Circular structures from the Precambrian Bass Formation in Grand Canyon National Park—biogenic or non-biogenic?

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ABSTRACT—Raymond Alf found circular structures on bedding planes of the Bass Formation in Grand Canyon National Park in the 1950s that he interpreted as jellyfish impressions, which were later identified as sedimentary structures and largely forgotten. More recently, Paleoproterozoic Stirling Biota medusoids similar in morphology to the Bass structures were reported from Australia, which inspired a reanalysis of the Bass Formation impressions that consist of two morphotypes. The smaller morphotype has concentric inner and outer rings, with a hypo-relief central core and pitted concentric annuli on the outer margin of the inner ring. The larger morphotype is similar in most respects but has an asymmetrical outer ring. Bass impressions are not rain imprints because rain discs lack the morphological complexity of the Bass structures nor are they holdfasts of fossil organisms because cross sections indicate sediment laminae were not disrupted. Bass Formation structures are probably the result of gas or gaseous fluid erupting through substrate via a gas dome sand volcano as the morphology of Bass impressions is similar to features of recent and Proterozoic sand volcanos/gas domes. The inner ring of Bass impressions represents the breached dome and its margin of highly disturbed sediment, and the outer ring represents substrate disruption that diminished laterally. Smaller morphotype impressions that abut represent adjacent sand volcanos, clusters of structures with disrupted inner and outer rings represent closely spaced eruptions, and mound-like structures appear to be unerupted domes. The Bass impressions are most likely sedimentary structures that superficially resemble extant algal colonies and fossil medusae impressions.

Introduction

The Bass Formation crops out along the Kaibab Trail on the South Rim of the Grand Canyon and at other localities within the park. The Bass Formation is composed primarily of dolomite and arkose interbedded with shale deposited about 1255 Ma (Hendricks and Stevenson, 1990; Timmons et al., 2005; Timmons et al., 2019). Raymond Alf, a teacher at The Webb Schools (Southern California secondary school) hiked the Kaibab Trail with his students in 1955 when they found discoidal impressions in the Bass Formation (Figure 1) which Alf believed were traces of jellyfish (Lofgren et al., 2019). Alf's search for fossils in the Bass Formation was probably inspired by an earlier discovery of a disc-like structure with radiating lobes in the Nankoweap Formation that was thought to represent a jellyfish (Van Gundy, 1937, 1951). Alf (1959) identified his Bass imprints

Figure 1. Raymond Alf and Webb Schools students searching for rocks bearing what Alf thought were jellyfish impressions from the Bass Formation in the Inner Gorge of the Grand Canyon in 1957 (Alf second from right).

Earliest Animal Fossil Found By Claremont Science Teacher

Billion-Year-Old Trace Turned Up on Field Trip

By HARRISON STEPHENS

CLAREMONT, — A science field trip by a group of Claremont schoolboys and their teacher has turned up what may be the earliest traces of animal life ever found on earth.

Raymond Alf, Webb School instructor who led the trip, said today other scientists have concurred with him in terming his finds the billion-year-old fossils of worms and jellyfish. If they are, they will change present theories on how long animal life has existed in the world.

"There'll be disputes over it," Alf said. "At least I hope so. Anything of significance usually starts an argument."

He plans to publish the facts on his discovery soon in a scientific journal. Then he'll wait and see what paleontologists have to say about it.

Found in Grand Canyon

Alf and his party of 10 Webb students and another teacher found the fossilized prints of the animals on a steep shale slope near the bottom of the Grand Canyon during an Easter vacation trip. The excursion was part of Alf's "History of Life" course.

The group had hiked 5½ miles down the Kaibab Trail from the South Rim of the canyon to study fossils of algae in the deep sedimentary deposits. These are the pre-Cambrian deposits. They represent the Proterozoic Era of geologic history, known among paleontologists for their almost total lack of animal fossils.

Alf spotted a piece of quartzite that had broken off a ledge and split. One half had impressed in it what looked like

sell and Malcolm McKenna, went back to the canyon to gather evidence on the find.

They found more pieces of the same rock with prints of another jellyfish and part of a third, and other rock fragments covered with fossilized worms. They located the ledge from which the fragments had broken 330 feet from the bottom of 12,000 feet of pre-Cambrian sediment. The minimum age of the sediment at this point is a billion years, Alf said.

"If jellyfish and worms occurred at the bottom of this series, we must figure back much further to allow for development of animal life to this point," Alf said. "These traces force us to realize that the origin of animal life on earth goes further back than many had dared think."

Alf theorized that the jellyfish made clear prints in what is now stone because of the chance location of their deaths. The soft bodied little creatures must have died in the shallow, quiet waters of a Proterozoic lagoon, he said. Their bodies sank into the ooze at the bottom. Before they could decay and disappear forever, they were covered with a thin layer of sediment from a river emptying into the lagoon. Their shapes were formed in the sand

May 12, 1955

Figure 2. Inland Valley Daily Bulletin article on impressions discovered by Ray Alf and Webb School students in 1955 from the Bass Formation that were reported as representing the earliest trace of animal life on Earth.

as jellyfish impressions, which if correct, would have extended the known record of metazoans by about 500 million years (Figure 2). Alf's bold hypothesis was rejected because the Bass impressions were considered inorganic in origin (Cloud, 1960, 1968; Nitecki, 1971). However, the genesis of the Bass structures did generate debate (Glaessner, 1962), and some Bass imprints did resemble extant algal colonies (Glaessner, 1969). Alf did not provide a detailed analysis of the circular Bass structures to rebut the sedimentary structure hypothesis and interest in the specimens waned, resulting in their omission from the Treatise on Invertebrate Paleontology focused on trace fossils and problematica (Hantzschel, 1975).

More recently, Precambrian cyclomedusoids were reported, particularly from Ediacaran strata (Liu et al., 2015). Also, circular structures first described as fossils, then identified as sedimentary structures (Cloud, 1968), were reinterpreted as fossil medusoids (Gehling et al., 2000). Moreover, the Stirling Range Formation in southwestern Australia yielded discoidal structures interpreted to represent impressions of holdfasts of Ediacaran age (Cruse et al., 1993; Cruse and Harris, 1994) in rocks previously considered Mesoproterozoic (Turek and Stephenson, 1966). These strata were later determined to be Paleoproterozoic (Rasmussen et al., 2002, 2004), and other records of Meso or Paleoproterozic metazoans were reported from India and China (Shixing and Huineng, 1995; Seilacher et al. 1998; Bengston et al., 2009). In light of these reports, we reevaluated the circular Bass structures to determine if they represent an early life form or a type of sedimentary structure.

Locality

Two distinct medusa-shaped morphotypes were recovered at RAM (Raymond Alf Museum of Paleontology) locality I94003 from interbedded quartzites and shales (about 60 ft thick) associated with an algal laminated limestone of the Bass Formation at an elevation of about 3,750 feet, adjacent to the Kaibab Trail in Grand Canyon National Park, Arizona (Alf, 1959). Note: both Alf (1959, fig. 2) and Cloud (1968 fig. 4C-D) provided images of the circular Bass structures that show recessed impressions, here referred to as negative hypo-relief impressions. Thus, we assume that the slab on which a negative impression was made represents the bedding plane on which the structure was first preserved. Sediment eventually filled the structure, creating a positive epi-relief impression as seen in slab pairs (Alf, 1959, fig. 1).

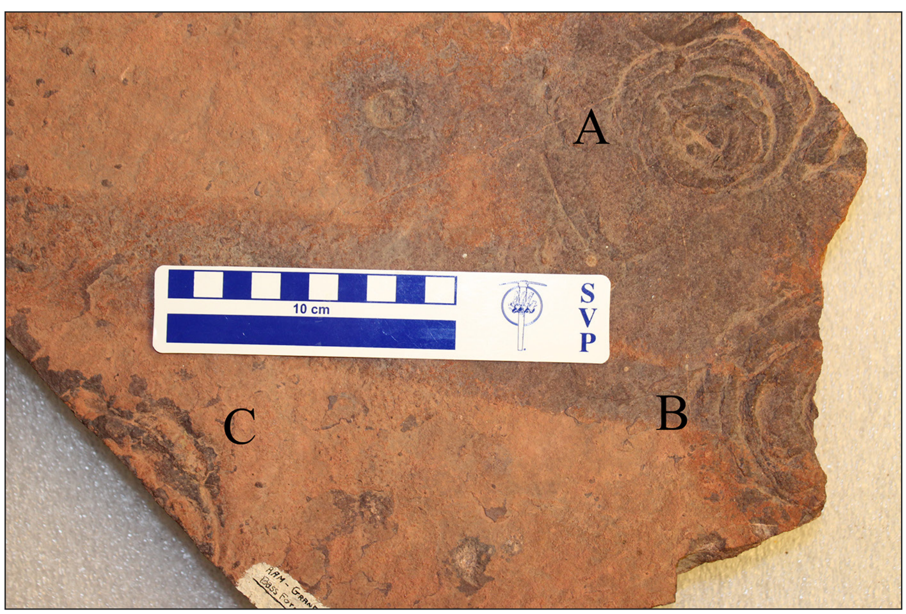

Figure 3. RAM 22007, negative impressions of larger Bass Formation morphotypes. A) most complete impression, B) about half of a complete impression, C) small fragment of impression.

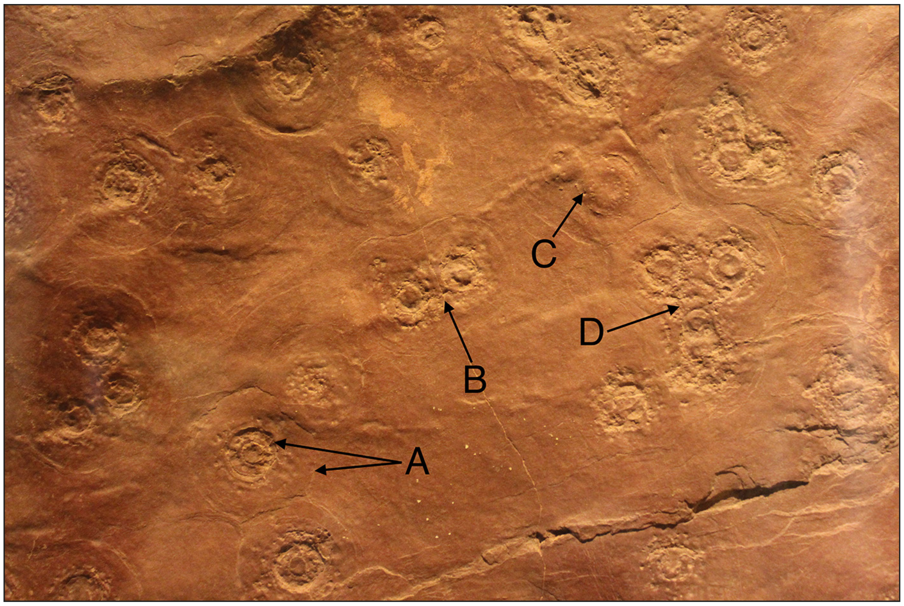

Figure 4. RAM 7140, negative impressions of smaller Bass Formation morphotypes. A) single impression with arrows pointing to outer margin of inner ring and outer margin of outer ring. B) pared impressions that abut but do not overlap, C) two dome shaped impressions that may represent unerupted gas dome sand volcanos, D) four or five closely spaced impressions whose inner and outer rings are highly to moderately disturbed; a chronologic order of impression formation is hard to discern in this cluster, but the upper right and left impressions are most intact and were probably last to form.

Larger morphotype

The larger morphotype is represented by imprints in two sets of paired slabs of quartzite (3.5 to 5 cm thick) which show negative and positive impressions of a partly asymmetrical medusa-like structure. An image of the most complete impression (now lost) shows a structure with a circular central area about 2.5 to 3 cm in diameter, with a partly distinct, asymmetrical outer margin that gives the impression a total diameter of about 7 cm (Alf, 1959, fig. 1, metric scale in photo). The slab margin appears to equal the outer edge of one side of the impression, and if so, the outer ring varies from 1.2 to 4 cm in width.

The second pair of slabs (RAM 22140 positive impression; RAM 22007 negative impression) has three incomplete impressions (Figure 3). The most prominent impression is about 80% complete (Figure 3A) and has a raised central boss 2.8 cm in diameter and a maximum outer edge diameter of 9.4 cm. The distinction between the central circular area and outer margin is not as evident compared to the lost slabs, but the central area was at least 4 cm in diameter and is ringed by one or two concentric annuli. The remainder of the outer part of the impression is less distinct, as outer annuli are faint and asymmetrical. The faint traces and the asymmetrical nature of the outer margin of the most complete impression (Figure 3A) were interpreted to represent successive imprints made by a jellyfish that impacted the substrate twice before making its final impression (Alf, 1959). Also, the central area appeared to exhibit a faint four- or five-fold radial symmetry (Alf, 1959). Although there is a faint four-fold division in the central area, the sections are unequal in area and therefore asymmetrical.

The other two impressions on RAM 22007 are much less complete (Figure 3B-C). Of the two, the more complete structure is truncated by breakage through its central area which is ringed by two apparently concentric annuli (Figure 3B), and there is no trace of the faint, asymmetrical outer annuli seen in the most complete impression (Figure 3A-B). The least complete impression preserves an arc of the outer part of the central area bordered by two partial outer annuli (Figure 3C).

Smaller morphotype

An image of the smaller Bass morphotype was provided by Alf (1959, fig. 2), and multiple examples are present on slabs in the RAM collections. Complete impressions (n=40) have a distinct inner and outer ring (Figure 4A), with the inner ring having a hypo-relief circular central core with raised

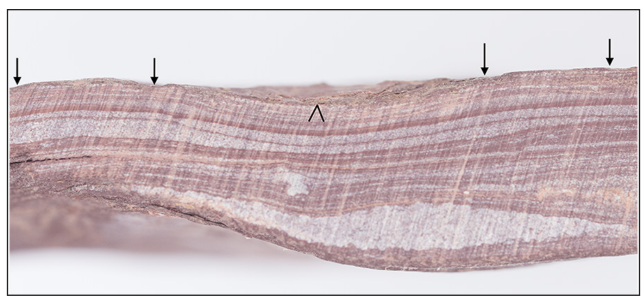

Figure 5. Cross section of negative impression of RAM 7140 that is 1 cm in thickness. Arrows denote central core and outside margins of both the inner and outer ring.

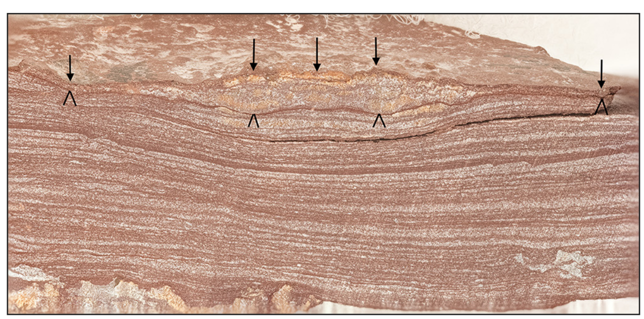

Figure 6. Slightly oblique cross section of positive impression of RAM 22078 that is 2 cm in thickness. Arrows denote the central core and outside margin of the inner and outer rings. Inverted V's denote the mud drape that capped the sediment lens filling the impression.

Table 1. Measurements in mm of the inner ring and total diameter of complete examples of the smaller morphotype from the Bass Formation.

Specimen Number	(Inner Ring and Total Diameters)
RAM 7140	(12.6, 28.7) (13.4, 31.2) (6.4, 25.7) (10.7, 27.3) (9.3, 28.0) (9.9, 26.2) (8.9, 28.8) (9.7, 31.4) (9.2, 30.0) (10.4, 34.7) (7.0, 28.0) (6.6, 24.6) (10.1, 28.0) (7.5, 27.9) (9.2, 29.3) (7.1, 26.1) (9.8, 33.6) (7.8, 34.3) (8.5, 37.3) (10.0, 34.5)
RAM 21995	(7.5, 28.7) (6.9, 25.1) (6.1, 27.4)
RAM 22678	(12.0, 30.4) (9.5, 25.6) (7.0, 22.5)
RAM 21926	(9.8, 27.4) (7.8, 22)
RAM 22080	(12.0, 26.0)
RAM 21989	(7.5, 24.8)
RAM 21971	(9.5, 32.7)
RAM 22065	(12.8, 26.2)
RAM 22034	(11.6, 40.2)
RAM 22023	(7.7, 30.6)
RAM 21935	(10.0, 32.0) (6.9, 22.0)
RAM 21951	(7.6, 23.4) (8.3, 29.7)
RAM 21928	(8.2, 23.0) (9.2, 23.4)

outer edges surrounded by a depressed concentric ring of undulating sediment exhibiting numerous pits. The depressed concentric inner ring rises at its outer margin which defines the boundary between the inner and outer ring; inner ring diameter is 6.1–13.4 mm (mean 8.9 mm). The outer ring is composed of a distinct horizontal band of faint concentric annuli whose outside edge defines its maximum extent; outer ring diameter is 22.0–40.2 mm (mean 27.2 mm) (Table 1).

There are many examples where outer rings of two adjacent impressions abut, each remaining intact, but their outer ring margins are deflected so they are no longer symmetrical (Figure 4B). A few impressions are concentric mounds with recessed central cores whose outside margin is defined by a low outer ring composed of faint annuli (Figure 4C). Clusters of multiple closely spaced impressions have highly deformed outer rings and moderately disrupted inner rings (Figure 4D).

The authors sectioned the negative hypo-relief (bedding plane impression) and positive epi-relief (cast of impression) parts of smaller morphotypes. A cross section of RAM 7140 (negative impression) shows a broad and shallow structure with distinct raised areas that define the outside edge of the inner ring. Faint raised areas also define the outside edge of the outer ring (Figure 5). A lens of thicker sediment corresponding to the inner ring is seen in a cross section of RAM 22078, a positive impression with depressions that conform to the outside edges of the inner ring (Figure 6). The lens thins throughout the extent of the outer ring before merging laterally with laminated sediment at the outside margins of the impression. Also, distinct mud drapes define the top and bottom of the lens (Figure 6).

Discussion

Bass Formation impressions have an intriguing morphology suggestive of a biogenic origin, but can this be convincingly demonstrated? Consider the case of *Brooksella canyonensis*, which was based on a single specimen found in the 1930s from the Nankoweap Formation and thought to represent a jellyfish (Van Gundy, 1937). Bassler (1941) described and named the specimen but was uncertain if it represented a jellyfish impression or some type of sedimentary structure. Probably in hopes of confirming its identification, Van Gundy (1951) searched for additional specimens, finding none, but still considered *Brooksella canyonensis* to represent a jellyfish impression. Later, *Brooksella canyonensis* was identified as a trace fossil (Seilacher, 1956), an inorganic sedimentary structure (Cloud 1960, 1968), and then was listed as Medusae Incertae Sedis by Hantzschel (1975). Similarly, in his only report on the Bass impressions, Alf (1959, p. 60) noted that "the purpose of the present paper is to call the attention of the scientific public to these specimens in the hope that professional comment may be forthcoming." However, the result was not as Alf expected because scientific scrutiny resulted in the Bass impressions being identified as inorganic structures (Cloud, 1968; Nitecki, 1971). However, Alf never accepted that the Bass impressions were nonbiogenic and considered them his greatest paleontological discovery (Lofgren et al., 2019). Whether the Bass structures represent rain drop imprints, holdfast scars, gas/fluid escape structures, or some type of fossil organism is discussed below.

Rain drop impressions

A drop of rain falling on unlithified sediment can leave a distinct circular impression. A specimen from the Permian Coconino Formation of Arizona in the RAM collection has simple circular impressions .5 to 1. cm in diameter on a bedding plane of fine sandstone. These impressions are smaller and lack the complexity of the inner and outer rings of the Bass structures. Also, the resulting impressions made experimentally by dropping water on soft plaster (Cloud, 1968, fig. 4A) do not resemble the Bass impressions, nor do rain drop impressions on red shale from Triassic strata in New Jersey (Lyell, 1851, fig. 2), which again are simple circles without multiple rings.

Holdfast scars

Aspidella terranovica, a Precambrian circular structure with radial lineations and a central cone thought to represent a type of metazoan from the late Neoproterozoic Fermeuse Formation in Newfoundland (Billings, 1872) was considered a sand volcano (Cloud 1968; Hoffman 1971, plate 5 figs. 3-4) or pseudo-fossil (Hantzschel, 1975), but was more recently reinterpreted as a body fossil based on restudy of the type locality (Gehling et al., 2000). Some morphs of *Aspidella* from the type locality in Newfoundland now interpreted as holdfasts of metazoans (Gehling et al., 2000, fig. 8, 15) closely resemble the smaller morphotype from the Bass Formation. Also, the smaller Bass morphotype and the Neoproterozoic specimens described by Gehling et al. (2000) exhibit mutually deformed boundaries where two or more abut, which is also a characteristic of other Ediacaran taxa (Wade, 1972, pl. 41, fig.1; Narbonne and Aitken, 1990, pl. 1, fig. 6). Some of these Neoproterozoic discoids, like these identified as *Aspidella*, were interpreted to represent holdfasts that had stem or frond-like extensions (Jenkins and Gehling, 1978; Gehling et al., 2000), and cross sections of these structures show disruption and/or truncation of sediment laminae (Gehling et al., 2000, fig. 10, 12).

The circular shape and morphology of the inner ring of the smaller Bass morphotype do resemble *Aspidella* and similar Ediacaran taxa. However, cross-sectioning of the smaller Bass morphotype shows undisturbed bedding (Figure 5), in contrast to *Aspidella* from the Neoproterozoic Fermeuse Formation where laminae are truncated (Gehling et al., 2000, fig. 12). Bass impressions also have a distinct outer ring with faint annuli (Figure 4A), features not seen in the Neoproterozoic discoids. Thus, the smaller Bass impressions are not consistent with holdfast scars.

Gas or fluid escape structures

Circular structures in sedimentary rocks that are the result of fluid/gas voiding through unlithified sediment are often referred to as "*Astropolithon*" or sand volcanos (Hantzschel, 1975; Dornbos et al., 2007). Originally, "*Astropolithon hindii*" was applied to circular structures with radial lines from Cambrian strata in Nova Scotia thought to be of biogenic origin (Dawson, 1878, 1890) and examples were reported elsewhere (Glaessner, 1966). However, Walter (1972) interpreted similar Precambrian structures as conical sand volcanoes, and Pickerill and Harris (1979) argued that "*Astropolithon hindii*" represented a type of sand volcano that left an imprint consisting of a low relief mound with a central apical depression surrounded by circular lineations. Sand volcanos can form on substrates with or without a biomat (Seilacher et al., 2002, figs. 7 and 8), and a substrate with a sediment biomat would crack radially as fluid erupted (Seilacher, 2007). Thus, circular impressions with radial lineations are referred to as "*Astropolithon*," and circular structures that lack radial lineations (made by sand volcanos erupting through substrates without biomats) are called "gas domes" (Dornbos et al., 2007). If such a distinction can be applied to the Bass Formation impressions, they would be gas dome sand volcanos.

Recent gas escape structures that are much larger than either Bass morphotype have a close similarity to the smaller morphotype as they have a recessed inner ring and an outer ring composed of a fairly horizontal band of sediment with distinct annuli (Maxson, 1940, fig. 4). Also, Cambrian structures that resemble the smaller Bass morphotype from the King Square Formation in New Brunswick, Canada, interpreted to represent sand volcanos, have a central depression with concentric rings and a broad trough surrounding the inner ring margin (Hagadorn and Miller 2011, fig. 2C-D). Additionally, where two of the Cambrian discoids abut, edges of their outer troughs always coalesce rather than overlap (Hagadorn and Miller, 2011, fig. 4G-K), similar to pairs of the smaller Bass morphotype (Figure 4B). Although these Cambrian structures have radial lineations ("*Astropolithon*") in some cases (Hagadorn and Miller 2011, fig. 4A-C), in most other respects, they closely resemble the smaller Bass impressions.

A schematic of sand volcano formation by Plummer (1980, fig. 2) shows that the result of the eruption is a shallow depression in the substrate which would correspond to the hypo-relief Bass impression (Figure 5), with subsequent infilling of sediment equivalent to the epi-relief Bass impression (Figure 6). Recent gas blisters in mud from a geyser field in New Zealand (Cloud, 1960, pl. 1, fig. 1) resemble the smaller Bass morphotype and were evidence cited to conclude that Bass Formation "jellyfish" impressions described by Alf (1959, fig. 2) were sedimentary structures caused by escaping gas (Cloud, 1960, 1968). The inner ring of Bass impressions would represent the breached dome and its margin of highly disturbed sediment, and the outer ring would represent a faint disruption of sediment that diminished laterally as the energy released from the eruption waned. Unerupted fluid or gas domes can also be associated with sand volcanos. RAM 7140 has two closely spaced dome-like structures (Figure 4C) on a bedding plane that also exhibits numerous structures that presumably represent erupted sand volcanos. The unerupted domes on RAM 7140 resemble experimentally developed silt domes with central depressions caused by trapped gas (Gill and Kuenen 1957, plate 36, 2-5) (Figure 4C).

Thus, multiple lines of observation suggest that the Bass Formation structures are consistent with gas dome sand volcanos where gas or gaseous fluid erupted through a muddy substrate lacking a biomat. However, a cross section of a Bass Formation structure (Figure 6) indicates sediment laminae immediately below the mud substrate interface are not disrupted, which might be expected as a result of the eruptive process; all other smaller Bass morphotype structure cross sections (n=8) also lack disrupted laminae below the mud substrate interface. Kirkland et al. (2016) argued that no indication of vertical fluid escape structures in the center of similar discoidal structures from Silurian strata in Norway was evidence that the discoids were not the result of sand volcano development. However, no vertical oriented sediment or fluid shaft was developed below the substrate surface in impressions seen in cross section of the discoid structures (once described as fossil medusae) from the Cambrian site in New Brunswick interpreted to represent sand volcanos (Hagadorn and Miller, 2011, fig. 5). Perhaps the Bass structures were made by a less disruptive process where gas/gaseous fluid escaped through permeable sediment laminae before erupting through the more impermeable mud substrate interface (perhaps a weakly developed biomat was present, so when the mud substrate was breached, radial lineations did not form). Kirkland et al. (2016) argued that irregular disc formation would be the result when multiple sand volcanos abut/overlap within a confined area, a feature seen in RAM 7140 where densely packed individual impressions are highly disrupted (Figure 4D), suggesting sand volcano activity on the Bass Formation bedding plane. Thus, other than the lack of a vertical shaft in cross section providing visual evidence of upward fluid/gas movement, the Bass impressions appear to be the result of the eruption of numerous gas dome sand volcanos that released gas or gaseous fluids through substrates that had weakly developed or lacked biomats.

Algal colony or jellyfish

Alf (1959) interpreted the Bass structures as imprints of jellyfish, but most reports of Precambrian medusae represent trace fossils or inorganic features such as fluid/gas escape structures (Young and Hagadorn, 2010). Also, fossil medusae are almost never perfectly radially symmetrical nor oriented parallel on a bedding plane (Young and Hagadorn, 2010) like the Bass impressions. In addition, fossil medusae from mass stranding events in the Cambrian Mt. Simon/Wonewoc sandstones do not closely resemble the Bass structures, as they usually have a central convex mound of sediment surrounded by a convex sediment ring (Hagadorn et al., 2002). These Cambrian medusae were interpreted to have ingested sediment, which after decay, left a convex mound of sediment on the substrate that resulted in the raised central sediment mound (Hagadorn et al., 2002, appendix 2). The positive impression of Bass Formation structures in cross section is similar to Cambrian medusae impressions as there is a distinct thickening of sediment that forms the positive Bass impression. If Bass Formation fossil medusae had indeed left a raised mound of sediment, the top of the mound would correspond to the sediment level indicated by inverted V's in Figure 6. Thus, the lens of sediment seen in cross section would represent a medusa, but if so, one would expect that the strata would split at this sediment interface rather than below as it does in all Bass impressions (Figure 6). Also, every example of a Bass impression has a positive counterpart, and it seems unlikely that every fossil medusae would ingest that much sediment because only some medusae from the mass stranding event in the Cambrian Mt. Simon/Wonewoc sandstones ingested sediment (Hagadorn et al., 2002). Finally, the lensoidal thickening of sediment in positive Bass impressions thins and merges laterally with laminae outside the margin of the imprint, so the lens is part of a sedimentation event independent of the formation of the negative impression. In any case, Young and Hagadorn (2010) argued that there are no bona fide Proterozoic medusae, a statement that now also includes the Bass Formation impressions (Hagadorn, pers. comm. October 2019).

Extant diatomaceous algae colonies from Australia have circular gelatinous sheaths with concentric rings, and when two colonies are adjacent, in outline they resemble abutting pairs of the smaller Bass impressions (Glaessner, 1969, figs, 2-3). Whether the imprints of algal colonies on a substrate of soft sediment would leave such a distinctive and complex impression as the Bass Formation structures is unknown. Thus, although unlikely, the interpretation that the Bass Formation structures are the result of some type of biologic activity cannot be disproven.

Summary

Discoidal structures in outcrops of the Mesoproterozoic Bass Formation in Grand Canyon National Park were first thought to represent jellyfish impressions (Alf, 1959), but were later interpreted as sedimentary structures (Cloud, 1960, 1968; Nitecki, 1971) and largely forgotten. In the 1990s, Precambrian medusoids similar to the Bass Formation structures were reported from the Stirling Range Formation of Australia (Cruse et al. 1993; Cruse and Harris, 1994) and dating of these strata indicated a Paleoproterozoic age for the Stirling Biota (Rasmussen et al., 2002, 2004; Bengtson et al., 2007). These reports inspired re-evaluation of the Bass Formation impressions.

Bass Formation impressions are probably the result of gas or gaseous fluid erupting through the substrate because features of recent and Proterozoic structures identified as gas dome sand volcanos are very similar in morphology. Key similarities are concentric inner and outer rings, a depressed central core, abutment of paired impressions, disruption of adjacent inner and outer rings in clusters, and doming of some impressions. Bass impressions are not rain imprints or holdfasts because raindrop discs lack the morphological complexity of the Bass structures and cross sections show no disruption of sedimentary laminae associated with holdfasts of fossil organisms. The Bass structures superficially resemble extant algal colonies and fossil jellyfish impressions, but the gas dome sand volcano hypothesis is much more robust. Caution was recommended by Cloud (1973) when attempting to identify fossil medusae based on circular imprints in Precambrian strata. Raymond Alf hoped that his Bass "jellyfish" impressions would eventually be recognized as fossil medusae (Lofgren et al., 2019), but we concur with Cloud (1960, 1968) and Nitecki (1971) that the Bass imprints are most likely sedimentary structures.

Acknowledgments

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