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Early Carboniferous nautiloids from the Ruddell Shale Member in Arkansas, Midcontinent North America

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Abstract. An early Chesterian (early Carboniferous; Late Mississippian) nautiloid fauna is described from the Ruddell Shale Member of the Moorefield Formation in Arkansas, Midcontinent North America. It consists of the three orthocerids, *Euloxoceras buffalowallowense* sp. nov., *Mitorthoceras perfilosum* Gordon and *Moorefieldoceras yochelsoni* gen. et sp. nov., and the two nautilids, *Tylonautilus* sp. and *Peripetoceras milleri* sp. nov. Reexamination of *M. perfilosum*, the type species of the genus, provides grounds for emendation of the generic concept emphasizing the supracentral position of the siphuncle. *Moorefieldoceras* is differentiated from comparable genera by its relatively rapid shell expansion, prominent annulations with a distinct ventral sinus, and relatively large siphuncle diameter with a central to subcentral position.

Key words: early Chesterian (early Carboniferous; Late Mississippian), *Moorefieldoceras* gen. nov., Nautilida, Orthocerida, Ruddell Shale Member

Introduction

The Ruddell Shale Member (*ca.* 30–80 m in thickness) in northern central Arkansas, Midcontinent North America is a black shale unit deposited in an off-shore marine environment with an anoxic to strongly dysoxic bottom. The unit occupies the uppermost part of the Moorefield Formation (e.g. Gordon, 1944; Nützel and Mapes, 2001; Mapes and Nützel, 2009).

The present report describes nautiloid cephalopods from the member on the basis of material (OUZC 5387–5447 in the Ohio University Zoological Collection—now located at American Museum of Natural History in New York City) accumulated in the past during more than 40 years by R. H. M. with his collaborators and students, and newly collected material in September, 2013. The fossil-bearing site is known as the "Buffalo Wallow" near Batesville, Independence County (locality register at Ohio University ARC-01; see Malinky and Mapes, 1982, text-fig. 1 for its geographic location). At this place the unit crops out and exposes a particularly fossiliferous horizon in a set of open glades and ravines. Biostratigraphically, this horizon belongs to the *Goniatites granosus-Dombarites choctawensis* ammonoid zone, indicating an early Chesterian (= late Visean of middle early Carboniferous; Late Mississippian) age (Malinky and Mapes, 1982).

Systematic paleontology

Subclass Nautiloidea Agassiz, 1847
Order Orthocerida Kuhn, 1940
Superfamily Pseudorthoceratoidea Flower and Caster, 1935
Family Pseudorthoceratidae Flower and Caster, 1935
Subfamily Spyroceratinae Shimizu and Obata, 1935

Genus *Euloxoceras* Miller, Dunbar and Condra, 1933

Type species.—*Euloxoceras greenei* Miller, Dunbar and Condra, 1933.

Euloxoceras buffalowallowense sp. nov.

Figures 1.1–1.12

Diagnosis.—Species of *Euloxoceras* with gradual conch expansion, roughly straight sutures, relatively long camerae having cameral form ratios (maximum width per length in dorsoventral section) of 2.3–2.6; dorsal brims recumbent, and contact with septa in rare cases;

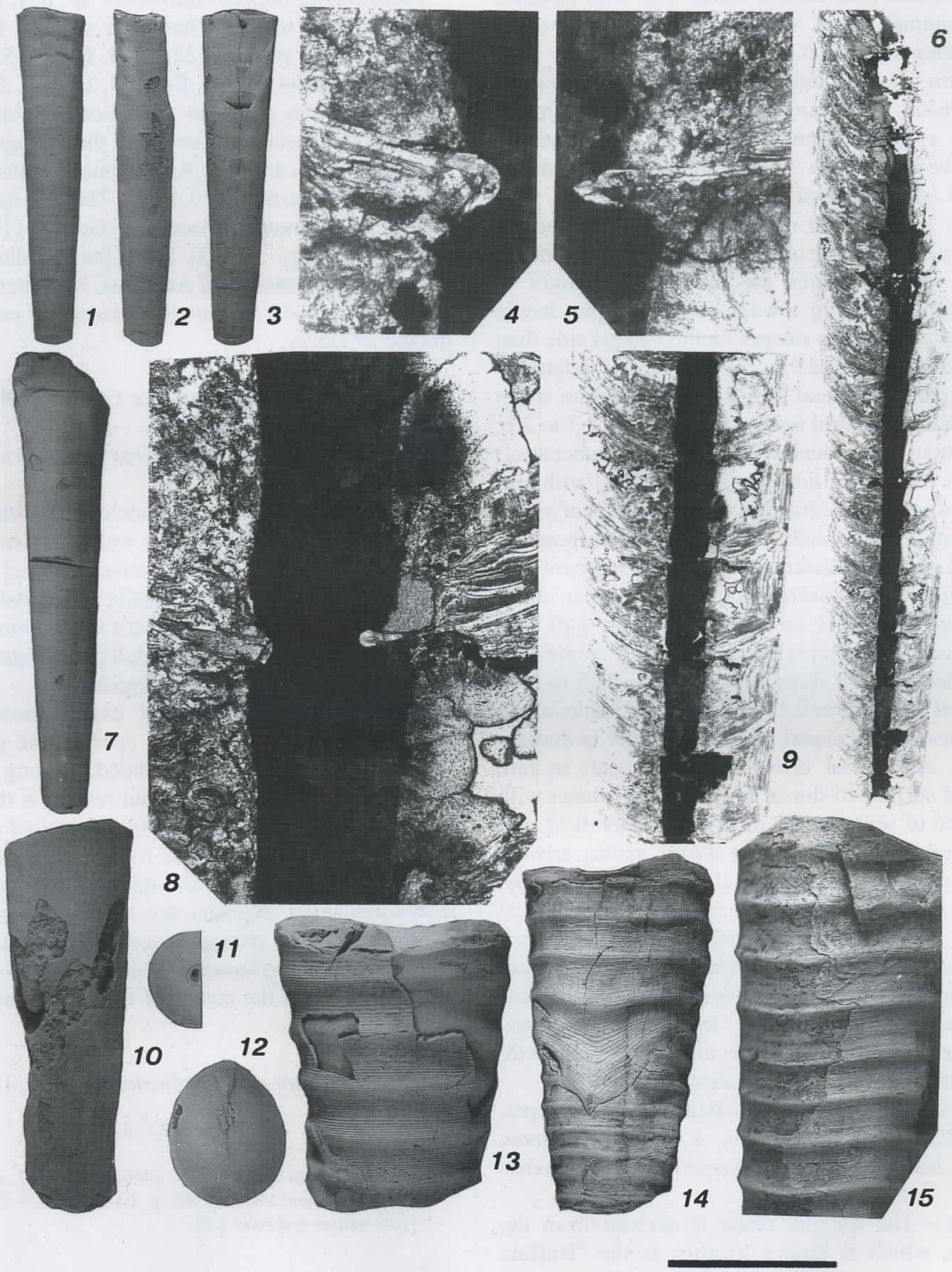

Figure 1. **1–12**, *Euloxoceras buffalowallowense* sp. nov.; 1–6, 8, 9, 11, holotype, OUZC 5414; 1, ventral view; 2, lateral view, venter on left; 3, dorsal view; 4, partial enlargement of Figure 1.6 to show details of ventral septal neck; 5, partial enlargement of Figure 1.6 to show details of dorsal septal neck; 6, dorsoventral thin section, venter on left; 8, partial enlargement of Figure 1.6 to show details of siphuncular foramina and connecting ring shapes, note recumbent brim contacts with septum; 9, partial enlargement of Figure 1.6 to show details of siphuncle and cameral deposits; 11, septal view of apical end, venter down; 7, 12, paratype, OUZC 5415; 7, lateral view, venter on left; 12, septal view of apical end, dorsal side slightly deformed, venter down; 10, paratype, OUZC 5416, side view of flattened body chamber. **13–15**, *Moorefieldoceras yochelsoni* gen. et sp. nov.; 13, paratype, OUZC 5411, dorsal view of body chamber; 14, paratype, OUZC 5391, side view of flattened conch, note triangular salient-like protrusion; 15, holotype, OUZC 5402, partial enlargement to show details of surface ornamentation. Scale bar is 15 mm in Figures 1.1–1.3, 1.15; 0.4 mm in Figures 1.4, 1.5; 6 mm in Figures 1.6, 1.11, 1.12; 20 mm in Figures 1.7, 1.10, 1,13, 1.14; 0.75 mm in Figure 1.8; 3 mm in Figure 1.9.

siphuncle situated near central conch axis with distance of septal foramen from ventral shell to dorsoventral conch diameter ratios of 0.52–0.59.

Description.—Longiconic orthocones with gradual conch expansion, whose angle is approximately 7° in lateral view; cross sections of conchs are laterally depressed; the holotype is 3.6 mm in dorsoventral diameter and 3.4 mm in lateral diameter at apical end, with approximate length of 30 mm; shell surface is smooth, marked only by fine growth lines, that form broad sinuses on venter. Sutures are essentially straight to slightly oblique inclining toward dorsum; septa deeply concave with concavities steeper on the ventral side than dorsal; camerae are moderate in length, but relatively long for the genus; cameral form ratios (maximum width per length in dorsoventral section) range from 2.3 to 2.6; siphuncle situated near central axis of conch (subcentral) and between center and dorsum (supracentral) with siphuncular position ratios (distance of central axis of septal foramen from ventral shell surface per corresponding dorsoventral conch diameter) of 0.52–0.59; ratios of siphuncular diameter per corresponding conch dorsoventral diameter range from 0.11 to 0.18; siphuncular wall consists of cyrtochoanitic septal necks and thin connecting rings; neck length very short, ranging from 0.08 to 0.09 mm in ventral and 0.12 to 0.17 mm in dorsal necks of the holotype; curvature of septal necks is stronger in dorsum than venter, and dorsal brims are recumbent; in rare cases, adoral surface of dorsal brims are in contact with apical surface of septa; width of brims is 0.09–0.12 mm in ventral and 0.12–0.14 mm in dorsal necks; area of adnation is relatively wide, but slightly narrower than brim width; shape of connecting rings is subcylindrical with abrupt constrictions at septal foramen and weak concavities at sides. Cameral deposits well developed, apparently thicker in venter than dorsum, and differentiated into episeptal-mural and hyposeptal deposits; episeptal deposits partly indicate mammiform growth; endosiphuncular deposits are not detected.

Material examined.—Holotype, OUZC 5414. Paratypes, OUZC 5415, 5416. In addition, a single specimen, OUZC 5417, is assigned to *Euloxoceras buffalowallowense* sp. nov.

Etymology.—The specific name is derived from the type locality, which is known locality as the "Buffalo Wallow".

Discussion.—Possession of the longitudinal costa on the adoral shell surface, which is the one of the most diagnostic characters of *Euloxoceras*, is not known in the type specimens of this species because the surface of these specimens is not adequately preserved. However, its supracentral siphuncular position and cyrtochoanitic septal necks warrant generic assignment.

Euloxoceras buffalowallowense sp. nov. most resembles a middle to late Chesterian species, *E. angustius* Gordon (1964, p. 127, 128, pl. 8, figs. 1–5, 25; Kröger and Mapes, 2004, p. 569, figs. 1.3, 1.5, 2.3, 5.8, 6.8, 6.9), from the Pitkin and Imo formations in Arkansas. The present new species differs from the younger species in having longer camerae. Approximate ratios of cameral form of *E. angustius* are 3.4–3.7. The new species is also similar to *E. greenei praecursor* Gordon (1964, p. 128, 129, pl. 8, figs. 10–13) from the middle Chesterian Fayetteville Formation in Arkansas. However, the siphuncular position of *E. greenei praecursor* is conspicuously dorsad of center.

Genus *Mitorthoceras* Gordon, 1960

Type species.—*Mitorthoceras perfilosum* Gordon, 1960.

Emended diagnosis.—Siphuncle subcentral and supracentral in position; siphuncular walls consist of suborthochoanitic septal necks and subcylindrical connecting rings; cameral deposits usually episeptal-mural and hyposeptal. For other characters see previous workers, including Gordon (1960) for adult and Kröger and Mapes (2005) for apex shell morphologies.

Discussion.—Based on our examinations of newly collected material of the type species, the generic concept of *Mitorthoceras* is emended. Among the present emendations, the most important respect is the siphuncle position. Niko and Mapes (2009) identified nine criteria by which to determine the living orientation on nautiloids. Based on the seventh criterion (cameral and endosiphuncular deposits are better developed on the ventral side of the phragmocone), we determined the orientation of *M. perfilosum* and concluded its siphuncle is situated between the center of the conch and the dorsal margin.

Mitorthoceras perfilosum Gordon, 1960

Figures 2.1–2.11

Mitorthoceras perfilosum Gordon, 1960, p. 136, 137, pl. 27, figs. 1–4, 8; Kröger and Mapes, 2005, p. 1005, figs. 7.4–7.6, 8, 9.3, 10.1 [with earlier synonym list].

Description.—Longiconic orthocones with gradual shell expansion and circular cross sections; the largest specimen (phragmocone, OUZC 5443) is approximately 14 mm in diameter; surface ornamentation consists of transverse lirae. Sutures straight and at right angles to conch axis; cameral length moderate, indicating form ratios (maximum width per length) of 1.8–2.6; siphuncle near central axis of conch (subcentral) and between cen-

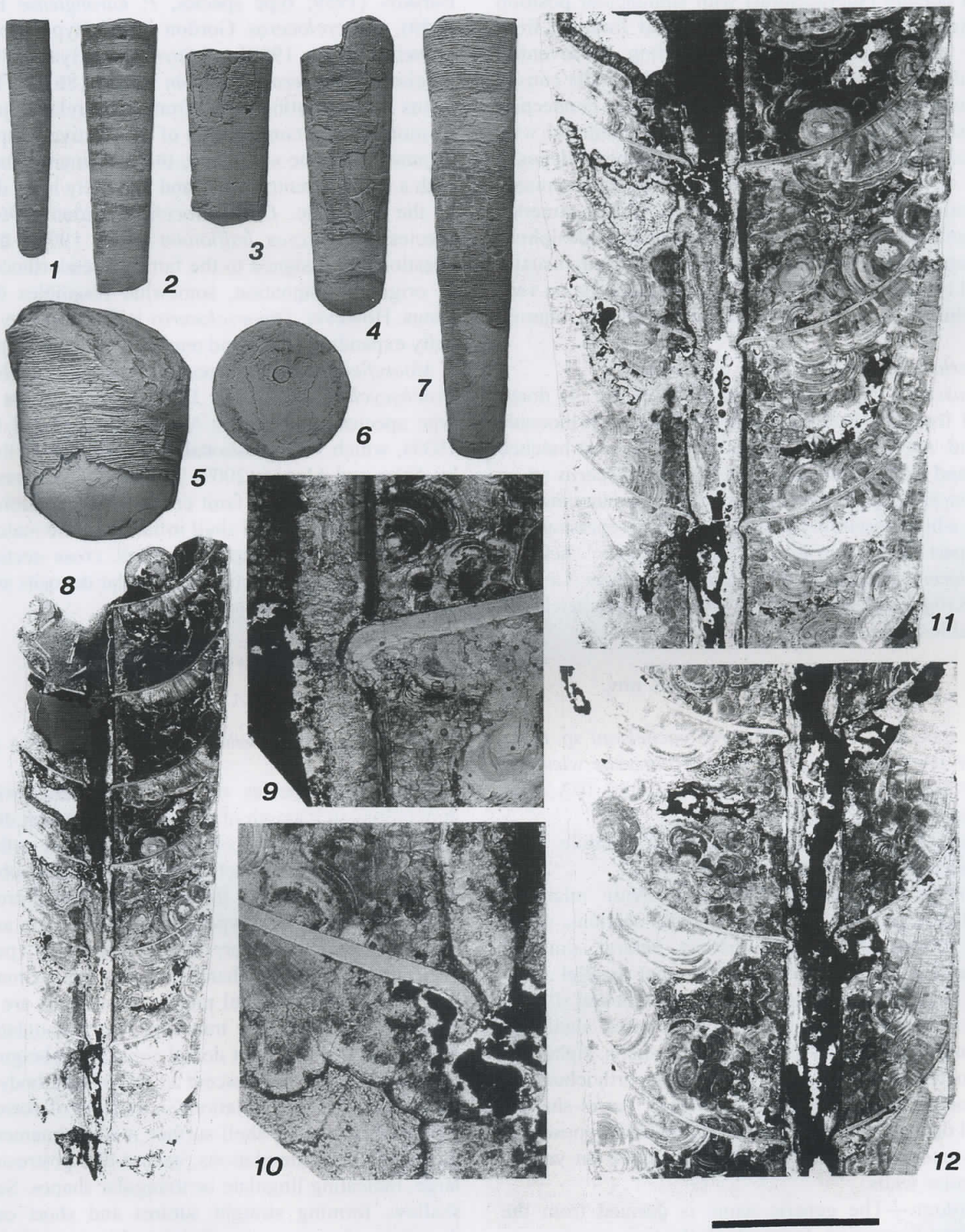

Figure 2. *Mitorthoceras perfilosum* Gordon, 1960; **1**, OUZC 5418, ventral view; **2**, OUZC 5427, ventral view; **3**, **12**, OUZC 5425; 3, lateral view, venter on right; 12, dorsoventral thin section, venter on left, showing details of siphuncle, and cameral and endosiphuncular deposits; **4**, **8–11**, OUZC 5426; 4, dorsal view; 8, dorsoventral thin section, venter on right; 9, partial enlargement of Figure 2.8 to show details of ventral septal neck, and lining of endosiphuncular deposits; 10, partial enlargement of Figure 2.8 to show details of dorsal septal neck and parietal endosiphuncular deposits; 11, partial enlargement of Figure 2.8 to show details of siphuncle, and cameral and endosiphuncular deposits; **5**, OUZC 5443, side view; **6**, **7**, OUZC 5428; 6, septal view of adoral end, venter down; 7, lateral view, venter on left. Scale bar is 15 mm in Figures 2.1–2.5, 2.7; 10 mm in Figure 2.6; 6 mm in Figure 2.8; 0.75 mm in Figures 2.9, 2.10; 3 mm in Figures 2.11, 2.12.

ter and dorsum (supracentral) with siphuncular position ratios (distance of central axis of septal foramen from ventral shell surface per corresponding dorsoventral conch diameter) of 0.59–0.62; siphuncular walls consist of suborthochoanitic septal necks and thin connecting rings; shape of connecting rings is subcylindrical with weak constrictions at septal foramen. Cameral deposits thicker in venter than dorsum, differentiated into episeptal-mural and hyposeptal deposits; in adoral camerae, hyposeptal deposits disappear in dorsal side; endosiphuncular deposits also thicker in venter than dorsum, usually parietal type; in apical portions, parietal deposits on ventral siphuncular walls fuse to form continuous internal lining.

Material examined.—OUZC 5418–5444.

Discussion.—Mapes and Nützel (2009, fig. 4) documented from the Ruddell Shale Member an orthoconic nautiloid specimen indicating the early post-hatched stages and tentatively assigned it to *Reticycloceras* sp. or *Mitorthoceras* sp. Based on the surface ornamentation, there is a high possibility that the specimen represents the apical part of *M. perfilosum*. The embryonic shells of *Reticycloceras* are diagnosed by longitudinal lirae (Gordon, 1964; Kröger and Mapes, 2004), whose character is not observable in the specimen.

Genus *Moorefieldoceras* gen. nov.

Type species.—*Moorefieldoceras yochelsoni* sp. nov.

Other included species.—*Brachycycloceras washingtonense* Gordon (1964, p. 108, 109, text-figs. 10A, 10B, pl. 5, figs. 4, 5, pl. 16, figs. 4, 5).

Range.—Early to middle Chesterian (middle early Carboniferous; Late Mississippian).

Diagnosis.—Annulated orthocones with relatively rapid shell expansion and circular cross sections; annulations prominent, forming distinct ventral sinus in phragmocone; ornamentation of lirae that parallel annulations; cameral length short; sutures straight and slightly oblique; siphuncular position central in apical shell segments and subcentral in larger diameter shells; siphuncular diameters relatively large; septal necks orthochoanitic to suborthochoanitic; connecting rings barrel-shaped; cameral deposits usually episeptal-mural and hyposeptal; parietal endosiphuncular deposits developed on ventral siphuncular walls.

Etymology.—The generic name is derived from the Moorefield Formation, from which the type species was collected.

Discussion.—*Moorefieldoceras* gen. nov. is comparable with some genera belonging the subfamily Spyroceratinae, namely *Cryptocycloceras* Shimansky (1968; type species, *C. alimbetense* Shimansky, 1968), *Pseudocycloceras* Barskov (1959; type species, *P. karanglense* Barskov, 1959), *Reticycloceras* Gordon (1960; type species, *R. croneisi* Gordon, 1960) and *Spyroceras* Hyatt (1884; type species, *Orthoceras crotalum* Hall, 1861). The new genus can be distinguished from these related genera in its morphologic combination of the relatively rapid shell expansion for the subfamily, the prominent annulations with a distinct ventral sinus and relatively large diameter of the siphuncle. *Dinocycloceras* Gordon (1964; type species, *Cycloceras ballianum* Girty, 1909), that was questionably assigned to the family Pseudorthoceratidae in original designation, somewhat resembles the new genus. However, *Dinocycloceras* is diagnosed by a gradually expanding conch and markedly eccentric siphuncle.

Moorefieldoceras is readily distinguishable from *Brachycycloceras* Miller, Dunbar and Condra (1933; type species, *B. normale* Miller, Dunbar and Condra, 1933), which was questionably assigned to Orthocerida by Niko and Mapes (2009). Distinctive features of the latter genus include a faint endogastric curvature in the immature shell, a rapid shell inflation of the mature part, and dorsoventrally depressed shell cross sections. In addition, cameral and endosiphuncular deposits are probably absent in *Brachycycloceras*.

Moorefieldoceras yochelsoni sp. nov.

Figures 1.13–1.15, 3.1–3.15

[?] *Dinocycloceras* cf. *D. ballianum* (Girty). Gordon, 1964, p. 130.

Diagnosis.—Species of *Moorefieldoceras* with 3–5 annulations in a length of corresponding conch diameter.

Description.—Longiconic and annulated orthocones with relatively rapid shell expansion for the subfamily; expansion angle ranges from 9° to 12°; shell cross sections are circular; holotype is 84 mm in length and 10.5 mm in apical diameter; largest specimen (paratype, OUZC 5413) of body chamber attains approximately 39 mm in diameter (internal mold); annulations are prominent and are essentially transverse; each annulation has distinct ventral and faint dorsal sinuses in phragmocone, but they become obsolescent in the mature body chamber; there are 3–5 annulations in a length of corresponding conch diameter; shell surface is also ornamented by lirae parallel to annulations; salient-like protrusions are large, indicating lingulate or triangular shapes. Septa are shallow, forming straight sutures and short camerae; direction of sutures is slightly oblique and inclined toward apex on dorsum; cameral form ratios (maximum width per length) range from 3.2 to 4.1; siphuncle central in juvenile conch, then shifts slightly ventrad to a subcentral position in more mature shells; thus, siphuncular position ratios (distance of central axis of septal foramen

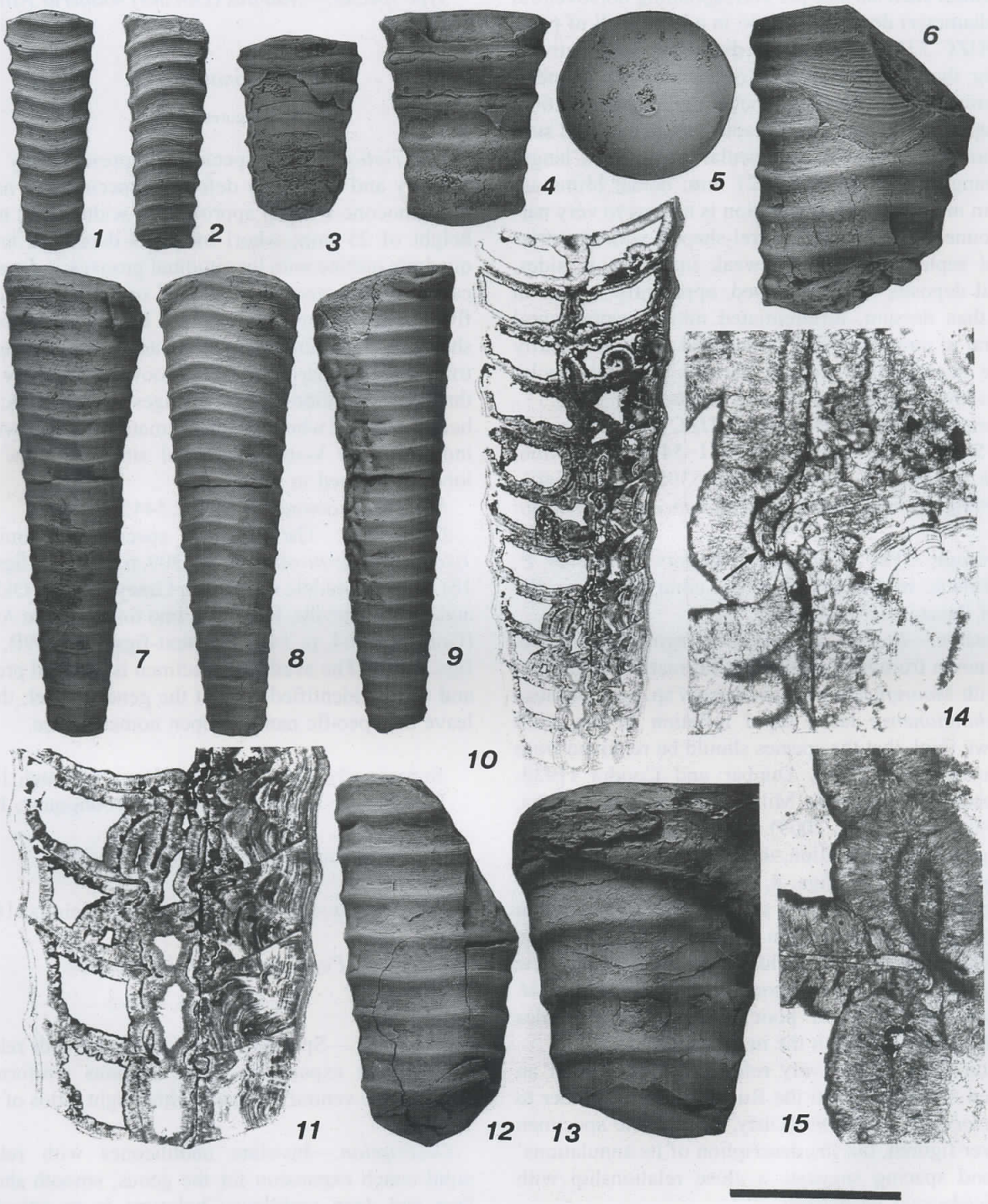

Figure 3. *Moorefieldoceras yochelsoni* gen. et sp. nov.; **1**, **2**, **10**, **11**, **14**, **15**, paratype, OUZC 5389; 1, ventral view, note distinct ventral sinuses in annulations; 2, lateral view, venter on left; 10, dorsoventral thin section, venter on right; 11, partial enlargement of Figure 3.10 to show details of siphuncle and cameral deposits; 14, partial enlargement of Figure 3.10 to show details of ventral septal neck and parietal endosiphuncular deposits (arrow); 15, partial enlargement of Figure 3.10 to show details of dorsal septal neck; **3**, paratype, OUZC 5388, ventral view, note slightly oblique sutures; **4**, **5**, paratype, OUZC 5396; 4, dorsal view; 5, septal view of apical end, venter down; **6**, paratype, OUZC 5398, lateral view, venter on left, note lingulate salient; **7–9**, holotype, OUZC 5402; 7, ventral view; 8, lateral view, venter on right; 9, dorsal view; **12**, paratype, OUZC 5397, ventral view; **13**, paratype, OUZC 5313, ventral view of body chamber (internal mold). Scale bar is 15 mm in Figures 3.1–3.4, 3.6, 3.12; 10 mm in Figure 3.5; 30 mm in Figures 3.7–3.9, 3.13; 6 mm in Figure 3.10; 3 mm in Figure 3.11; 0.75 mm in Figures 3.14, 3.15.

from ventral shell surface per corresponding dorsoventral conch diameter) decrease to 0.46 in adoral shell of paratype OUZC 5389; siphuncular diameters are relatively large for the subfamily; ratios of siphuncular diameter per corresponding conch diameter range from 0.16 to 0.23; septal necks are orthochoanitic in ventral and subortho choanitic in dorsal siphuncular walls; neck length short, ranging from 0.15 to 0.27 mm; dorsal brims are 0.05 mm in width; area of adnation is narrow to very narrow; connecting rings are barrel-shaped with constrictions at septal foramen and weak inflations at sides. Cameral deposits well developed, apparently thicker in venter than dorsum, differentiated into episeptal-mural (or mural in rare cases) and hyposeptal types, and partly indicate mammiform growth; parietal endosiphuncular deposits are developed on ventral siphuncular walls.

Material examined.—Holotype, OUZC 5402. Paratypes, OUZC 5387–5392, 5396–5399, 5411–5413. In addition, fourteen specimens, OUZC 5392–5395, 5400, 5401, 5403–5410, are assigned to *Moorefieldoceras yochelsoni* sp. nov.

Etymology.—The specific name honors the late Dr. E. L. Yochelson, in recognition of his contributions in the study of Palaeozoic molluscs.

Discussion.—*Brachycycloceras washingtonense* Gordon, 1964, known from the Fayetteville Formation, is comparable with *Moorefieldoceras yochelsoni* sp. nov. Because *B. washingtonense* lacks rapid inflation in the adult shells, we think that the species should be removed from *Brachycycloceras* Miller, Dunbar and Condra (1933; type species, *B. normale* Miller, Dunbar and Condra, 1933; Niko and Mapes, 2009) and placed in *Moorefieldoceras* gen. nov. In addition, the holotype (pl. 16, fig. 4) and a paratype (pl. 5, figs. 4, 5) of *B. washingtonense* may belong to two different species. The former taxon can be clearly separated from *M. yochelsoni* by having more densely spaced annulations than those of the new species. The latter taxon more closely resembles *M. yochelsoni*; however, its poor preservation precludes accurate comparison with the new species.

Gordon (1964) tentatively referred a fragment of an annulated orthocone from the Ruddell Shale Member to *Dinocycloceras ballianum* (Girty, 1909). The specimen was never figured, but the description of its annulations' shape and spacing suggests a close relationship with *Moorefieldoceras yochelsoni.*

Order Nautilida Agassiz, 1847
Superfamily Tainoceratoidea Hyatt, 1883
Family Tainoceratidae Hyatt, 1883

Genus *Tylonautilus* Pringle and Jackson, 1928

Type species.—*Nautilus* (*Discites*) *nodiferus* Armstrong, 1866

Tylonautilus sp.

Figures 4.1–4.3

Description.—This species is represented by a fragmentary and somewhat deformed specimen of nautiloid phragmocone with an approximate width of 32 mm and height of 23 mm; whorl indicates depressed and subquadrate outline with longitudinal grooves; a deeply concaved median groove developed on venter; in addition, five shallow grooves recognized in area of ventrolateral shoulder, flank and dorsolateral angle with bilateral distribution; boundaries of these grooves marked by ridges; three rows of nodes occur on ridges in each flank; width/height ratio of whorl is approximately 1.4; growth lines indicate deep V-shaped ventral sinus. Shallow lateral lobes developed in sutures.

Material examined.—OUZC 5445.

Discussion.—The present species is similar to *Tylonautilus gratiosus* (Girty, 1909, p. 50, pl. 5, figs. 1, 1a, 1b) from the middle Chesterian Caney Shale in Oklahoma and the Fayetteville, Pitkin and Imo formations in Arkansas (Gordon, 1964, p. 141, 142, text-figs. 19A, 19B, pl. 11, figs. 5–12). The available specimen is not well preserved and can be identified only at the generic level; thus, we leave the specific name in open nomenclature.

Superfamily Clydonatiloidea Hyatt *in* Zittel, 1900
Family Liroceratidae Miller and Youngquist, 1949

Genus *Peripetoceras* Hyatt, 1884

Type species.—*Nautilus freieslebeni* Geinitz, 1841.

Peripetoceras milleri sp. nov.

Figures 4.4–4.8, 5.1, 5.2

Diagnosis.—Species of *Peripetoceras* with relatively rapid conch expansion; whorl sections reniform with subquadrate ventral outline; width/height ratios of whorls 1.1–1.3.

Description.—Involute nautilicones with relatively rapid conch expansion for the genus, smooth shell surface and deep umbilicus; holotype is an apical body chamber with the last septum and paratype is a fragment of an adoral body chamber with imperfect peristome; adoral and apical ends of holotype are respectively 19 mm width (reconstructed from half width) and 17 mm height and 29 mm width and 24 mm height; width of paratype more than 36 mm; whorl sections are depressed and reniform with subquadrate ventral outline; apical end

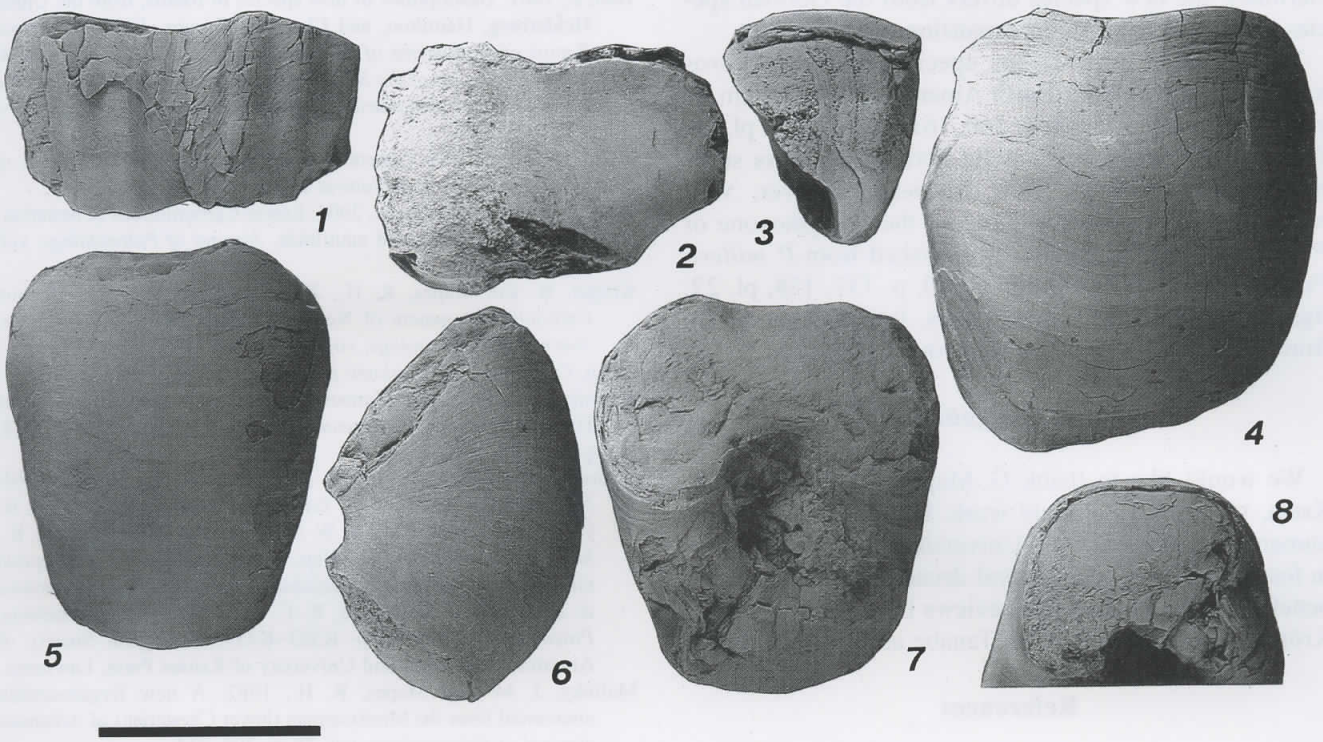

Figure 4. **1–3**, *Tylonautilus* sp., OUZC 5445; 1, ventral view; 2, cross sectional view, venter up; 3, lateral view, vicinity of dorsolateral angle eroded, venter up. **4–8**, *Peripetoceras milleri* sp. nov.; 4, paratype, OUZC 5447, ventral view; 5–8, holotype, OUZC 5446; 5, ventral view; 6, lateral view, venter on right; 7, dorsal view; 8, septal view of apical end, venter up. Scale bar is 20 mm.

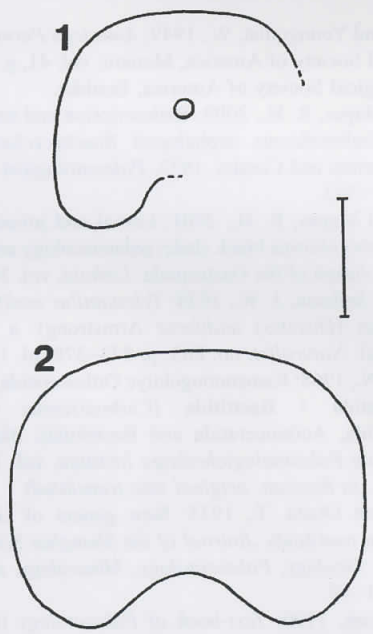

Figure 5. Whorl sections of *Peripetoceras milleri* sp. nov., holotype, OUZC 5446, venter up; **1**, at the last septum; **2**, body chamber. Scale bar is 10 mm.

(= at the last septum) of holotype has flattened venter, rounded ventrolateral shoulders, weakly inflated flanks converge slightly toward venter, rounded umbilical zones and deep impressed area; in body chamber, whorl sections become more rounded and conversion of flanks disappears; width/height ratios of whorl are 1.1–1.3; peristome and growth lines exhibit wide ventral (= hyponomic) sinus; shell constriction is developed near aperture of paratype as possible mature modification. Septal curvature is weak; suture indicates very shallow ventral and shallow lateral lobes; siphuncle shifts slightly dorsal from central position with growth and is approximately 0.15 mm in diameter.

Material examined.—Holotype, OUZC 5446. Paratype, OUZC 5447.

Etymology.—The specific name honors the late Dr. A. K. Miller, in recognition of his contributions in the study of Palaeozoic cephalopods.

Discussion.—Although shapes of the whorl sections of *Peripetoceras milleri* sp. nov. are similar to those of the type species, *P. freieslebeni* (Geinitz, 1843, p. 95, figured in Geinitz, 1841, pl. 11, figs. 1a–c; Kummel, 1963, p. 353–355, pl. 10, figs. 1–3, pl. 11, figs. 1, 2; Kummel, 1964, figs. 285.F, 324.6a–c), from the Permian of

Germany, the new species differs from the German species by having more rapid expansion of the conch.

Three early Carboniferous species of *Peripetoceras* have been known from North America. Among them, *P. ozarkense* Gordon (1964, p. 160, 161, text-fig. 20, pl. 15, figs. 7, 8) from the Fayetteville Formation shows some relationships with the new species. However, well rounded reniform cross sections of the phragmocone of *P. ozarkense* can be easily distinguished from *P. milleri*. *Peripetoceras whitei* Gordon (1960, p. 137, 138, pl. 27, figs. 6, 7) from the Coal Measures, Indiana also differs from *P. milleri* by having a well rounded venter.

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