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CYLINDRICHNUS CONCENTRICUS TOOTS IN HOWARD, 1966 (TRACE FOSSIL) IN ITS TYPE LOCALITY, UPPER CRETACEOUS, WYOMING

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Abstract: *Cylindrichnus concentricus* is a widespread trace fossil in shallow marine sedimentary rocks of Mesozoic and Cenozoic age. This paper clarifies the ichnotaxonomy of *C. concentricus* by offering an emended diagnosis of the ichnogenus and a new diagnosis of the ichnospecies. The broad, bow-shaped architecture of *C. concentricus* with two openings at the sediment surface suggests that the trace maker was either a filter-feeding animal that captured suspended food particles from the water column or else a surface deposit feeder that employed tentacles or an eversible pharynx to collect nutritious sediment from the surface around one or both of the burrow openings. Although *C. concentricus* has been reported in a variety of different sedimentary environments around the world, in its type locality in the Cretaceous of Wyoming the trace fossil is found in low-diversity or monoichnospecific beds that exhibit hummocky cross stratification. This occurrence suggests the burrower's tolerance (or perhaps preference) for an episodic high-energy hydrodynamic environment related to major storms.

Key words: Bioturbation, Cretaceous, *Cylindrichnus concentricus*, type locality, Wyoming.

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INTRODUCTION

The trace fossil *Cylindrichnus concentricus* is widespread in shallow marine sedimentary rocks of Mesozoic and Cenozoic age around the world (Toots, 1962; Howard, 1966; Noda, 1984; Frey & Howard, 1985), and it has captured the interest of international researchers because of its palaeoenvironmental and palaeoecologic significance (Frey & Howard, 1990; Goldring, 1996; Głuszek, 1998; Nara & Ekdale, 2006; Belaústegui & Gibert, 2009, 2013; Ekdale & Harding, 2011). It is a trace fossil that sometimes is misidentified, due in part to major confusion regarding its ichnotaxonomy, and possibly also because its type locality and type specimens are not easily available to researchers. This paper clarifies the twists and turns of the ichnotaxonomic history of *C. concentricus* and elaborates on the nature of its occurrence in its type locality in southeastern Wyoming, U.S.A.

GEOLOGICAL SETTING

Cylindrichnus concentricus is a gently curved, slightly conical burrow with a concentrically lined sediment fill. The traces are prevalent in sandstone in a low, discontinuous roadcut along U.S. Highway 30 east of the town of Rock River in Albany County, Wyoming (Fig. 1), from which type specimens of the ichnospecies were collected. *C. concentricus* is abundant in large rounded sandstone concretions of the Upper Cretaceous Rock River Formation, Mesaverde Group (Ekdale & Harding, 2011). The outcrop exposes the middle concretionary zone of the Rock River Formation, which was mapped by Gill *et al.* (1970), who found that it is mainly confined to the Laramie Basin in southeastern Wyoming. The formation consists of fossiliferous marine siliciclastic deposits with a maximum thickness of approximately 475 m within the shallow marine palaeoenvironment of the Cretaceous Western Interior Seaway. To the east the formation grades into the deeper marine Pierre Shale, and to the west it intertongues with nonmarine rock units. The formation overlies the Steele Shale and lies beneath the Pine Ridge Sandstone (Gill *et al.*, 1970).

The Rock River Formation consists of weakly cemented, fine-grained sandstone that is highly weathered, but large brown sandstone concretions remain as remnants in low ridges in the outcrop (Gill *et al.*, 1970). *Cylindrichnus concentricus* is abundant in several of these large concretions at the type locality. Hummocky cross stratification and possible swaley cross stratification can be observed in the sandstone concretions. This is attributed to oscillating cur-

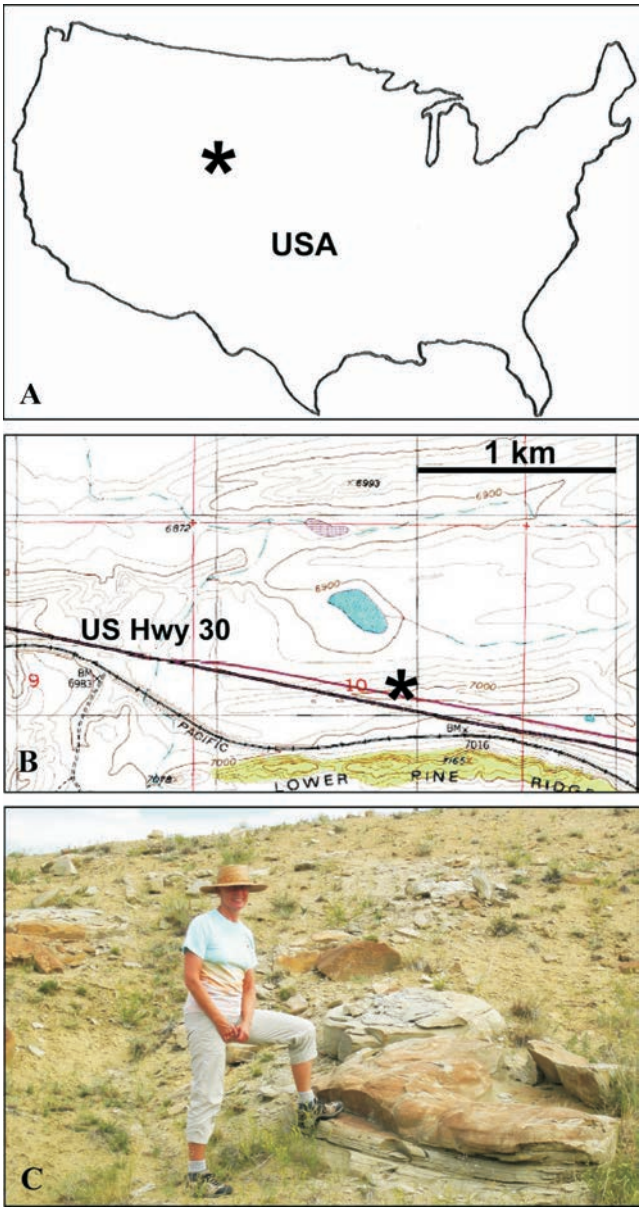

Fig. 1. Type locality (asterisks) of *Cylindrichnus concentricus* along U.S. Highway 30 in Albany County, southern Wyoming, western United States. **A.** Map of the United States showing location of the type locality in Wyoming. **B.** Map detail. C. Outcrop view. Note sandstone concretions of the trace fossil-bearing strata.

rents associated with storms, which suggests a shoreface sedimentary environment (Dumas and Arnott, 2006). *C. concentricus* also has been reported as a common trace fossil in hummocky cross stratified sandstone in the Upper Cretaceous of Utah (Frey, 1990). Thus, episodic storm activity may define the preferred depositional environment of *C. concentricus* in its type locality.

Marine invertebrate body fossils, although abundant at several levels within the Rock River Formation (Stanton & Knowlton, 1897; Toots, 1962), are rare to absent at the *C. concentricus* type locality. In the same formation, but at different stratigraphic levels from the *C. concentricus* occurrences, Toots (1962) reported a diverse association of fully marine body fossils, including serpulid annelids (*Serpula markmani* Henderson), bryozoans (*Dysenoetopora demissa* and *Conopeum ramosum* Toots and Cutler), bivalves (*Pinna*, *Inoceramus*, *Pteria*, *Ostrea*, *Trigonia*, *Pecten*, *Modiolus*, *Laternula*, *Cymella*, *Cardium*, *Legumen* and *Crenella*), cephalopods (*Baculites*, *Oxybeloceras* and *Didymoceras*), scleractinian corals (*Microbacia americana* Meek and Hayden) and unidentified shark teeth. It seems that the *C. concentricus* producers thrived in different environmental conditions than the benthic community that is represented by the highly diverse assemblage of body fossils in other parts of the formation.

ICHNOTAXONOMIC NOTE

Cylindrichnus concentricus was described initially (and informally) as a "new form" by Heinrich Toots (1962, p. 65) in his unpublished master's thesis at the University of Wyoming as he conducted palaeoecologic studies of the Upper Cretaceous Mesaverde Formation in the Laramie Basin in southern Wyoming. Toots accessioned a hand sample (#A11975) (Fig 2.) and a thin section (#A11977) (Fig. 3A), which he named *C. concentricus*, in the Geology and Geophysics Department fossil collections at the University of Wyoming in Laramie, Wyoming. In his thesis, he noted the exact location of the outcrop from which those specimens were collected as a roadcut along U.S. Highway 30 in Albany County, Wyoming.

Subsequently, widespread outcrop occurrences of *Cylindrichnus* in the Upper Cretaceous of central Utah were reported by James Howard (1966), who accepted Toots' ichnogeneric name for the trace fossil without emending or expanding on Toots' description of it and without designating any curated specimens of the trace fossil from Utah.

Frey and Howard (1985) attempted to codify the description of *Cylindrichnus concentricus* by publishing a formal diagnosis of the ichnogenus, but they neglected to offer a diagnosis for the ichnospecies. They designated Toots' original specimens from Wyoming as the holotype (hand specimen, #A11975) and paratype (thin section, #A11977) for *C. concentricus.* This has caused significant confusion for ichnologists, because the holotype from Wyoming does not contain the complete trace fossil, and the ichnogeneric diagnosis written by Frey and Howard (1985) apparently was based on their observations of incomplete examples of the trace fossil seen in the field in Utah rather in the Wyoming type locality.

At the time when Frey and Howard (1985) formalized the name and ichnogeneric description of *Cylindrichnus concentricus*, they regarded it as the same, at least in part, as the trace fossil *Anemonichnus* Chamberlain and Clark, 1973, in the Carboniferous of Utah. They further suggested that *C. concentricus* in the Cretaceous of Utah closely resembles the "small basal stem" of the trace fossil *Rosselia socialis* Dahmer, 1937. However, instead of recommending that *C. concentricus* be designated as a junior synonym of *R. socialis,* Frey and Howard (1985) argued that both trace fossil names should be retained. While that may seem confusing, it probably was reasonable, since it was uncertain that the Utah specimens of *C. concentricus* actually were

exactly the same as the Wyoming specimens. Frey and Howard (1985) distinguished *C. concentricus* from *Rosselia* by its lack of the bulbous form that typifies the upper part of *Rosselia*, and distinguished it from *Skolithos* by its concentrically lined fill that is absent from *Skolithos*.

Nara and Ekdale (2006) examined numerous occurrences of *C. concentricus* in the Utah outcrops that were studied by Frey and Howard (1985), and they noted that the characteristic concentric, cone-in-cone arrangement of the *C. concentricus* laminae differs from the irregularly concentric laminae in *Rosselia*, so they too argued that the ichnogenus *Cylindrichnus* should be retained as distinct from *Rosselia*.

Goldring (1996) examined similar trace fossils in the Cretaceous of England, and he opined that the ichnotaxon *Cylindrichnus concentricus* should be considered as a *nomen dubium*. Subsequently, Belaústegui and Gibert (2009, 2013; Belaústegui *et al.*, 2011) described the well-displayed *Cylindrichnus* ichnofabric in the Middle Miocene of northeastern Spain. Based on a detailed functional analysis of the burrow morphology and sediment infill, they argued persuasively that *Cylindrichnus concentricus* should be retained as a valid ichnogenus and ichnospecies.

In 2010, the authors of this present paper examined the holotype and paratype of Toots' (1962) *Cylindrichnus concentricus* in the collections at the University of Wyoming and also examined abundant complete (or nearly complete) topotype specimens exposed in outcrop at the type locality in Albany County, Wyoming. On the basis of those examinations, the authors offer here an emended ichnogeneric diagnosis of *Cylindrichnus* Frey and Howard 1985 and a new ichnospecific diagnosis of *C. concentricus.* In order to avoid unnecessary confusion in the scientific literature, the authors advocate retention of Toots' original name, *Cylindrichnus concentricus*, for the trace fossil.

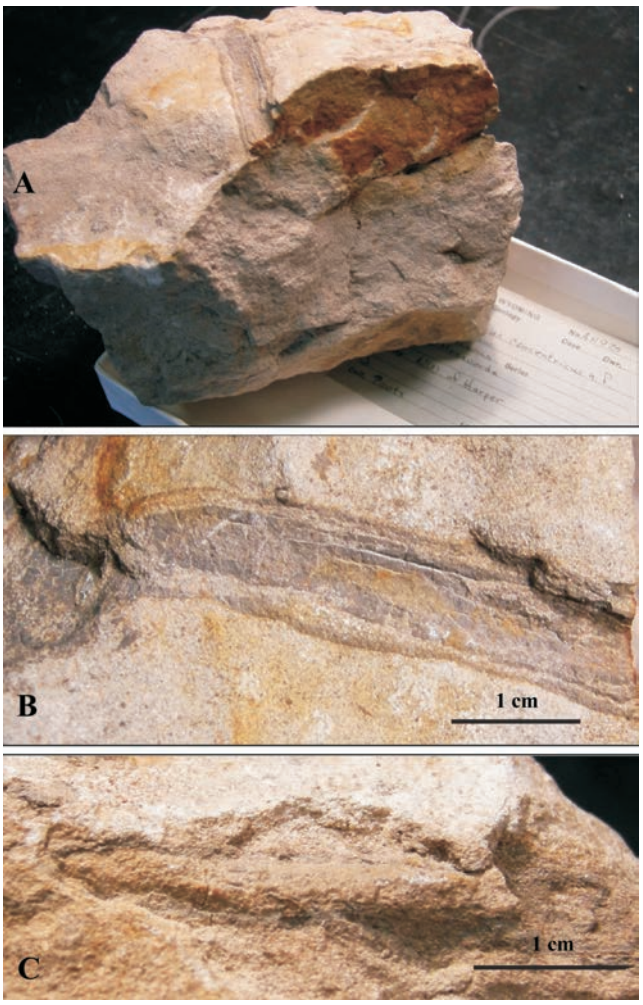

Fig. 2. Close-up photos of holotype of *Cylindrichnus concentricus*, described by Toots, 1962. **A.** View of entire holotype. **B.** Concentric lining inside the burrow is clearly visible. C. Sediment filling the core of the burrow.

SYSTEMATIC ICHNOLOGY

Ichnogenus *Cylindrichnus* Toots in Howard, 1966
Figs 2, 3

Emended diagnosis: Gently curved, unbranched, slightly conical, downward tapering burrows, nearly circular in cross-section with concentrically lined sediment fill (modified after Frey and Howard, 1985, p. 375).
Type ichnospecies: *Cylindrichnus concentricus* Toots, 1962 in Howard, 1966.
Remarks: The burrows typically are preserved in full relief as endichnia within sandstone or calcarenite. Although predominantly oriented vertically or subvertically, the burrow typically curves downwards to a subhorizontal or horizontal orientation. The concentric linings apparently originated as burrow lumens rather than as collapse features.

Cylindrichnus concentricus Toots in Howard, 1966
Figs 2, 3

1962 *Cylindrichnus concentricus* ichnosp. nov. – Toots, p. 94, pl. 5–7.
* v 1966 *Cylindrichnus concentricus* Toots, 1962 – Howard, p. 44, fig. 10.
1985 *Cylindrichnus concentricus* Toots, 1962 – Frey and Howard, p. 378, figs 8-1, 9.
1990 *Cylindrichnus concentricus* Toots, 1962 – Frey and Howard, p. 814, figs 17-1, 19-3.
2009 *Cylindrichnus concentricus* Toots, 1962 – Belaústegui and Gibert, p. 99, figs 2–4.
2011 *Cylindrichnus concentricus* Toots, 1962 – Ekdale and Harding, p. 130, figs 1, 2.
2013 *Cylindrichnus concentricus* Toots, 1962 – Belaústegui and Gibert, p. 121, figs 3–5.

Material and types: The holotype (A11975) and one paratype (thin section; A11977) at University of Wyoming. Seven topotype specimens (UUIC 3197, 3198, 3199, 3200, 3201, 3202 and 3248) at University of Utah. Multiple specimens in the outcrop at the type locality. The holotype (specimen #A11975) is a small hand specimen containing fragments of several different *C. concentricus* burrows (Figs 2, 3B), and the paratype (specimen #A11977) is a thin section (plus chip) that was cut transversely across one burrow to illustrate the concentric lining (Fig. 3A). The holotype and paratype were collected by Toots, and both now reside in the palaeontological collections of the Geology and Geophysics Department, University of Wyoming, Laramie, Wyoming.
Emended diagnosis: *Cylindrichnus* forming a broadly arcuate "U" shape, longer than deep, with vertical to slightly inclined,

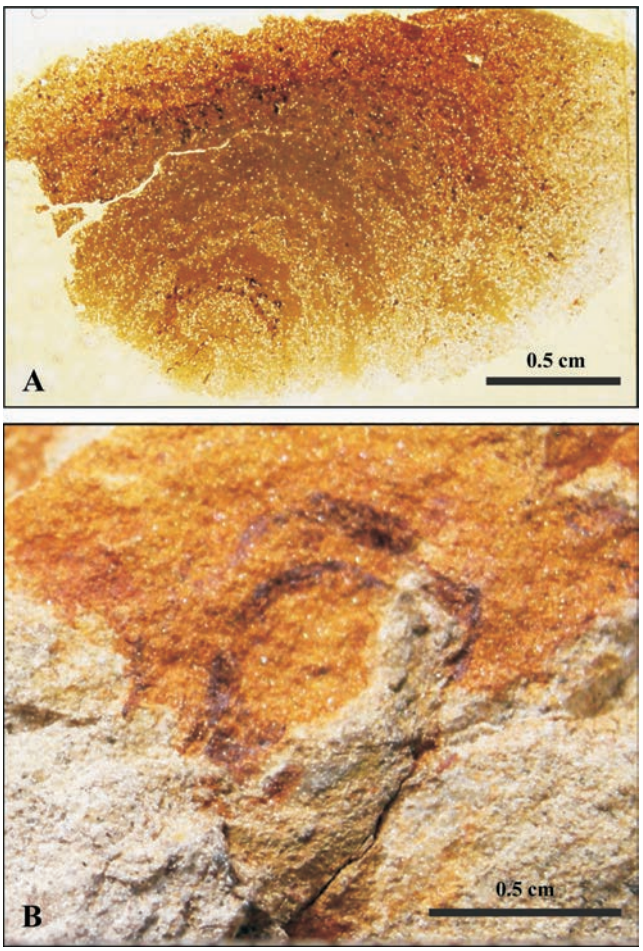

Fig. 3. Type specimens of *Cylindrichnus concentricus*. **A.** Thin section of paratype (A11977). **B.** Close-up view of a portion of the holotype (A11975). Note concentric mud linings in the cross-sectional view.

Fig. 4. Idealized form of *Cylindrichnus concentricus.* The upper ends of the vertical burrow shafts apparently were truncated erosionally by storm events. Note hummocky and swaley cross stratification in the host substrate.

downward tapering, side shafts connected below by a long, more narrow, bow-shaped, horizontal tunnel; concentrically lined throughout.

Description: "U"-shaped burrow is up to 15 cm deep and 50 cm long; burrow diameter ranges from 0.8 to 2.0 cm (Fig. 4).

Type locality: The type locality is in Albany County, southeastern Wyoming, situated 3 to 4 miles (approximately 4 to 6 km) east of Rock River on U.S. Highway 30 (Fig. 1). *C. concentricus* are prevalent in a low, discontinuous roadcut on the north side of the highway (also known as "The Lincoln Highway") (Fig. 1A, B). Map coordinates are the middle of Section 10, T20N, R76W, on the Rock River 7.5 minute quadrangle map. Geographic coordinates (latitude and longitude) are 41°43 N and 105°54 W.

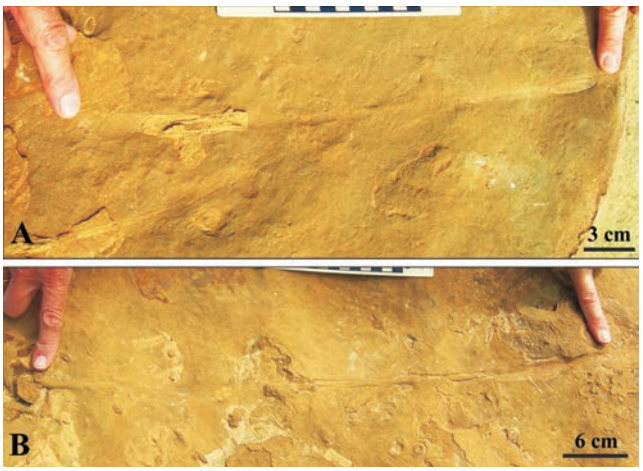

Fig. 5. *Cylindrichnus concentricus* tunnels in plan view in outcrop, showing the horizontal lower parts of the arcuate, bow-shaped burrows.

Type formation: Rock River Formation, Mesaverde Group.
Stratigraphic age: Campanian, Upper Cretaceous.
Remarks: Because the holotype of *C. concentricus* is a partial specimen, topotype specimens exposed in outcrop at the type locality must be observed in order to see the entire geometry of the complete burrow. In addition to its occurrence in the type locality in Wyoming (see also Ekdale and Harding, 2011), *Cylindrichnus concentricus* has been reported elsewhere in the western United States, especially in the Book Cliffs and Wasatch Plateau of central Utah (Howard, 1966; Frey and Howard, 1985, 1990; Nara and Ekdale, 2006). At the ichnogeneric level, *Cylindrichnus* has been recognized worldwide, such as in England (Goldring, 1996; Goldring *et al.*, 2002) and Japan (Nara and Ekdale, 2006), and at the ichnospecific level, *Cylindrichnus concentricus* has been recognized in northeastern Spain (Belaústigui and Gibert, 2009, 2013). Some workers have described other different ichnospecies of the ichnogenus *Cylindrichnus*, including *C. elongatus* Noda, 1984, *C. pustulosus* Frey and Bromley, 1985, *C. errans* D'Alessandro and Bromley, 1986, *C. operosus* Orłowski, 1989, *C. candelabrus* Głuszek, 1998, and *C. helix* Gibert *et al.*, 2006, none of which have ever been reported in the western United States. Because those subsequent descriptions post-date the original descriptions of *C. concentricus*, it is appropriate that *C. concentricus* be regarded as the type ichnospecies of the ichnogenus. No attempt is made here to evaluate the distinction and validity of those other ichnospecies of *Cylindrichnus*.

CYLINDRICHNUS CONCENTRICUS IN ITS TYPE LOCALITY

At its type locality, *Cylindrichnus concentricus* is the dominant ichnospecies, and it is locally very abundant, exhibiting an ichnofabric index (*ii*) ranging from 1 to 3. The burrows are well preserved, but often incomplete, in these rocks. They occur in various orientations – horizontally, obliquely, and vertically. Horizontal burrows are seen most commonly, with fairly straight tunnels that are curved upward at both ends to form a concave-up, arcuate shape. Some of the horizontal parts of the burrow are half a metre (or more) long (Fig. 5). Diagonal and subvertical burrow

shafts also occur, which are generally shorter (5 to 15 cm long; Fig. 6). Cross cutting of one burrow by another is common (Fig. 7), although the tunnels remain solitary and unbranched. There is no bundling of numerous tubes, as is seen in *Schaubcylindrichnus* (Nara, 2006), which is a common trace fossil in other Upper Cretaceous sandstone deposits in the Western Interior Seaway, but not seen at the *C. concentricus* type locality. The most prominent characteristic of *C. concentricus* is its concentric linings, which testify to multiple (up to 4) linings, which are circular or subcircular in transverse section. The burrow entries are narrow, downward tapering, slightly curved cones with concentric wall linings. Although the complete burrow usually cannot be seen, the abundant partial burrows observed in the rocks give a clear impression that the entire structure has a broad, shallow, bow shape (Fig. 4).

The holotype of *Cylindrichnus concentricus* is a small, incomplete piece of what was a much larger trace fossil, and the paratype is a thin section of a transverse cut through one burrow showing the concentric laminae inside the burrow. Even though only small portions of complete burrows are present in the holotype, the concentric internal structure is readily observable.

Fig. 6. *Cylindrichnus concentricus* in vertical view in outcrop. Note the multiple orientations of various portions of burrows. Lumpy weathering surface of the outcrop should not be misidentified as pellets inside the burrow or in the host sediment.

Fig. 7. Plan view of multiple cross-cutting *Cylindrichnus concentricus*. Concentric lining inside the burrows is evident in various cross-sectional views.

PALAEOETHOLOGICAL AND PALAEOECOLOGICAL INTERPRETATIONS

Nara and Ekdale (2006) discussed the possible ethology responsible for the construction of *Cylindrichnus concentricus* in Upper Cretaceous exposures in Utah, and they compared morphologic details of the burrow with those seen in the similar trace fossils, *Rosselia socialis* and *Schaubcylindrichnus coronus*, with which *C. concentricus* co-occurs in some places. All three trace fossils have observable morphologic differences, but all three most likely were constructed for a similar purpose by some type of infaunal worm, perhaps a burrowing polychaete annelid or enteropneust of uncertain identity (Nara, 1995, 2006). The bow-shaped architecture of *C. concentricus* with two openings at the sediment surface, as can be seen in the Wyoming type locality, suggests either a filter-feeding animal that captured suspended food particles from the water column or else a surface deposit feeder that employed tentacles (as in a terebellid polychaete) or an eversible pharynx (as in an arenicolid polychaete) to collect nutritious sediment from the surface around one or both of the burrow openings. The concentric fill of *C. concentricus* suggests that the occupant frequently went up and down inside its burrow during its normal activities. The lack of a spreite, as one would see in *Diplocraterion* or *Rhizocorallium*, indicates that the occupant was not deposit-feeding in a progressively downward direction in the sediment.

The palaeoecological interpretation and palaeoenvironmental range of *Cylindrichnus concentricus* suggest that the trace makers were opportunistic organisms living in a lower shoreface or offshore setting in the broad epicontinental seaway of the Upper Cretaceous in Wyoming and Utah. In several of the Utah occurrences, *C. concentricus* commonly is found in a high-diversity trace fossil assemblage alongside *Schaubcylindrichnus*, *Chondrites* and other fully marine ichnogenera. In both Utah and the Wyoming type locality, it also is found in low-diversity or monoichnospecific beds that exhibit hummocky cross stratification, thus suggesting the burrower's tolerance (or perhaps even preference) for an episodic high-energy hydrodynamic environment, presumably related to major storms. It is hoped that this description of *C. concentricus* in its type locality will generate further study into its preferred environment of origin.

CONCLUSIONS

Regardless of its confusing ichnotaxonomic history, *Cylindrichnus concentricus* is recognized as a valid ichnogenus and ichnospecies, and it should be retained as an ichnotaxon that is distinct from *Rosselia socialis.* Its most diagnostic characteristics include the concentric sediment

fill and the broad, arcuate, nearly flat-bottom, bow shape with steeply inclined, tapering limbs. *C. concentricus* is by far the most prominent ichnospecies at its type locality in Wyoming, and so its occurrence there may be described as a *Cylindrichnus* ichnofabric.

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