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New Mexico Geology, v. 24, n. 4 pp. 121-130, Print ISSN: 0196-948X, Online ISSN: 2837-6420.
https://doi.org/10.58799/NMG-v24n4.121

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A Late Pennsylvanian outer shelf marine fauna from a highstand systems tract, Derry Hills, south-central New Mexico

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Abstract

We describe an unusual mollusc-dominated Missourian fauna of low diversity from a l5-m-thick, dark-gray shale unit in the Bar B Formation of the Derry Hills, Sierra County, New Mexico. The 45-m-thick (148-ft-thick) Bar B sequence that contains this shale unit displays facies ranging from lower shoreface carbonate to outer shelf shale, arranged in a series of eight upward-shallowing cycles or parasequences bounded by marine flooding surfaces. The dark-gray shale interval contains outer to middle shelf facies displaying an aggradational progressing to progradational parasequence stacking pattern, which is characteristic of the early part of the highstand systems tract. The fossils in the shale unit are preserved typically in a severely crushed condition and include one brachiopod, ten gastropod, seven bivalve, and one rostroconch species. Bellerophontoids, especially *Bellerophon* (*Bellerophon*) sp., comprise 96% of the gastropod specimens, and the bivalves are dominated by two nuculoid species, *Nuculopsis anodontoides* and *N. girtyi*, which comprise 81% of all bivalve specimens. These three species together represent 83% of the more than 2,000 specimens collected from the shale unit. The low diversity of this fauna, its dominance by only three mollusc species, and the lithology and sequence stratigraphy of the shale unit suggest that this fauna lived in a relatively deep, quiet marine environment, on a soft, organic-rich, low-oxygen, muddy substrate. The shale interval was deposited during a transgressive episode along the western margin of the late Paleozoic Orogrande Basin. These conditions were unsuitable for the more stenotopic invertebrates that are common constituents of Pennsylvanian shallow marine environments in New Mexico.

Introduction

Pennsylvanian strata in New Mexico preserve a wide variety of depositional environments. Most of our knowledge of Pennsylvanian marine faunas in the state is based upon paleocommunities that inhabited shallow marine shelf environments. These typically are dominated by stenohaline groups such as brachiopods, bryozoans, echinoderms, and locally, fusulinaceans (in offshore environments), and by some brachiopods, together with bivalves and gastropods (in shallow nearshore environments). Less information is available for paleocommunities that lived in deeper marine conditions and that are preserved in dark-gray shales and mudstones. Here, we report a fauna of Missourian age dominated by bellerophontoid gastropods and nuculoid bivalves from a sequence of dark-gray shale beds deposited during the maximum flooding stage and early highstand systems tract of a sequence within the Bar B Formation exposed in the Derry Hills, Sierra County, New Mexico. All specimens discussed in this paper are catalogued in the paleontology collections of the Department of Earth and Planetary Sciences, University of New Mexico (UNM).

Location and stratigraphic context

The dark-gray shale from which this fauna was collected is within the Bar B Formation and crops out along a hillslope in the center NW¼ sec. 33 T17S R4W, a short distance north of the Garfield interchange of I–25, in the southern Derry Hills, Sierra County (Fig. 1). Mack et al. (1998, figs. 1.16, 1.21) provided a map and photo of the locality and briefly discussed the stratigraphy. At this locality, a 45-m-thick (148-ft-thick) partial section of the Bar B Forma-

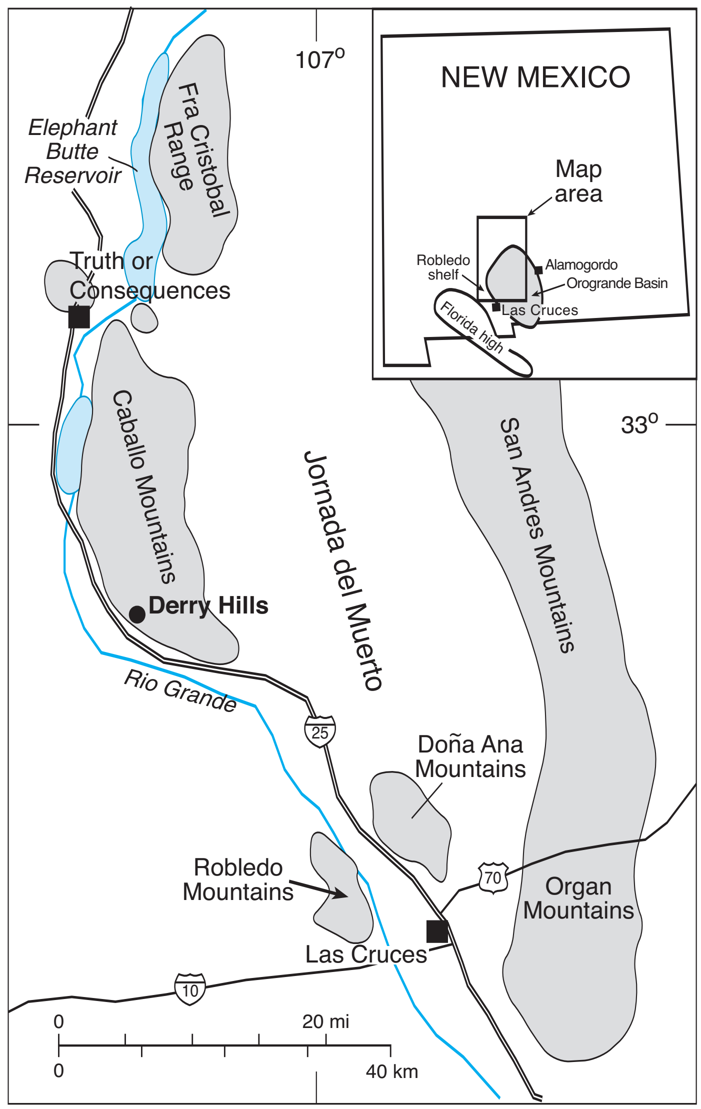

FIGURE 1—Reference map of south-central New Mexico, showing location of Derry Hills section. From Lawton et al. (2002).

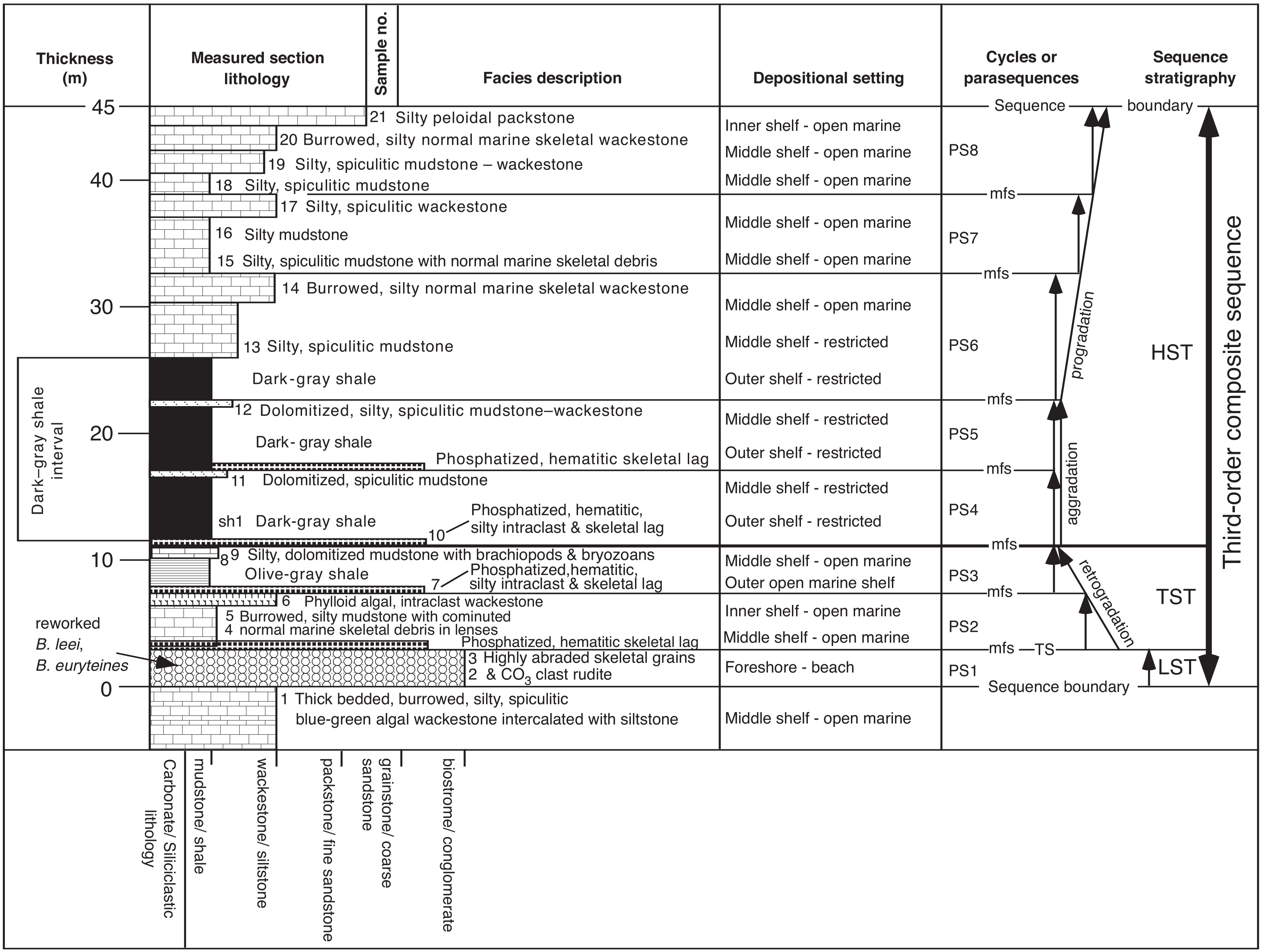

FIGURE 2—Stratigraphic section of part of Bar B Formation at the Derry Hills locality with facies descriptions and depositional environment, cycle, and sequence stratigraphic interpretations. Abbreviations include: highstand systems tract (**HST**), transgressive systems tract (**TST**), lowstand systems tract (**LST**), maximum flooding surface (**mfs**), and transgressive sequence (**TS**).

tion was measured and described (Fig. 2), and the carbonate strata were analyzed petrographically to determine lithofacies and to interpret their depositional setting.

The shale interval is approximately 15 m (49 ft) thick here (Fig. 2) and occupies a position near the middle of the Bar B Formation. The total thickness of the Bar B Formation in this area is approximately 90 m (295 ft; Singleton, 1990; Seager and Mack, 1991). The shale interval is interrupted by two thin (<0.5 m; <1.5 ft) ledges of dark-gray, dolomitized, silty, spiculitic mudstone to wackestone located approximately 6 and 11 m (20 and 36 ft) above the base of the shale interval. Fusulinacean data (Thompson, 1991) indicate that the Bar B Formation in the Derry Hills ranges from Middle Pennsylvanian (Desmoinesian) to Early Permian (Wolfcampian) in age, with major intraformational unconformities removing most of the Virgilian part of the section (Lawton et al., 2002). A conglomerate bed approximately 10 m (33 ft) below the shale interval contains highly abraded early Desmoinesian fusulinaceans (*Beedeina leei*, *B. euryteines*) that were likely reworked during lowstand incision. We infer a Desmoinesian–Missourian unconformity at the base of this conglomerate. The uppermost part of the formation is equivalent in age to the latest Virgilian or earliest Wolfcampian Bursum Formation (Lawton et al., 2002), indicating a second major unconformity within the upper part of the Bar B Formation. The shale unit yielding the invertebrates discussed in this paper is Missourian in age.

Methods and fossil preservation

Fossil collections from the shale unit were mainly of specimens that had eroded free on the surface of the exposure, but some samples of the shale were also taken to verify the presence of these taxa within the shale unit. No differences in taxonomic composition or relative abundances of taxa were observed through the dark-gray shale interval.

The fossils from the Bar B shale interval are unusual in that they were crushed or otherwise severely distorted by post-depositional compression. The patterns of shell crushing experienced by various taxa appear to reflect both variation in shell strength and the postmortem orientation of the shells in and on the substrate. Thus, most bivalve specimens, which are nearly always articulated, were crushed laterally, flattening and cracking the two valves, displacing them slightly, and compressing them into each other. The articulated valves of one species, *Nuculopsis girtyi*, are commonly dorsoventrally crushed. The relatively thick, inflated valves of this species, with low, nearly terminal beaks, were apparently more susceptible to ventral rather than to lateral compressive stresses.

Similarly, the shells of most bellerophontoids, by far the most abundant gastropod group, are dorsoventrally to obliquely flattened. This pattern of distortion would be predicted from the morphology of these planispirally coiled shells, which includes a relatively thin, flaring, anterior margin around a large aperture, that would collapse on the earlier part of the shell with ventrally directed stress. The presumed life (and death) orientation of these gastropods relative to the substrate (aperture opening anteriorly or obliquely toward the substrate) would also be consistent with the observed flattening of most bellerophontoid shells. However, about 10% of the bellerophontoid specimens have been crushed laterally, so that their originally globose shells resemble laterally flattened discs with the umbilical regions located in the center of each side of the disc. Possibly this condition resulted from ventral compression of shells that were on their sides rather than in life position on the substrate. Further information on the preservation of shells within the shale interval is included with the descriptions of individual taxa.

Sequence stratigraphy

The sequence stratigraphy of the 45-m-thick (148-ft-thick) section of the Bar B that includes the fauna reported here was interpreted based on the identification of marine flooding surfaces, parasequences, parasequence stacking patterns, and the character of the major unconformity surfaces or sequence boundaries. The depositional facies present in this interval range from wave-winnowed shoreface carbonates to outer shelf shales (Fig. 2). The facies are arranged into a series of eight upward-shallowing successions bounded by marine flooding surfaces, which define parasequences or cycles. The base of the section is a major erosional surface overlain by an abraded skeletal and carbonate clast rudite/conglomerate containing abundant reworked early Desmoinesian fusulinaceans and fragments of brachiopods, echinoderms, and bryozoans. The conglomerate is separated from the overlying middle to inner shelf deposits by a phosphatized, hematitic, skeletal pebbly conglomerate, which we interpret as a lag deposit on a marine flooding surface. Carbonate-dominated parasequences that lie above this surface and below the dark-gray shale beds display a retrogradational stacking pattern (parasequences 1–3, Fig. 2). Marine flooding surfaces directly below and within the dark-gray shale interval comprise thin (<3 cm; <1 inch), phosphatized, silicified, hematitic, silty intraclast and skeletal conglomerate beds. These highly diagenetically altered, coarser-grained beds formed in response to winnowing and stratigraphic condensation processes during marine flooding events, and represent periods of very slow sedimentation on the shelf (e.g., Loutit et al., 1988). The overlying parasequence set is dominated by middle to inner shelf carbonate facies comprising a relatively diverse normal marine fauna containing brachiopods, bryozoans, and echinoderms.

The 45-m-thick (148-ft-thick) succession that contains the shale interval constitutes a single depositional sequence (Fig. 2). The conglomerate is the shallowest depositional facies present in the measured section. It represents foreshore facies that were depositionally detached from the overlying lower shoreface shelf environments. This represents a basinward shift in depositional facies from the underlying middle shelf deposits and is separated from the overlying middle shelf carbonate parasequences by a transgressive surface. Therefore, the underlying erosional unconformity is the sequence boundary, and the conglomerate bed is the lowstand systems tract of the sequence. The retrogradational stacking pattern of the overlying carbonate parasequences is characteristic of the transgressive systems tract (Van Wagoner et al., 1990). The stacking pattern of the dark-gray shale parasequences is aggradational, progressing to progradational upward, which is characteristic of the early highstand systems tract. The sequence is capped by an erosional unconformity.

Faunal summary

The Bar B dark-gray shale fauna described below consists almost entirely (98%) of molluscs (Table 1). Ten species of gastropods comprise about 45% of the total of more than 2,000 specimens examined, and seven species of bivalves represent about 53% of the total specimens. Of the gastropods, 90% of the specimens are *Bellerophon* (*Bellerophon*) sp., and total bellerophontoids comprise 96% of all gastropods. The bivalves are dominated by two nuculoid species, *Nuculopsis anodontoides* and *N. girtyi*, which together account for about 81% of the total bivalve specimens. The addition of two other moderately common nuculoid species, *Nuculopsis* n. sp. and *Polidevcia bellistriata*, increases the nuculoid component of the bivalves to about 87%. The only other bivalve species present in moderate numbers is *Astartella concentrica*. The entire assemblage is thus of relatively low species diversity and is strongly dominated by only three species, which together comprise 83% of the total specimens collected.

The environment represented by the dark-gray shale facies was clearly not suitable for most Pennsylvanian marine organisms. The muddy to silty sediments are rich in unoxidized organic matter and therefore probably were somewhat deficient in available oxygen. Nuculoid bivalves were (and are) shallow burrowing

TABLE 1—Macroinvertebrate species from the dark shale unit, Bar B Formation, Derry Hills, New Mexico

Species	No. of specimens	Percentage
BRACHIOPODS		
Leiorhynchoidea rockymontana	1	< 0.1
GASTROPODS		
Euphemites enodis	38	1.9
Bellerophon (Bellerophon) sp.	832	40.5
Pharkidonotus percarinatus	12	0.6
Retispira tenuilineata	1	< 0.1
Knightites (Cymatospira) montfortianum	2	0.1
Amphiscapha cf. *A. subrugosa*	4	0.2
Trepospira cf. *T. illinoisensis*	5	0.2
Glabrocingulum (Glabrocingulum) grayvillense	13	0.6
Worthenia cf. *W. tabulata*	3	0.1
Anomphalus cf. *A. verruculiferus*	1	< 0.1
BIVALVES		
Nuculopsis anodontoides	582	28.3
Nuculopsis girtyi	294	14.3
Nuculopsis n. sp.	40	1.9
Polidevcia bellistriata	25	1.2
Solemya trapezoides	1	< 0.1
Acanthopecten sp.	2	0.1
Astartella concentrica	91	4.4
ROSTROCONCHS		
Apotocardium lanterna	1	< 0.1

deposit/detritus feeders (Stanley, 1970; Hoare et al., 1979) that in the late Paleozoic are commonly most abundant in dark, organic-rich shales and siltstones. The association of the two dominant Bar B bivalve species, *Nuculopsis anodontoides* and *N. girtyi*, has been reported from many other units, from the Appalachian Basin (Hoare et al., 1979), midcontinent region (e.g., Girty, 1915; Wanless, 1958), and north-central New Mexico (Kues, 1984).

Bellerophontoid gastropods have been reported from a wide variety of late Paleozoic depositional environments, with an ample record from facies representing muddy siliciclastic substrates and unstable, relatively deep, or less than optimum marine environments (see Wahlman, 1992, for summary). Often they are the dominant taxon in low-diversity faunas. Although several modes of life and feeding behaviors have been suggested for bellerophontoids, many undoubtedly lived on or partially within soft substrates and were deposit or detritus feeders (e.g., Harper and Rollins, 1985; Wahlman, 1992).

The low diversity of the Bar B dark-gray shale fauna, its dominance by nuculoid bivalves and bellerophontoids, and the lithology and sequence stratigraphy of the strata in which this fauna was preserved suggest the following interpretation of the paleoenvironment. The fine-grained, siliciclastic sediments were deposited in relatively deep, quiet marine conditions below storm wave base, during an episode of marine transgression, along the western margin of the Orogrande Basin. At this time, the basin was located on the western coast of Pangea, less than 5° of latitude south of the equator (Scotese, 1997; Soreghan et al., 2000), and therefore tropical marine temperatures prevailed during Bar B deposition. The fine-grained siliciclastic sediments, rich in organic material, produced a soft substrate depleted in dissolved oxygen. Some eurytopic molluscs, feeding on organic detritus within the sediments, thrived in this restricted environment. However, the soft substrate, lowered oxygen level, and influx of fine-grained siliciclastic sediments were unsuitable for the more stenotopic Pennsylvanian marine invertebrates (e.g., brachiopods, echinoderms, bryozoans, corals, cephalopods, fusulinaceans), which preferred more open, shallow, clear, well-oxygenated marine shelf environments with little to no influx of fine-grained siliciclastic sediments. The restricted conditions were apparently confined to the period of maximum flooding of the shelf during the earliest highstand systems tract.

Some features of this environment, possibly oxygen level, sedimentation rate, or abundance of organic matter, also restricted the number of bivalve and gastropod species able to successfully inhabit it. In contrast, other dark shale facies, such as the Desmoinesian, shallow prodelta sequence in the Flechado Formation of north-central New Mexico, supported far greater diversities of bivalves and gastropods (Kues, 1984; Kues and Batten, 2001).

In the following sections, the identifiable taxa of macroinvertebrates from the Bar B dark-gray shale unit are briefly described and illustrated. Sampling for microfossils was not included in this study, but an investigation of the microfauna would likely add some additional taxa to those included in this paper.

Brachiopods

Brachiopod specimens are rare in the Bar B dark shale interval, comprising only about 2% of the total specimens collected. Of these specimens, judging from the matrix associated with their valves, most are derived from argillaceous limestones higher in the section, and therefore were not a part of the community that inhabited the dark shale environment. These fragmentary specimens represent the genera *Neospirifer*, *Composita*, *Crurithyris*, *Derbyia*, *Neochonetes*, and the productoids *Antiquatonia*, *Linoproductus*, *Cancrinella*, and *Juresania*. All of these genera are common constituents of Late Pennsylvanian shallow marine shelf faunas in New Mexico.

One brachiopod species, however, was a part of the mollusc-dominated dark-gray shale community, as indicated by the complete flattening of its valves in a manner similar to that of the other taxa in the shale interval. This species, *Leiorhynchoidea rockymontana* (Marcou), is represented by a single specimen (Fig. 3A) approximately 21 mm long and 23 mm wide. Its outline is subtriangular, narrow at the hingeline and expanding broadly anteriorly. The pedicle valve has a shallow sulcus containing two short anterior placations, and the brachial valve has a fold with three short plications.

Leiorhynchoidea rockymontana was first described by Marcou (1858) from strata now known to be of Virgilian age near Pecos, New Mexico, but Sutherland and Harlow (1973), who redescribed Marcou's specimens, were unable to discover additional specimens from the area of the type locality. There are no other verified reports of this species from New Mexico, but it has been described from Desmoinesian to early Virgilian strata in the midcontinent region (Dunbar and Condra, 1932; Hoare, 1961).

Gastropods

Euphemites enodis Sturgeon

Euphemites enodis Sturgeon, 1964, p. 197, pl. 32, figs. 1–5.

Specimens of *Euphemites enodis* (Figs. 3B–D), typically dorsoventrally or obliquely crushed and missing the anterior margin, are moderately common in the Bar B shale fauna. Specimens are small to medium in size, reaching a maximum width of approximately 25 mm. They are not geniculate, and have a narrow medial selenizone that is flush with the shell surface, and a deep, relatively wide sinus. The lateral lips meet the sides of the shell in a gentle curve, and an umbilicus is lacking. Ornamentation consists of approximately

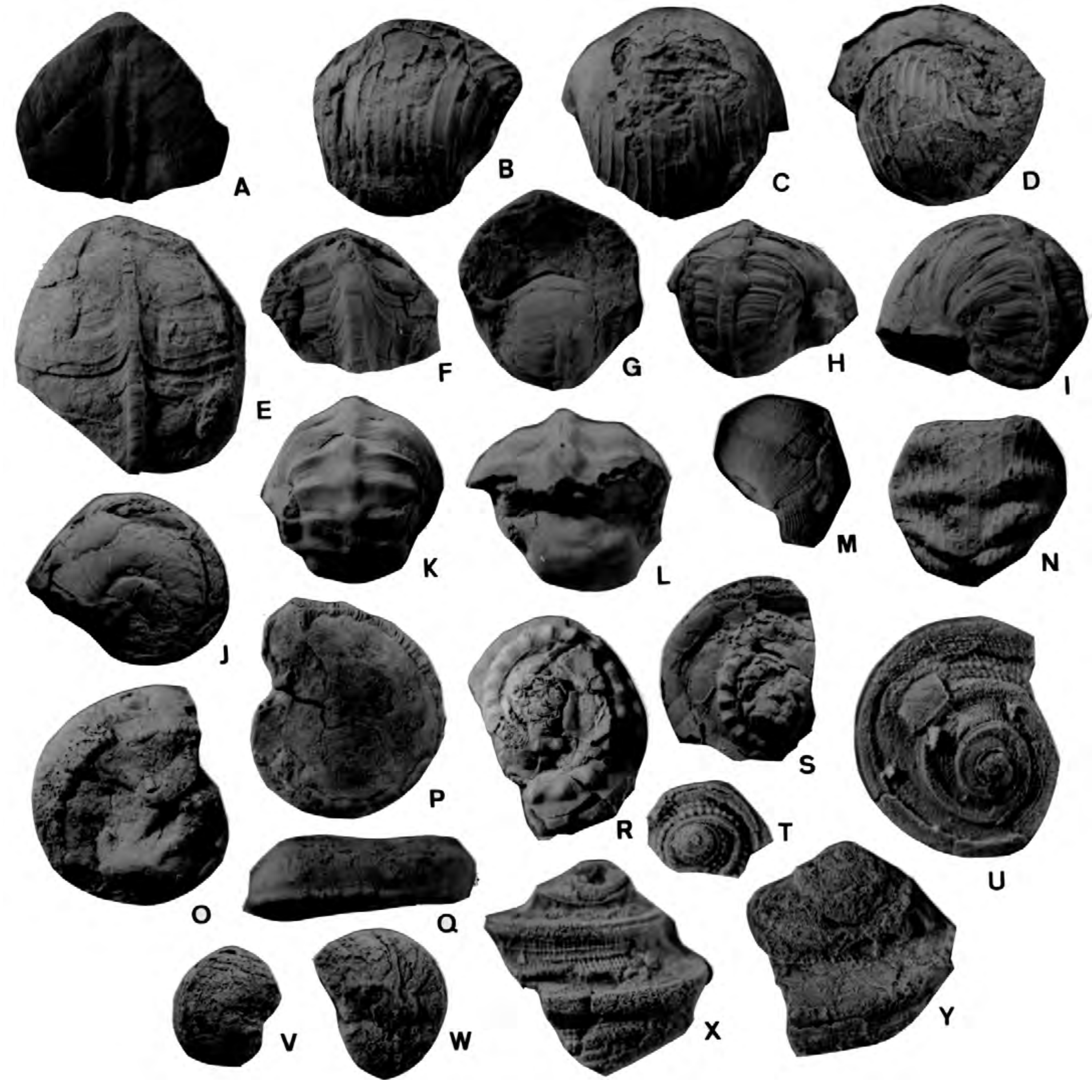

FIGURE 3—Brachiopod (**A**) and gastropods (**B–Y**) from the Bar B Formation shale unit, southern Derry Hills, New Mexico.
A, *Leiorhynchoidea rockymontana*, flattened pedicle valve, UNM 13,146, x1.5.
B–D, *Euphemites enodis*: **B**, posterior top view, crushed specimen, UNM 13,147, x2; **C**, top view, crushed specimen, UNM 13,148, x2; **D**, oblique apetural view, crushed specimen, UNM 13,149, x2.
E–J, *Bellerophon* (*Bellerophon*) sp.: **E**, top front view of a large, crushed specimen, UNM 13,151, x2; **F**, front view, showing high selenizone and growth lines, UNM 13,152, x2; **G**, apertural view, crushed specimen, UNM 13,153, x2; **H**, posterodorsal view, obliquely crushed specimen, showing strong transverse ornamentation, UNM 13,154, x2; **I**, posterodorsal view, obliquely crushed specimen, UNM 13,155, x2; **J**, left side view, laterally compressed specimen, UNM 13,157, x2.4.
K–L, *Pharkidonotus percarinatus*: **K**, dorsal view of crushed specimen with unusually well developed nodes, UNM 13,159, x2.25; **L**, anterior view of same specimen, showing thickened inductural callus, x2.5.
M, *Retispira tenuilineata*, oblique top view, incomplete specimen, UNM 13,161, x2.
N, *Knightites* (*Cymatospira*) *montfortianum*, top view, incomplete crushed specimen, UNM 13,162, x2.
O–Q, *Amphiscapha* cf. *A. subrugosa*, top, ventral, and side views of undistorted shell embedded in matrix, UNM 13,163, x2.
R, S, *Trepospira* cf. *T. illinoisensis*: **R**, dorsal view, crushed specimen, UNM 13,165, x2; **S**, dorsal view, crushed specimen, UNM 13,166, x2.
T, U, *Glabrocingulum* (*Glabrocingulum*) *grayvillense*: **T**, dorsal view of small, incomplete specimen with relatively coarse subsutural nodes, UNM 13,169, x3; **U**, oblique dorsal view of crushed specimen with muted ornamentation, UNM 13,168, x3.
V, W, *Anomphalus* cf. *A. verruculiferus*, dorsal (x2.5) and ventral (x3) views of severely weathered specimen, UNM 13,173.
X, Y, *Worthenia* cf. *W. tabulata*, side views of laterally crushed, incomplete specimens, UNM 13,171, x3, and UNM 13,172, x2.

18–22 sharp, widely spaced inductural lirae, separated by interspaces two to three times the width of a lira.

These specimens closely resemble *Euphemites enodis* from the Desmoinesian of the Appalachian Basin (Sturgeon, 1964) and north-central New Mexico (Kues and Batten, 2001) and are considered conspecific. Some Bar B specimens differ from the Desmoinesian form in attaining a larger size and in having a greater number of, and slightly more closely spaced, inductural lirae.

Bellerophon (Bellerophon) sp.

A small to medium-sized species of *Bellerophon* (*Bellerophon*) (Figs. 3E–J) is by far the most abundant gastropod in the Bar B assemblage. All specimens are severely distorted, most by dorsoventral flattening that obscures the anterior lips and aperture, sharply folds the early part of the body whorl, and stretches the dorsal body whorl surface, accentuating growth lines and other irregularities. As noted above, some shells are laterally flattened into narrow discoidal specimens, and some shells are compressed obliquely. Such severe distortion of shell morphology renders detailed comparison with other, undistorted late Paleozoic species difficult, and these Bar B specimens are not assigned to a species.

In general these bellerophons are globose in shape, nongeniculate, and range from 15 to 20 mm in maximum width; the largest specimens were an estimated 25 mm wide before distortion. The shell widens moderately anteriorly, and the aperture appears to be relatively broad and high. The anterior lips are broadly convex in outline and curve medially into a short sinus. The parietal inductura extends a short distance beyond the plane of the aperture and appears to be relatively thick for *Bellerophon*, although compressional bending of the shell in this area often increases the apparent thickness of the inductura. The lateral lips intersect the anomphalous to cryptomphalous umbilical region of the body whorl with a slight curve.

The selenizone is moderately wide and conspicuously elevated throughout growth, forming a prominent median welt that is flat to gently arched, and bears arcuate fine to relatively coarse lunulae. Shell ornamentation varies, ranging from fine growth lines to sharp, widely spaced, irregular collabral lirae that define sublamellate transverse bands across each side of the body whorl. On many specimens, the ornamentation is coarser and more irregular, with growth bands raised or lowered, some resembling low wrinkles or even ribs. These irregularities do not extend across the selenizone, which, though elevated, never develops nodes or local thickenings. Careful examination of the shell surface of hundreds of specimens suggests that original irregularities in the collabral ornamentation have been accentuated by expansion or stretching of the dorsal part of the shell during dorsoventral or oblique post-depositional compression.

Morphological changes owing to compression and shell distortion suggest caution in assigning these specimens to a species, as subtle details of shape, profile, anterior and lateral lips, and height and width of the selenizone are among the characters used to distinguish species of late Paleozoic *Bellerophon* (*Bellerophon*) (e.g., Yochelson, 1960). Among Pennsylvanian North American species, the Bar B specimens share with *B.* (*B.*) *crassus* Meek and Worthen, *B.* (*B.*) *wewokanus* Girty, and *B.* (*B.*) *graphicus* Moore a conspicuously elevated selenizone and an anomphalous to cryptomphalous umbilical area. Compared to the specimens at hand, *B.* (*B.*) *wewokanus* has a more widely flaring aperture and *B.* (*B.*) *crassus* attains a much larger size. A small, partly crushed Desmoinesian specimen assigned to *B.* (*B.*) *crassus* by Hoare (1961) displays the combination of high selenizone and irregular collabral ornamentation shown by many of the Bar B specimens. *Bellerophon* (*B.) graphicus* (Virgilian of Kansas) has a slightly laterally compressed shell and a less elevated selenizone, but resembles the Bar B specimens in its relatively coarse, irregular growth lines. The shells of some Early Permian species (e.g., *B.* (*B.*) *parvicristatus* Yochelson and *B.* (*B.*) *deflectus* Chronic) are broadly similar to these Pennsylvanian species (Yochelson, 1960). For the present, we do not formally assign the Bar B specimens to a species.

Pharkidonotus percarinatus (Conrad)

Bellerophon percatinatus Conrad, 1842, p. 268.

Preservation of most Bar B specimens of *Pharkidonotus percarinatus* (Figs. 3K, L) is poor; the shells are crushed, incomplete, and typically severely weathered. The best preserved specimen is approximately 14 mm wide (but is missing the lateral lips) and sharply bent near the anterior end. The shell surface is characterized by a prominent, elevated, median ridge that bears a narrow selenizone on its crest, and by closely spaced, conspicuous collabral folds that form nodes where they meet the medial ridge and curve gently laterally across the shell surface to the umbilical region. Approximately eight folds are present on the body whorl of a typical specimen. Other than these folds, the shell surface is smooth and lacks ornamentation. The inductura is thickened and knob-like, and undulates where it covers collabral folds early on the body whorl. The lateral lips meet the sides of the body whorl with slight curvature, producing an anomphalous umbilical area.

The Bar B specimens are within the range of variation of *Pharkidonotus percarinatus*, a common, widespread, and morphologically variable North American Pennsylvanian species. On some Bar B specimens, the medial nodes are more pronounced and the collabral folds are coarser than is the case in other assemblages of this species, such as those from the Desmoinesian of north-central New Mexico (Kues and Batten, 2001). The Bar B specimens of *P. percarinatus* differ from the more abundant *Bellerophon* (*Bellerophon*) sp., which may have an irregularly banded appearance augmented by distortion (see above), in having stronger and more regular collabral folds, possessing conspicuous, regularly spaced nodes along the medial ridge where the opposing collabral folds impinge, and in having a thick, knob-like inductura.

Retispira tenuilineata (Gurley)

Bellerophon tenuilineata Gurley, 1884, p. 10.

One crushed specimen (Fig. 3M) with good preservation of most of the shell and ornamentation is assigned to this long-ranging species. The shell is approximately 13 mm long; is rather strongly arched across the midline; has large, open umbilical areas; bears a medial, relatively wide selenizone that is flush with the adjacent shell surface; contains about 12 very fine spiral lirae; and is bordered on each side by a low ridge composed of three coalesced lirae. Shell ornamentation consists of many fine (5/mm) spiral lirae, approximately 30 on each side of the selenizone, crossed by sinuous collabral lirae that are nearly as strong as the spiral lirae but more widely spaced. These collabral lirae are strongest early on the body whorl, where they create a subcancellate pattern, but dwindle to fine growth lines much less conspicuous than the spiral lirae on the anterior one-third to one-half of the shell.

This specimen displays all of the salient features of *Retispira tenuilineata*, more closely resembling in ornamentation typical Missourian–Virgilian specimens than earlier (Desmoinesian) examples, which tend to have a more strongly cancellate ornamentation (Kues and Batten, 2001).

Knightites (Cymatospira) montfortianum (Norwood and Pratten)

Bellerophon montfortianus Norwood and Pratten, 1855, p. 74, pl. 9, figs. 5a–c.

The two specimens of *Knightites* (*Cymatospira*) *montfortianum* are dorsoventrally crushed and incomplete, but the shell displays the characteristic features of the species. The largest specimen (Fig. 3N) is approximately 15 mm wide, and bears approximately eight pairs of rather sharp-crested collabral folds on the dorsal flanks of the shell. Each pair of folds is in opposition across the depressed medial area, which bears the narrow, flat, very slightly elevated selenizone. Spiral ornamentation consists of fine lirae that cross the collabral folds and occur in two ranks, with each pair of primary lirae separated by two or three smaller secondary lirae. A thick inductural knob occupies the early part of the body whorl and protrudes a short distance beyond the aperture. The widely flaring apertural lips of this species are not preserved on these fragmentary Bar B specimens.

Amphiscapha cf. _A. subrugosa_ Meek and Worthen

Straparollus (Euomphalus) subrugosus Meek and Worthen, 1873, p. 606.

Two crushed specimens embedded in matrix and small fragments of two other shells indicate the presence of an *Amphiscapha* (Figs. 3O–Q) of moderate size (estimated width, 22 mm) in the Bar B shale fauna. The keel on the outer margin of the dorsal surface is strongly rugose to subnodose, and the basal bourrelet is slightly swollen and also rugose, both characteristic features of the common Late Pennsylvanian species *A. subrugosa*. Because some areas of the shell, including the earlier whorls, could not be observed, assignment to this species is tentative.

Trepospira cf. _T. illinoisensis_ (Worthen)

Pleurotomaria illinoinensis Worthen, 1884, p. 4.

The few specimens of *Trepospira* (Figs. 3R, S) in the Bar B shale fauna are all incomplete, and both dorsoventrally and to a lesser extent laterally crushed. The largest specimen was approximately 19 mm wide before distortion. The shell is discoid in shape, with a wide, shallow umbilicus lined with a thickened inductura. The only ornamentation is a row of conspicuous nodes on a raised spiral ridge immediately below the upper suture, numbering from 16 (small specimen) to a maximum of 22 on the body whorl. The observable shell features are all consistent with the characteristics of *T. illinoisensis* (e.g., Kues and Batten, 2001), but poor preservation precludes positive assignment to that species.

Glabrocingulum (Glabrocingulum) grayvillense (Norwood and Pratten)

Pleurotomaria grayvillensis Norwood and Pratten, 1855, p. 75, p. 9, figs. 7a, b.

Glabrocingulum (*Glabrocingulum*) *grayvillense* is represented by a small number of incomplete, severely dorsoventrally crushed shells reaching a maximum width of approximately 13 mm (Fig. 3U). The turreted, low-spired shell possesses one or two nodose subsutural cords on the upper whorl surface, with several finer subnodose spiral lirae on the outer half of this surface. These are crossed by prosocline collabral lirae of similar size but closer spacing, and on well-preserved specimens faint, much finer spiral lirae cover the entire surface, including the nodes. The selenizone, situated on the outer margin of the upper whorl surface, just above the whorl shoulder, is narrow, relatively deep, and bordered by a single sharp lira on each side. The lower whorl surface and base of the shell has strong, widely spaced spiral cords, which are subnodose where crossed by closely spaced, sinuous collabral lirae. The umbilical region is not well preserved on any of the specimens but appears to have a thin inductural covering but no thickened callus, a feature separating *G. grayvillense* from some other species of this genus.

Most Bar B specimens have the relatively muted ornamentation characteristic of New Mexico Desmoinesian specimens of *G. grayvillense* (Kues and Batten, 2001) and of specimens from the Appalachian Basin assigned to *G.* cf. *G. wannense* Newell by Sturgeon (1964). A few small specimens (Fig. 3T) possess relatively strong subsutural nodes and closely resemble examples assigned to *G. grayvillense* by Sturgeon (1964).

Worthenia cf. _W. tabulata_ (Conrad)

Turbo tabulatus Conrad, 1835, p. 267, pl. 12, fig. 1.

Three specimens of *Worthenia* cf. *W. tabulata* (Figs. 3X, Y) are incomplete and severely laterally crushed. The largest has an estimated maximum height of approximately 15 mm. The shell is moderately high spired and turreted, and the whorls embrace low on the outer whorl face of the preceding whorl. The upper whorl surface is flat to gently concave and bears fine spiral lirae and prosocline collabral lirae of about the same strength, which produce subsutural interference nodes where they cross. A nodose selenizone is situated along the outer margin of the upper whorl surface, at the whorl shoulder, and marks the whorl periphery. The lower whorl surface bears three or four widely spaced spiral cords and more closely spaced orthocline collabral lirae, with small interference nodes. Below the basal angulation, several widely spaced, relatively strong spiral lirae are crossed by gently sinuous growth lirae. The aperture and umbilical areas are not preserved on the available specimens.

Anomphalus cf. _A. verruculiferus_ (White)

Rotella verruculifera White, 1881, p. 32, pl. 4, figs. 7a–d.

One incomplete, slightly crushed, coarsely recrystallized specimen (Figs. 3V, W) is approximately 8 mm wide. The shell is very low spired and discoidal in shape and lacks ornamentation, and the aperture is large and subcircular. A prominent callus plugs the umbilicus, a distinctive feature of *Anomphalus verruculiferus*, which is common in the Desmoinesian of north-central New Mexico (Kues and Batten, 2001).

Bivalves

Nuculopsis anodontoides (Meek)

Nucula anodontoides Meek, 1871, p. 71.

Nuculopsis anodontoides (Figs. 4A–D), one of the dominant elements of the Bar B shale fauna, is represented by hundreds of laterally crushed articulated specimens. The species is distinguished by valves of moderate size, reaching a maximum of approximately 19 mm in length, and having a suboval outline. The beaks are relatively high, nearly orthogyrate to opisthogyrate, and are situated about two-thirds of the distance from the anterior to posterior margins. The anterior valve margin is more acutely convex than the more broadly rounded posterior margin, and the posterodorsal margin is slightly convex. Ornamentation consists of fine, closely spaced, locally irregular, comarginal growth lines. Slight displacement of the valves on a few specimens reveals as many as 15 taxodont hinge teeth anterior to the beak. These are small and rectangular opposite the beak but become progressively larger and more chevron shaped anteriorly.

The Bar B specimens are closely similar to, but tend to be larger than, specimens from the Desmoinesian of north-central New Mexico (Kues, 1984), with which they have been directly compared.

Nuculopsis girtyi Schenck

Nuculopsis girtyi Schenck, 1934, p. 29, pl. 2, fig. 19, pl. 4, figs. 2a, b.

Articulated specimens of *Nuculopsis girtyi* (Figs. 4E–H) are abundant in the Bar B shale fauna and attain a maximum length of 19 mm. The valves are elongate-oval in outline, strongly inflated, and possess low, strongly opisthogyrate beaks situated subterminally near the posterior margin. Below the beaks, the posterodorsal margin is distinctly concave, and the lunule and escutcheon are weak to obscure. On relatively undistorted specimens, the width/length ratio exceeds the height/length ratio. Ornamentation is limited to irregular, often obscure growth lines. Comparison with a large sample of *N. girtyi* specimens from the Desmoinesian of north-central New Mexico (Kues, 1984) indicates that the Bar B specimens tend to be lower and more elongate, have less prominent beaks, and attain a larger size.

Most of the Bar B specimens have been dorsoventrally compressed, rather than laterally compressed, which is the case with co-occurring specimens of *N. anodontoides*. This type of distortion appears to be related to the unusually inflated umbos, posteriorly situated beaks, and elongate outline of *N. girtyi*; less stress was apparently required to compress these articulated shells ventrally than laterally. Relatively undistorted specimens of the two species may be distinguished by the lower, more elongate valve outline, more inflated

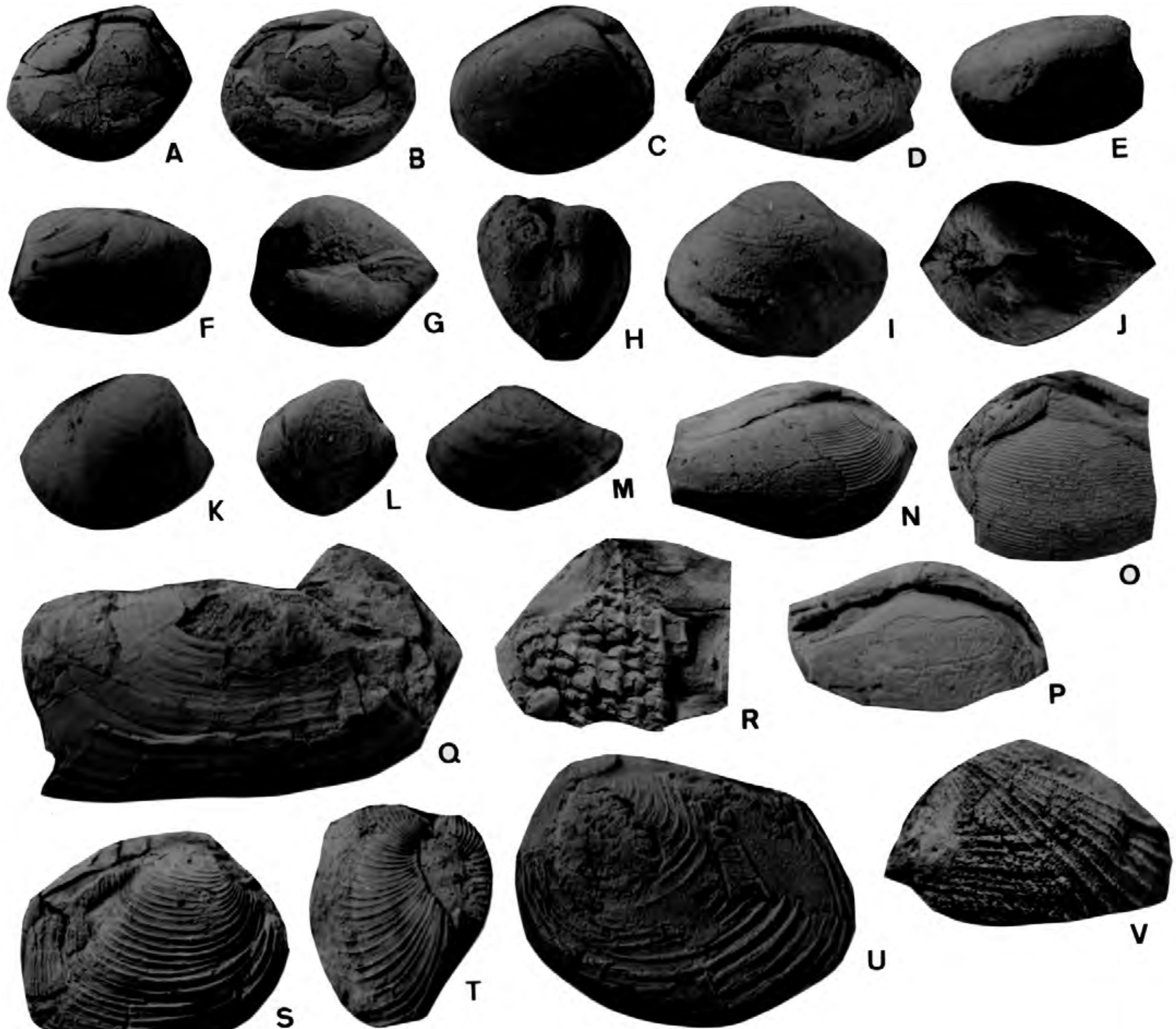

FIGURE 4—Bivalves (**A–U**) and rostroconch (**V**) from Bar B Formation shale unit, southern Derry Hills.
A–D, *Nuculopsis anodontoides*: **A**, left view of laterally crushed specimen, UNM 13,174, x2; **B**, left view of laterally crushed specimen, UNM 13,175, x2.25; **C**, left view of laterally crushed specimen, UNM 13,176, x2.25; **D**, right view of incomplete specimen with displaced valves, displaying hinge teeth on left valve, UNM 13,177, x2.
E–H, *Nuculopsis girtyi*: **E**, left view, UNM 13,179, x2.5; **F**, right view, UNM 13,180, x2.5; **G**, dorsal view, UNM 13,182, x2.5; **H**, posterior view, UNM 13,183, x2.5.
I–M, *Nuculopsis* n. sp.: **I**, left view of slightly ventrally crushed specimen, UNM 13,185, x2.5; **J**, dorsal view, same specimen, x2.5; **K**, left view, undistorted specimen, UNM 13,186, x2.5; **L**, left view, undistorted specimen, UNM 13,188, x2; **M**, left view, ventrally crushed specimen, UNM 13,187, x2.5.
N–P, *Polidevcia bellistriata*: **N**, right view, incomplete and laterally crushed specimen, UNM 13,190, x2.5; **O**, anterior portion of left valve, incomplete, laterally crushed specimen, UNM 13,191, x2.75; **P**, right view, incomplete weathered specimen, showing some hinge teeth, UNM 13,192, x2.75.
Q, *Solemya trapezoides*, incomplete left valve, UNM 13,194, x1.
R, *Acanthopecten* sp., valve fragment, UNM 13,195, x2.
S–U, *Astartella concentrica*: **S**, laterally crushed right valve, UNM 13,196, x2; **T**, oblique, anterior view of articulated valves, UNM 13,197, x2; **U**, laterally crushed left valve; note worm tube (arrow), UNM 13,198, x3.
V, *Apotocardium lanterna*, left view of incomplete specimen, UNM 13,200, x2.65.

valves, lower and more strongly curved and more posteriorly situated beaks, and concave rather than convex posterodorsal margin of *N. girtyi*. As noted above, co-occurrence of these two nuculoid species is common in the Pennsylvanian of the United States.

Nuculopsis n. sp.

A third species of *Nuculopsis* (Figs. 4I–M) is much less common than *N. anodontoides* and *N. girtyi* in the Bar B shale unit. Like *N. girtyi*, the valves are inflated at the umbos, but the opisthogyrate beaks are higher and are located subcentrally to moderately posteriorly rather than subterminally, producing a higher height/width ratio than is the case with *N. girtyi*. The posterodorsal margin of both species is concave, but that of *N.* n. sp. is longer than on *N. girtyi* and the posterior margin is more acutely convex. The lunule and escutcheon of *N.* n. sp. are more pronounced than on *N. girtyi*. A well-preserved, undistorted specimen of *N.* n. sp. is 13.8 mm long, 11.3 mm high, and 9.8 mm wide; the largest specimen in the collections is approximately 17 mm long. Ornamentation is limited to weak, irregular, comarginal growth lines.

Specimens of *N.* n. sp. that are compressed dorsoventrally, comparable to *N. girtyi*, display well the more centrally located beaks, and the more elongate posterior portion of the valve is considerably more produced than on similarly crushed specimens of *N. girtyi*. Those specimens that are compressed laterally typically have the valves displaced, producing specimens that appear shorter and higher, and with more pronounced beaks, than undistorted or dorsoventrally crushed specimens. The range of preservational morphologies is shown in the figures.

Although resembling *Nuculopsis girtyi* in some respects, *N.* n. sp. differs significantly in several important features, and these specimens do not appear to be conspecific with any previously described North American late Paleozoic nuculoid.

***Polidevcia bellistriata* (Stevens)**

Leda bellistriata Stevens, 1858, p. 261.

Fragmentary and laterally crushed but otherwise typical specimens of *Polidevcia bellistriata* (Figs. 4N–P) are moderately common in the Bar B shale fauna. The specimens are typically missing all or most of the elongate, narrow, posterior portion of the valves but attained an estimated 25 mm in length when complete. The beaks are high, narrow, strongly curved, and opisthogyrate, and although the specimens are crushed, remnants of a shallow escutcheon are preserved along the hingeline. The ornamentation is the distinctive pattern of step-ribs—narrow comarginal bands that are high dorsally but slope ventrally (Yancey, 1978)—that characterize the species. On weathered specimens the high margins of these bands tend to become isolated, giving the appearance of sharp, comarginal lirae. This species is known from the Desmoinesian (Kues, 1984) to latest Virgilian (Laborcita Formation; Kues, 1991) of New Mexico, and occurs throughout the central and eastern United States as well.

***Solemya trapezoides* (Meek)**

Solenomya trapezoides Meek, 1874, p. 582.

One fragmentary left valve (Fig. 4Q) documents the presence of *Solemya trapezoides* in the Bar B Formation. This valve is large (an estimated 65 mm long when complete), very thin, and elongate-oval in outline, with the inferred position of the missing beaks about two-thirds of the distance from the broadly convex anterior to the more acutely convex posterior margins. The valve surface lacks ornamentation except for irregular, comarginal wrinkles. Although incomplete, the unusual size as well as the shape and proportions of this valve leave little doubt that it is *S. trapezoides*, a species thoroughly discussed by Pojeta (1988) and described from Virgilian strata of central New Mexico by Kues (1992).

***Acanthopecten* sp.**

A small valve fragment (Fig. 4R) displays widely spaced, narrow radial ribs that are interrupted by arched comarginal ridges that cross them; both characters of the ornamentation of the pectinacean bivalve *Acanthopecten*. Several species are known from the Pennsylvanian–Early Permian of the United States (Newell, 1937). The ornamentation of the Bar B specimen resembles that of both *A. meeki* Newell and *A. coloradoensis* (Newberry), but not enough of the valve is preserved for definite identification. Assignment to the common and widespread species *A. carboniferus* (Stevens) is ruled out by the sharp, narrow ribs of the Bar B specimen, quite different from the wide, low, radial ribs of *A. carboniferus*.

***Astartella concentrica* (Conrad)**

Nuculites concentrica Conrad, 1842, p. 248.

Bar B specimens of *Astartella concentrica* (Figs. 4S–U) are mostly laterally crushed, and the valves have a suboval to subrectangular shape with low beaks situated about one-fourth to one-third of the distance from the anterior to posterior margins. The characteristic deep circular lunule below the beaks, and deep fusiform escutcheon along the posterodorsal margin are preserved on a few of the specimens. The length/height ratio of the valves averages approximately 1.35, and they attain a maximum length of approximately 30 mm. Ornamentation consists of high, sharp, widely spaced comarginal ribs, approximately 6–7/5 mm near the center of the valve. These ribs are evenly spaced except near the ventral valve margin, where they become irregular. Fine growth lines are present between the ribs.

Although most specimens are laterally compressed, some have been obliquely distorted or dorsoventrally crushed, which produces a wide range of variation in valve shape. Oblique compression produced elongate, relatively low valves with the beaks displaced anteriorly. Dorsoventral compression typically increased the apparent width of the articulated valves and broke them near midheight, producing specimens that appear low and elongate in outline, superficially resembling the shape of genera such as *Parallelodon*. Characters of the beaks, dorsal margin, and ornamentation of such specimens are exactly the same as on typical specimens of *Astartella*.

Rostroconchs

***Apotocardium lanterna* (Branson)**

Conocardium lanterna Branson, 1965, figs. 1–9.

The single rostroconch specimen, *Apotocardium lanterna* (Fig. 4V), is incomplete; most of the left side but little of the right side of the shell is preserved. The shell body is moderately inflated and grades without significant discontinuity into the subtriangular snout region. The body displays seven major radial ribs, six of which begin near the beak and one of which was intercalated at about midheight. The ribs are crossed by much finer, very closely spaced growth lines. The interspaces are about twice the width of a rib near the ventral margin. The posterior rib is slightly enlarged and marks a sharp break with the short rostral area. Approximately 13 finer radial ribs are present on the snout, and these are crossed by strong, irregular, comarginal growth lines of nearly equal strength. The ventral margin of the snout region displays a moderate gape, and several stout denticles are preserved along these margins.

Although incomplete, the preserved parts of the shell agree well with the Desmoinesian–Missourian species *Apotocardium lanterna* (e.g., Branson, 1965; Hoare et al., 1982, 2002). Typical specimens of this species have a greater number (about 20) of fine radiating ribs on the snout, but on the Bar B specimen the anterior end of the snout has been broken away.

Matrix adhering to this specimen is light-gray argillaceous limestone, suggesting that it may not have been derived from the dark shale interval that is the subject of this study. Nevertheless, it is described here because of the rarity of Pennsylvanian rostroconchs in New Mexico.

Acknowledgments

We thank Roger Batten and Maya Elrick for reviewing an earlier version of this paper and offering suggestions that helped to improve it.

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