Title

A New Species of an Enigmatic Fossil Taxon: Ischadites n. sp., a Middle Ordovician Receptaculitid From the Great Basin, Western USA

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Publication Date

2014

Peer reviewed|Thesis/dissertation

UNIVERSITY OF CALIFORNIA
RIVERSIDE

A New Species of an Enigmatic Fossil Taxon: *Ischadites* n. sp., a Middle Ordovician Receptaculitid From the Great Basin, Western USA

A Thesis submitted in partial satisfaction
of the requirements for the degree of

Master of Science

in

Geological Sciences

by

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June 2014

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ACKNOWLEDGEMENTS

First and foremost, I would like to express my sincere gratitude to my advisor, Dr. Mary L. Droser, for her continuous support throughout my graduate studies, field work, and research. I'd additionally like to thank the rest of my committee: Dr. Nigel C. Hughes and Dr. Richard Minnich for their encouragement, insight, and guidance. Dr. Ganqing Jiang of the University of Nevada, Las Vegas, assisted with stratigraphic measurements and provided valuable consultation on sedimentological interpretation in the field. Illustrations of *Ischadites* n. sp. were produced by my very talented brother, Mr. Keith R. Henry. Several field assistants allowed for large bulk sampling of fossils over multiple field work excursions: T. Beck, M. Nonu, R. Theroux, and J. Minor. Special thanks to L. Graham and T. Beck for lab work assistance. Field work required for this project was funded by the Geological Society of America, the Society for Sedimentary Geology, and the Gulf Coast Section of the Society for Sedimentary Geology. Lastly, I have to thank my parents, Kim and Susan Henry, for their unwavering support, patience, and encouragement.

TABLE OF CONTENTS

Introduction 1

Geologic Setting..3

Location 3
Geologic History 4
The Pogonip Group (Goodwin Limestone and Antelope Valley Limestone) 9
Age 10
Depositional Environment 11
Arrow Canyon Range Lithofacies 13

Terminology..16

Previous Investigations 18

Methods and Materials..22

Systematic Paleontology 25

Diagnosis...25
Description...26
Data 29
Size...34
Ontogeny..35

Microstructure...36

Outer Plates...36
Merom Interlocking Pattern..37

Discussion 40

Comments on Previous Research...41

Conclusions...42

Photographic Plates...43

References...45

Appendix I 53

LIST OF FIGURES

Figure 1. Maps and photo of field location..4

Figure 2. Correlation of the Ordovician units in Great Basin area 8

Figure 3. Stratigraphic age relationships in Great Basin 11

Figure 4. Schematic diagram of formations and depositional environments.....................12

Figure 5. Photographs of macluritid gastropod and *Girvanella* oncoids 13

Figure 6. Stratigraphic columns...15

Figure 7. Schematic diagram of receptaculitid to illustrate terminology...........................17

Figure 8. Reconstructions of adult form of *Ischadites* n. sp. 26

Figure 9. Graph of body length vs. body width 29

Figure 10. Graph of length of nucleus to lacuna midpoint vs. lacuna diameter 30

Figure 11. Graph of length from nucleus to lacuna vs. width at that point 31

Figure 12. Graph of distance from nucleus vs. merom concentration 32

Figure 13. Graph of body length vs. nuclear angle...33

Figure 14. Size distribution histograms 34

Figure 15. Reconstructions of four ontogenetic stages in *Ischadites* n. sp. 35

Figure 16. Photograph of outer plates in *Ischadites* n. sp. 36

Figure 17. Microscopic photograph of cross-sectional view of specimen.........................38

Figure 18. Schematic diagram of microstructure of *Ischadites* n.sp.................................38

Figure 19. Photograph of tangential rays exposed by weathering 39

Figure 20. Photograph of *Ischadites barrendei* 40

LIST OF PHOTOGRAPHIC PLATES

Photographic Plate 1 43

Photographic Plate 2 44

LIST OF TABLES

Table 1. Data on body length vs. body width 29

Table 2. Data on length of nucleus to lacuna midpoint vs. lacuna diameter 30

Table 3. Data on length from nucleus to lacuna vs. width at that point.............................31

Table 4. Data on distance from nucleus vs. merom concentration 32

Table 5. Data on body length vs. nuclear angle..33

INTRODUCTION

Receptaculitids are calcareous, marine, solitary, invertebrate fossils that were locally common during the Ordovician through Devonian Periods. These generally globose fossils have a relatively simple gross morphology but a mineralogically complex skeleton. Receptaculitids are identified by the intricate network of distinctive skeletal elements called meroms, which are unknown in any other organism. Each receptaculitid body structure consists of up to thousands of individual meroms that are interwoven with neighboring meroms in a Fibonacci-like helicoid arrangement, ultimately producing beautiful, tightly tessellated outer surfaces. This enigmatic fossil taxon has fueled a phylogenetic debate among paleontologists for over 200 years and has been variously classified as sponges, calcareous green algae, and an extinct clade of problematic organisms that are unrelated to any other taxa (Nitecki et al., 1999). A definitive conclusion on their taxonomic affinity is still yet to be resolved.

Receptaculitids first appear during the Early Ordovician and are relatively common in Ordovician limestones and dolomites, utilized locally as index fossils. Along with sponges, receptaculitids were the largest sessile benthic organisms during Early to Middle Ordovician time and occupied reef environments that had previously been occupied by the archaeocyathids, but were essentially vacated by the Late Cambrian (Nitecki et al., 1999). Receptaculitids are known from all continents except Antarctica and remained widespread through the Middle Devonian. Receptaculitids became rare by the Late Devonian and disappeared during the Permian Period (Nitecki et al., 2004).

This paper defines a new species of Middle Ordovician receptaculitid from the Arrow Canyon Range in the Great Basin, *Ischadites* n. sp. These fossils exhibit a unique morphology and are restricted to a small geographic range in eastern California and southern Nevada. A discussion of the geologic setting, history, and depositional environment of the collection site is presented here. Receptaculitid terminology is defined, previous investigations reviewed, and methods and materials outlined. The systematic paleontology of *Ischadites* n. sp. is presented with investigations into morphology, size, ontogeny, and microstructure, followed by discussion on results, comments on previous research, and conclusions.

GEOLOGIC SETTING

Location

The Arrow Canyon Range (ACR) lies within the Basin and Range Province, a region characterized by north-south trending mountain ranges separated by semi-arid, alluviated valleys. The ACR trends north-south and runs approximately 40 km long and ranges from 1 to 6 km in width, and the field location for this study lies on the western flank. This is located in the Arrow Canyon quadrangle map, which ranges from 36.325° N to 36.750° N latitude and 114.875°W to 115.000°W longitude (Page, 1998). The ACR is located in southeastern Nevada and runs parallel to the I-93, which branches off of the I-15 approximately 41.4 km (25.7 mi) northeast of Las Vegas, Clark County, NV. The receptaculitids are restricted to a very narrow horizon of a few meters of strata, with the primary collection site located at 36.726° N and 114.892° W (Figure 1). The site is accessible from the I-93, turning off the eastern side of the road just north of mile marker #77 at 36.721° N, 114.933° W. Travel east on the graded gravel and dirt road for 2 miles until the road dead-ends relatively close to the base of the range, where Member C of the Pogonip Group unit dips to the subsurface (Gunn, 1998).

Figure 1. Moving clockwise, top left map (maps.google.com) shows location of the ACR field location in southeastern Nevada in the western United States; right map (maps.google.com) shows location in relation to highways and Las Vegas, NV; bottom left depicts the Arrow Canyon Range, with the collection site located well below the dark band of Devonian strata and 80 m below the base of the thin orange band (Eureka Quartzite).

Geologic History

The evolution of the Great Basin from the late Proterozoic to the present time can be characterized as follows:

1. From Late Proterozoic (~800 Ma) to mid-Paleozoic time (~375 Ma), intracontinental extension led to the development of a passive continental margin (Levy & Christie-Blick, 1989). A miogeoclinal wedge formed thickening westward along the eastern margin of the Great Basin to over 6,000 m in thickness, the upper portion of which consists of peritidal carbonates and mudstones of Middle Cambrian to Devonian age (Stewart & Poole, 1974).
2. From the late Devonian (~375 Ma) through early Eocene time (~50 Ma), there was crustal shortening, accretion of terranes of varying affinity, and subduction-related magmatism (Levy & Christie-Blick, 1989). From Mesozoic to early Cenozoic time, especially from ~150 to ~50 Ma, most of the overall crustal shortening occurred along the eastern margin of the Great Basin with deformation migrating progressively toward the east. Thrusting was mostly eastward and overall crustal shortening is estimated to have been at least 104-135 km (Levy & Christie-Blick, 1989). In the Late Tertiary, the North American Plate overrode a segment of the East Pacific Rise, creating extensive fault blocks that produced the north-south trending mountain ranges of the Basin and Range complex (Osmond, 1971).

3. From mid- to late Cenozoic time (~37 Ma) to the present time, the entire region between the Colorado Plateau and the Sierra Nevada was subject to lithospheric extension and widespread magmatism (Levy & Christie-Blick, 1989).

The regionally conformable Cordilleran miogeocline is exposed across the entire width of the Basin and Range province near the latitude of Las Vegas, and although disrupted by Mesozoic thrust faults, these faults are distinctive and well-spaced enough that long sequences of Paleozoic strata can be well-studied and age-constrained (Wernicke, Axen, and Snow, 1988). Exposure is generally excellent in the region because it lies at low elevation and in the rain shadow of the Sierra Nevada and carbonate rocks crop out especially well in desert regions (Wernicke et al., 1988). Over 3,000 m of late Cambrian through Permian rocks (primarily carbonates) crop out within the Arrow Canyon Range near Las Vegas in Clark, County, Nevada (Langenheim et al., 1962). Between the Pogonip Group (more recently separated into the Goodwin Limestone and Antelope Valley Limestone by Page, 1998), Eureka Quartzite, and Ely Springs Dolomite, there are nearly 900 m of exposed Ordovician strata at the ACR (Langenheim et al., 1962).

Stratigraphic Framework

Ordovician stratigraphy in the Basin and Range province is characterized by stratigraphic sections as thick as 1500 m in provincial basins on the carbonate platform (Droser and Sheehan, 1997). Ordovician strata are divided into Lower, Middle, and Upper units.

After the late Cambrian, carbonate shelf sedimentation patterns in the western United States shifted: outer-shelf-edge or slope limestones graded eastward into interior-shelf, shallow-water algal banks, which prograded intermittently westward through Ibexian (Lower Ordovician) time within equatorial latitudes (Ross, 1977). There are approximately 800 m of predominantly shallow subtidal and intertidal platform carbonates and calcareous siltstones, including formations such as the House Formation, Fillmore Formation, Wah Wah Limstone, Goodwin Limestone, and Ninemile Shale (Ross, 1977); (Figure 2).

Whiterockian (Middle Ordovician) deposition was initiated by the accumulation of shallow-water carbonate mounds, followed by the extensive deposition of great algal banks covering most of southern and east-central Nevada (Ross, 1977). East and north of this bank was a lagoonal system floored by green muds of the richly fossiliferous Kanosh Shale (Ross, 1977). Additional middle Ordovician units in the Great Basin include the Antelope Valley Limestone, Juab Limestone, Lehman Limestone, and Crystal Peak Dolomite (Ross, 1977); (Figure 2). There are indications that there was a brief transgression of the carbonate shelf in the north during early Whiterockian to late Whiterockian time (Ketner, 1968). By earliest Cincinnatian time (Late Ordovician), sand smothered nearly all carbonate deposition (Ross, 1977). At the ACR, this extensive sand deposition is recorded as the Eureka Quartzite (see Figure 6).

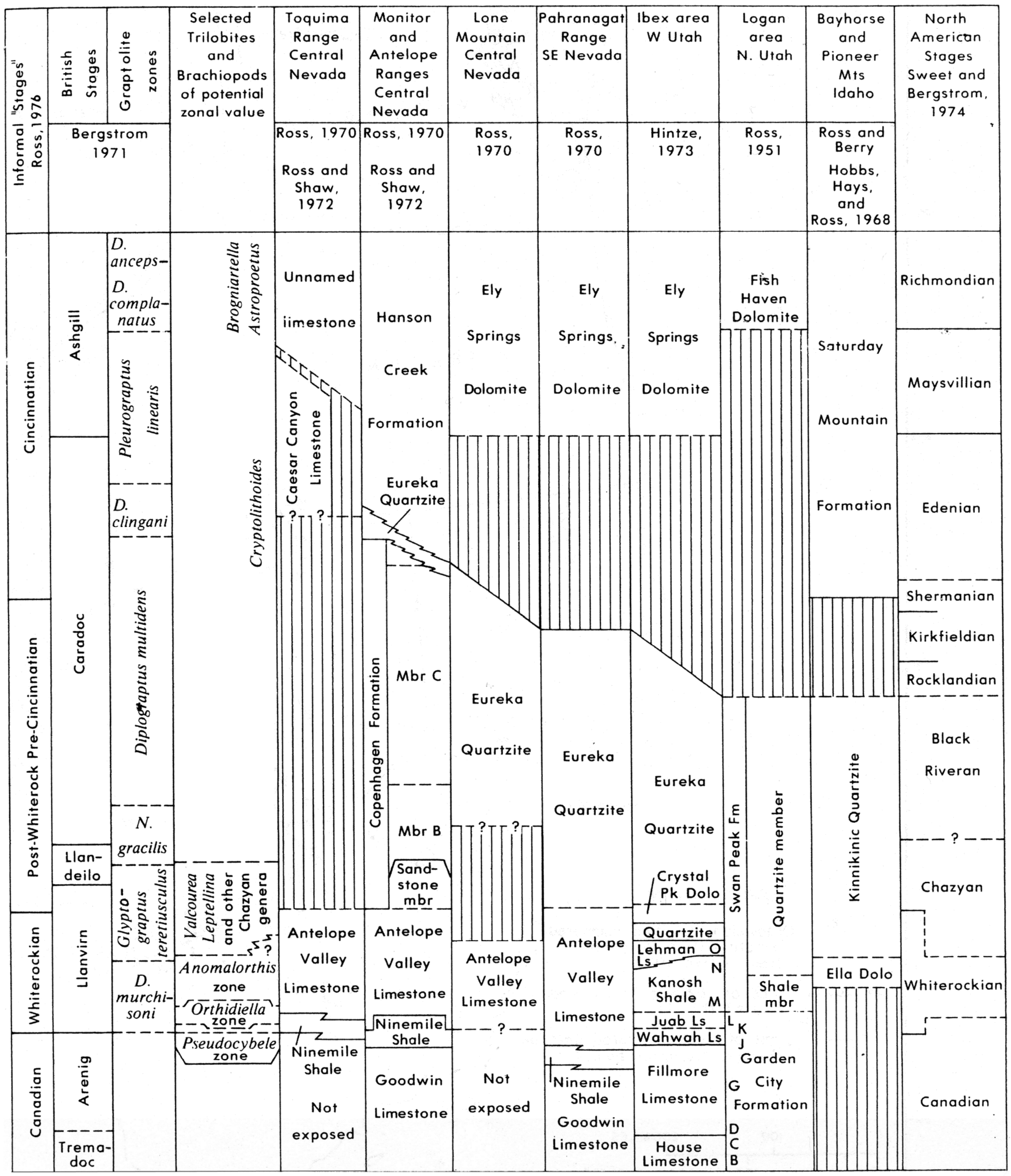


Figure 2. Correlation of the Ordovician units in key areas of the Basin Ranges (from Ross, 1977).

The Pogonip Group
(Goodwin Limestone and Antelope Valley Limestone)

The Middle Ordovician Pogonip Group is recognized across a large portion of the Great Basin of the western United States of America. The Pogonip Group is approximately 730 m thick at the ACR and is subdivided into six units, Members A through F and noted as Opa, Opb, Opc, Opd, Ope, and Opf (Langenheim et al., 1962). Well-preserved receptaculitids occur in great abundance in limestones of the Ordovician Pogonip Group Member F (Opf). This portion of strata in Opf correlates to the Antelope Valley Limestone (Nolan et al., 1956). The most recent USGS quadrangle map of the Arrow Canyon Range (Page, 1998) reassigns the Pogonip Group strata with its 6 members Opa through Opf (Langenheim et al., 1962), in favor of the Goodwin Limestone (Opg) and the Antelope Valley Limestone (Opa – not to be confused with Langenheim's identically abbreviated term for Member A of the Pogonip Group).

Nolan et al. (1956) divided the Pogonip Group into three different formations at Eureka, Nevada. In agreement with Hintze (1951), the definitions selected for the Pogonip Group confine the group name to post-Cambrian rocks. The Goodwin Limestone is the lowest formation of the three and is composed of well-bedded, massive, gray limestones. The Ninemile Formation (which is not present at the ACR) overlies the Goodwin Limestone and is composed of platy, thin-bedded limestones. The uppermost of the three formations, the Antelope Valley Limestone, consists of thick-bedded, massive, medium-gray limestones with abundant fossils. Receptaculitids occur in the Antelope Valley Limestone in many locations throughout the Great Basin (See Appendix I).

Age

Langenheim et al. (1962) documented the first detailed description of the Arrow Canyon Range, measuring 2400 feet (732 m) of the Pogonip Group. They divided this strata into the previously mentioned units of Opa through Opf: Ordovician Pogonip Group Members A through F. Ross (1964) correlated Opa to both the Goodwin Limestone and Ninemile Formation and correlated Opb through Opf to the Antelope Valley Limestone. Siewers (1995) refined the ages for parts of the Pogonip Group by using established trilobite-brachiopod zones in the Great Basin in conjunction with mid-continent and North Atlantic conodont zones. At the Arrow Canyon Range, he assigned Opd to Ibexian time, Ope to Lower to Middle Whiterockian time, Opf to Middle Whiterockian time, and the Eureka Quartzite to Upper Whiterockian time (Figure 3). In this system, the Whiterockian Series represents approximately 12 million years of Early Middle Ordovician time (Siewers, 1995). The collection site for this paper lies in Opf, which is stratigraphically equivalent to the Upper Antelope Valley Limestone, the Crystal Peak Dolomite, the Lehman Limestone, and the Kanosh Shale based on the aforementioned criteria.

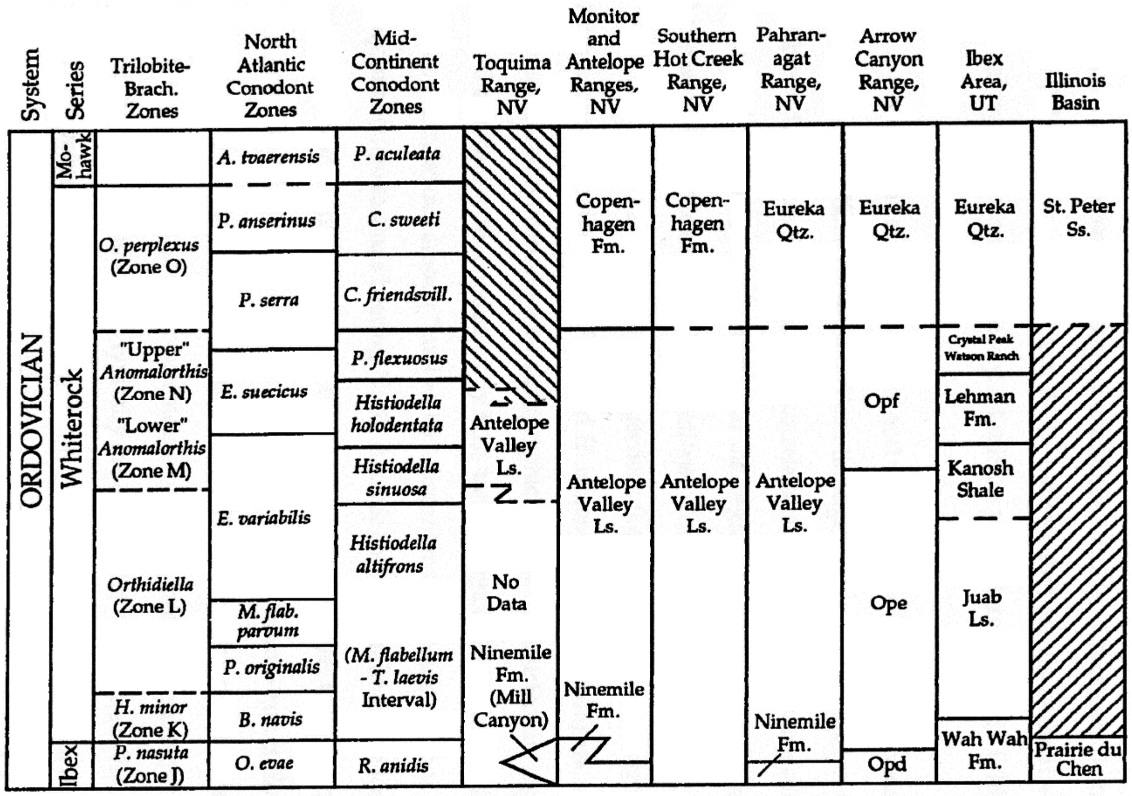


Figure 3. Stratigraphic age relationships based on established trilobite-brachiopod zones in the Great Basin and conodont zones across the United States (from Siewers, 1995, revised from Ross, 1977).

Depositional Environment

The paleogeography of the Great Basin during Whiterockian time consisted of a westward facing continental shelf and slope to deep basin that was approximately centered on the equator (Ross, 1989). At the time, the field location at ACR was in shallow, tropical ocean waters off of the western coast of Laurentia and in the equatorial zone (Ross, 1977). Ross et al. (1989) classified the Whiterockian miogeocline into two major depositional facies based on lithologic and stratigraphic framework: the platform facies (nearshore setting) and the shelf edge or platform margin facies (the edge of the carbonate shelf). The collection site is part of the shelf edge or platform margin facies, characterized by an oncolotic shoal unit between the shelf and slope facies, discontinuous outer-shelf, scattered spongal buildups, and a peritidal carbonate lithofacies consisting of meter-scale cycles of subtidal, intertidal, and supratidal sequences (Ross et al., 1989; (Figure 4)).

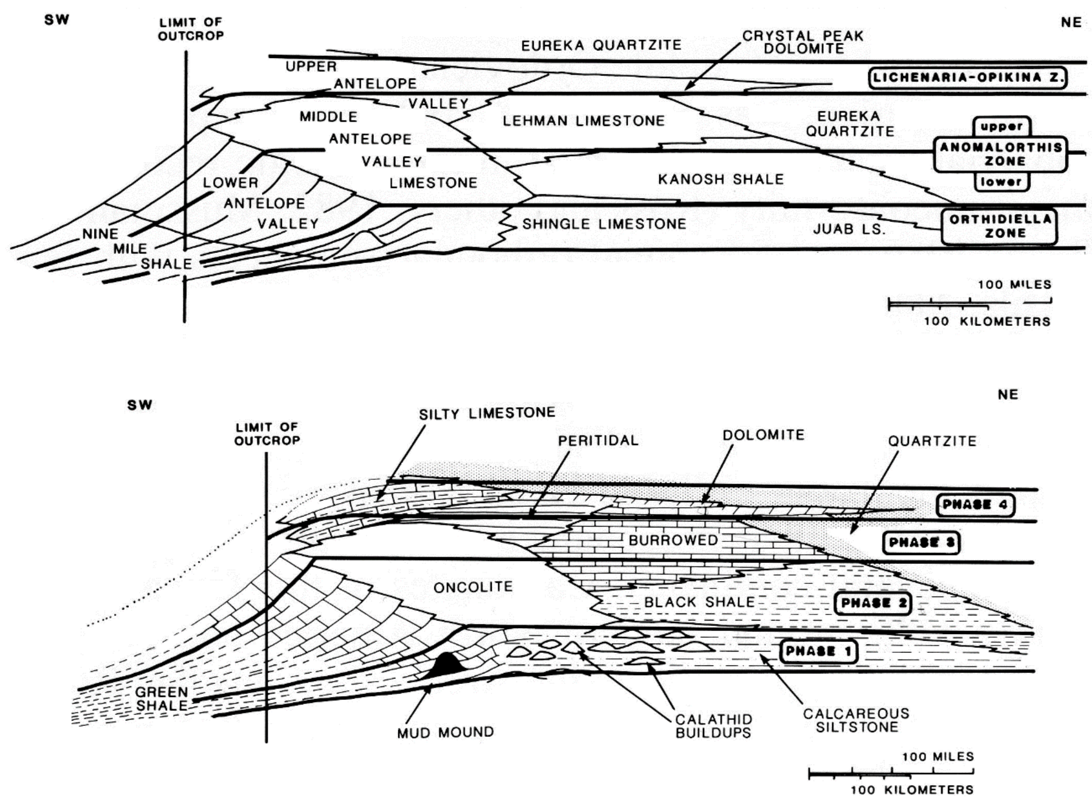


Figure 4. From Ross et al., 1989 – Schematic diagram of formations and depositional environments.

Siewers (1995) modified Ross et al.'s (1989) depositional facies to lithological units on the basis of wave base interpretations from detailed field and petrographic analysis. The collection site for this study (previously assigned to the platform margin facies by Ross et al., 1989) was reassigned to the "middle ramp facies" by Siewers (1995) in the subsidiary lithofacies of the argillaceous bioclastic wackestone-grainstone unit, characterized by receptaculitids, large, filter-feeding gastropod species *Palliseria* and *Maclurites* (Figure 5A), oncoids (Figure 5B), brachiopods, trilobites, bryozoans, ostracods, and echinoderms (for a complete, detailed listing of Siewer's facies descriptions and subsidiary lithofacies descriptions, see Siewers, 1995.). Throughout the Great Basin, receptaculitids are commonly found in conjunction with the extensive *Girvanella* oncolitic shoal banks and *Palliseria* and *Maclurites* snails, and the ACR displays this same assemblage type. It is relatively uncommon to find receptaculitids in the Great Basin in the absence of these other components, and this assemblage has become somewhat of a trademark of the Antelope Valley Limestone to Great Basin geologists.

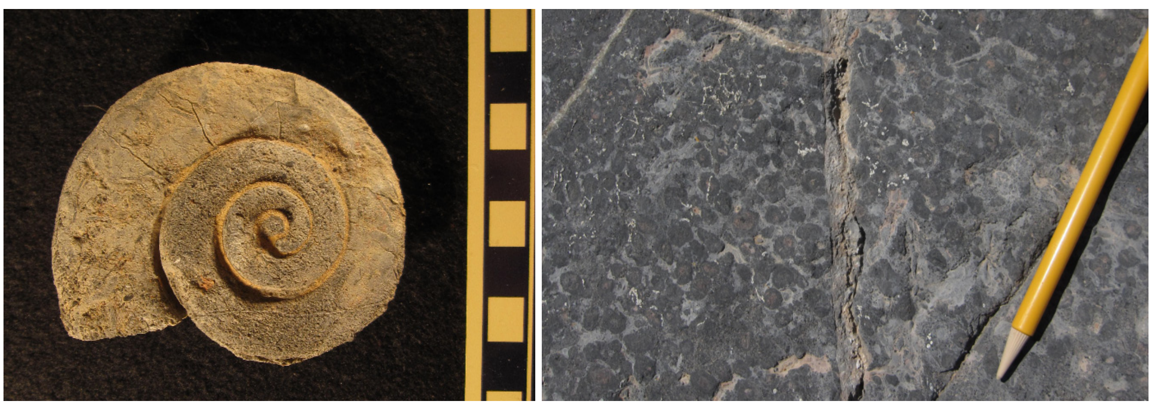


Figure 5A. (Left) Photograph of a representative macluritid snail fossil collected from ACR, with cm scale bar. **5B**. (Right) Photograph taken in the field of densely packed *Girvanella* oncoids located just below the receptaculitid horizon at ACR. The pencil included for scale is approximately 8 mm in width.

Arrow Canyon Range Lithofacies

The primary lithologies in Opf (lower Middle Whiterockian) are grainstones and wackestones with interbedded mudstones (Figure 6). The receptaculitids are restricted to a narrow horizon of approximately 5 m, starting 20 m above the base of Opf in bioclastic packestone. This lithofacies consists of thin to thick interbedded packestones that are medium gray and can weather to a brown-orange color. Receptaculitids are abundant and range in size from 2 cm to 19 cm in length. *Girvanella* oncoids (Figure 5B) are common, but less common than lower in Opf (Figure 6). *Palliseria* and *Maclurites*, large, filter-feeding snails, are common and can range up to 6 cm in size (Figure 5A). Also common are crinoid ossicles, bryozoans, fragments of orthoconic cephalopods, orthid brachiopods, and rare fragments of trilobites. For a complete analysis and description of the entirety of the Opf unit, see Gunn (1998), who assessed the paleoenvironment and paleoecology of Opf and also addressed its unusual lack of abundance and dominance of brachiopods and trilobites.

The paleoenvironment at the collection site is interpreted to be one of subtidal nature, based on abundant shell fragments and bioturbation, placing it between fairweather wave base and storm wave base (Gunn, 1998; Siewers, 1995). It has slightly less energy than the oncolitic-grainstone lithofacies present below it, based on the less abundant oncoids and the presence of significant amounts of silt at the receptaculitid horizon. Based on this information, it is interpreted that the receptaculitids were likely inhabiting the area of the oncolitic shoal that was just over the crest of the oncolitic shoal unit on the eastern, lagoonal side. This is in disagreement with other previously suggested receptaculitid life positions as at the crest of the oncolite bank (Kaya, 1997). Energy levels at the crest of the shoal would have been too high to allow for the deposition of silt that is found associated with the receptaculitid horizon at the Arrow Canyon Range. The *Girvanella* (cyanobacteria) oncoids imply a high-energy, subtidal environment, with a water depth of at least 6-12 m and in a position near the paleoequator (Kaya, 1997).

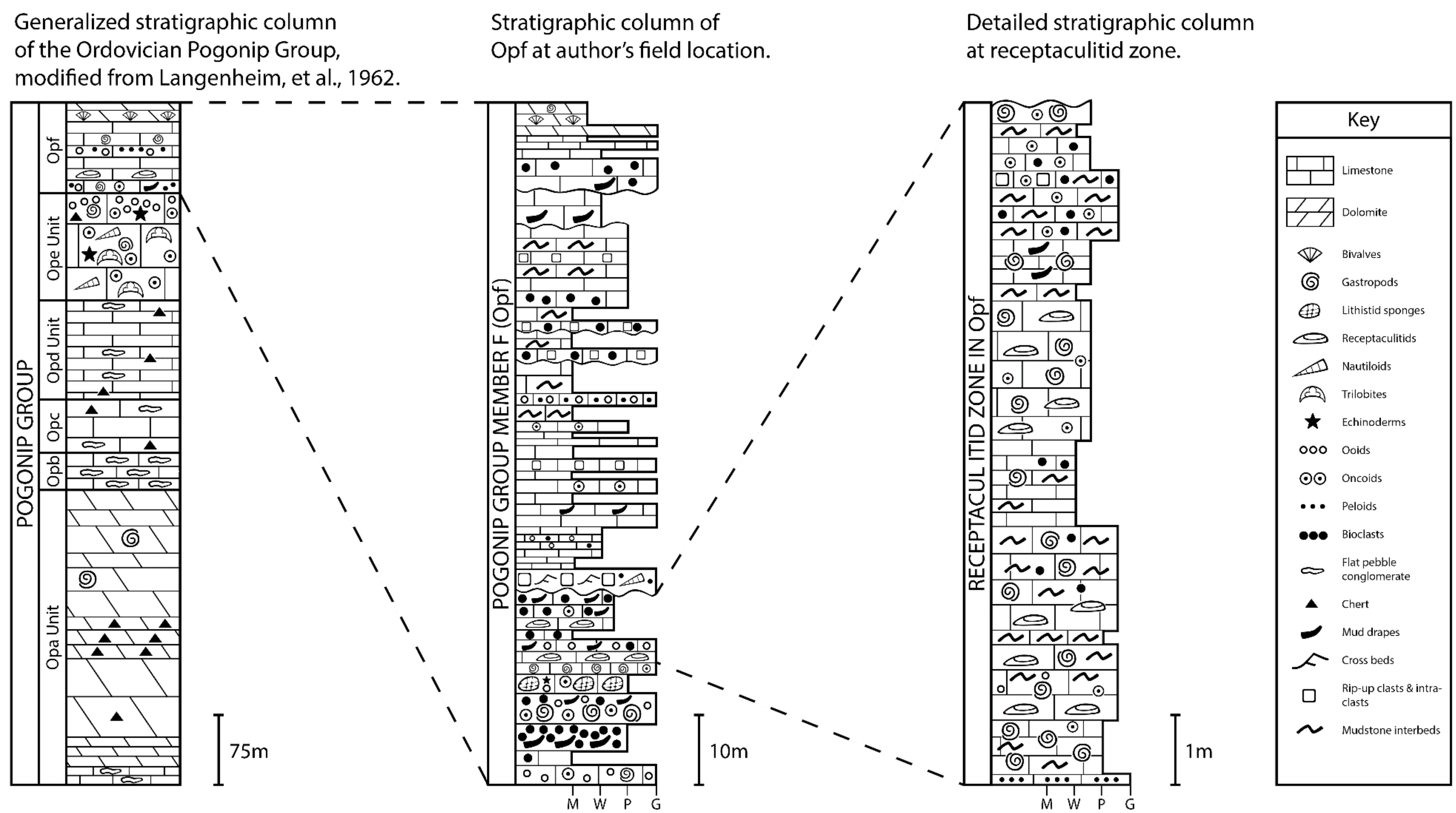


Figure 6. Stratigraphic columns. Leftmost column is based on Langenheim et al. (1962) and the two rightmost columns were measured for this study. Constructed by K. R. Henry, 2014.

TERMINOLOGY

Because receptaculitids have been aligned with both algal models and sponge models by previous authors, the terminology used in publications on these organisms has fluctuated regularly. Since the phylogenetic relationships of receptaculitids are unknown, the terminology used to describe their morphology should be as neutral as possible so as not to imply function or phylogenetic relationships (Nitecki et al., 1999). Neutral terminology was established by Nitecki (et al., 1999) and was based on Rauff (1892a), Rietschel (1969), Fisher and Nitecki (1982a), and Finney et al. (1994). This terminology has been adopted for use here and is listed below with a few minor, noted exceptions.

Apex (Rauff) – Terminal end of the skeleton that is furthest from the nucleus.

Axiomorph - the central axis of symmetry, about which whorls or circlets of meroms are arranged.

Body – the receptaculitid body consists of two components, the *axiomorph* and the *meroms*. Also referred to as *thallus* in many papers (e.g., Finney et al., 1994).

Central cavity – the empty space at the center of each specimen.

Connecting neck – The short cylindrical process connecting the outer plate and the tangential rays.

Distal ray – the meridional tangential ray directed toward the apex. Of the tangential rays, the distal ray is the furthest below the outer plate.

Lacuna – The opening, aperture, or orifice around which the last-formed (oldest) lacunar whorl or circlet consisting of numerous meroms encircles

Lateral rays (Hinde) – the two tangential rays paralleling the horizontal row of elements.

Meridional rays (Rauff) – The two tangential rays paralleling the vertical row of elements that run from the nucleus to apex.

Merom – Each individual structural/skeletal element or unit in a receptaculitid specimen. These meroms are arranged in whorls about the axiomorph to create the body of the receptaculitid.

Nucleus – the acute, closed lower end of a receptaculitid, consisting of the first-formed whorl or circlet of four to eight meroms.

Outer plate – the rhombic or subrhombic structure located at the extremity of the element nearest the outside of the specimen. The plates cap the outer end of each shaft.

Proximal ray (Hinde) – the meridional tangential ray directed toward the nucleus. Of the tangential rays, the proximal ray is the closest to the outer plate.

Shaft – The portion of the merom directed toward the central cavity and situated below the tangential rays.

Tangential rays – The four blades lying approximately at right angles to one another and located slightly below the outer plate. These rays are distinguished from one another as the *lateral rays* and the *meridonal rays* (*distal and proximal*).

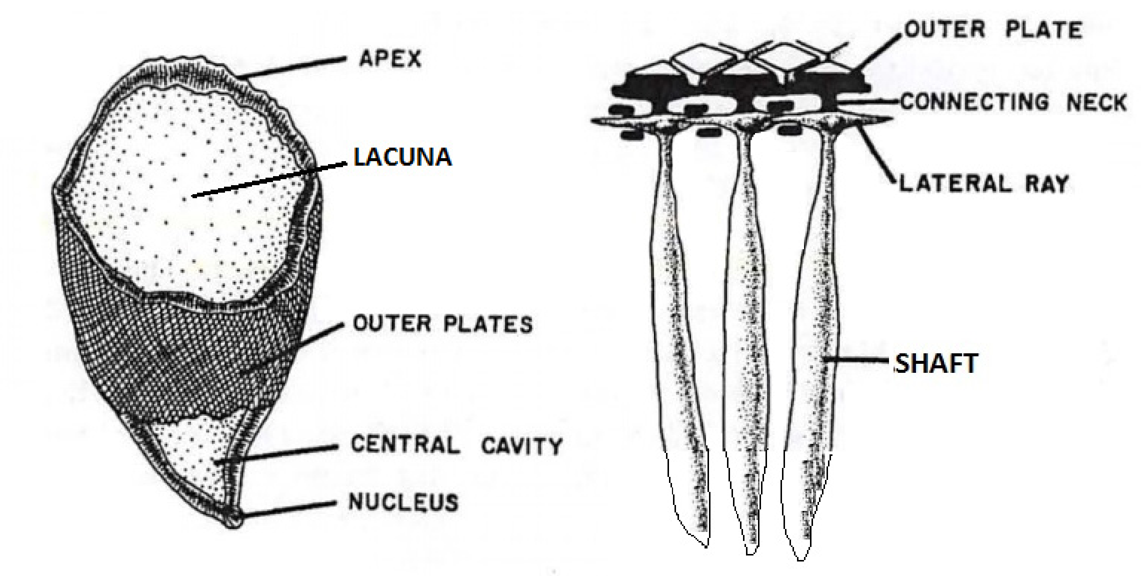


Figure 7. Schematic diagram of a receptaculitid to illustrate terminology (Modified from Foster, 1973).

PREVIOUS INVESTIGATIONS

Receptaculitids have fueled such a strong phylogenetic debate that even the highest taxonomic assignment has been questioned, with some authors assigning the organisms to Kingdom Animalia (suggesting they are sponges or sponge-like animals) and others to Kingdom Plantae (suggesting that they are a type of dasycladacean green algae). Barring their clear assignment to either sponges or algae is the inimitability of the way receptaculitids meroms are arranged: in whorls or circlets around the central axis of symmetry in a unique pattern that is absent in sponges and dasyclads (Nitecki et al., 2004). Another possibility is that receptaculitids are a problematic taxon that is neither poriferan nor algal, but rather a phylum unto its own: an initially successful marine taxon that met an evolutionary dead end (Nitecki et al., 1999). Despite the extensive and lengthy debate, the majority of paleontologists (especially in recent years) have largely shifted toward the position that receptaculitids are likely proper members of Kingdom Animalia (based on comprehensive receptaculitid classification index in Appendix I of Nitecki et al., 1999, and subsequent publications).

Receptaculitids have been extensively studied and at least 120 species have been named, 48 of them from the Ordovician Period (Nitecki et al., 1999). During the Ordovician Period, there were 4 families, 9 genera, and 48 species of receptaculitids. The three dominant receptaculitid families are Soanitidae, Ischaditidae, and Receptaculitidae (Nitecki et al., 1999) and are described below. The fourth family, referred to as "Family Unknown" by Nitecki et al. (2004) is composed of two monospecific short-ranged genera, both of which are based on a single locality (one in Kentucky and one in Ohio). Specimens were documented in the 1880s by Ulrich, who stated that their "position… is somewhat doubtful", that their "general aspect… is suggestive of the *Hexactinellidae*" [hexactinellid sponges], which aligns them with *Dictyospongidae* sponges and "less strongly, the *Receptaculitidae*" (Ulrich, 1889). In addition to this very weak suggestion of receptaculitid identification, these specimens lack fine preserved detail (Ulrich, 1889) that would allow proper study. Lastly, these two species lack the features characteristic of other receptaculitids (outlined below), such as a branching calathid structure or inner and/or outer rhomboidal or hexagonal plates. The three dominant receptaculitid families are Soanitidae, Ischaditidae, and Receptaculitidae (Nitecki et al., 1999).

The oldest receptaculitid family of these three is Family Soanitidae, commonly known as calathids. Soanitids are the only branching type of receptaculitids and they have a distinctive porous structure that lacks the distinctive outer plates all other receptaculitids possess. Soanitids have more recently been proposed to be reclassified into Phylum Porifera (Bingli et al., 2005) or a possible transition group between sponges and receptaculitids (Church, 2009). Family Ischaditidae have rhomboidal plates and take globular forms with fewer, larger plates relative to their body size when compared to some other receptaculitids. They are found relatively frequently throughout the Great Basin and around the world in shallow carbonates and siliciclastic sediments during the Ordovician (Appendix I). Its largest genus is *Ischadites*, with 12 species defined (Nitecki, et al., 2004). Lastly, Family Receptaculitidae is characterized by having an inner wall in addition to their outer wall, with plates at both the "head" and "foot" of each shaft. Ischaditids only have an outer wall of plates and do not have this additional inner wall and also have more slender shafts. The most common genus, and arguably the most well-known genus, within the Family Receptaculitidae is *Receptaculites*.

A special note on the incorrect usage of the genus name *Receptaculites*:

The proper term for a member of the Phylum Receptaculita is "receptaculitid". However, the genus name *Receptaculites* has frequently and incorrectly been used in place of "receptaculitid" in many publications, often when documenting the presence of receptaculitids within a stratigraphic column. Many Great Basin stratigraphers simply listed *Receptaculites* or *Receptaculites* sp. when they were often looking at *Ischadites* specimens, as *Receptaculites* had become the casual, overly-inclusive term for receptaculitids in general (Appendix 1). This is an incorrect usage and in fact, *Receptaculites* is a Devonian genus that is not present during the Ordovician (Finney & Nitecki, 1979). The only Ordovician genus from Family Recetaculitidae was *Fisherites* (Nitecki, et al., 2004) which is not recorded within the Great Basin.

This study addresses a unique morphotype discovered in the Middle Ordovician Great Basin at the Arrow Canyon Range. The only other example of this particular receptaculitid morphology (to be discussed in the next section) was described by Foster (1973) of samples he collected in temporally equivalent strata in the Grapevine Mountains of eastern California, approximately 200 km west of our ACR locality. Foster remarked that the specimens he collected seemed to fall into one highly variable species, *Receptaculites mammillaris* as named by Walcott (1884; and originally proposed in manuscript by Newberry, 1880). However, he noted that these specimens lacked the inner plates that are characteristic of *Receptaculites* and possessed longer and more slender merom shafts. Foster (1973) reassigned the species to *Ischadites* because of its greater similarity to species in that genus, but speculated that species differed enough from other species of *Ischadites* to provide some grounds for establishing it as the type for an entirely new genus of receptaculitids, although he did not propose one at the time. Foster (1973) collected approximately 75 specimens from his field area. Abundant receptaculitids at our field location at ACR has yielded over 300 collected specimens, which has provided a more clear view of the complex ontogeny of these organisms and a second opportunity to consider whether these unique and highly morphologically variable specimens are indeed 1.) a single species, 2.) if it is a new species, and 3.) if that species is different enough from other *Ischadites* species that it constitutes a new, monospecific genus, as Foster (1973) postulated.

METHODS AND MATERIALS

A section of 188 m was measured at the Arrow Canyon Range using a Brunton compass and Jacob's staff. Over 300 receptaculitid specimens were collected, the vast majority of which were collected from float just below the narrow receptaculitid horizon located approximately 25 m above the base of the Pogonip Group Member F (Opf). Many samples stood out in relief from the outcrop, providing helpful data regarding life orientation. *In situ* samples were also collected by breaking off blocks with a sledgehammer, noting the orientation on the sample, and recording the collection site within the measured stratigraphic column. While many specimens were conveniently weathered out of the limestone matrix, others required portions of matrix material to be carefully removed from the fossil surface using a Dremel tool.

In the laboratory, receptaculitids were processed and measured for a checklist of morphological features:

- Body length
- Body width
- Lacuna (aperture) diameter
- Length from nucleus to midpoint of lacuna
- Angle of widening from nucleus toward apex
- Length from nucleus to nuclear end of lacuna
- Width of body at nuclear end of lacuna
- Merom concentration counts wherever visible, noting distance from nucleus

Of the over 300 specimens collected from the Arrow Canyon Range, 13 were complete and well-preserved enough to process for the above measurement parameters (Plate II). Body length and width were measured in two ways: true length and width were recorded for 13 samples, with projected lengths also noted. These projected numbers for length, width, lacuna diameter, and other aspects were only recorded when enough of the fossil remained intact that an estimate could be made based on basic symmetry and remaining features of the specimen. Merom concentration counts were taken by using a single square cm grid, laid over the surface of the receptaculitid where shafts are exposed (plates are rarely preserved but circular shafts indicate individual meroms that would have each been capped with 4 tangential rays and an outer, rhomboidal plate), and oriented in accordance with the whorl pattern such that the maximum number of shafts are within the cm grid. Counts were taken using a hand lens and recorded along with the distance from the nucleus to the position centered in the cm grid for that count. Size measurements were taken at the maximum length possible and considered well-exposed, weathered out specimens and blocks in which only portions of a receptaculitid are visible in cross section. The longest visible section is measured and recorded to within 1 cm blocks for size distribution histograms.

Tangential ray structures were observed with magnification and photography to show depth of tangential ray interlocking patterns exposed by the weathering away of outer plates. This proved to be the most useful method of observation, with many specimens weathered in a way that effectively displayed these features. Thin sections taken in cross sectional cuts of specimens provided further insight into the nature of the tangential rays and the pattern that meroms were arranged in to create the receptaculitid skeletal structure. Additional confirmation of the pattern of tangential rays was achieved by slowly polishing through the outer plates in stages to reveal the orientation of the delicate structures. Between polishing stages, high-resolution images were collected via wet scanning that allowed for later three dimensional reconstruction that was in direct agreement with observations using the first two methods. These images are not as visually demonstrative as the first two methods described here and thus have not been included in this manuscript.

SYSTEMATIC PALEONTOLOGY

Phylum RECEPTACULITA Myagkova, 1987

Class RECEPTACULITIDA Weiss, 1954

Order RECEPTACULITIDAE James, 1885

Family ISCHADITIDAE Müller, 1968

Genus ISCHADITES Murchison, 1839

This systematic paleontology is in agreement with recent publications (specifically Nitecki, et al., 1999), but these assignments have been debated over the years, reclassified and renamed multiple times, and publications throughout the decades reflect the frequent changes and arguments regarding the systematic assignment of receptaculitids. Notable groups that are part of the receptaculitid phylum but which have names outside of the above systematic classification are Class Squamiferida (Sushkin, 1962) and Order Receptaculitida (Müller, 1968). The microstructural pattern of connection between meroms, outer plate shape, and overall gross morphology are the main criteria for identification and classification of receptaculitids (Nitecki et al., 1999).

Diagnosis.—A species of *Ischadites* with common tangential ray structures, but with smaller, more numerous meroms and a unique gross morphology: large body structures shaped like a shallow, open bowl with one section of wall tapered to a point (Figure 8). Adults have a large, open lacuna oriented upward.

Description.— Adults reached an average size of 13.6 cm in length from nucleus to apex, with one exceptionally large specimen reaching a projected 22 cm in length, based on the proportions of the surviving fossil fragment (Plate I, photo E). The following dimensions for a reconstructed representative (illustrated below) are based on measurements of the 10 best preserved, most articulated specimens selected within a collection of over 300 specimens, the great majority of which were fragments. Other data collected also considered 3 juveniles in addition to the adult specimens, though these specimens were excluded from the adult reconstruction here.

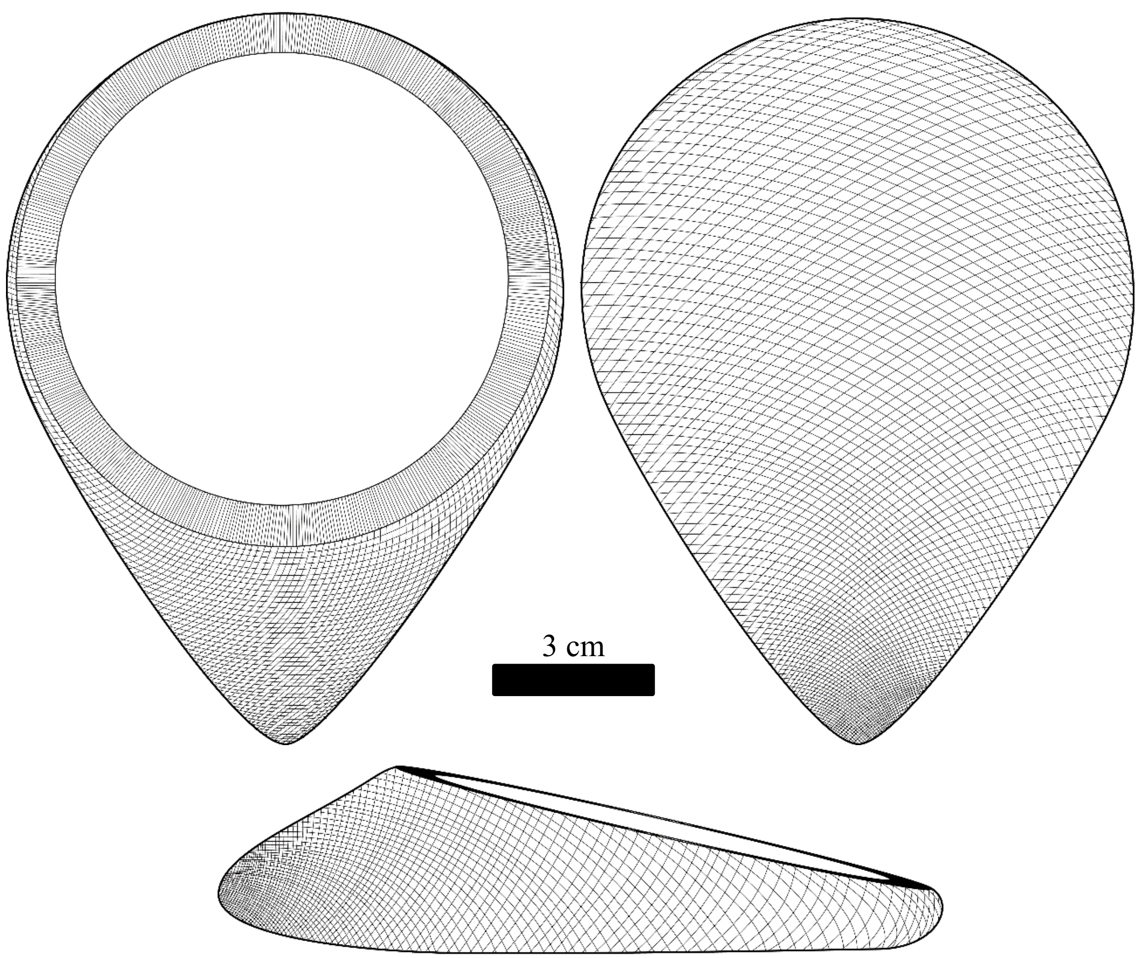
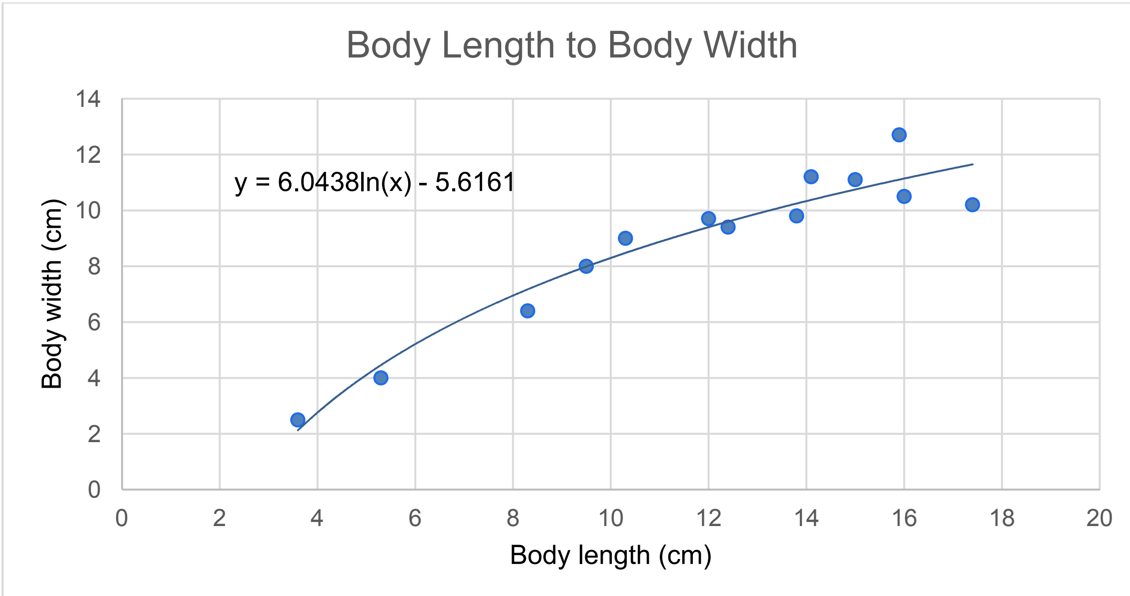


Figure 8A, 8B, and **8C** (starting top left and moving clockwise). Reconstructions of top, bottom, and profile views of the average dimensions of a full grown adult receptaculitid (Tables 1-4). Illustrations by K. R. Henry, 2014.

Ischadites n. sp. has a unique gross morphology and is shaped like a slipper or shoe. In the mature body the nucleus lies at the pointed "toe" and a large, open, upward-facing lacuna is located at the "heel". From the nuclear end, the receptaculitid expands at a relatively consistent 67.9° angle for about two thirds of the total length before rounding out around a nearly circular, but sometimes slightly ovoid aperture. For the average 13.6 cm long specimen, the lacuna has a diameter of 8.7 cm, with the midpoint of the lacuna lying 8.8 cm from the nucleus.

The pointed nuclear "toe" end is the oldest portion of the receptaculitid and the meroms at this extremity are often difficult to observe due to heavy recrystallization. Other authors have noticed similar conditions and have postulated that the plates near the nucleus were fused, either during life or post-mortem (Nitecki et al., 1999). The body is covered in an unusually large number of meroms that are exceptionally small when compared to other species of *Ischadites*. Specimens of *Ischadites* n. sp. from ACR have over 130 meroms per square cm near the nucleus and less than 50 meroms per square cm at the apical end (Table 4). As such, the outer plates of meroms are approximately 75% larger at the apical end than the nuclear end. For an average adult specimen that is 13.6 cm in length, the major diagonal length of the rhombic outer plates ranges from about 0.9 mm to 1.6 mm within a single adult specimen.

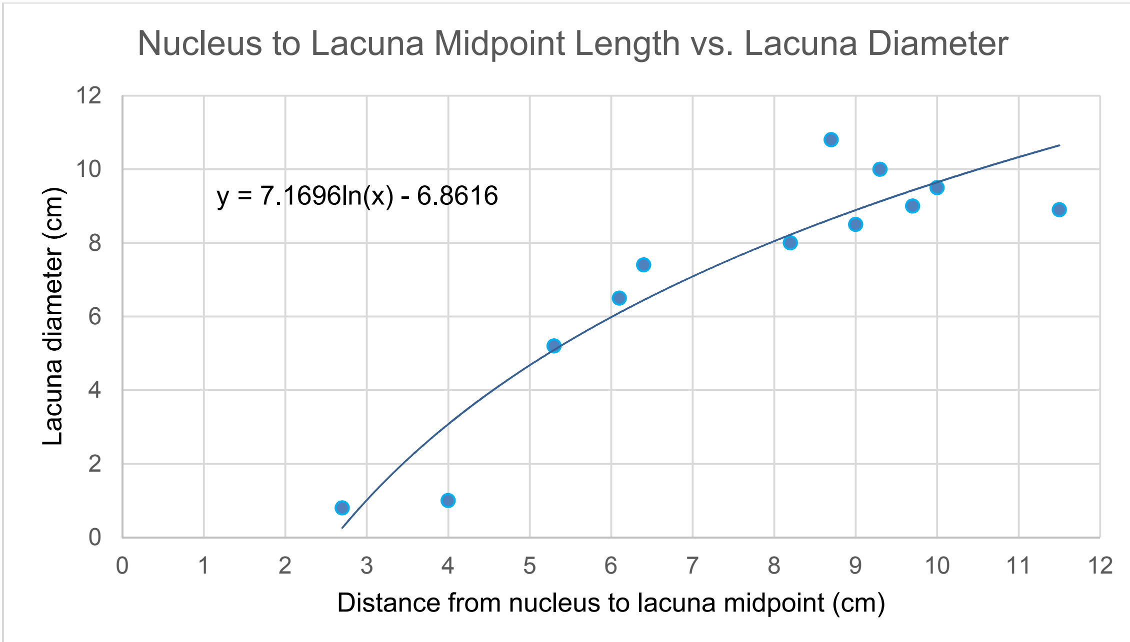
All data are listed in the following charts and graphs. Italicized numbers indicate that the measurement was at least partially projected. Data was plotted logarithmically as logarithmic transformation of size data typically produces a more accurate representation of population structure and better reflects age distributions than non-transformed data (Darroch et al., 2013; Bak and Meesters, 1999; Meesters et al., 2001).



n = 13

Sample	Length	Width	
A	10.3	9.0	
B	*16.0*	10.5	
C	*13.8*	*9.8*	
D	*14.1*	*11.2*	
E	*15.0*	*11.1*	
F	*17.4*	*10.2*	
G	*15.9*	*12.7*	
H	*12.0*	*9.7*	
I	9.5	8.0	
J	5.3	4.0	
K	3.6	2.5	
L	*12.4*	*9.4*	
M	*8.3*	*6.4*	
n = 13 Average	11.8	8.8	*All sizes*
n = 10 Average	13.6	10.2	*Adults only*

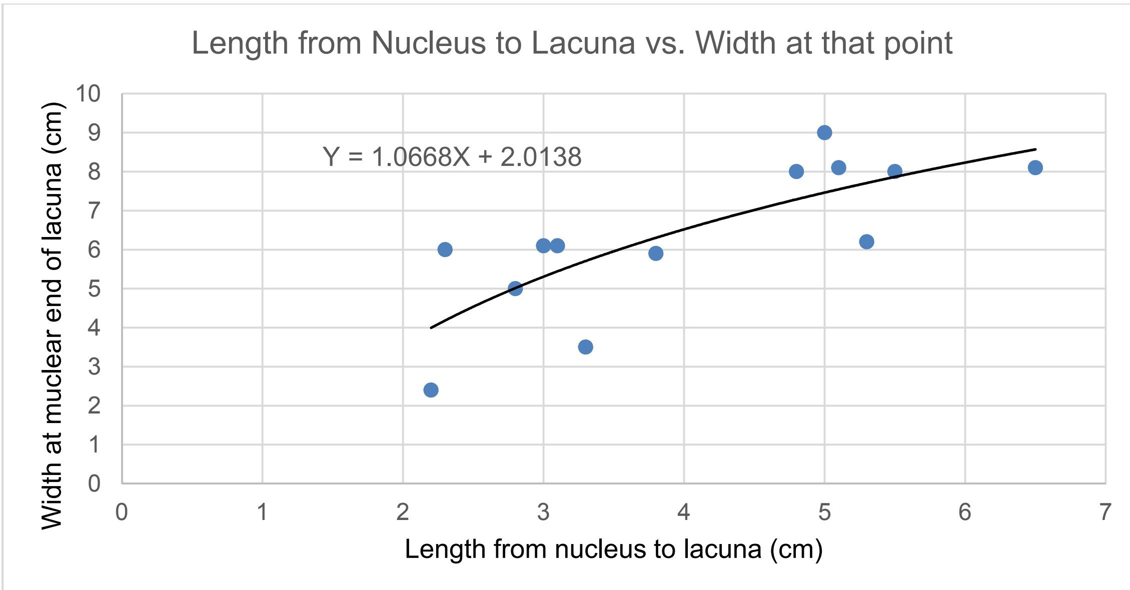
Figure 9 and **Table 1**, depicting length and width data collected from 13 samples. There is a clear and distinctive trend when graphed logarithmically, even between the juvenile and adult forms.



n = 12

	Sample	Dist. from nucleus	Width of aperture	
	A	6.4	7.4	
	B	10.0	9.5	
	C	9.0	8.5	
	D	9.3	10.0	
	E	9.7	9.0	
	F	11.5	8.9	
	G	8.7	10.8	
	I	6.1	6.5	
	J	4.0	1.0	
	K	2.7	0.8	
	L	8.2	8.0	
	M	5.3	5.2	
n=12	Average	7.6	7.1	*All sizes*

Figure 10 and **Table 2**, depicting data on the length from the nucleus to the midpoint of the lacuna vs. the diameter of the lacuna (both in cm). Data was collected from 13 samples. There is a clear and distinctive trend when graphed logarithmically, even between the juvenile and adult forms.

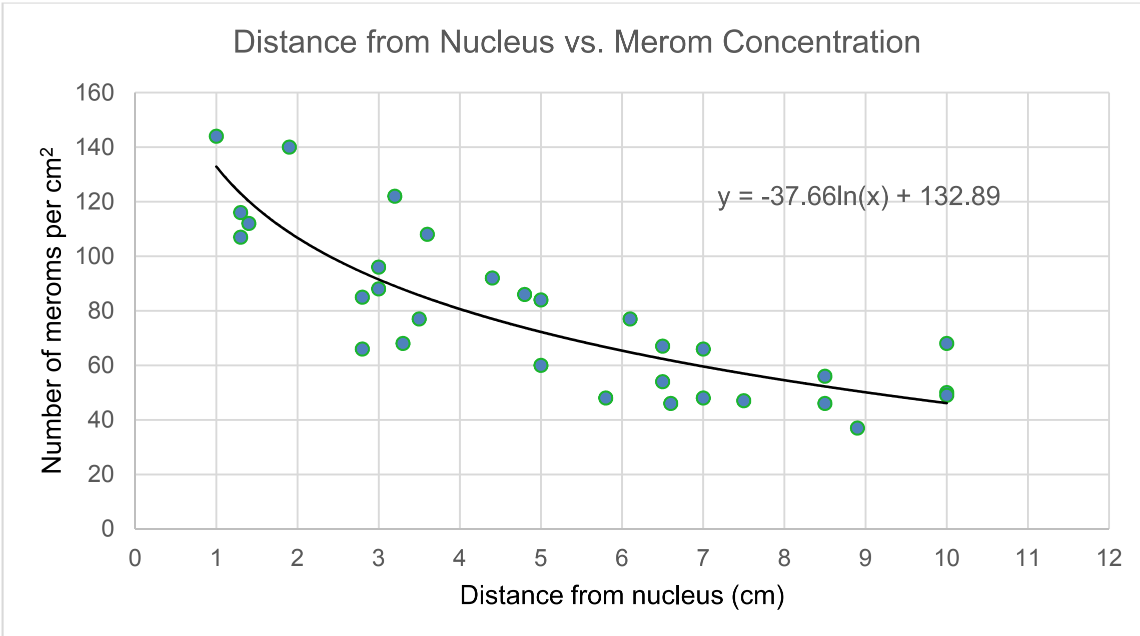


n = 13

Sample	Length	Width
A	3.0	6.1
B	6.5	8.1
C	*5.5*	*8.0*
D	3.1	6.1
E	4.8	*8.0*
F	5.3	6.2
G	*2.3*	6.0
H	*5.0*	*9.0*
I	3.8	5.9
J	3.3	3.5
K	2.2	2.4
L	*5.1*	*8.1*
M	2.8	*5.0*

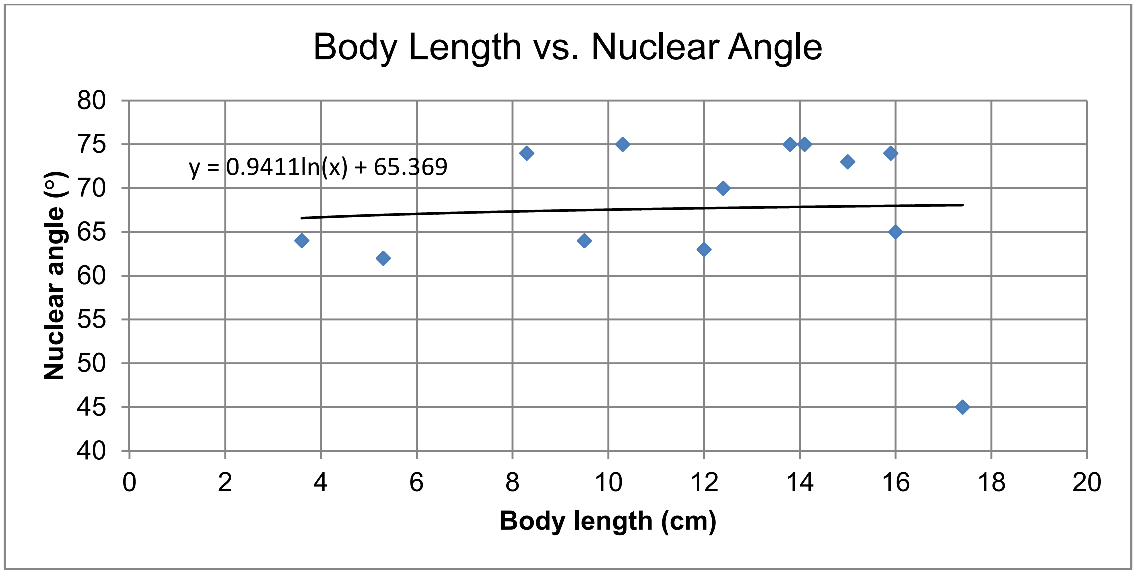
n = 13	Average	4.1	6.3	*All sizes*
n = 10	Average	4.4	7.2	*Adults only*

Figure 11 and **Table 3**, depicting data on the length from the nucleus to the nuclear end of the lacuna vs the width of the body at that point. Data was collected from 13 samples. There is a vague trend when graphed logarithmically, but not as strong as the trends plotted in Graphs 1 and 2.



Sample	Dist. from nucleus	Meroms per cm^2	Sample	Dist. from nucleus	Meroms per cm^2
A	10.0	68	H	1.9	140
B	3.2	122	H	3.6	108
B	4.8	86	H	5.0	84
B	8.5	56	I	3.3	68
C	1.3	107	I	6.6	46
C	2.8	85	I	7.0	48
C	6.5	67	J	1.0	144
C	7.0	66	J	3.0	96
D	10.0	50	J	4.4	92
D	10.0	49	K	1.3	116
E	6.1	77	K	1.4	112
G	2.8	66	K	3.0	88
G	5.8	48	L	3.5	77
G	8.9	37	L	5.0	60
H	1.9	140	L	6.5	54
H	3.6	108	L	7.5	47
H	5.0	84	L	8.5	46

Figure 12 and **Table 4**, depicting data on the length from the nucleus vs number of meroms in a single square cm grid. Data was collected from 31 square cm surfaces on 11 different specimens. There is a very strong logarithmic trend between data points collected from both adults and juveniles.



n = 13

	Sample	Length	Angle	
	A	10.3	75	
	B	*16.0*	65	
	C	*13.8*	75	
	D	*14.1*	75	
	E	*15.0*	73	
	F	*17.4*	45	
	G	*15.9*	74	
	H	*12.0*	63	
	I	9.5	64	
	J	5.3	62	
	K	3.6	64	
	L	*12.4*	70	
	M	*8.3*	74	
n = 13	Average	11.8	67.6	*All sizes*
n = 10	Average	13.6	67.9	*Adults only*

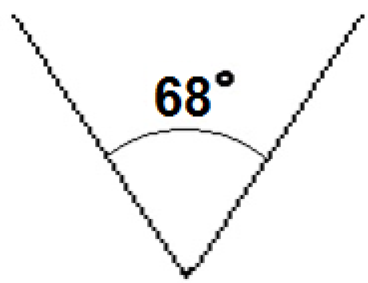


Figure 13 and **Table 5**, depicting data on body length vs. nuclear angle. Data was collected from 13 samples including adults and juveniles. As shown in Graph 5, there is no particular change in the nuclear angle despite overall size. The average angle falls at 67.6° for all sizes. Average taken for adults only is almost identical, at 67.9°.

Size.—The receptaculitids at the Arrow Canyon Range are remarkably larger than receptaculitids in other portions of the Antelope Valley Limestone. A much less intensive search at Lone Mountain, approximately 400 km north of ACR near Eureka, NV, yielded 41 samples. These were measured and compared to the size distribution of receptaculitids collected from ACR, and although the sample size is small, a clear trend is present (see below histograms). The samples from Lone Mountain are limited to less than 7 cm in length and are generally around 4 to 5 cm in length, while samples from ACR have a much wider distribution, measuring up to nearly 20 cm in length. In both categories, no receptaculitids under 1 cm in length were observed.

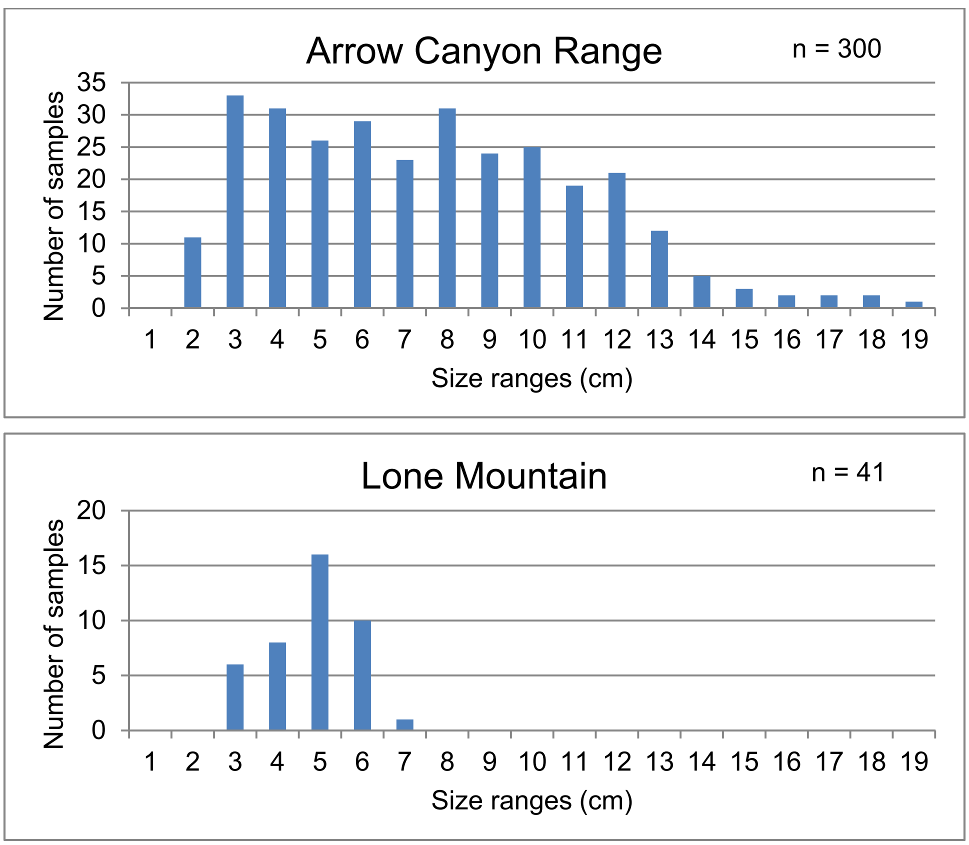


Figure 14A and **14B** (top and bottom, respectively). Size distribution charts for samples collected from ACR (n=300) and Lone Mountain (n=41). Longest exposed dimension was measured for each sample and binned by width to the cm. For example, samples binned in Size Range 7 cm are between 6 and 7 cm in length at the longest exposed dimension.

Ontogeny.—Younger, smaller specimens have skeletal structures shaped like inverted, hemispherical domes with an open top, later growing and slumping over into a cornucopia-like shape, and ultimately growing as large as 20 cm in length in a unique but consistently body shape. This large morphotype resembles a pointed slipper or an ancient oil lamp, shaped like a shallow, open bowl with one section of wall tapered to a point. See Photographic Plates I and II for specimens in various stages of growth.

Throughout ontogeny, the receptaculitid makes modifications that keep the aperture oriented upward or at least angled upward. The overwhelming majority of samples found in life position have their lacuna pointed mostly upright, although not completely level, with the apical end slightly lower in profile such that the lacuna points upward and slightly away from the nucleus (Figures 8 and 15). There is a strong tendency toward larger forms at ACR and young juvenile forms are present, but rare.

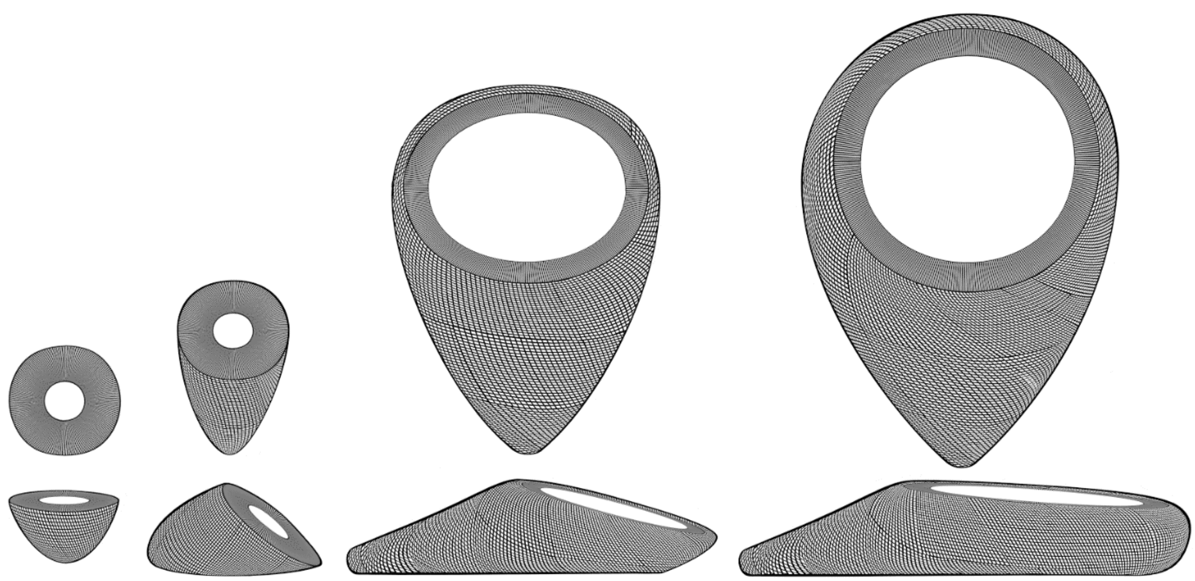


Figure 15. Schematic reconstructions of top and profile views at four stages of growth, with the youngest on the left and the full-size adult on the right with and average total length of 13.6 and average total width of 10.2 cm (see Table 1). Illustration by K. R. Henry (2014).

MICROSTRUCTURE

Outer Plates

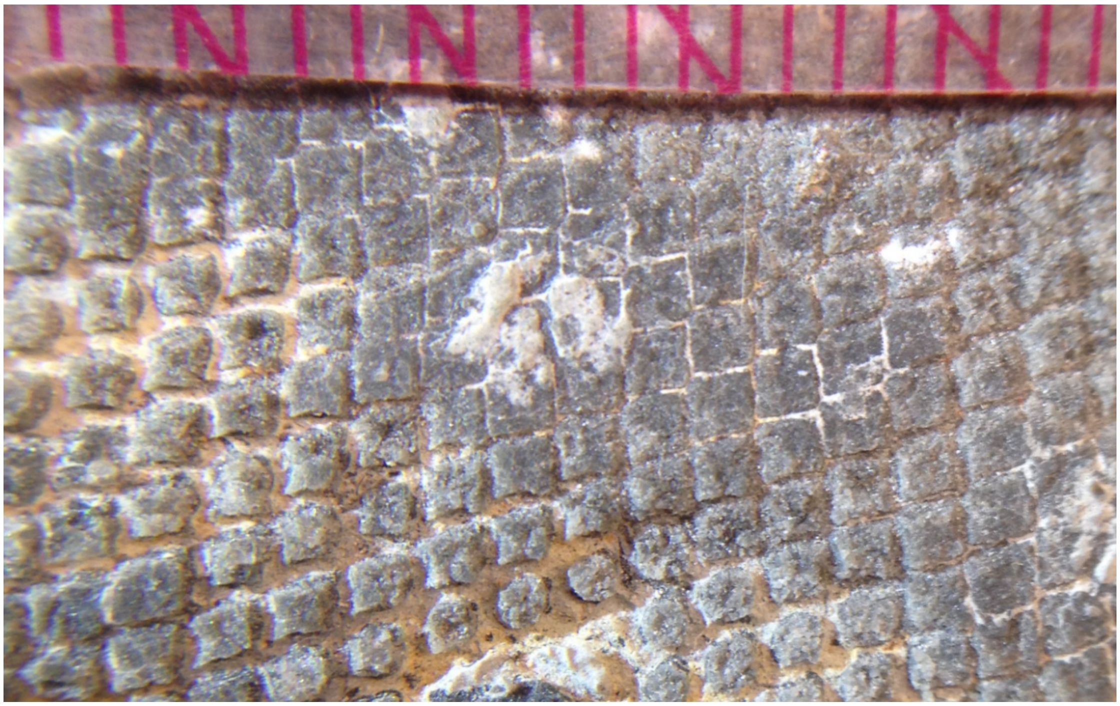


Figure 16. Rare specimen in which rhombic outer plates are retained. Increments marked by horizontal red lines represent mm units.

The outer plates are almost always missing from the specimens (less than 10% of the over 300 collected), leaving exposed shafts that look circular in top view (Photographic Plate I, photos A and D). When plates are preserved (Figure 16), they are rhomboidal in shape. Edges of these thin outer plates vary slightly in order to fit with neighboring meroms. As previously stated, these outer plates range in major diagonal length from around 0.9 mm to 1.6 mm and possibly larger (based on calculations from Table 4 data), although neither merom shafts nor outer plates were preserved in the largest (over 20 cm in length) specimens and this could not be absolutely confirmed.

Merom Interlocking Patterm

The microstructure of the meroms and the interlocking pattern between sets of tangential rays reveals that *Ischadites* n. sp. retains the same microstructural patterns as other species in the genus, despite the extreme gross morphological differences. Figure 17 is a microscopic photograph that shows an exceptionally well-preserved specimen prepared as a thin section, cut to show a cross-sectional view of an adult receptaculitid specimen. The photo clearly shows the interwoven pattern of tangential rays between five meroms. The thin outer plates are at the top of the specimen, which is at the top of the photo. Directly below the outer plates are proximal rays jutting outward to the right from each merom shaft. Just below the proximal rays are the lateral rays, which run parallel to the horizontal rows of meroms. The lateral rays are seen here as the pairs of circles, tucked between the overlying, rightward-pointing proximal rays and the underlying, leftward-pointing distal rays. These lateral rays are oriented at right angles to the meridional rays (the proximal and distal rays) and thus are oriented directly toward the camera view, protruding from the meroms directly behind and in front of the row of shafts seen here. Below the pairs of lateral rays are the distal rays pointing leftward, three of which are clearly seen in the middle of the photo. Also of interest is a broken merom shaft that has turned at a right angle away from the camera view, and is tucked between the two leftmost shafts.

Figure 17. Microscopic view of shafts in cross section from an adult receptaculitid. True size of the above cross-sectional view is approximately 3.5 mm wide and 2.1 mm tall.

The schematic, labeled diagrams below (Figure 18) more clearly show the orientation and network of tangential rays for *Ischadites*, which are also exhibited by the newly defined *Ischadites* n. sp. Figures 19A and 19B also effectively display this microstructure.

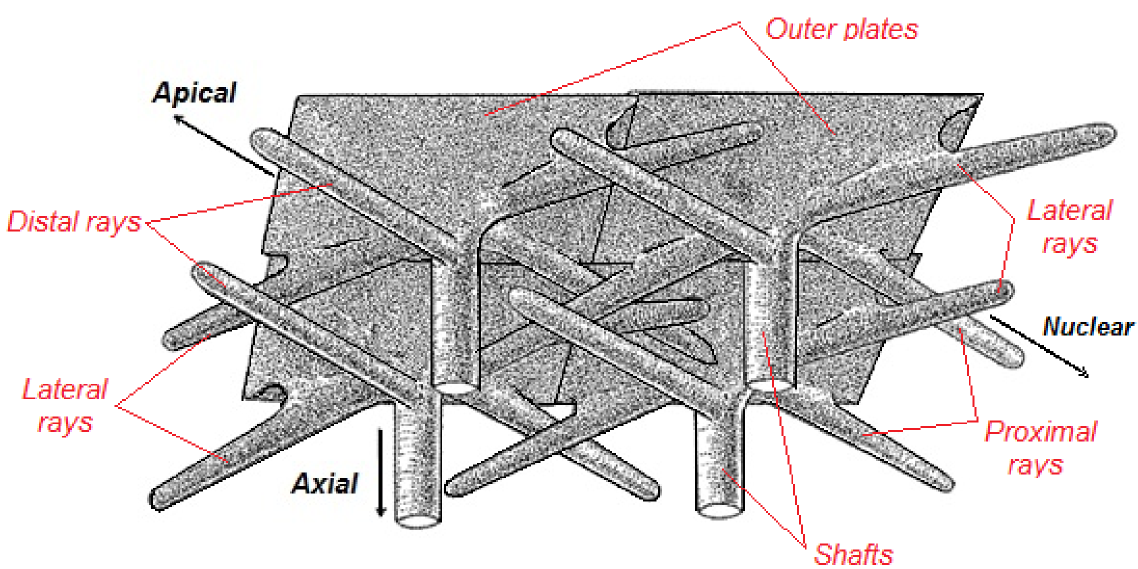


Figure 18. Reconstruction of distal portion of meroms in ischaditid receptaculitids, seen in oblique view, with terminology labeled. Orientation is shown by the arrows. Recreated from Fisher & Nitecki, 1978.

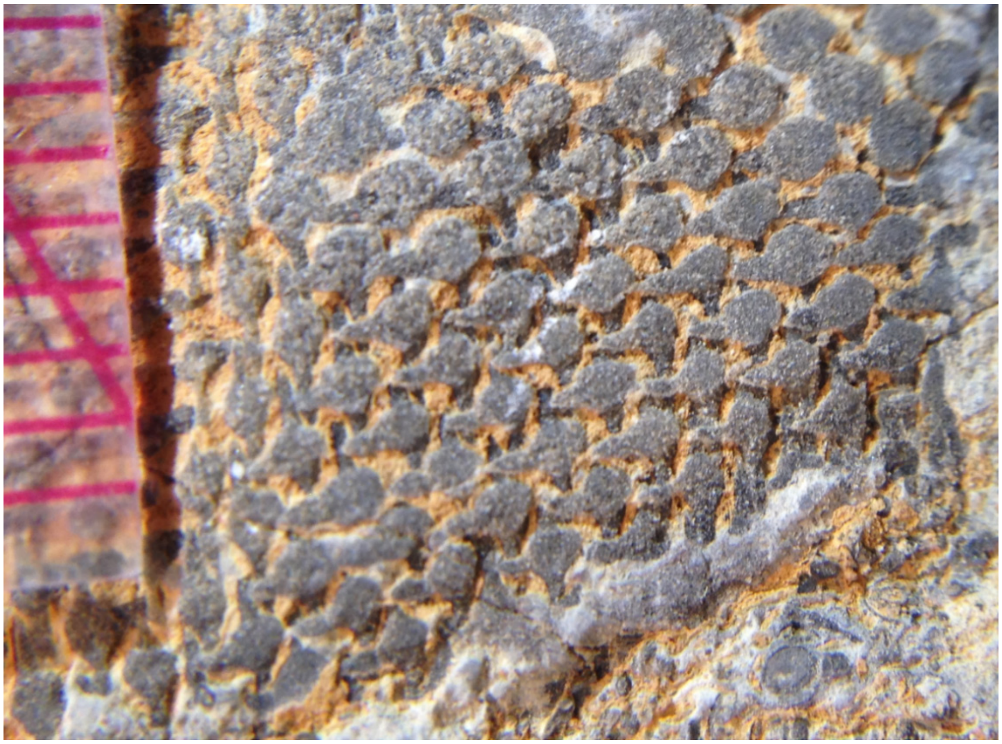
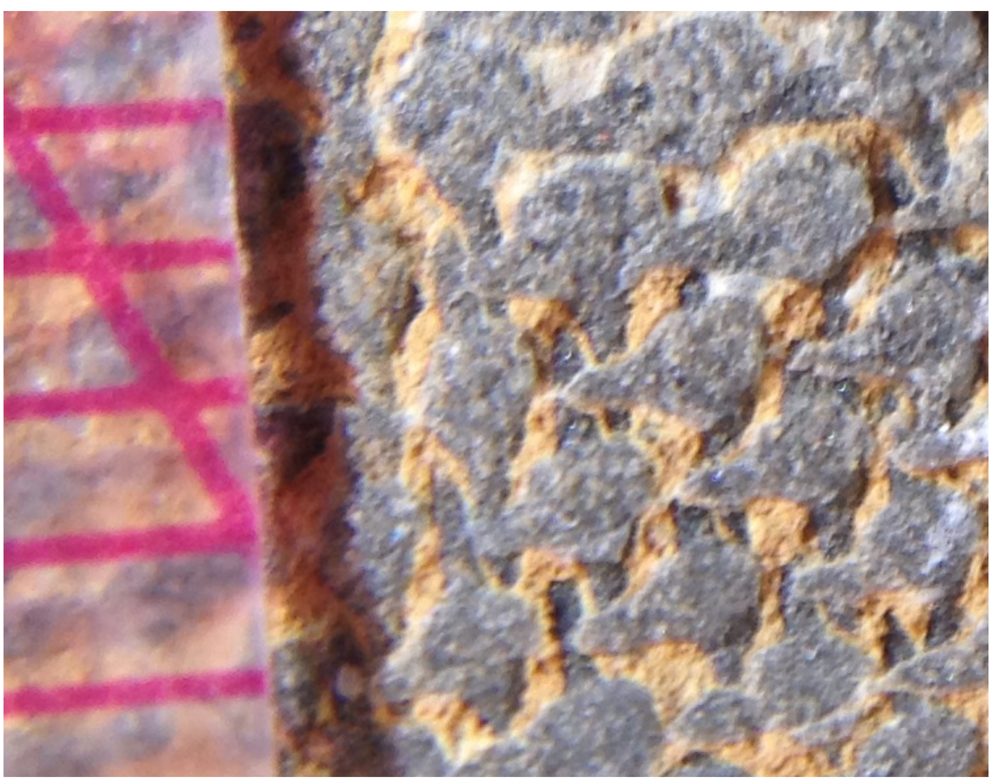


Figure 19A (above) and **19B** (below). Tangential rays exposed by natural weathering processes. Increments marked by horizontal red lines represent mm units.



DISCUSSION

The body or thallus of *Ischadites* n. sp. is covered in an unusually large number of meroms that are exceptionally small when compared to other species of *Ischadites*. For example, a more typical *Ischadites* specimen is pictured here (Figure 20): *Ischadites barrandei*. Notice the large plate size to body size on this specimen, with the white scale bar representing 1 cm, as well as the overall small size of the receptaculitid. This ischaditid has approximately 56 meroms per square cm at its nucleus and as few as 25 meroms per square cm as the meroms increase in size as the whorls spiral away from the nucleus. This is in stark contrast to the over 130 meroms per square cm exhibited near the nucleus of specimens of *Ischadites* n. sp. collected from the Arrow Canyon Range. At the apical ends of these *Ischadites* n. sp. specimens, where the plates are largest, there is still no less than 46 meroms per square cm recorded. Another clear difference is in gross morphology and size, with other *Ischadites* species exhibiting radially symmetrical, globular or disk-shaped body types without a distinctive aperture, and maintain significantly smaller body sizes.

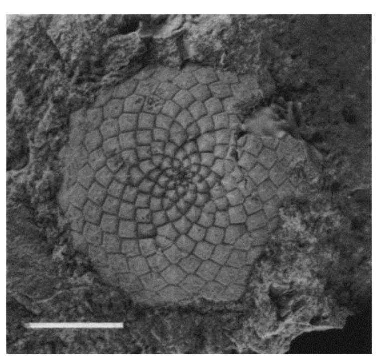


Figure 20. Photo of *Ischadites barrandei* (Fisher and Nitecki, 1982). White scale bar represents 1 cm. Note the large plate size to body size.

Comments on Previous Research

Ischadites n. sp. displays the same microstructure type exhibited in other species in this genus which would not necessarily justify the erection of a new genus of receptaculitids, as Foster (1973) had suggested regarding similar fossils recovered in the Grapevine Mountains. In addition to the unusually high number of meroms and their small size, Foster had based this suggestion on what he described and depicted as an interlocking zone further down the shafts of each merom, in addition to the tangential ray interlocking zone. However, this was not observed in any of the ACR fossils collected. It should be noted that relatively heavy recrystallization has obscured the terminal ends (the ends on the inside of the body) of merom shafts in most ACR samples that could potentially obscure these features, but it was not observed in any of the best preserved samples.

CONCLUSIONS

Large, well-preserved receptaculitids from the Middle Ordovician Pogonip Group of the Arrow Canyon Range in southeastern Nevada have been collected and studied. A new receptaculitid species, *Ischadites* n. sp., is described and will be named in a forthcoming manuscript. These highly variable specimens are regarded as intrapopulational variants of this new species, with the variety arising primarily from the occurrence of individuals at various stages of growth.

This species differs from the similar species of *Ischadites* in the following features: 1.) small, numerous outer plates, 2.) large body size, 3.) unique gross morphotype that defers from strict radial symmetry, and 4.) exceptionally large aperture to body size ratio.

PHOTOGRAPHIC PLATE I

Plate I (above). Photos of ten representative receptaculitids demonstrating the size and variability among specimens. Banded scale bar is in cm increments. Photos are referred to as A through H, lettered from left to right, top row to bottom row.

Plate II (next page). Photos of the top and bottom views (positioned at the top and bottom, respectively) thirteen samples selected for having the greatest proportions of measurable features and best preserved microstructure with the least amount of surface area obstructed by heavy calcite recrystallization. Banded scale bar is in cm increments. Specimens have been labeled as Specimens A through M, lettered from left to right in the photo, top row to bottom row, such that A is the top left sample and M is at the bottom right.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APPENDIX I – Literature Documenting Receptaculitids in the Great Basin, Listed by Species

AUTHOR	YEAR	LOCATION	REGION	COUNTY	ST	AGE	GROUP	FORMATION	MEMBER	SPECIES	PAGE NO.
Gans	1974	Red Rock Canyon			NV	Middle to Upper Ord		Mountain Springs Fm		*Calathium*	p. 196-198
Hintze	1973a	Ibex area		Millard	UT	Ordovician	Pogonip	Fillmore Fm	Fossil Zone I	*Calathium*	p. 51
Hintze	1973b	Northwestern UT			UT	Lower Ordovician		Garden City Ls		*Calathium*	p. 121
Hintze	1973b	Northwestern UT			UT	Lower Ordovician		Fillmore Ls		*Calathium*	p. 133
Hintze	1979	Ibex area		Millard	UT	Lower Ordovician		Fillmore Fm	In 4 members	*Calathium*	p. 16
Hintze	1979	Ibex area		Millard	UT	Lower Ordovician		Wah Wah Ls		*Calathium*	p. 16
Hintze et al.	1969	Ibex area		Millard	UT	Lower Ordovician		Fillmore Ls		*Calathium*	p. 23
Rigby	1971	UT, NV, and CA				Ordovician				*Calathium*	p. 1378
Merriam	1963	Antelope Valley area			NV	Chazyan	Pogonip	Antelope Valley Ls		*Calathium (?) sp.*	pp. 25-26
Hintze	1973c	Ibex area		Millard	UT	Lower Ordovician		Fillmore Ls		*Calathium (R. elongatus)*	6, 10-11, 22, 26

AUTHOR	YEAR	LOCATION	REGION	COUNTY	ST	AGE	GROUP	FORMATION	MEMBER	SPECIES	PAGE NO.
Kirk	1934	"Southern NV"			NV	Ordovician (Lower?)		Yellow Hill Ls		*Calathium sp.*	452,54,56,60
Kirk	1934				UT	Ordovician (Lower?)		Garden City Ls		*Calathium sp.*	452,54,56,60
Nitecki & Debrenne	1979	?			NV	Ordovician		?		*Calathium sp.*	?
Westgate & Knopf	1932	Ely Springs Range			NV	Ordovician		Yellow Hill Ls		*Calathium sp.*	p. 14
Church	1991	Southern House Range		Millard	UT	Lower Ordovician		Fillmore Fm		*Calathium yersini* n. sp.	pp. 602-610
Church	1991	Confusion Range		Millard	UT	Lower Ordovician		Fillmore Fm		*Calathium yersini* n. sp.	pp. 602-610
Church	1991	Yersin Hills		Millard	UT	Lower Ordovician		Fillmore Fm		*Calathium yersini* n. sp.	pp. 602-610
Hintze	1973c	Ibex area		Millard	UT	Lower Ordovician		Kanosh Shale		*Ischadites*	p. 6
Foster	1973	Grapevine Mountains	Death Valley, eastern CA		CA	Middle Ordovician	Pogonip	Antelope Valley Ls		*Ischadites mammillaris*	pp. 35-65
Kay	1962	Ikes Canyon			NV	Ordovician		Antelope Valley Ls		*Nidulites (?) sp.*	p. 1424
Kay	1962	Yellow Gulch			NV	Ordovician		Antelope Valley Ls		*Nidulites (?) sp.*	p. 1424

AUTHOR	YEAR	LOCATION	REGION	COUNTY	ST	AGE	GROUP	FORMATION	MEMBER	SPECIES	PAGE NO.
Hague	1892	Hamburg Ridge (just east)	Eureka District		NV	Ordovician		Pogonip Ls		*R. ellipticus*	p. 52
Hague	1892	White Mountain	Eureka District		NV	Ordovician		Pogonip Ls		*R. ellipticus*	p. 52
Hague	1892	Fish Creek Mountains	Eureka District		NV	Ordovician		Pogonip Ls		*R. ellipticus*	p. 53
Westgate & Knopf	1932	Ely Springs Range			NV	Ordovician		Tank Hill Ls		*R. ellipticus*	p. 15
Wheeler & Lemmon	1939	Eureka district			NV	Ordovician		Pogonip Ls		*R. ellipticus*	p. 28
Cornwall & Kleinhampl	1961	Bare Mountains		Nye	NV	Early to Middle Ord	Pogonip	Antelope Valley Ls		*R. elongatus*	Geologic map
Hague	1892	White Mountain	Eureka District		NV	Ordovician		Pogonip Ls		*R. elongatus*	p. 52
Hague	1892	Fish Creek Mountains	Eureka District		NV	Ordovician		Pogonip Ls		*R. elongatus*	p. 53
Hintze	1951a	Western Utah			UT	Lower Ordovician	Pogonip	Fillmore Ls		*R. elongatus*	52, 56
Hintze	1951a	Western Utah			UT	Lower Ordovician		Garden City Ls		*R. elongatus*	p. 92
Hintze	1952	Utah and Nevada			UT, NV	Ordovician				*R. elongatus*	Need to check

AUTHOR	YEAR	LOCATION	REGION	COUNTY	ST	AGE	GROUP	FORMATION	MEMBER	SPECIES	PAGE NO.
Humphrey	1960	Eureka area		White Pine?	NV	Lower Ordovician		Pogonip Fm	Member 4	*R. elongatus*	18, 20-21, 23
Johnson & Hibbard	1957		Atomic Energy Commission proving grounds		NV	Early to Middle Ord	Pogonip			*R. elongatus*	p. 348
Kellogg	1963	Egan Range			NV	Ordovician		Canadian Shingle Ls		*R. elongatus*	p. 693-694
Kellogg	1963	Egan Range			NV	Middle Ordovician		Kanosh Shale (lower)		*R. elongatus*	p. 693-694
Merriam	1963	Antelope Valley area			NV	Chazyan	Pogonip	Antelope Valley Ls		*R. elongatus*	pp. 25-26
Nolan et al.	1956	Eureka District			NV	Ordovician	Pogonip	Antelope Valley Ls		*R. elongatus*	p. 25, 29
Webb	1958	Utah			UT	Ordovician		Garden City Ls		*R. elongatus*	p. 2356
Wheeler & Lemmon	1939	Eureka district			NV	Ordovician		Pogonip Ls		*R. elongatus*	p. 28
Ferguson	1933	Hot Creek Range	Tybo District (E H.C. Range)		NV	Ordovician		Pogonip Ls		*R. mammillaris*	p. 19
Hague	1883	Eureka District			NV	"Silurian [Ordovician]"		Pogonip Ls	upper portion	*R. mammillaris*	p. 261
Hague	1892	White Mountain	Eureka District		NV	Ordovician		Pogonip Ls		*R. mammillaris*	p. 52

AUTHOR	YEAR	LOCATION	REGION	COUNTY	ST	AGE	GROUP	FORMATION	MEMBER	SPECIES	PAGE NO.
Hague	1892	Fish Creek Mountains	Eureka District		NV	Ordovician		Pogonip Ls		*R. mammillaris*	p. 53
Hague	1892	Surprise Peak	Eureka District		NV	Ordovician		Pogonip Ls		*R. mammillaris*	p. 53
Hague	1892	Caribou Hill	Eureka District		NV	Ordovician		Pogonip Ls		*R. mammillaris*	p. 53
Hintze	1951a	Western Utah			UT	Lower Ordovician	Pogonip	Kanosh Shale		*R. mammillaris*	19, 62, 76-77
Hintze	1951a	Western Utah			UT	Lower Ordovician		Swan Peak Fm		*R. mammillaris*	p. 94
Hintze	1952	Utah and Nevada			UT, NV	Ordovician				*R. mammillaris*	Need to check
Hintze et al.	1969	Ibex area		Millard	UT	Lower Ordovician		Kanosh Shale		*R. mammillaris*	p. 24
Humphrey	1960	Eureka area		White Pine?	NV	Lower Ordovician		Pogonip Fm	Member 4	*R. mammillaris*	18, 20-21, 23
Johnson & Hibbard	1957		Atomic Energy Commission proving grounds		NV	Early to Middle Ord	Pogonip			*R. mammillaris*	p. 348

AUTHOR	YEAR	LOCATION	REGION	COUNTY	ST	AGE	GROUP	FORMATION	MEMBER	SPECIES	PAGE NO.
Kellogg	1963	Egan Range			NV	Middle Ordovician		Kanosh Shale (lower)		*R. mammillaris*	p. 693-694
Langenheim et al.	1960			White Pine	NV	Middle Ordovician		Lehman Fm		*R. mammillaris*	p. 149-150
Merriam	1963	Antelope Valley area			NV	Chazyan	Pogonip	Antelope Valley Ls		*R. mammillaris*	pp. 25-26
Nolan et al.	1956	Eureka District			NV	Ordovician	Pogonip	Antelope Valley Ls		*R. mammillaris*	p. 25, 29
Walcott	1884	Eureka District			NV	Lower Silurian	Pogonip			*R. mammillaris*	p.4
Walcott	1891	Eureka district			NV	Ordovician		Pogonip Ls		*R. mammillaris*	pp. 316-317
Webb	1956					Middle Ordovician		Swan Peak?		*R. mammillaris*	←
Westgate & Knopf	1932	Ely Springs Range			NV	Ordovician		Tank Hill Ls		*R. mammillaris*	p. 15
Wheeler & Lemmon	1939	Eureka district			NV	Ordovician		Pogonip Ls		*R. mammillaris*	p. 28
Gans	1974	Red Rock Canyon			NV	Middle to Upper Ord		Mountain Springs Fm		*R. oweni*	p. 196
Ross	1964	S-most NV & adj. CA			NV, CA	Ord (M & L?)		Ely Springs Dm		*R. oweni*	←

AUTHOR	YEAR	LOCATION	REGION	COUNTY	ST	AGE	GROUP	FORMATION	MEMBER	SPECIES	PAGE NO.
Ross	1967	Arrow Canyon Range			NV	Middle Ordovician		Eureka Quartzite	Dolomite unit	*R. oweni*	p. 11 ?
Barnes	1967	Specter Range (W side)		Nye	NV	Middle Ordovician	Pogonip	Antelope Valley Ls	Aysees Member	*Receptaculites*	p. 34
Cebull	1970	Southern Grant Range		Nye	NV	Ordovician	Upper Pogonip			*Receptaculites*	p. 1839
Cooper	1956	Antelope Valley			NV	Ordovician	Pogonip		*Pallaseria* zone	*Receptaculites*	p. 127
Cooper	1956	Toquima Range			NV	Ordovician	Pogonip		*Pallaseria* zone	*Receptaculites*	p. 127
Flower	1961	Montoya Group			NM	Ordovician	Montoya	Second Value Fm		*Receptaculites*	pp. 11-12
Gans	1974	Red Rock Canyon			NV	Middle to Upper Ord		Mountain Springs Fm		*Receptaculites*	p. 196-198
Gunn	1998	Arrow Canyon Range		Clark	NV	Middle Ordovician	Pogonip		Opf	*Receptaculites*	
Hintze	1973a	Ibex area		Millard	UT	Ordovician	Pogonip	Fillmore Fm ?	Fossil Zone M	*Receptaculites*	p. 51
Hintze	1973b	Northwestern UT			UT	Middle Ordovician		Kanosh Shale		*Receptaculites*	p. 121, 135

AUTHOR	YEAR	LOCATION	REGION	COUNTY	ST	AGE	GROUP	FORMATION	MEMBER	SPECIES	PAGE NO.
Hintze	1973b	Northwestern UT			UT	Middle Ordovician		Swan Peak Fm		*Receptaculites*	p. 122-123
Hintze	1979	Ibex area		Millard	UT	Lower Ordovician		Kanosh Shale		*Receptaculites*	p. 16
Kaya	1997	Lone Mountain			NV	Middle Ordovician	Pogonip	Antelope Valley Ls		*Receptaculites*	136, 145-146
Kaya	1997	Ninemile Canyon			NV	Middle Ordovician	Pogonip	Antelope Valley Ls		*Receptaculites*	136, 145-146
Kaya	1997	Martin Ridge			NV	Middle Ordovician	Pogonip	Antelope Valley Ls		*Receptaculites*	136, 145-146
Kaya	1997	Whiterock Canyon			NV	Middle Ordovician	Pogonip	Antelope Valley Ls		*Receptaculites*	136, 145-146
Raymond	1922	Eureka District			NV	Ordovician	Pogonip		about midway	*Receptaculites*	p. 205
Reso	1963	Pahranagat Range		Lincoln	NV	Ordovician	Pogonip	"Upper Ls Fm"?		*Receptaculites*	p. 906
Ross	1964	S-most NV & adj. CA			NV, CA	Ord (M & L?)		Antelope Valley Ls		*Receptaculites*	←
Ross	1964	S-most NV & adj. CA			NV, CA	Ord (M & L?)	Pogonip			*Receptaculites*	←
Ross	1964	S-most NV & adj. CA			NV, CA	Ord (M & L?)	Mazourka	Badger Flat Ls		*Receptaculites*	←
Ross	1970	Groom Range			NV	Ordovician	Pogonip	Antelope Valley Ls		*Receptaculites*	12, 30, 34, 37
Ross	1970	Lone Mountain			NV	Ordovician	Pogonip	Antelope Valley Ls		*Receptaculites*	12, 30, 34, 37

AUTHOR	YEAR	LOCATION	REGION	COUNTY	ST	AGE	GROUP	FORMATION	MEMBER	SPECIES	PAGE NO.
Walcott	1891	Eureka district			NV	Ordovician		Pogonip Ls		*Receptaculites*	pp. 316-317
Washburn	1970	Toiyabe Peak		Lander	NV	Ordovician		Antelope Valley Ls		*Receptaculites*	p. 281
Hague	1883	Eureka District			NV	"Silurian [Ord]"		Pogonip Ls		*Receptaculites* (2 other sp)	p. 261
Merriam	1963	Antelope Valley area			NV	Upper Chazyan	Pogonip	Copehagen Fm		*Receptaculites cf. occidentalis*	pp. 25-26
Kellogg	1963	Egan Range			NV	Ordovician		Canadian Shingle Ls		*Receptaculites n. sp.*	p. 693-694
Hazzard	1937	Nopah Range (W front)			NV	Lower Ordovician		"Pogonip Dolomite"?		*Receptaculites sp.*	p. 276, 323
Hintze	1951a	Western Utah			UT	Lower Ordovician	Pogonip	Kanosh Shale		*Receptaculites sp.*	p. 66
Hintze	1960	Southern Egan Range			NV	Ordovician	Pogonip	Kanosh Shale		*Receptaculites sp.*	p. 59
Hopper	1947	Panamint Range			CA	Upper Ordovician (?)		Ely Springs Dm (?)		*Receptaculites sp.*	p. 407
Hopper	1947	Panamint Range			CA	Lower Ordovician				*Receptaculites sp.*	p. 407
Hyde & Huttrer	1970	Central Grant Range?			NV	Ordovician	Pogonip			*Receptaculites sp.*	p. 506
Kerr	1962	Seetoya Mountains		Elko	NV	Ordovician	Smith Creek seq.	Eureka Quartzite		*Receptaculites sp.*	p. 445
Kerr	1962	Seetoya Mountains		Elko	NV	Ordovician	Burns Creek seq.	Eureka Quartzite		*Receptaculites sp.*	p. 445
Kirk	1934	Pioche & Eureka districts			NV	Ordovician				*Receptaculites sp.*	p. 454-456

AUTHOR	YEAR	LOCATION	REGION	COUNTY	ST	AGE	GROUP	FORMATION	MEMBER	SPECIES	PAGE NO.
Kirk	1934	Las Vegas Quadrangle			NV	Ordovician				*Receptaculites sp.*	p. 454-456
Langenheim et al.	1962	Arrow Canyon Quadrangle		Clark	NV	Ordovician	Pogonip		Uppermost unit	*Receptaculites sp.*	p. 596, 598
Longwell et al.	1965			Clark	NV	Lower & Middle Ord	Pogonip		upper unit	*Receptaculites sp.*	p. 22
McKee	1976	Toquima Range			NV	Ordovician		Antelope Valley Ls		*Receptaculites sp.*	p. 11-12
Nelson	1966	Deep Creek Range			N-U	Ordovician	Pogonip	Kanosh Shale		*Receptaculites sp.*	p. 932
Ross	1970	Horse Heaven Quad			NV	Ordovician	Pogonip	Copenhagen Fm		*Receptaculites sp.*	12, 30, 34, 37
Ross	1970	Lone Mountain			NV	Ordovician	Pogonip	Antelope Valley Ls		*Receptaculites sp.*	12, 30, 34, 37
Ross & Shaw	1972	Antelope Valley			NV	Ordovician		Copenhagen Fm		*Receptaculites sp.*	p. 4, 9
Ross & Shaw	1972	Independence Mountains			NV	Ordovician	Burns Creek seq.	Eureka Quartzite	Dolomite unit	*Receptaculites sp.*	p. 4, 9
Schaeffer	1960	Silver Island Range			UT	Ordovician	Pogonip	Kanosh Shale		*Receptaculites sp.*	p. 42, 45
Stricker & Carozzi	1973	Arrow Canyon Range			NV	Ordovician	Pogonip			*Receptaculites sp.*	p. 505, 511
Webb	1956					Middle Ordovician	Pogonip	Kanosh?		*Receptaculites sp.*	←
Webb	1956					Middle Ordovician	Pogonip		(undivided)	*Receptaculites sp.*	←
Webb	1958	Eastern NV			NV	Ordovician		Lehman Fm		*Receptaculites sp.*	p. 2362
Webb	1958	Eastern NV			NV	Ordovician		Copenhagen Fm		*Receptaculites sp.*	2356-2364?

AUTHOR	YEAR	LOCATION	REGION	COUNTY	ST	AGE	GROUP	FORMATION	MEMBER	SPECIES	PAGE NO.
Webb	1958	Eastern NV			NV	Ordovician	Pogonip Group			*Receptaculites sp.*	2356-2364?
Webb	1958	Western UT			NV	Ordovician		Kanosh Shale		*Receptaculites sp.*	p. 2362
Byers et al.	1961	Aysees Peek	NV Test Site & vacinity	Lincoln	NV	Lower Ordovician	Pogonip	Antelope Valley Ls	Aysees Member	*Receptaculites* sp.	p. 108
Byrd	1970	Ely Springs Range		Lincoln	NV	Lower Ordovician		Yellow Hill Ls		*Receptaculites* sp.	p. 29
Byrd	1970	Ely Springs Range		Lincoln	NV	Lower Ordovician		Lehman Fm		*Receptaculites* sp.	p. 29
Byrd	1970	Ely Springs Range		Lincoln	NV	Lower Ordovician		Ely Springs Dm		*Receptaculites* sp.	p. 30
Hintze	1951b	Chazyan of central UT			UT	Ordovician	Pogonip		Unit 5	Receptaculitids	p. 40
Hintze	1973c	Ibex area		Millard	UT	Lower Ordovician		Kanosh Shale		Receptaculitids	p. 31
Rigby	1962	Western UT & eastern NV				Canadian (Ord)	Pogonip			Receptaculitids	pp. 51-52