CIRCULICHNIS LEOMONTI, A NEW RING-LIKE ICHNOSPECIES (TRACE FOSSIL) FROM THE LATE CAMBRIAN LION MOUNTAIN MEMBER, RILEY FORMATION, BURNET COUNTY, TEXAS

Ryan F. Morgan[1]*, Kris L. Juntunen[1], Ashley Scott[2] and Marion Landreth[1]
[1]*Department of Chemistry, Geosciences, and Physics, Tarleton State University, Stephenville, TX 76401*
[2]*Department of Geological and Environmental Sciences, Western Michigan University, Kalamazoo, MI 49008*
**Corresponding author; Email: rmorgan@tarleton.edu*

Abstract.–*Circulichnis* is a well-known ichnogenus demonstrating broad stratigraphic and geographic distribution with known habitats spanning from deep-marine to terrestrial environments. Although commonly small in size, a recent discovery in Central Texas demonstrates a much larger early member of this ichnogenus. Compared to previous identifications of *Circulichnis*, the findings presented herein express a larger trace string width exceeding the average for this ichnogenus. This expansion in morphometric parameters emphasizes the importance of overall dimensions in ichnospecies descriptions in concert with descriptive taxonomy.

Keywords: *Circulichnis*, ring trace, Paleozoic

As a simple ring-shaped trace found on bedding surfaces, *Circulichnis* Vialov, 1971, is easily distinguishable from other ichnogenera. As previous workers have noted (e.g., Uchman & Rattazzi 2019), traces that are interpreted as feeding traces should exhibit both entrance and exit openings. However, *Circulichnis* typically displays neither, casting both interpretations of ethology and trace construction hypotheses into doubt. Known from sediments dating from the Ediacaran period through to the Oligocene epoch, this trace is poorly understood, despite its large range and relative ease of diagnosis. Here we discuss a new occurrence of the ichnogenus from the Cambrian deposits of Central Texas.

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MATERIALS & METHODS

Location.–The material for this study is described from an outcrop exposure of the Lion Mountain Member (Cambrian) northwest of Burnet, Texas. The specific outcrop location is 4.8 km north of the intersection of Ranch Roads 2341 and 690 (Fig. 1). The Lion Mountain Member is recognized on the north side of Ranch Road 2341 as it curves westward around the glauconitic bluffs. GPS coordinates for the location are 30.8446° N, 98.3402° W.

Geologic Setting.–The late Cambrian period in Central Texas is represented by the Riley Formation, which was deposited along a passive margin of the Iapetus Ocean. It is composed of three members:

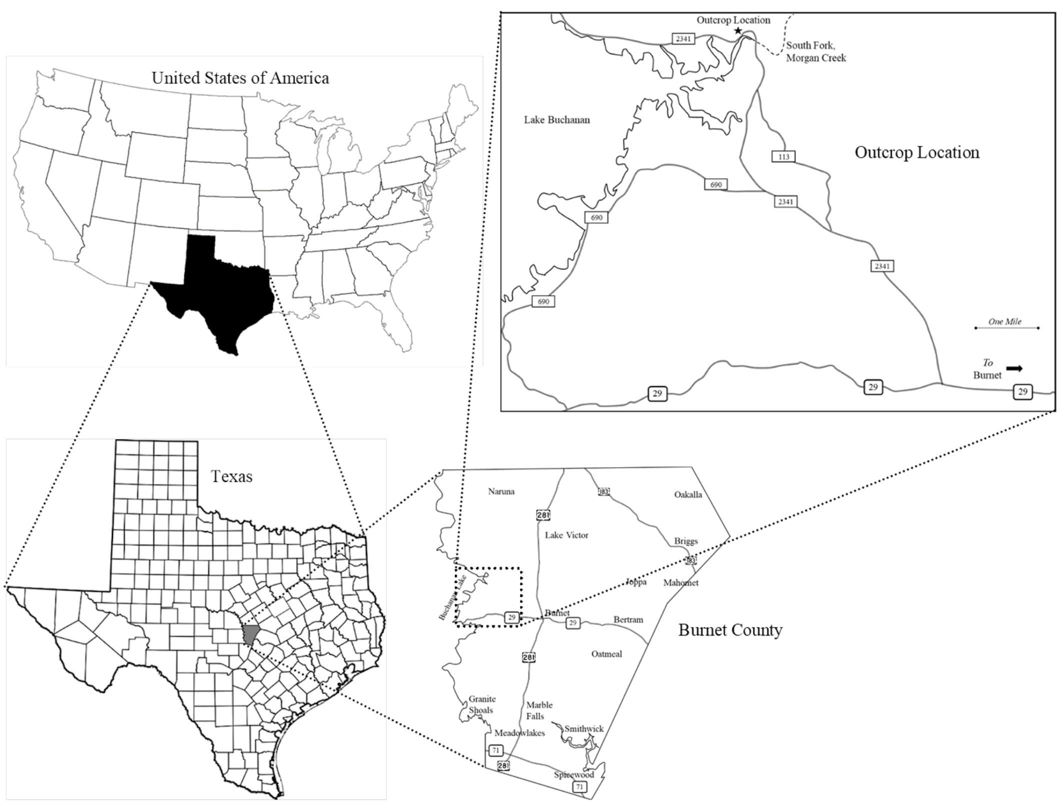

Figure 1. Field location map, with major roadways labeled and outcrop location marked with a star (GPS Coordinates: 30.8446° N, 98.3402° W).

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the Hickory Sand Member, the Cap Mountain Member, and the Lion Mountain Member. The cross bedded glauconitic sandstones exposed at this locality are typical of the Lion Mountain Member and are in agreement with previously published works (e.g., Comstock 1889; Sellards et al. 1912; Bridge 1937; Cloud et al. 1946; Dekker 1966). The Riley Formation unconformably overlies the Precambrian granitic Town Mountain Formation and displays an overall transgression of glauconitic quartz sandstone to a partially dolomitic limestone dominated system (e.g., Dekker 1966; Cornish 1975).

The Lion Mountain Member and related units have been studied sporadically. Originally described as part of the Potsdam Formation (Shumard 1861; Walcott 1884, 1891), the Potsdam Formation was later renamed as the Hickory Formation by Comstock (1889) due to its well-developed exposure in the vicinity of Hickory Creek. The Cap Mountain Formation, containing what would later become the Lion Mountain Member, was separated from the Hickory Formation by Paige (1912). Bridge (1937), in comparing the Texas units to the better studied Missouri sections, separated the Lion Mountain Member from the Cap Mountain Formation. Cloud et al. (1945) established the Riley Formation as the parent unit, and designated the Hickory, Cap Mountain, and Lion Mountain as members.

Specimens.–The material used for this study and ichnospecies description was found in float, interpreted by lithology, shape, and bedding characteristics to have fallen from approximately 6 m (20 feet) above from an overhanging ledge. Overprints of presumed *Circulichnis* are exposed in hypichnia on the overhanging ledge mirroring those of the specimens found in float, matching that of the described material. As the source bed was impossible to reach safely, the exact stratigraphic layer is not described in this study.

Eleven specimens of measured *Circulichnis leomonti* n. sp. are preserved on the surface of a single slab in apparent epichnia. These are easily discernable due to the contrast of the surrounding siltstone with the glauconized sandfill. The slab is roughly triangular in shape and

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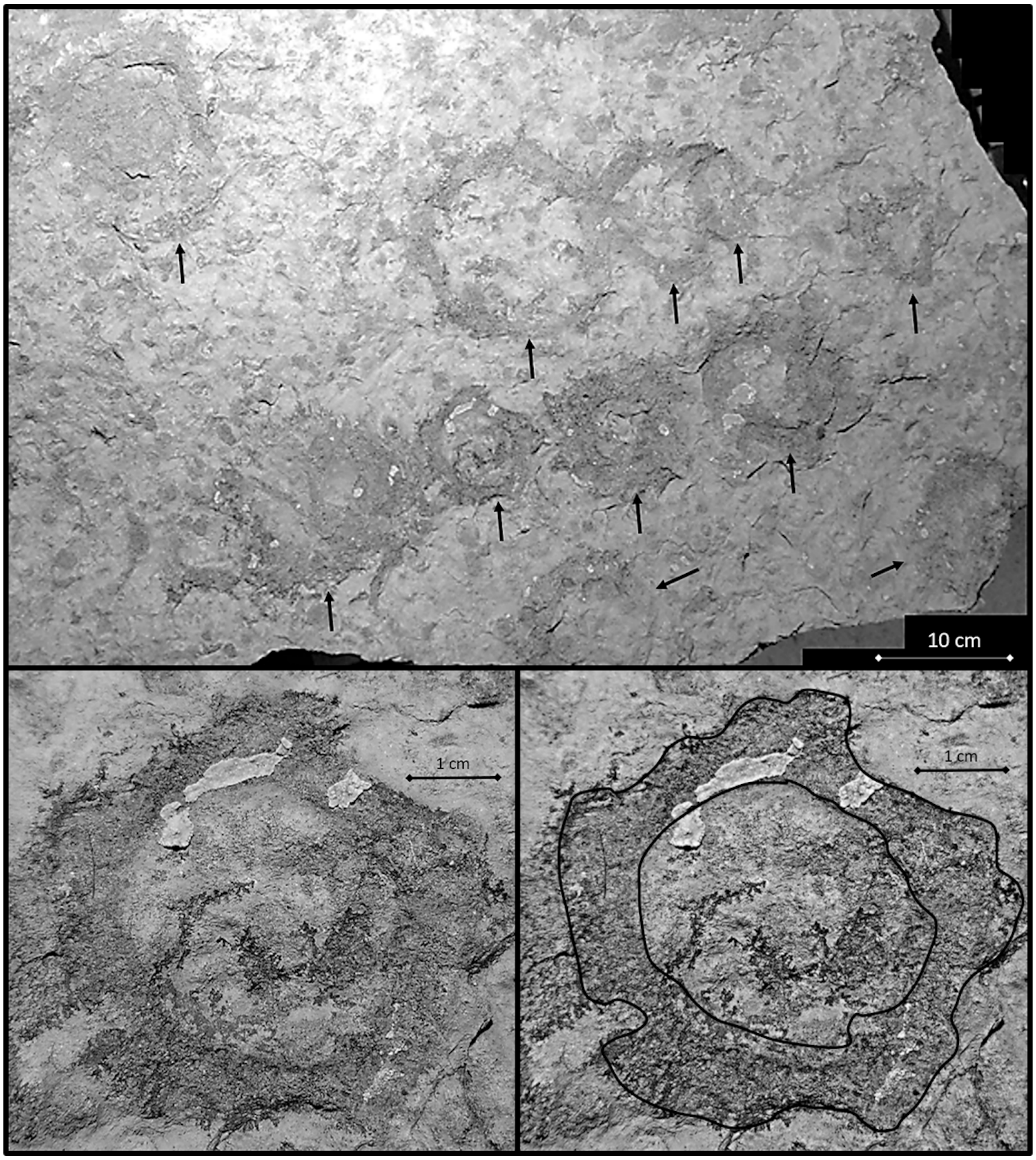

Figure 2. *Circulichnis leomonti* n. sp. *Top*: View of upper surface of the slab, with *Circulichnis leomonti* holotype and multiple paratypes, showing partial overlapping characteristic (indicated with arrows). *Lower left*: enlarged view of the *Circulichnis leomonti* holotype, demonstrating wide trace width and ring size. *Lower right*: outline of *Circulichnis leomonti* holotype, demonstrating multiple straight-to-slightly-curved sections.

measures 90 by 76 by 68 cm (35.5 by 30 by 27 in) on top and is 22.8 cm (9 in) thick. *Circulichnis leomonti* n. sp. is preserved along the upper surface of the slab (Fig. 2).

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RESULTS

Systematic Ichnology

Ichnogenus. *Circulichnis* Vialov, 1971

Type ichnospecies. *Circulichnis montanus* Vialov, 1971

Modified diagnosis (Uchman & Rattazzi 2019). Horizontal, circular to oval ring-like burrow.

Remarks.–This ichnogenus has had a long and convoluted history, especially considering its improper but accepted naming format (Keighley & Pickerill 1997; Uchman & Rattazzi 2019). While attempts have been made to change the genus name *Circulichnis* to the more common *Circulichnus* Keighley & Pickerill, 1997, this name is now considered as junior synonym of *Circulichnis* and is not recommended for use under Article 33.2 of the International Code of Zoological Nomenclature (ICZN) (Uchman & Rattazzi 2019).

The definition of *Circulichnis* has been subject to much mistranslation and interpretation without formal amendment for years; however, Uchman & Rattazzi (2019) thoroughly summarized these attempts over the years. Despite this, Uchman & Rattazzi (2019), in bringing the definition of *Circulichnis* closer to the original description in Russian by Viavlov (1971), missed a character which they indicated as important in distinguishing this ichnogenus from other, potentially similar traces. Specifically, the frequently looping and winding trace of *Gordia* Emmons, 1844 can be confused with overlapping *Circulichnis* if the diagnosis does not differentiate them on distinctive features; namely, the lack of apparent entrance or exit to *Circulichnis* in-plane with the trace is a distinct characteristic of this ichnogenus. Further, their use of the term ‘cylindrical’ is unfortunate, as it would potentially exclude those traces which formed from a non-cylindrical trace maker, e.g., oblong or other burrow shapes. Thus, the generic description above is further modified to reflect these physiognomies.

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Circulichnis leomonti new species (Fig. 2).

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Derivation of name. '*Leo*-', from the Latin, for 'lion'; '-*monti'* from the Latin, for 'mountain'. In reference to the Lion Mountain Member of the Riley Formation, from which it was discovered.

Type Material. NPL94419 (Jackson School of Geosciences Non-vertebrate Paleontology Lab, University of Texas at Austin); slab displaying eleven specimens; see Fig. 2 for location of type and paratypes.

Diagnosis. Horizontal trace in the shape of a continuous circular or ovoid ring, constructed by a series of linear to slightly curved connected segments, with wide string diameter, no breaks or deviant branches.

Type Description: The type specimen is one of many examples on the surface of the slab recovered from the Lion Mountain Member (Fig. 2). Type burrow is infilled with coarse sediment, distinguishing the coarse glauconitic sand infill from the fine silt walls. Burrow lining present, constructed of thinly laminated fine silt. The circular structure has a mean diameter of 29.71 mm with a mean burrow diameter of 8.46 mm. Burrow appears to be constructed of multiple lobes, which have been overlapped or chained together to create an elliptical structure. Further, burrows occasionally observed to continue into a looping double ring. No entrance or exit burrow apparent. Associated *Skolithos*-like vertical burrows and lingulid debris present throughout the material. Description and naming of specimen is in keeping with the recommendations of Bertling et al. (2006).

Paratype Descriptions: On the same slab (NPL94419) there are ten other burrows of *Circulichnis* present representing paratypes of *Circulichnis leomonti*. Burrows are variable in width (6–17 mm) and diameter (29–80mm). Burrows are infilled with coarse substrate and have fine-grained lining.

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Remarks. *Circulichnis leomonti* should be considered as distinct from *C. ligusticus, C. sinensis,* and from *C. montanus*. *Circulichnis leomonti* presents a distinct physiognomy in the ratio between its burrow diameter and overall ring diameter, which varies considerably from that of the other three species (Fig. 3, 4). Additionally, this trace is observed to continue into a double ring pattern, a characteristic unreported for other *Circulichnis* species.

Of the two *Circulichnis* ichnospecies recognized by Uchman & Rattazzi (2019), *C. leomonti* is more similar to that of *C. montanus. Circulichnis montanus,* as described by Viavlov (1971) and redescribed by Uchman & Rattazzi (2019), is diagnosed as a "horizontal, cylindrical burrow, which shows a course along a regular circle or ellipse." The

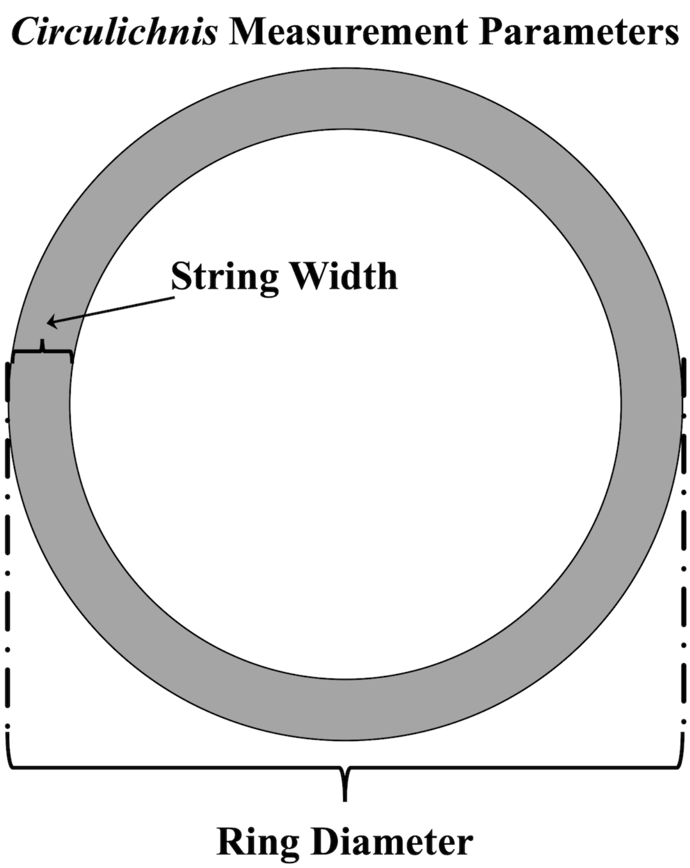

Figure 3. Generalized *Circulichnis* measurement parameters: diameter of burrow and ring structure.

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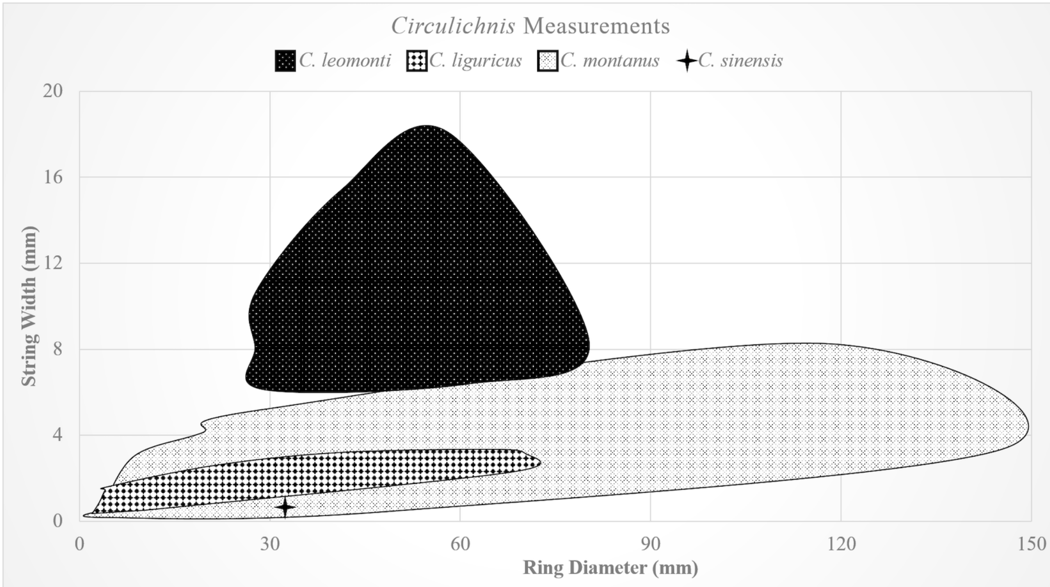

Figure 4. Plotted maximum ring diameters and burrow cross-sections *for C. leomonti, C. ligusticus, C. sinensis*, and *C. montanus*, with convex hulls plotted for each.

description is non-specific in regards to ratios of those parts, which greatly affects the overall aspect of the trace, and should be taken into account. Uchman & Rattazzi (2019), in their remarks, suggested that *C. montanus* should be limited in a scope similar to the type species dimensions, with a ring diameter of 35–41 mm, a string width of 0.7–1.5 mm, and trace vertical height of 1.5 mm (Fig. 4). Confusingly, Uchman & Rattazzi (2019) also suggested that the distinction between *C. montanus* and *C. ligusticus* is arbitrary and all other derivations of *Circulichnis* should be ascribed to either *C. montanus* or *C. ligusticus*. This is rejected, as it excludes any other morphology of *Circulichnis*, including *C. leomonti*, which shows distinctions from both *C. montanus* and *C. ligusticus*.

The second species, *C. ligusticus* (Uchman & Rattazzi 2019) possesses a ‘knotted’ or broken/winding characteristic to the trace, and is unlike any sample observed of *C. leomonti*. While *C. leomonti* is segmented, the trace maintains a continuous course and does not

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deviate from circumscribing an ellipse, unlike *C. ligusticus*. In addition, the overall ring diameter and trace ring width of *C. ligusticus* are typically very small, less than half of the size of the typical *C. leomonti*. *Circulichnis montanus* is much more variable and demonstrates a large distribution through time.

Fan et al. (2021a, 2021b) have revived *C. sinensis* Yang 1990 as an ichnospecies, despite its rejection by Uchman & Rattazzi (2019). *Circulichnis sinensis* provides a differing interpretation of the genus, with multilobate segments to the ring-like burrow. Fan et al. (2021a) recognized that there may be taphonomic factors influencing the discernibility between *C. sinensis* and *C. montanus*, but emphasized that they should be kept distinct. Fan et al. (2021b) later demonstrated that *C. sinensis* may be a linking of complex segments approximating a ring-like burrow or feeding structure. In comparison to *C. leomonti*, *C. sinensis* is apparently more fragmented in the figured type specimen; however, this distinction is blurred by the differing morphologies of *C. sinensis*. As the segmentation of *C. sinensis* is debated, and the potential overlap between *C. sinensis* and *C. montanus*, we recommend that *C. sinensis* be held as a distinct ichnospecies of the genus.

Discussion

Ethology.–*Circulichnis* is identified from a variety of environments and time periods and lacks interpretable features, making ethological determination difficult. It is suggested that this simple trace is made by a variety of organisms. Viavlov (1971) attributed the trace to a simple locomotory action by a worm or worm-like animal. Buatois & Mangano (2011) considered this to be a simple, shallow tier feeding trace and implied that the likely trace maker was an arthropod. While other authors have agreed with the fodichnion assertion (e.g., Uchman & Rattazzi 2019), the lack of definitive scratch traces or joint impressions makes arthropods a less viable candidate over more smooth sided or flexible organisms, such as annelids or polychaetes. Uchman & Rattazzi (2019) attributed the large stratigraphic range (Cambrian–Recent) of this trace as evidence for an organism with an expansive

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evolutionary history for formation of *Circulichnis*. Simple vertical shafts, likely *Skolithos*, occur in the same bed as *C. leomonti.* There is a high preponderance of lingulid brachiopod and trilobite debris in the beds, and it is likely that the *Skolithos*-like burrows were formed by these organisms, although that in no way implies that *C. leomonti* was formed by the same. The variability in burrow width and overall ring construction leaves further room for doubt in ascribing a specific trace-maker or group to this ichnogenus. These observations, in conjunction with the broad stratigraphic range and presumed environments, from deep-marine to deltaic to fresh water, for *Circulichnis* make designation of ethology incredibly difficult and potentially suggest convergent behaviors among a variety of trace producers.

Taphonomic Considerations.–Fan et al. (2021b) discussed the taphonomic considerations of *C. sinensis* and related traces in detail. Of particular interest are the many angled burrows which were demonstrated to have interconnected to create the ring-like structure known as *Circulichnis*. While it is not known if this is how all *Circulichnis* were constructed by their trace makers, or if this demonstrates a connection to other, more elaborate ichnogenera, this material does demonstrate that taphonomy may have a role in the appearance of *Circulichnis* traces through time; *i.e.,* the lack of entrance or exit burrows, as well as the overall shape, may be an effect of the taphonomic constraints, rather than purely burrow construction.

Conclusion.–*Circulichnis leomonti* demonstrates a new and distinct morphology among *Circulichnis* traces in both size and trace construction. The size of the trace is large, especially considering the trace ring width, which is many times larger than that of the type specimens of *C. ligusticus* and *C. montanus*. The segmented path construction is also distinct compared to other *Circulichnis* species. The occurrence of *C. leomonti* in the Cambrian is indicative of experimental organism behavior, or indicative of early *Circulichnis* trace construction techniques. This is important, as it clearly demonstrates that *Circulichnis* is not limited to simple ellipses or circuitous paths, and may provide further insight into the ethology of the trace maker.

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