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THE PENNSYLVANIAN SECTION AT CHAVES BOX, RIO ARRIBA COUNTY, NEW MEXICO

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Abstract.—At Chaves Box, southeast of Chama (T29N, R4E, Rio Arriba County), a 130-m-thick section of Pennsylvanian strata crops out between Proterozoic quartzite and the Upper Triassic Chinle Group. These strata can be assigned to a lower interval A of quartzose sandstone and an upper interval B of arkosic sandstone and marine limestone. The marine limestone yields a moderately diverse but poorly preserved normal-marine invertebrate fossil assemblage that consists of 11 species of brachiopods, of which *Composita subtilita* and *Anthracospirifer* cf. *curvilateralis chavezae* are by far the most abundant; an unidentified hexactinellid sponge; crinoid fragments**,** bryozoans, including *Prismopora*; the gastropod *Retispira tenuilineata*; the bivalves *Aviculopecten, Myalina* and *Polidevcia*; and rare trilobites. The fusulinids *Beedeina haworthi* (Beede) and *Wedekindellina euthysepta* (Henbest) indicate a middle Desmoinesian age**,** as do the brachiopods. The Pennsylvanian section at Chaves Box can be assigned to the Hermosa Group, probably as a clastic facies equivalent to part of the Paradox Formation. The Pennsylvanian strata at Chaves Box document the changeover from quartzose deposition during final erosion and collapse of the San Luis uplift to initial deposition of arkosic clastics shed from the Uncompahgre uplift. This event, which occurred across the early-middle Desmoinesian boundary, is accompanied by a major regional marine transgression that extended marine deposition as far north and east as Chaves Box.

INTRODUCTION

Pennsylvanian marine strata are not well exposed in the Chama Basin of north-central New Mexico. They are mostly confined to the heavily wooded and poorly exposed northern dip slope of the Nacimiento Mountains south of Gallina (Woodward, 1987). However, one small outcrop of Pennsylvanian marine strata is present in the northern Chama Basin at Chaves Box in section 1, T29N, R24E, Rio Arriba County (Fig.1). Little has been written about this outcrop beyond the original description by Muehlberger (1957, 1967), and it has not figured in regional syntheses of Pennsylvanian tectonics, sedimentation and paleogeography (e.g., Wengerd and Matheny, 1958; Fetzner, 1960; Mallory, 1972; Sutherland, 1972; Baars and Stevenson, 1984; Huffman and Condon, 1993; Kues and Giles, 2004). Here, we detail the lithostratigraphy, sedimentary petrology, paleontology, biostratigraphy and depositional environments of the Pennsylvanian section at Chaves Box to discuss its implications for Pennsylvanian tectonics and paleogeography in nothern New Mexico.

LITHOSTRATRATIGRAPHY

The Pennsylvanian strata exposed at Chaves Box (Fig. 2) are up to 130 m thick. They rest nonconformably on Proterozoic quartzite, and the basal bed of the Pennsylvanian strata is a quartzite-pebble conglomerate a few meters thick. The quartzite pebbles are locally derived from the Proterozoic quartzite. Strata overlying the basal conglomerate are mostly covered (siltstone or shale?) but include two prominent ledges of sandstone. The lower ledge is approximately 20 m thick and consists of grayish red, very fine-grained quartzose sandstone, in two thick beds. The upper ledge is approximately 6 meters thick and consists of grayish red, coarse-grained arkosic sandstone. Above the upper ledge, a 5-10 m thick interval of siltstone includes light gray, fossiliferous limestone nodules. The fossils described below were collected from those nodules at NMMNH locality 5256 (UTM zone 13, 369527E, 4069776N, datum: NAD 27). Above them, the section is covered, and Upper Triassic strata at the base of the Chinle Group overlie the Pennsylvanian strata (Muehlberger, 1957, 1967; Lucas et al., 2003).

As Muehlberger (1967) indicated, the Pennsylvanian section at Chaves Box can be divided into two distinctive lithologic intervals separated by an apparent disconformity. The lower interval (interval A) is characterized by quartzose sandstones and thick covered intervals and is up to 60 m thick. The upper interval (interval B) is characterized by arkosic sandstone and marine limestone of Middle Pennsylvanian age (see below).

SEDIMENTARY PETROGRAPHY

Petrographic study of sandstones in the Chaves Box Pennsylvanian section supports the recognition of two lithologically distinct intervals in the section (Fig. 2). We studied the petrography of two sandstone units that show a significant difference in mineralogical composition reflecting a difference in their source rocks.

Petrographic sample 2 (Figs. 2, 3B) is a medium- to coarse-grained, poorly-sorted, angular to subangular quartzarenite. Monocrystalline quartz is by far the most abundant constituent, and poly-

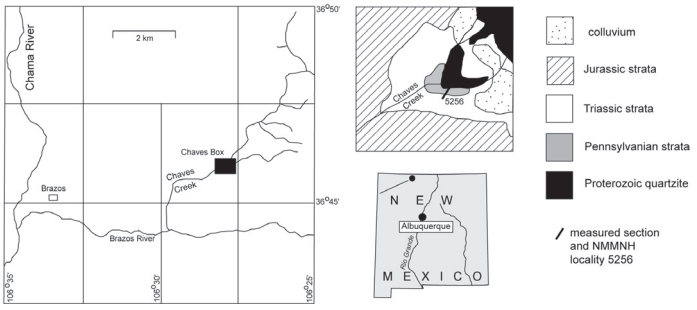


FIGURE 1. Location map and geologic map (after Muehlberger, 1968) of Chaves Box in northern New Mexico.

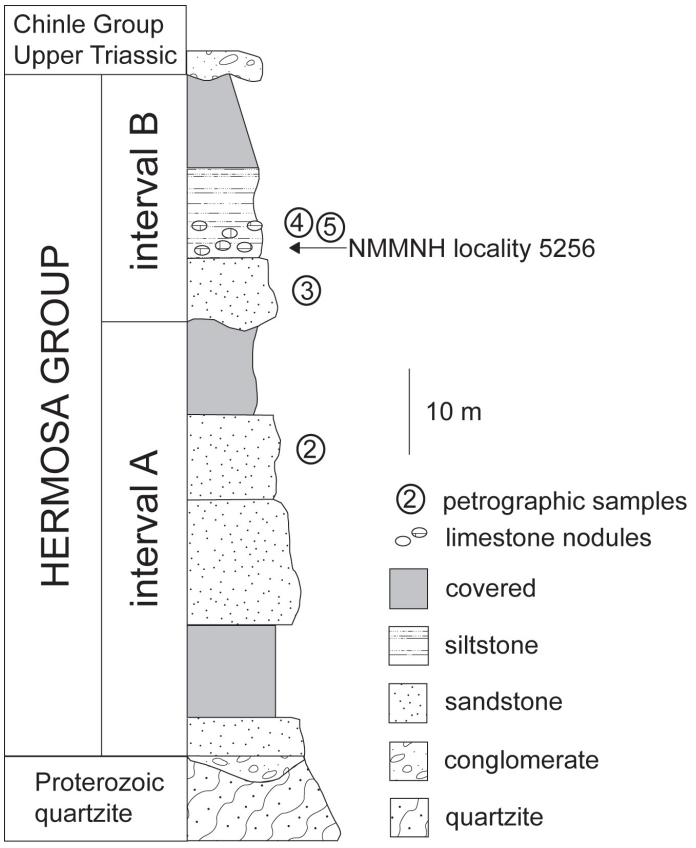


FIGURE 2. Stratigraphic section of Pennsylvanian strata at Chaves Box showing stratigraphic levels of petrographic samples and fossil locality.

crystalline quartz is rare. Detrital feldspars and rock fragments are lacking. Accessory minerals are zircon and tourmaline. The matrix is stained dark brown–black by iron hydroxides and hematite.

Petrographic sample 3 (Figs. 2, 3A) is a coarse-grained, moderately sorted, angular to subangular arkosic arenite composed of abundant monocrystalline quartz, many polycrystalline quartz grains and detrital feldspars. Most feldspars appear fresh (unaltered) and are broken in-situ. Untwinned potassium feldspars, perthitic feldspars, microcline and rare polysynthetic plagioclases are present. Rock fragments are rare and consist of feldspar and quartz. The sandstone also contains a few detrital micas (biotite and muscovite) and chert grains. The pore space is filled with reddish-brown matrix. Locally, detrital quartz grains display authigenic overgrowths.

We also examined two characteristic limestone samples. Petrographic sample 4 (Fig. 3E-F) is a bioclastic wackestone composed of gray, bioturbated micritic matrix that contains relatively few bioclasts, including large fragments (up to several cm) of bryozoans, bivalves, brachiopods, fusulinid tests, small gastropods, echinoderm fragments (partly silicified), echinoderm spines, ostracods, very rare smaller foraminifers and abundant calcified spicules. Petrographic sample 5 (Fig. 3D) is a bioclastic wackestone/packstone (spiculite) composed of abundant, locally densely packed spicules that are partly calcified. Locally smaller foraminifers, mostly tubular species, are also abundant. Ostracods and a few small echinoderm fragments are present. The bioclasts are cemented by calcite; locally small amounts of gray micrite are present. The rock is bioturbated.

For comparison, we examined samples from the Cutler Group in El Cobre Canyon. El Cobre Canyon is about 60 km southeast of Chaves Box and would have been in a similar paleogeographic position during the Pennsylvanian. It exposes red bed siliciclastic sediments of the Pennsylvanian-Permian Cutler Group. These are sediments shed from the Uncompahgre uplift, so this comparison establishes the likelihood of an Uncompahgre source for the petrographically similar upper sandstones at Chaves Box. Sandstones in the lowermost part containing plant fossils (Fig. 3C) and are greenish-gray, fine-grained and are moderately- to well-sorted. Grains are angular to subangular and consist of mono- and polycrystalline quartz, abundant fresh and altered detrital feldspars (mostly untwinned potassium feldspars, many microclines, perthitic feldspars and a few polysynthetic twinned plagioclases). Some of the detrital feldspars are strongly altered to clay minerals. Detrital grains of greenish biotite are numerous, constituting about 5-10% of all grains; subordinate muscovite is present too. Rock fragments of quartz and feldspar, some containing micas and brownish chert fragments are rare. The sandstone is cemented by coarse, poikilotopic calcite, which replaces detrital quartz and feldspar grains.

In the Cutler Group at El Cobre Canyon, the red sandstones are fine- to coarse-grained, moderately to well sorted, angular to subangular subarkoses to arkoses containing large amounts of detrital feldspars. Grains are mono- and polycrystalline quartz (granitic and schistose-metamorphic), detrital feldspars (mostly untwinned potassium feldspars, some perthitic, microclines, rarely plagioclases displaying karlsbad and polysynthetic twins). Some feldspars occur as large grains. Many detrital feldpars are partly altered to clay minerals. Rock fragments are composed of quartz and feldspar. Some are fine-grained, schistose and composed of micas and quartz (reworked phyllitic rock fragments). Detrital micas are abundant in the lower part (greenish biotite, muscovite, rarely chlorite), and rare in the higher part of the section (muscovite). Some silty chert grains are present. Some sandstone beds contain sedimentary rock fragments composed of reddish-brown, fine-crystalline carbonate, some of which contain a few small grains of angular quartz, feldspar and micas (reworked caliche crusts). Volcanic rock fragments composed of recrystallized volcanic glass and inclusions of volcanic quartz are rarely present. Sandstones are cemented by coarse, poikilotopic calcite which randomly replaces detrital quartz and feldspar. In many sandstones most grains display thin hematite coatings which seem to prevent replacement of quartz and feldspar by calcite. Locally, small amounts of black-stained matrix (hematite) occur. A few detrital quartz grains display thin authigenic overgrowths.

Arkosic sandstones of the Cutler Group indicate a dominantly granitic source, as well as subordinate metamorphics (schists, phyllites) and acid volcanics that have also been reworked. Sedimentary rock fragments are reworked intraclasts derived from eroded caliche horizons which locally are preserved within the Cutler Group. Arkosic sandstones of the Cutler Group are very similar in composition and textural maturity to sandstone 3 of the Chaves Box section, and this implies a common source in the Uncompahgre uplift.

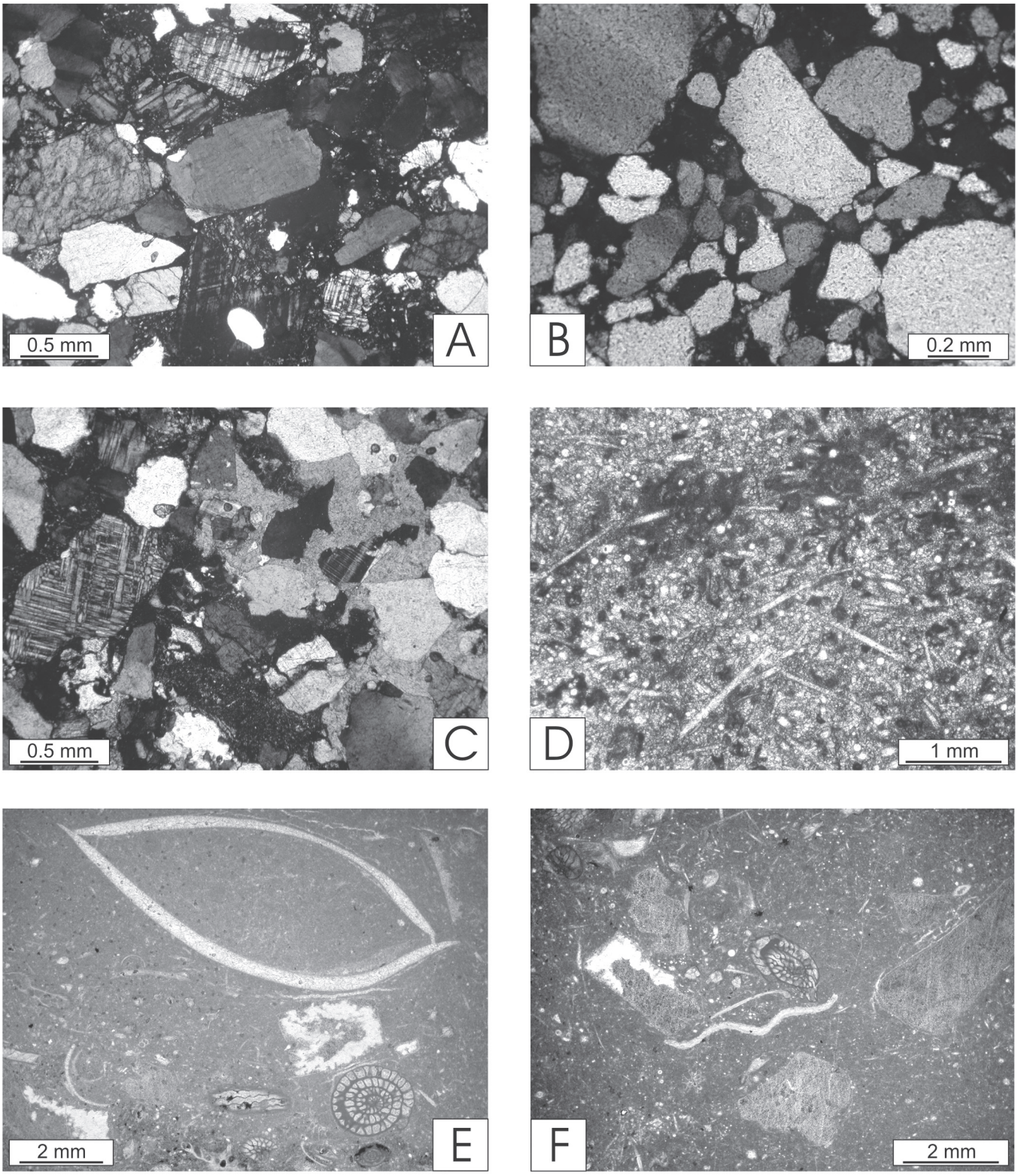


FIGURE 3. Petrographic thin sections of selected rocks at Chaves Box (see Figure 2) and from the Cutler Group at El Cobre Canyon, New Mexico. Sample 3.A, Coarse-grained, arkosic arenite composed of angular – subangular quartz grains and abundant potassium feldspars (crossed nicols). Chaves Box, sample 3.B, Medium- to coarse-grained, poorly sorted, angular-subangular quartzarenite composed mostly of monocrystalline quartz crossd nicols). Chaves Box, sample 2.C, Coarse-grained, subarkosic-arkosic arenite containing angular subangular quartz and feldspar grains cemented by calcite (crossed nicols). Cutler Group, El Cobre Canyon (lower part).D, Spiculite composed of abundant, partly calcified spicules and some gray micrite (plane light). Chavez Box, sample 5.E- F, Bioclastic wackestone composed of gray micrite and relatively few larger fossil fragments including bivalves, brachiopod fragments, echinoderms (partly silicified), fusulinids, bryozoans, ostracods and rare smaller foraminifers (plane light). Chaves Box, sample 4.

PALEONTOLOGY

Introduction

In their stratigraphic studies of the Chaves Box area, Muehlberger (1957, 1967) and Muehlberger et al. (1960), hereafter cited as Muehlberger (1967), listed two fusulinid species and about a dozen invertebrate taxa, mainly brachiopods, from a nodular limestone near the top of the Pennsylvanian section. The fusulinids (*Wedekindellina euthysepta*, *Fusulina* [now *Beedeina*] *haworthi*) and invertebrates (*Prismopora* sp., Bryozoa [two forms other than *Prismopora*], *Mesolobus* sp., *Derbya* [sic] sp., *Dictyoclostus* sp., *Spirifer* sp., *Neospirifer* [juvenile], *Composita* sp., *Squamularia* [now *Phricodothyris*] *perplexa*, *Punctospirifer kentuckyensis*, and crinoid fragments) were said to constitute a middle Desmoinesian assemblage. We recollected this limestone at the Chaves Box locality, and here briefly describe a larger assemblage than reported by these earlier workers, provide revised names and more detailed documentation of the taxa, and add further evidence for the middle Desmoinesian age indicated by these taxa. All specimens discussed here are catalogued in the paleontology collections of the New Mexico Museum of Natural History and Science (NMMNH), Albuquerque, New Mexico.

The fossils described here are preserved in three kinds of limestone. The most common lithology is hard, coarsely crystalline, pinkish gray, micritic limestone, which weathers to dark red. Fossils range from complete shells to dense bioclastic debris. Locally, this limestone displays hematized crusts and millimeter-scale layers of quartz sand grains, possibly concentrated by dissolution of the limestone. A second, less common lithology is finely crystalline, medium-gray to slightly-greenish gray, dense limestone bearing a lesser number of fossil remains. Finally, some medium-gray limestone samples are packed with white, recrystallized crinoid skeletal fragments, which locally may compose more than one half of the total rock volume. Fossils embedded in these limestones are difficult to extract for study and typically are exposed in an exfoliated state that obscures surface details. Because of poor preservation, many taxa cannot be precisely identified.

Taxa identified from the Chaves Box limestones are listed in Table 1, and most are illustrated in Fig. 4. Brachiopods, especially *Anthracospirifer* and *Composita*, dominate the identifiable taxa, and other stenohaline groups, such as crinoid and bryozoan fragments and small fusulinids, are locally common. Few gastropods and bivalves are present, and sponge and trilobite remains are rare. The composition of this assemblage indicates normal-marine salinity in a shallow marine environment. The brachiopods are discussed first and at some length, then other invertebrates, followed by discussion of the age of this assemblage.

TABLE 1. Invertebrate taxa and number of identified specimens from Desmoinesian limestone in Chaves Box. Abundance estimates: C, common; MC, moderately common; UC, uncommon.

TAXON	SPECIMENS
Fusulinids	MC
Sponges	2
Bryozoans	
Fenestellids	UC
Prismopora sp.	MC
Encrusting bryozoans	UC
Brachiopods	
Orbiculoidea cf. *O. youngi*	2
Mesolobus cf. *M. profundus*	4
Echinaria cf. *E. knighti*	1
Buxtonia sp.	1
Antiquatonia cf. *A. hermosana*	1
Linoproductus cf. *L. planiventralis*	1
Composita subtilita	34
Neospirifer cf. *N. cameratus*	4
Anthracospirifer cf. *A. curvilateralis chavezae*	39
Punctospirifer kentuckyensis	1
Phricodothyris perplexa	1
Gastropods	
Retispira tenuilineata	2
Stegocoelia (Taosia)? sp.	1
Strobeus? sp.	1
Bivalves	
Polidevcia sp.	1
Myalina sp.	1
Aviculopecten sp.	1
Unidentified pectinids	1
Unidentified trilobite pygidium	1
Crinoid stem elements	C

Brachiopods

Orbiculoidea cf. *O. youngi* Sutherland and Harlow

The inarticulate brachiopod *Orbiculoidea* is represented in the Chaves Box collection by a complete but partially exfoliated brachial valve (Fig. 4A, B) and a smaller fragment of a nearly flat pedicle valve. The brachial valve is broadly oval in outline and slightly wider around the anterior relative to the posterior margin. The valve is large for the genus, with a maximum width of 22 mm and a length of 26 mm. It is relatively high (14.5 mm) and broadly conical in shape with a blunt apex situated subcentrally, slightly displaced toward the posterior margin. The anterior and posterior slopes are very gently convex from the apex to the base. External ornamentation consists of sharp, narrow, widely-spaced concentric lirae (7 to 8 lirae per 2 mm on the anterior slope), with interspaces about three or four times the width of a lira. Internal surfaces of the brachial valve show vague, slightly undulating radial markings, but no indications of internal septa are preserved. The occurrence of *Orbiculoidea* in this coarsely crystalline limestone is unusual, as Pennsylvanian specimens are typically found in dark gray shales.

This specimen differs from *Orbiculoidea missouriensis* (Shumard) in being much larger, with a more centrally located apex. *Orbiculoidea capuliformis* (McChesney) is as much as 30 mm long but is virtually circular in outline, with a lower brachial valve. The brachial valve of *O. tenuilineata* (Meek and Hayden) is apparently unknown, and *O. meekana* (Whitfield) is similar in size but has a concave posterior slope and an apex located close to the posterior margin. Sutherland and Harlow (1973) described "*O.*" *youngi* from Atokan strata in the Sangre de Cristo Mountains, north-central New Mexico. The Chaves Box specimen is similar in size, lateral profile, and elevation and position of the apex, but the holotype of "*O.*" *youngi* is slightly wider than long

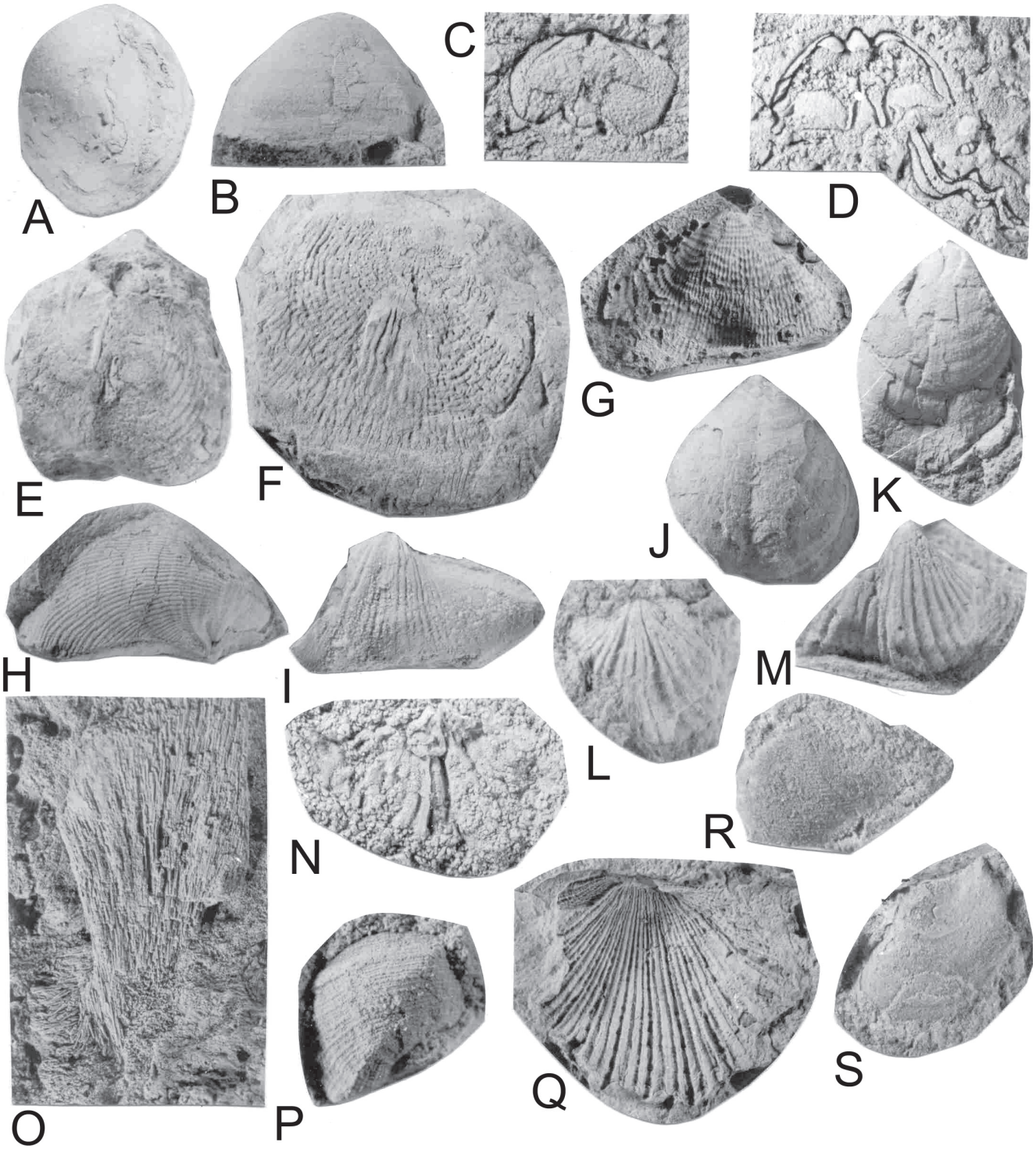


FIGURE 4. Middle Pennsylvanian invertebrate fossils from Chaves Box, New Mexico. A-N, brachiopods; O, sponge; P, gastropod; Q-S, bivalves. **A. B.** *Orbiculoidea* cf. *O. youngi*, top and side views, NMMNH P-45,401, x1.5. **C. D.** *Mesolobus* cf. *M. profundus*; **C.** exfoliated pedicle valve, NMMNH P-45,402, x3.65; **D.** transverse cross-sectional views through two articulated specimens, NMMNH P-45,403, x 3.25. **E.** *Echinaria* cf. *E. knighti,* interior of incomplete brachial valve in matrix, NMMNH P-45,404, x1. **F.** *Buxtonia* sp., external mold of brachial valve, NMMNH P-45,405, x1. **G.** *Antiquatonia* cf. *A. hermosana*, external mold of partial pedicle valve, NMMNH P-45,406, x1. **H.** *Linoproductus* cf. *L. planiventralis*, side view of partial pedicle valve, NMMNH P-45,407, x1.5. **I.** *Neospirifer cameratus*, incomplete pedicle valve, NMMNH P-45,408, x1.5. **J. K.** *Composita subtilita*; **J.** pedicle valve, NMMNH P-45,409, x2; **K.** flattened pedicle valve, NMMNH P-45,410, x2. **L. M.** *Anthracospirifer* cf. *curvilateralis chavezae*; **L.** partial brachial valve, NMMNH P-45,411, x2.5; **M.** partial pedicle valve, NMMNH P-45,412, x2.5. **N.** *Punctospirifer kentuckyensis*, internal view of exfoliated flattened pedicle valve, NMMNH P-45,413, x 3. **O,** root tuft of hexactinellid sponge, NMMNH P-45,414, x2.67. **P,** *Retispira tenuilineata*, oblique view of left side of partial specimen, showing ornamentation and selenizone, NMMNH P-45,415, x4. **Q,** *Aviculopecten* sp., NMMNH P-45,416, x1.5. **R.** *Polidevcia* sp., NMMNH P-45,418, x3.25. **S.** *Myalina* sp., NMMNH P-45,417, x1.75.

and nearly circular in outline. As the valve outline is susceptible to subtle postdepositional distortion, this is perhaps not a significant difference, and the specimens at hand are assigned provisionally to *O. youngi*. The Chaves Box specimen appears to be conspecific with an incomplete but even larger (length = 32 mm) specimen from the Desmoinesian Flechado Formation near Taos.

***Mesolobus* cf. *M. profundus* Sutherland and Harlow**

The few fragmentary specimens of the chonetoid *Mesolobus* (Fig. 4C, D) do not allow positive assignment to species. The largest valve is about 10 mm wide. In general, the characteristic mesial lobe on the pedicle valve is well defined, relatively narrow, not quite as high as the swollen adjacent valve surfaces, and separated from these surfaces by narrow grooves.

Mesolobus is a common Atokan-Desmoinesian genus in the Midcontinent (e.g., Dunbar and Condra, 1932) and Appalachian basin (e.g., Hoare and Sturgeon, 1984); in neither region is it present above the Desmoinesian. The same is true in the Sangre de Cristo Mountains, where Sutherland and Harlow (1973) described three species having short, nonoverlapping ranges. The Chaves Box specimens exceed the maximum size attained by the upper middle Desmoinesian species *M. euampygus* (Girty), and, although poor preservation precludes definite identification, the well-developed mesial lobe suggests later (lower Desmoinesian) morphologies of *M. striatus* Weller and McGehee and especially its upper lower and middle Desmoinesian successor *M. profundus* Sutherland and Harlow.

***Echinaria* cf. *E. knighti* (Dunbar and Condra)**

The single specimen, the interior surface of an incomplete brachial valve (Fig. 4E), is gently concave and had an estimated maximum width of about 45 mm when complete. A distinct medial sulcus in the exposed surface marks a low fold on the external surface (which is embedded in matrix) that presumedly reflected a median sulcus in the opposing pedicle valve. Fine transverse bands, about seven per centimeter, are preserved on the lateral part of the specimen, reflecting original external ornamentation. On each band is evidence of one or two irregular transverse rows of small spines. Towards the anterior margin of this specimen numerous randomly oriented spines are present, representing the typical condition on the interior surface of *Echinaria* (e.g., Muir-Wood and Cooper, 1960; Sutherland and Harlow, 1973). Traces of the median septum and adductor muscle scars are also preserved.

The size and inferred shape of this valve, presence of a low medial fold, and fine spinose banding all indicate probable assignment to *Echinaria knighti*, the common Desmoinesian species in the Midcontinent (e.g., Dunbar and Condra, 1932). Sutherland and Harlow (1973) reported *E.* cf. *E. knighti* from the Desmoinesian of the Sangre de Cristos, noting that their specimens differed from those of the Midcontinent in having a narrower umbo and more pointed beak, and in being considerably larger (up to 77 mm long). The Chaves Box specimen is closer to the usual size of the Midcontinent examples, but poor preservation precludes definite assignment.

***Buxtonia* sp.**

One external mold of a large brachial valve is referred to the productoid *Buxtonia* (Fig. 4F). Maximum width and length are subequal at about 55 mm. Preservation leaves much to be desired but does indicate that the valve is nearly flat and is ornamented with fine radial costellae, crossed by equally fine rugae that produce small nodes at the intersection points. Numerous pits in the mold indicate the presence of small spines scattered across the valve surface, apparently extending from the rugae. Traces of long (up to 9 mm) prostrate spines are densely clustered across the anterior few millimeters of the valve.

Fine radial as well as concentric ornamentation, together with numerous spines and absence of discrete bands suggests assignment to *Buxtonia* (e.g., Muir-Wood and Cooper, 1960). Sutherland and Harlow (1973) reported a large species, *B. grandis*, from the Morrowan of the Sangre de Cristo Mountains, and an unnamed species (*Buxtonia* n. sp. B) that is approximately the same size as the Chaves Box valve from Desmoinesian strata of that area. Definite assignment of the specimen is prevented by poor preservation, but it is likely one or the other of these taxa.

***Antiquatonia* cf. *A. hermosana* (Girty)**

A single external mold of a fragmentary pedicle valve represents a moderately large (incomplete width about 40 mm) specimen of the productoid *Antiquatonia* (Fig. 4G). The specimen is ornamented with relatively coarse, closely spaced radial costae (12-14 per 10 mm at surface length of about 20 to 30 mm), which are crossed by more widely spaced concentric rugae, producing radially elongate nodes at the intersection points. The radial costae are continuous but a little narrower between the rugae, and no evidence of spines was observed on the mold.

The beak, hingeline, ears, and anterior trail are not preserved, so precise identification is not possible, but none of the observed morphological features are at odds with *Antiquatonia hermosana*. This species is common in the early and middle Desmoinesian of the Sangre de Cristo Mountains (Sutherland and Harlow, 1973), and collections measured by these workers average 12-13 costae per 10 mm at surface lengths of 20 to 30 mm, closely similar to the density on the Chaves Box specimen. This is possibly the form referred to as *Dictyoclostus* by Muehlberger (1967). A related species, *Antiquatonia portlockianus* (Norwood and Pratten), occurs only in higher Desmoinesian strata in the Sangre de Cristos, and is characterized by coarser radial costae, averaging 9 to 11 per 10 mm at 20-30 mm surface lengths.

***Linoproductus* cf. *L. planiventralis* Hoare**

The productoid *Linoproductus* is represented by one fragmentary specimen embedded in limestone (Fig. 4H). The pedicle valve is of moderate size (estimated length = 35 mm), evenly convex and lacking a medial sulcus, and is ornamented with fine, simple, regular, rounded, closely spaced radial costellae (about 7 per 5 mm near the commissure). No spines were observed on the valve surface. Although the ears and beak are not preserved, well-

developed concentric wrinkles are evident on the lateral slopes of the valve near the hingeline. From the portions of the valve that are preserved, this specimen is similar to specimens in the Desmoinesian part of the Flechado Formation near Taos (UNM collections), and to specimens identified as *L. planiventralis* by Sutherland and Harlow (1973) from Atokan to middle Desmoinesian strata of the Sangre de Cristo Mountains.

***Composita subtilita* (Hall)**

Composita subtilita (Figs. 4J, K) is common in the limestones at Chaves Box, although most specimens are incomplete. They attain a modest size for the species; a typical specimen is 19 mm long, 16 mm wide, and has a moderately deep commissural sulcus. Most specimens are longer than wide, but a few wide *C.* "*ovata*" morphs are also present.

***Neospirifer* cf. *N. cameratus* (Morton)**

Only a few fragmentary specimens of *Neospirifer* are present in the collections but the largest specimen, part of a pedicle valve (Fig. 4I), displays the earlier parts of the sulcus and lateral areas fairly well. The estimated width of the valve (when complete) was about 44 mm. The pedicle beak is sharp, relatively narrow, and strongly incurved. The P costae, which border the sulcus, are well developed, and bifurcate once laterally to form the first primary lateral costa. The next two primary lateral costae each bifurcate twice rather early in growth to produce fascicles of three costae. The fourth lateral costa bifurcates once, and the remainder remain undivided, to produce a total of about 15 costae on each side of the valve. Sulcal costae are obscured by exfoliation, but an undivided M (middle) costa is present and at least two others on each side develop close to the beak.

Lateral costa bifurcation patterns are exactly as shown by Sutherland and Harlow (1973, fig. 36A) for *Neospirifer cameratus*, a common Atokan-Desmoinesian species in the Sangre de Cristo Mountains. The bifurcation patterns visible on the largest but incomplete specimen are relatively simple, and were more indicative of Atokan than Desmoinesian specimens observed by these authors. However, because complete specimens with the anterior parts of the valve are not available from Chaves Box, this apparent simplicity may be an artifact of preservation, as additional branching of costa may not be preserved.

***Anthracospirifer* cf. *A. curvilateralis chavezae* Sutherland and Harlow**

The most abundant spiriferids in the Chaves Box assemblage are small to medium sized (up to about 25 mm wide), and have simple, generally unbranched radial costae that indicate assignment to *Anthracospirifer* (Figs. 4L, M). These are probably the brachiopods referred to as *Spirifer* by Muehlberger (1967). Typically, only the posterior (earlier) part of the valves are visible because the anterior portions are embedded in the matrix or are broken off. Most specimens are pedicle valves having sharply curved beaks and P-costae on the margins of the sulcus that divide once laterally. Costae on the lateral flanks of the valves are broadly rounded and simple, displaying no bifurcation or development of fascicles as on *Neospirifer*. Most specimens possess eight to ten lateral costae on each side of the valve. Within the sulcus three costae are typically evident, one medial M-costa and a single costa on each side of the M-costa, which develop by medial bifurcation of the P-costae early in growth. Larger specimens have an additional smaller sulcus costa developing from each P-costa late in growth, to make a total of five. The opposing fold, on the brachial valve of one specimen, is relatively narrow and bears four costae, two of which are central, with one additional costa branching developing laterally by early bifurcation.

Sutherland and Harlow (1973) referred the most abundant *Anthracospirifer* in the Pennsylvanian of the Sangre de Cristo Mountains to *A. curvilateralis* (Easton) and established two temporal subspecies, *A. c. tanoensis* (Morrowan-lower Atokan) and *A. c. chavezae* (upper Atokan-upper Desmoinesian). These subspecies are chiefly distinguished by the number of costae in the sulcus, which typically number three in *A. c. tanoensis* and five in *A. c. chavezae*. On most of the Chaves Box specimens only three costae are visible. However, the last two costae of *A. c. chavezae* are typically small and develop late in growth, rather near the anterior margin, a portion of the shell that is not visible on most of the specimens at hand. This, and the fact that a few specimens display the full complement of five costae, suggest that the Chaves Box specimens are *A. c. chavezae* rather than the earlier subspecies *A. c. tanoensis.*

Sutherland and Harlow (1973) distinguished a few other species of *Anthracospirifer* from the Lower and Middle Pennsylvanian of the Sangre de Cristos, that are either poorly known or differ from the much more abundant subspecies of *A. curvilateralis* in subtle valve features (e.g., valve convexity, beak shape, depth of sulcus) that cannot be adequately evaluated among the poorly preserved specimens at hand.

***Punctospirifer kentuckyensis* (Shumard)**

The small spiriferid *Punctospirifer kentuckyensis* is rare in the Chaves Box collections. The only identifiable specimen (Fig. 4N), from a thin red sandstone layer, has a more or less complete outline but has been compressed and exfoliated. Its width is about 14 mm and maximum length is 7.5 mm. The pedicle valve is characterized by a wide, flat-bottomed sulcus and displays about six strong, simple radial plicae on each lateral surface. The characteristic strong external lamellae are not visible on this specimen because only the internal surface of the valve is exposed, but this surface does display many small but conspicuous circular punctae across all portions of the valve.

***Phricodothyris perplexa* (McChesney)**

Phricodothyris perplexa is rare in the collections, though reported by Muehlberger (1967). Fragmentary, exfoliated specimens are small (less than 12 mm long), biconvex, subequal in length and width, and display traces of the characteristic concentric bands of short spines.

Other Invertebrates

In addition to brachiopods, numerous other invertebrate groups are present in the Chaves Box assemblage (see Table 1). A few comments are made here for some of these taxa, and some are illustrated.

Two specimens (Fig. 4O) are remnants of sponges. These are elongate clusters of long, densely packed, needle-like siliceous spicules. The largest of these masses is about 40 mm long, and some individual spicules are at least 20 mm in length. Shorter but otherwise similar spicules splay out from the base of the clusters. These appear to be root-tufts of an unidentified hexactinellid sponge.

Bryozoans include fenestrates (probably fenestellids), and fragments of and cross sections through the cystoporate *Prismopora*. *Prismopora* is characterized by branches that are triangular in cross section, with each of the three sides gently concave. A typical specimen is about 4 mm wide. *Prismopora* has been widely reported in Pennsylvanian, especially Desmoinesian, strata in New Mexico, including the Sangre de Cristo, Jemez and Nacimiento Mountains (e.g., Wood and Northrop, 1946; Clark and Read, 1972; Toomey, 1980), and was reported by Muehlberger (1967) at Chaves Box. Another unidentified bryozoan, observed only in cross section, formed thick (up to 4 mm) encrustations over isolated brachiopod valves.

Gastropods and bivalves are rare. The only relatively well-preserved gastropods are specimens of the bellerophontoid *Retispira tenuilineata* (Gurley) (Fig. 4P), a species common in the Desmoinesian of the Sangre de Cristo Mountains (e.g., Kues and Batten, 2001). These specimens display the large umbilicus, nearly flush, welt-like selenizone, and shell ornamentation of fine, closely spaced spiral lirae that distinguish this species. Bivalves are represented by a few fragmentary pectinids, including *Aviculopecten* (Fig. 4Q), a mold of a partial valve of *Myalina* (Fig. 4S), and a mold of a valve with the elongate, curved posterior margin and fine comarginal lirae of *Polidevcia* (Fig. 4R).

AGE

Muehlberger (1967) assigned a middle Desmoinesian age to the limestones near the top of the Pennsylvanian section at Chaves Box, based mainly on the occurrence of the fusulinids *Beedeina haworthi* (Beede) and *Wedekindellina euthysepta* (Henbest), identified by S. P. Ellison. The late Garner Wilde (personal commun., 2003) confirmed these identifications. Both species have been reported widely across New Mexico, including areas of marine Pennsylvanian exposures that are in closest proximity to the isolated Chaves Box section. Thus, Sutherland and Harlow (1973) noted *W. euthysepta* (together with *B. novamexicana*) as characteristic of lower Desmoinesian strata in the southern Sangre de Cristo Mountains, and *B. haworthi* in the immediately overlying middle Desmoinesian fusulinid zone in this region. Henbest and Read (1944) reported *W. euthysepta* in the lower to middle Desmoinesian of the Jemez Springs area. Myers (1988) reported *W.* aff. *W. euthysepta* in lower and middle Desmoinesian strata (fusulinid assemblage subzones of *B. novamexicana* and *B. rockymontana*), and *B.* aff. *B. haworthi* in middle to upper Desmoinesian strata (lower part of fusulinid assemblage subzone of *B. sulphurensis*) in the Manzano Mountains. Connolly (1992 and unpublished figures) compiled the Desmoinesian range zones of all North American species of *Beedeina* and *Wedekindellina*, and reported significant overlap of the range zones of *B. haworthi* and *W. euthysepta* in the middle Desmoinesian of the western United States. Further, the youngest occurrence of the genus *Wedekindellina* is in the early middle Desmoinesian (Wilde, 2004), placing a minimum age on the Chaves Box assemblage. Thus, based on more recent work on the biostratigraphy of the fusulinids, the middle Desmoinesian age of the Chaves Box limestone unit assigned by Muehlberger (1967) is quite accurate.

The brachiopods discussed here also indicate a Desmoinesian age. Although most cannot be assigned definitely to species because of poor preservation, the most likely specific assignments are consistent with and suggestive of a Desmoinesian age. Especially convincing in this regard are specimens of *Mesolobus* cf. *M. profundus*, which have a morphology that rules out assignment to an upper middle Desmoinesian species (*M. euampygus*), and strongly suggests assignment to the upper lower and middle Desmoinesian species *M. profundus*, which is common in the Sangre de Cristo Mountains.

DEPOSITIONAL ENVIRONMENTS

At Chaves Box, interval A consists of a basal, locally-derived, quartzite-pebble conglomerate overlain by quartzose sandstone and covered strata. It comprises two, fining-upward successions. No bedding is discernable in the sandstone, largely because of cover, diagenesis and metamorphism, and it lacks fossils. We tentatively identify interval A as a nonmarine fluvial deposit.

Interval B, in contrast, is mostly of obvious marine origin. We interpret it as a transgressive, fining-upward succession with a basal sandstone fining up to siltstone with marine limestone lenses. Limestone sample 4 indicates a shallow, low-energy, normal marine environment, and abundance of sponge spicules in sample 5 points to deposition in a deeper marine environment (several tens of meters). The composition of the invertebrate fossil assemblage from interval B indicates normal-marine salinity in a shallow marine environment.

DISCUSSION

As noted earlier, the Pennsylvanian strata at Chaves Box have not been incorporated into regional understanding of Pennsylvanian tectonics, sedimentation and paleogeography. Nevertheless, these strata do fit a model of regional Pennsylvanian tectonics and sedimentation last summarized by Baars and Stevenson (1984), though they do require some modifications of their (and others) regional Middle Pennsylvanian paleogeography.

The Pennsylvanian section at Chaves Box can be assigned to the Hermosa Group, probably as a clastic facies equivalent to part of the Paradox Formation (cf. Baars et al., 1967). The age of interval A at Chaves Box (Fig. 2) is not known with certainty, but these strata bear no close resemblance to any of the pre-Penn-

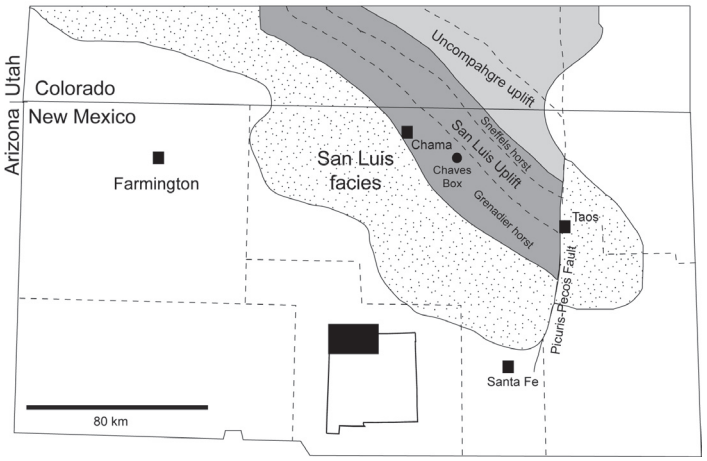


FIGURE 5. Paleogeographic map of the San Luis (darker gray) and Uncompahgre (lighter gray) uplifts in Morrowan to middle Desmoinesian time showing the location of Chaves Box (modified from Baars and Stevenson, 1984, fig. 5).

sylvanian strata of the Paradox basin (Baars and See, 1968). Instead, interval A strata include quartzose sandstones that are readily interpreted as rocks of the "San Luis facies" of the Hermosa Group (Baars and Stevenson, 1984; Baars, 1988). Overlying strata of interval B are arkosic and demonstrably of middle Desmoinesian age.

Baars and Stevenson (1984; also see Baars, 1966, 1988) proposed that two late Paleozoic uplifts influenced sedimentation in the Paradox basin. An older (Morrowan-early Desmoinesian) San Luis uplift shed quartzose sediments, whereas a younger (middle Desmoinesian-Early Permian) Uncompahgre uplift shed arkosic sediments. In their paleogeographic reconstruction of the San Luis uplift, Baars and Stevenson (1984) identified it as consisting of two northwest-southeast-trending quartzite-cored horsts (Fig. 5). The southerly, Grenadier horst encompasses the Chaves Box Pennsylvanian outcrop. Deposition of interval A, quartzose sediments derived from the San Luis uplift, is thus readily interpreted as the deposition of San Luis facies lapping over and locally burying the Grenadier horst as it eroded.

Interval B at Chaves Box, with arkosic sandstone at its base, was deposited during initial uplift of the Uncompahgre uplift after collapse of the San Luis uplift. Baars (1966) and Baars and Stevenson (1968) posit this changeover in uplifts as an event at the end of the early Desmoinesian. The biostratigraphy at Chaves Box indicates that deposition influenced by the Uncompahgre uplift had occurred by middle Desmoinesian time. Baars and Stevenson (1984) suggested rapid burial of the San Luis uplift, and we believe some erosion and collapse of the San Luis uplift must have taken place during early Desmoinesian time.

Desmoinesian time was an interval of regional transgression and highstand (Kues and Giles, 2004). Huffman and Condon (1993, fig. 11) presented a Desmoinesian paleogeographic reconstruction for northwestern New Mexico that is generalized and thus misses an important change in regional paleogeography within the Desmoinesian. This change, well documented at Chaves Box, is the changeover from quartzose deposition during final erosion of the San Luis uplift to initial deposition of arkosic clastics shed from the Uncompahgre uplift. This event, which occurred across the early-middle Desmoinesian boundary, is accompanied by a major regional marine transgression that extended marine deposition as far north and east as Chaves Box. The Pennsylvanian strata at Chaves Box thus fit well into the concept of two late Paleozoic uplifts influencing sedimentation in the Paradox basin.

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