

1 **Palynology of the Permian and Triassic of the Tesero and Bulla sections (Western Dolomites,**
2 **Italy) and consideration about the enigmatic species *Reduviasporonites chalastus*.**

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9

10 **Abstract**

11 A palynological study of two Permian-Triassic sections of Southern Alps (Tesero and Bulla
12 sections) was carried out in order to correlate the palynological data with the available conodont
13 zones. Both the sections crop out in the western Dolomites, the Tesero section in Fiemme Valley
14 and the Bulla section in Badia valley.

15 The two sections include the uppermost Bellerophon Formation and the overlying Werfen
16 Formation. In the latter the Permian/Triassic boundary (Farabegoli et al., 2007) has been defined by
17 conodonts. The palynological assemblages collected in both sections throughout the Bellerophon up
18 to the Wefern formations show compositional variation marked by: a) a dominance of taeniate and
19 non taeniate bisaccates in the Bellerophon Formation dated as Late Permian; b) a bloom of the
20 *incertae sedis Reduviasporonites chalastus* in the lower Tesero Member (Werfen Formation), found
21 only in the Tesero section. This interval should stratigraphically lie below the Permian/Triassic
22 boundary, as defined by conodonts recorded in the Bulla section; c) poorly preserved acavate and
23 bisaccate taxa in the upper Tesero Member, above the Permian/Triassic boundary, and in the
24 overlying Mazzin Member of the Tesero section. The origin and the ecological preferences of
25 *Reduviasporonites chalastus* and the implications of its worldwide distribution across the
26 Permian/Triassic boundary are also discussed.

27

28 **Keywords:** Permian-Triassic boundary, Western Dolomites, Italy, Tesero section, Bulla section,
29 *Reduviasporonites chalastus*.

30

31 **1. Introduction**

32 In the Southern Alps of Italy, the Val Gardena Sandstone and the Bellerophon Formation are the
33 two principal lithostratigraphic units spanning from the Middle(?) to Upper Permian. The two units
34 have been regarded as a composite transgressive sequence (Massari and Neri, 1997). The Val
35 Gardena Sandstone is composed of siliciclastics and red beds, deposited in alluvial fans, braided
36 streams and meandering rivers under semiarid conditions (Massari and Neri, 1997). The
37 Bellerophon Formation is characterized by carbonates and evaporites, deposited in a coastal sabkha
38 to shallow-shelf environments. The Bellerophon Formation wedges out westward and disappears
39 west of the Adige Valley by merging into continental deposits of the Val Gardena Sandstone. Both
40 formations are overlaid by the shallow-marine Lower Triassic Werfen Formation. The Tesero
41 section includes the upper part of Bellerophon and Werfen formations. The area has been subject of
42 numerous studies e.g.: Bosellini, 1964; Assereto et al., 1973; Broglio Loriga et al., 1988; Magaritz
43 et al., 1988; Perri, 1991; Neri et al., 1999; Nicora and Perri, 1999; Farabegoli et al., 2007; Groves et
44 al., 2007. The Tesero section is well known since the discovery of the so-called "mixed fauna",

45 characterized by *in situ* Permian-type brachiopods and foraminifers located at about 1.5-2.0 m
46 above the Bellerophon-Werfen lithostratigraphical boundary (Neri and Pasini, 1985). This finding
47 allowed a reconsideration of the Permian/Triassic Boundary (PTB) position, traditionally placed at
48 the base of Werfen Formation. Successively, the recording of conodont faunas in the Tesero section
49 enabled the PTB to be precisely located. Five conodont zones have been documented (Nicora and
50 Perri, 1999), including the *Hindeodus parvus* Zone (recorded within the Mazzin Member), which
51 according to the International Subcommission on Triassic Stratigraphy (STS) marks the base of the
52 Triassic system (Yin et al., 2001).

53 In the Bulla section (including Bellerophon and Werfen formations), the first occurrence of *Hi.*
54 *parvus* and thus the PTB was recorded at 1.3 m from the base of the Tesero Member (Farabegoli
55 and Perri, 1998; Farabegoli et al., 2007). According to the authors this interval should correspond to
56 the uppermost part (subunit 5a) of the Tesero Member in the Tesero section, where Nicora and Perri
57 (1999) documented some conodonts showing transitional features between *Hi. praeparvus* and *Hi.*
58 *parvus*. Based on these findings, the first occurrence of *Hi. parvus* in the Tesero section has been
59 considered below the Mazzin Member (Nicora and Perri, 1999; Farabegoli et al., 2007). The Bulla
60 section has been recommended as the PTB parastratotype for the shallow marine western Tethys
61 (Farabegoli et al., 2007). In the present article, a palynological study of these two important and
62 better known Permian-Triassic independently dated sections of the Southern Alps was carried out.
63 Additionally, we discuss the origin and the ecological preferences of the organic microfossil
64 *Reduviasporonites chalastus*, and the implications of its worldwide distribution across the PTB.

65

66 **2. Stratigraphy**

67 *2.1 Tesero section*

68 The Tesero section, about 40 m thick, is located in the Fiemme Valley (Western Dolomites) where
69 the Bellerophon and Werfen formations are quite well exposed in a road-cut near the Tesero village
70 (Fig. 1). It includes the uppermost Bellerophon and the lower Werfen formations (Fig. 2). The
71 Bellerophon Formation is mainly characterized by lagoonal to peritidal dolostones and marls (Neri
72 et al., 1999). The exposed tract does not exceed 10 m. The formation has been divided into three
73 informal units (Neri et al., 1999; Perri and Farabegoli, 2003): the lowest, the Fossiliferous Dolomite
74 facies, consists of dolostones and dolomitic limestones (mudstones and wackestones) alternating
75 with marls. Its depositional environment has been interpreted as a restricted, probably hyperhaline,
76 lagoon. This facies corresponds to Unit 1 of Neri et al. (1999). It is overlaid by the Ostracod and
77 peritidal dolomite unit (Unit 2 of Neri et al., 1999) consisting of marly dolostone with thin pelite
78 interlayers. Mud-cracks and root-traces attest to subaerial exposure surfaces. A sharp
79 unconformable-paraconformable erosional surface (U1 of Farabegoli et al., 2007) separates this unit

80 from the overlying Bulla Member. At the base of the Bulla Member (Unit 3 of Neri et al., 1999),
81 blackish pelite has been recognised, grading upwards into calcareous marls and bioclastic
82 wackestone and packstone. A sharp paraconformable-unconformable surface (U2 of Farabegoli et
83 al., 2007) separates the Bulla Member from the overlying Tesero Member at the base of the Werfen
84 Formation. The Tesero Member has been subdivided into three informal units (Neri et al., 1999;
85 Perri and Farabegoli, 2003). Of these the lowest, Unit 4, is characterized by a lower interval
86 (subunit 4a, less than 10 cm in thickness), of grainstones and packstones that grades upwards into
87 the first oolitic bank of the Tesero Member (subunit 4b, about 90 cm in thickness). The overlying
88 Unit 5, characterized by a lateral variability, has been subdivided into three subunits: subunit 5a
89 consisting of oolitic calcarenite beds with marly interlayers; subunit 5b mainly characterized by
90 bioclastic wackestone and packstone; and subunit 5c is marked by oolitic-bioclastic calcarenites,
91 with mudstone/wackestone intercalations. The uppermost informal Unit 6 consists of two
92 coarsening upwards parasequences, evolving from micritic limestones with a slight marly content at
93 the base, to oolitic-bioclastic-intraclastic grainstones and packstones at the top. The Tesero Member
94 is overlaid by the Mazzin Member, which has been also subdivided into two informal units (Neri et
95 al., 1999): Unit 7 is composed of bioturbated to laminated marly lime mudstones, and of thin
96 biocalcarene storm layers. The overlying Unit 8 is mainly formed by marly lime mudstones,
97 locally with siliciclastics.

98 The palaeontological content of the Tesero section is very rich and diversified as reported by
99 numerous authors (i.e. Neri and Pasini, 1985; Italian IGCP 203 Group, 1986; Broglio Loriga et al.,
100 1988; Posenato, 1988; 1999; Perri, 1991; Nicora and Perri, 1999; Groves et al., 2007). Notably, in
101 the first oolitic bank (subunit 4b; Fig. 2), is the presence of brachiopods as *Ombonia* and abundant
102 specimens of *Bellerophon vaceki*, which is considered a Triassic taxon (Posenato, 1988). Nicora
103 and Perri (1999) recorded the first occurrence of the conodont *Hi. praeparvus* and *Hi. parvus*
104 respectively in the Tesero Member at 0.30 cm and in the Mazzin Member, 11 m above the
105 lithostratigraphical boundary Bellerophon-Werfen formations. The overlying conodont Zones are the
106 *staeschei* Zone and the *isarcica* Zone respectively at 14.3 m and the at 26 m from the base of
107 Werfen Formation.

108

109 2.2 Bulla section

110 The Bulla section (Figs. 1; 2), about 80 m thick, crops out near the Bulla village (20 km north of
111 Tesero) and exposes the whole sequence from the PTB to the supposed Induan/Olenekian boundary
112 (i.e. uppermost Bellerophon Fm and Werfen Fm with Tesero Mb, Mazzin Mb, Andraz Mb, Seis Mb
113 and lower Campill Member). In this study, we investigated the first 12 m of the Bulla section
114 including the uppermost part of the Bellerophon Formation and the overlying Tesero and Mazzin

115 members of the Werfen Formation. The section starts with the upper part of the Bellerophon
116 Formation (about 3.5 m) composed of grey silty dolomitic carbonates alternating with grey to
117 reddish shale levels from the Ostracod and peritidal dolomite Unit described by Farabegoli et al.
118 (2007) and followed by the Bulla Member This latter is, characterized by dark-grey packstones
119 alternating with wackestones and thin clayey siltstones, and it overlies the Ostracod Unit with an
120 unconformable-paraconformable erosional surface, referred to as “U1” by Farabegoli et al. (2007).
121 Another sharp paraconformable-unconformable surface, referred to as “U2” by Farabegoli et al.
122 (2007), marks the boundary between the Bellerophon and Werfen formations. According to Perri
123 and Farabegoli (2003) and Farabegoli et al. (2007), the Werfen Fm is composed by the lower
124 Tesero Member overlaid by the lower Mazzin Member followed by the upper Tesero Member and
125 then by the upper Mazzin Member (Fig. 2). The lower Tesero Member (2.30 m thick) contains basal
126 packstones and grainstones intercalated to mudstone, wackestone and oolitic packstone. The lower
127 Mazzin Member (2.9 m thick) consists of mudstone and wackestone and the upper Tesero Member
128 is marked by the oolitic packstone and grainstone bearing beds (1.35 m thick). The overlying upper
129 Mazzin Member consists of mudstone intercalated to siltstone and packstone (Perri and Farabegoli,
130 2003; Farabegoli et al., 2007).

131 The Bulla section yielded important fossil fauna as documented by numerous contributions (e.g
132 Broglio Loriga et al., 1988; Perri, 1991; Farabegoli and Perri, 1998; Perri and Farabegoli, 2003;
133 Farabegoli et al., 2007; Crasquin et al., 2008). The upper part of the Bulla Member yielded the most
134 diverse foraminifera assemblage of the Bellerophon Formation in the Southern Alps and a very rich
135 ostracod fauna. In the lower Tesero Member the conodonts *Hi. praeparvus* and *Hi. parvus* have
136 been recorded respectively at 0.20 m and 1.30 m above the base of the Werfen Formation In the
137 Mazzin Member, the condonts *Is. lobata*, *Is. staeschei* and *Is. aequabilis* and *Is. Isarcica* have been
138 recorded (Perri, 1991; Farabegoli and Perri, 1998).

139

140 **3. Material and methods**

141 Palynological analyses were performed on a total of 52 samples (31 samples from the Tesero
142 section and 21 from the Bulla section). All samples were treated by standard palynological acid
143 maceration, density separation of the organic matter, and filtration of the organic-rich residue at 10
144 µm. Light microscope observations were performed on palynological slides using a Leica DM 1000
145 microscope with Differential Interference Contrast (DIC) technique in transmitted light. Images
146 were captured with the digital microscope camera and successively corrected for contrast and
147 brightness using the open-source Gimp software. Palynological slides are stored at the Sedimentary
148 Organic Matter Laboratory of the Physics and Geology Department (Perugia University, Italy).
149 Authors of the species names are given on the species list of palynomorphs (Appendix 1) and in the

150 plate descriptions.

151

152 **4. Palynology**

153 *4.1 Tesero section*

154 Diverse and abundant palynological associations occur in the Bellerophon Formation showing a
155 gradual change from bottom to top, while in the overlying Werfen Formation, the microflora
156 generally lacks diversity. The microflora content includes 45 species of miospores and the abundant
157 *incertae sedis Reduviasporonites chalastus* (Tab. 1; Pls. 1, 2). At the base of the Bellerophon
158 Formation (AS1 to AS4 levels), the microfloristic assemblage is mainly characterized by several
159 taeniate bisaccates as *Protohaploxylinus* spp., *Lunatisporites* spp., *Lueckisporites* spp.,
160 *Striatoabieites* spp. and *Striatopodocarpites* spp., non taeniate bisaccates as *Klausipollenites* spp.,
161 *Alisporites* spp. and *Jugasporites delasauei* associated to trilete spores as *Calamospora* sp.,
162 *Leiotriletes adnatus* and *Gondisporites* sp.. The *incertae sedis R. chalastus* is abundant in few levels
163 (AS1 and AS2) of the Bellerophon Formation. The Tesero Member (from its base to AS21 level), is
164 poor in sporomorphs and *R. chalastus* characterizes almost the entire organic content of the
165 palynofacies (Fig. 3). Upwards, from the uppermost Tesero Member to the lower Mazzin Member
166 (AS26), immediately before the first occurrence of *Hi. parvus*, palynological assemblage contains
167 taeniate bisaccates as *L. noviaulensis* and *L. virkkiae*, less abundant than in Bellerophon Formation,
168 and common *Protohaploxylinus* sp.. Minor non taeniate bisaccates such as *K. schaubergeri* and
169 *Sulcatisporites* sp. and acavate long-ranging trilete spores, e.g. *Calamospora* sp. also occur. The last
170 sampled level in the uppermost part of the Mazzin Member yielded *Cycadopites follicularis*, a few
171 *Calamospora* sp. and *R. chalastus*.

172

173 *4.2 Bulla section* Palynological assemblage from the Bulla section is not diversified and well
174 preserved. Only four levels (MC6, MC8, MC10, MC12) of the Bellerophon Formation yielded
175 palynomorphs (Tab. 2; Pl. 3). The microflora includes bisaccate taeniate pollen as *Lunatisporites*
176 *pellucidus*, *L. noviaulensis*, *Lunatisporites* sp. and *Lueckisporites* sp., non taeniate as *Jugasporites*
177 *delasauei*, *Jugasporites* sp. and *Klausipollenites* sp. and laevigate, acavate spores.

178 The paucity of sporomorphs mostly represented by bisaccates can be linked to palaeoenvironmental
179 conditions. As suggested by Farabegoli et al. (2007) the Bulla succession could be deposited in
180 more distal environment, far from the shoreline, than the Tesero one. Under such conditions, only
181 the most buoyant saccate pollen grains can be dispersed for long distances by wind and water
182 currents (Tyson, 1995).

183

184 *4.3 Discussion*

185 Previous studies reported analogous Late Permian palynological assemblages also in other localities
186 of the Southern Alps, always characterized by *L. virkkiae*, *L. noviaulensis*, *L. parvus*, *J. delasaucei*
187 and *K. schaubergeri* (Visscher and Brugman, 1988; Massari et al., 1988; 1994; Cirilli et al., 1998).
188 Accordingly, this palynological association shows close similarities with those recorded from the
189 Late Permian (Lopingian) of many areas of the world. In the Meishan section (China), ratified as
190 GSSP for basal boundary of Triassic System (Yin et al., 2001), *L. virkkiae* and *K. schaubergeri*
191 have been found in the *Vittatina-Protohaploxypinus* Assemblage attributed to the Changhsingian-
192 Lower Griesbachian on the basis of the conodont zones (Ouyang and Utting, 1990).
193 Other similarities have been noted with the Lopingian microflora from Northern Europe (e.g.
194 Germany: Leschik, 1956; Grebe, 1957; Schaarschmidt, 1963; Great Britain: Clarke, 1965; Ireland:
195 Visscher, 1971; Hungary: Haas et al., 1988; Barents Sea: Mangerud, 1994; Greenland: Twitchett et
196 al., 2001) and from the Kazanian type sequence of Russia (Utting et al., 1997).
197 Correlation with the Gondwana region shows that the taeniate pollen *L. virkkiae*, *L. pellucidus*, *L.*
198 *noviaulensis* and the non-taeniate *K. schaubergeri* are present also in the Late Permian of Pakistan
199 (Balme, 1970; Jan et al., 2009) and *L. virkkiae*, *Protohaploxypinus* spp., *Striatopodocarpites* spp. in
200 the Middle East (Stephenson et al., 2003). Similar assemblage, referred as *L. virkkiae* Zone, have
201 been documented also in the Late Permian of Israel (Eshet, 1992).
202 The microfloristic assemblages from the uppermost Bellerophon Formation in both Tesero and
203 Bulla sections, confirm an Upper Permian age, also indicated by other fossiliferous assemblages
204 (i.e. brachiopods, Posenato, 1999) documented in the literature. A gymnospermous pollen decrease
205 has been observed within the Tesero and Mazzin members, after the occurrence of *Hi. parvus* (Figs.
206 2; 3). Here, not well preserved long-ranging acavate spores with bisaccoid pollen as *L. virkkiae*
207 were still found. The presence of these “Permian type” bisaccates within the Lower Triassic strata is
208 still debated as they are differently considered in literature: a) as reworked from the Upper Permian
209 Bellerophon Formation; b) as ranging into Lower Triassic (i.e. Visscher and Brugman, 1988;
210 Ouyang and Utting, 1990; Mangerud, 1994).

211

212 **5. Previous studies and some considerations about the affinity and the distribution of** 213 ***Reduviasporonites chalastus* (Foster) Elsik 1999**

214 In the present study, *Reduviasporonites chalastus* was found in various abundances at different
215 stratigraphic levels of the Bellerophon and Werfen formations either in the latest Permian and in
216 the earliest Triassic (Fig. 3; Tab.1; Pl. 4). The origin of the species has been largely debated in the
217 literature. Foster (1979), defined *Chordecytia chalasta* (junior synonym of *R. chalastus*), as a
218 microfossil *incertae sedis*. Balme (1980), in his original description of *Tympanicysta stoschiana* (a
219 junior synonym of *C. chalasta* in Jansonius and Hills, 1981; cd. 3926), considered it to belong to

220 the plant kingdom, probably representing a stage in a fungal or algal lifecycle. Nevertheless the
221 author did not reject the possibility that *T. stoschiana* could be of animal origin. Elsik (1999)
222 formally established *Reduviasporonites* Wilson 1962 as a senior synonym of *Chordecystia* and
223 *Tympanicysta* and formally proposed the new combinations *Reduviasporonites chalastus* (Foster,
224 1979) Elsik 1999 and *Reduviasporonites stoschianus* (Balme, 1970) Elsik 1999. In this study, we
225 followed the suggestions of Foster et al. (2002) that considered *R. chalastus* as senior synonym of
226 *R. stoschianus*.

227 Several authors (e.g. Elsik, 1999; Visscher et al., 2011) interpreted *Reduviasporonites* as fungal
228 remains, representing hyphae and conidia of ascomycetes similar to those of the modern
229 *Rhizoctonia*. The proliferation of *R. chalastus* recorded at the PTB in various localities (e.g. Israel,
230 Southern Alps, Australia, South Africa) has been close associated to the Permian-Triassic mass
231 extinction event (Eshet et al., 1995; Visscher et al., 1996; Steiner et al., 2003; Sandler et al., 2006).
232 This close relationship led several palynologists to suppose that saprophytic fungi may have
233 metabolised the dead vegetation formed during the extinction event. They considered the acme of
234 the resulting "fungal spores" as a proxy bio-event for recognising the Permian-Triassic transition
235 throughout the world. Foster et al (2002) demonstrated, by radio-isotopic study on the cell wall of
236 *Reduviasporonites* from the Mazzin Member (Austria), that it is isotopically lighter (in terms of
237 $\delta^{13}\text{C}_{\text{org}}$) than the plant remains associated to it. Hence, it was unlikely to have consumed this
238 material as food, as would be expected for a fungal saprophyte and, for this reason, the authors
239 suggested an algal origin for *Reduviasporonites*. This result has been strongly contrasted by
240 Sephton et al. (2009) sustaining that *Reduviasporonites* has not any distinctive biomarkers of either
241 fungi or algae.

242 Afonin et al. (2001) also proposed an algal affinity and demonstrated that the spores assigned to
243 *Reduviasporonites* are more closely allied to the Zygnematalean algae *Spirogyra* Link and/or
244 *Mougeotia* Agardh of the Division Chlorophyta (green algae), a genus having a wide distribution.
245 In this study we noted several common traits between the morphological characteristics of *R.*
246 *chalastus* and those of *Spirogyra* and/or *Mougeotia*. For example a resemblance regards the
247 organisation of the dark-cell infill inner bodies (resembling to the "accumulation bodies" of
248 dinoflagellate cysts) that in few specimens of *R. chalastus* seem to be organised spirally such as the
249 chloroplasts of *Spirogyra* (Pl. 4). However, in other specimens of *R. chalastus* the inner bodies do
250 not seem to be arranged in any particular manner, but they appear as a granular mass lining the cell
251 walls. Anyway, lingering doubts indicate that more detailed studies are still needed, for example,
252 for understanding the reason of the lack of zygospores in several levels rich in *R. chalastus*.
253 Commonly, in *Spirogyra*, the zygospores are characterized by a rounded shape and very thick,
254 robust wall that made them more resistant than the filaments. Hence, they should be better

255 preserved and easier to find than the filaments. In assemblages with abundant *R. chalastus*, no
256 zygnematacean spores such as *Brazilea* (supposedly a fossil spore of the genus *Spirogyra*), nor
257 *Tetraporina* (supposedly a fossil spore form of the genus *Mougeotia*), nor *Maculatasporites*
258 (considered by Grenfell, 1995, to represent spores of any of the recent genera of *Zygnema*,
259 *Zygnemopsis*, *Zygonium*) have been found. Finding the affinity of *R. chalastus* to *Spirogyra*
260 and/or *Mougeotia* not very convincing, we tentatively compared it to other genera of chlorophycean
261 algae. Thus, we found *R. chalastus* showing close morphological similarities to some algae
262 belonging to the Order Trentepohliales (Pl. 4). The trentepohliacean algae are not aquatic, but rather
263 subaerial, growing on humid soil, rocks, tree bark, leaves, stems and fruits. The presence of
264 sporopollenin-like substances in the cell walls, as well as special structures of carbohydrates and
265 alcohols (Patterson and Van Valkenburg, 1991), probably are adaptive features against desiccation
266 in the subaerial habitat. Some species of the Trentepohliales are endophytic or parasitic, whereas
267 others grow in close association with lichen forming fungi (Chapman and Waters, 2002). According
268 to López-Bautista et al. (2002), the sporopollenin-like substances in the cell wall of
269 trentepohliacean algae would have facilitated their preservation as fossils.

270 The trentepohliacean alga *Trentepohlia* Martius is organised in branching filaments and, as in *R.*
271 *chalastus*, the cell-shape is spherical to ellipsoidal; although its chloroplasts can assume also a
272 spiral shape, in general they are arranged as a globular mass in the centre of each cell like often the
273 cell-infill inner bodies of *R. chalastus*. Differently that in *Spyrogira*, the zoosporangia of
274 *Trentepohlia* are mainly diffused by the wind. This feature could explain the reason of their absence
275 in the association with *R. chalastus* in the Tesero levels.

276 Although *R. chalastus* shares some morphological features with the Trentepohliales algae, and
277 shows similarity to Zygnematales algae, it displays additional traits typical of other green algae. For
278 this reason, we think that it is a chlorophycean alga probably living in brackish waters.

279 Wood (1995), Eshet et al. (1995), Visscher et al. (1996), Steiner et al. (2003), Sandler et al. (2006)
280 stressed the importance of the so called “fungal event” as a reflection of environmental change
281 across the Permian – Triassic boundary and thus considered as a chronostratigraphic marker for
282 worldwide correlation. On the contrary, Foster et al. (2002) observed that *R. chalastus* appears to
283 have thrived outside the postulated time of mass extinction, consequently it cannot be used as
284 “practical” chronostratigraphic marker. We agree with this consideration because we often find *R.*
285 *chalastus* or similar organic remains in stressed palaeoenvironment of different age.

286 In the Tesero Member the proliferation of *R. chalastus* could be related to the presence of
287 hypersaline ponds in flat coastal areas and its bloom strictly linked to the ecological parameters of
288 the depositional palaeoenvironment. Consequently it should be not used as practical biomarker for
289 worldwide correlation of the PTB.

290

291 **6. Conclusions**

292 The present study was carried out in order to correlate the palynological assemblage across the
293 Permian-Triassic boundary ratified by conodont zones in two of the better known Permian-Triassic
294 sections of Southern Alps. Additionally the origin and the paleocological preferences of *R.*
295 *chalastus* and the inference on its worldwide distribution across the PTB are discussed.

296 The Tesero section yielded well preserved and diversified microfloristic assemblages in respect to
297 the Bulla section where the palynological content is less abundant. In the Bulla section, indicated as
298 the parastratotype of the PTB for the western Tethyan domain (Farabegoli et al., 2007), the putative
299 PTB has been placed in the Tesero Member and correlated to the upper Tesero Member in the
300 Tesero section (Farabegoli et al., 2007).

301 In this stratigraphic framework and extending the above considerations also to the Tesero section,
302 the features of the palynological assemblages can be summarized as follows:

303 - The microflora content from the the Bellerophon Formation is dominated by non taeniate and
304 taeniate bisaccates that in the Tesero section, where the assemblage is more diversified, are mostly
305 represented by bisaccate taeniate (e.g. *Protohaploxylinus* spp., *Lunatisporites* spp., *Lueckisporites*
306 spp., *Striatoabieites* spp. and *Striatopodocarpites* spp.) and non taeniate (e.g. *Klausipollenites* spp.,
307 *Alisporites* spp. and *Jugasporites delasauei*) and, more rarely, trilete spores associated with few *R*
308 *chalastus*.

309 - In the Bulla section, the Bellerophon formation yields a microflora less diversified and only
310 containing bisaccates such as *Lueckisporites* sp., *L. pellucidus* and *J. delasauei*. No remains of *R.*
311 *chalastus* were found. The different amount of the total organic matter (palynomorphs including)
312 could be related to more distal position from the land masses of the Bulla depositional environment.
313 Nevertheless the blooming of taeniate and non-taeniate sporomorphs, among which *Lueckisporites*
314 sp. and *J. delasauei* is indicative of a late Permian age.

315 - The palynological content of the Tesero Member, in both the investigated section is generally rather
316 scarce or absent due to the lack of a lithology that might preserve palynomorphs such as oolitic
317 limestone which is the peculiar facies of this member.

318 - The lower-middle portion of the Tesero Member, in the Tesero section, yielded palynofacies
319 dominated by *R. chalastus* associated to rare sporomorphs (Fig. 3). The amount of *R. chalastus*
320 drastically decreases in the uppermost part of the Tesero Mb, (above the supposed PTB) and in the
321 lower Mazzin Member. Here few pollen as *L. virkkiae*, *K. schaubergeri* are associated with long
322 ranging spores. The occurrence of few "Permian type" pollen within these lower Triassic strata can
323 be explained in two ways: a) these species can range into Early Triassic as suggested by several
324 authors (i.e. Ouyang and Utting, 1990; Mangerud, 1994); b) they are reworked from the underlying

325 strata.

326 - The good preservation of the green alga *R. chalastus* is probably due to the organic composition of
327 the wall, highly resistant to processes such as bacterial degradation and chemical breakdown (i.e.
328 oxidation; Tappan, 1980) that characterized the depositional environment of the Tesero Member. Its
329 palaeoecological preference should be related to anomalous water salinity ranging from brackish to
330 hyperhaline. Being the distribution and abundance of *R. chalastus* controlled by ecological
331 parameters at local and large scale it cannot be further used as a chronostratigraphic marker. The
332 abundance of *R. chalastus* in the Tesero section and its absence in the Bulla section should confirm
333 the distal position as depositional environment of the latter. Due to its probable ecological
334 preference, *R. chalastus* could easier colonize and grow in coastal ecosystems.

335

336

337 **Acknowledgements**

338 This paper is dedicated to Jan Jansonius passed away after a long illness on January 25, 2013. He
339 was 84 years old. A.S. met him with J.U. in Calgary in December 2001 during her PhD. Jan with
340 John helped Amalia to grow not only from the scientific point of view but also as human being.

341 We are indebted to many colleagues who provided assistance during the course of our study. Many
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343 Cornamusini (Siena University) for the optical microscope photos. We are grateful to Prof. Bruno
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345 features of *Spirogyra* and *Trentepohlia*.

346

347

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501 **Appendix 1: List of taxa**

502 - Pollen:

503 Bisaccate taeniate:

504 *Hamiapollenites* sp.

505 *Lueckisporites parvus* Klaus 1963

506 *Lueckisporites virkkiae* Potonié and Klaus 1954

507 *Lueckisporites* sp.

508 *Lunatisporites albertae* Jansonius 1962

509 *Lunatisporites hexagonalis* Jansonius 1962

510 *Lunatisporites interruptus* Jansonius 1962

511 *Lunatisporites noviaulensis* (Leschik) Foster 1979

512 *Lunatisporites pellucidus* (Goubin) Balme 1970

513 *Lunatisporites* sp. cf. *transversundatus* Jansonius 1962

514 *Lunatisporites* sp.

515 *Protohaploxypinus limpidus* (Balme and Hennelly) Balme and Playford 1967

516 *Protohaploxypinus microcorpus* (Schaarschmidt) Clarke 1965

517 *Protohaploxypinus samoilovichiae* (Jansonius) Hart 1964

518 *Protohaploxypinus* sp.

519 *Striatoabieites* sp.

520 *Striatoabieites richteri* (Klaus) Hart 1964

521 *Striatopodocarpites communis* (Wilson) Hart 1964

522 *Striatopodocarpites fusus* (Balme and Hennelly) Potonie 1958

523 *Striatopodocarpites* sp.

524 Bisaccate non taeniate:

525 *Alisporites landianus* Balme 1970

526 *Alisporites* sp. cf. *splendens* (Leschik) Foster 1979

527 *Alisporites splendens* (Leschik) Foster 1979

528 *Alisporites tenuicorpus* Balme 1970

529 *Alisporites* spp.

530 *Jugasporites delasaucei* (Potonié and Klaus) Leschik 1956

531 *Jugasporites* sp.

532 *Klausipollenites decipiens* Jansonius 1962

533 *Klausipollenites* forma Y Jansonius 1962

534 *Klausipollenites schaubergeri* (Potonié and Klaus) Jansonius 1962

535 *Klausipollenites vestitus* Jansonius 1962

- 536 *Klausipollenites* sp.
- 537 *Pinuspollenites* sp.
- 538 *Sulcatisporites kraeuselii* Mädlér 1964
- 539 *Sulcatisporites* spp.
- 540 Monosaccate:
- 541 *Cordaitina* sp. cf. *vulgaris* (Zauer) Varyukhina 1971
- 542 Monocolpate:
- 543 *Cycadopites follicularis* Wilson and Webster 1946
- 544 *Sverdrupollenites agluatus* Utting 1994
- 545 - Trilete spores:
- 546 Acavate:
- 547 *Calamospora* sp.
- 548 *Dictyotriletes* sp.
- 549 *Leiotriletes adnatus* (Kosanke) Potonié and Kremp 1955
- 550 *Punctatisporites fungosus* Balme 1970
- 551 *Simeonospora* sp. cf. *minuta* (Jansonius) Utting 1994
- 552 Cavate:
- 553 *Densoisporites* sp.
- 554 *Proprisporites pocockii* Jansonius 1962
- 555 - *Incertae sedis*:
- 556 *Reduviasporonites chalastus* (Foster) Elsik 1999
- 557

558 **Figure captions:**

559 Fig. 1: Location map of Bulla and Tesero sections

560 Fig. 2: Schematic stratigraphic logs of the Bulla and Tesero sections (redrawn from Neri et al., 1999
561 and Farabegoli et al., 2007). Our sampling followed the measurement of Farabegoli et al. (2007) in
562 order to better correlate palynological and conodont data.

563 Fig. 3: Quantitative changes in sporomorph suprageneric groups and in *R. chalastus* at the Tesero
564 section. Due to paucity of sporomorphs no quantitative analysis was performed for the
565 palynological content of the Bulla succession.

566 Plate 1: Bisaccate pollen from Tesero section. Scale bar indicates 10 µm.

567 1. *Platysaccus* sp. (slide AS4, 97.7/45.5)

568 2. *Jugasporites delasaucei* (Potonié and Klaus) Leschik 1956 (slide AS4, 110/38)

569 3, 8. *Klausipollenites shaubergeri* (Potonié and Klaus) Jansonius 1962 (3: slide AS1, 37.8/48.5; 8:
570 slide AS21, 42/110)

571 4. *Lueckisporites virkkiae* Potonié and Klaus 1954 (slide AS4, 38.1/119.2)

572 5. *Lueckisporites* sp. (slide AS4, 35.5/103.5)

573 6. *Klausipollenites* sp. (slide AS25, 41.2/108.9)

574 7, 12, 13, 15. *Alisporites* spp. (7: slide AS1, 29.9/111.1; 12: slide AS4, 32.2/100.3; 13: slide AS4,
575 30/100; 15: slide AS4, 27.7/99.1)

576 9. *Protohaploxypinus limpidus* (Balme and Hennelly) Balme and Playford 1967 (slide AS4,
577 25.5/97.8)

578 10. *Striatopodocarpites* sp. (slide AS4, 32.2/107.2)

579 11. *Striatopodocarpites fusus* (Balme and Hennelly) Potonie 1958 (slide AS4, 30.7/104.1)

580 14. *Pinuspollenites* sp. (slide AS4, 25.4/97.7)

581

582 Plate 2: Bisaccate pollen from Tesero section. Scale bar indicates 10 µm.

583 1-4. *Sulcatisporites* spp. (1: slide AS4, 30.6/97.2; 2: slide AS5, 26.6/120.4; 3: slide AS25, 28/99; 4:
584 slide AS30, 34.4/118)

585 5. *Alisporites landianus* Balme 1970 (slide AS1, 26/115.2)

586 6. *Alisporites* sp. (slide AS2, 34.1/119.9)

587 7, 15. *Lueckisporites virkkiae* Potonié and Klaus 1954 (7: slide AS23, 30/101; 15: slide AS1,
588 28.8/109)

589 8, 9: *Klausipollenites shaubergeri* (Potonié and Klaus) Jansonius 1962 (8: slide AS3, 26/95.1; 9:
590 28.6/106)

591 10. *Lunatisporites noviaulensis* (Leschik) Foster 1979 (slide AS4, 37.1/117)

- 592 11. *Klausipollenites decipiens* Jansonius 1962 (slide AS3, 46.6/118.1)
- 593 12. *Lunatisporites pellucidus* (Goubin) Balme 1970 (slide AS4, 65.5/132)
- 594 13. *Striatopodocarpites fusus* (Balme and Hennelly) Potonie 1958 (slide AS4, 49.9/117.1)
- 595 14. *Protohaploxypinus microcorpus* (Schaarschmidt) Clarke 1965 (slide AS4, 42.2/100)
- 596
- 597 Plate 3: Bisaccate pollen from Bulla section (Scale bar indicates 10 µm).
- 598 1. *Alisporites* sp. cf. *splendens* (Leschik) Foster 1979 (slide MC10, 95.2/30.4)
- 599 2. *Jugasporites* sp. (slide MC8, 33/102)
- 600 3, 4. *Alisporites* sp. (3: slide MC 12, 37/110.3; 4: slide MC10, 102/25)
- 601 5. *Lueckisporites* sp. (slide MC6, 49/98)
- 602 6. *Jugasporites delasaucei* (Potonié and Klaus) Klaus 1963 (slide MC8, 44.5/109)
- 603 7. *Klausipollenites* sp. (slide MC10, 102/17.5)
- 604 8, 9. *Lunatisporites noviaulensis* (Leschik) Foster 1979 (8: slide MC12b, 25.6/108.9; 9: slide
- 605 MC12, 29.9/101.1)
- 606 10, 11. *Lunatisporites pellucidus* (Goubin) Helby 1972 (10: slide MC12, 35.4/100; 11: slide MC12,
- 607 33.3/102)
- 608 12. *Lunatisporites* sp. (slide MC12, 31/100)
- 609
- 610 Plate 4:
- 611 1-7, 13-17. *Reduviasporonites chalastus* (Foster) Elsik 1999 from the Tesero section.
- 612 8, 9, 12. Some examples of *Spirogyra* (from Bourrelly, 1990; 8: filament with aplanospore; 9:
- 613 filament with spirally arranged chloroplasts; 12: zygote).
- 614 10, 11. Some examples of *Trentepohlia* (from Bourrelly, 1990).
- 615



616

617 Figure 1

618

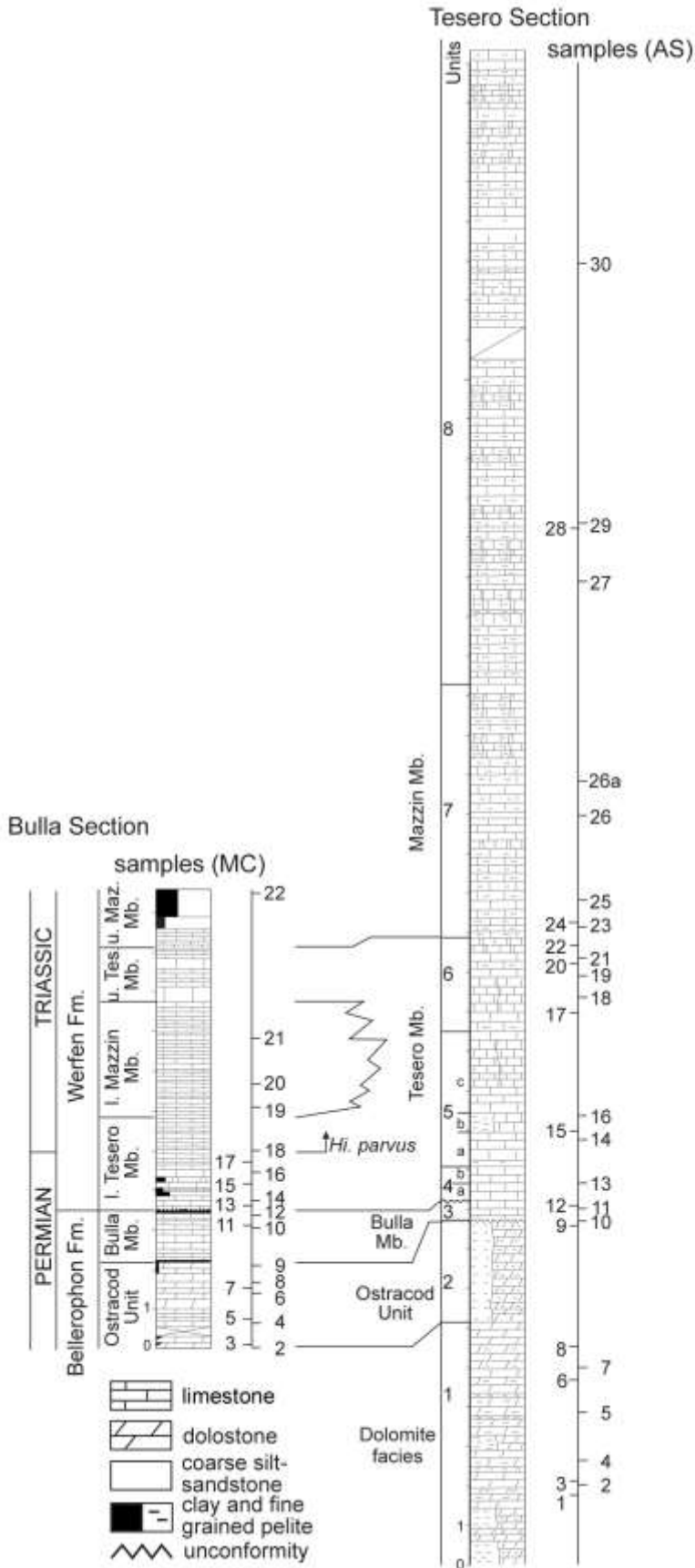


Figure 2

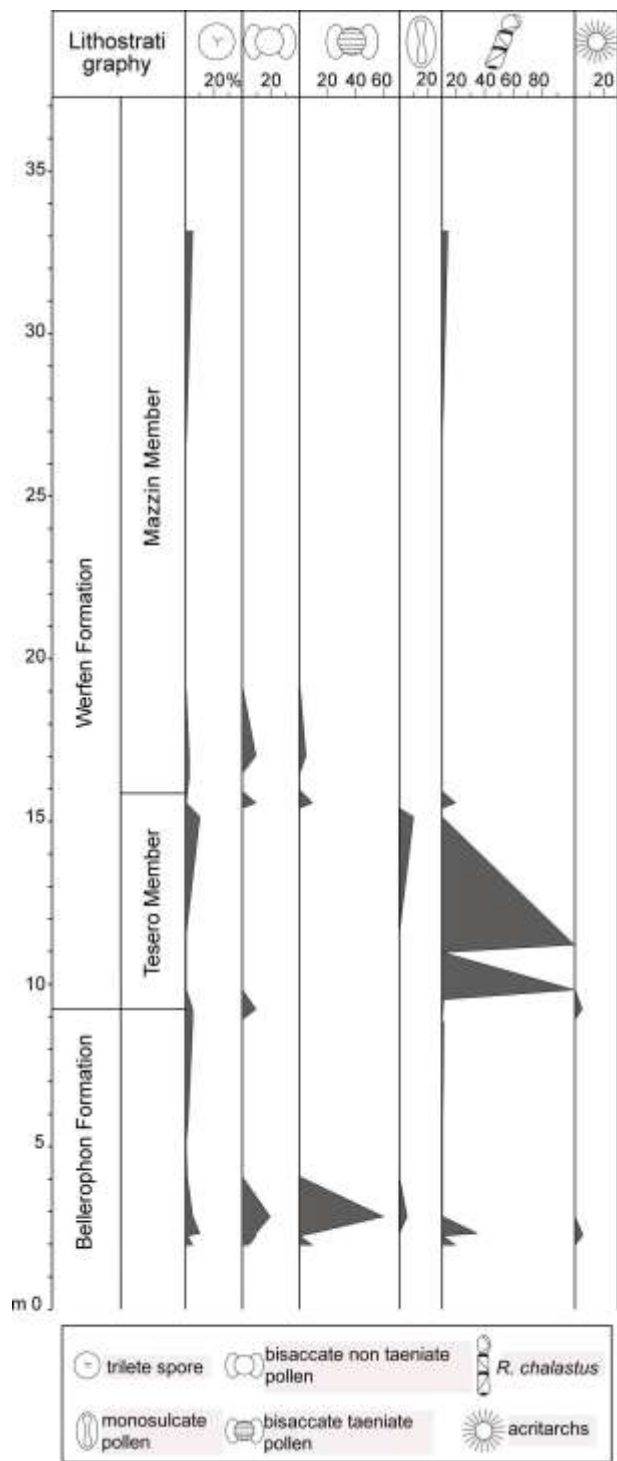
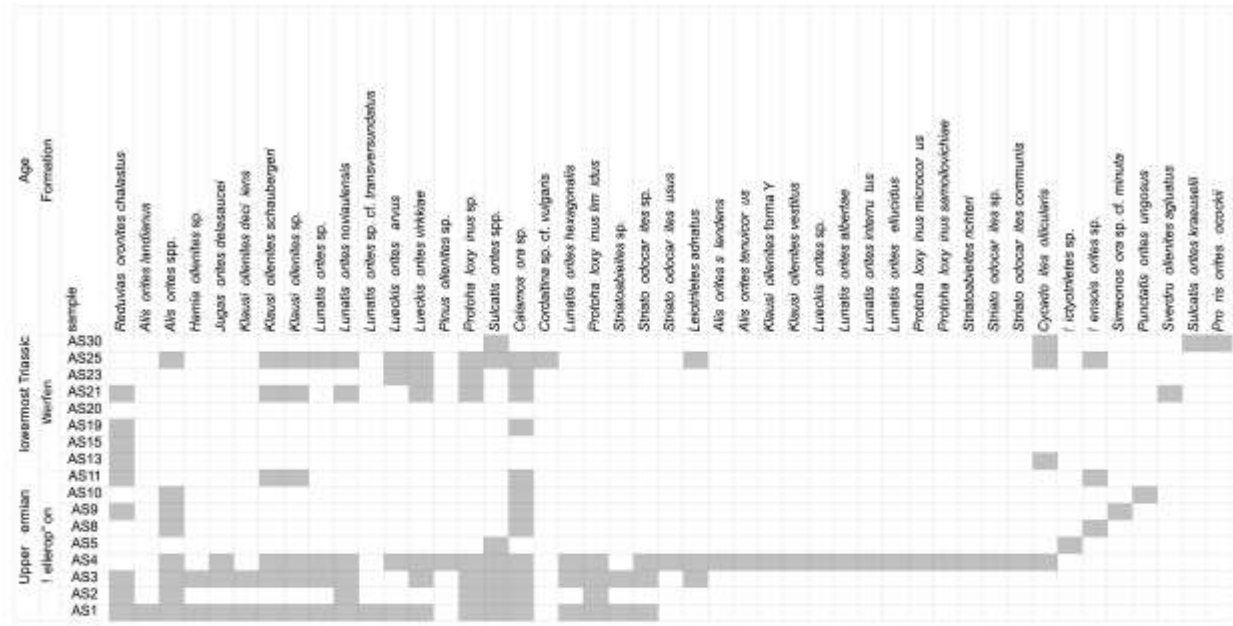


Figure 3

622

623



624

625 Tab. 1

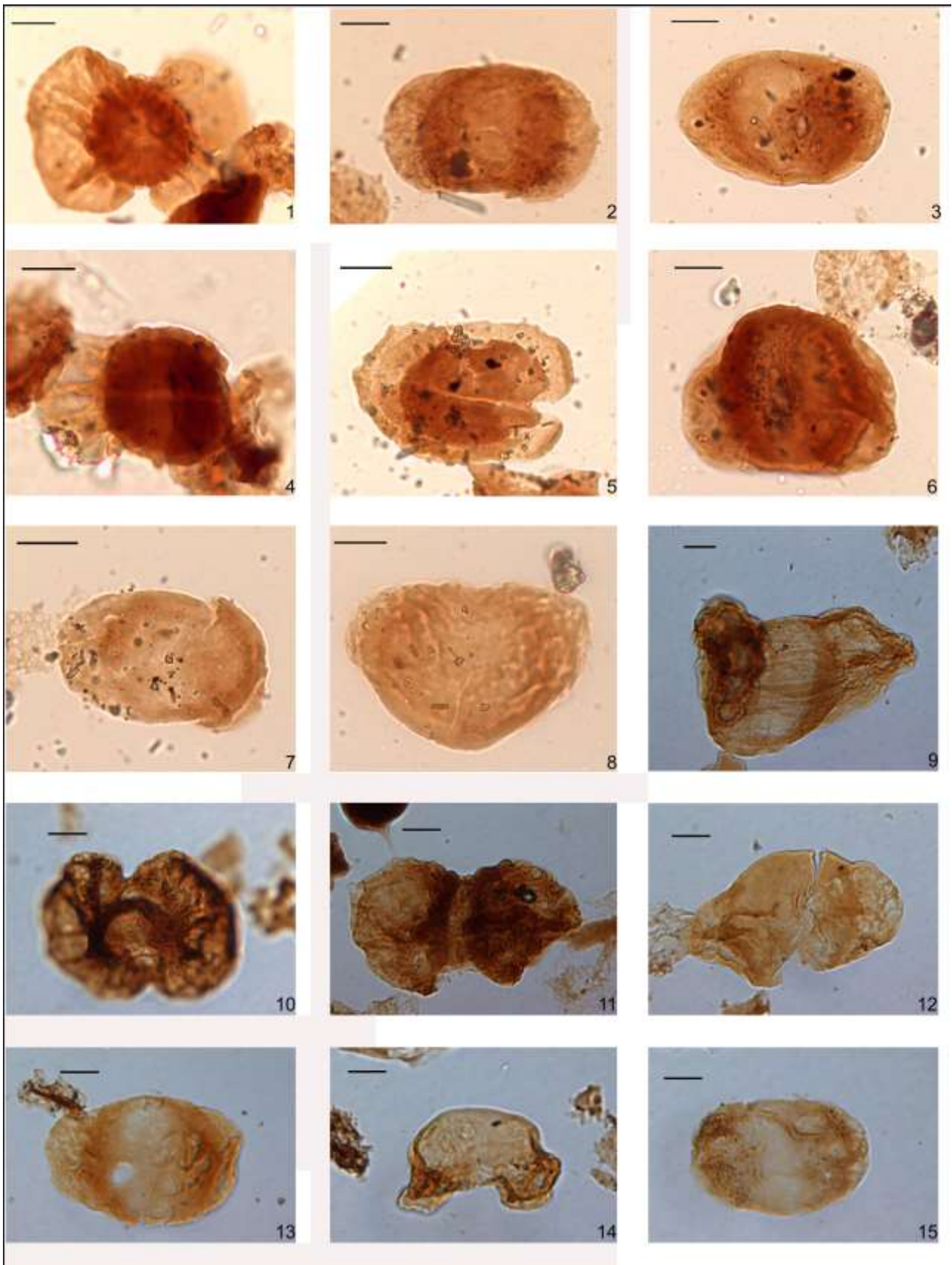
626

U. Permian Bellerophon	sample	A. e Formation
MC12	Caleniospora sp.	
MC10	Punctatisporites fungosus	
MC8	Leachisporites sp.	
MC6	Lomatiosporites sp.	
	Alisporites sp.	
	Jugosporites delasauzei	
	Jugosporites sp.	
	Kiautapotamites sp.	
	Alisporites sp. cf. splendidus	
	Lomatiosporites pellucidus	
	Lomatiosporites novataiensis	

627

628 Tab. 2

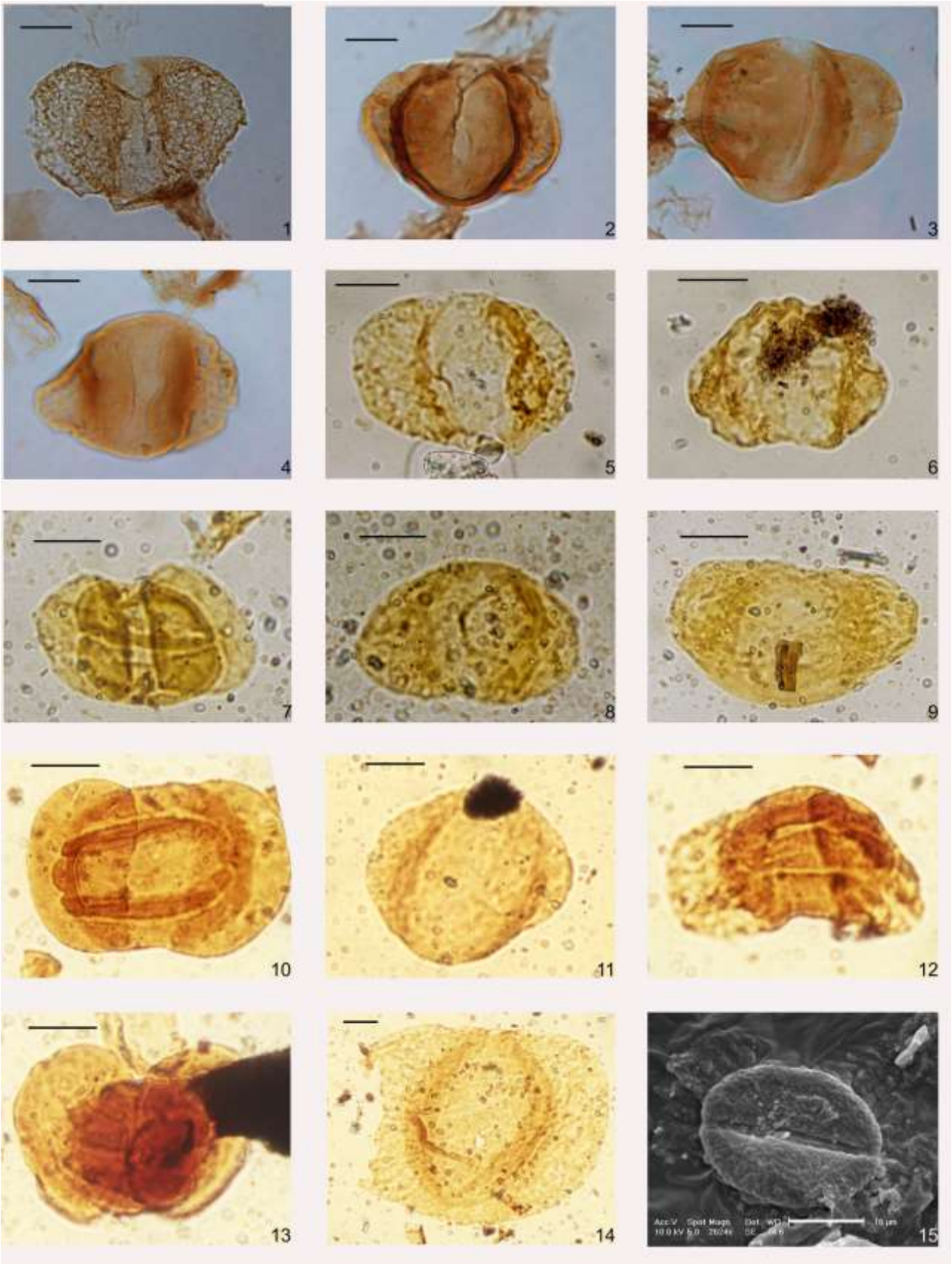
629



630

631 Plate 1

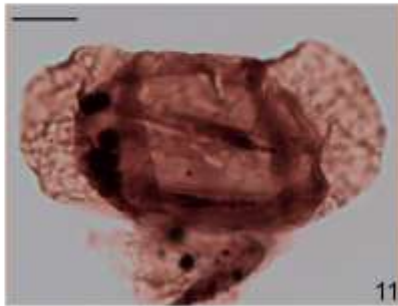
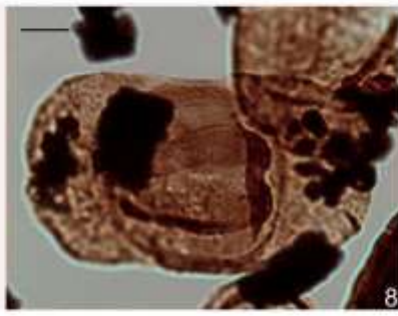
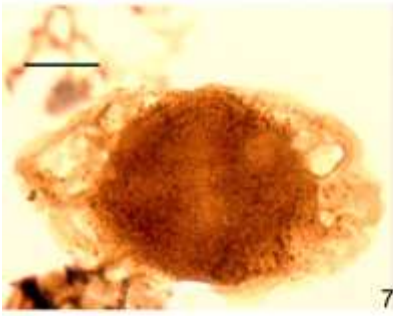
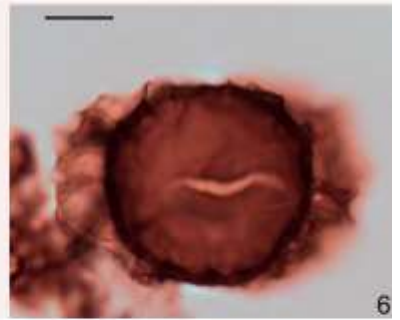
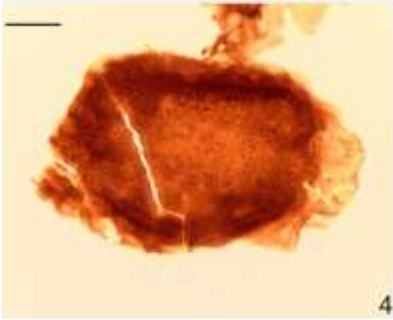
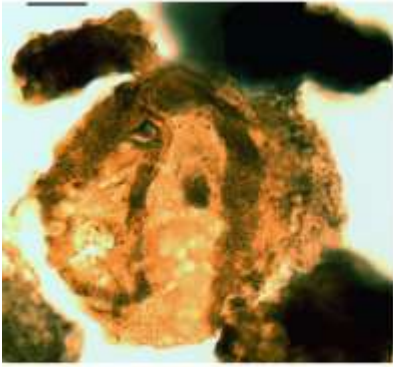
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634 Plate 2

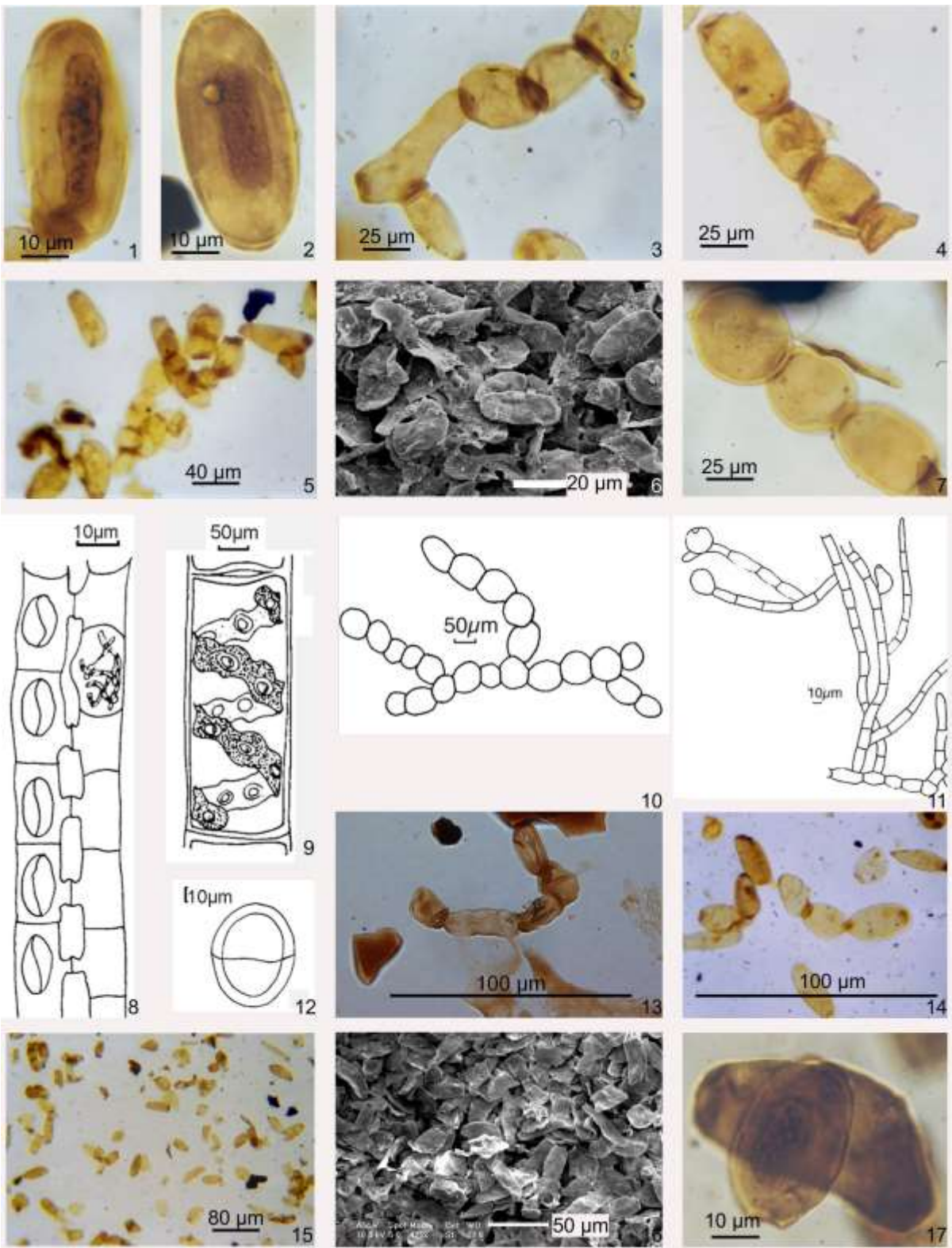
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637 Plate 3

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640 Plate 4