vertebrate faunachrons) that Lucas (2006) proposed for Permian time. In terms of diversity of taxa, abundance of specimens, and quality of preservation the Lower Permian vertebrate assemblages of New Mexico clearly rank as among the most prolific in North America, which are dominated by the amphibian lepospondyls, temnospondyls (particularly dissorophoids), and anthracosaurs, the reptilian captorhinomorphs and araeoscelids, the diadectomorphs (?reptiles), and the basal synapsids ("pelycosaurs") (Berman et al., 2015). In New Mexico, tetrapod assemblages of the Cobrean, Coyotean and Seymouran LVFs are identified by stratigraphically superposed, tetrapod-dominated assemblages from the Cutler Group, Bursum Formation and the Abo Formation. In New Mexico-Texas, these and the younger Early Permian LVFs can be cross correlated to the provincial marine timescale with some fair precision (Fig. 2) (Lucas, 2006).

Tetrapod footprint assemblages from the Abo, Sangre de Cristo and Robledo Mountains formations and the lower Yeso Group can be divided into two biochrons—the latter part of the *Dromopus* biochron of Lucas (2007), which encompasses all but the uppermost Abo Formation and lower Yeso Group footprints, and the *Erpetopus* biochron of the uppermost Abo Formation and the lower Yeso Group (Fig. 2) (Voigt and Lucas, 2013, 2015). The footprint assemblages of the Abo Formation and the Robledo Mountains Formation are dominated by those of temnospondyls (*Batrachichnus*) and araeoscelids (*Dromopus*) with some eupelycosaur (*Dimetropus*) tracks (e. g., Lucas and Heckert, 1995; Lucas et al., 2011b; Minter and Braddy, 2009; Voigt and Lucas, 2013, 2015). The helical burrow *Augerinoichnus* (Minter et al., 2008) also is known only from the Abo and Robledo Mountains formations.

In contrast, ichnoassemblages of the lower part of the Yeso Group (Arroyo de Alamillo Formation) in central New Mexico are dominated by "captorhinomorph" tracks (especially of *Varanopus*), have only rare *Batrachichnus* and *Dromopus,* lack *Augerinoichnus* and include the lowest occurrence of the shallow arthropod burrow *Sphaerapus* (Lucas et al., 2013d). The change in ichnoassemblages is the boundary between the *Dromopus* (older) and *Erpetopus* (younger) biochrons (Fig. 2) (Lucas, 2007; Voigt and Lucas, 2013).

Fossil plant assemblages from the Lower Permian nonmarine red beds are of low diversity and monotonous in composition. Assemblages are dominated by walchian conifers with local dominance by the peltasperm *Supaia*. Localized occurrences of callipterids, such as *Autunia conferta* and sphenopsids, are reported (Hunt, 1983; DiMichele et al., 2007, 2013; Voigt et al., 2013). The only potentially biostratigraphically significant fossil taxon in these red-beds assemblages is *Gigantopteridium* (Read and Mamay, 1964), known only from rare occurrences; its presence in the Robledo Mountains Formation (DiMichele et al., 2015) is consistent with a Leonardian age for these strata.

Permian-Carboniferous macrofloral assemblages from strata other than the Abo Formation red beds (and equivalents) have been described from several locations and stratigraphic intervals in central New Mexico. For the most part, however, these are only of the broadest use for correlation because they preserve floras principally associated with seasonally dry climatic conditions, for which detailed biostratigraphic ranges are less well characterized within the global paleoequatorial region. Nearly all preserve some wetland elements, reflecting habitat heterogeneity, but these are most often long-ranging, broadly distributed taxa or contain rare, but significant, species for which stratigraphic ranges have not been confidently established. Macrofloras of the Bursum Formation (Tidwell and Ash, 2004; DiMichele et al., 2004), for example, indicate a mixture of typically wetland and dryland taxa, typical of the Carboniferous-Permian transition elsewhere in western Pangea (e.g., Tabor et al., 2012).

Little palynology has been undertaken of the Lower Permian strata in central New Mexico beyond studies of the Bursum Formation at Carrizo Arroyo (Traverse and Ash, 1999; Utting et al., 2004). These palynological studies are consistent with other investigations and find the Carrizo Arroyo deposits to be close to the Pennsylvanian-Permian boundary, likely earliest Permian. Conchostracans and insect fossils are rare above the Bursum interval (Martens and Lucas, 2005), so little biostratigraphy can be based on them.

Work continues on biostratigraphy and correlation in the Lower Permian nonmarine-marine depositional systems in central New Mexico. Thus, this is a progress report on a project that we hope to present in final form in the next few years.

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