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Original article

Taxonomy, biostratigraphy and paleoecology of Cenomanian and Turonian ostracodes from the Western Interior Basin, Southwest Utah, USA

Taxonomie, biostratigraphie et paléoécologie des ostracodes du Cénomanien et du Turonien du Bassin de Western Interior, sud-ouest de l'Utah, États-Unis

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Abstract

Cenomanian–Turonian ostracodes are reported from the western Colorado Plateau (Western Interior Basin) in the United States. Fifteen genera and twenty species are illustrated, six of which are new: *Cytheromorpha perornata* nov. sp., *Looneyella leckiei* nov. sp., *Asciocythere posterangulata* nov. sp., *Asciocythere arizonensis* nov. sp., *Cytheropteron clavifragilis* nov. sp. and *Hourcqia dakotaensis* nov. sp. Three ostracode interval zones are proposed that broadly correspond to the existing late Cenomanian through to Middle Turonian Ammonite-zones of Kauffman et al. (1993). Paleoenvironments range from estuarine to coastal plain.

Résumé

Des ostracodes sont identifiés dans le Cénomanien–Turonien du Plateau du Colorado occidental, Bassin de Western Interior, sud-ouest de l'Utah, aux États-Unis. Quinze genres et vingt espèces sont illustrées, six d'entre elles étant nouvelles : *Cytheromorpha perornata* nov. sp., *Looneyella leckiei* nov. sp., *Asciocythere posterangulata* nov. sp., *Asciocythere arizonensis* nov. sp., *Cytheropteron clavifragilis* nov. sp. et *Hourcqia dakotaensis* nov. sp. Trois zones d'intervalle basées sur les ostracodes sont proposées ; elles se corrèlent approximativement avec les zones d'ammonites du Cénomanien supérieur–Turonien moyen de Kauffman et al. (1993). Les paléoenvironnements sont représentés par des biofaciès d'estuaire et de plaine côtière.

Keywords: Ostracodes; Taxonomy; Biostratigraphy; Paleoecology; Upper Cretaceous; Cenomanian; Turonian; Western Interior; United States

Mots clés : Ostracodes ; Taxonomie ; Biostratigraphie ; Paléoécologie ; Crétacé Supérieur ; Cénomanien ; Turonien ; Western Interior ; États-Unis

1. Introduction

The Colorado Plateau contains an exceptionally well-preserved suite of sedimentary rocks that were deposited during the highest sea level of the Mesozoic (Hancock and Kauffmann, 1979; Haq et al., 1988). In the central United States, the Cenomanian–Turonian Greenhorn Marine Cycle records this widespread sea level highstand. The bathyal and neritic macro- and microfossil assemblages of the Cenomanian–Turonian Western Interior Basin (WIB) have been studied in detail (Eicher and Worstell, 1970; McNeil and Caldwell, 1981; Elder, 1991; Caldwell et al., 1993; Kauffman et al., 1993; Kirkland, 1996; Kennedy et al., 2000). Furthermore, chemical and physical stratigraphic studies on the distal facies are well known (Pratt et al., 1993; Leithold, 1994; Sageman et al., 1997, 1998). The siliciclastic sedimentary rocks that comprise the land–sea coastal deposits yield few, normal marine, mollusk taxa. Therefore, correlation to the offshore framework is problematic and

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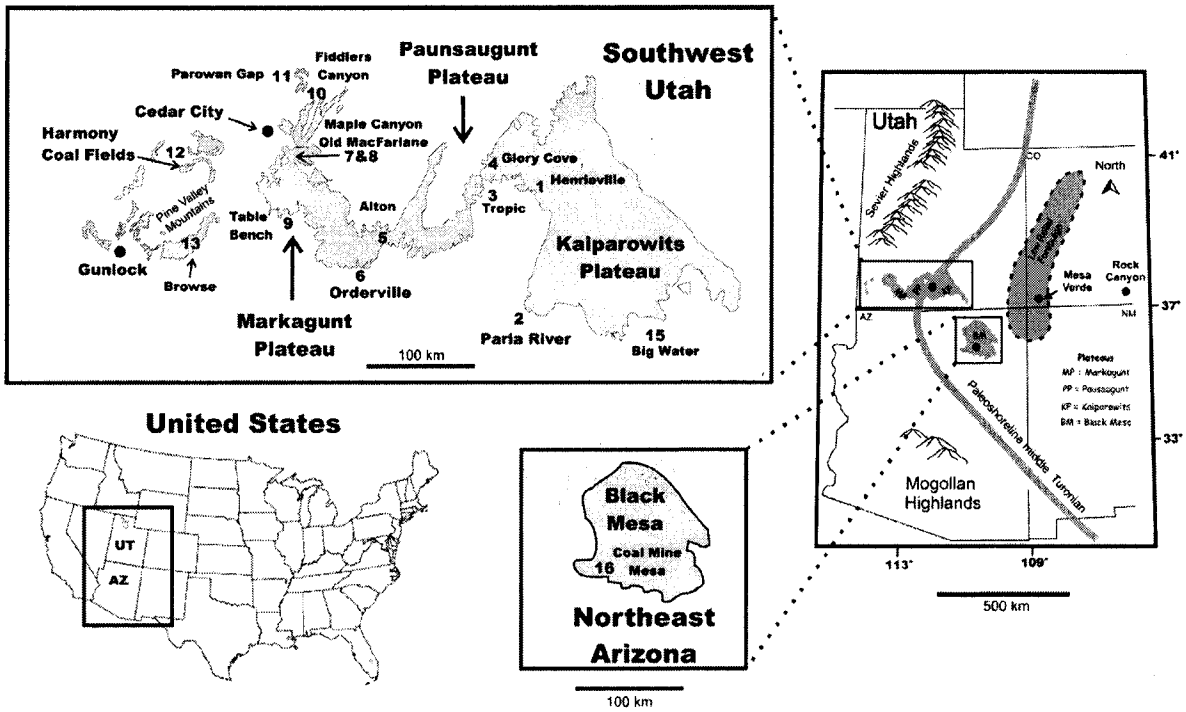


Fig. 1. Map presenting the fossil localities from southwest Utah. Positions are superimposed on the generalized geologic map where the grey shaded areas denote Cretaceous exposures (modified from Hintze, 1980). Details are provided in Table 1.

Fig. 1. Carte des localités fossilifères du sud-ouest de l'Utah. Les positions sont superposées à une carte géologique dans laquelle les zones en grisé représentent les affleurements du Crétacé (modifié d'après Hintze, 1982). Les détails se trouvent sur le Tableau 1.

microfossils provide a practical medium to correlate to the Cenomanian–Turonian deposits worldwide. The primary objective of this manuscript is to formally document and summarize the spatial and temporal distribution of the little studied marginal marine ostracode taxa that were collected across a greater transect from Mesa Verde, Colorado to the Pine Valley Mountains, Utah (Fig. 1). This Cenomanian–Turonian microfossil synthesis from Utah is a pioneering attempt to provide the biostratigraphic framework to correlate the coal-bearing strata to existing stratigraphic systems recognized in North America (Fig. 2).

2. Samples localities and stratigraphic overview

A subsiding fore-deep basin developed in southwestern Utah during the late Cretaceous (Molenaar, 1983; Ryer, 1984; Eaton and Nations, 1991; Elder and Kirkland, 1993). Deposition occurred in a series of structurally parallel topographic lows that form a V-shaped embayment known as the Grand Canyon Bight (Stokes and Heylmun, 1963). During late Cenomanian–Middle Turonian time (~94.5–90.5 Ma), brackish water facies were deposited around the perimeter of this embayment extending from Black Mesa, Arizona, to southwestern Utah where today, a series of plateaus record a nearly continuous stratal succession (Fig. 1). The marginal marine facies comprise the Dakota Formation, Tropic Shale (and correlative units of the lower Mancos Shale), the lower part of the Straight Cliffs Formation (Tibbet Canyon and Smoky Hollow Members), and the westernmost correlative Iron Springs Formation (Figs. 1–3) (Eaton et al., 1997, 1999, 2001; Tibert et al., 2003a, 2003b; Tibert and Leckie, 2004).

Approximately 350 samples from 20 individual stratigraphic sections were collected during four field seasons on the Colorado Plateau. Twenty formal localities and sub-localities are listed in Table 1. Figs. 4–7 illustrate the 4 primary reference sections for the new species provided within modified from Tibert (2002). Locality 1, Henrieville (Fig. 4) encompasses marginal marine strata assigned to the Middle-to-late Cenomanian. Locality 15 at Bigwater, Utah (Fig. 5) is the stratigraphic section that encompasses the shallow marine facies of the Greenhorn Cycle and its subsequent biozones. Locality 7 at Maple Canyon, Utah (Fig. 6) comprises the latest Cenomanian and earliest Turonian marginal marine facies marking the Cenomanian–Turonian boundary interval. Finally, Localities 8a–b at Cedar Canton (Fig. 7) comprises a stratigraphic sequence best representing the marginal facies deposited during the Turonian.

Kennedy et al. (2000) have formally proposed that the Cenomanian–Turonian boundary interval at Pueblo Colorado be elected as the global boundary stratotype. This is an exciting aspect for global comparisons; yet, some changes to the ammonite and bivalve zones of the WIB have also been proposed (Kennedy et al., 2000). To maintain consistency with the most recent paleontologic studies in the immediate southwestern region (Elder, 1991; Kirkland, 1991; Elder and Kirkland, 1993; Elder et al., 1994; Kirkland, 1996), we have chosen to retain the scheme of Kauffman et al. (1993). Widespread dated

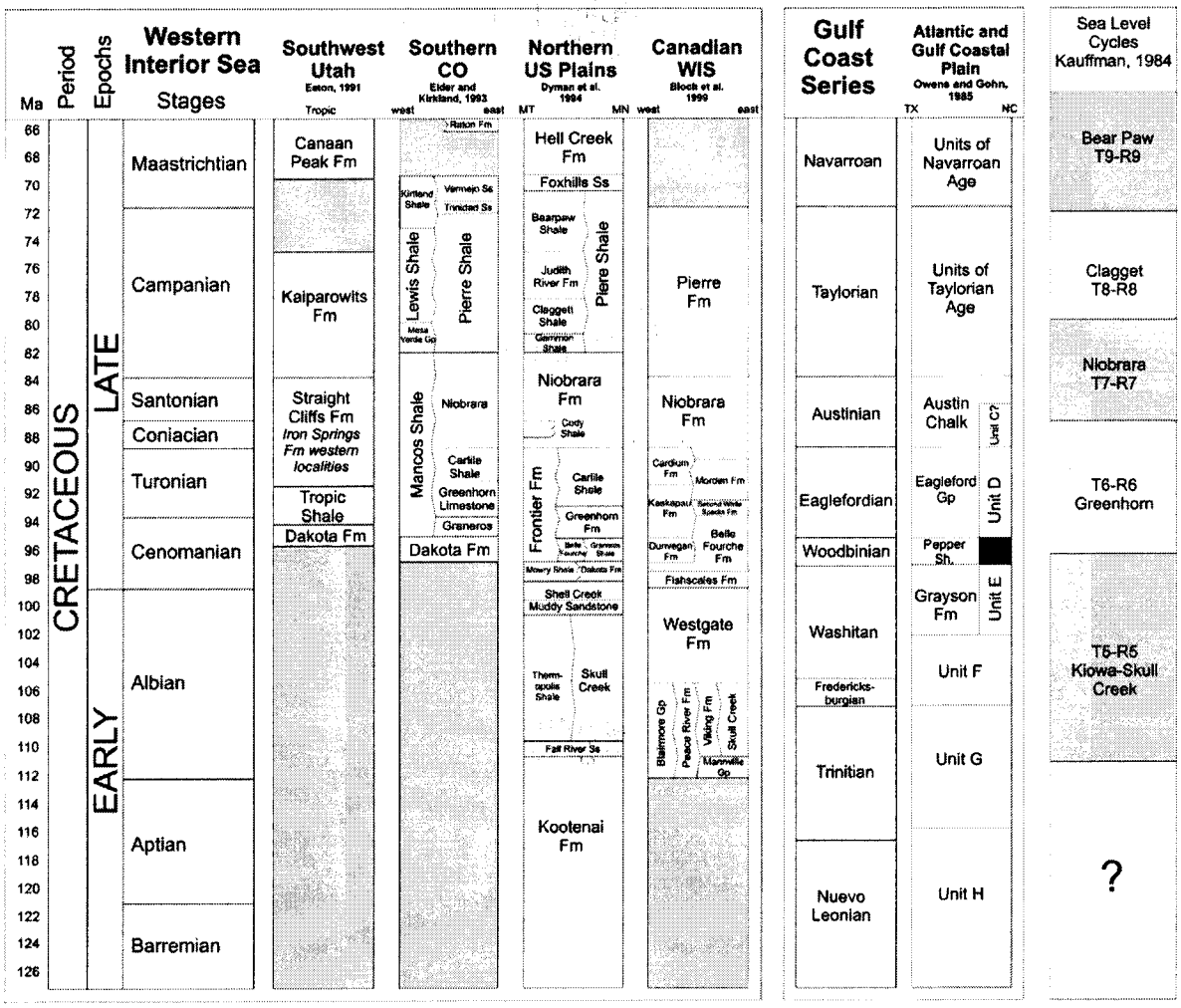


Fig. 2. Summary of North American lithostratigraphic units.
Fig. 2. Synthèse des unités lithostratigraphiques d'Amérique du Nord.

and calibrated bentonite beds (Obradovich, 1993) are recognized across the western margin of the seaway (Zelt, 1985; Elder, 1988, 1991; Kirkland, 1991, 1996; Elder et al., 1994; Leithold, 1994; Leithold and Dean, 1998; West et al., 1998). Observation of these beds in the Tropic Shale at Big Water (locality 15) provides tight temporal control (10^5 years), which facilitated correlation with the westernmost coastal plain adjacent to the Sevier thrust belt (Fig. 3) (Tibert et al., 2003a).

3. Systematic descriptions (N.E.T. and J.-P.C)

Holotypes and paratypes of newly described species are deposited in the National Museum of Natural History in Washington DC (USNM).

Class OSTRACODA Latreille, 1806
Subclass PODOCOPA Sars, 1866
Order PLATYCOPIDA Sars, 1866
Suborder PLATYCOPINA Sars, 1866
Superfamily CYTHERELLOIDEA Sars, 1866
Family CYTHERELLOIDAE Sars, 1866
Genus ***Cytherella*** Jones, 1894

Cytherella sp. A
Plate 1, Fig. 1
Material: Tens of specimens.
Dimensions: L = 0.534–0.632 mm; h = 0.280–365 mm.
Remarks: A smooth species characterized by a median highest height, a shallow median vertical sulcus and an oblique truncated posterior.
Age and distribution: Upper Cenomanian–Middle Turonian, Tropic Shale, Henrieville, Table Bench, Big Water, Utah (localities 1, 9, 15).

Cytherella sp. B
Plate 1, Figs. 2a, b
Material: Tens of specimens.
Dimensions: L = 0.570–0.610 mm; h = 0.330–0.350 mm.
Remarks: Differs from *Cytherella* sp. A with respect to its valve punctation and ovate outline. Similar forms have been

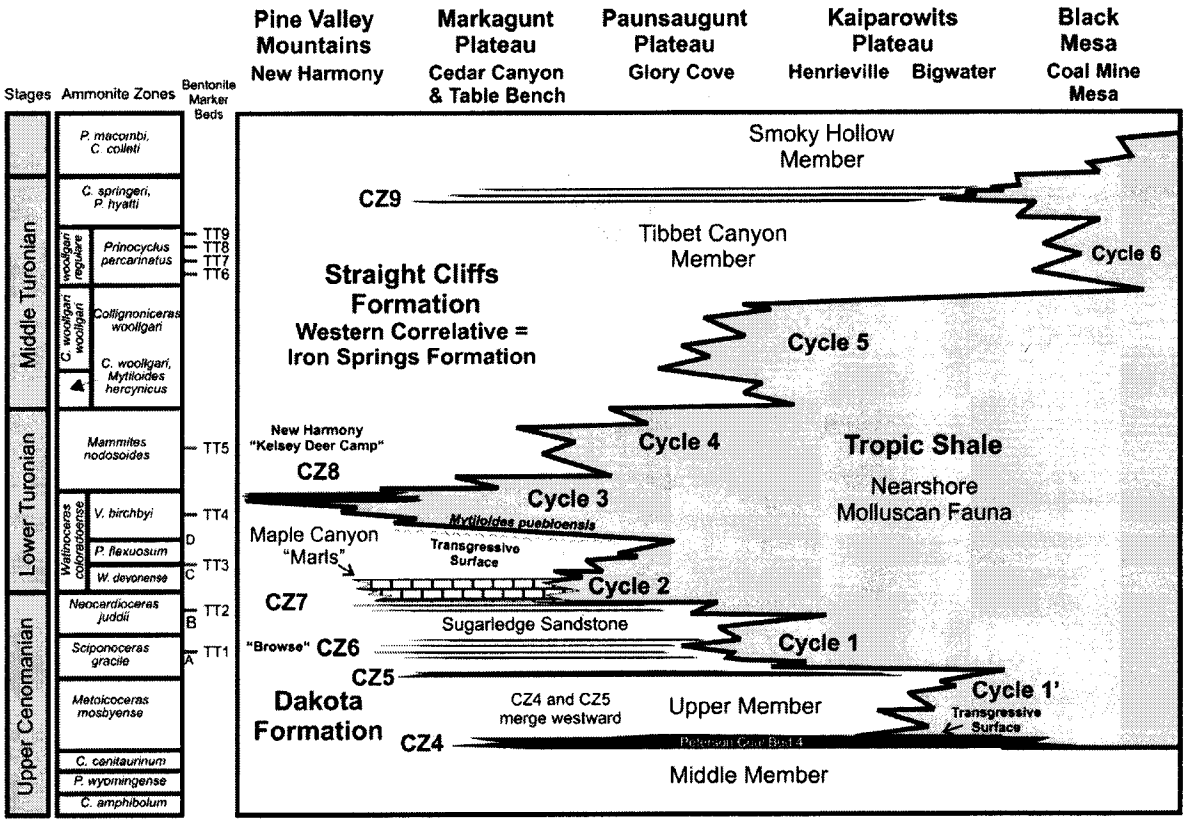


Fig. 3. Regional stratigraphy of the western Colorado Plateau area (modified from Tibert et al., 2003a). Note that this illustration represents a generalized transect from the Pine Valley Mountains to Kaiparowits Plateau to Balck Mesa Arizona (see Fig. 1). The coal zones represent the correlative units to the marine Tropic Shale (see Tibert et al., 2003a). The Iron Springs Formation is regarded as the nonmarine equivalent to the Straight Cliffs Formation exclusive to the localities in the Pine Valley Mountains. Bentonites from Leithold (1994). Ammonite-zones after Kauffman et al. (1993).

Fig. 3. Stratigraphie régionale du Plateau du Colorado occidental (modifié de Tibert et al., 2003a). Cette illustration représente un transect Pine Valley Mountains, Kaiparowits Plateau, Black Mesa Arizona (voir Fig. 1). Les zones à charbon représentent des unités corrélatives de la Formation marine des Tropic Shales (voir Tibert et al., 2003a). La Formation d'Iron Springs est considérée comme un équivalent non-marin de la Formation de Straight Cliffs des Pine Valley Mountains. Bentonites d'après Leithold (1994). Zones d'ammonites d'après Kauffman et al. (1993).

illustrated by Puckett (1996) as *Cytherella* sp. 1 and by Crane (1965) as *Morrowina* sp. from the Upper Cretaceous of the Gulf Coast.

Age and distribution: Upper Cenomanian–Middle Turonian, Tropic Shale, Big Water, Utah (locality 15).

Order PODOCOPIDA G.W. Müller, 1894
Suborder CYTHEROCOPINA Baird, 1850
Superfamily CYTHEROIDEA Baird, 1850
Family CYTHERIDAE Baird, 1850
Subfamily CYTHERINAE Baird, 1850
Tribe CYTHERINI Baird, 1850
Genus ***Cytheromorpha*** Hirschmann, 1909

Cytheromorpha perornata nov. sp. Tibert and Colin
Plate 1, Figs. 3a–g

2002. *Cytheromorpha* spp. - Tibert, pp. 313–314, Pl. 9, Fig. h, Pl. 16, Figs. e–g, Pl. 18, Fig. i, Pl. 19, Figs. a–d.

2003a. *Cytheromorpha* spp. - Tibert et al., p. 294, Figs. 7, 10h, 11i.

2004. *Cytheromorpha* sp. - Tibert and Leckie, p. 131, Pl. 1, Fig. h.

Derivatio nominis: Latin for heavily ornate.

Holotype: Female carapace, USNM 528530 (Pl. 1, Fig. 3f).

Paratypes: USNM 528525–528529, 528531 (Pl. 1, Figs. 3a–e, g).

Type locality: Turonian, Iron Springs Formation, New Harmony, Utah (locality 12).

Material: Hundreds of specimens.

Diagnosis: Species of *Cytheromorpha* characterized by thickened reticulation in the central region of the carapace giving an appearance of a false lateral ridge and very pronounced sexual dimorphism.

Description: Dorsal margin straight and ventral margin sloping upward to the posterior extremity (females). Pronounced sexual dimorphisms where males are elongate and quadrate, with dorsal and ventral margins subparallel (Pl. 1, Fig. 3d). Coarsely reticulate carapaces that are especially prominent in the central regions. Weakly developed ocular tubercle. Hinge lophodont.

Dimensions: Holotype L = 0.265 mm; h = 0.145 mm. Paratypes, females L = 0.195–0.270 mm; h = 0.100–0.150 mm; males L = 0.325 mm; h = 0.165 mm.

Remarks: *Cytheromorpha* is an estuarine genus that is relatively uncommon in the Cretaceous. The closest related

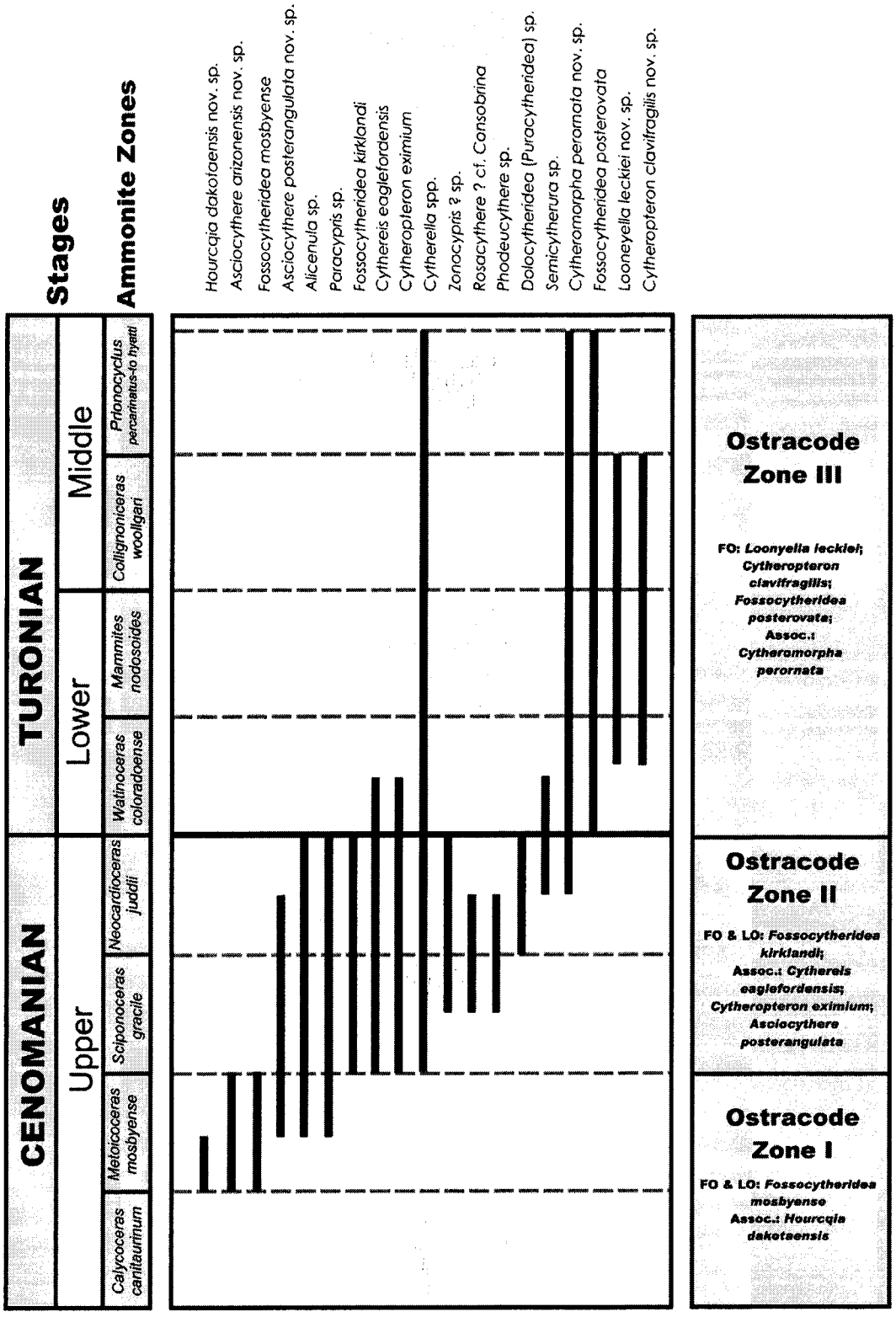


Fig. 4. Ostracode taxa plotted against stratigraphic height from Utah Locality 1, Henrieville Utah. Please refer to Gustason (1989), Ulicny (1999), and Tibert et al. (2003b) for further stratigraphic and paleoenvironmental information.

Fig. 4. Répartition stratigraphique des espèces d'ostracodes dans la localité Utah 1, Henrieville. Pour plus d'informations concernant la stratigraphie et les paléoenvironnements, voir Gustason (1989), Ulicny (1999) et Tibert et al. (2003b).

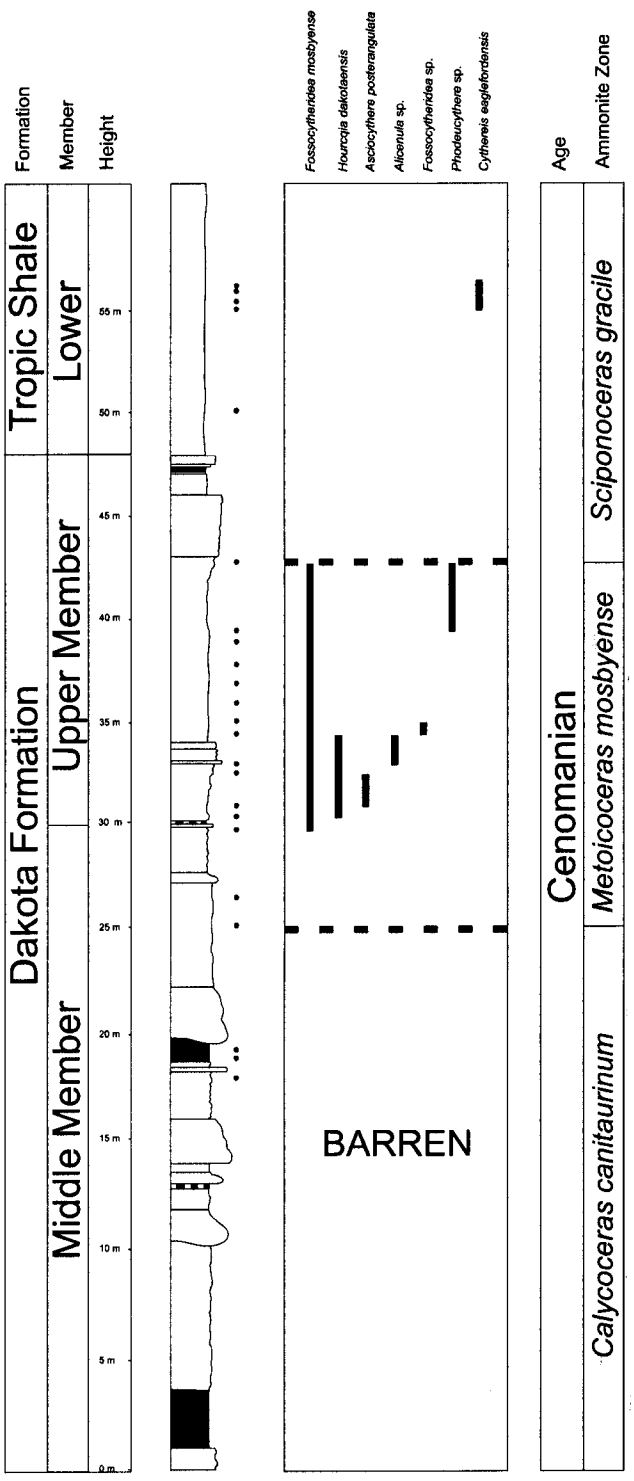


Fig. 5. Ostracode taxa plotted against stratigraphic height from Utah Locality 15 Bigwater Utah. Please refer to Leithold (1994) and Tibert et al. (2003b) for further stratigraphic and paleoenvironmental information.

Fig. 5. Répartition stratigraphique des espèces d'ostracodes dans la localité Utah 15, Bigwater, Utah. Pour plus d'informations concernant la stratigraphie et les paléoenvironnements, voir Leithold (1989) et Tibert et al. (2003b).

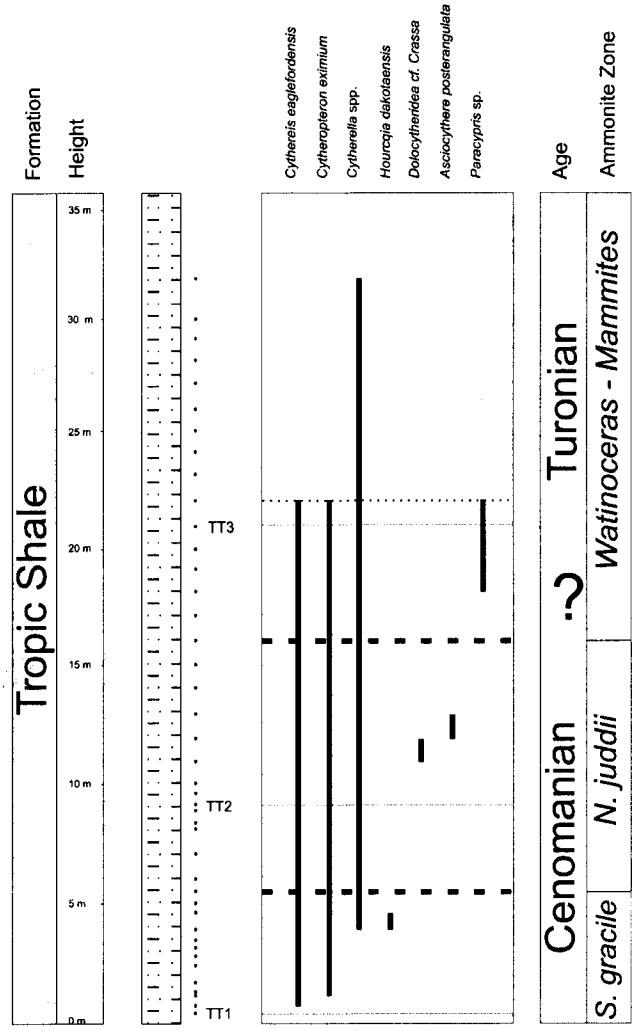


Fig. 6. Ostracode taxa plotted against stratigraphic height from Utah Locality 7 Maple Canyon, Utah. Please refer to Gustason (1989), Eaton et al. (2001), and Tibert et al. (2003b) for further stratigraphic and paleoenvironmental information.

Fig. 6. Répartition stratigraphique des espèces d'ostracodes dans la localité Utah 7, Maple Canyon, Utah. Pour plus d'informations concernant la stratigraphie et les paléoenvironnements, voir Gustason (1989), Eaton et al. (2001) et Tibert et al. (2003b).

species is *Cytheromorpha ornatissima* described from the "Post-Campanian" of the Paris Basin (Margerie, 1968) and the Maastrichtian of SW France (Blanc and Colin, 1975). This species also bears strong morphological affinities with *Polylophus asper* Crane, 1965, from the Maastrichtian of the Gulf Coast (Crane, 1965; Puckett, 1996).

Age and distribution: Upper Cenomanian, Dakota Formation, Canyon (Utah locality 7); Lower and Middle Turonian, Straight Cliffs and Iron Springs Formations, Cedar Canyon, Utah (localities 8c–d), New Harmony, Utah (locality 12).

Subfamily PROGONOCYTHERINAE Sylvester-Bradley, 1948

Genus ***Looneyella*** Peck, 1951

Looneyella leckiei nov. sp. Tibert and Colin

Plate 1, Figs. 4a–c

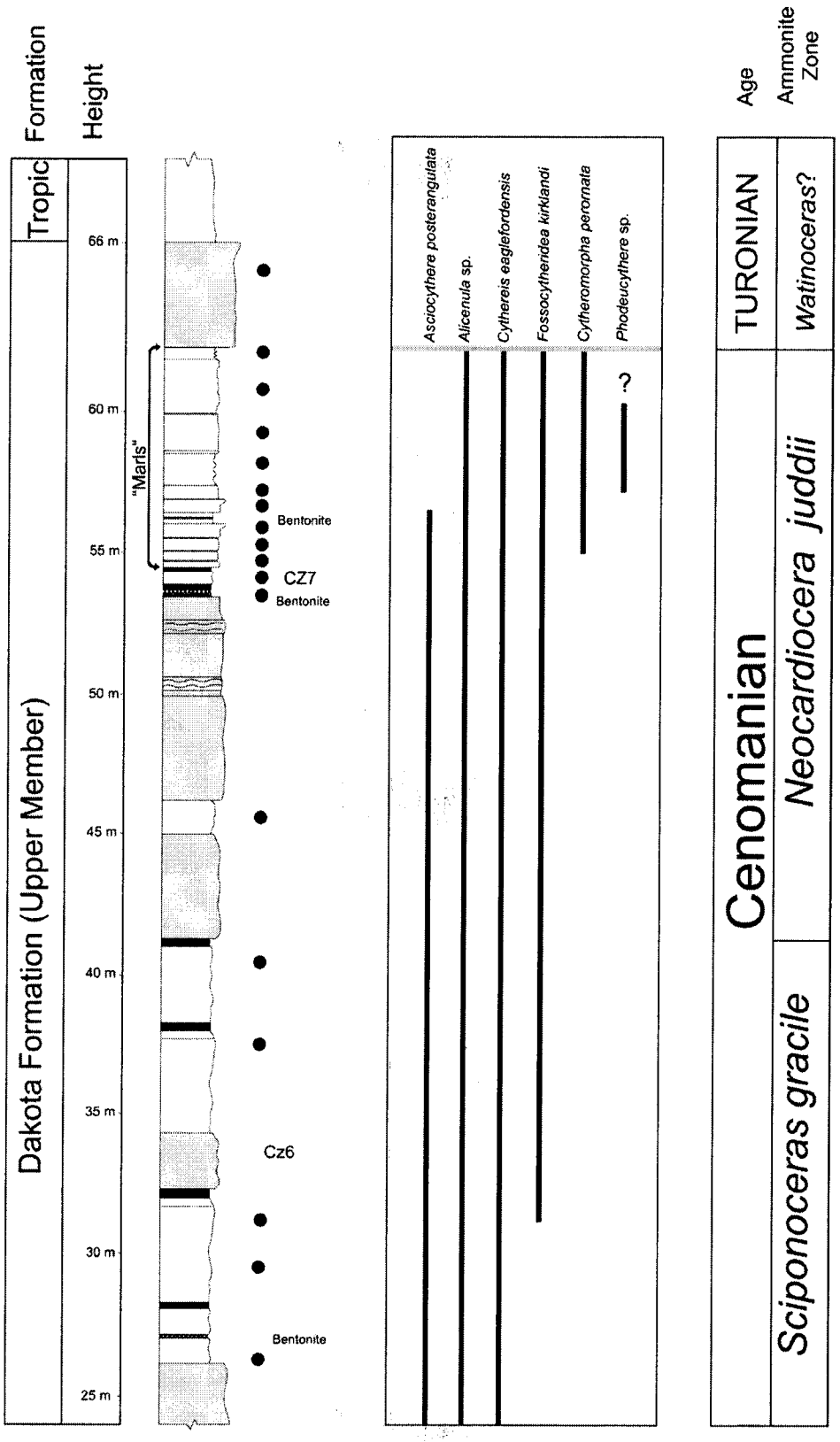


Fig. 7. Ostracode taxa plotted against stratigraphic height from Utah Locality 8a–b Cedar Canyon, Utah. Please refer to Gustason (1989), Eaton et al. (2001), and Tibert et al. (2003b) for further stratigraphic and paleoenvironmental information.

Fig. 7. Répartition stratigraphique des espèces d'ostracodes dans la localité Utah 8–a–b, Cedar Canyon, Utah. Pour plus d'informations concernant la stratigraphie et les paléoenvironnements voir Gustason (1989), Eaton et al. (2001) et Tibert et al. (2003b).

2002. *Looneyella* n. sp. 1. - Tibert, pp. 314–316, Pl. 18, Figs. f, g.

2002. *Looneyella* n. sp. 2. - Tibert, pp. 316, Pl. 18, Fig. h.

2003a. *Looneyella* n. sp. 1. - Tibert et al., p. 294, Figs. 11f, g.

2003a. *Looneyella* n. sp. 2. - Tibert et al., p. 294, Fig. 11h.

Derivatio nominis: Named after R.M. Leckie, paleontologist.

Holotype: Carapace, USNM 528532 (Pl. 1, Fig. 4a).

Paratypes: USNM 528533, 528534 (Pl. 1, Figs. 4b, c).

Type locality: Lower Turonian, Straight Cliffs Formation, Cedar Canyon, Utah (locality 8d).

Material: Dozens of specimens.

Diagnosis: Species of *Looneyella* characterized by an elongated triangular carapace with two nodes at the dorso-median and dorso-anterior positions respectively.

Description: Dorsal margin straight with a ventral slope that is most prominent in the posterior position. Two nodes occupy the dorso-median and dorso-anterior positions. A swollen ridge that contains at least four striae marks the ventral margin. The posterior extremity is acute, compressed, and smooth. Hingement is modified merodont (Pl. 1, Fig. 4c). Inner margin is widest at the ventro-posterior position. Heteromorphs lack nodes and the carapaces are generally inornate (Pl. 1, Fig. 4b).

Dimensions: Holotype L = 0.765 mm; h = 0.370 mm. Paratypes L = 0.655–0.725 mm; h = 0.320–0.330 mm.

Remarks: *Looneyella leckiei* sp. nov. differs from *Looneyella monticula* (Jones, 1893) from the Albian Bear River Formation of Wyoming (Peck, 1951; Swain, 1999) because it is slightly smaller and more elongated. Furthermore, the primary node is in the dorso-median position whereas Peck's illustrated material shows the primary node is the postero-dorsal position.

Age and distribution: Lower and Middle Turonian, Straight Cliffs Formation, Henrieville, Glory Cove, Cedar Canyon and Cedar Mountain, Utah (localities 8c–e).

Family LIMNOCYTHERIDAE Klie, 1938

Subfamily TIMIRIASEVIINAE Mandelstam, 1947, emend. Colin and Danielopol, 1978

Genus ***Rosacythere*** Colin, 1980, emend. Colin and Carbonel, 1996

Rosacythere? cf. *consobrina* (Jones, 1893)

Pl. 1, Figs. 5a, b

1893. *Metacypris consobrina* nov. sp. - Jones, p. 388, Pl. 15, Figs. 1a–c.

1895. *Metacypris consobrina* Jones - White p. 62, Pl. 11, Figs. 1a–c.

1958. *Metacypris consobrina* Jones - Howe and Laurencich, p. 396.

1980. *"Metacypris" consobrina* Jones - Colin and Danielopol, Pl. 14, Figs. 1–4.

1999. *"Metacypris" consobrina* Jones - Swain, p. 210, Pl. 27, Figs. 34, 35.

2002. *Rosacythere* sp. indet. - Tibert, pp. 312–313, Pl. 13, Figs. d, f.

Material: Approximately a dozen poorly preserved specimens.

Dimensions: L = 0.390–0.450 mm; h = 0.270–0.385 mm.

Remarks: Our species differs from Jones' type as it lacks a vertical constriction in the median position (see illustration in Colin and Danielopol, 1980).

Age and distribution: Upper Cenomanian, Dakota Formation, Cedar Canyon, Utah (localities 8a–b). Originally described from the Albian, Lower Bear River Formation or Gannett Group, Cokeville, Wyoming (Jones, 1893).

Family EUCYTHERIDAE Puri, 1954

Genus ***Phodeucythere*** Gründel, 1978

Phodeucythere sp.

Plate 2 Figs. 1a, b

Material: Few poorly preserved specimens.

Dimensions: L = 0.375–0.415 mm; h = 0.220–0.250 mm.

Remarks: *Eucythere lowei* Howe, 1936, sensu Herrig, 1966, is the closest related species reported from the Maastrichtian of northern Germany. The German species have a steeper and straighter dorsal margin than our material.

Age and distribution: Upper Cenomanian, Dakota Formation, Cedar Canyon, Utah (locality 8b).

Family CYTHERIDEIDAE Sars, 1925

Subfamily CYTHERIDEINAE Sars, 1925

Tribe CYTHERIDEIDINI Sars, 1925

Genus ***Asciocythere*** Swain, 1952, emend. Pokorny, 1984 (=*Stravia*, Neale, 1963)

Asciocythere arizonensis nov. sp. Tibert and Colin

Plate 3, Figs. 2a–c.

2002. *Clithrocytheridea graysonensis* (Alexander) - Tibert, pp. 293–294, Pl. 9, Figs. a, d.

2003a. *Clithrocytheridea*? *graysonensis* (Alexander) - Tibert et al., p. 294, Figs. 10a, d.

Derivatio nominis: After the type locality in northeastern Arizona.

Holotype: Carapace, USNM 528338 (Pl. 3, Fig. 2a).

Paratypes: USNM 528339, 528340 (Pl. 3, Figs. 2b, c).

Type-locality: Hopi Reservation, Black Mesa, Arizona (locality 16), Dakota Formation, Upper Cenomanian.

Material: Approximately 60 specimens.

Diagnosis: A species of *Asciocythere* characterized by a compressed anterior and posterior margin.

Description: The carapace is subtriangular with a well rounded anterior margin. The maximum height is anterior to mid length. The left valve overlaps the right valve along the entire margin. The anterior and posterior margins are strongly compressed and smooth whereas the rest of the carapace is coarsely punctate. The hinge is antimerodont with the median element clearly crenulated and a heart-shaped anterior element.

Dimensions: Holotype L = 0.595 mm; h = 0.365 mm. Paratype L = 0.585 mm; h = 0.345 mm.

Remarks: This species resembles species of *Antibythocypris* from the Maastrichtian Atlantic coast (Brouwers and Hazel,

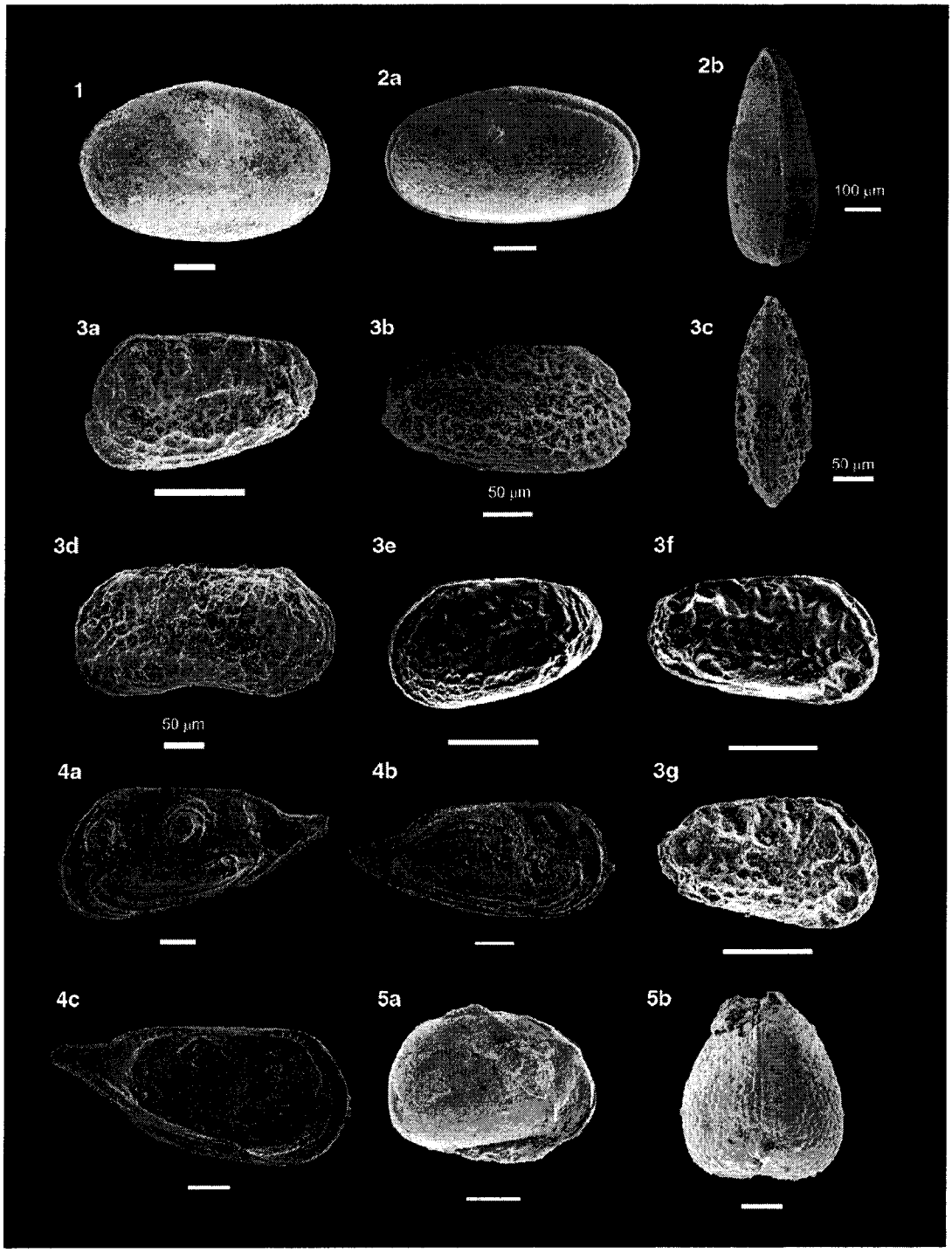


Plate 1. Scale bar = 100 µ; 3b–d = 50 µ. C = carapace, LV = left valve, RV = right valve. **Figs. 1, 2a, b**. *Cytherella* spp., Tropic Shale. 1. RV, smooth morphotype. **2a**. C, left view, punctate morphotype. **2b**. C, dorsal view. **Fig. 3a–g.** *Cytheromorpha perornata* nov. sp. **a**. C, female, left view, Dakota Fm. **b**. C, female, right view, Dakota Fm. **c**. C, female, dorsal view, Dakota Fm. **d**. C, male, left view, Straight Cliffs Fm. **e**. C, female, left view, Straight Cliffs Fm. **f**. C, female, holotype (USNM 528530), right view, Straight Cliffs Fm. **g**. C, female, right view, Straight Cliffs Fm. **Fig. 4a–c**. *Looneyella leckiei* nov. sp., Straight Cliffs Fm. **a**. C, holotype, left view. **b**. C, non-noded morphotype, right view. **c**. LV, internal view. **Fig. 5a, b**. *Rosacythere*? cf. *consobrina* (Jones, 1893), Dakota Fm. **a**. Internal mould, right view. **b**. C dorsal view.

Planche 1. Échelle = 100 µ; 3b–d = 50 µ. C = carapace, VD = valve droite, VG = valve gauche. **Figs. 1, 2a, b**. *Cytherella* spp., Tropic Shale. **1**. VD, morphotype lisse. **2a**. C, vue gauche, morphotype ponctué. **2b**. C, vue dorsale. **Fig. 3a–g**. *Cytheromorpha perornata* nov. sp. **a**. C, femelle, vue gauche, Dakota Fm. **b**. C, femelle, vue droite, Dakota Fm. **c**. C, femelle, vue dorsale, Dakota Fm. **d**. C, mâle, vue gauche, Straight Cliffs Fm. **e**. C, femelle, vue gauche, Straight Cliffs Fm. **f**. C, femelle, holotype (USNM 528530), vue droite, Straight Cliffs Fm. **g**. C, femelle, vue droite, Straight Cliffs Fm. **Fig. 4a–c**. *Looneyella leckiei* nov. sp., Straight Cliffs Fm. **a**. C, holotype, vue gauche. **b**. C, morphotype non-nodé, vue droite. **c**. VG, vue interne. **Fig. 5a, b**. *Rosacythere*? cf. *consobrina* (Jones, 1893), Dakota Fm. **a**. Moule interne, vue droite. **b**. C, vue dorsale.

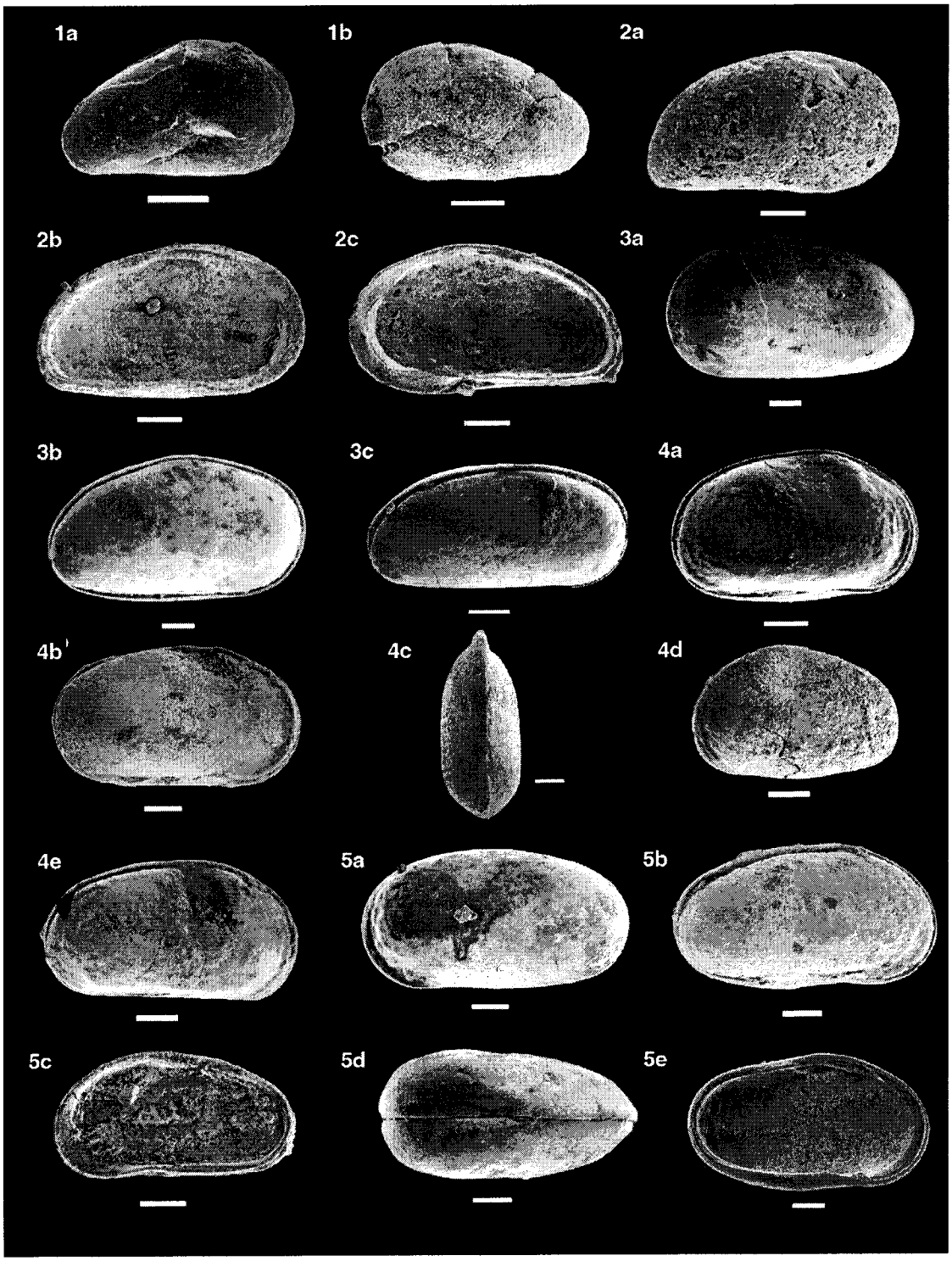


Plate 2. Scale bar = 100 µ, C = carapace, LV = left valve, RV = right valve. **Fig. 1a, b.** *Phodeucythere* sp., Dakota Fm. **a.** C, right view. **b.** C, left view. **Fig. 2a–c.** *Dolocytheridea (Puracytheridea)* sp., Tropic Shale. **a.** RV. **b.** LV, internal view. **c.** RV, internal view. **Fig. 3a–c.** *Fossocytheridea mosbyensis* Tibert et al., 2002. Dakota Fm., Cenomanian. **a.** C, left view. **b.** C, right view. **c.** C, right view. **Fig. 4a–e.** *Fossocytheridea kirklandi* Tibert et al., 2002. Dakota Fm. **a.** C, dorsal view. **b.** C, right view. **c.** C, dorsal view. **d.** C, left view. **e.** C, right view. **Fig. 5a–e.** *Fossocytheridea posterovata* (Lankford, 1953), Straight Cliffs Fm. **a.** C, left view. **b.** C, right view. **c.** RV, internal view. **d.** C, dorsal view. **e.** LV, internal view.

Planche 2. Échelle = 100 µ. C = carapace, VD = valve droite, VG = valve gauche. Fig. 1**a, b.** *Phodeucythere* sp., Dakota Fm. **a.** C, vue droite. **b.** C, vue gauche. **Fig. 2a–c.** *Dolocytheridea (Puracytheridea)* sp., Tropic Shale. **a.** RV. **b.** LV, vue interne. **c.** VD, vue interne. **Fig. 3a–c.** *Fossocytheridea mosbyense* Tibert et al., 2002, Dakota Fm. **a.** C, vue gauche. **b.** C, vue droite. **c.** C, vue droite. **Fig. 4a–e.** *Fossocytheridea kirklandi* Tibert et al., 2002., Dakota Fm. **a.** C, vue droite. **b.** C, vue droite. **c.** C, vue dorsale. **d.** C, vue gauche. **e.** C, vue droite. **Fig. 5a–e.** *Fossocytheridea posterovata* (Lankford, 1953), Straight Cliffs Fm. **a.** C, vue gauche. **b.** C, vue droite. **c.** VD, vue interne. **d.** C, vue dorsale. **e.** VG, vue interne.

1978) in both hingement and muscle scar patterns, but the illustrated latest Cretaceous material lack the angular carapace (distinct cardinal angles) and exhibit large normal pores. This species differs from *Asciocythere posterangulata* nov. sp. by its rounded posterior margin as seen on the right valve, punctate carapace, and compressed anterior and posterior margins. This species also resembles *Clithrocytheridea? holoreticulata* Swain, 1982, from the Washitan (Late Albian–Early Cenomanian) of Florida. The closest related species is *Asciocythere margeriei* Babinot, 1980, from the Lower Turonian of SE France which differs essentially by exhibiting much more compressed anterior and posterior margins and a rounded posterior extremity.

Age and distribution: Upper Cenomanian, Dakota Formation, Black Mesa, Arizona (locality 16).

Asciocythere posterangulata nov. sp. Tibert and Colin
Plate 3, Figs. 1a–d
2002. *Clithrocytheridea* cf. *circumdata* Donze - Tibert, pp. 294–296, Pl. 10, Figs. a–e.
2003a. *Clithrocytheridea*? sp. 2 - Tibert et al., Figs. 5, 7.
Derivatio nominis: Latin for angular posterior.
Holotype: Carapace, USNM 528535 (Pl. 3, Fig. 1a).
Paratypes: USNM 528536, 528537 (Pl. 3, Figs. 1b, c).
Type locality: Upper Cenomanian, Dakota Formation, Cedar Canyon, Utah (locality 8b).
Material: Approximately 50 specimens.
Diagnosis: A species of *Asciocythere* with a finely punctate carapace and a well-marked posterior cardinal angle.
Description: Carapace subtriangular where the left valve strongly overlaps the right. The maximum height is situated anterior of the median. The anterior margin is broadly rounded and this is in stark contrast to the posterior. More specifically, the posterior slope exhibits a terminal concavity. The hinge is antimerodont with a deeply crenulated anterior and posterior element, the medial hinge bar is moderately crenulated. The inner margin is widest at the anterior-ventral margin where it is marked with a vestibule. There are approximately 15, sinuous to straight, radial pore canals. Females are more robust with respect to width and height than the elongated males.
Dimensions: Holotype L = 0.640 mm; h = 0.390 mm. Paratype L = 0.620 mm; h = 0.370 mm.
Remarks: *Asciocythere posterangulata* resembles *Asciocythere circumdata* (Donze, 1964) from the Berriasian of SE France, *Clithrocytheridea? ventricola* Damotte and Grosdidier, 1963, from the Albian of the Paris Basin, and *Tlichrocytheridea heslertonensis* (Kaye, 1963) from the Albian of England with respect to lateral outline. These taxa apparently do not yield the crenulated median hinge elements and therefore belong to *Tlichrocytheridea* Gründel, 1978. *Asciocythere brevis brevicula* (Baynova, 1965), from the Albian of Bulgaria is similar in hingement (distinct cardinal angle), overlap, and in shape, but it is more triangular.
Age and distribution: Upper Cenomanian, Dakota Formation, Tropic, Cedar Canyon, Utah (localities 3 and 8a–b.).

Genus ***Dolocytheridea*** Triebel, 1938
Subgenus ***Puracytheridea*** Gründel, 1971

Dolocytheridea (*Puracytheridea*) sp.
Plate 2, Figs. 2a–c
2002. *Dolocytheridea* sp. indet. - Tibert, pp. 296–297, Pl. 11, Figs. c–e.
Material: Several poorly preserved specimens.
Dimensions: L = 0.580–0.620 mm; h = 0.330–0.350 mm.
Remarks: Our material is similar in lateral outline, but smaller than *Dolocytheridea (Puracytheridea) crassa* Damotte, 1971, from the Cenomanian of southern France. *Paracyprideis graysonensis* (Alexander, 1929) from the Cenomanian Grayson Formation of Texas (see also Swain, 1952) is slightly larger and has a more pointed posterior extremity than our illustrated material. Females attributed to *Dolocytheridea iberica* Andreu, 1981 (Cenomanian, Portugal) and to *Dolocytheridea (Puracytheridea) lethiersi* Cabral, 1995 (Middle Albian, Portugal) are larger (0.9–1.25 mm) than our Utah specimens. Potentially related species from the Cenomanian–Santonian deposits in Germany include *Paracyprideis (Mutacyprideis) attenuata* (Reuss, 1846) and *Paracyprideis (Mutacyprideis) morla* (described by Gründel, 1974).
Age and distribution: Upper Cenomanian, Tropic Shale, Big Water, Utah (locality 15).

Tribe CYPRIDEIDINI Kollmann, 1960
Genus ***Fossocytheridea*** Swain and Brown, 1964

Fossocytheridea mosbyense Tibert, Colin, Leckie and Babinot, 2003a
Plate 2, Figs. 3a–c
2002. *Fossocytheridea mosbyense* nov. sp. (nomen nudum) - Tibert, pp. 297–300, Pl. 14, Figs. a, f.
2003a. *Fossocytheridea mosbyense* nov. sp. - Tibert et al., pp. 212–215, Pl. 1, Figs. h–l.
Material: Hundreds of specimens.
Dimensions: L = 0.760–0.910 mm; h = 0.420–0.500 mm.
Remarks: See Tibert et al. (2003b) for detailed description.
Age and distribution: Upper Cenomanian, Dakota Formation, Henrieville, Tropic, Utah (localities 1 and 3).

Fossocytheridea kirklandi Tibert, Colin, Leckie and Babinot, 2003a
Plate 2, Figs. 4a–e
2003b. *Fossocytheridea* nov. sp. - Tibert et al., p. 294, Figs. 10e–f.
2003a. *Fossocytheridea kirklandi* nov. sp. - Tibert et al., pp. 215–216, Pl. 1, Figs. m–s.
Material: Hundreds of specimens.
Dimensions: L = 0.580–0.740 mm; h = 0.360–0.450 mm.
Remarks: See Tibert et al. (2003b) for detailed description.
Age and distribution: Upper Cenomanian, Dakota Formation, Cedar Canyon; Table Bench; Browse, Utah (localities 8a–b, 9, 13).

Fossocytheridea posterovata (Lankford, 1953)

Plate 2, Figs. 5a–e

1953. *Cytheridea posterovata* nov. sp. - Lankford in Peterson et al Pl. 15, Figs. 3a–c.

1953. *Cytheridea trisulcata* nov. sp. - Lankford in Peterson et al., Pl. 15, Figs. 5a–c.

1953. *Cytheridea posterovata* var. *alta* - Lankford in Peterson et al., Pl. 15, Figs. 4a–c.

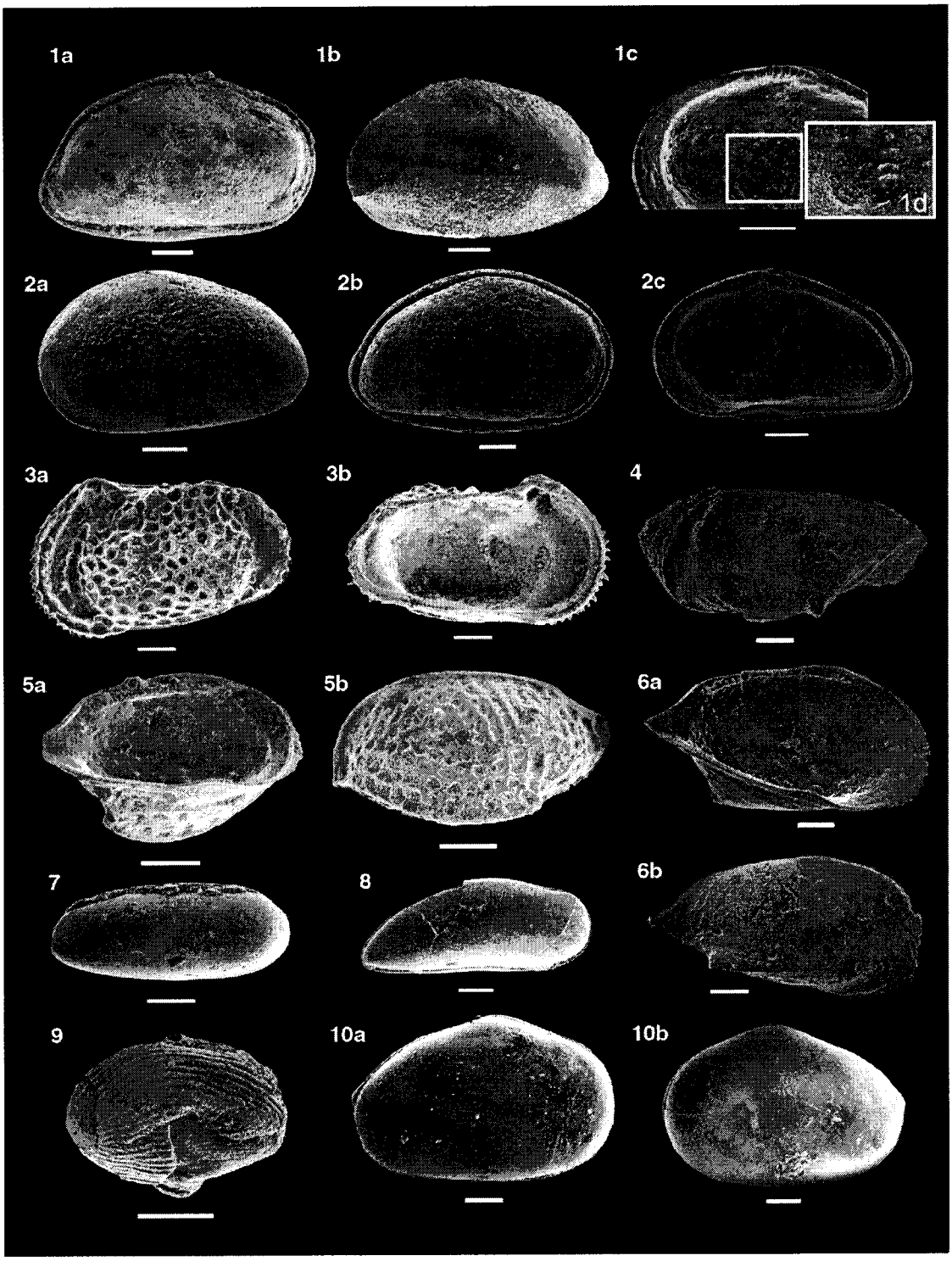
2002. *Fossocytheridea posterovata* (Lankford) - Tibert, pp. 303–307, Pl. 15, Fig. f, Pl. 17, Figs. a–g., Pl. 18, Figs. a–c.

2003b. *Fossocytheridea posterovata* (Lankford) - Tibert al., p. 294, Figs. 11a–c.

2003. *Fossocytheridea posterovata* (Lankford) - Tibert et al., pp. 216–220, Pl. 2, Figs. a–e, g.

Material: Hundreds of specimens.

Dimensions: L = 0.740–0.850 mm; h = 0.360–0.500 mm.



Remarks: See Tibert et al. (2003b) for detailed description.

Age and distribution: Lower to Middle Turonian, Straight Cliffs and Iron Springs Formation, Henrieville, Glory Cove, Cedar Canyon, Cedar Mountain, New Harmony, Utah (localities 1, 4, 8c–e, 12). Species originally described from the Middle Turonian of north-eastern Utah (Coalville, Summit County).

Family TRACHYLEBERIDIDAE Sylvester-Bradley, 1948

Subfamily TRACHYLEBERIDINAE Sylvester-Bradley, 1948

Tribe VEENIINI Puri, 1973

Genus ***Cythereis*** Jones, 1849

Cythereis eaglefordensis Alexander, 1929

Plate 3, Figs. 3a, b

1929. *Cythereis eaglefordensis* nov. sp. - Alexander, p. 98, Figs. 9, 12.

1958. *Cythereis eaglefordensis* Alexander - Howe and Laurencich, p. 197.

1964. *Cythereis eaglefordensis* Alexander - Swain and Brown, Pl. 3, Figs. 6a–h.

1969. *Cythereis eaglefordensis* Alexander - Hazel, p. 157, Figs. 2a–1.

2002. *Cythereis eaglefordensis* Alexander - Tibert, pp. 317–319, Pl. 10, Figs. g, h.

2003a. *Cythereis eaglefordensis* Alexander - Tibert et al., Figs. 5, 7.

Material: Dozens of specimens.

Dimensions: L = 0.699–0.717 mm; h = 0.369–0.430 mm; w = 0.332–0.345 mm.

Remarks: This species is apparently the only trachyleberid ostracode in southwest Utah. Andreu (1991) illustrated closely related specimens from the Upper Cenomanian and Early Turonian of Morocco that were identified as *Oertliella? tarfayaensis* Reyment, 1978. *Cythereis eaglefordensis* differs as it exhibits rounded anterior and posterior regions, a less prominent lobation, and a pronounced coarse reticulation.

Age and distribution: *Cythereis eaglefordensis* is most abundant in the *Sciponoceras gracile* and *Neocardioceras juddii* Ammonite-zones in the Tropic Shale (locality 15). The last occurrence is immediately above the TT3 Bentonite that marks the approximate position of the Cenomanian–Turonian boundary (Leithold, 1994; Tibert et al., 2003a). Specimens were recovered from localities 1, 2, 7, 8a–b, and 10 and all of those beds occur in strata assigned to the *Sciponoceras gracile-Neocardioceras juddii* Ammonite-zones. *Cythereis eaglefordensis* was originally described from the late Cenomanian Eagleford formation of Texas (Alexander, 1929). This taxon was reported from Turonian strata in the Atlantic basin (Neale, 1977; Swain, 1978).

Family CYTHERURIDAE G.W. Müller, 1894

Subfamily CYTHERURINAE G.W. Müller, 1894

Genus ***Semicytherura*** Wagner, 1957

Semicytherura sp.

Plate 3, Fig. 4

Material: 12 poorly preserved specimens.

Dimensions: L = 0.701 mm; h = 0.338 mm.

Age and distribution: Upper Cenomanian, Dakota Formation, Cedar Canyon (Utah locality 7).

Subfamily CYTHEROPTERINAE Hanai, 1957

Genus ***Cytheropteron*** Sars, 1866

Cytheropteron eximium Alexander, 1933

Plate 3, Figs. 5a, b

1933. *Cytheropteron eximium* sp. nov. - Alexander, p. 193, Pl. 27, Figs. 4a, b.

1958. *Cytheropteron eximium* Alexander - Howe and Laurencich, p. 299.

1991. *Cytheropteron* sp. aff. *eximium* Alexander - Swain and Xie, Pl. 2, Figs. 24, 25.

2002. *Cytheropteron eximium* Alexander - Tibert, pp. 308–309, Pl. 12, Figs. e, f.

Material: Tens of well-preserved specimens.

Dimensions: L = 0.380 mm; h = 0.260 mm.

Age and distribution: Cenomanian–Turonian, Tropic and Mancos Shale, Utah localities 1 and 15. *Cytheropteron eximium* was originally described from the Cenomanian Eagleford Shale of Texas in association with the ammonite *Metoicoceras whitei* which was once considered Turonian (Alexander, 1933). This

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Plate 3. Scale bar = 100 μ, C = carapace, LV = left valve, RV = right valve. **Fig. 1a–d**. *Asciocythere posterangulata* nov. sp., Dakota Fm., Cedar Canyon. **a**. C, holotype (USNM 528535), right view. **b**. C, left view. **c**. RV, internal view, detail. **d**. RV, muscle scars. **Fig. 2a–c**. *Asciocythere arizonensis* nov. sp., Black Mesa, Arizona, Dakota Fm. **a**. C, holotype (USNM 528338), left view. **b**. C, holotype, right view. **c**. RV, internal view. **Fig. 3a, b**. *Cythereis eaglefordensis* Alexander, 1929. **a**. C., left view. **b**. LV, internal view. **Fig. 4**. *Eucytherura* sp., Dakota Fm., LV. **Fig. 5a, b**. *Cytheropteron eximium* Alexander, 1933, Tropic Shale. **a**. LV, internal view. **b**. LV. **Fig. 6a, b**. *Cytheropteron clavifragilis* nov. sp., Straight Cliffs Fm. **a**. LV, internal view. **b**. RV, holotype. **Fig. 7**. *Alicenula* sp., Dakota Fm., C, left view. **Fig. 8**. *Paracypris* sp. Tropic Shale, C, right view. **Fig. 9**. *Zonocypris*? sp., Dakota Fm., Cedar Canyon, C, right view. **Fig. 10a, b**. *Hourcqia dakotaensis* nov. sp., Dakota Fm. **a**. C, holotype (528543), right view. **b**. C, left view.

Planche 3. Échelle = 100 μ, C = carapace, VD = valve droite, VG = valve gauche. **Fig. 1a–d**. *Asciocythere posterangulata* nov. sp., Cedar Canyon, Dakota Fm. **a**. C, holotype (USNM 528535), vue droite. **b**. C, vue gauche. **c**. VD, vue interne, détail. **d**. VD, empreintes musculaires. **Fig. 2a–c**. *Asciocythere arizonensis* nov. sp., Black Mesa, Arizona, Dakota Fm. **a**. C, holotype (USNM 528338), vue gauche. **b**. C, vue droite. **c**. VD, vue interne. **Fig. 3a, b**. *Cythereis eaglefordensis* Alexander, 1929. **a**. C, vue gauche. **b**, VG, vue interne. **Fig. 4**. *Eucytherura* sp., Dakota Fm., VG. **Fig. 5a, b**. *Cytheropteron eximium* Alexander, 1933, Tropic Shale. **a**. VG, vue interne. **b**. VG. **Fig. 6a, b**. *Cytheropteron clavifragilis* nov. sp., Straight Cliffs Fm. **a**. VG, vue interne. **b**. VD, holotype (USNM 528542). **Fig. 7**. *Alicenula* sp., Dakota Fm., C, vue gauche. **Fig. 8**. *Paracypris* sp., Tropic Shale, C, vue droite. **Fig. 9**. *Zonocypris*? sp., Dakota Fm., C, vue droite. **Fig. 10a, b**. *Hourcqia dakotaensis* nov. sp., Dakota Fm. **a**. C, holotype (USNM 528543), vue droite. **b**. C, vue gauche.

species is always associated with *Cythereis eaglefordensis* in the Tropic Shale (locality 15) and the Mancos Shale (Schmidt, 1990). Also reported from Albian–Cenomanian beds in the COST wells from the western North Atlantic (Swain and Xie, 1991).

Cytheropteron clavifragilis nov. sp. Tibert and Colin
Plate 3, Figs. 6a, b
2003a. *Cytheropteron* n. sp. 1. - Tibert et al., p. 294, Figs. 11d, e.
Derivatio nominis: Latin for fragile spike or rudder.
Holotype: USNM 528541 (Pl. 3, Fig. 6b).
Paratype: USNM 528542 (Pl. 3, Fig. 6a).
Type locality: Lower and Middle Turonian, Cedar Canyon, Utah localities 8c–d.
Material: Tens of well-preserved specimens.
Diagnosis: Small size; smooth, delicate carapace; denticles mark the antero-ventral region; striations (6–8) mark the under side of the alae.
Description: Carapaces are translucent in reflected light. The general shape is trapezoidal where the anterior is broadly rounded and the posterior is sharply acuminate with a terminal, long caudal process; dorsal margin is gently arched from an external aspect, but, it appears straight from the internal perspective. The inner margin is widest at the anterior. Entomodont hinge with coarsely crenulated elements.
Dimensions: Holotype L = 0.710 mm; h = 0.370 mm. Paratype L = 0.780 mm; h = 0.380 mm.
Remarks: This species is assigned to the genus *Cytheropteron* because of its distinct upturned caudal process, ventral alae, convex dorsal margin, and the entomodont hinge. It resembles *Cytheropterina* Mandelstam, 1956, but differs in the general shape and does not possess the diagnostic accommodation groove above the median element.
Age and distribution: Middle Turonian, Straight Cliffs Formation, Cedar Canyon, Utah (localities 8c–d).

Suborder CYPRIDOCOPINA Baird, 1845
Superfamily CYPRIDOIDEA Baird, 1845
Family CANDONIDAE Kaufmann, 1900
Subfamily PARACYPRIDINAE Sars, 1923
Genus ***Paracypris*** G.W. Müller, 1912

Paracypris sp.
Plate 3, Fig. 8
Material: Few poorly preserved specimens.
Dimensions: L = 0.650 mm; h = 0.270 mm.
Remarks: This species differs from other Cretaceous *Paracypris* from the United States (Alexander, 1929; Howe and Laurencich, 1958) essentially by its less acuminate posterior extremity.
Age and distribution: Upper Cenomanian, Dakota Fm., Henrieville, Cedar Canyon, Utah (localities 1, 8a).

Family CYPRIDIDAE Baird, 1845
Subfamily CYPRINOTINAE Bronstein, 1947

Genus ***Hourcqia*** Krömmelbein, 1965 (=*Pattersoncypris* Bate, 1972)

Hourcqia dakotaensis nov. sp. Tibert and Colin
Plate 3, Figs. 10a, b
2002. *Hourcqia* cf. *angulata* Krömmelbein and Weber - Ti-bert, pp. 286–288, Pl. 12, Figs. a, b.
Derivatio nominis: From the Dakota Formation.
Holotype: Carapace, USNM 528543 (Pl. 3, Fig. 10a).
Paratypes: USNM 528544 (Pl. 3, Fig. 10b).
Material: Dozens of specimens.
Type-locality: Henrieville, Utah (locality 1), Dakota Formation, Upper Cenomanian.
Diagnosis: Species of *Hourcqia* with a smooth carapace, obliquely truncated posterior margin and bearing a distinct projection of the left valve at the postero-dorsal angle.
Description: Medium-sized, smooth, thinly calcified carapace. The maximum height occurs just forward of the mid-length; a prominent hump marks this position. There is a distinct projection (overlap) of the left valve at the postero-dorsal angle, especially visible on right views. The posterior margin is obliquely truncated.
Dimensions: Holotype L = 0.685 mm; h = 0.435 mm. Paratype L = 0.715 mm; h = 0.475 mm.
Remarks: Species closely related to *Hourcqia angulata* Krömmelbein and Weber, 1971, from the Aptian pre-salt of Brazil and West Africa. It differs from other species of this genus (Krömmelbein and Weber, 1971) mostly by the presence of a distinct projection (overlap) of the left valve at the postero-dorsal angle. Do Carmo et al. (2005) regard *Hourcqia* as a junior synonym of *Harbinia* Tsao, 1959.
Age and distribution: Upper Cenomanian, Dakota Formation, Henrieville, Cedar Canyon, Utah (localities 1 and 8a–b).

Subfamily CYPRIDOPSINAE Bronstein, 1847
Genus ***Zonocypris*** G.W. Müller, 1898

Zonocypris? sp.
Plate 3, Fig. 9
Material: A dozen poorly preserved specimens.
Dimensions: L = 0.290 mm; h = 0.185 mm.
Remarks: This species, tentatively assigned to the genus *Zonocypris*, differs from other closest related Cretaceous species *Zonocypris* sp. from the Albian of the Araripe Basin (Brazil) in being more elongate (Colin and Dépêche, 1997).
Age and distribution: Upper Cenomanian, Dakota Fm., Cedar Canyon, Utah (localities 8a, b).

Suborder DARWINULOCOPINA Sohn, 1988
Superfamily DARWINULOIDEA Brady and Norman, 1889
Family DARWINULIDAE Brady and Norman, 1889
Genus ***Alicenula*** Rossetti and Martens, 1998

Alicenula sp.
Plate 3, Fig. 7
Material: Approximately 60 poorly preserved specimens.
Dimensions: L = 0.500 mm; h = 0.195 mm.

Table 1
List of sampled localities
Tableau 1
Liste des localités échantillonnées

Loc.	Town and geographic landmarks	Quad. info. USGS 7.5	Formations	Stages	Past research
1	Henrieville, UT-Entrance to Grand Staircase National Park	T37S, R2W Route 12	Dakota; Straight Cliffs	Cenomanian-Turonian	Gustason, 1989 Section 12
2	Paria River, UT-South Cottonwood Canyon	T47S, R2W North of Route 89	Dakota	Cenomanian	Gustason, 1989 Section 14; Elder et al., 1994 Section 9; Ulicny, 1999 Sections 9–10
3	Tropic, UT-Bulldog Bench	T37S, R3W Route 14	Dakota	Cenomanian	Gustason, 1989 Tropic/Cannonville Section; Ulicny, 1999 Section 2
4	Glory Cove, UT-North of Tropic	T36S, R3W Route 12	Straight Cliffs	Turonian	Eaton et al., 1997 MNA Locality 994
5	Alton, UT-West of Kanab Creek	T39S, R6W Route 89	Dakota	Cenomanian	Gustason, 1989 Kanab Creek Section
6	Orderville, UT-Concretion Pit	T41S, R7W	Tropic Shale	Cenomanian	Elder, 1991
7	Cedar Canyon UT-Maple Canyon	T36S, R10W -Route 14 Mile Marker 6	Dakota	Cenomanian	Gustason, 1989 Section 2; Elder et al., 1994 Section 1
8a	Cedar Canyon UT-McFarlane Mine (southwest slope)	T36S, R10W Marker 9	Dakota Tropic Shale	Cenomanian-Turonian	Averitt, 1962
8b	Cedar Canyon Northeast-Coal Creek (Old MacFarlane Mine northeast slope) Route 14 Mile Marker 8–9	T36S, R10W	Dakota	Cenomanian	Averitt, 1962
8c	Cedar Canyon, UT-Southern Utah State University Field Station	T36S, R10W Route 14 Mile Marker 16	Straight Cliffs	Turonian	Eaton et al., 1997 Locality 1258
8d	Cedar Canyon, UT-Crow Creek (Cori's Brackish Water Site)	T37S, R10W Route 14	Straight Cliffs	Turonian	Eaton et al., 1997 Localities 1222, 1223; Eaton et al., 1999 UMNH VP Locality 66
8e	Cedar Mountain, UT-Kolob Reservoir	T37S, R10W	Straight Cliffs	Turonian	Eaton et al., 1997
9	Table Bench, UT-North Fork of the Virgin River	T40S, R9W	Dakota Tropic Shale	Cenomanian-Turonian	Gustason Section 4–5 and Elder et al., 1994 Section 3
10	Fiddlers Canyon, UT-north of Cedar City	T35S, R10W	Dakota Tropic Shale	Cenomanian-Turonian	Eaton et al., 1999
11	Parowan, UT-west of Parowan center	T33S, R10W	Iron Springs	Cenomanian-Turonian	
12	New Harmony UT-Kelsey Deer Camp	T37S, R13W	Iron Springs	Turonian	Cook, 1957 Section 8; Eaton et al., 1997 MNA Locality 1232
13	Browse, UT-Pine Valley Mountains	T39S, R13W	Iron Springs	Cenomanian	Eaton et al., 1997 MNA Localities 1219, 1220, 1221
14	Mesa Verde National Park, CO	Southwest CO	Dakota	Cenomanian	Leckie et al., 1997
15	Big Water, UT	T40S, R1W	Tropic Shale	Cenomanian-Turonian	Leithold (1994); Leithold and Dean (1998)
16	Black Mesa, AZ-Hopi Reservation	Coal Mine Mesa	Dakota	Cenomanian	Fursich and Kirkland, 1986; Kirkland, 1996

Remarks: This species seems to be closely related to *Alicenula leguminella* (Forbes, 1855), a very common species from the Upper Jurassic–Lower Cretaceous of Europe, but it is much smaller (see Schudack, 1994).

Age and distribution: Cenomanian of Utah, localities 1 and 8a–b.

4. Biostratigraphy

We propose three new ostracode interval zones based on the first and last occurrences of the prominent taxa collected from the southwestern Colorado Plateau. The zones are calibrated to the absolute and relative stratigraphic schemes of Obradovich (1993) and Kauffman et al. (1993). A summary of the new interval zones and the composite stratigraphic ranges of the taxa are presented in Fig. 8. A List of all the ostracode species with respect to their spatial (localities and temporal (formations, stages and Ammonite-zones) occurrences can be found in Table 2.

4.1. Ostracode interval-zone I

Strata assigned to the *Metoicoceras mosbyense* Ammonite-zone record evidence for the initial flooding of the Greenhorn Cyclothem. The first and last occurrence of *Fossocytheridea mosbyense* defines this zone (Fig. 8). Although Henrieville Utah is the principal reference section, similar assemblages were

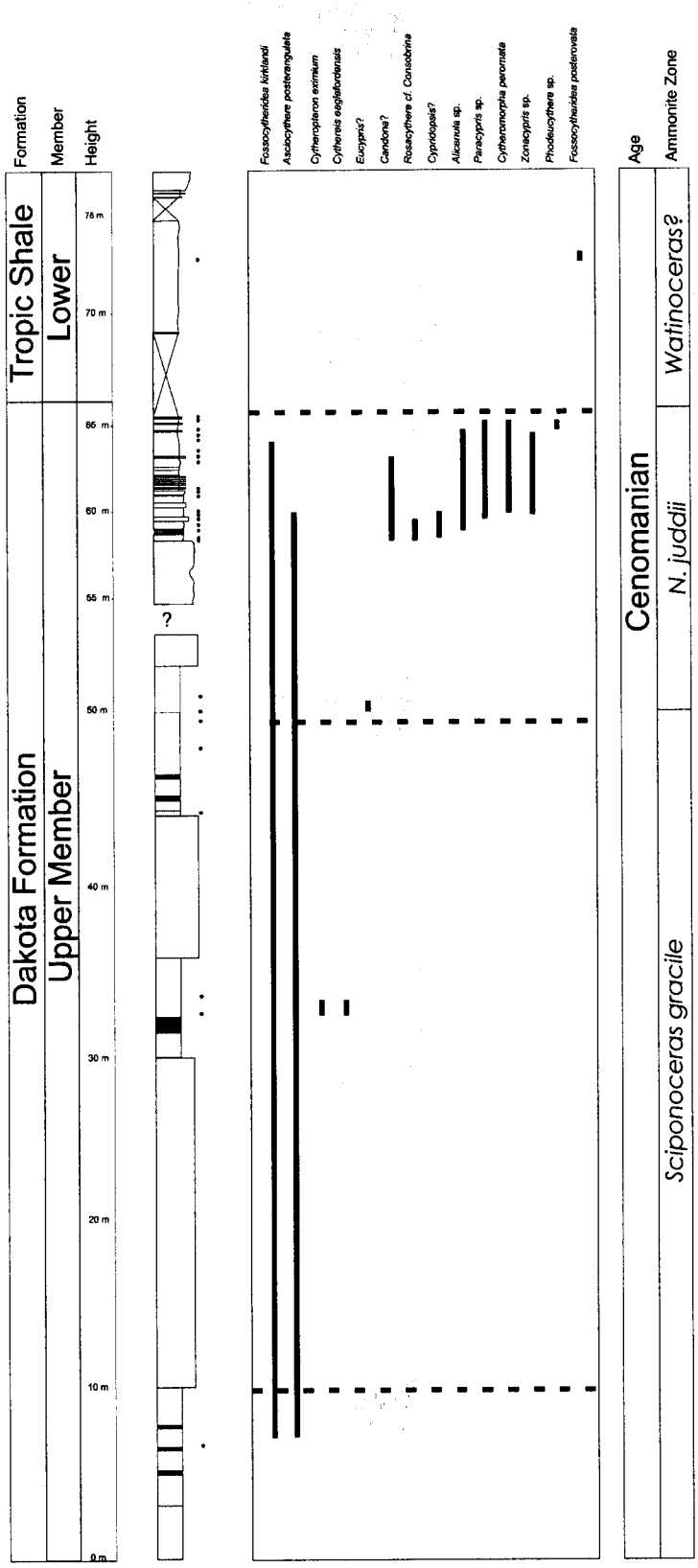

Fig. 8. Composite biostratigraphic ranges across the Cenomanian-Turonian boundary interval. Data are plotted relative to the Ammonite-zones of Kauffman et al. (1993).

Fig. 8. Charte biostratigraphique composite au niveau de la limite Cénomanien-Turonien. Les données sont calibrées sur les zones d'Ammonites de Kauffman et al. (1993).

Table 2
List of ostracode species with respect to their spatial and temporal occurrences to include localities, formations, Ammonite-zones (after Kauffman et al., 1993), and geologic stages
Tableau 2
Liste des espèces d'ostracodes avec leur répartition spatio-temporelle : localités, formations, zones d'ammonites (d'après Kauffman et al., 1993) et étages géologiques

Species	Localities	Formations	Ammonite Zones	Stages
Cytherella sp. A and B	Utah 1, 9, 15	Tropic Shale	*Sciponoceras gracile-Prionocyclus hyatti*	Late Upper Cenomanian–Middle Turonian
Cythermorpha perornata nov. sp.	Utah 4, 7, 8c–d, 12	Dakota, Iron Springs, and Straight Cliffs Formations	*Neocardioceras juddii-Prionocyclus hyatti*	Late Upper Cenomanian– Middle Turonian
Looneyella leckiei nov. sp.	Utah 8c–e	Straight Cliffs Formation	*Watinoceras coloradoense-Collignoniceras woollgari*	Lower-to early Middle Turonian
Rosacythere? cf. *consobrina*	Utah 8a–b	Dakota Formation	*Sciponoceras gracile-Neocardioceras juddii*	Late Upper Cenomanian
Phodeucythere sp.	Utah 8b	Dakota Formation	*Sciponoceras gracile-Neocardioceras juddii*	Late Upper Cenomanian
Asciocythere arizonensis nov. sp.	Arizona 16	Dakota Formation	*Metoicoceras mosbyense*	Upper Cenomanian
Asciocythere posterangulata nov. sp.	Utah 3, 8a–b	Dakota Formation	*Metoicoceras mosbyense-Neocardioceras juddii*	Upper Cenomanian
Dolocytheridea (*Puracytheridea*) sp.	Utah 15	Tropic Shale	*Neocardioceras juddii*	Late Upper Cenomanian
Fossocytheridea mosbyense	Utah 1, 3	Dakota Formation	*Metoicoceras mosbyense*	Upper Cenomanian
Fossocytheridea kirklandi	Utah 8a–b, 9, 13	Dakota Formation	*Sciponoceras gracile-Neocardioceras juddii*	Late Upper Cenomanian
Fossocytheridea posterovata	Utah 1, 4, 8c–e, 12	Straight Cliffs and Iron Springs Formations	*Watinoceras coloradoense-Prionocyclus hyatti*	Lower-to Middle Turonian
Cythereis eaglefordensis	Utah 1, 2, 7, 8a–b, 10, 15	Dakota Formation and Tropic Shale	*Sciponoceras gracile-Watinoceras coloradoense*	Upper Cenomanian–earliest Turonian
Semicytherura sp.	Utah 7	Dakota Formation	*Neocardioceras juddii*	Latest Cenomanian
Cytheropteron eximium	Utah 1, 15	Tropic Shale	*Sciponoceras gracile-Watinoceras coloradoense*	Upper Cenomanian-earliest Turonian
Cytheropteron clavifragilis nov. sp.	Utah 8c–d	Straight Cliffs Formation	*Watinoceras coloradoense-Collignoniceras woollgari*	Lower-to early Middle Turonian
Alicenula sp.	Utah 1, 8a–b	Dakota Formation	*Metoicoceras mosbyense-Neocardioceras juddii*	Upper Cenomanian
Paracypris sp.	Utah 1, 8a	Dakota Formation	*Metoicoceras mosbyense-Neocardioceras juddii*	Upper Cenomanian
Hourcqia dakotaensis nov. sp.	Utah 1, 8a–b	Dakota Formation	*Metoicoceras mosbynese*	Upper Cenomanian
Zonocypris? sp.	Utah 8a–b	Dakota Formation	*Sciponoceras gracile-Neocardioceras juddii*	Late Upper Cenomanian

recovered from Coal Mine Mesa (Arizona, locality 16) and Tropic (Utah, locality 3). Associated ostracodes include *Asciocythere arizonensis* nov. sp., and *Hourcqia dakotaensis* nov. sp. This latter taxon is prominent at locality 1 and additional specimens were recovered from the lowermost red-green strata of the Dakota Formation at Cedar Canyon (localities 8a–b).

4.2. Ostracode interval-zone II

The brackish strata at Table Bench (locality 9), Browse (locality 13), Maple Canyon (locality 7), and Cedar Canyon (localities 8a–b) all yielded specimens of *Fossocytheridea kirklandi*. The first and last occurrence of this taxon define this ostracode interval-zone. The encompassing strata are assigned to the *Sciponoceras gracile* and *Neocardioceras juddii* Ammonite-zones of Kauffman et al. (1993). Associated ostracodes include *Cytheromorpha perornata* nov. sp., *Semicytherura* sp., and *Asciocythere posterangulata* nov. sp.

In the calcareous mudstones of the Tropic Shale, the first occurrences of the ostracodes *Cythereis eaglefordensis* and *Cytheropteron eximium* mark the base of this interval zone (Fig. 8). Their occurrences are largely restricted to strata assigned the *Sciponoceras gracile* and *Neocardioceras juddii* Ammonite-zones between Bentonites TT1 and TT3 (Figs. 3 and 8), although several specimens were recovered from strata that superimpose the latter "boundary" Bentonite TT3.

According to Hazel (1969), the occurrence of the ostracode *Cythereis eaglefordensis* is an excellent marker for the latest Cenomanian across the continental United States. Swain (1978) and Neale (1977) challenge this proposition and they report ranges that terminate in the earliest Turonian in the north Atlantic region. Our results herein support Swain (1978) and Neale (1977) given the last occurrence of *Cythereis eaglefordensis* and *Cytheropteron eximium* above bentonite TT3 at Big Water (Fig. 8).

4.3. Ostracode interval-zone III

Turonian ostracodes are relatively sparse in the Tropic Shale, with the exception the *Cytherella*, *Cytherelloidea*, and *Dolocytheridea*. In contrast, Turonian coal zones on Markagunt Plateau contain an abundance of *Fossocytheridea posterovata* and *Cytheromorpha perornata*, the first occurrence of the former marks the basal Turonian. *Cytheromorpha perornata* nov. sp. first occurs at Maple Canyon in the marlstone beds immediately below the Cenomanian–Turonian boundary bed (see Tibert et al., 2003a). *Looneyella leckiei* nov. sp. and *Cytheropteron clavifragilis* nov. sp. occur in Turonian strata on Markagunt Plateau (localities 8c–e) and they should be regarded as indicators for late Lower-to early Middle Turonian.

5. Paleoenvironments

5.1. Estuarine expansion biofacies (early late Cenomanian)

Ostracode interval-zone I (=*Metoicoceras mosbyense* Ammonite-zone) comprises a population dominated by brackish *Fossocytheridea mosbyense* (Tibert et al., 2003b), *Asciocythere arizonensis* nov. sp., *Hourcqia dakotaensis* nov. sp., and rare *Paracypris* sp., *Alicenula* sp., *Zonocypris*? sp. and *Rosacythere*? cf. *consobrina*. Associated foraminifera are largely agglutinated dominated by the extant estuarine morphotypes *Trochammina*, *Ammobaculites*, and *Miliammina* (Tibert et al., 2003a). The encompassing strata represent the initial transgressive facies of the Greenhorn Cyclothem deposited during the late Cenomanian (Fürsich and Kirkland, 1986; Elder et al., 1994; Ulicny, 1999; Tibert et al., 2003a). The deposits are generally regarded as estuarine/lagoonal which particular reference to Coal Zones 4–5 of Tibert et al. (2003a) and Units 4–6 of Ulicny (1999) (Fig. 3).

5.2. Mature estuarine biofacies (latest Cenomanian)

Ostracode interval-zone II (=*Sciponoceras gracile-Neocardioceras juddii* Ammonite-zones) comprises an ostracode population dominated by *Fossocytheridea kirklandi*, *Asciocythere posterangulata* nov. sp., and rare *Cytheromorpha perornata* nov. sp. Associated foraminifera are agglutinated where the extant estuarine morphotypes *Trochammina*, *Ammobaculites*, and *Miliammina* dominate the assemblage. Tibert et al. (2003a) report a distal-to proximal estuarine assemblage that occurs in strata deposited during peak transgression of the Greenhorn Cyclothem (Fig. 3: Coal Zones 6–7); this interval corresponds to the Culver Coal Zone of Averitt (1962) and Units 9–10 of Laurin and Sageman, 2001. *Fossocytheridea kirklandi* occurs at the most proximal, westernmost deposits in the Pine Valley Mountains (locality 13) associated with charophytes and hydrobid snails interpreted as hyposaline (Tibert et al., 2003b).

The prodeltaic facies of the Tropic Shale at Big Water comprise populations of *Cythereis eaglefordensis*, *Cytheropteron eximium*, *Asciocythere posterangulata* nov. sp., *Dolocytheridea* (*P.*) sp., *Paracypris* sp., and *Cytherella* spp. interpreted as a normal marine, distal basin association (Tibert et al., 2003a). Foraminiferal populations that are dominated by the planktonic genus *Whiteinella* corroborate this interpretation (West et al., 1998; Leckie et al., 1998; Tibert, 2002).

5.3. Low gradient coastal plain biofacies (Turonian)

The early-to Middle Turonian paleoenvironment of southwest Utah can be best characterized as a low gradient coastal plain that was periodically inundated by the sea (Eaton, 1991; Eaton et al., 1997, 1999; Tibert et al., 2003b; Tibert and Leckie, 2004). Shelly mudstones associated with lignite bearing facies contain abundant *Fossocytheridea posterovata*, *Cytheropteron perornata* nov. sp., and *Looneyella leckiei* nov. sp. interpreted as a brackish bay (Tibert et al., 2003a, 2003b; Tibert and Leckie, 2004). Pore morphometrical analysis of *Fossocytheridea* (Tibert et al., 2004; Tibert et al., in prep.) reveals small, circular pit openings and pores that indicate lowered salinities following the model developed by Rosenfeld and Vesper, 1977. Isotopic values for specimens of *Fossocytheridea posterovata* ranged from approximately –14 to –9‰ VPD (Tibert et al., 2004). Given that normal Cenomanian–Turonian values for the WIB approximate 0–1‰ PDB (Pagani and Arthur, 1998) and freshwater values from mollusks in the WIB range from approximately –13 to –15‰ VPDB (Holmden et al., 1997), the geochemical values of *Fossocytheridea* indicate that the waters were less than normal marine (=brackish) (Tibert et al., 2004).

6. Conclusions

Coal bearing strata of the Dakota, Iron Springs, and Straight cliffs Formations contain abundant ostracodes (15 genera and 20 species). New taxa include: *Asciocythere posterangulata* nov. sp., *Asciocythere arizonensis* nov. sp., *Cytheromorpha perornata* nov. sp., *Cytheropteron clavifragilis* nov. sp., *Hourcqia dakotaensis* nov. sp. and *Looneyella leckiei* nov. sp. The ostracode associations comprise three primary zones: Ostracode interval-zone I (late Upper Cenomanian); Ostracode interval-zone II (latest Cenomanian-earliest Turonian); and Ostracode interval-zone III (early-to-Middle Turonian).

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References

Alexander, C.I., 1929. Ostracoda of the Cretaceous of north Texas. University of Texas Bulletin 2907, 1–137.

Alexander, C.I., 1933. Shell structure of the ostracode genus *Cytheropteron*, and fossil species from the Cretaceous of Texas. Journal of Paleontology 7, 181–214.

Andreu, B., 1981. Nouvelles espèces d'ostracodes de l'Albien et du Cénomanien d'Estremadura (Portugal). Ciências da Terra (UNL) 6, 117–152.

Andreu, B., 1991. Les ostracodes du Crétacé Moyen (Barrémien à Turonien), le long d'une transversale Agadir-Nador (Maroc). Strata 14 (11), 762.

Averitt, P., 1962. Geology and coal resources of the Cedar Mountain Quadrangle, Iron County, Utah, United States. Geological Survey Professional Paper 389, 1–59.

Babinot, J.-F., 1980. Les ostracodes du Crétacé supérieur de Provence. In: Travaux du Laboratoire de Géologie Historique et de Paléontologie. Université de Marseille 10, pp. 1–635.

Baynova, E., 1965. Ostracodes de l'Albien de la partie ouest et centrale de Bulgarie du Nord. Review of the Bulgarian Geological Society 26, 287–315.

Blanc, P.-L., Colin, J.-P., 1975. Étude micropaléontologique et paléoécologique du Maastrichtien de Cézan-Lavardens (Gers S. O. France). Palaeontographica A 148, 109–131.

Brouwers, E.M., Hazel, J.E., 1978. Ostracoda and correlation of the Severn Formation (Navarroan, Maestrichtian) of Maryland. SEPM. Paleontological Monograph 1, 1–52.

Cabral, M.C., 1995. Ostracodos do Cretácico Inferior do Algrave e da região de Lisboa: sistemática, bioestratigrafia, aspectos paleoecológicos et paleobiogeográficos. PhD Thesis Faculdade de Ciências de Lisboa (unpublished).

Caldwell, W.G.E., Diber, R., Eicher, D.L., Fowler, S.P., North, B.R., Stelck, C.R., Von Holdt, W.L., 1993. Foraminiferal biostratigraphy of Cretaceous marine cyclothems. In: Caldwell, W.G.E., Kauffman, E.G. (Eds.), Evolution of the Western Interior Basin. Geological Association of Canada Special Paper, Toronto 39, pp. 477–520.

Colin, J.-P., Carbonel, P., 1996. Early records of the limnic ostracod genus *Rosacythere* (Limnocytheridae, Timiriaseviinae) in the Middle Jurassic of France: implications on the origin and evolution of the *Kovalesvkiella* group. Journal of Micropalaeontology 15, 187–191.

Colin, J.-P., Danielopol, D.L., 1978. New data on the systematics of the Limnocytheridae (Ostracoda Cytheracea). Geobios 11, 563–567.

Colin, J.-P., Danielopol, D.L., 1980. Sur la morphologie, la systématique et l'évolution des ostracodes Timiriaseviinae (Limnocytheridae). Paléobiologie Continentale 11, 1–52.

Colin, J.-P., Dépêche, F., 1997. Faunes d'ostracodes lacustres des bassins intracratoniques d'âge albo-aptien en Afrique de l'Ouest (Cameroun Tchad) et au Brésil. Africa Geoscience Review 4, 431–450.

Cook, E.F., 1957. Geology of the Pine Valley Mountains, Utah. Utah Geological and Mineralogical Survey Bulletin 58, 111.

Crane, M.J., 1965. Upper Cretaceous ostracodes of the Gulf Coast area. Micropaleontology 11, 191–254.

Damotte, R., 1971. Quelques ostracodes du Cénomanien de Dordogne et de Touraine. Revue de Micropaléontologie 14, 3–20.

Damotte, R., Grosdidier, E., 1963. Quelques ostracodes du Crétacé de la Champagne humide: 1. Albien-Cénomanien. Revue de Micropaléontologie 6, 51–66.

Do Carmo, A., De Queiroz Neto, J.V., Whatley, R., Coimbra, J.C., 2005. On the taxonomic status of the Lower Cretaceous non-marine ostracod species *Cypridea africana* (Krömmelbein, 1965) and *Harbinia micropapillosa* (Bate 1972). In: Kohring, R., Sames, B. (Eds.), 15th International Symposium on Ostracoda, Program and Abstracts Berliner Paläobiologische Abhandlungen 6, pp. 27–28.

Donze, P., 1964. Ostracodes berriasiens des massifs subalpins septentrionaux (Bauges et Chartreuse). Travaux du Laboratoire de Géologie de la Faculté des Sciences de Lyon n.s. 11, pp. 103–160.

Eaton, J.G., 1991. Biostratigraphic framework for Upper Cretaceous rocks of the Kaiparowits Plateau, southern Utah. In: Nations, J.D., Eaton, J.G. (Eds.), Stratigraphy, depositional environments and sedimentary tectonics of the western margin, Cretaceous Western Interior seaway. Geological Society of America Special Paper, Boulder 260, pp. 47–63.

Eaton, J.G., Diem, S., Archibald, J.D., Schierup, C., Munk, H., 1999. Vertebrate paleontology of the Upper Cretaceous rocks of the Markagunt Plateau, southwestern Utah, 99. Miscellaneous Publication, Utah Geological Survey, pp. 323–334.

Eaton, J.G., Kirkland, J.I., Hutchison, J.H., Denton, R., O'Neill, R.C., Parrish, J.M., 1997. Nonmarine extinction across the Cenomanian-Turonian (C-T) boundary, southwestern Utah, with a comparison to the Cretaceous-Tertiary (K-T) extinction event. Geological Society of America Bulletin, Boulder 109, 560–567.

Eaton, J.G., Laurin, J., Kirkland, J.I., Tibert, N.E., Leckie, R.M., Sageman, B.B., et al., 2001. Cretaceous and Early Tertiary geology of Cedar and Parowan Canyons, Western Markagunt Plateau Utah. In: Erskine, M.C., Faulds, J.E., Bartley, J.M., Rowley, P.D. (Eds.), The geologic transition, High Plateaus to Great Basin. Utah Geological Association and Pacific Section AAPG UGA Publication 30, pp. 337–363.

Eaton, J.G., Nations, J.D., 1991. Tectonic setting along the margin of the Cretaceous Western Interior Seaway, southwestern Utah and northern Arizona. In: Nations, J.D., Eaton, J.G. (Eds.), Stratigraphy, depositional environments, and sedimentary tectonics of the western margin, Cretaceous Western Interior seaway. Geological Society of America Special Paper, Boulder 260, pp. 1–8.

Eicher, D.L., Worstell, P., 1970. Cenomanian and Turonian foraminifera from the Great Plains, United States. Micropaleontology 16, 269–324.

Elder, W.P., 1988. Geometry of Upper Cretaceous bentonite beds; implications about volcanic source areas and paleowind patterns, Western Interior, United States. Geology 16, 835–838.

Elder, W.P., 1991. Molluscan paleoecology and sedimentation patterns of the Cenomanian-Turonian extinction interval in the southern Colorado Plateau region. In: Nations, J.D., Eaton, J.G. (Eds.), Stratigraphy, depositional environments, and sedimentary tectonics of the western margin, Cretaceous Western Interior seaway. Geological Society of America Special Paper, Boulder 260, pp. 113–137.

Elder, W.P., Gustason, E.R., Sageman, B.B., 1994. Correlation of basinal carbonate cycles to nearshore parasequences in the Late Cretaceous Greenhorn Seaway Western Interior U. S. A. Geological Society of America Bulletin 106, 892–902.

Elder, W.P., Kirkland, J.I., 1993. Cretaceous paleogeography of the Colorado Plateau and adjacent areas. In: Morales, M. (Ed.), Aspects of Mesozoic geology and paleontology of the Colorado Plateau. Museum of Northern Arizona Press Bulletin 59, pp. 129–152.

Fürsich, F.T., Kirkland, J.I., 1986. Biostratinomy and paleoecology of a Cretaceous brackish lagoon. Palaios 1, 543–560.

Gründel, J., 1974. Die Ostracoden aus dem Salzbergmergel des Salzberges bei Quedlinburg (unter Ausschluss der Trachyleberididae). Abhandlungen des staatlichen Museums für Mineralogie und Geologie 21, 101–118.

Gustason, E.R., 1989. Stratigraphy and sedimentology of the middle Cretaceous (Albian-Cenomanian) Dakota Formation, southwestern Utah. PhD. Thesis University of Colorado, Boulder (unpublished).

Hancock, J.M., Kauffmann, E.G., 1979. The great transgressions of the Late Cretaceous. Journal of the Geological Society 136, 175–186.

Haq, B.U., Hardenbol, J., Vail, P.R., 1988. Mesozoic and Cenozoic chronostratigraphy and cycles of sea-level change. Society of Economic Paleontologists and Mineralogists Special Publication 42, 71–108.

Hazel, J.E., 1969. Cythereis eaglefordensis Alexander, 1929, a guide fossil for deposits of latest Cenomanian age in the Western Interior and Gulf Coast regions of the United States. Geological Survey Professional Paper P650-D, 155–158.

Herrig, E., 1966. Ostracoden aus der Weißen Schreibkreide (Unter-Maastricht) der Insel Rügen. Paläontologische Abhandlungen A 2 (4), 693–1024.

Hintze, L.F., 1980. Geologic Map of Utah. Utah Geological and Mineralogical Survey Map scale 1:500000.

Holmden, C., Creaser, R.A., Muelenbachs, K., 1997. Paleosalinities in ancient brackish water systems determined by 87 Sr/86Sr ratios in carbonate fossils; a case study from the Western Canada sedimentary basin. Geochimica et Cosmochimica Acta 61, 2105–2118.

Howe, H.V., Laurencich, L., 1958. Introduction to the Study of Cretaceous Ostracoda. Louisiana State University Press, Baton Rouge.

Jones, T.R., 1893. On some fossil ostracoda from S W. Wyoming and from Utah. Geological Magazine 10, 291–395.

Kauffman, E.G., Sageman, B.B., Kirkland, J.I., Elder, W.P., Harries, P.J., Villamil, T., 1993. Molluscan biostratigraphy of the Cretaceous Western Interior Basin, North America. In: Caldwell, W.G.E., Kauffman, E.G. (Eds.), Evolution of the Western Interior Basin. Geological Association of Canada Special Paper, Toronto 39, pp. 397–434.

Kaye, P., 1963. The interpretation of the Mesozoic ostracod genera of the family Cytherideidae Sars 1925. Revue de Micropaléontologie 6, 23–40.

Kennedy, W.J., Walasaczyk, I., Cobban, W.A., 2000. Pueblo, Colorado, USA, candidate Global Boundary Stratotype Section and Point for the base of the Turonian stage of the Cretaceous, and for the base of the middle Turonian substage, with a revision of the Inoceramidae (Bivalvia). Acta Geologica Polonica 50, 295–334.

Kirkland, J.I., 1991. Lithostratigraphic and biostratigraphic framework for the Mancos Shale (late Cenomanian to middle Turonian) at Black Mesa, northeastern Arizona. In: Nations, J.D., Eaton, J.G. (Eds.), Stratigraphy, depositional environments and sedimentary tectonics of the western margin, Cretaceous Western Interior seaway. Geological Society of America Special Paper, Boulder 260, pp. 85–111.

Kirkland, J.I., 1996. Paleontology of the Greenhorn cyclothem (Cretaceous: Late Cenomanian to Middle Turonian) at Black Mesa, northeastern Arizona. New Mexico Museum of Natural History and Science, 1–131.

Krömmelbein, K., Weber, R., 1971. Ostracoden des "Nordost-Brasilianischen Wealden". Beihefte zum Geologischen Jahrbuch 115, 1–93.

Laurin, J., Sageman, B.B., 2001. Tectono-sedimentary evolution of the western margin of the Colorado Plateau during the latest Cenomanian and Early Turonian. Utah Geological Association Publication 30, 57–74.

Leckie, R.M., Kirkland, J.I., Elder, W.P., 1997. In: Anderson, O.J., Kues, B.S., Lucas, S.G. (Eds.), Stratigraphic framework and correlation of a principal reference section of the Mancos Shale (Upper Cretaceous), Mesa Verde, Colorado. Mesozoic geology and paleontology of the four corners region.New Mexico Geological Society, 48th annual field conference, Cortez, NM, United States, pp. 163–216.

Leckie, R.M., Yuretich, R.F., West, O.L.O., Finkelstein, D., Schmidt, M., 1998. Palaeoceanography of the southwestern Western Interior Sea during the time of the Cenomanian-Turonian boundary (Late Cretaceous). In: Dean, W., Arthur, M.A. (Eds.), Stratigraphy and paleoenvironments of the Cretaceous Western Interior seaway, U.S.A. SEPM Concepts in Sedimentology and Paleontology 6, pp. 101–126.

Leithold, E.L., 1994. Stratigraphical architecture at the muddy margin of the Cretaceous Western Interior Seaway, southern Utah. Sedimentology 41, 521–542.

Leithold, E.L., Dean, W.E., 1998. Depositional processes and carbon burial on a Turonian prodelta at the margin of the Western Interior Seaway. In: Dean, W.E., Arthur, M.A. (Eds.), Stratigraphy and paleoenvironments of the Western Interior seaway. SEPM Concepts in Sedimentology and Paleontology 6, pp. 189–200.

Margerie, P., 1968. Inventaire des ostracodes conservés dans les couches inférieures de formations post-campaniennes du Mont-Aimé (Marne), 2e Partie: Cytheracea. Mémoires de la Société d'Agriculture, Commerce, Sciences et Arts du Département de la Marne 83, 7–36.

McNeil, D.H., Caldwell, W.G.E., 1981. Cretaceous rocks and their foraminifera in the Manitoba escarpment. Geological Association of Canada Special Paper 21, 1–439.

Molenaar, C.M. S, 1983. Major depositional cycles and regional correlations of Upper Cretaceous rocks southern Colorado Plateau and adjacent areas. In: Reynolds, M.W., Dolly, E.B. (Eds.), Mesozoic paleogeography of West-Central United States. SEPM Rocky Mountain Paleogeography Symposium, Denver 2, pp. 201–224.

Neale, J.W., 1977. Cretaceous ostracoda of the North Atlantic Basin. In: Swain, F.M. (Ed.), Stratigraphic micropaleontology of the Atlantic Basins and borderlands. Elsevier, Amsterdam, pp. 245–270.

Obradovich, J.D., 1993. A Cretaceous time scale. In: Caldwell, W.G.E., Kauffman, E.G. (Eds.), Evolution of the Western Interior Basin. Geological Association of Canada Special Paper, Toronto 39, pp. 379–398.

Pagani, M., Arthur, M.A., 1998. Stable isotope studies of Cenomanian-Turonian proximal marine fauna from the U S. western interior seaway. In: Dean, W., Arthur, M.A. (Eds.), Stratigraphy and Paleoenvironments of the Cretaceous Western Interior Seaway USA. SEPM Concepts in Sedimentology and Paleontology 6, pp. 201–225.

Peck, R., 1951. A new ostracode genus from the Cretaceous Bear River Formation. Journal of Paleontology 25, 575–577.

Peterson, R.H., Gauger, D.J., Lankford, R.R., 1953. Microfossils of the Upper Cretaceous of northeastern Utah and southwestern Wyoming. Utah Geological and Mineralogical Survey Bulletin 47, 1–158.

Pokorny, V., 1984. *Asciocythere bonnemai* (Ostracoda, Crustacea) in the Boreal Upper Cretaceous of Europe. Acta Universitatis Carolinae. Geologica 4, 309–329.

Pratt, L.M., Arthur, M.A., Dean, W.E., Scholle, P.A., 1993. Paleo-oceanographic cycles and events during the Late Cretaceous in the Western Interior seaway of North America. In: Caldwell, W.G.E., Kauffman, E.G. (Eds.), Evolution of the Western Interior Basin. Geological Association of Canada Special Paper, Toronto 39, pp. 333–353.

Puckett, T.M., 1996. Ecologic atlas of Upper Cretaceous ostracodes of Alabama. Geological Survey of Alabama Monograph 14, 1–175.

Rosenfeld, A., Vesper, B., 1977. The variability of the sieve pores in recent and fossil species of *Cyprideis torosa* (Jones, 1850), as an indicator for salinity and paleosalinity. In: Löffler, H., Danielopol, D. (Eds.), Aspects of ecology and zoogeography of recent and fossil ostracoda. Dr. W. Junk b. v. Publishers, The Hague, pp. 55–68.

Ryer, T.A., 1984. Transgressive-regressive cycles and the occurrence of coal in some Upper Cretaceous strata of Utah USA. In: Rahmani, R.A., Flores, R.M. (Eds.), Sedimentology of coal and coal-bearing Sequences. Special Publication of the International Association of Sedimentologists 7, pp. 217–227.

Sageman, B.B., Rich, J., Arthur, M.A., Birchfield, G.E., Dean, W.E., 1997. Evidence for Milankovitch periodicities in Cenomanian-Turonian lithological and geochemical cycles, Western Interior U.S.A. Journal of Sedimentary Research 67, 286–302.

Sageman, B.B., Rich, J., Arthur, M.A., Dean, W.E., Savdra, C., Bralower, T.J., 1998. Multiple Milankovitch Cycles in the Bridge Creek Limestone (Cenomanian-Turonian), Western Interior Basin. In: Dean, W., Arthur, M.A. (Eds.), Stratigraphy and paleoenvironments of the Cretaceous Western Interior seaway, USA. SEPM Concepts in Sedimentology and Paleontology 6, pp. 153–171.

Schmidt, M.G., 1990. Micropaleontology and Paleoecology of the Mancos Shale (Late Cretaceous), Lohali Point, Black Mesa Basin, Arizona [Master of Science thesis]: University of Massachusetts.

Schudack, U., 1994. Revision Dokumentation und Stratigraphie der Ostracoden des nordwestdeutschen Oberjura und Unter-Berriasium. Berliner Geowissenschaftliche Abhandlungen E 11, 1–193.

Stokes, W.L., Heylmun, E.B., 1963. Tectonic history of southwestern Utah. In: Heylmun, E.B (Ed.), Guidebook to the Geology to Southwestern Utah. Intermountain Association of Petroleum Geologists 12th Annual Field Conference, pp. 19–25.

Swain, F.M., 1952. Ostracoda from wells in North Carolina. Part 2. Mesozoic ostracoda. United States Geological Survey Professional Paper 234/B, 59–93.

Swain, F.M., 1978. Some Middle Cretaceous ostracoda from northern Spain and their interregional relationships. Revista Española de Micropaleontología 10, 245–265.

Swain, F.M., 1982. Marine and brackish-water Cretaceous ostracoda from wells in central and southern Florida. Journal of Micropalaeontology 1, 115–128.

Swain, F.M., 1999. Fossil nonmarine ostracoda of the United States. Elsevier, Amsterdam.

Swain, F.M., Brown, P.M., 1964. Cretaceous ostracoda from wells in the southeastern United States. North Carolina Department of Conservation and Development Division of Mineral Resources Bulletin 78, 1–55.

Swain, F.M., Xie, C.L., 1991. Jurassic and Lower Cretaceous ostracoda from COST Atlantic wells, western North Atlantic Ocean. Revista Española de Micropaleontología 23, 57–98.

Tibert, N.E., 2002. Systematic paleontology, paleoecology, and biostratigraphy of ostracodes and agglutinated foraminifera from the western margin of the Cenomanian-Turonian Western Interior Sea, Southwest Utah. PhD Thesis University of Massachusetts Amherst.(unpublished).

Tibert, N.E., Colin, J.-P., Leckie, R.M., Babinot, J.-F., 2003a. Revision of the ostracode genus Fossocytheridea Swain and Brown, 1964 Mesozoic ancestral root for the modern eurytopic *Cyprideis* Jones. Micropaleontology 49, 205–230.

Tibert, N.E., Leckie, R.M., 2004. High-resolution estuarine sea level cycles from the Late Cretaceous: amplitude constraints using agglutinated foraminifera. Journal of Foraminiferal Research 34, 130–143.

Tibert, N.E., Leckie, R.M., Eaton, J.G., Kirkland, J.I., Colin, J.-P., Leithold, E.L., et al., 2003b. Recognition of relative sea level change in upper Cretaceous coal-bearing strata: A paleoecological approach using agglutinated foraminifera and ostracodes to detect key stratigraphic surfaces. In: Olson, H., Leckie, R.M. (Eds.), Microfossils as proxies for sea level change and stratigraphic discontinuities. SEPM Special Publication, Tulsa 75, pp. 263–299.

Tibert, N.E., Patterson, W., Odegaard, L., Tanko, O.S., Ludvigson F.G., Colin, J.-P., 2004. A multi-disciplinary proxy for Cenomanian-Turonian (late Cretaceous) brackish seawater: Normal pore morphometrics and oxygen isotope signatures of the ostracode Fossocytheridea. Geological Society of America Abstracts with Programs, 2004 National Meeting, Denver Colorado 36, p. 96.

Ulicny, D., 1999. Sequence stratigraphy of the Dakota Formation (Cenomanian), southern Utah: interplay of eustasy and tectonics in a foreland basin. Sedimentology 46, 807–836.

West, O.L.O., Leckie, R.M., Schmidt, M., 1998. Foraminiferal paleoecology and paleoceanography of the Greenhorn Cycle along the southwestern margin of the Western Interior sea. In: Dean, W., Arthur, M.A. (Eds.), Stratigraphy and paleoenvironments of the Cretaceous Western Interior seaway USA. SEPM Concepts in Sedimentology and Paleontology 6, pp. 79–99.

White, C.A., 1895. The Bear River Formation and its characteristic fauna. United States Geological Survey Bulletin 128, 1–108.

Zelt, F.B., 1985. Natural gamma-ray spectrometry, lithofacies, and depositional environments of selected Upper Cretaceous marine mudrocks, western United States including Tropic Shale and Tununk Member of Mancos Shale. PhD Thesis, Princeton University.(unpublished).