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1 **Fossil weathering and preparation mimic soft**
2 **tissues in eocrinoid and somasteroid echinoderms**
3 **from the Lower Ordovician of Morocco**

4
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16 **Abstract:** Investigation of the Fezouata Shale has added to our knowledge on the
17 initial diversification of metazoans. These Lower Ordovician deposits yielded
18 abundant and diverse remains of cuticularized to lightly sclerotized organisms, in
19 addition to numerous soft tissues. Described fossilized soft parts recovered from the
20 Fezouata Shale belong mainly to arthropods. Soft tissues in echinoderms, a main
21 component of the Fezouata Biota, remain largely unexplored. Here, we show that
22 soft tissue-like impressions previously reported in eocrinoid and somasteroid
23 echinoderms from this formation are the results of modern weathering and fossil
24 preparation that involved the use of latex molds: they do not reflect any original (soft)

25 anatomical features of these organisms. These two examples suggest that reports of
26 putative soft parts, especially in taxa with no current representatives, need to be
27 thoroughly and critically evaluated.

28

29 **Keywords:** Echinoderms, Exceptional Preservation, Fezouata Lagerstätte, Morocco,
30 Ordovician, SEM, X-ray fluorescence maps

31

32 Introduction

33 Exceptional fossil preservation consists of the preservation of non-biomineralized
34 soft parts (e.g. digestive and nervous systems of animals) in the geological record.
35 Fossiliferous localities showing this type of preservation are called *Konservat-*
36 *Lagerstätten*. The late Tremadocian Fezouata Shale in the Anti-Atlas of Morocco,
37 deposited approximately 480 million years ago, is the only Ordovician period
38 *Konservat-Lagerstätte* to yield a fully marine diverse exceptionally preserved fauna
39 [1]. The ~900 meter thick siltstones of the Fezouata Shale have yielded over 200
40 taxa of marine invertebrates [2]. Most of them belong to arthropods and echinoderms
41 [2,3]. In these deposits, exceptionally preserved soft parts (e.g. guts) are well-
42 documented in various groups of arthropods (e.g., anomalocaridids, trilobites)
43 [1,2,4,5], annelids [6], hyolithids [7], molluscs [8], and palaeoscolecid worms [9,10].

44 In marked contrast, very few occurrences of exceptionally preserved soft parts
45 have been reported from Fezouata echinoderms: a putative gut was mentioned in
46 one specimen of *Solutan* [11], and more abundant remains (water-vascular system,
47 gut) were described in stylophorans [12]. The water-vascular (or ambulacral) system
48 is a complex, non-biomineralized; coelomic, hydraulic structure, which is unique to

49 echinoderms. It consists of ambulacral canals leading to lateral sets of smaller tube
50 feet, which are used for feeding, locomotion and respiration.

51 Such a rarity of exceptionally preserved soft parts in echinoderms from the
52 Fezouata Shale is not surprising. In spite of some recent spectacular reports, e.g. in
53 the Silurian Herefordshire *Lagerstätte*, UK [13,14,15] or the Devonian Hunsrück
54 Slate, Germany [16], very few examples of soft-parts have been described in fossil
55 echinoderms. This situation mainly results from the fast post-mortem disarticulation
56 of their multi-element calcite skeleton, and hence, their low preservation potential,
57 [3,17]. Experimental taphonomy, the study of how organisms decay and become
58 fossilized, on modern echinoderms suggests that both skeletal elements and soft
59 parts disarticulate and degrade within a few days after death [18]. Consequently, due
60 to taphonomic biases [19], the preservation of complete echinoderm specimens
61 yielding soft tissues is extremely rare even within *Lagerstätten*. Because of these
62 biases, understanding the preservational pathway of an organism is vital prior to any
63 paleontological description especially for animal groups with no current
64 representatives. In this study, we aim at understanding the preservation of eocrinoids
65 and somasteroids from the Fezouata Shale [20, 21] and critically evaluate the recent
66 reports of putative soft tissues (water-vascular system) in these two groups.

67

68 **Material and Methods**

69 The taphonomy of soft parts was analyzed in the two best-preserved specimens of
70 eocrinoid and somasteroid echinoderms from the Fezouata Shale [20, 21]. This
71 material is deposited in the paleontological collections of the Musée des
72 Confluences, Lyon, France (acronym 'ML'), and Claude Bernard Lyon 1 University,
73 Villeurbanne, France (acronym 'UCBL-FSL'), respectively. The eocrinoid specimen

74 (ML20-269159, Reboul collection) was collected at Bou Izargane, about 18 km north
75 of Zagora, Morocco. This locality is a well-known fossiliferous site, where abundant
76 and diverse late Tremadocian exceptionally preserved fossils have been collected
77 (e.g. anomalocaridids, marrellomorphs, palaeoscolecids), including trilobites and
78 stylophoran echinoderms with soft parts [5,12,22]. The somasteroid specimen
79 (UCBL-FSL 424962, Vizcaïno collection) is from an unknown locality, probably late
80 Tremadocian in age, from the Ternata plain, north of Zagora, Morocco.

81 The two specimens were characterized using a FEI Quanta 250 scanning electron
82 microscope (SEM) equipped with a backscattered electron detector in addition to an
83 energy-dispersive X-ray analyzer (EDX) at accelerating voltages that varied from 5 to
84 15 kV. The backscattered electron detector allowed the acquisition of images with
85 dark pixels corresponding to light elements (i.e. small atomic number Z) and white
86 pixels corresponding to spots with heavy elements (i.e. high atomic number Z). The
87 EDX allowed, at low voltages, optimized acquisition of spectra revealing the
88 distribution of light elements (i.e. carbon). At high voltages, heavy elements, such as
89 iron, were detected. In addition, X-ray fluorescence (XRF) elemental maps of these
90 two specimens were obtained using a Bruker M4 Tornado micro-XRF instrument
91 operating under vacuum at 50kV and 600uA..

92 As both specimens were not completely flattened it was difficult to assess if
93 negative elemental results were due to the actual absence of elements in the
94 analyzed spot, or if the negative results were due to a topographic effect that
95 inhibited the beam from reaching the spot. For this reason general elemental maps of
96 rhodium Rh, the source of the XRF machine, were made. When Rh signal was
97 absent it indicated that topographical effects prevented the beam from reaching the
98 spot. Presence of Rh implied that the beam did reach the surface and the absence of

99 an element was due to actual absence of this element from the chemical composition
100 of the analyzed area.

101

102 **Results**

103 The eocrinoid specimen (Figure 1A) is entirely preserved in iron (Fe) which is
104 shown by the green fluorescence in Figure (1C) and the SEM EDX map in Figure 1E.
105 This contrasts with the matrix, which is rich in silicon (Si) as shown by the red
106 fluorescence in Figure 1B and the SEM EDX map in Figure 1E. Some Fe-rich small
107 and repetitive structures are present within the brachioles (skeletonized arm-like
108 feeding appendages) (Figure 1D). Most of the Fe-rich areas are preserved in small
109 iron crystals that do not have any specific shape (i.e. star-like minerals that are not
110 euohedral nor framboidal; Figures 2A-D).

111 The somasteroid specimen (Figure 3A) is preserved as an imprint in the rock, and
112 it shows the same elemental signature as the matrix, which is rich in Si (Figure 3B).
113 However, some areas of the fossil appear to be depleted in Si (Figure 3B). Rh
114 distribution shows that some of these anomalies are due to the actual absence of Si
115 (i.e. when Rh is present Rh+; Figure 3C), while the absence of Si in other regions is
116 simply due to a hidden zone that was not analyzed by the beam (i.e. Rh-; Figure 3C).
117 The Rh+ zones are rich in carbon that is mostly detected when analyzing the
118 specimen at 5kV (Figure 3D). The carbon shows a repetitive pattern of small identical
119 structures along the arms of the somasteroid (Figures 4A, B). However, carbon is
120 also present elsewhere in the specimen (Figures 4C-F).

121

122 **Interpretation and Discussion**

123 The structures found in both the eocrinoid (Figure 1D) and somasteroid (Figures
124 4B, C) specimens resemble tube feet of the water vascular system, as e.g. those
125 evidenced in stylophoran echinoderms from the Fezouata Shale [12]. However, both
126 the elemental and mineralogical signatures are different in these three occurrences.

127 Soft parts in exceptionally preserved fossils from the Fezouata Shale are
128 preserved in both euhedral and framboidal pyrite [23]. These mineralogical
129 morphologies are indicative of an early authigenic pyritization that occurred under
130 anoxic conditions at time of burial [24], replicating soft tissues that are the most prone
131 to decay [25]. After that, pyrite was transformed due to recent weathering to iron
132 oxides [12,23]. This situation was observed in the soft parts reported in the
133 stylophoran material from Bou Izargane [12].

134 In contrast, the near absence of both euhedral and framboid minerals in the
135 eocrinoid specimen indicates that iron-rich minerals that are found in this fossil are
136 not the result of the combined activity of authigenic mineralization and recent
137 weathering. In this fossil, the iron oxides are simply related to the activity of recent
138 weathering and, thus, they do not replicate any original anatomy. The distribution of
139 these Fe-rich minerals in all anatomical parts of the specimen, including skeletal
140 plates (Figure 1c), validates this hypothesis.

141 The somasteroid specimen shows a totally different elemental distribution in the
142 tube feet-like structures, with the total absence of Fe and the presence of carbon.
143 Carbonaceous films are the main mode of preservation of soft tissues, especially in
144 the Paleozoic era [26]. However, in surface sediments of the Fezouata Shale, carbon
145 is absent from all fossils that have been analyzed [9,10,12]. The porous aspect of C-
146 rich deposits in the analyzed specimen is strikingly different from the texture of
147 carbon films in exceptionally preserved biotas [26]. Moreover, in the somasteroid

148 specimen, carbon is not limited to any specific region, but appears to fill all micro-
149 depressions of the specimen (Figures 4D-G). Thus, it is very likely that this carbon is
150 the consequence of preparation artefacts: numerous latex casts were made to study
151 the detailed morphology of this specimen. Apparently, latex was not completely
152 removed from small cavities located between skeletal plates, thus mimicking
153 regularly branching tube feet along the ambulacral canal, in the arm region of the
154 analyzed specimen.

155

156 **Conclusion**

157 This study confirms the validity of the interpretation as soft parts of the
158 structures identified in stylophoran echinoderms from the Fezouata Shale [12].
159 However, it also shows that it is probable that reports of putative soft parts in
160 eocrinoids and somasteroids from the Fezouata Shale [20, 21] are either preparation
161 artefacts or the result of recent weathering. In addition, it shows that understanding
162 the history of a specific fossil, from the excavation to preparation, is essential for
163 proper paleontological interpretation, especially when it comes to the description of
164 soft tissues in extinct taxa. These results should be taken into consideration when
165 studying any new fossil, whether it is purchased from a private collector or comes
166 from a museum collection.

167

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181

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212

213 **Figure Captions**

214

215 **Figure 1:** Analyzed specimen of eocrinoid echinoderm, late Tremadocian, Fezouata
216 Shale, Bou Izargane, Zagora area, Morocco; ML20-269159. (A) photograph of the
217 specimen; (B) X-ray fluorescence image of inset shown in Figure 1A. Red indicates a
218 high concentration of silicon distribution; (C) X-ray fluorescence of iron distribution
219 (green) from the inset region of Figure 1A; (D) tube feet-like structures of the putative
220 water vascular system showing iron distribution; (E) SEM-EDX elemental distribution
221 in the matrix and the fossil.

222

223 Figure 2: SEM-EDX images showing amorphous shape of particles and iron rich
224 areas (white regions).

225

226 **Figure 3:** Analyzed specimen of somasteroid, late Tremadocian, Fezouata Shale,
227 unknown locality, Zagora area, Morocco; UCBL-FSL424962. (A) photograph of the
228 specimen; (B) XRF, Si distribution; (C) XRF, superposition of Rh (blue) with K; (D)
229 SEM-EDX elemental distribution in the tube feet-like structures.

230

231 Figure 4. (A-B) Carbon particles (black) in tube feet-like structures of the putative
232 water vascular system, (C-F) Carbon particles found in other random structures
233 showing the same carbon distribution as tube feet-like structures.







