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1 The dynamic influence of microbial mats on sediments: fluid escape and
2 pseudofossil formation in the Ediacaran Longmyndian Supergroup, UK

3 LATHA R. MENON^{1*}, DUNCAN MCILROY², ALEXANDER G. LIU³, and MARTIN D.
4 BRASIER^{1,2 †}

5 ¹*Department of Earth Sciences, University of Oxford, South Parks Road, Oxford, OX1 3AN, UK*

6 ²*Department of Earth Sciences, Memorial University of Newfoundland, St John's, NL, A1B 3X5,*
7 *Canada*

8 ³*School of Earth Sciences, University of Bristol, Life Sciences Building, 24 Tyndall Avenue,*
9 *Bristol BS8 1TQ*

10 [†]*Deceased*

11 **Corresponding author (e-mail: menon891@btinternet.com)*

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15

16 **Abstract:** Microbial mats are thought to have been widespread in marine settings before the
17 advent of bioturbation, and the range of their influence on sediments is gradually becoming
18 recognized. We propose that mat sealing can dynamically affect pore-water conditions and
19 enable the build-up of overpressure that can drive dewatering and degassing to produce a suite of
20 atypical fluid-escape features. Finely bedded silty and sandy laminae from the *c.* 560 Ma Burway
21 Formation of the Longmyndian Supergroup, Shropshire, England, reveal evidence for sediment
22 injection, including disrupted bedding, clastic injections, sill-like features, and sediment
23 volcanoes at sub-millimetre scale. These features are associated with crinkly laminae diagnostic

24 of microbial matgrounds. Matground-associated fluid injection can explain the formation of
25 several types of enigmatic discoidal impressions, common in marginal marine facies of this age,
26 which have previously been attributed to the Ediacaran macrobiota. Serial grinding of
27 Longmyndian forms previously described as *Medusinites* aff. *asteroides* and *Beltanelliformis*
28 demonstrate that such discoidal features can be fully explained by fluid escape and associated
29 load structures. Our observations emphasize the non-actualistic nature of shallow-marine
30 Ediacaran sediments. Matground-associated sediment injection features provide a new insight
31 into the interpretation of Proterozoic rocks and the biogenicity of their enigmatic discoidal
32 markings.

33

34 **Supplementary material:** A document containing further images of fluid escape and loading
35 features observed in the upper Burway Formation at Ashes Hollow, together with an annotated
36 diagram of features appearing in one typical vertical cross-section, is available at
37 www.geolsoc.org.uk/SUP00000.

38

39 The abundance and importance of microbial mats on the Ediacaran seafloor has been widely
40 discussed (e.g. McIlroy & Walter 1997; Seilacher 1999; Gehling 1999; Liu *et al.* 2011).
41 Microbially mediated sedimentary structures resulting from seafloor biostabilization and build-
42 up of decay gases below matgrounds (e.g. gas domes, “sponge pore” fabrics) are now well
43 characterized (see Gerdes *et al.* 1994; Noffke 2010; Schieber *et al.* 2007). Most studies have
44 focused on structures formed in association with cyanobacterial mats in intertidal settings, but
45 many of the fundamental properties required to generate such forms are inferred to apply to all
46 types of microbial mat.

47

48 Here we document features from the Ediacaran Longmyndian Supergroup, Shropshire, England
49 that are considered to arise from the dynamic influence of mat sealing on unconsolidated fluid-
50 rich sediment. We also demonstrate that some of the enigmatic sedimentary structures
51 commonly observed within late Ediacaran successions - and interpreted as fossils - should now
52 be re-interpreted in terms of mat-driven processes. Our model provides a physical explanation
53 for at least three forms of discoidal impression observed in these strata: *Medusinites* aff.
54 *asteroides*, *Beltanelliformis brunsa* Menner, and *B. minutae* (cf. McIlroy *et al.* 2005).

55

56 **Lithology, palaeoenvironmental context, and surface features**

57 The specimens discussed here were collected from a disused quarry in Ashes Hollow, from
58 horizons approximately 75 m below the Cardingmill Grit, close to the top of the Burway
59 Formation, Stretton Group, Longmyndian Supergroup (Fig. 1). The discoidal fossils occur in
60 heterolithic facies of mudstone to fine siltstone interlaminated with fine sandstone (Pauley 1986;
61 McIlroy *et al.* 2005). The lamination, typically <0.2–1 mm in width, is mostly plane parallel,
62 with some cross-lamination and contorted laminae in places stretching a few centimetres, with
63 occasional small microfaults. Grains include a significant volcanic and plutonic component from
64 the Uriconian Volcanic Complex underlying the Stretton Group (Pauley 1986, 1990). The
65 chloritic mudstone and siltstone are greenish-grey in hand specimen, while the amalgamated
66 sandstone is dark brown due to the presence of haematite (Pauley 1986). Intermittent thin (<0.3
67 mm), white laminae have previously been identified as hosting mineralized microbial mats
68 preserved in a white aluminosilicate mineral (Callow & Brasier 2009). The colour contrast
69 between the mudstone and inter-laminated sandstone allows sub-millimetric sediment fabrics to

70 be studied in polished vertical section. The age of the Burway Formation is currently constrained
71 by U/Pb SHRIMP geochronology to between 566.6 ± 2.9 Ma in a lapilli tuff at the base of the
72 underlying Stretton Shale Formation, and 555.9 ± 3.5 at the top of the stratigraphically higher
73 Lightspout Formation (Compston *et al.* 2002).

74
75 Sole surfaces of some Ashes Hollow beds are covered with millimetre-scale mounds, typically of
76 2 mm diameter, and pinhead-like protuberances (“pimples”), with rimless counterpart pits on the
77 tops of underlying beds (Fig. 2a–c; Table 1). Shallow (0.5 mm depth), rimless discoidal
78 depressions, generally larger and lacking the sharp edges of the counterpart pits, are also found
79 on top surfaces (Fig. 2d; Table 1). Discoidal forms were first noted in the Burway and Synalds
80 Formations of the Longmyndian Supergroup in the 19th century (Salter 1856; described in
81 Callow *et al.* 2011). They were originally inferred to be biological structures of simple animals
82 (Salter 1856; Darwin 1859), but this interpretation has subsequently been much debated (e.g.
83 Cobbold 1900; Pauley 1986, 1990; Toghil 2006; Liu 2011). The possible interpretation of
84 circular impressions as rain-pits, that would in any case be rimmed, is ruled out by the
85 recognition of subaqueous deposition of the Burway Formation (Pauley 1990). The discoidal
86 forms have more recently been regarded as fossils of simple Ediacaran organisms belonging to
87 form taxa *Medusinites* aff. *asteroides*, *Beltanelliformis brunsa*, and *B. minutae* (McIlroy *et al.*
88 2005).

89
90 The most distinctive discoidal fossil from the Burway Formation is *Medusinites* aff. *asteroides*, a
91 blister-like mound of 1–6 mm diameter, sometimes with a central boss, locally found in large
92 numbers on the soles of beds (Fig. 2a). *Medusinites* mounds in cross-section are typically filled

93 with dark sandy sediment, sometimes with a tube-like extension above, which was thought to
94 represent the passage of either gas or an organism (Cobbold 1900). Since gas-escape structures
95 are rarely preserved in this way, McIlroy *et al.* (2005) tentatively concluded that *Medusinites*
96 may be a trace fossil.

97

98 Microbial-mat-associated “elephant skin”, wrinkle textures, and thread-like markings are also
99 seen on surfaces of Stretton Group rocks in association with discoidal markings (McIlroy *et al.*
100 2005; Fig. 2e). Widespread filamentous microfossils consistent with mat fabrics have also been
101 observed from the Burway and Lightspout Formations (Peat 1984; Callow & Brasier 2009).

102

103 **Methodology**

104 We investigated serial polished vertical cross-sections through hand samples bearing
105 *Medusinites*, “pimples”, and the *Beltanelliformis*-like shallow depressions, to examine the
106 discoidal structures, the potential trace fossils, and the associated matground fabrics. Hand
107 specimens were first cut in a series of slices of 1 cm depth and the cross-sections polished, to
108 form a general impression of the features in cross-section. Individual discoidal specimens were
109 then hand-ground with 15- μm carborundum powder on a glass plate, and photographed at
110 intervals of 1 minute, with the removal of ~ 0.1 mm of rock between grinds, for detailed study,
111 and at intervals of 5 minutes, with the removal of ~ 0.25 mm of rock between grinds, for
112 confirmation and checking of features. This hand-grinding process proved to be sufficient for the
113 interpretation of the features.

114

115 In addition, two specimens of the more complex lobate form, and one *Medusinites*, were
116 subjected to mechanical grinding to facilitate detailed three-dimensional visualization. These
117 samples were ground on a Logitech LP30 lapping and optical polishing machine at the Oxford
118 University Museum of Natural History. Specimens were embedded in resin, and ground at 20 μm
119 intervals. Photographs were taken after each grinding stage following wetting of the specimens
120 with water to increase image contrast. The SPIERS software package (Sutton *et al.* 2012) was
121 used to align and edit the image sequences, and to reconstruct virtual 3D models of the
122 specimens.

123

124 **Upper Burway Formation rocks in vertical section**

125 Examination of beds with crinkly laminae in vertical cross-section revealed a suite of
126 sedimentary features that disrupt laminae at scales of < 0.5 to 10 mm, of which the columns of
127 sandstone above *Medusinites* form only a part (Fig. 3a; Table 1). These features include
128 irregular, often widening, sub-vertical columns of sandstone that have horizontal branches
129 penetrating into associated laminae (Fig. 3b). Larger areas of vertical disruption encompassing
130 over 2 cm of sediment thickness (Fig. 3c), with displaced and locally discontinuous laminae and
131 fragments of green mudstone laminae within the zone of disruption, are associated with
132 strikingly crinkled whitish sedimentary laminae that would be conventionally attributed to
133 microbial matgrounds (Noffke 2010). Such white laminae have previously been shown to
134 contain intermeshed microbial filaments (Callow & Brasier 2009). Serial grinding through one
135 such area demonstrated that the disrupted region was less than 5 mm wide. Moreover, the
136 laminae cut by the disturbance do not show systematic displacement; some laminae are
137 displaced, others simply discontinuous. This contrasts with the small microfaults observed in

138 these sections, and indicates that the feature results from localized soft-sediment deformation.
139 Where the sediment columns reach bedding surfaces (e.g. Fig. 3c and d), they are associated with
140 small apex-up cones and craters of 1–5 mm in diameter and 0.5–1.5 mm height (Fig. 3e).

141
142 Petrographic study of these lithologies provides substantial evidence for the former presence of
143 widespread microbial mats, including crinkled laminae, intermeshed filaments angled at
144 approximately 45° to bedding, trapped and bound sediment grains, and the preferential alignment
145 of muscovite and other elongated grains within the matground facies (cf. Noffke 2010; Figs 4, 5;
146 see also Peat 1984; Callow & Brasier 2009).

147
148 All simple mound-like *Medusinites* examined in cross-section by serial grinding reveal a
149 protruding mound that is wholly filled with dark sandstone of the same lithology as the
150 surrounding sandstone laminae, frequently with a sub-vertical columnar extension (Fig. 6a and
151 b). This sediment column distorts and cuts mudstone laminae above the discoidal impression,
152 and typically terminates at an overlying sandstone bed (Fig. 6b). *Medusinites* with a central boss
153 have a partial fill of sandstone, encompassing the boss and widening laterally a little above the
154 centre of the mound (Fig. 6c and d). Negative counterparts of *Medusinites* found on the tops of
155 beds (Fig. 2b) are underlain by irregular dark-coloured sandstone structures that intersect the
156 centre of the pit (Fig. 6e and f). These sandstone features are of the same lithology and texture as
157 the surrounding sandstone laminae. Cross-sections through the pimple-like impressions on bed
158 soles attributed to *B. minutae* (McIlroy *et al.* 2005; Fig. 2a and c) show narrow columnar features
159 (Fig. 6g and h).

160

161 A tetra-lobate form, comprising a mound divided into four lobes by shallow radial grooves
162 extending from the central pimple (Fig. 2a) was also examined by serial grinding. This form is
163 found in association with normal, rounded *Medusinites* in patches on some bedding planes, and
164 has been regarded as a variant of *Medusinites* (Pauley 1986). The tetra-lobate form appears to
165 represent the most symmetrical example of a wider tendency towards lobe formation in
166 *Medusinites*. Many *Medusinites*, up to ~20% of specimens in some patches, show between 3 and,
167 more typically, 5 poorly formed lobes. In cross-section the lobed forms have sandstone fills very
168 similar to those of non-lobed forms of *Medusinites* (cf. Fig. 6c and d) and the lobes are found to
169 be composed of un-laminated mudstone with an admixture of 20–40% sandstone (Fig. 7a–h).

170

171 Shallow depressions on the tops of beds from the locality with *Medusinites* (Fig. 2d), previously
172 described as *Beltanelliformis brunsa* (McIlroy *et al.*, 2005), were also serially ground, both in
173 vertical cross-section and parallel to bedding, revealing roughly apex-down conical structures
174 composed of dark sandstone, again of the same lithology and texture as the surrounding
175 sandstone laminae (Fig. 8a–c; Table 1). These conical structures do not reach the impression-
176 bearing surface but terminate just below it, as a sill-like spread with central depression (Fig. 8c).
177 Such conical structures are seen in vertical cross-section to extend downwards as meandering,
178 tapering columns, often linking the conical structure to a sandstone bed below (Fig. 8a, b and d).

179

180 **Interpretation**

181 The features observed in our material strongly suggest small-scale injection of sand slurries.
182 Features suggesting fluid escape processes include highly disturbed and torn laminae, fragments
183 of green mudstone and white matgrounds entrained in lamina-cutting features filled with

184 sandstone, and small sand volcanoes (Fig. 3c–e; Fig. 4a; Fig. 6b, h). The sediment deformation
185 fits the pattern of injected (non-neptunian) clastic dykes and sills (cf. Dżułyński & Walton 1965),
186 but at a much smaller scale. Clastic dykes occur at scales of centimetres to many metres and are
187 usually associated with slumping and tectonic instability (Smith & Rast 1958). Dykes and sills
188 resulting from loading and sediment compaction are also known (e.g. Harazim *et al.* 2013), but
189 these too are larger in scale. Small-scale dewatering structures have been reported from regions
190 of rapid sedimentation in some Ediacaran deposits (e.g. Farmer *et al.* 1991). There is no evidence
191 of slumping or rapid sedimentation in the upper Burway Formation. Apart from the small-scale
192 disruptions, and occasional examples of low-angle cross-lamination, the laminae are plane
193 parallel and suggest a low energy, shallow-marine environment (Pauley 1986, 1990). We
194 propose that the very small-scale (predominantly millimetric) fluid injection features result from
195 the influence of the microbial mats.

196

197 The effects of microbial mats on sealing and gas exchange in intertidal settings have previously
198 been noted (Gerdes *et al.* 1994; Noffke 2010; Schieber *et al.* 2007). In fully marine conditions,
199 microbial mat sealing can also affect pore pressure in unconsolidated sediments, allowing the
200 build-up of overpressure in sub-matground sediments (Harazim *et al.* 2013). The suite of features
201 described here is considered to result from the dewatering of pore-water-rich unconsolidated
202 sediments, driven by sediment loading and the sealing effect of microbial mats. Sediment
203 injection, which occurs during compaction of sediments, requires the rise of pore waters at
204 sufficient force to mobilize and entrain sediment grains, and tends to produce fluid-escape
205 structures in fine-grained sands overlain by cohesive layers such as clay (Lowe 1975; Nichols *et*
206 *al.* 1994; Frey *et al.* 2009). Here, in spite of relatively quiet and stable conditions of

207 sedimentation, the effect of cohesive, sealing matgrounds on sediments that appear from the
208 examples of soft-sediment deformation to have overlain pore-water rich muds would have been
209 sufficient to produce sediment injection on a small scale. The scale may also reflect the thin
210 sedimentary laminae involved (<0.5 mm thick), which may have limited the amount of
211 sedimentary material available for sediment-injection during dewatering of any particular
212 horizon.

213

214 The correlation of regions of high sediment disruption with indicators of decayed microbial
215 matgrounds (see e.g. Fig. 4a) is consistent with mat sealing operating as a fundamental process in
216 such sediments. In thin section, the interaction between matgrounds and porewater-rich sediment
217 evinces the role of mats in sediment sealing and in constraining and modifying the features of
218 mobilized sediment (Fig. 4b and c). Intermeshed mat filaments are observed to surround loading
219 structures and are inferred to influence their shape (Fig. 4b and c). Additionally, matgrounds
220 appear to obstruct the upward injection of sediment columns (e.g. Fig. 6d; Fig. 7b, c, f, and h).
221 Microbial metabolism and necrosis are known to result in the build-up of gas in association with
222 matgrounds, and may form such features as gas domes and pustules on the sediment surface,
223 some of which may burst before burial (see e.g. Gerdes 2007). The escape of such gases
224 following sedimentation may have left paths for porewaters to subsequently follow during burial
225 compaction.

226

227 Upward injection and spread of sand slurries resulting from mat sealing is here inferred to have
228 caused deformation of sedimentary laminae to produce loading structures on bed soles that have
229 previously been attributed to *Medusinites* (Fig. 9). If sand slurry is injected with sufficient force

230 to spread at stratigraphically higher levels than the preserved discoidal impression, the injection
231 point may be preserved as a central boss (Figs 2a, 6c). Immediate spread of the sand slurry on
232 injection results in loading of the whole injection area, producing a smooth mound on the bed
233 sole (Fig. 6a and b). Grinding of “Medusinites” counterparts from the Longmyndian confirms
234 that a sandstone column extends below the centre of this structure, supporting the abiogenic
235 injection model for creation of these features (Fig. 6e and f). Injections that rise without
236 spreading produce isolated pimples on bed soles (and counterpart pits on underlying beds)
237 previously identified as *Beltanelliformis minutae* (Fig. 2a and c; Fig. 6g and h). Lobe formation
238 around the injection point in some Longmyndian “Medusinites” is a subtle feature that we
239 suggest arises from the particular hydrostatic conditions of these fluid injection, and the rheology
240 of the sediment at the bedding plane in question. Without knowledge of the precise conditions of
241 fluid injection, it is difficult to investigate such features experimentally. However, the significant
242 point here is that the irregular and widening spread of sand slurry above the lobate forms rules
243 out the possibility that these impressions are either body or trace fossils of Ediacaran organisms.
244 Their abiogenic origin is hereby established.

245

246 The shallow rimless depressions, formerly described as Longmyndian *Beltanelliformis brunsa*
247 and found on some top surfaces of upper Burway Formation beds, can also be explained in terms
248 of fluid movement and sediment loading above porewater rich unconsolidated muds, which
249 produces the inverted conical sandstone features observed in cross-section in the underlying
250 laminae (Fig. 8a–b). The injection of sand slurry into overlying sediment results in a small
251 horizontal spread of sand slurry between laminae (Fig. 8c). This additional sand concentrated
252 around the injection pipe is inferred to cause loading into the underlying unconsolidated

253 porewater rich muds to produce an inverted cone with a central depression, causing distortion of
254 laminae in the mudstone (Fig. 8a–b; Fig. 9). The presence of a sinking cone in a lamina just
255 below the bedding surface causes the surface layer to drop (Fig. 8b), thereby producing the
256 characteristic rimless depression of *B. brunsa* (Fig. 9).

257

258 Our interpretation of the Long Mynd sediments explains many of the conical, columnar, and
259 discoidal features seen in the Burway Formation as fluid injection structures rather than trace or
260 body fossils. The Longmyndian form of *Medusinites*, “*Beltanelliformis minutae*”, and the rimless
261 depressions in the Burway Formation previously called *Beltanelliformis brunsa* can now
262 confidently be regarded as pseudofossils.

263

264 **Conclusions**

265 This study widens the range and scale of the dynamic influence exerted by microbial mats on
266 Ediacaran marine sediments. Microbial mats are already understood to play a key role in
267 capturing and promoting the rapid lithification of moulds of Ediacaran organisms, leading to
268 their being cast by unconsolidated sandy sediment from above or below (the “death mask”
269 scenario; Gehling 1999). In that case, the movement of sediment is passive, filling the void
270 resulting from the decay of the organism. In the model proposed here, the sediment sealing effect
271 of microbial matgrounds is considered to have driven small-scale fluid escape and remobilization
272 of unconsolidated sediment during the early stages of sediment dewatering close to the sediment-
273 water interface. As a consequence, at least some of the distinctive Longmyndian discoidal
274 markings, whose biogenicity has been debated for over a century, are hereby shown to be
275 pseudofossils resulting from fluid-escape associated with sediment dewatering.

276

277 In many parts of the world, fossil assemblages of latest Ediacaran age are characterised not by
278 distinctive members of the ‘vendobiont’ Ediacaran biota, but by circular discoidal impressions.
279 The simplicity of circular interface impressions makes objective assessments of biogenicity
280 difficult to prove or refute based on external morphology alone. Our study highlights the critical
281 importance of examining ancient structures in cross-section. The small-scale mat-driven fluid
282 injection features described here (summarized in Fig. 9), should now be sought in other
283 matground-dominated palaeoenvironments. While such features may arise in any
284 unconsolidated, fine sediments with microbial mat layers, both Recent and ancient, their
285 potential for producing abiogenic discoidal structures is particularly significant for interpreting
286 Precambrian palaeobiology, palaeoecology, and taphonomy, and consequently for our
287 understanding of the early evolution of complex animal life. In the light of this work, the
288 biogenicity of some of the simple circular bedding plane impressions claimed as very old fossils,
289 such as the “Twitya discs” (Hofmann *et al.* 1990), requires careful reassessment.

290

291

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375 **FIGURE CAPTIONS**

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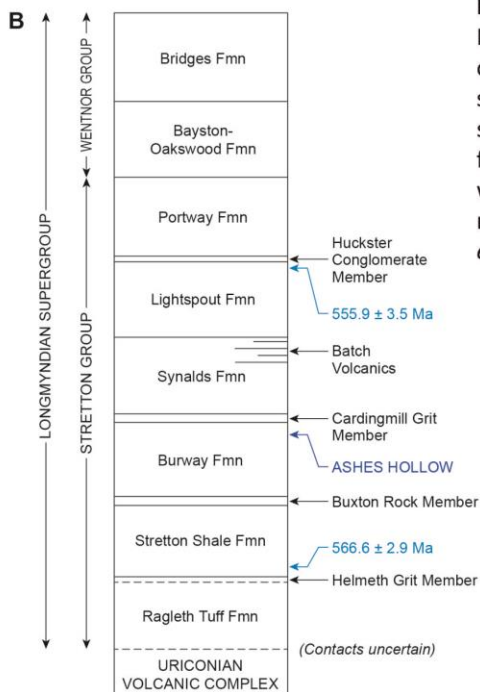
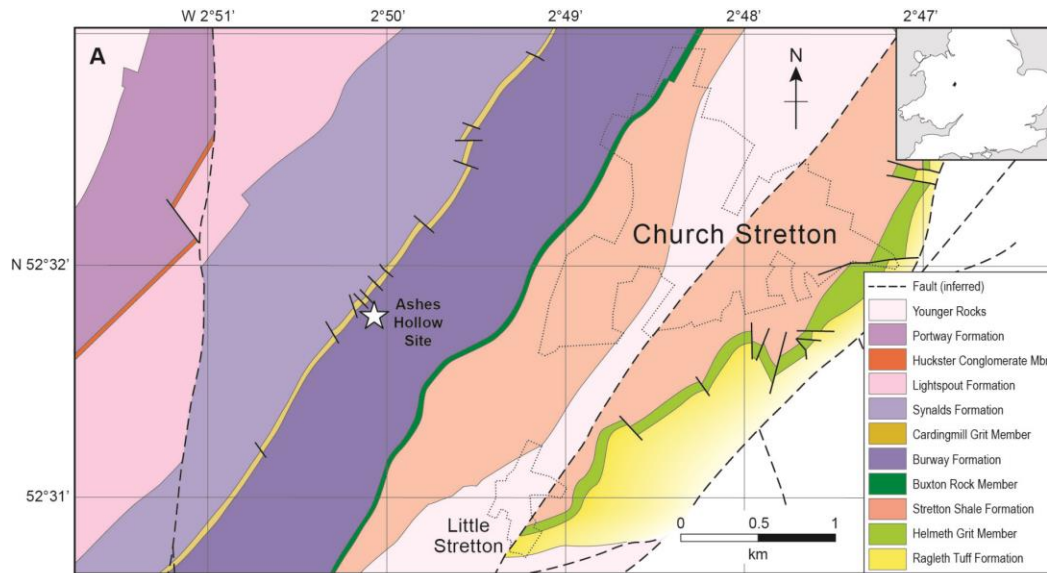


Fig. 1. Location and stratigraphic position of Ashes Hollow area of study. **(a)** Simplified geological map of area with site of specimens indicated. Inset map shows position of the Long Mynd within Britain; **(b)** stratigraphy of the Longmyndian Supergroup, following the interpretation of Pauley (1990, 1991), with stratigraphical position of Ashes Hollow site marked, together with dates measured by Compston *et al.* (2002).

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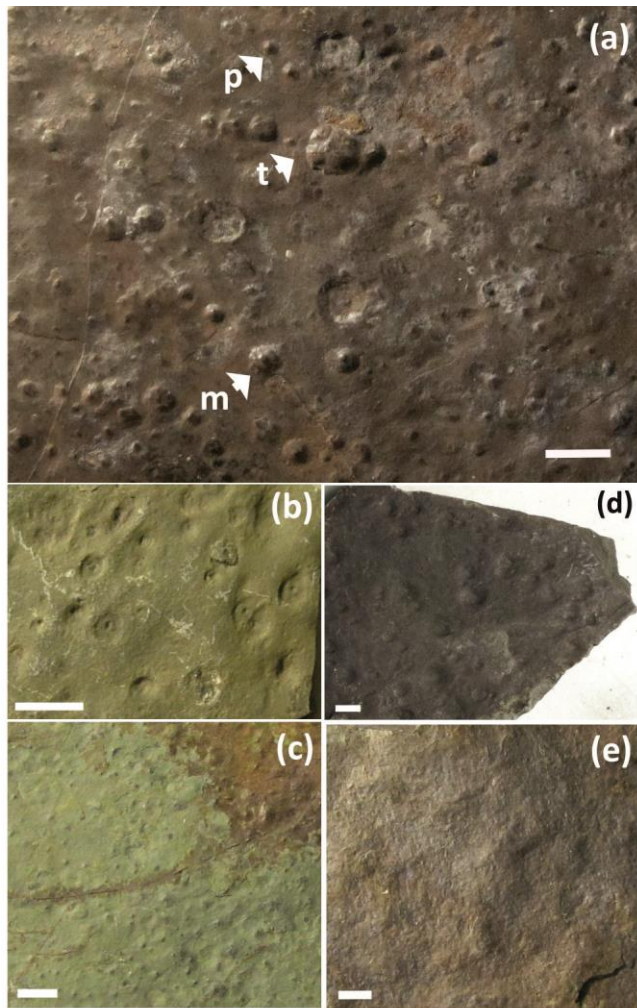


Fig. 2. (a) Sole of block showing abundant small Longmyndian *Medusinites* ('m'), individual pimple protrusions described as *Beltanelliformis minutae* ('p'), and occasional tetra-lobate discs ('t'); **(b)** negative epirelief counterparts of *Medusinites* on top of bed; **(c)** sole surface covered with *B. minutae*; **(d)** Shallow, rimless depressions, described as Longmyndian *B. brunsae*, on top of bed; **(e)** microbial-mat-associated texture on top surface. Scale bars: 5 mm.

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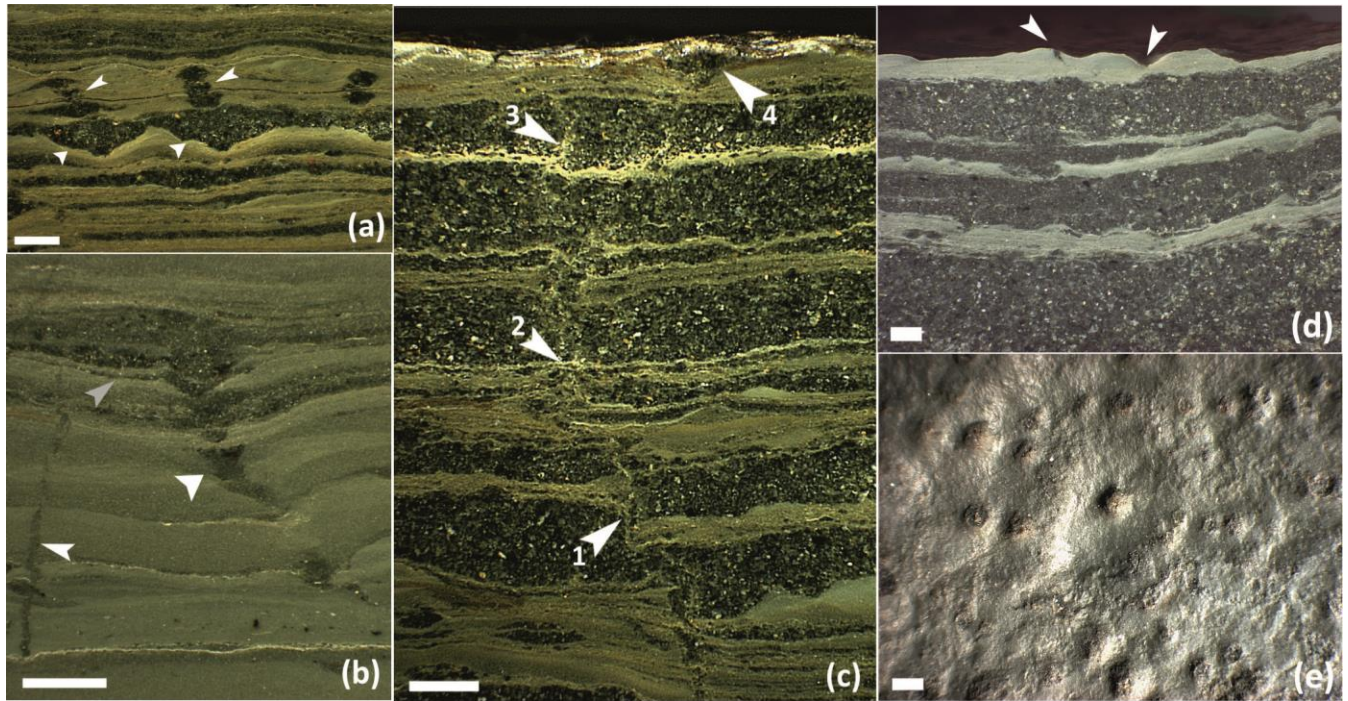


Fig. 3. (a) Two *Medusinites* in ground cross-section (wide arrows) showing columnar extensions of sandstone above (fine arrows), in context amid other sandstone protrusions; (b) ground cross-section showing widening vertical sandstone feature (wide arrow) with horizontal branches penetrating into laminae (grey arrow), and a fine zigzag structure (fine arrow); (c) ground cross-section showing narrow, extended vertical disturbance, with vertically displaced laminae in some parts (1), but not in others (2), and fragments of laminae extending along the line of disturbance (3). The disturbance culminates at the top surface in a small sand volcano (4); (d) ground cross-section showing disrupted laminae and craters on top surface (arrowed), one with fine sandstone column within; (e) view of top surface of block in (d), showing small craters with dark sandstone within. Scale bars: 1 mm.

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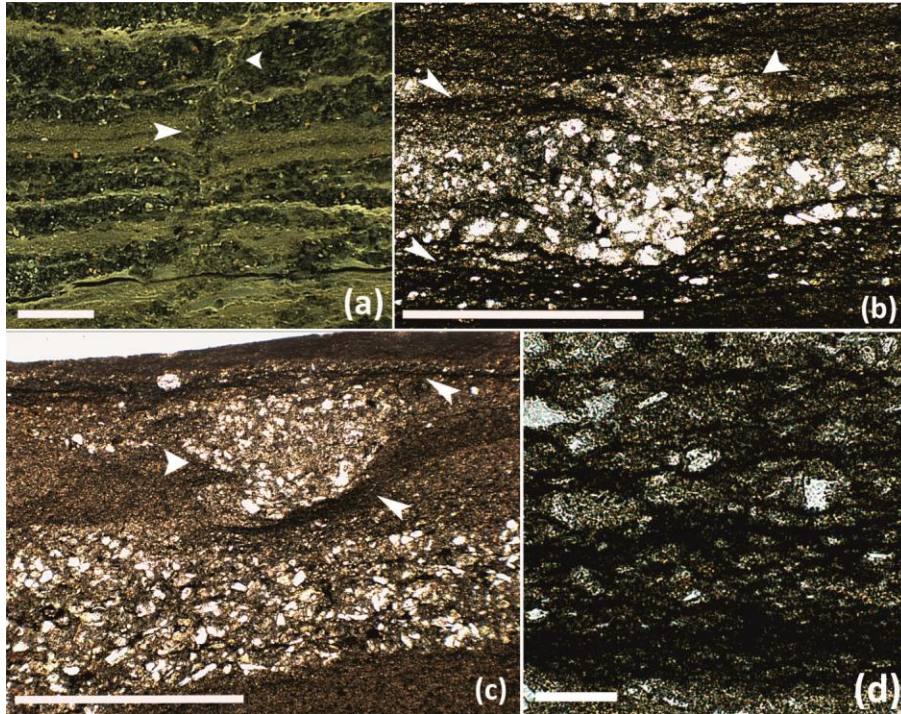


Fig. 4. Microbial mats in cross-section. **(a)** Ground cross-section showing crinkly laminae surrounding a vertical disturbance (disturbance indicated with fine arrow). Note fragments of white lamina extending upwards along the disturbance (wide arrow); **(b and c)** photomicrographs of thin sections showing microbial mat layers (fine arrows) constraining sandy sediment structures (wide arrows). Note narrow sinuous connection of V-shaped structure in (c) to sandstone lamina below; **(d)** photomicrograph of thin section showing trapping and binding of sediment grains by microbial mat. Scale bars: (a-c), 1 mm; (d), 100 μm .

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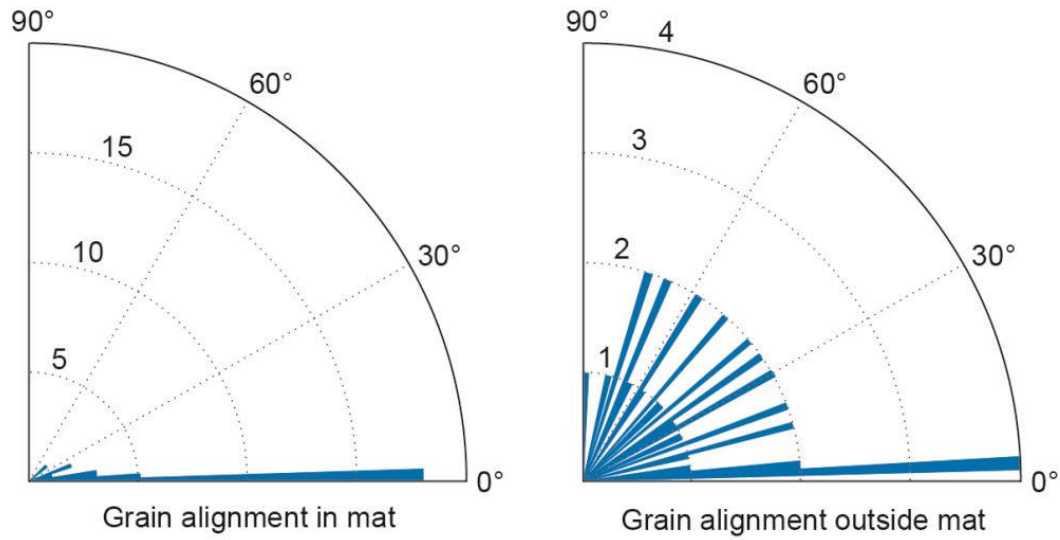


Fig. 5. Comparison of angles of grains trapped in proposed microbial mat (left) compared to those in sandstone layer (right), showing striking grain alignment in the mat layer resulting from trapping and orienting of individual grains within the mat plane by microbes. Total number of grains measured, $N = 40$.

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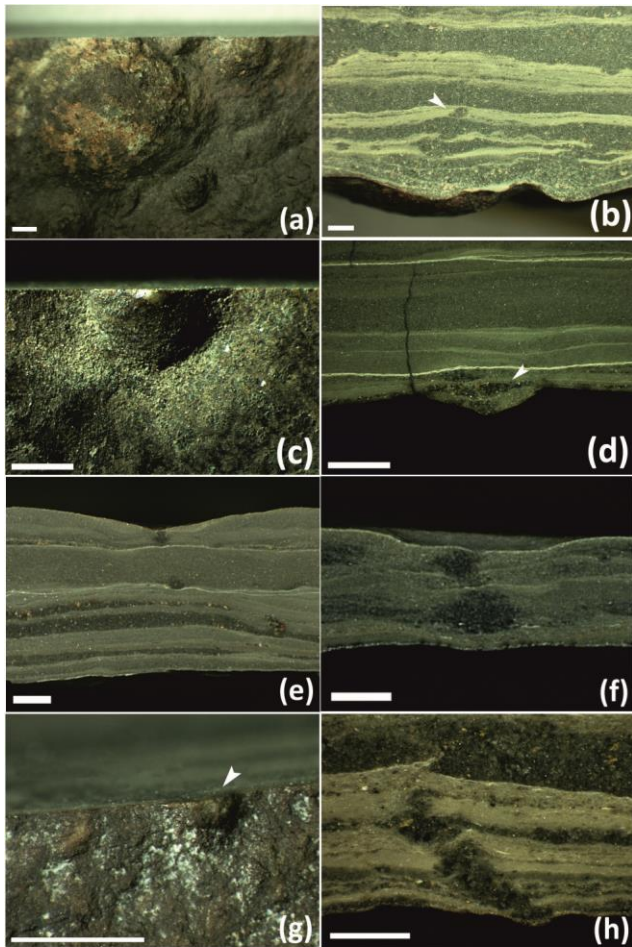


Fig. 6. (a) Large and small mound-like *Medusinites* on bed sole before grinding; **(b)** ground cross-section through *Medusinites* shown in (a), illustrating broken and distorted laminae and central oblique sandstone column (arrowed); **(c)** partially ground *Medusinites* with central boss on bed sole; **(d)** ground cross-section through *Medusinites* in (c), showing widening sandstone fill centred on boss (arrowed); **(e and f)** ground cross-sections through negative *Medusinites* counterparts on tops of beds, showing sandstone below centre; **(g)** "pimple" or *B. minutae* (arrowed) on bed sole; **(h)** ground cross-section through pimple shown in (g). Scale bars: 1 mm.

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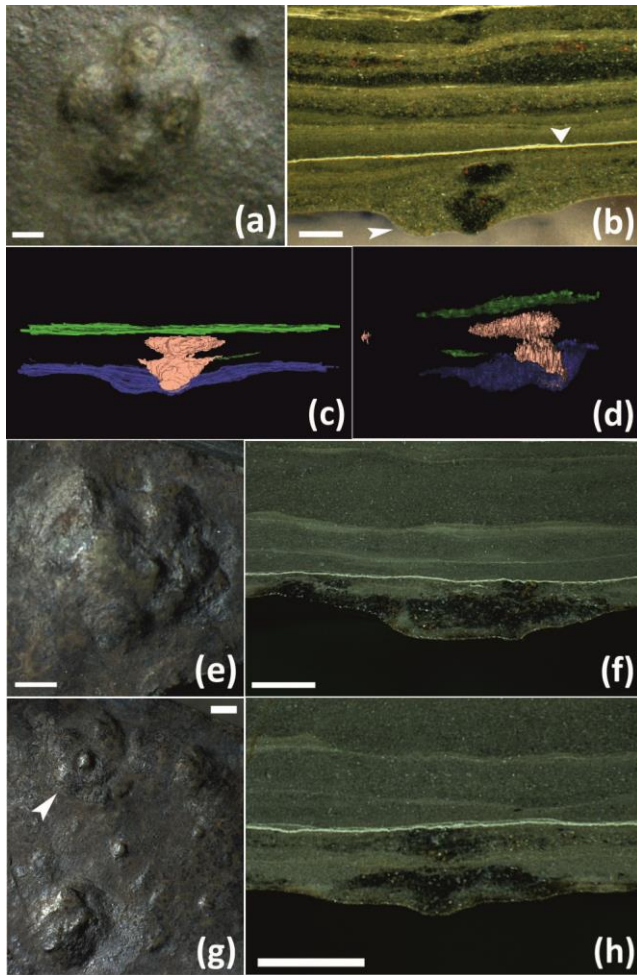


Fig. 7. Lobed *Medusinites* in cross-section. **(a)** Tetralobate form with central boss on bed sole, prior to serial grinding; **(b)** ground cross-section through centre of lobate impression in (a), showing dark sand structure centred on boss, and disturbed sediment in surrounding lobes (fine arrow). Note constraining white, crinkly microbial layer above (wide arrow); **(c and d)** digital 3D model of specimen created using SPIERS software package (Sutton et al., 2012). Green = white marker horizon seen in (b); blue = basal surface of block, showing disc outline; pink = dark sediment centred on the lobate impression; **(e)** irregular lobed form with five lobes on bed sole, abutted against mound; **(f)** ground cross-section through lobate form shown in (e); **(g)** several *Medusinites* showing lobate tendency, together with isolated pimples, on bed sole; **(h)** ground cross-section through arrowed *Medusinites* with poorly formed lobes in (g). Compare with cross-section through well-formed lobate impression shown in (b). Scale bars: 1 mm.

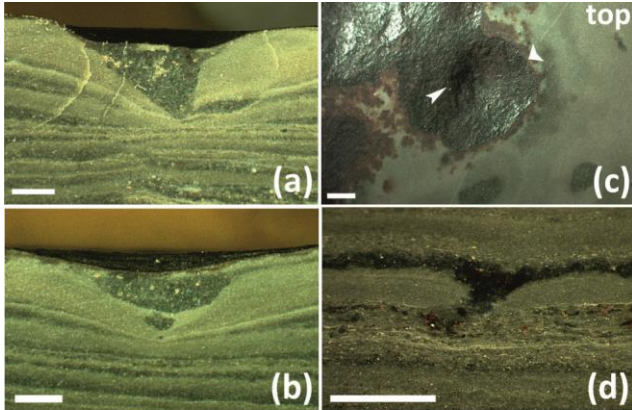


Fig. 8. (a and b) Ground cross-sections through shallow, rimless depressions (Longmyndian *B. brunsaee*), showing conical sandstone structures in laminae just below top surface. Note distortion of laminae surrounding cone; **(c)** grinding of top surface parallel to bedding reveals wide top of cone (wide arrow) directly below, resulting from sill-like spread of sandy sediment. Note central dip in top of cone (fine arrow), and also small round dark patches to bottom and right of picture, being cross-sections through vertical sand columns; **(d)** similar conical structures observed within ground cross-sections through blocks show cone extending as fine column and often linking to a lower sandstone bed. Note dip in centre of top of cone. Scale bars: 1 mm.

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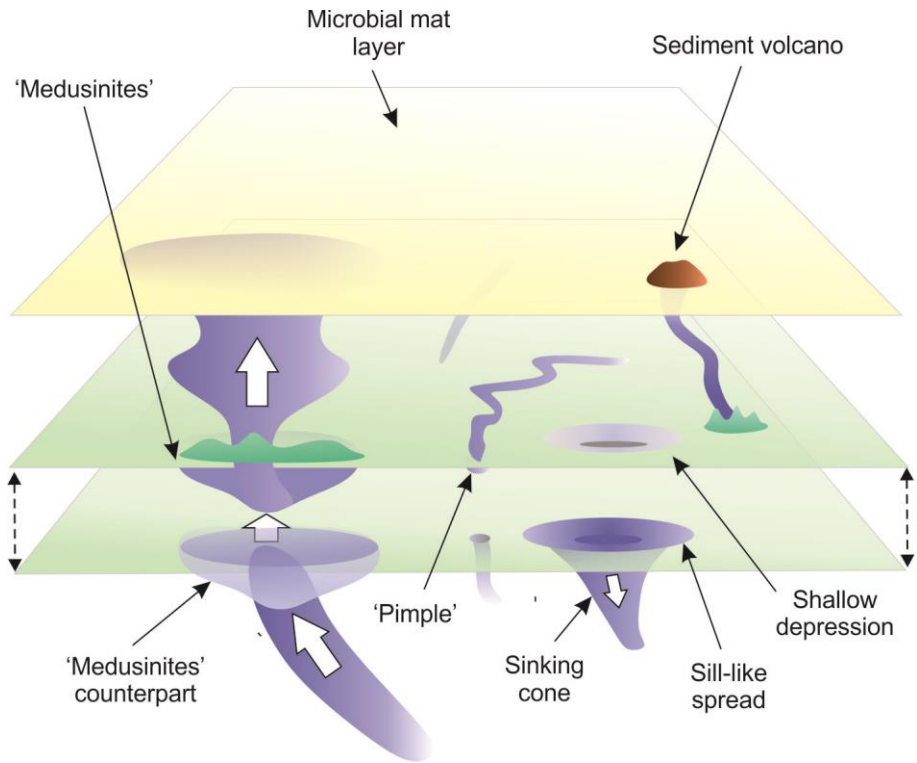


Fig. 9. Schematic 3D representation of proposed model for formation of *Medusinites*-like forms and shallow depressions in the upper Burway Formation. Exploded view of two contiguous surfaces at the bottom of the diagram (dashed arrows) shows markings on sole of bed and counterparts on top of lamina below. To left, "Medusinites" feature is formed by injection and spread of sand slurry, resulting in displacement and loading of sediment. To right, shallow, *B. brunsa*-like depression is produced by sinking, through loading, of a conical sand body in lamina directly below. Formation of smaller scale "pimple" ("*B. minutae*") and sediment volcano are also shown.

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