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**The Berriasian–Valanginian boundary in the
Mediterranean Province of the Tethyan Realm:
Ammonite and calcareous nannofossil biostratigraphy of
the Vergol section (Montbrun-les-Bains, SE France),
candidate for the Valanginian GSSP**

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1 **Green text = corrections related to the comments made by Dr. Otilia Szives (1st**
2 **reviewer).**

3 **Blue text = corrections related to the comments by Miguel Company (2nd reviewer);** he
4 contacted us to say that “he forgot to sign his report“.

5 **Red text = other corrections.**

6

7 **The Berriasian–Valanginian boundary in the Mediterranean Province of the Tethyan**
8 **Realm: ammonite and calcareous nannofossil biostratigraphy of the Vergol section**
9 **(Montbrun-les-Bains, SE France), candidate for the Valanginian GSSP**

10

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20

21 **Abstract**

22 The Vergol locality (Montbrun-les-Bains, South-East France), a candidate section for the
23 Valanginian GSSP (Global Stratotype Section and Point), was studied in detail for ammonites
24 and calcareous nannofossils. A bed-by-bed sampling and a quantitative approach were carried
25 out on this expanded succession presenting a continuous record of calcareous-marl

26 alternations covering the uppermost Berriasian and lowermost Valanginian. The ammonite
27 distribution observed allows a precise characterization of the Berriasian–Valanginian
28 boundary with the recognition of the *Tirnovella alpillensis* (latest zone of the Berriasian) and
29 “*Thurmanniceras*” *pertransiens* (earliest zone of the Valanginian) standard zones. The base of
30 the Valanginian is here defined by the First Appearance Datum of “*T.*” *pertransiens*; this
31 boundary can be well-characterized by ammonite assemblages and by using various
32 calcareous nannofossil bioevents, like the First Occurrence of *Calcicalathina oblongata*. A
33 tidy comparison with previous works on the Vergol section is made in order to integrate data
34 on calpionellids. A discussion on the choice of the primary marker (ammonites *versus*
35 calpionellids) for the Valanginian GSSP is proposed.

36

37 **Keywords**

38 Ammonite, Calcareous nannofossil, Biostratigraphy, Valanginian, GSSP, France

39

40 **1. Introduction**

41 Since five decades (Cretaceous Symposium, Lyon 1963, Barbier and Thieuloy, 1965a,b;
42 Busnardo and Le Hégarat, 1965), vigorous discussions on the definition of the Berriasian–
43 Valanginian boundary have taken place in the different groups of the IUGS Subcommittee
44 on Cretaceous Stratigraphy (Birkelund et al., 1984; Bulot et al., 1996). For the Mediterranean
45 Province of the Mediterranean–Caucasian Subrealm (Tethyan Realm), many biostratigraphic
46 studies were achieved for the interval around the boundary in South–East France and South–
47 East Spain in order to establish a zonation based on ammonites (Le Hégarat, 1973; Allemann
48 et al., 1975; Busnardo and Thieuloy, 1979; Hoedemaeker, 1981; 1982; 1983; Company and
49 Tavera, 1982; Tavera, 1985; Company, 1987). Due to some differences in taxonomic
50 concepts (i.e., misidentifications of some species) and biostratigraphic methodologies (i.e.,

51 heterogeneous zonations and problems with their reproductibility), it was difficult to reach a
52 consensus on the basis of previous works. Thus the establishment of an ammonite standard
53 zonation is needed; this was already the aim of the Lower Cretaceous Cephalopod Team
54 (LCCT; Hoedemaeker et al., 1990). Concerning the base of the Valanginian, the LCCT
55 correlated it with the base of the “*Thurmanniceras*” *otopeta* Ammonite Zone (AZ; see
56 [Appendix A](#)), as proposed by Busnardo and Thieuloy (1979), as also recommended by
57 Birkelund et al. (1984); in the zonal scheme of Le Hégarat (1973), such a solution
58 corresponds (approximatively) to the base of “*Thurmanniceras*” *pertransiens* Ammonite
59 Subzone of the author (ASZ; his *Kilianella roubaudiana* AZ) as its lower part includes the
60 interval corresponding to the “*T.*” *otopeta* AZ *sensu* Busnardo and Thieuloy (1979). The
61 LCCT (Hoedemaeker et al., 1990; 1993) rejected the suggestion of Hoedemaeker (1982) who
62 defined the base of Valanginian with the base of his *Tirnovella alpillensis* ASZ that roughly
63 corresponds to the *Berriasella calisto* ASZ of Le Hégarat (1973).

64 In order to define effective chronostratigraphic subdivisions based upon biostratigraphy, the
65 main trend was to develop a homogeneous Valanginian ammonite zonation based on the
66 recognition of successive faunal turnovers and by using interval zones of index-species,
67 defined by the First Appearance Datums (FAD), and characterized by their association (for
68 SE France see: Reboulet et al., 1992; Bulot et al., 1993a, b; Bulot, 1995; Bulot and Thieuloy,
69 1995; Reboulet, 1996; Reboulet and Atrops, 1999). According to this approach, Bulot and
70 Thieuloy (1993) and Bulot et al. (1993a, b) preferred to place the base of the Valanginian at
71 the base of the “*T.*” *pertransiens* AZ. This horizon corresponds (approximatively) to the
72 historical definition of the Berriasian–Valanginian boundary *sensu* Kilian (1910; base of his
73 *Holplites* (*K.*) *roubaudiana* AZ) and Mazonot (1939; base of his *Neocomites neocomiensis*
74 AZ; for complete correlation between different zonal schemes established for over a century,
75 see tables 2 and 3 in Busnardo and Thieuloy, 1979; tables 2 and 5 in Bulot, 1995; fig. 2 in

76 Aguado et al., 2000). This position of the boundary was adopted by the IUGS Lower
77 Cretaceous Ammonites Working Group (the Kilian Group) and the “*T.*” *otopeta* AZ was
78 downgraded to the rank of a subzone of the *Fauriella boissieri* AZ (Hoedemaeker et al.,
79 2003); this scheme was maintained in the successive meetings of the group (Reboulet et al.,
80 2006; 2009; 2011; 2014). Based on the PhD thesis of Kenjo (2014), the Kilian Group agreed
81 to change the standard zonation around the boundary as follows: for the uppermost Berriasian
82 the *T. alpillensis* AZ, subdivided in *T. alpillensis* and “*T.*” *otopeta* ASZ, and for the
83 lowermost Valanginian, the “*T.*” *pertransiens* AZ with the *Neocomites premolicus* ASZ
84 (Reboulet et al., 2018).

85 Two candidate sections have been proposed for the Valanginian GSSP, namely Vergol
86 (Montbrun-les-Bains, SE France; Blanc et al., 1994) and Barranco de Cañada Luenga
87 (Cehegin, Caravaca, SE Spain; Aguado et al., 2000). As classical sections of the Vocontian
88 basin (for example Berrias, Ardèche; Angles, Alpes-de-Haute-Provence; Barret-le-Bas,
89 Hautes-Alpes; see Le Hégarat, 1973 and Busnardo and Thieuloy, 1979) are characterized by
90 reworked sediments or hiatus or paucity in ammonites for the uppermost Berriasian–
91 lowermost Valanginian interval, Blanc et al. (1994) selected the well-developed succession of
92 Montbrun-les-Bains (see also Blanc, 1996). These authors mainly described the calpionellid
93 succession; data on ammonites are less abundant and their distribution is discontinuous.
94 However, as they observed that the **First Occurrences (FOs) FADs** of *Calpionellites darderi*
95 and “*T.*” *pertransiens* are almost synchronous, they confirmed the suggestion of Bulot and
96 Thieuloy (1993) and Bulot et al. (1993a, b) to define the base of the Valanginian Stage using
97 an ammonite as primary marker, namely the FAD of “*T.*” *pertransiens*. Aguado et al. (2000)
98 established an integrated stratigraphy for SE Spain (Caravaca–Cehegin region) by using
99 ammonites, calpionellids and calcareous nannofossils; their biostratigraphy was plotted
100 against the magnetic scale. These latter authors defined the Berriasian–Valanginian boundary

101 on the basis of the FAD of *C. darderi* following the provisional recommendation of the
102 Valanginian Working Group to use calpionellids as primary marker (base of the
103 *Calpionellites* zone E, Bulot et al., 1996).
104 Calcareous nannofossils have been also used for characterizing the Berriasian–Valanginian
105 boundary (Thierstein, 1971; Manivit, 1979; Perch-Nielsen, 1979; Bralower et al., 1989;
106 Mutterlose, 1992; Bown, 1998; 2005; Aguado et al., 2000). This boundary is characterized by
107 several bioevents of calcareous nannofossils, like the **First Occurrences** FO of *Calcicalathina*
108 *oblongata*, which identifies the base of *C. oblongata* **Nannofossil Zone (NZ)** in the lower
109 Valanginian, and *Tubodiscus jurapelagicus*, *Tubodiscus verenae*, *Eiffellithus windii*
110 (Bralower et al., 1989; Bown, 1998). However, changes in nannofossil assemblages allowing
111 characterization of the Berriasian–Valanginian boundary have been comparatively less
112 studied.

113 The aims of our work is (1) to establish an integrated biostratigraphic scheme between
114 ammonites and calcareous nannofossils, useful for large-scale correlations; and to (2) discuss
115 the choice of the primary marker (ammonites *versus* calpionellids). The newly established
116 bio- and chrono-stratigraphic scheme should enable us to discuss the Berriasian–Valanginian
117 boundary at Vergol within the framework of a new GSSP.

118

119 **2. Geological setting of the Vergol section**

120 The Vergol section was palaeogeographically located in the central part of the epicontinental
121 Vocontian basin (South-East France), at a palaeolatitude of approximately 30°N (Savostin et
122 al., 1986; Fig. 1A). This basin was surrounded by carbonate platforms (Cotillon et al., 1980;
123 Gréselle and Pittet, 2010), such as the Jura platform to the North, and the Provence platform
124 to the South (Fig. 1B). The Vocontian basin belonged to the European Tethyan passive
125 margin and it was infilled by a sequence of sediments which were deposited in a hemipelagic

126 environment (Gréselle et al., 2011; Martinez et al., 2013). The Vergol section is composed of
127 marl-limestone alternations that represent the typical sedimentary pattern of Mesozoic series
128 in the Vocontian basin. As shown by Cotillon et al (1980), the Valanginian alternations are
129 remarkably continuous within this basin; they are stacked in bundles becoming more
130 calcareous stratigraphically upwards and can be correlated over a large area. Recently, the
131 Vergol site was used by Reboulet et al. (2003), Gréselle et al. (2011) and Martinez et al.
132 (2013) as a case study for the formation of marl-limestone alternations.

133 At Vergol (44°12'10''N; 5°25'06''E), three successive sites of observations were selected to
134 provide a continuous log from the upper Berriasian (*T. alpillensis* AZ) to the middle part of
135 the lower Valanginian ("*T.*" *pertransiens* AZ and *N. neocomiensiformis* AZ *p.p.*). Two long
136 outcrops are located along the road D159 where the lithologic succession is easily and
137 continuously followed. A third intermediate outcrop occurs laterally, along the small creek
138 orthogonal at the road. Thus, a very careful observation and lateral correlation allowed us to
139 complete the stratigraphic gap (a few meters in thickness) reported by Blanc (1996, fig. 62) in
140 the upper Berriasian. The studied interval of the Vergol section consists of a succession of 87
141 meters (53 m from the bed VGL-B95 until the base of the slump and 34 m from the base of
142 the slump until the bed VGL-V69; Fig. 1C). Small cycles formed of 4 to 6 calcareous beds
143 can be recognized. The base of the studied interval (upper Berriasian) is characterized by
144 thick limestone beds (as VGL-B100 and VGL-B101) alternating with thin marly beds.
145 Limestone beds become thinner stratigraphically upwards while marl interbeds are thicker.
146 The uppermost Berriasian is characterized by a limestone-dominated interval of 12 calcareous
147 beds (calcareous bundle VGL-B118 to VGL-B129) named the "Otopeta bundle" that is
148 located just below the Berriasian–Valanginian boundary (*sensu* Kenjo 2014, this work).
149 Around this boundary and in the lowermost Valanginian, the limestone beds tend to be
150 thinner while marlstones are thicker, even if the marly interbeds remain generally thinner than

151 limestones. From bed VGL-V30 until the slump (VGL-V44), marly interbeds become
152 generally thicker than limestones. Above the slump, marly interbeds are still generally thicker
153 than limestones, except for beds VGL-V63 and 64. In the middle part of layer VGL-V48,
154 marlstones are finely laminated with pyritous ammonites and nodules. The beds VGL-V61-62
155 are characterized by numerous bivalves (lumachelles); similar observations were made in the
156 beds LPD-64-65 of the Les Prades section (Drôme; Reboulet, 1996) providing two
157 characteristic layers for correlations between these two sections. Above the bed VGL-V69,
158 litho-biostratigraphic data of the lower Valanginian and the lower part of the upper
159 Valanginian have been published by Reboulet (1996), Reboulet et al. (2003) and Reboulet
160 and Rard (2008). **-Fig. 1, here-**

161

162 **3. Materials and Methods**

163 **3.1. Macrofauna**

164 The selected interval of the Vergol section was studied for its content of pelagic and benthic
165 macrofauna. 1623 specimens of ammonites were sampled. 113 aptychus, 7 rhyncholites, 35
166 belemnites, 227 bivalves, 15 gastropods, 3 brachiopods and 4 echinoids have been also found.
167 Around one hour and one half was spent for the extraction of the macrofauna from every
168 limestone bed of the Vergol section (122 beds). Concerning ammonites, only the preserved
169 specimens for which the identification was possible (see Appendix A) were transferred to the
170 laboratory where extraction was completed using a vibratory device, and determination
171 effectuated (using the palaeontological worksheet). The specimens doubtfully identified are
172 indicated by a question mark. When the identification was impossible, the ammonites were
173 counted as undetermined species (420 specimens). Dissolution of shells is usual ~~the norm~~ and
174 ammonites are preserved as internal calcareous moulds. Their fragmentation is relatively
175 frequent and compaction is important, particularly for the phragmocones. Consequently, some

176 characteristics, such the whorl section and the strength of ribs and tubercules, and how they
177 change between the inner and outer whorls, cannot be correctly observed and compared for a
178 part of the material. The specimens are stored in the “Collections de géologie” of the
179 “Université Claude Bernard” (Lyon, France; collection of Kenjo and Reboulet).

180

181 **3.2. Calcareous nannofossils**

182 Eighty-two samples have been studied for calcareous nannofossils contents in the Vergol
183 section. Samples were systematically taken from adjacent marl-limestone couplets. Sample
184 spacing was quite large (every one meter) at the base of the section and much closer around
185 the Berriasian–Valanginian boundary (bed by bed). The method used for the preparation of
186 slides (Random Setting Technique) was first described by Beaufort (1991) and modified by
187 Geisen et al. (1999). This method is used to calculate the absolute abundance of nannofossils
188 (specimens per gram of rock). These slides were observed in optical microscope by using
189 immersion oil and polarized light with a magnification 1000X. Samples and calcareous
190 nannofossil slides **are labelled with a FSL number and curated at** the “Collections de
191 géologie” of the “Université Claude Bernard” (Lyon, France; collection of Kenjo, Mattioli
192 and Reboulet).

193 The absolute abundance and composition of the assemblage were studied through the
194 determination of nannofossils species. In each slide, 500 nannofossils were counted in a
195 variable number of fields of view. **Such count provides us with a probability of 0.5-1% not to**
196 **record species as rare as representing 1% of the assemblage (Hay, 1972).** Each sample was
197 then re-analyzed thoroughly in order to detect rare species potentially useful for
198 biostratigraphical purposes.

199 We calculate the absolute abundance using the following equation:

$$200 \quad X = (N * V) / (M * A * F * H);$$

201 X: Number of nannofossils per gram of rock;

202 N: Total number of specimens counted;

203 V: Volume of water used (475 ml);

204 M: Mass of powder used;

205 F: Number of fields of view observed under the microscope;

206 A: Surface of a field of view ($3.14 * 10^{-4} \text{ cm}^2$);

207 H: height of the water column above the slide in the settling box (2.1 cm).

208 Principal Component Analysis (PCA) was used to treat nannofossil assemblages in order to
209 interpret this complex data set and reduce the large data matrix, which is composed of several
210 variables (78 taxa were recorded in 82 samples, see Appendix B) into a small number of
211 factors representing the main modes of variations (Beaufort and Heussner, 2001). PCA was
212 computed with the PAST software 3.01. Because of the presence of dominant taxa (e.g., *W.*
213 *barnesiae*) and in order to reduce the impact of the closed-sum effect, the relative abundance
214 was transformed in log using PAST before running the PCA. Some clusters were created by
215 grouping the species belonging to the same genus and having significant correlations. Thus,
216 all the species of the genus *Rhagodiscus* except *R. asper*, all the small *Zeugrhabdotus*, the
217 *Biscutum*, the pentoliths, the *Cretarhabdus* plus *Retecapsa*, were lumped for PCA. The
218 *Nannoconus* species were all grouped for the analysis. The matrix in our study consists of the
219 relative abundances of 22 taxa representing more than 90% of the total counted nannofossils.
220 The rare and discontinuously recorded taxa (i.e., less than 2% on average) were not integrated
221 in the analysis.

222 As the values obtained for the various parameters are largely fluctuating according to the
223 lithology, a LOESS smoothing with a 0.2 factor and a 9999 bootstrap was applied to the
224 loading factor values, to absolute abundance data and to the Shannon diversity index by using

225 PAST. Such a smoothing allows a better appreciation of changes through time of different
226 parameters.

227

228 4. Results

229 4.1. Ammonites

230 4.1.1. Systematic remarks

231 The ammonite fauna of the studied section (Fig. 2A, B) consists of twenty (sub-)genera
232 grouped into seven families, using the supra-classification proposed by Klein (2005) and
233 Klein et al. (2007, 2009; Appendix A). The systematic revision of all species was made
234 during the PhD thesis of one of us (S. Kenjo, 2014). Here, only palaeontological comments
235 are proposed for some taxa and quantitative data are also given. Further information on
236 stratigraphy and taxonomy is available in the papers of Le Hégarat (1973), Company (1987),
237 Reboulet et al. (1992), Bulot et al. (1993b), Bulot (1995), Reboulet (1996), Reboulet and
238 Atrops (1999), Joly (2000), Busnardo et al. (2003), Busnardo (*in* Gauthier et al., 2006),
239 Wippich (2001; 2003), Ettachfini (2004), and Company and Tavera (2015). **-Figs. 2A,2B,**
240 **approximately here (in the paper, it would be preferable that they are facing each**
241 **other)-**

242 Neocomitids are represented by eight genera in the Vergol section. The species *B. calisto*
243 (Fig. 3A), *Berriasella picteti* and *F. boissieri* (Fig. 3B) are overall rare. In agreement with
244 Company's comments (personal communication, 2014), Kenjo (2014) discussed the
245 possibility of a dimorphism between *B. calisto* (microconch) and *F. boissieri* (macroconch). If
246 this dimorphism holds true, *F. boissieri* should be considered as a junior synonymy of *B.*
247 *calisto*. The similarity between these two taxa was already suggested by Mazenot (1939; p.
248 108). The Berriasian interval is also well characterized by the occurrences of *T. alpillensis*
249 (Fig. 3C-D), *Erdenella paquieri* (Fig. 3E), and "*T.*" *otopeta* (Fig. 4A-B) that is relatively

250 abundant in beds VGL-B127-B128-B129 (Fig. 2A). **-Fig. 3, approximately here-** The
251 genus “*Thurmanniceras*” also occurs in the lower Valanginian with “*T.*” *pertransiens* (Fig.
252 4C-H) and “*Thurmanniceras*” *gratianopolitense* (Fig. 4I) that are recorded as common and
253 rare, respectively. The generic name “*Thurmanniceras*” is cited with inverted commas to
254 indicate that the assignment of the species to that genus is provisional and they await revision
255 (Kenjo, 2014; Reboulet et al., 2014; Company and Tavera, 2015). The taxonomy of “*T.*”
256 *gratianopolitense* is well discussed in Kenjo (2014), who acknowledged the point of view of
257 Aguado et al. (2000). These latter authors support that “*Fauriella*” *kiliani* should be put in
258 synonymy with “*T.*” *gratianopolitense* because, in the neritic facies of the western High Atlas
259 (Morocco), there are large specimens that very closely resemble to the type of “*T.*”
260 *gratianopolitense*; their juvenile stages are comparable to the small specimens characteristic
261 of the Mediterranean (hemi-)pelagic facies for which Bulot (1995) created the species “*F.*”
262 *kiliani* (*nomen nudum*). Large specimens identified as “*T.*” *gratianopolitense* have also been
263 found by one of us in some neritic sections of western High Atlas (Morocco; S. Reboulet,
264 work in progress). The good preservation of these Moroccan specimens allowed us to observe
265 changes in the ornamentation: ribs are generally grouped in pairs at the umbilicus in the
266 juvenile stage, while they are isolated in the adult stage. According to these observations,
267 large Moroccan specimens identified as “*Thurmanniceras*” *thurmanni* by Wippich (2001; pl.
268 19, fig. 1; pl. 20, fig. 1) could correspond to “*T.*” *gratianopolitense*, which is attributed to the
269 genus “*Thurmanniceras*” and not to the genus *Fauriella* as suggested by Bulot (1995) and
270 Klein (2005). **-Fig. 4, approximately here-** The lower Valanginian assemblage (Fig. 2A,
271 B) is also characterized by the occurrences of *N. premolicus* (Fig. 5A) and *Neocomites*
272 *neocomiensiformis* (Fig. 5A,B) ~~found below and above the slumped interval, respectively~~
273 ~~(Fig. 2A, B)~~. Other neocomitids are represented by *Kilianella* (one *K. lucensis* Fig. 5C and

274 mainly *K. roubaudiana* Fig. 5D), and few specimens of *Luppovella* (*L. superba*, Fig. 5E) and
275 *Sarasinella* (*S. ambigua* and *S. eucyrta* Fig. 5F). -**Fig. 5, approximately here-**

276 Olcostephanids are mainly represented by *Olcostephanus* that is generally rare in the studied
277 section but slightly more abundant in its uppermost part (Fig. 2A, B). Due to their poor
278 preservation, as indicated by Bulot (1990) for lower Valanginian specimens of SE France, the
279 identification at the specific level was very often impossible; only few specimens of
280 *Olcostephanus* aff. *tenuituberculatus* (Fig. 6A) and *Olcostephanus josephinus* have been
281 recognized in bed VGL-V62. One specimen has been identified as *Spiticerus multiforme* (bed
282 VGL-B112; Fig. 6B).

283 Haploceratids, with *Neolissoceras*, are relatively common. Three species have been
284 identified: *Neolissoceras grasianum*, *Neolissoceras (Vergolicerus) extracornutum* (Fig. 6C
285 and *Neolissoceras (Vergolicerus) salinarium* (Fig. 6D). According to Reboulet et al. (2003)
286 and Kenjo (2014), even if *Vergolicerus* is well characterized by a ventral keel, this taxon is
287 here considered as a subgenus of *Neolissoceras*, and not as a separate genus as suggested by
288 Klein et al. (2009).

289 Lytoceratids are rare to common. This family is represented by *Lytoceras honnoratianum*
290 (Fig. 6E), that seems restricted to the Berriasian interval of the Vergol section, and *Lytoceras*
291 *quadrisulcatum* (Fig. 6F).

292 Phylloceratids are common to frequent. Three species have been recognized:
293 *Holcophylloceras silesiacum* (Fig. 6G), *Ptychophylloceras (Semisulcatoceras) semisulcatum*
294 (Fig. 6H) and *Phylloceras (Hypophylloceras) tethys* (Fig. 6I).

295 Heteromorphs are represented by Bochianitids, with *Bochianites neocomiensis* (Fig. 6J) that
296 is rare, and Protancyloceratids, with *Leptoceras* and *Protancyloceras* (Fig. 6K) that are very
297 rare and poorly preserved. -**Fig. 6, approximately here-**

298

299 **4.1.2. Biostratigraphic implications**

300 The analysis of the stratigraphic distribution of the species done by Kenjo (PhD thesis, 2014)
301 allowed us to establish a new ammonite zonation of the Vergol section. This zonal scheme
302 was presented by one of us (S. Reboulet) to the Kilian Group at the 2017 Vienna meeting
303 (Reboulet et al., 2018). In order to follow the standard ammonite zonation built for the
304 Mediterranean Province, only ammonite zones and subzones (respectively AZ and ASZ)
305 adopted by the Kilian Group are presented here for the Vergol section. Thus, from bottom to
306 top of the studied interval, the (sub-)zones are: the *T. alpillensis* AZ (latest zone of the
307 Berriasian; with the *T. alpillensis* and “*T.*” *otopeta* ASZs), “*T.*” *pertransiens* AZ (earliest zone
308 of the Valanginian; with the *N. premolicus* ASZ), and the *N. neocomiensiformis* AZ. In this
309 work, ammonite zones are interval zones and they are defined by the interval between the
310 FAD of two successive **ammonite-indices** (Hedberg, 1976). As it was proposed by Reboulet
311 and Atrops (1999), who modified the zonal scheme for the uppermost lower Valanginian–
312 lower Hauterivian to correlate more precisely biostratigraphic subdivisions with ammonite
313 evolution, the boundaries of the interval zones of the uppermost Berriasian–lower
314 Valanginian correspond to major changes in the ammonite fauna (Kenjo, 2014; Company and
315 Tavera, 2015) allowing a better faunal characterizati**o**n of the zones.

316

317 **The *T. alpillensis* Ammonite Zone, and the *T. alpillensis* and “*T.*” *otopeta* Ammonite** 318 **Subzones**

319 The *T. alpillensis* AZ used here is defined by the FAD of *T. alpillensis*, as proposed by Bulot
320 et al. (1993a, b; see also Bulot, 1995) for the *T. alpillensis* ASZ. According to this definition,
321 the *T. alpillensis* AZ replaces the upper part of the *Fauriella boissieri* AZ of Le Hégarat
322 (1973). Consequently, the former late Berriasian *F. boissieri* AZ (composed of the
323 *Malbosiceras paramimounum*, *B. picteti*, *T. alpillensis* and “*T.*” *otopeta* ASZs; Hoedemaeker

324 et al., 1993, 2003) has been modified and restricted to its lower part that corresponds now to
325 the *F. boissieri* AZ *sensu* Kenjo (2014) with *M. paramimounum* and *B. picteti* ASZs *sensu* Le
326 Hégarat (1973). Kenjo (2014, p. 103–106) provided a detailed discussion about the *F.*
327 *boissieri* AZ and the choice of a new index-species for this interval.

328 The *T. alpillensis* ASZ is risen to the rank of zone for the following reasons: (1) the *T.*
329 *alpillensis* ASZ, introduced by Hoedemaeker (1982), was already used in the standard
330 zonation and adopted as an acme zone during the 1992 Mula meeting (Hoedemaeker et al.,
331 1993); it corresponds to the “un-named association” evoked during the 1990 Digne meeting
332 (Hoedemaeker et al., 1990); (2) *T. alpillensis* is easy to identify and has been well-described
333 by Le Hégarat (1973), Tavera Benítez (1985), Company (1987), Bulot (1995), Kenjo (2014);
334 (3) specimens of *T. alpillensis* are found in almost all the corresponding zone and it is
335 abundant as reported by Company (1987), Aguado et al. (2000), and Kenjo (2014). According
336 to Bulot (1995), this species disappeared in the lowermost part of the “*T.*” *pertransiens* AZ;
337 (4) *T. alpillensis* occurs both in proximal (platform) and distal (basin) palaeoenvironments
338 (Bulot, 1995); (5) it is a quite ubiquitous species in the Mediterranean Province (Company,
339 1987; see the synonymy of *T. alpillensis* in Klein, 2005); (6) in the *T. alpillensis* AZ (mainly
340 in the “*T.*” *otopeta* ASZ), there is a characteristic ammonite assemblage of latest Berriasian
341 and earliest Valanginian taxa (Bulot et al., 1993a, b; Bulot, 1995), which is very different with
342 respect to the assemblages of ammonite subzones in the interval below (approximately *M.*
343 *paramimounum* and *B. picteti* ASZs); an ammonite faunal turnover occurs at the top of the *B.*
344 *picteti* ASZ (Bulot et al., 1993a, b); (7) the base of *T. alpillensis* AZ roughly corresponds to
345 the base of the D3 calpionellid Zone (Bulot et al., 1993a, b; Bulot, 1995).

346 In the Vergol section (Fig. 2A), the *T. alpillensis* AZ is characterized by many species that are
347 quite characteristic of the upper Berriasian like *B. picteti*, *B. calisto*, *F. boissieri*, *E. paquieri*,
348 “*T.*” *otopeta*, *S. multiforme*, *L. honnoratianum* and *Leptoceras* sp. ind. Other taxa which cross

349 the Berriasian–Valanginian boundary are also found in the uppermost Berriasian, like *N.*
350 *grasianum*, *L. quadrisulcatum*, *P. (H.) tethys*, *P. (S.) semisulcatum*, *H. silesiacum*,
351 *Protancyloceras* sp. ind. and *B. neocomiensis*.

352 The *T. alpillensis* AZ is subdivided into a lower *T. alpillensis* ASZ and an upper “*T.*” *otopeta*
353 ASZ (Kenjo, 2014). The earliest specimen of *T. alpillensis* has been found from the base of
354 the studied interval (VGL-B96; Fig. 2A); as no sampling has been made below this layer, ~~this~~
355 ~~FO cannot be considered as the FAD of the index species and thus~~ it cannot be excluded that
356 the *T. alpillensis* ASZ/AZ is partly represented in the studied interval. **Lithologic correlations**
357 **show that the bed VGL-B96 should correspond to bed COUR-96 of the Courchons section**
358 **(Saint-André-les-Alpes, Alpes-de-Haute-Provence; Kenjo, 2014). In this last section, the FO**
359 **of *T. alpillensis* is observed around one meter below (bed COUR-92), but this specimen was**
360 **identified with doubt.** The base of the “*T.*” *otopeta* ASZ, introduced by Busnardo and
361 Thieuloy (1979) as a zone, is defined by the FAD of “*T.*” *otopeta*; its FO is recorded in the
362 bed VGL-B116; **the consistent record of this index-species begins in the bed VGL-B121.**
363 **Even if the specimen of bed VGL-B116 is doubtful, the base of the “*T.*” *otopeta* ASZ can be**
364 **maintained at the base of this bed. Indeed, in the Courchons section (~~Saint-André-les-Alpes,~~**
365 **~~Alpes-de-Haute-Provence;~~ Kenjo, 2014), the base of the “*T.*” *otopeta* ASZ is placed at the**
366 **base of bed COUR-122 that is correlated to the bed VGL-B117 (less one meter above the base**
367 **of the bed VGL-B116). The index-species, which is recorded in almost the entire**
368 **corresponding subzone, is very commonly recorded in SE France, mainly in basinal sections**
369 **~~whilst it is rare in SE Spain~~ (Company, 1987; Bulot, 1995).**

370

371 **The “*T.*” *pertransiens* Ammonite Zone, and the *N. premolicus* Ammonite Subzone**

372 The “*T.*” *pertransiens* AZ was created by Le Hégarat and Remane (1968) as a subzone of the
373 “*K. roubaudiana*” AZ; their “*T.*” *pertransiens* ASZ included the interval corresponding to the

374 “*T.*” *otopeta* ASZ. More recently, the “*T.*” *pertransiens* ASZ has been elevated to the rank of
375 zone and its base is defined by the FAD of “*T.*” *pertransiens* (Company, 1987; Blanc et al.,
376 1994; Bulot, 1995; Aguado et al., 2000; Kenjo, 2014). The FO of this species is recorded in
377 the bed VGL-B136 (Fig. 2A). The assemblage of the “*T.*” *pertransiens* AZ is characterized by
378 many species belonging to *Neocomites*, *Neolissoceras* (*Vergoliceras*), *Kilianella* and
379 *Sarasinella*. Other taxa which cross the Berriasian–Valanginian boundary are also found in
380 the “*T.*” *pertransiens* AZ like *N. grasianum*, *L. quadrisulcatum*, *P. (H.) tethys*, *P. (S.)*
381 *semisulcatum*, *H. silesiacum* and *B. neocomiensis*. “*T.*” *gratianopolitense* and
382 *Protancyloceras* sp. ind. are only recorded in the lowermost part of this zone where latest
383 specimens of *Berriasella* sp. ind. occur.

384 Kenjo (2014) proposed to subdivide the “*T.*” *pertransiens* AZ into two parts, namely the *N.*
385 *premoliticus* and *N. (V.) salinarium* ASZs. Only the earliest subzone was accepted by the
386 Kilian Group (Reboulet et al., 2018). The *N. (V.) salinarium* ASZ was not adopted as there
387 are some discrepancies with the ~~FAD~~ FO of the index-species (see Ettachfini, 2004; Kenjo,
388 2014 *versus* Company and Tavera, 2015), thus for the moment the upper part of the “*T.*”
389 *pertransiens* AZ of the standard zonation is not characterised by any subzone. Consequently,
390 the Kilian Group agreed to consider provisionally the *N. premoliticus* ASZ as a total range
391 subzone. It starts at the base of the “*T.*” *pertransiens* AZ in order that their bases coincide, and
392 ends at the last occurrence (LO) of *N. premoliticus*. In the Vergol section, the FO of *N.*
393 *premoliticus* is recorded in the bed VGL-B141, just five beds above the FO of “*T.*”
394 *pertransiens* (Fig. 2A; Kenjo, 2014). This author also acknowledged that *N. premoliticus* first
395 occurs in the basal part of the “*T.*” *pertransiens* AZ in the Courchons section (~~Saint-André-~~
396 ~~les-Alpes, Alpes-de-Haute-Provence~~). According to Bulot and Thieuloy (1995) and Bulot
397 (1995), the FOs of *N. premoliticus* and “*T.*” *pertransiens* are very close to each other in other
398 sections of the SE France basin. *N. premoliticus* first occurs in SE Spain at the base of the “*T.*”

399 *pertransiens* AZ and is reported as abundant in its lower part (Company, 1987; Aguado et al.,
400 2000; Company and Tavera, 2015). The FO of *N. premolicus* was used by Ettachfini (2004) to
401 recognize the base of the Valanginian in the Atlas-Atlantic of Morocco, due the (quasi-)
402 absence of “*T.*” *pertransiens* in this region. Reboulet (work in progress) also uses *N.*
403 *premoliticus* to put the base of this stage in the studied Moroccan sections. *N. premolicus* is
404 easy to identify and relatively frequent in France (Kenjo, 2014), Spain (Company and Tavera,
405 2015) and Morocco (Ettachfini, 2004; Reboulet, work in progress); for a detailed
406 palaeobiogeographic distribution of this taxon, see Klein (2005, p. 309–310). Thus, the
407 introduction of the *N. premolicus* ASZ in the standard zonation allows a good characterisation
408 of the lowermost part of the Valanginian and the establishment of solid biostratigraphic
409 correlations between the sections of the northern and southern Mediterranean areas.

410

411 **The *N. neocomiensiformis* Ammonite Zone**

412 Company and Tavera (2015) proposed the *N. neocomiensiformis* AZ for the middle part of the
413 lower Valanginian. This proposal was accepted by the Kilian Group and introduced in the
414 standard zonation of the Lower Cretaceous (Reboulet et al., 2014). The base of this zone is
415 defined by the FAD of the species index. In the Vergol section, the FO of *N.*
416 *neocomiensiformis* is recorded in the bed VGL-V38 (Fig. 2B). This zone is characterized by
417 an assemblage of several taxa, like *K. roubaudiana*, *L. superba*, *O. aff. tenuituberculatus*, *N.*
418 *(V.) salinarium*, *N. (V.) extracornutum*, *L. quadrisulcatum*, *P. (H.) tethys*, *P. (S.)*
419 *semisulcatum*, and *B. neocomienis*. A single specimen of *O. josephinus* was recorded
420 (Fig.2B); according to Company and Tavera (2015), this species seems to be restricted to the
421 *N. neocomiensiformis* AZ. As observed by these authors for some Spanish sections, the basal
422 part of the range of *N. neocomiensiformis* can overlap the uppermost part of the range of “*T.*”
423 *pertransiens* in the Vergol section where both species co-occur in the bed VGL-V38.

424 Kenjo (2014) proposed to characterize the lower part of the *N. neocomiensiformis* AZ by the
425 *L. superba* ASZ. However, this proposal was not validated by the Kilian Group as there are
426 some discrepancies with the ~~FAD~~ FO of the index-species (see Bulot, 1995; Ettachfani, 2004;
427 Kenjo, 2014 *versus* Company and Tavera, 2015).

428

429 **4.2. Calcareous nannofossil distribution, events and zonation**

430 In this work, taxonomy is based upon Bralower et al. (1989), Bown (1998), Aguado (1994)
431 and Aguado et al. (2000). The zonation of calcareous nannofossils is based on interval zones,
432 which are identified by the FO and LO of marker species (in the rest of manuscript:

433 Nannofossil Zone = NZ; Nannofossil Subzone = NSZ). Although preservation is commonly
434 poor to moderate with specimens severely overgrown (Figs. 7 and 8), many bioevents are
435 recorded across the Berriasian–Valanginian boundary of the Vergol section (Fig. 9; Table 1).

436 ~~-Figs 7; 8; 9, approximatively here - Table 1 in supplementary data/material-~~

437 The presence of *Retecapsa angustiforata* (previously considered as *Cretarhabdus*
438 *angustiforatus*) is observed from the base of the section (bed VGL-B95). This record allows
439 recognition of the *C. angustiforatus* NZ, NK-2 that is subdivided into two nannofossil
440 subzones, namely *Assipetra infracretacea* NK-2A and *Percivalia fenestrata* NK-2B. The NK-
441 2A/NK-2B boundary was originally draft by Bralower et al. (1989) within the *F. boisseri* AZ,
442 *B. picteti* ASZ (Fig. 10). The top of *A. infracretacea* NSZ is placed in the bed VGL-B112M
443 (M = Marlstones) because of the FO of *P. fenestrata*; in the same sample, ~~also first occurs the~~
444 ~~FO of *Ethmorhabdus hauterivianus* is observed~~ (Fig. 9). This subzone boundary is placed
445 within the *T. alpillensis* ASZ of the present work. Our record is consistent with Aguado et al.
446 (2000; Fig. 11). The species *Haqius circumradiatus* first occurs shortly afterwards, in the
447 sample VGL-B113c M (Fig. 9). This event is however documented earlier by Bown (1998) in
448 the basal part of the *F. boisseri* AZ (Fig. 10). It is possible that the discontinuous record of

449 this species accounts for the inconsistency of the event. Following this event, *Retecapsa*
450 *surirella* first occurs in the bed VGL-B117M (Fig. 9). *Tubodiscus frankiae* is recorded from
451 bed 134 M. This species, which is the earliest known of the genus, has been recently
452 introduced by Bown (2005) and attributed to the NK-2A NSZ. Our record ~~if confirmed by~~
453 ~~other studies, would~~ allows to place the onset of *Tubodiscus* genus in the “*T.*” *otopeta* ASZ of
454 the Vergol section. The species *Zeughrabdotos trivectis* was found in the bed VGL-B136M at
455 the base of the “*T.*” *pertransiens* AZ. This record is shortly earlier than previously reported
456 (uppermost part of the former *Busnardoites campylotoxus* AZ, early Valanginian by Bown,
457 1998, Fig. 10); uppermost part of “*T.*” *pertransiens* AZ of the Angles section by Duchamp-
458 Alphonse et al., 2007; Fig. 11). The FO of *Staurolithites crux* is recorded at the base of “*T.*”
459 *pertransiens* AZ, in the bed VGL-B143L (L = Limestone; Fig. 9). This species was already
460 reported in the upper part of early lower Valanginian of the Vergol section (Mattioli et al.,
461 2014), as well as in the “*T.*” *otopeta* ASZ Zone of the Cañada Lengua section (Subbetic area,
462 Spain; Aguado, 1994; considered as a zone in his work), and in a single Berriasian sample
463 from Crimea (Gradstein et al., 2019). Our record at the base of the Valanginian is a very
464 confirms therefore a new datum; in fact this species was previously reported as occurring in
465 the upper Hauterivian by Bown (1998; p. 102). *Tubodiscus jurapelagicus* first occurs in the
466 bed 145M. This event was reported slightly earlier by Bralower et al. (1989; at the top of the
467 *B. calisto* ASZ; Fig. 10) and Aguado et al. (2000; *F. boissieri* AZ, *T. alpillensis* ASZ; Fig.
468 11). The FO of *Calcicalathina oblongata* is recorded in the bed VGL-B146M that
469 corresponds to the lowermost part of “*T.*” *pertransiens* AZ (Fig. 9). This record is consistent
470 with previous biostratigraphic data; in fact Bown (1998) in its synthesis of Tethyan
471 nanofossil data report it at the base of the “*T.*” *pertransiens* AZ and Bralower et al. (1989) at
472 the lowermost part of their *K. roubaudiana* AZ by means of indirect correlation of calcareous
473 nanofossil bio-horizons, magnetostratigraphy and ammonite zones (Fig. 10). Duchamp-

474 Alphonse et al. (2007) record consistently the FO of *C. oblongata* in the lowermost part of
475 “*T.*” *pertransiens* AZ of the Angles section (Fig. 11); it should be noted that the base of this
476 zone is questionably identified at Angles (see Busnardo and Thieuloy, 1979). Conversely,
477 Aguado et al. (2000) reported the FO of *C. oblongata* from the uppermost part of the “*T.*”
478 *pertransiens* AZ, but in their plates they showed a forms with a smaller average size and a
479 thicker rim, *C. praeoblongata* occurring in the *F. boissieri* AZ, *T. alpillensis* ASZ. However,
480 the pictures they illustrate of *C. praeoblongata* rather figure out a large *Rhagodiscus asper*
481 (Erba, personal communication 2019). The FO of *C. oblongata* allows the identification of the
482 top of the *C. angustiforatus* NZ. The *C. oblongata* NZ spans the entire “*T.*” *pertransiens* AZ
483 to the top of studied interval (Fig. 9). The FO of *Eiffellithus windii* is noticed in the bed VGL-
484 B150 (basal part of “*T.*” *pertransiens* AZ). This bioevent occurs later in other sections: in the
485 middle part of *K. roubaudiana* AZ for Bralower et al. (1989), in the former *B. campylotoxus*
486 AZ for Bown (1998) (Fig. 10), and in the *Olcostephanus stephanophorus* AZ (= current *N.*
487 *neocomiensiformis* AZ) of the Angles section studied by Duchamp-Alphonse et al. (2007)
488 (Fig. 11). The FO of *Tubodiscus verенаe* is also recorded at Vergol in the “*T.*” *pertransiens*
489 AZ (VGL-V1b M; Fig. 9). This event was reported in the Angles section in the
490 “*alpillensis/callisto* subzone“ by Bergen (1994; cf. text-figure 2), but later Duchamp-
491 Alphonse et al. (2007) do not show this event in the same section. Other discrepancies are
492 observed in the ranking of nannofossil events when looking at these two papers reporting on
493 the same section. The FO of *T. verенаe* is reported by Aguado et al. (2000) in the *T.*
494 *alpillensis* ASZ (Fig. 11). but Bralower et al. (1989) placed it at in an interval time-equivalent
495 of the lowermost part of *K. roubaudiana* AZ (Fig. 10). These latter authors thoroughly
496 discussed the ranking of the FOs of *T. jurapelagicus*, *T. verенаe* and *C. oblongata*. They
497 acknowledge the biostratigraphic value of these three events although their respective FOs is
498 slightly controversial. This inconsistency might be also due to the presence of early specimens

499 (likely corresponding to *T. frankiae*) in some of their studied sites. The FO of *Micrantholithus*
500 *speetonensis* is noticed in the bed VGL-V4M (“*T.*” *pertransiens* AZ; Fig. 9). This species has
501 a very short range, disappearing in the bed VLG-V31M within the “*T.*” *pertransiens* AZ. A
502 similar pattern is reported for the ~~Boreal Realm by Bown (1998)~~ north-western Europe by
503 Crux (1989), where *M. speetonensis* is used to define a total range zone spanning the
504 *Paratollia* spp. and *Polytichites* spp. AZs of England (Fig. 10). According to the inter-
505 regional correlation of zonal schemes for north-west Europe and south-east France proposed
506 by Kemper et al. (1981), these two ammonite zones would cover the uppermost Berriasian
507 (current “*T.*” *otopeta* ASZ) and nearly the whole lower Valanginian (“*T.*” *pertransiens* AZ
508 and a large part of the former *B. campylotoxus* AZ of the Mediterranean area). More recently,
509 the lower Valanginian of England has been subdivided into three ammonite zones:
510 *Peregrinoceras albidum*, *Paratollia* spp. and *Polyptichites* spp. (Rawson, 2006). Gardin in
511 Bulot et al. (1996) as well as Lakova et al. (1999) noticed this boreal, early Valanginian
512 species within the late Berriasian of the Mediterranean region. However, Duchamp-Alphonse
513 et al. (2007) reported sporadic occurrence of *M. speetonensis* in the “*T.*” *pertransiens* AZ of
514 the Angles section. ~~The FO of~~ *Staurolithites mutterlosei* is recorded in the bed VGL-V31M
515 (“*T.*” *pertransiens* AZ; Fig. 9). ~~This record allows us~~ If this record corresponded to a real FO,
516 ~~it would allows us~~ to precise the FO distribution of the species, which was previously reported
517 from an ?early Valanginian age by Bown (1998; p. 102). The LO of *Rhagodiscus nebulosus* is
518 recorded in the bed VGL-V36M. This species, which is reported to have a mid Berriasian–
519 Valanginian range by Bralower et al. (1989) has been recorded very discontinuously in the
520 Vergol section, but never observed from the interval above the “*T.*” *pertransiens* AZ
521 (Mattioli, personal observation). Aguado et al. (2000) report the last consistent record of
522 *Percivalia nebulosa* (the basionym is *Rhagodiscus nebulosus*) in the upper part of *T.*
523 *alpillensis* ASZ, but very sporadic occurrences are recorded in the “*T.*” *otopeta* ASZ.

524 Duchamp-Alphonse et al. (2007) report *R. nebulosus* in the lowermost part of the “T.”
525 *otopeta* ASZ (Fig. 11). The LO of *Helenea quadrata* is in the sample VGL-V38M (Fig. 9).
526 Although Bergen (1994) notice the LO of *Grantarhabdus quadratus* (synonym of *H.*
527 *quadrata*) in the upper Hauterivian of Angles, and Bown (1998) report a Berriasian–
528 Hauterivian range for this species, it has never been recorded later in the Valanginian of the
529 Vergol section (Mattioli, personal observation). In the uppermost part of the studied section
530 (VGL-V42M), two other distinctive *Zeugrhabdotus*, namely *Z. diplogrammus* and *Z. xenotus*,
531 are recorded in the lower part of the *N. neocomiensiformis* AZ. These two taxa are consistent
532 components of the nannofossil assemblages of the upper part of the Vergol section (upper part
533 of lower Valanginian to upper Valanginian) studied by Mattioli et al. (2014). The record of *Z.*
534 *diplogrammus* is quite consistent with the Angles section, where its FO is reported in the early
535 lower part of the *O. stephanophorus* AZ (Duchamp-Alphonse et al., 2007; Fig. 11). *Z.*
536 *diplogrammus* and *Z. xenotus* FOs are both reported by Bown (1998) in the former *B.*
537 *campylotoxus* AZ (Fig. 10).

538 In synthesis, nineteen bioevents have been recorded (Fig. 11) in the studied interval of
539 Vergol, mainly first occurrences. The majority of these bioevents occur around the
540 Berriasian–Valanginian boundary allowing its precise characterization. In spite of the fact that
541 these events may have in some cases a local extent, they allow the boundary characterization
542 at Vergol. -Figs. 10 and 11, approximatively here-

543

544 **4.3. Abundances, species richness and principal component analysis of calcareous** 545 **nannofossil assemblages**

546 In order to check if calcareous nannofossil assemblages did significantly changed across the
547 Berriasian–Valanginian boundary, a PCA using the PAST software 3.01 was applied and the
548 Shannon diversity index was calculated (Fig. 12; Table 2). PCA factor 1 receives loading on

549 positive values by *Watznaueria fossacincta*, *Biscutum constans/ellipticum*, and
550 *Diazomatolithus lehmanii* and by *W. barnesiae* on negative values. PCA factor 2 shows
551 positive loadings of *Nannoconus* and pentaliths (*Micrantholithus hoschulzii* and *M. obtusus*).
552 PCA factor 3 has *B. constans/ellipticum*, *Rhagodiscus asper* and *D. lehmanii* on positive
553 loading and *W. britannica*-*W. fossacincta* on negative loading.
554 PCA factorial scores show significant trends (Fig. 13). A temporary decrease of factor 1
555 scores occurred at the Berriasian–Valanginian boundary. A significant decrease of PCA 1 is
556 observed later in the upper part of “*T.*” *pertransiens* AZ. PCA factor 2 shows fluctuating
557 values across the studied interval but **wihout** any significant shift. For PCA factor 3, a net
558 decrease of values precisely starts at the Berriasian–Valanginian boundary. This trend mirrors
559 a parallel increase of absolute abundance values starting at the base of Valanginian. Absolute
560 abundances are largely fluctuating according to the lithologies: low abundances are recorded
561 in limestones and higher values in marlstones. In spite of this already known pattern
562 (Reboulet et al., 2003), a trend can be observed with lower values in the upper Berriasian
563 (0.01 to $0.45 * 10^9$ specimens per gram of rock) and higher values being recorded starting
564 from the “*T.*” *pertransiens* AZ ($0.01 - 1.1 * 10^9$ specimens per gram of rock). Shannon
565 diversity index displays a relevant decrease from 2.2 to 1.3 within the *T. alpillensis* ASZ,
566 followed by a return to values around 2.1 in the “*T.*” *otopeta* ASZ. **-Figs. 12 and 13,**
567 **approximately here- Table 2 in supplementary data/material-**

568

569 **5. Discussion**

570 **5.1. Characterization of the Berriasian–Valanginian boundary by an integrated** 571 **biostratigraphy of ammonites and calcareous nannofossils**

572 Blanc et al. (1994) used the integrated zonation of ammonites and calpionellids for the
573 characterization of the Berriasian–Valanginian boundary in the Vergol section. This boundary

574 has been identified by the authors at the base of the bed 210 that is marked by the FO of “*T.*”
575 *pertransiens* which is quasi-synchronous with respect to the FO of *C. darderi* recorded in the
576 bed 209. According to these authors, few meters below this bed, ammonite assemblage is
577 characterized by a Berriasian fauna (*F. boissieri* AZ, “*T.*” *otopeta* ASZ) in which occur some
578 taxa as *F. gr. boissieri*, *T. alpillensis*, “*T.*” *otopeta* and *E. paquieri*. However, taking into
579 account our new biostratigraphic data (FO of “*T.*” *pertransiens* in VGL-B136; Fig. 2A) and
580 the lithological correlations suggested in Figure 14 (bed 210 = bed VGL-V1b), the interval
581 considered by Blanc et al. (1994) as Berriasian should be dated as ~~lower~~ **early** Valanginian
582 (“*T.*” *pertransiens* AZ, *N. premolicus* ASZ, see faunal assemblage in Fig. 2A). Indeed, they
583 observed the ~~Last Occurrence~~ **LO** of “*T.*” *otopeta* in their bed 206 that corresponds to bed
584 VGL-B150 of our new log. Conversely, in our work this event is recorded in bed VGL-B135
585 (Figs. 2; 14). Thus, the stratigraphic correlation with the work of Blanc et al. (1994) indicates
586 two different ammonite assemblages for the same interval in the Vergol section. This
587 discrepancy cannot be clearly explained, but a misidentification of some taxa cannot be
588 excluded. However, most of the ammonite species, such as *T. alpillensis*, “*T.*” *otopeta* or *E.*
589 *paquieri* are relatively easy to identify, thus the risk for a misidentification of all the species
590 of this assemblage is limited. As an alternative explanation, an error in the stratigraphic
591 correlations of the Vergol sections *sensu* Kenjo (2014; this work) and *sensu* Blanc et al.
592 (1994) might have occurred. However, a 6-metre offset in the bed-by-bed correlation from
593 VGL-B135 (= LO of “*T.*” *otopeta sensu* Kenjo, 2014 and this work) to bed 206 (= LO of “*T.*”
594 *otopeta sensu* Blanc et al., 1994) cannot be probably supported. A miscalculation in the
595 construction of the section *sensu* Blanc et al. (1994) could be also invoked as different points
596 of observation are needed in the field in order to establish a continuous succession. According
597 to our correlations (Fig. 14), the bed in which Blanc (1996) recorded the FO of “*T.*” *otopeta*
598 would be the equivalent of bed VGL-B135 that corresponds in our work to the end of the

599 range of this species. As the ammonite distribution is not precisely documented by Blanc et
600 al. (1994) and Blanc (1996; where the FO of few species are only indicated), it is likely that
601 they did not make a bed-by-bed sampling for macrofauna (but this does not explain the
602 occurrence of “*T.*” *otopeta* above bed VGL-B135 up to bed VGL-B150 **observed** by these
603 authors). Moreover, the highest probability to find this species during its acme (VGL-B128-
604 129; Figs. 2; 14) was not possible for these authors as their **log of the Vergol** section is not
605 continuous (gap) around this event. **-Fig. 14, approximatively here-**

606 The analysis of calcareous nannofossils seems to confirm that the interval just below the bed
607 210 (= VGL-V1b), can be dated as **lower early** Valanginian (Kenjo, 2014, this work) and not
608 as **upper late** Berriasian as proposed by Blanc et al. (1994). Indeed, the FO of *C. oblongata* is
609 observed in the bed VGL-B146M (Figs. 7, 14) and its appearance is typical for the lower part
610 of Valanginian. **This** species has systematically been recorded in the basal Valanginian
611 (Thierstein, 1971; Sissingh, 1977; Perch-Nielsen, 1985; Bralower et al., 1989; Bown, 1998),
612 even though Aguado et al. (2000) reported a *C. praeoblongata* from the upper Berriasian and
613 *C. oblongata* from the upper part of the “*T.*” *pertransiens* AZ of SE Spain.

614 Few papers present a detailed comparison between ammonite and nannofossil biostratigraphy
615 for the Berriasian–Valanginian boundary. A comparison is made here (Fig. 11) between the
616 Vergol section and other sections located in the Vocontian basin (Angles, Duchamp-Alphonse
617 et al., 2007) and in SE Spain (several localities, Aguado et al., 2000). The ammonite zonation
618 used by Duchamp-Alphonse et al. (2007) comes from Bulot and Thieuloy (1995; **it is**
619 **noticeable that, in the Angles section, these latter authors only provide biostratigraphic data**
620 **around the lower (*Karakaschiceras inostranzewi* AZ)–upper (*Saynoceras verrucosum* AZ)**
621 **Valanginian boundary interval**); this zonation presents some differences with respect to the
622 one used in the present work. In ~~their paper~~ **Duchamp-Alphonse et al. (2007)**, the uppermost
623 Berriasian is characterized by the *T. alpillensis* and “*T.*” *otopeta* ASZ (*F. boissieri* AZ *p.p.*)

624 that have been recognized in our *T. alpillensis* AZ. Even if the *Kilianella thieuloyi* ASZ
625 ~~Ammonite Horizon (sensu Bulot and Thieuloy, 1995); presented as an Ammonite Subzone in~~
626 ~~the Angles section by Duchamp-Alphonse et al., 2007)~~ has not been recognized in the upper
627 part of the “*T.*” *otopeta* ASZ in the Vergol section, the conception of the base of this latter
628 ammonite subzone is not changed as it is an interval subzone defined by the ~~FO~~ FAD of the
629 index-species. Duchamp-Alphonse et al. (2007) placed the base of the Valanginian stage at
630 the base of the “*T.*” *pertransiens* AZ in the Angles section, using the same criteria as those
631 applied to the Vergol section (Kenjo, 2014; this work). The base of the *O. stephanophorus* AZ
632 (Bulot and Thieuloy, 1995) can be correlated with the base of the *N. neocomiensiformis* AZ
633 (see explanations in Reboulet et al., 2014). Aguado et al. (2000) also used the *T. alpillensis*
634 and “*T.*” *otopeta* ASZ (*F. boissieri* AZ *p.p.*) and the “*T.*” *pertransiens* AZ to establish the
635 zonal schemes in the sections they studied in Spain. These authors supported the proposal of
636 the 1995 Brussels meeting (Bulot et al., 1996) to define the base of the Valanginian Stage at
637 the FAD of *C. darderi*; they observed that the FO of this index-species practically coincides
638 with the FO of “*T.*” *pertransiens*. Consequently, the zonal schemes used by Aguado et al.
639 (2000) and Duchamp-Alphonse et al. (2007) can be easily correlated with the zonal scheme of
640 the Vergol section (Kenjo, 2014; this work). The distributions of species having a
641 biostratigraphic interest in the Vergol (Kenjo, 2014; this work) and Spanish (Aguado et al.,
642 2000) sections are very similar as far as the interval around the Berriasian–Valanginian
643 boundary is concerned. In both areas, the disappearances of “*T.*” *otopeta*, *F. boissieri*, *B.*
644 *callisto*, *E. paquieri*, *T. alpillensis* and *Leptoceras* occur in the “*T.*” *otopeta* ASZ (mainly in
645 its upper part); also the appearances of “*T.*” *pertransiens*, “*T.*” *gratianopolitense*, *N.*
646 *premolicus*, *K. roubaudiana* occur in the lowermost part of the “*T.*” *pertransiens* AZ.
647 Ammonite distribution is not shown for Angles by Bulot and Thieuloy (1995) and Duchamp-
648 Alphonse et al. (2007) for the interval around the Berriasian–Valanginian boundary.

649 Concerning the nannofossil zones, Duchamp-Alphonse et al. (2007) and Aguado et al. (2000)
650 used the Bralower et al. (1989) biostratigraphical scheme, which was also applied in the
651 present work. The uppermost Berriasian corresponds in the three papers to the *C.*
652 *angustiforatus* NZ. The lower boundary of *C. oblongata* NZ corresponds to the lower part of
653 the “*T.*” *pertransiens* AZ in Vergol (this work) and Angles sections (Duchamp-Alphonse et al.,
654 2007), but *C. oblongata* is recorded later in the upper part of the “*T.*” *pertransiens* AZ in SE
655 Spain (Aguado et al., 2000). This difference is probably related to the introduction of a new
656 form (Aguado et al., 2000) morphologically similar to *C. oblongata* but with more primitive
657 characters; this new species has been named *C. praeoblongata*. Aguado et al. (2000) found *C.*
658 *praeoblongata* in the lower part of their *T. alpillensis* ASZ. The pictures of *C. praeoblongata*
659 shown by Aguado et al. (2000, fig. 8, pictures 28-33) look like overgrown specimens of *R.*
660 *asper* (Erba, personal communication 2019). Thus, the discrepant range of *C. oblongata* in SE
661 France and SE Spain could be related to different taxonomical concepts.

662 Some discrepancies have been observed between these three works. The FO of *T.*
663 *jurapelagicus* has been placed in the upper Berriasian (*T. alpillensis* ASZ, *A. infracretacea*
664 NSZ) in SE Spain, but in Vergol this species appears just below *C. oblongata*. The same
665 pattern has been observed for *T. verenae* recorded in the basal Valanginian (“*T.*” *pertransiens*
666 AZ; *C. oblongata* NZ) in Vergol and, conversely, reported from the upper Berriasian (*T.*
667 *alpillensis* ASZ) and matching with the FO of *P. fenestrata* in Aguado et al. (2000). The
668 relationships between the FOs of *T. jurapelagicus*, *C. oblongata* and *T. verenae* have been
669 thoroughly discussed by Bralower et al. (1989) who observed some discrepancies in the
670 sections/cores they studied. A part of the problem is the occurrence of earlier transitional
671 forms (Bralower et al., 1989), which likely correspond to *T. frankiae* (a slightly smaller form)
672 which was introduced by Bown (2005) and considered in the present work.

673 Another difference between the present paper and previous literature is the occurrence of *P.*
674 *nebulosa*/*R. nebulosus*, which last occurred in the *P. fenestrata* NSZ in the Angles section
675 (Duchamp-Alphonse et al., 2007) and SE Spain (Aguado et al., 2000), but its LO is recorded
676 much later in the *C. oblongata* NZ (early Valanginian) in Vergol. Likely, this later record has
677 related to the very discontinuous and rare occurrence of *R. nebulosus*.

678 The comparison between our work with earlier similar works, like Aguado et al. (2000) or
679 Duchamp-Alphonse et al. (2007), indicates that calcareous nannofossil bioevents recorded in
680 the present work characterize very finely the interval Berriasian–Valanginian, because a
681 number of calcareous nannofossil events have recorded around the Berriasian–Valanginian
682 boundary in Vergol section (Fig. 9).

683 Furthermore, the PCA analysis compared to absolute abundance and Shannon diversity index
684 point to an important change in nannofossil assemblage composition and abundance starting
685 at the biostratigraphic boundary as defined by ammonites. PCA factors indicate a prominent
686 change occurring in correspondence of the Berriasian–Valanginian boundary, with factor 1
687 showing an excursion encapsulating the boundary, while factor 3 reveals a longer-term
688 decrease and steady values in the rest of Valanginian. Assemblages from the lower
689 Valanginian are richer both in terms of diversity and of absolute abundances. Following such
690 an enrichment, values stay quite steady although fluctuating for the rest of the lower
691 Valanginian (this work; Mattioli et al., 2014). The understanding of the palaeoenvironmental
692 reasons explaining such a change in calcareous nannofossil assemblage are behind the scope
693 of the present work, because other independent proxies (such as carbon or oxygen stable
694 isotopes, total organic matter content, etc.) are not yet available to discriminate between the
695 influence of palaeoenvironmental parameters, such as surface water fertility or temperature
696 controlling nannofossil assemblages. Also, the observed changes might be due to evolutionary
697 patterns, as the Berriasian–Valanginian saw the new entry of several coccolith species.

698 However, if confirmed in other areas this lower Valanginian change in nannofossil
699 assemblages may represent a further argument to differentiate the Berriasian from the
700 Valanginian as proposed in the present work.

701

702 **5.2. Discussion on the choice of the primary marker and the candidate section for the** 703 **Valanginian GSSP**

704 As previously stated, in Spain (Company and Tavera, 1982; Aguado et al., 2000) and France
705 (Blanc et al., 1994; Blanc, 1996) the base of *Calpionellites* zone E (FO of *C. darderi*)
706 coincides with the base of the “*T.*” *pertransiens* AZ (FO of this index-species). However,
707 Aguado et al. (2000) noticed some discrepancies in the compared distribution of these
708 ammonite and calpionellid species as the FO of *C. darderi* reported at a much higher
709 stratigraphic level in the Miravetes succession (Rio Argos area, SE Spain, see Hoedemaeker
710 and Leereveld, 1995); according to Aguado et al. (2000), this could be due to problems of
711 preservation of calpionellids in this section. Biostratigraphic remarks on the compared
712 distribution of both these species could be also made for two classical sections of the
713 Vocontian basin, namely Barret-le-Bas and Angles sections (for the Vergol section, see part
714 5.1). According to Blanc (1996), *C. darderi* first occurs just two beds above the FO of “*T.*”
715 *pertransiens* in the Barret-le-Bas section; however, just below these both events there is a
716 slump of 15 m thick that does not allow to have data on ammonite and calpionellid
717 distributions. It should be also noted that the specimen identified as “*T.*” *pertransiens* by
718 Busnardo and Thieuloy (1979, fig. 13) and occurring in bed number “-1” (bed below the
719 slump) was not indicated in Bulot (1995, fig. 3). In the Angles section, Allemann and Remane
720 (1979, fig. 29) observed the FO of *C. darderi* slightly above the bed number 220; this event
721 was noticed lower in the succession by Bulot (1995, fig. 53) who put the FO of this species in
722 bed number 207. In this section, the distribution of “*T.*” *pertransiens* was not given (Busnardo

723 and Thieuloy, 1979; Bulot, 1995); as noted by Blanc (1996), the interval around the
724 Berrisian–Valanginian boundary is very poor in ammonites. Consequently, ~~there is not a good~~
725 ~~continuous~~ the fossil record is not well documented in this interval of the Barret-le-Bas (cf.
726 slump) and Angles (cf. rarity of ammonites) sections ~~this which~~ do not allow to provide
727 robust results for the discussion on the synchronism of *C. darderi* versus “*T.*” *pertransiens*.
728 As far as the Vergol section is concerned, the ~~FADs FOs~~ of *C. darderi* and “*T.*” *pertransiens*
729 are considered as being almost synchronous, occurring in beds 209 and 210, respectively
730 (Blanc et al., 1994) or beds MB210 and MB211, respectively (Blanc, 1996). Blanc et al.
731 (1994) proposed the Montbrun-les-Bains (Vergol) section as a potential boundary stratotype
732 between the Berriasian and Valanginian stages, and they proposed to put the golden spike at
733 the base of bed 210 in which they recorded the FO of “*T.*” *pertransiens*. However, the
734 provisional recommendation of the Valanginian Working Group (Bulot et al., 1996) was to
735 place the boundary at the base of *Calpionellites* Zone E (FAD of *C. darderi*, bed 209 in the
736 candidate section, Blanc et al., 1994). Compared to the ammonite “*T.*” *pertransiens*, the
737 working group emphasized the broader geographic distribution of the calpionellid index-
738 species (recorded from Mexico to Turkey). In the Geologic Time Scale 2016 (Ogg et al.,
739 2016), the proposed Valanginian GSSP marker is the FAD of *C. darderi* (base of
740 *Calpionellites* Zone E). However, if *C. darderi* has a wider palaeogeographic distribution than
741 “*T.*” *pertransiens*, it seems that the occurrence and abundance of this calpionellid species is
742 more dependant on the preservation effect, as observed by Aguado et al. (2000) for some
743 Spanish sections ~~and reiterated in the Geologic Time Scale 2012 (Ogg et al., 2012)~~. In SE
744 France, Allemann and Remane (1979) reported that Valanginian calpionellid faunas of the
745 Vocontian basin were impoverished compared to that of “South Mediterranean area” (see also
746 Le Hégarat in Cotillon et al., 1984) and they stressed out the scarcity of *C. darderi* although
747 its earliest occurrence can be recorded if numerous fields of view are studied. When Bulot et

748 al. (1993a) described the evolution of calpionellids, they stated that no important turnovers
749 occurred at the Berriasian–Valanginian boundary and that “*Lorenziella hungarica*, whose first
750 appearance defines the base of D3, **remains always rare**. The same **is true as** for *C. darderi*
751 (base of zone E)”.

752 Taking into account the ammonite data and the correlations proposed in this work (Fig. 14),
753 the FO of “*T.*” *pertransiens* (VGL-B136) occurs around 7 m below the FO of *C. darderi*
754 (VGL-V1). Contrarily to the observations of Blanc et al. (1994; see also Blanc, 1996), these
755 two bioevents are not synchronous in the Vergol section. If priority is given to the FAD of *C.*
756 *darderi* to define the base of the Valanginian, then the base of the “*T.*” *pertransiens* AZ
757 (currently considered as the earliest zone of the Valanginian) would be placed in the upper
758 Berriasian. Two options stay possible.

759 First, it can be considered that it is not problematic to have the lower part of the historical
760 Valanginian “*T.*” *pertransiens* AZ in the late Berriasian and that the earliest zone of the
761 Valanginian overlaps the Berriasian–Valanginian boundary, because this would be defined by
762 another group, namely the calpionellids. A similar case can be cited with the Albian–
763 Cenomanian boundary. The base of the Cenomanian stage (ratified GSSP at Mont Risou,
764 Hautes-Alpes, France, Kennedy et al., 2004) is defined by the FAD of *Rotalipora*
765 *globotruncanoides* (foraminifera). This event occurs in the upper part of the former
766 *Arrhaphoceras briacensis* ASZ, now considered as a zone (Reboulet et al., 2011). Thus, this
767 last unit of the Albian zonal scheme is Albian in age for its lower part and Cenomanian in age
768 for its uppermost part.

769 As a second solution, adopted here, the base of the Valanginian is defined by the FAD of “*T.*”
770 *pertransiens*. This species has a large distribution and it is relatively well represented in the
771 Mediterranean Province of the Mediterranean–Caucasian Subrealm (Tethyan Realm;
772 Company, 1987; Bulot, 1995; Klein, 2005; Kenjo, 2014). The base of the “*T.*” *pertransiens*

773 AZ coincides with a significant ammonite faunal renewal (further details in Kenjo, 2014;
774 Company and Tavera, 2015; this work). According to ammonite and calcareous nannofossil
775 data provided by Kenjo (2014) and this work, the Berriasian–Valanginian boundary is also
776 well-characterized by the FO of the ammonite *N. premolicus* (bed VGL-B141; Fig. 2A) and
777 the FO of the calcareous nannofossil *C. oblongata* (VGL-B146M, Fig. 9). Both bioevents are
778 recorded respectively only 2 and 4 m above the FO of “*T.*” *pertransiens* (bed VGL-B136) in
779 the candidate section. *N. premolicus* was used to recognize and/or characterize the base of the
780 Valanginian in some areas of the Mediterranean Province (Ettachfini, 2004; Kenjo, 2014;
781 Company and Tavera, 2015) and *C. oblongata* is consistently recorded in the lowermost part
782 of “*T.*” *pertransiens* AZ (Bralower et al., 1989; Bulot et al., 1996; Bown, 1998; Duchamp-
783 Alphonse, 2007; Kenjo, 2014; this work). The choice of an ammonite index-species is also
784 motivated by a pragmatic approach. The base of Phanerozoic stages is often defined by
785 biologic markers (GSSP table of ICS, <http://www.stratigraphy.org/index.php/ics-gssps>) that
786 are ammonites for all stages of the Jurassic **System Period** (ratified GSSPs or proposals in
787 progress for other stages). Indeed, for this period and also for Cretaceous, studies on
788 ammonites generally provides the highest biostratigraphical resolution of stages to establish
789 their subdivision and define their base. Consequently, [taking into account that “*T.*”](#)
790 [pertransiens has a large palaeogeographic distribution allowing a good correlation](#), a priority
791 is given here to ammonite biostratigraphic data in order to make a good and workable
792 correspondence in the subdivision of the Valanginian Stage (ammonite (sub-)zones) and the
793 definition of its base (the base of the Valanginian corresponds to the base of the earliest zone,
794 namely the “*T.*” *pertransiens* AZ).

795 Taking into account previous synthetic studies (Birkelund et al., 1984; Bulot et al., 1996; Ogg
796 et al., 2016), ammonites, calpionellids and calcareous nannofossils, are the three main groups
797 that can be used to define the Berriasian–Valanginian boundary. According to Ogg et al.

798 (2012), the age model for the Berriasian–Barremian ammonite zonal scheme is mainly
799 derived from correlations to the M-sequence of marine magnetic anomalies, linearization of
800 strontium isotope trends, and/or cycle stratigraphy. Concerning the magnetostratigraphy, the
801 previous sampling made on the Vergol section has not allowed to provide significant
802 geomagnetic reversals (Blanc, 1996; Bulot et al., 1996). For the other candidate GSSP section
803 at Barranco de Cañada Luenga (south of Cehegin, SE Spain), a direct calibration of
804 magnetostratigraphic reversals against biostratigraphic scales was proposed. In order to
805 recognize and characterize the Valanginian Weissert Event in SE France, **stable** isotopic data
806 (oxygen and carbon isotope curves) are relatively abundant for the Vergol section from the
807 middle part of the lower Valanginian (*N. neocomiensiformis* AZ) to the middle part of the
808 upper Valanginian (*Neocomites peregrinus* AZ; McArthur et al., 2007; Gréselle et al., 2011;
809 Kujau et al., 2012). However, data are scarcer for the interval around the Berriasian–
810 Valanginian boundary (McArthur et al., 2007). These last authors also provided $^{87}\text{Sr}/^{86}\text{Sr}$
811 trends that enable global correlation and relative dating, but the curve was also built with
812 isotopic data coming from different sections. In Vergol, the interval from the uppermost
813 Berriasian (*T. alpillensis* AZ) to the middle part of the upper Valanginian (*N. peregrinus* AZ)
814 has been scaled using astronomically-forced cycle stratigraphy, especially using the long-term
815 eccentricity cycles (medium-scale sequences to 405-kyr) and short-term eccentricity cycles
816 (small-scale sequences to 100-kyr; Gréselle et al., 2011; Martinez et al., 2013). Based on an
817 integrated stratigraphy of the Vergol-la Charce (Drôme) and Reynier-Angles (Alpes-de-Haute
818 Provence) composite sections from the Vocontian basin, Martinez et al. (2013) suggested a
819 duration of 5.08 Ma for the Valanginian stage. After an astrochronological study of the
820 Hauterivian Stage and using new radiometric ages extracted from tuff levels in the middle
821 Hauterivian in the Neuquén Basin (Argentina), Martinez et al. (2015) calculated an age of
822 137.05 ± 1.0 Ma for the base of the Valanginian Stage.

823 The interest of these studies on the Vergol locality is mainly due to a very good sedimentary
824 record for the uppermost Berriasian–lowermost Valanginian interval (Fig. 2). This succession
825 made of a calcareous-marl alternation is more expanded than the Cañada Luenga section, at
826 least for the interval around the Berriasian–Valanginian boundary. Indeed, in this Spanish
827 section, the stratigraphic interval dated from the “*T.*” *otopeta* ASZ is composed of 5 beds for a
828 2-m-thick interval (see fig. 5 in Aguado et al., 2000); in the Vergol section (Fig. 2A), the
829 interval corresponding to the “*T.*” *otopeta* ASZ is composed by 20 beds for a 8-m-thick
830 interval (or at least 15 beds for 6 m, if the specimen from bed VGL-B116 identified with
831 doubt as “*T.*” *otopeta* is not considered as the FO of this index-species). In the Cañada Luenga
832 section, the stratigraphic interval dated from the “*T.*” *pertransiens* AZ is composed of 20 beds
833 for a 13-m-thick interval (see fig. 2 in Company and Tavera, 2015); in the Vergol section
834 (Fig. 2A), the interval corresponding to the “*T.*” *pertransiens* AZ is composed by 53 beds
835 (and most of them are composed of 2 or 3 layers) for a 30-m-thick interval. Thus, as far as
836 these intervals are concerned, the Vergol section is around 2.5 times thicker than the Cañada
837 Luenga section. The limited thickness of the Cañada Luenga section with respect to Vergol
838 might explain the co-occurrence of “*T.*” *pertransiens* and *C. darderi* in the same layer. A
839 similar assumption can be made to explain their co-occurrence in Bulgaria (Petrova et al.,
840 2011) in the Barlya section for which the whole lower Valanginian is around 30 m thick with
841 respect to Vergol where the substage is represented by a succession of 108 m thick. It cannot
842 be excluded that *C. darderi* occurred lower in the Vergol section (from bed VGL-B136 to
843 VGL-B151) along with the earliest “*T.*” *pertransiens*. However, as previously discussed for
844 some Spanish sections, the lack of *C. darderi* in this interval might also be related to a
845 preservation effect.

846 For the purposes of the Valanginian GSSP proposal (chairs M. Company and S. Reboulet), a
847 new study on calpionellid distribution is in preparation on the Vergol section in order to check

848 the hypothesis evoked previously. Concerning the magnetostratigraphy, a second attempt
849 using a different method should be made in order to calibrate magnetic reversals against
850 biostratigraphy.

851

852 **6. Conclusions**

853 A quantitative palaeontological study of ammonites and calcareous nannofossils was
854 performed in the Vergol reference section (Montbrun-les-Bains, SE France, Vocontian basin),
855 in order to refine the previously proposed biostratigraphic frame for the interval around the
856 Berriasian–Valanginian boundary. The analysis of the ammonite distributions shows a major
857 turnover and allowed the establishment of a detailed zonal scheme; it corresponds to the
858 standard zonation built for the Mediterranean Province of the Mediterranean–Caucasian
859 Subrealm (Tethyan Realm) that is partly based on ammonite data from the Vergol section
860 (Kenjo, 2014; Reboulet et al., 2018; this work). The FAD of *T. alpillensis* allows the definition
861 of the base of the latest Berriasian zone that is subdivided into *T. alpillensis* and “*T.*” *otopeta*
862 ASZs. The earliest Valanginian zone is defined by the FAD of “*T.*” *pertransiens*; the
863 appearance of *N. premolicus* can also be used to recognize the base of this zone. The lower
864 boundary of *C. oblongata* NZ corresponds to the lower part of the “*T.*” *pertransiens* AZ. The
865 interval around the Berriasian–Valanginian boundary is also characterized by other bioevents
866 of calcareous nannofossil species, mainly first occurrences, but also by a prominent change in
867 the assemblage composition and an increase in absolute abundance.

868 The comparison with the work of Blanc et al. (1994) and Blanc (1996) points to some
869 discrepancies in ammonite bioevents and the lower boundary of “*T.*” *pertransiens* AZ must
870 therefore be moved downwards in the section (around 7 m below) with respect to the
871 boundary proposed by these authors. So, contrarily to their assertion, it seems that the FO of
872 “*T.*” *pertransiens* is not synchronous with the FO of *C. darderi* that is the index-species for

873 the base of the Valanginian Stage as provisionally recommended by the Valanginian Working
874 Group (Bulot et al., 1996). Taking into account that ammonite and calcareous nannofossil
875 bioevents allow a precise characterization of the Berriasian–Valanginian boundary (*sensu*
876 Kenjo, 2014; this work) and that some studies are still in progress on the Vergol candidate
877 section for the Valanginian GSSP (cf. proposal), the choice has been made to **identify define**
878 the base of the stage by using the FAD of “*T.*” *pertransiens*, index-species of the first current
879 Valanginian AZ. ~~that~~ **This** corresponds to the historical definition of the boundary *sensu*
880 Kilian (1910) and Mazonot (1939).

881

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888

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1273

1274 **Appendix A - Taxonomic list of ammonites**

1275 Perisphinctoidea STEINMANN

1276 Neocomitidae SALFELD

1277 Berriasellinae SPATH

1278 *Berriasella* UHLIG; considered as a subgenus of *Berriasella* according to Klein

1279 (2005, p. 163)

1280 *Berriasella calisto* (D’ORBIGNY)

1281 *Berriasella picteti* (KILIAN)

1282 *Malbosiceras* GRIGORIEVA

1283 *Malbosiceras paramimounum* (MAZENOT)

1284 Neocomitinae SALFELD

1285 *Fauriella* NIKOLOV

1286 *Fauriella boissieri* (PICTET)

1287 “*Fauriella*” *kiliani* BULOT (*nomen nudum*)

- 1288 *Erdenella* NIKOLOV
- 1289 *Erdenella paquieri* (SIMIONESCU)
- 1290 *Tirnovella* NIKOLOV
- 1291 *Tirnovella alpillensis* (MAZENOT)
- 1292 “*Thurmanniceras*” COSSMANN; the inverted commas indicate that the assignment of
- 1293 the species to that genus is provisional and they await revision (Kenjo, 2014;
- 1294 Reboulet et al., 2014; Company and Tavera, 2015)
- 1295 “*Thurmanniceras*” *gratianopolitense* (SAYN); included in *Fauriella* according to
- 1296 Klein (2005, p. 262)
- 1297 “*Thurmanniceras*” *otopeta* THIEULOUY
- 1298 “*Thurmanniceras*” *pertransiens* (SAYN)
- 1299 “*Thurmanniceras*” *thurmanni* (PICTET & CAMPICHE)
- 1300 *Neocomites* UHLIG; considered as a subgenus of *Neocomites* according to Klein
- 1301 (2005, p. 304)
- 1302 *Neocomites neocomiensiformis* (UHLIG); included in *Busnardoites*? According to
- 1303 Klein (2005, p. 323)
- 1304 *Neocomites neocomiensis* (D’ORBIGNY)
- 1305 *Neocomites peregrinus* (RAWSON & KEMPER)
- 1306 *Neocomites premolicus* SAYN
- 1307 *Kilianella* UHLIG
- 1308 *Kilianella lucensis* (SAYN)
- 1309 *Kilianella roubaudiana* (D’ORBIGNY)
- 1310 *Kilianella thieuloyi* BULOT (nomen nudum)
- 1311 *Sarasinella* UHLIG
- 1312 *Sarasinella ambigua* (UHLIG)

- 1313 *Sarasinella eucyrta* (SAYN)
- 1314 *Luppovella* NIKOLOV; considered as a subgenus of *Luppovella* according to Klein
- 1315 (2005, p. 294)
- 1316 *Luppovella superba* (SAYN)
- 1317 *Busnardoites* NIKOLOV
- 1318 *Busnardoites campylotoxus* (UHLIG)
- 1319 *Karakaschiceras* THIEULOY
- 1320 *K. inostranzewi* (KARAKASCH)
- 1321 Olcostephanidae HAUG
- 1322 Spiticeratinae SPATH
- 1323 *Spiticeras* UHLIG
- 1324 *Spiticeras multiforme* DJANÉLIDZÉ
- 1325 Olcostephaninae HAUG
- 1326 *Olcostephanus* NEUMAYR
- 1327 *Olcostephanus josephinus* (D'ORBIGNY)
- 1328 *Olcostephanus stephanophorus* (MATHERON)
- 1329 *Olcostephanus tenuituberculatus* BULOT
- 1330 *Saynoceras* MUNIER-CHALMAS
- 1331 *Saynoceras verrucosum* (D'ORBIGNY)
- 1332 Polyptychitidae WEDEKIND
- 1333 *Paratollia* CASEY
- 1334 *Peregrinoceras* SAZONOVA
- 1335 *Peregrinoceras albidum* CASEY
- 1336 *Polychtichites* PAVLOW
- 1337 Haploceratoidea VON ZITTEL

- 1338 Haploceratidae VON ZITTEL
- 1339 *Neolissoceras* SPATH
- 1340 *Neolissoceras grasianum* (D'ORBIGNY)
- 1341 *Neolissoceras* (*Vergoliceras*) ATROPS & REBOULET; *Vergoliceras* is considered as a
- 1342 genus according to Klein et al. (2009, p. 263)
- 1343 *Neolissoceras* (*Vergoliceras*) *salinarium* (UHLIG)
- 1344 *Neolissoceras* (*Vergoliceras*) *extracornutum* (CECCA)
- 1345 Lytoceratoidea NEUMAYR
- 1346 Lytoceratidae NEUMAYR
- 1347 Lytoceratinae NEUMAYR
- 1348 *Lytoceras* SUESS; as underlined by Klein et al. (2009, p. 134 and appendix n°18, p.
- 1349 310), *Protetragonites* is probably a subjective synonym of *Lytoceras*)
- 1350 *Lytoceras honnoratianum* (D'ORBIGNY); included in *Protetragonites* according to
- 1351 Klein et al. (2009, p. 139)
- 1352 *Lytoceras quadrisulcatum* (d'ORBIGNY); included in *Protetragonites* according
- 1353 to Klein et al. (2009, p. 142)
- 1354 Phylloceratoidea VON ZITTEL
- 1355 Phylloceratidae VON ZITTEL
- 1356 Phylloceratinae VON ZITTEL
- 1357 *Phylloceras* (*Hypophylloceras*) SALFELD
- 1358 *Phylloceras* (*Hypophylloceras*) *tethys* (D'ORBIGNY)
- 1359 Ptychophylloceratinae COLLIGNON
- 1360 *Ptychophylloceras* (*Semisulcatoceras*) JOLY
- 1361 *Ptychophylloceras* (*Semisulcatoceras*) *semisulcatum* (D'ORBIGNY)
- 1362 Calliphylloceratinae SPATH

- 1363 *Holcophylloceras* SPATH
- 1364 *Holcophylloceras silesiacum* (OPPEL)
- 1365 Bochianitoidea SPATH
- 1366 Bochianitidae SPATH
- 1367 *Bochianites* LORY
- 1368 *Bochianites neocomiensis* (D'ORBIGNY)
- 1369 Protancyloceratoidea BREISTROFFER
- 1370 Protancyloceratidae BREISTROFFER
- 1371 *Leptoceras* UHLIG
- 1372 *Protancyloceras* SPATH
- 1373 Hoplitoidea DOUVILLÉ
- 1374 Hoplitidae DOUVILLÉ
- 1375 Hoplitinae DOUVILLÉ
- 1376 *Arrhaphoceras briacensis* SCHOLZ
- 1377
- 1378 **Appendix B - Taxonomic list and remarks on calcareous nannofossils**
- 1379 *Axopodorhabdus dietzmannii* Reinhardt, 1965
- 1380 *Anfractus harrisonii* (Medd, 1979)
- 1381 *Assipetra terebrodentarius* (Applegate et al. in Covington and Wise, 1987) Rutledge and
- 1382 Bergen in Bergen, 1994
- 1383 *Biscutum constans* (Górka, 1957) Black in Black and Barnes, 1959
- 1384 *Biscutum ellipticum* (Gorka, 1957) Grün in Grün and Allemann, 1975. This form is
- 1385 considered the synonym of *B. constans*
- 1386 *Calcicalathina oblongata* (Worsley, 1971) Thierstein, 1971. Some authors reported
- 1387 *Calcicalathina erbae* Bergen, 1998 (synonym of *Calcicalathina* sp. A Bergen, 1994 and of

1388 *Calcicalathina praeoblongata* Aguado et al., 2000) from the base of the Berriasian.

1389 *Calcicalathina praeoblongata*, which must be considered as a younger synonym of *C. erbae*

1390 Bergen 1984, is described as being smaller than *Calcicalathina oblongata* and having a wider

1391 rim. *Calcicalathina erbae* is described as a species of *Calcicalathina* with a low central area.

1392 According to the pictures shown (Aguado et al., 2000 fig. 8, plates 29-33; Bergen, 1994 pl. 1,

1393 fig. 11a, b; Bergen, 1998 pl. 1, figs 28, 29), we consider these specimens as very overgrown

1394 *Rhagodiscus asper* rather than as *Calcicalathina*. In fact, the diagnostic feature of

1395 *Calcicalathina* is to possess a high wall and a central area structure which rises above the

1396 distal margin of the wall forming a dome-like structure. Bergen (1998) describes *C. erbae* as a

1397 species of *Calcicalathina* “with a low central area”, which is not consistent with the genus

1398 diagnosis. The specimens of *C. praeoblongata* figured by Aguado et al. (2000) have a low

1399 wall (better corresponding to the genus *Rhagodiscus*) and central area structures which do not

1400 rise above the wall. Also, Bergen (1998) states that overgrown specimens of *Rhagodiscus* can

1401 be confused with *Calcicalathina erbae*. This may explain the earlier record (Berriasian) of

1402 these forms, namely *C. erbae* and *C. praeoblongata*, with respect to true *C. oblongata* (base

1403 of Valanginian).

1404 *Conusphaera mexicana* subsp. *mexicana* (Trejo, 1969)

1405 *Conusphaera rothii* (Thierstein, 1971) Jakubowski, 1986

1406 *Cretarhabdus conicus* Bramlette & Martini, 1964

1407 *Cretarhabdus inaequalis* Crux, 1987

1408 *Crucielipsis cuvillieri* (Manivit, 1966) Thierstein, 1971

1409 *Cyclagelosphaera margerelii* Noël, 1965

1410 *Discorhabdus ignotus* (Górka, 1957) Perch-Nielsen, 1968. This is considered here as the same

1411 species as *D. rotatorius* of some authors (e.g., Erba et al., 2004)

1412 *Diadorhombus rectus* Worsley, 1971

- 1413 *Diazomatolithus lehmanii* Noël, 1965
- 1414 *Diazomatolithus subbeticus* Grün, 1975
- 1415 *Ethmorhabdus hauterivianus* (Black, 1971) Applegate et al. in Covington and Wise, 1987
- 1416 *Eiffellithus windii* Applegate and Bergen, 1988
- 1417 *Helenea chiastia* Worsley, 1971
- 1418 *Helenea quadrata* (Worsley, 1971) Rutledge and Bown in Bown et al., 1998
- 1419 *Haqius circumradiatus* (Stover, 1966) Roth, 1978. This taxa is found very overgrown in
- 1420 Vergol
- 1421 *Haqius ellipticus* (Grün in Grün and Allemann, 1975) Bown, 1992 emend. Bown, 2005
- 1422 *Kokia curvata* Perch-Nielsen, 1988
- 1423 *Micrantholithus hoschulzii* (Reinhardt, 1966) Thierstein, 1971
- 1424 *Micrantholithus obtusus* Stradner, 1963
- 1425 *Micrantholithus speetonensis* Perch-Nielsen, 1979
- 1426 *Nannoconus bermudezii* Brönnimann, 1955
- 1427 *Nannoconus broennimanni* Trejo, 1959
- 1428 *Nannoconus bucheri* Brönnimann, 1955
- 1429 *Nannoconus colomi* Kamptner, 1938
- 1430 *Nannoconus dolomiticus* Cita and Pasquare, 1959
- 1431 *Nannoconus globulus* subsp. *globulus* Brönnimann, 1955
- 1432 *Nannoconus globulus* subsp. *minor* (Brönnimann, 1955) Bralower in Bralower et al., 1989
- 1433 *Nannoconus inornatus* Rutledge and Bown, 1996
- 1434 *Nannoconus kamptneri* subsp. *minor* (Brönnimann, 1955) Bralower in Bralower et al., 1989
- 1435 *Nannoconus kamptneri* subsp. *kamptneri* Brönnimann, 1955
- 1436 *Nannoconus oviformis* Perch-Nielsen, 1988
- 1437 *Nannoconus quadratus* (Noël 1959) Deres and Achéritéguy 1980

- 1438 *Nannoconus steinmannii* subsp. *steinmannii* Kamptner, 1931
- 1439 *Nannoconus steinmannii* subsp. *minor* (Kamptner, 1931) Deres and Achéritéguy, 1980
- 1440 *Nannoconus wintereri* Bralower & Thierstein, 1989
- 1441 *Percivalia fenestrata* (Worsley, 1971) Wise, 1983
- 1442 *Retecapsa angustiforata* Black, 1971
- 1443 *Retecapsa octofenestrata* Bralower in Bralower et al., 1989
- 1444 *Retecapsa surirella* (Deflandre and Fert, 1954) Grün in Grün and Allemann, 1975
- 1445 *Rhagodiscus asper* (Stradner, 1963) Reinhardt, 1967
- 1446 *Rhagodiscus gallagheri* (Rutledge and Bown, 1996)
- 1447 *Rhagodiscus nebulosus* (Bralower in Bralower et al., 1989)
- 1448 *Rhagodiscus pseudoangustus* (Crux, 1987)
- 1449 *Rucinolithus wisei* (Thierstein, 1971)
- 1450 *Sollasites horticus* (Stradner et al. in Stradner and Adamiker, 1966) Cepek and Hay, 1969
- 1451 *Staurolithites crux* (Deflandre and Fert, 1954) Caratini, 1963
- 1452 *Staurolithites laffittei* Caratini, 1963
- 1453 *Staurolithites mutterlosei* Crux, 1989
- 1454 *Tubodiscus frankiae* Bown, 2005
- 1455 *Tubodiscus jurapelagicus* (Worsley, 1971) Roth, 1973
- 1456 *Tubodiscus verенаe* Thierstein, 1973
- 1457 *Umbria granulosa* Bralower and Thierstein in Bralower et al., 1989
- 1458 *Watznaueria barnesiae* (Black in Black and Barnes, 1959) Perch-Nielsen, 1968
- 1459 *Watznaueria fossacincta* (Black, 1971) Bown in Bown and Cooper, 1989. This taxa is
- 1460 considered in this work as a morphotype of *W. barnesiae*, according to biometric studies
- 1461 performed by Bornemann and Mutterlose (2006)
- 1462 *Watznaueria biporta* (Bukry, 1969)

- 1463 *Watznaueria britannica* (Stradner, 1963) Reinhardt, 1964
- 1464 *Watznaueria communis* Reinhardt, 1964
- 1465 *Watznaueria manivittiae* Bukry, 1973
- 1466 *Watznaueria ovata* Bukry, 1969
- 1467 *Zeugrhabdotus diplogrammus* (Deflandre in Deflandre and Fert, 1954) Burnett in Gale et al.,
1468 1996
- 1469 *Zeugrhabdotus elegans* (Gartner 1968) Burnett in Gale et al. 1996
- 1470 *Zeugrhabdotus embergeri* (Noël, 1958) Perch-Nielsen, 1984
- 1471 *Zeugrhabdotus erectus* (Deflandre in Deflandre and Fert, 1954) Reinhardt, 1965
- 1472 *Zeugrhabdotus fissus* Grün and Zweili, 1980
- 1473 *Zeugrhabdotus trivectis* Bergen, 1994
- 1474 *Zycolithus xenotus* Stover, 1966

1475

1476 **Figure captions**

1477 Figure 1. Geological setting. Fig.1A. Location map of the Vergol section (Montbrun-les-
1478 Bains, Drôme, France). Fig. 1B. Palaeogeographic map of the Vocontian basin (SE France,
1479 Lower Cretaceous). Fig. 1C. Lithology of the Vergol section; the Berriasian–Valanginian
1480 boundaries *sensu* Blanc et al. (1994) and *sensu* Kenjo (2014, this work) are indicated, see
1481 arrows 1 and 2, respectively; the numbering of beds is made using two letters, “B” and “V”
1482 for “Berriasian” and “Valanginian”, respectively, according to the former position of the
1483 Berriasian–Valanginian boundary *sensu* Blanc et al. (1994); OB: the “Otopeta bundle” that is
1484 composed by 12 calcareous beds (from VGL-B118 to VGL-B129).

1485

1486 Figure 2. Stratigraphic distribution of macrofauna (mainly ammonites) in the Vergol section
1487 and ammonite zonation; Fig. 2A: part A, succession below the slump i.e. from layers VGL-

1488 B95 to V43; Fig. 2B: part B, succession above the slump i.e. from layers VGL-V45 to V69.
1489 Layers of sampling and number of specimens are indicated. A question mark is added when
1490 identification is doubtful. N = Neocomitidae; O = Olcostephanidae; H = Haploceratidae; L =
1491 Lytoceratidae; P = Phylloceratidae; B = Bochianitidae; P = Protancyloceratidae.

1492

1493 Figure 3. Ammonites (Neocomitids) of the Vergol section (collection Kenjo and Reboulet,
1494 UCBL-FSL, University of Lyon, France); see appendix A for taxonomy. A, *B. calisto*,
1495 UCBL-FSL 485412, VGL-B113, *T. alpillensis* (Sub-)Zone. B, *F. boissieri*, UCBL-FSL
1496 485591, VGL-B125, *T. alpillensis* Zone, “*T.*” *otopeta* Subzone. C, *T. alpillensis*, UCBL-FSL
1497 485603, VGL-B116, *T. alpillensis* Zone, “*T.*” *otopeta* Subzone. D, *T. alpillensis*, UCBL-FSL
1498 485397, VGL-B112, *T. alpillensis* (Sub-)Zone. E, *E. paquieri*, UCBL-FSL 485337, VGL-
1499 B121 *T. alpillensis* Zone, “*T.*” *otopeta* Subzone. Scale bars represent 1 cm.

1500

1501 Figure 4. Ammonites (Neocomitids) of the Vergol section (collection Kenjo and Reboulet,
1502 UCBL-FSL, University of Lyon, France); see appendix A for taxonomy. A, “*T.*” *otopeta*,
1503 UCBL-FSL 485350, VGL-B129, *T. alpillensis* Zone, “*T.*” *otopeta* Subzone. B, “*T.*” *otopeta*,
1504 UCBL-FSL 485345, VGL-B127, *T. alpillensis* Zone, “*T.*” *otopeta* Subzone. C, “*T.*”
1505 *pertransiens*, UCBL-FSL 485377, VGL-V1b, “*T.*” *pertransiens* Zone, *N. premolicus*
1506 Subzone. D, “*T.*” *pertransiens*, UCBL-FSL 485382, VGL-B146, “*T.*” *pertransiens* Zone, *N.*
1507 *premollicus* Subzone. E, “*T.*” *pertransiens*, UCBL-FSL 485380, VGL-V22, “*T.*” *pertransiens*
1508 Zone ~~*N. premolicus* Subzone~~. F, “*T.*” *pertransiens*, UCBL-FSL 485379, VGL-B136, “*T.*”
1509 *pertransiens* Zone, *N. premolicus* Subzone. G, “*T.*” *pertransiens*, UCBL-FSL 485376, VGL-
1510 B148, “*T.*” *pertransiens* Zone, *N. premolicus* Subzone. H, “*T.*” *pertransiens*, UCBL-FSL
1511 485546, VGL-V16, “*T.*” *pertransiens* Zone ~~*N. premolicus* Subzone~~. I, *T.*” *gratianopolitense*,

1512 UCBL-FSL 485386, VGL-B149, “T.” *pertransiens* Zone, *N. premolicus* Subzone. Scale bars
1513 represent 1 cm.

1514

1515 Figure 5. Ammonites (Neocomitids) of the Vergol section (collection Kenjo and Reboulet,
1516 UCBL-FSL, University of Lyon, France); see appendix A for taxonomy. A, *N.*
1517 *neocomiensiformis*, UCBL-FSL 485389, VGL-V43, “N.” *neocomiensiformis* Zone, ~~*N.*~~
1518 ~~*premolieus*~~—Subzone. B, *N. neocomiensiformis*, UCBL-FSL 485571, VGL-V68, *N.*
1519 *neocomiensiformis* Zone. C, *K. lucensis*, UCBL-FSL 485440, VGL-V9, “T.” *pertransiens*
1520 Zone, *N. premolicus* Subzone. D, *K. roubaudiana*, UCBL-FSL 485439, VGL-V31, “T.”
1521 *pertransiens* Zone, ~~*N. premolieus*~~—Subzone. E, *L. superba*, UCBL-FSL 485663, VGL-V64, *N.*
1522 *neocomiensiformis* Zone. F, *S. eucyrta*, UCBL-FSL 485446, VGL-V28, “T.” *pertransiens*
1523 Zone ~~*N. premolieus*~~—Subzone. Scale bars represent 1 cm.

1524

1525 Figure 6. Ammonoids (Olcostephanids, Haploceratids, Phylloceratids, Lytoceratids and
1526 Heteromorphs) of the Vergol section (collection Kenjo and Reboulet, UCBL-FSL, University
1527 of Lyon, France); see appendix A for taxonomy. A, *O. aff. tenuituberculatus*, UCBL-FSL
1528 485474, VGL-V62, *N. neocomiensiformis* Zone. B, *S. multiforme*, UCBL-FSL 485476, VGL-
1529 B112, *T. alpillensis* (Sub-)Zone. C, *N. (V.) extracornutum*, UCBL-FSL 485468, VGL-V46,
1530 ~~“T.”~~ *pertransiens* *N. neocomiensiformis* Zone ~~*N. premolieus*~~—Subzone. D, *N. (V.) salinarium*,
1531 UCBL-FSL 485463, VGL-V2, “T.” *pertransiens* Zone, *N. premolicus* Subzone. E, *L.*
1532 *honoratianum*, UCBL-FSL 485455, VGL-B121, *T. alpillensis* Zone, “T.” *otopeta* Subzone.
1533 F, *L. quadrisulcatum*, UCBL-FSL 485449, VGL-V16, “T.” *pertransiens* Zone ~~*N. premolieus*~~
1534 ~~Subzone~~. G, *H. silesiacum*, UCBL-FSL 485795, VGL-B103, *T. alpillensis* (Sub-)Zone. H, *P.*
1535 (*S.*) *semisulcatum*, UCBL-FSL 485458, VGL-V9, “T.” *pertransiens* Zone, *N. premolicus*
1536 Subzone. I, *P. (H.) tethys*, UCBL-FSL 485774, VGL-V29, “T.” *pertransiens* Zone ~~*N.*~~

1537 ~~*premollicus*~~—Subzone. J, *B. neocomiensis*, UCBL-FSL 485760, VGL-V64, *N.*
1538 *neocomiensiformis* Zone. K, *Protancyloceras* sp. ind., UCBL-FSL 485766, VGL-B141, “T.”
1539 *pertransiens* Zone, *N. premollicus* Subzone. Scale bars represent 1 cm.

1540

1541 Figure 7. Micrographs of selected calcareous nannofossil species recorded at Vergol with the
1542 sample where the specimens have been recorded. White bar = 5 μ m. (1) *A. dietzmannii* VGL-
1543 V2CM. (2) *B. constans* VGL-V2CM. (3) *C. oblongata* VGL-B146M, the earliest recorded
1544 specimen at Vergol. Note the wall which is faint grey in optical microscope, from where rise
1545 up a dome-like structure which appears much brighter. (4) *C. oblongata* VGL-V3M. (5) *C.*
1546 *oblongata* VGL-V3M. (6) *C. rothii* VGL-V2CM. (7) *C. cuvillieri* VGL-V12. (8) *C.*
1547 *margerelii* VGL-B108M. (9) *D. lehmanii* VGL-B108M. (10) *D. subbeticus* VGL-B113CM.
1548 (11) *D. ignotus* VGL-B150M. (12) *E. windii* VGL-B151. (13) *K. curvata* VGL-B112M. (14)
1549 *M. hoschulzii* VGL-V2CM. (15) *M. obtusus* VGL-B112M. (16) *M. speetonensis* VGL-V38M.
1550 (17) *M. quadratus* VGL-V2CM. (18) *N. colomii* VGL-B113CM. (19) *N. steinmannii*
1551 *steinmannii* VGL-B108M. (20) *N. globulus globulus* VGL-V34M. (21) *N. kamptneri*
1552 *kamptneri* VGL-V34M. (22) *P. fenestrata* VGL-B112M. (23) *P. fenestrata* VGL-B151M.
1553 (24) *R. angustiforata* VGL-V2CM. (25) *R. octofenestrata* VGL-V34M.

1554

1555 Figure 8. Micrographs of selected calcareous nannofossil species recorded at Vergol with the
1556 sample where the specimens have been recorded. White bar = 5 μ m. (1) *R. surirella* VGL-
1557 V34M. (2) *R. achylostaurion* VGL-V12. (3) Large *R. asper* VGL-V1b. (4) Large and
1558 overgrown *R. asper* VGL-V1b (closely resembling to *C. erbae* Bergen, 1998 and *C.*
1559 *praeoblongata* Aguado et al., 2000). It is well visible that the central area structure does not
1560 rise from the wall (as is in the diagnosis of the genus *Calcicalathina*), but the insertions of the
1561 central area grid on the inner part of the wall are visible. (5) *R. dekaenelii* VGL-V1b. (6) *R.*

1562 *gallagheri* VGL-V42M. (7) *R. nebulosus* VGL-V2CM. (8) *R. aff. R. pseudoangustus* VGL-
1563 V2CM. (9) *R. laffitei* VGL-V34M. (10) *R. wisei* VGL-V2CM. (11) *S. crux* VGL-V2C. (12)
1564 *S. mutterlosei* VGL-V31M. (13) *T. frankiae* VGL-V2CM. (14) *T. frankiae* VGL-V2CM. (15)
1565 *T. jurapelagicus* VGL-V3M. (16) *W. barnesiae* VGL-B108M. (17) *W. biporta* VGL-B116M.
1566 (18) *W. britannica* VGL-V12. (19) *W. fossacincta* VGL-B108M. (20) *W. manivittiae* VGL-
1567 B113CM. (21) *Z. elegans* VGL-V2C. (22) *Z. embergerii* VGL-B113CM. (23) *Z. embergerii*
1568 VGL-B113CM. (24) *Z. erectus* VGL-B151. (25) *Z. trivectis* VGL-V3M.

1569

1570 Figure 9. Nannofossil events recorded in the Vergol section. Nannofossil zones are after
1571 Thierstein (1971) modified by Bralower et al. (1989).

1572

1573 Figure 10. Comparison of the biostratigraphic and magnetic zonal schemes of Bralower et al.
1574 (1989) and Bown et al. (1998) for the interval around the Berriasian–Valanginian boundary.

1575

1576 Figure 11. Comparison of the biostratigraphic zonal schemes of Aguado et al. (2000),
1577 Duchamp-Alphonse et al. (2007) and Kenjo (2014; this work) for the interval around the
1578 Berriasian–Valanginian boundary.

1579

1580 Figure 12. Principal Component Analysis (PCA) applied to percentages (log values) of
1581 calcareous nannofossil taxa. For further explanation, see the text.

1582

1583 Figure 13. Stratigraphical evolution of PCA factorial scores, nannofossil absolute abundance,
1584 Shannon diversity index in the Vergol section. The shaded area represents the interval around
1585 the Berriasian–Valanginian boundary where major changes occurred in calcareous
1586 nannofossil assemblages.

1587

1588 Figure 14. Correlations of lithology and zonal schemes of the Vergol section *sensu* (Kenjo,
1589 2014; this work) *versus* Blanc et al. (1994) and Blanc (1996).

1590

1591 **Table 1. Distribution of all the recorded calcareous nannofossil taxa in the Vergol section.**
1592 **The FSL number is shown for each sample.**

1593

1594 **Table 2. Numerical values for PCA results, absolute abundance and species diversity as**
1595 **calculated in this work.**

1596

1597 **NB: Tables 1 and 2 are in Supplementary data/material.**

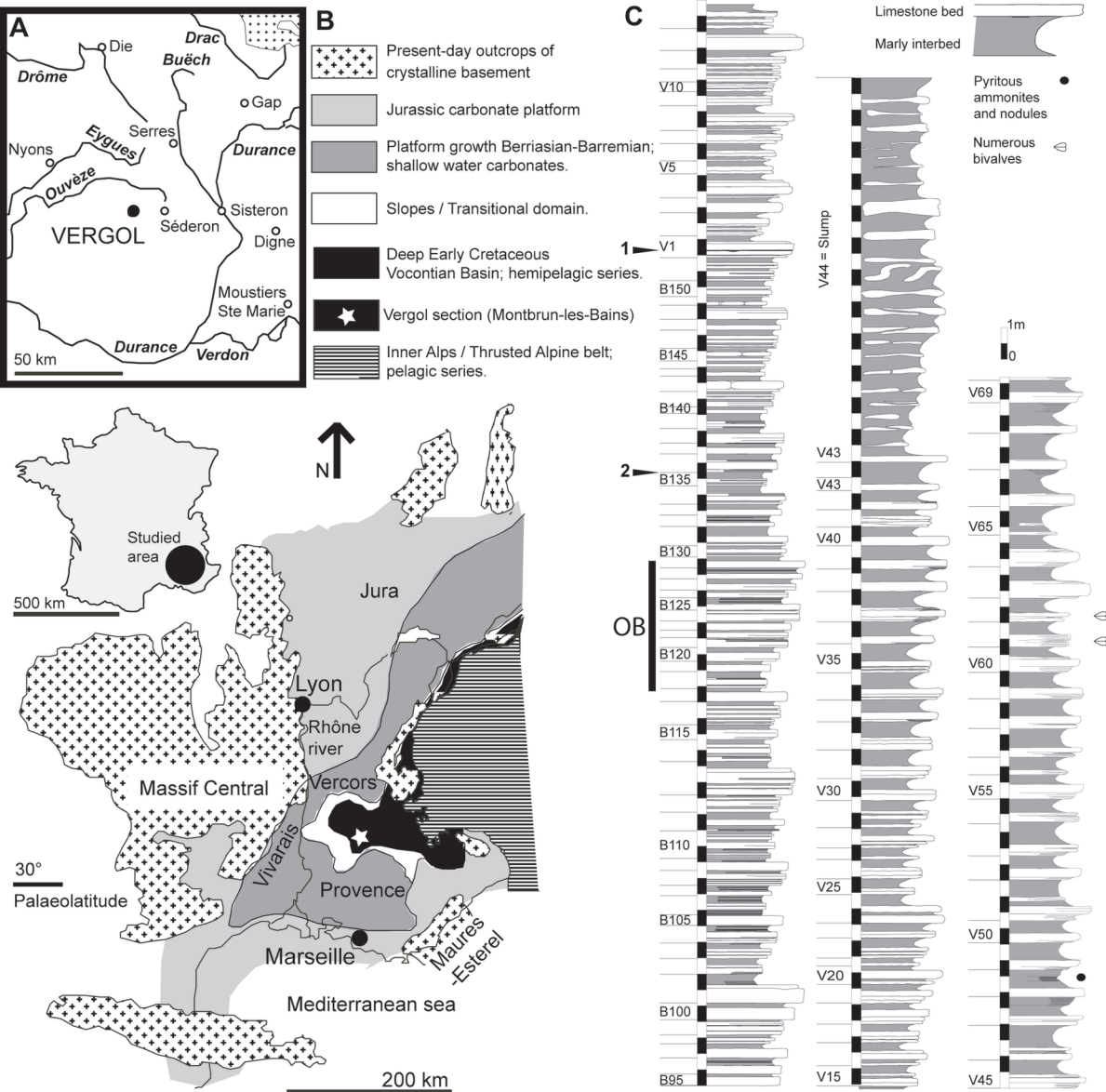


Figure 1 - 2 column fitting image

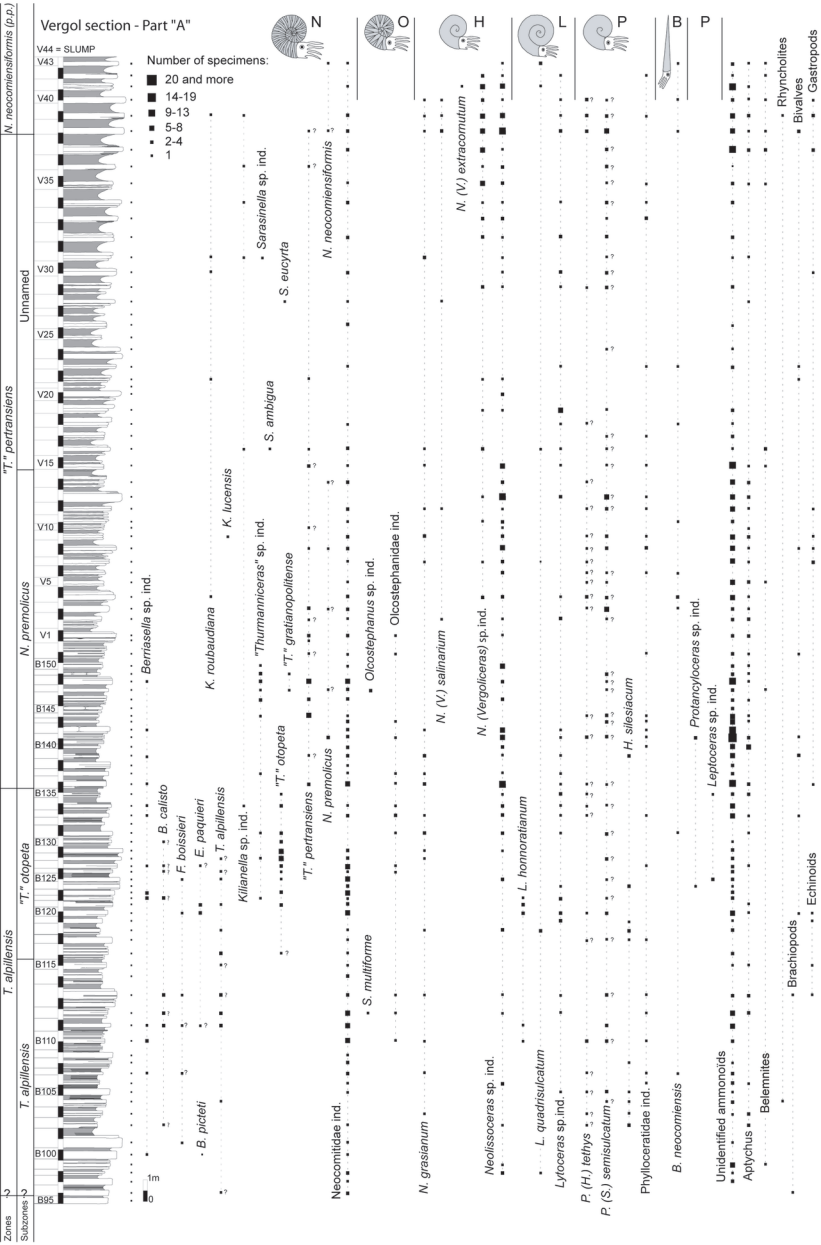


Figure 2A - 2 column fitting image

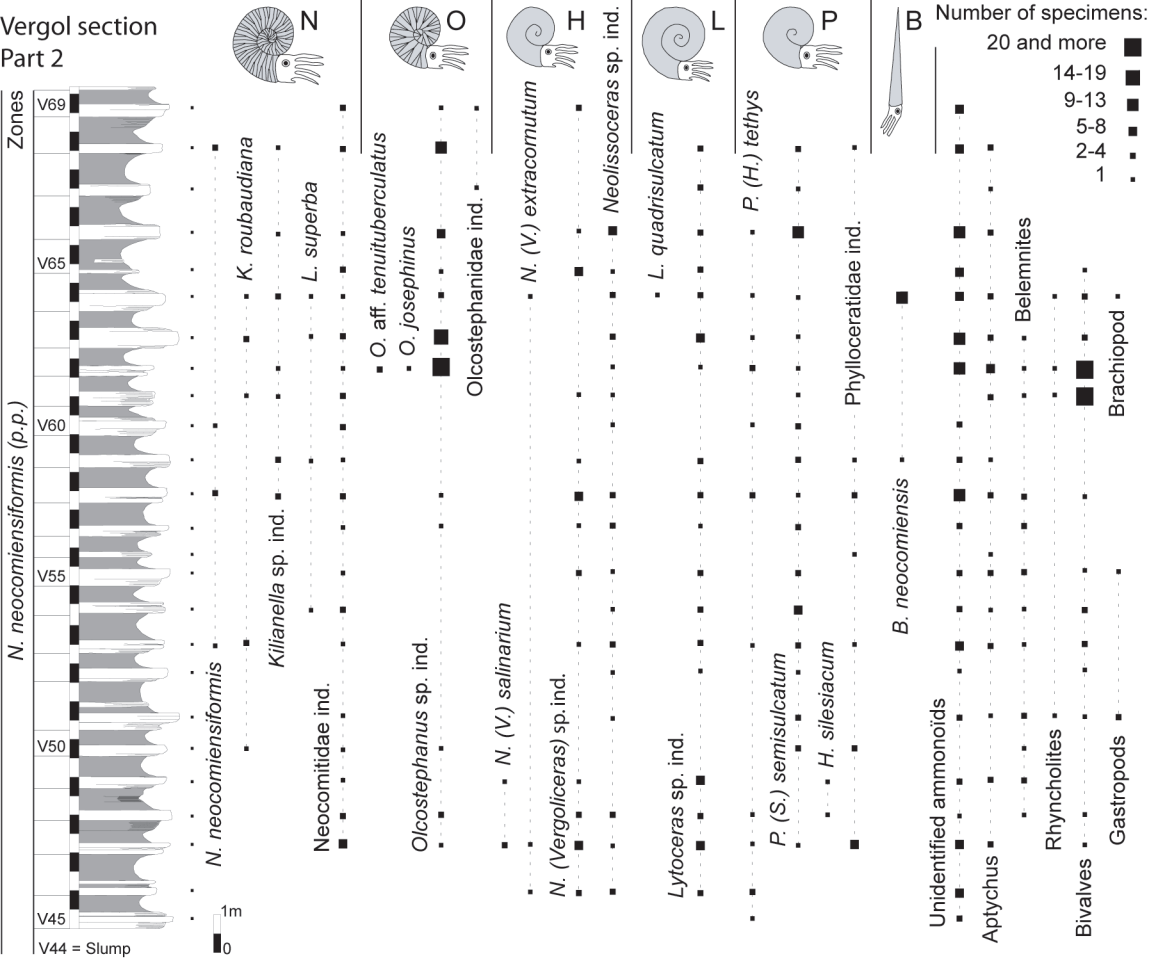


Figure 2B - 2 column fitting image

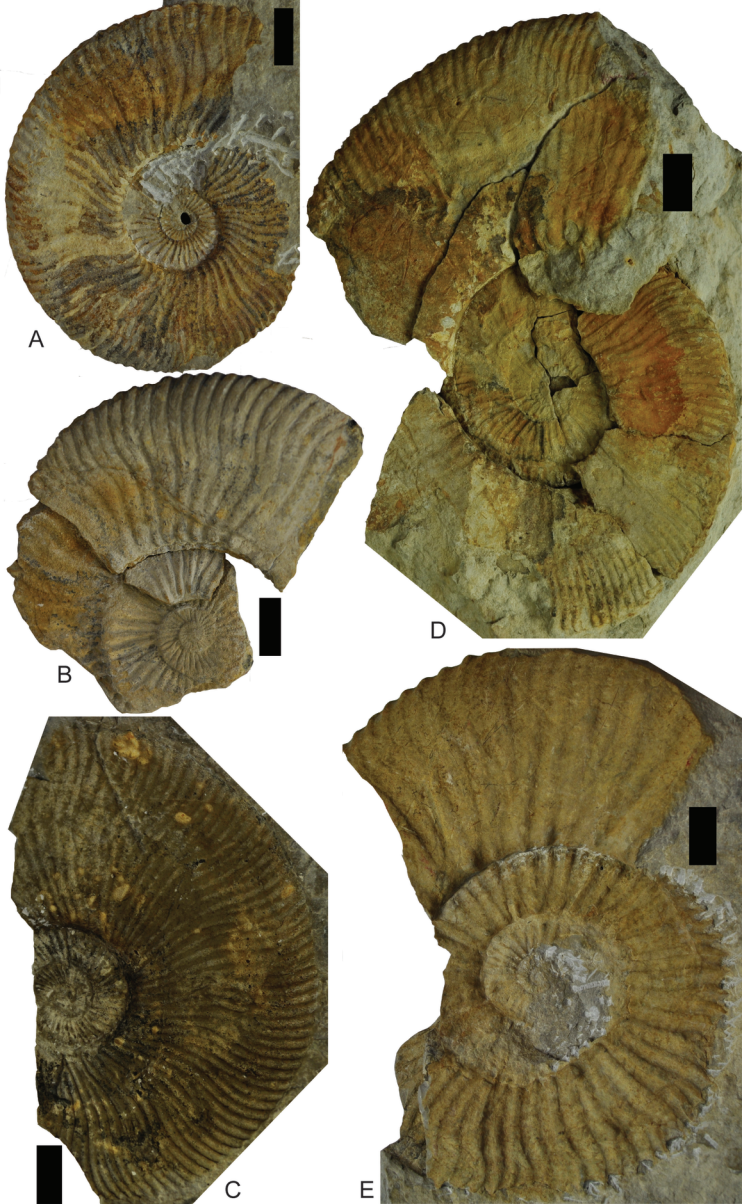


Figure 3 - 2 column fitting image

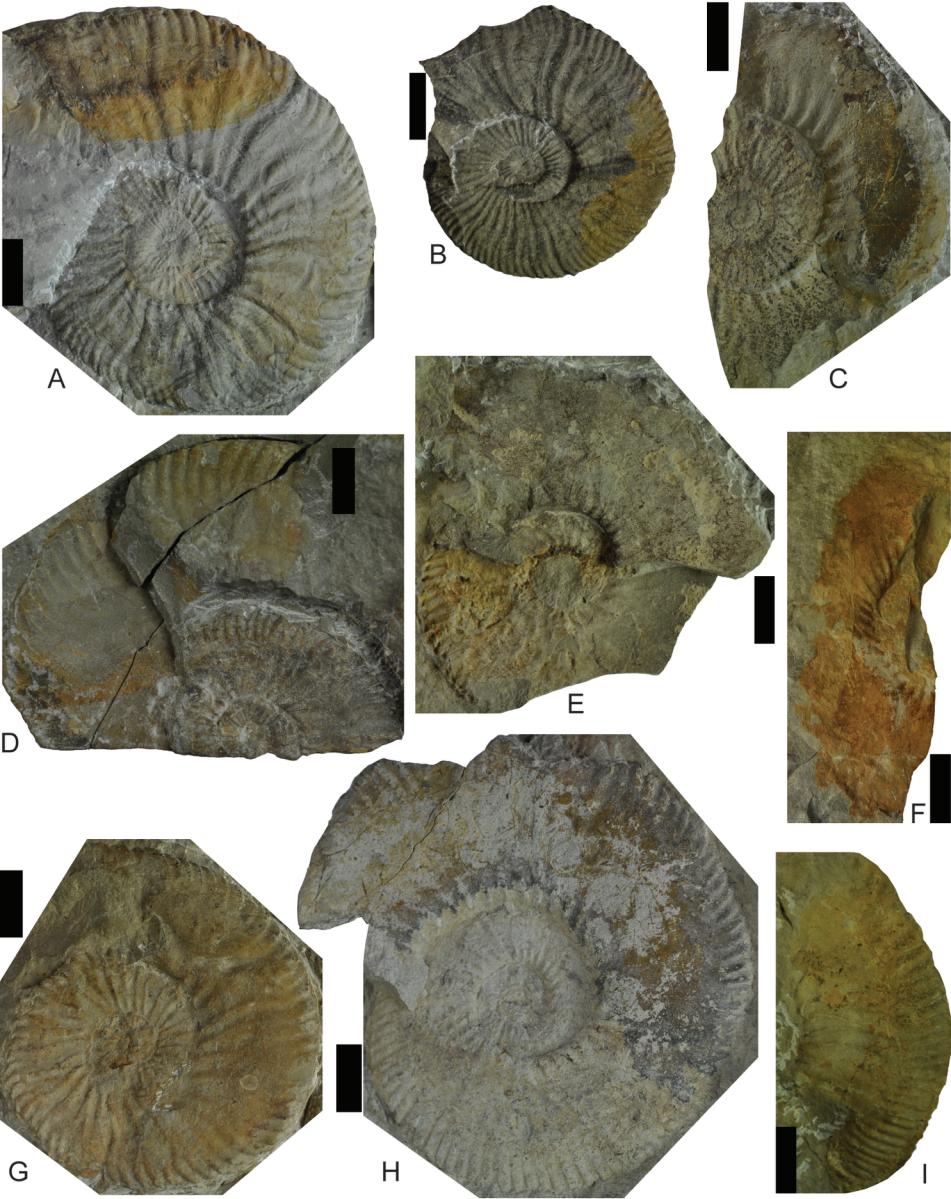


Figure 4 - 2 culumn fitting image

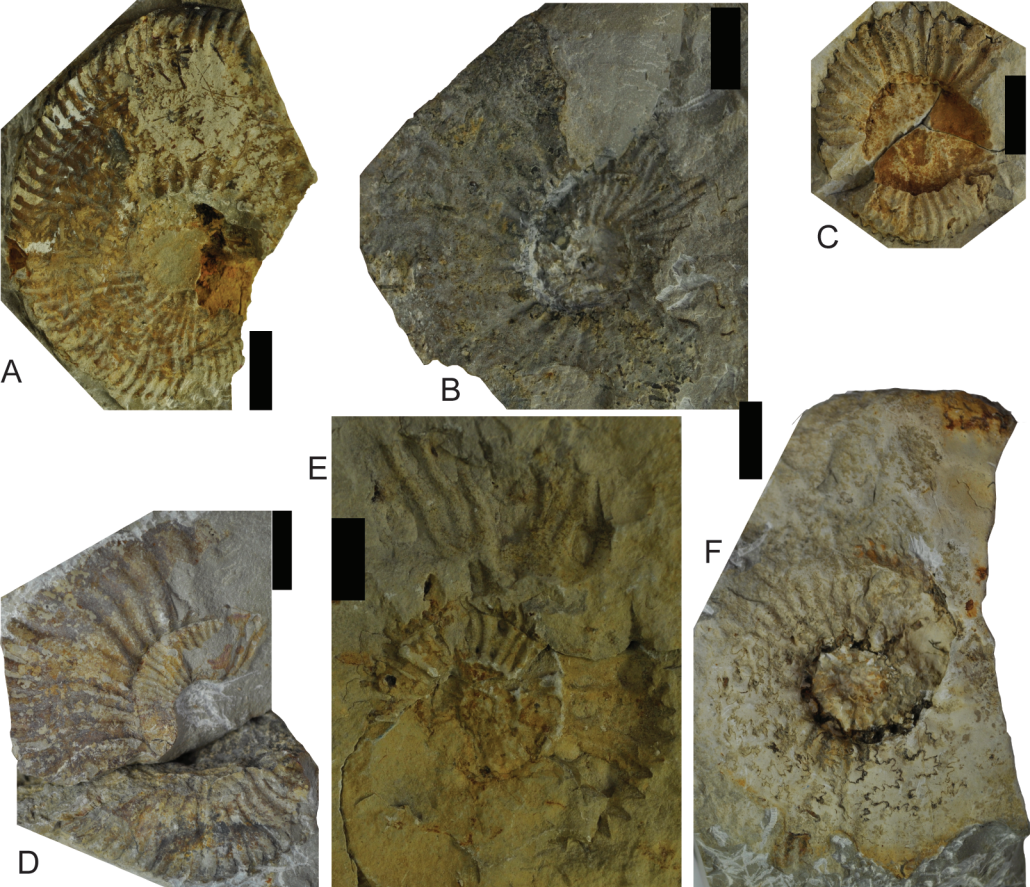


Figure 5 - 2 column fitting image

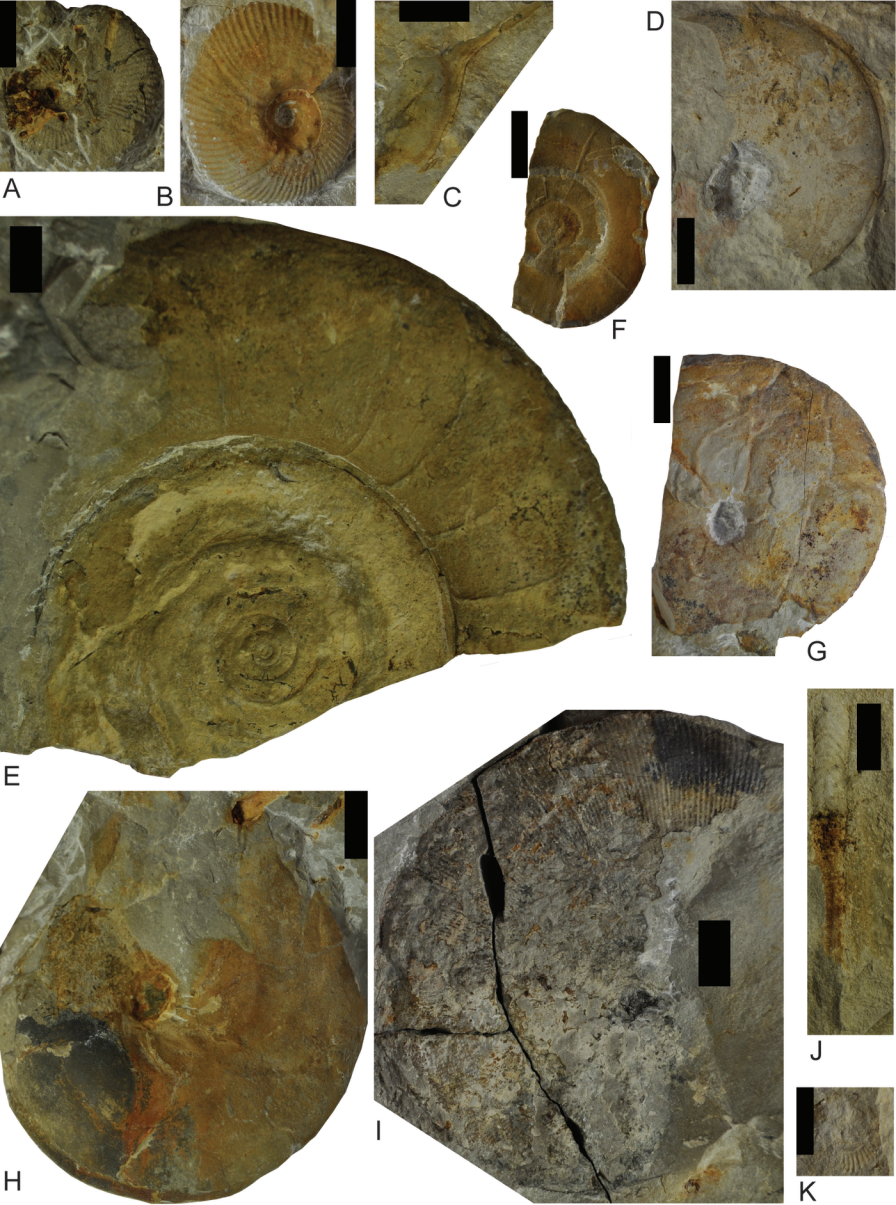


Figure 6 - 2 culumn fitting image

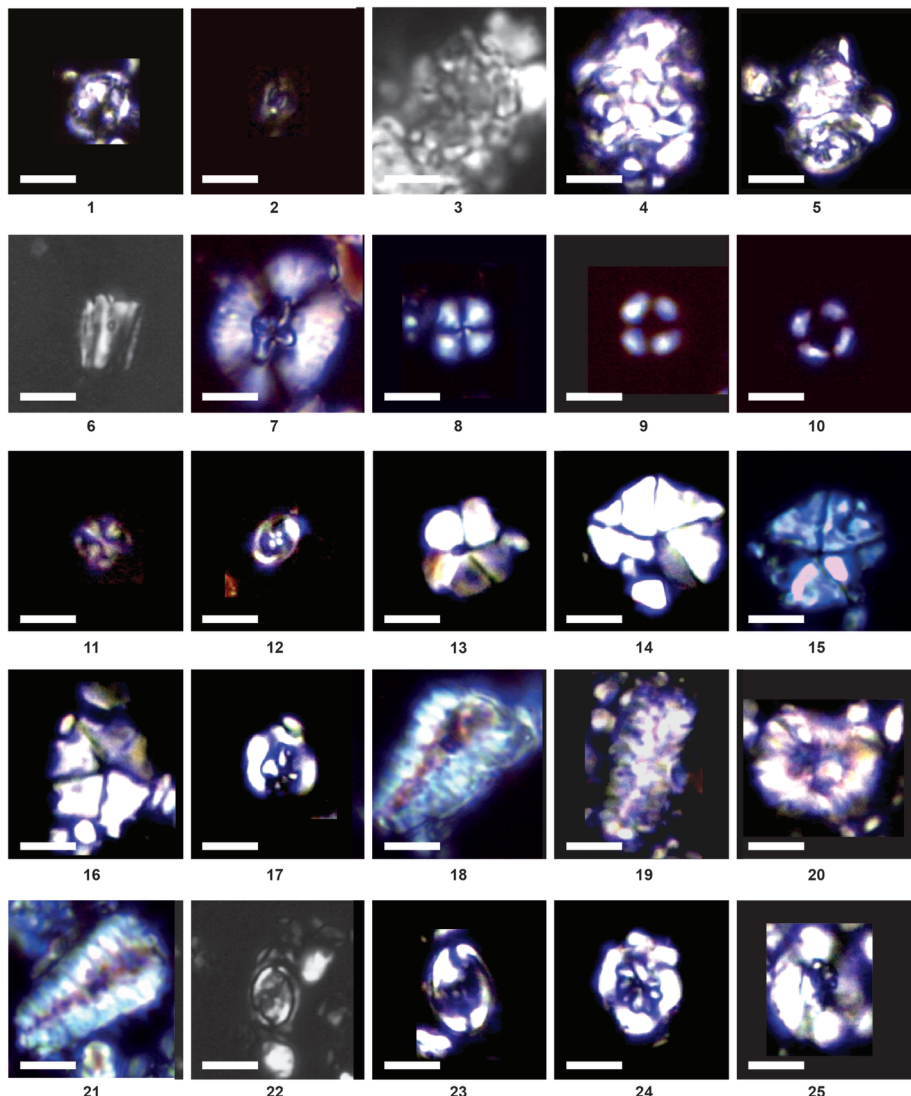


Figure 7

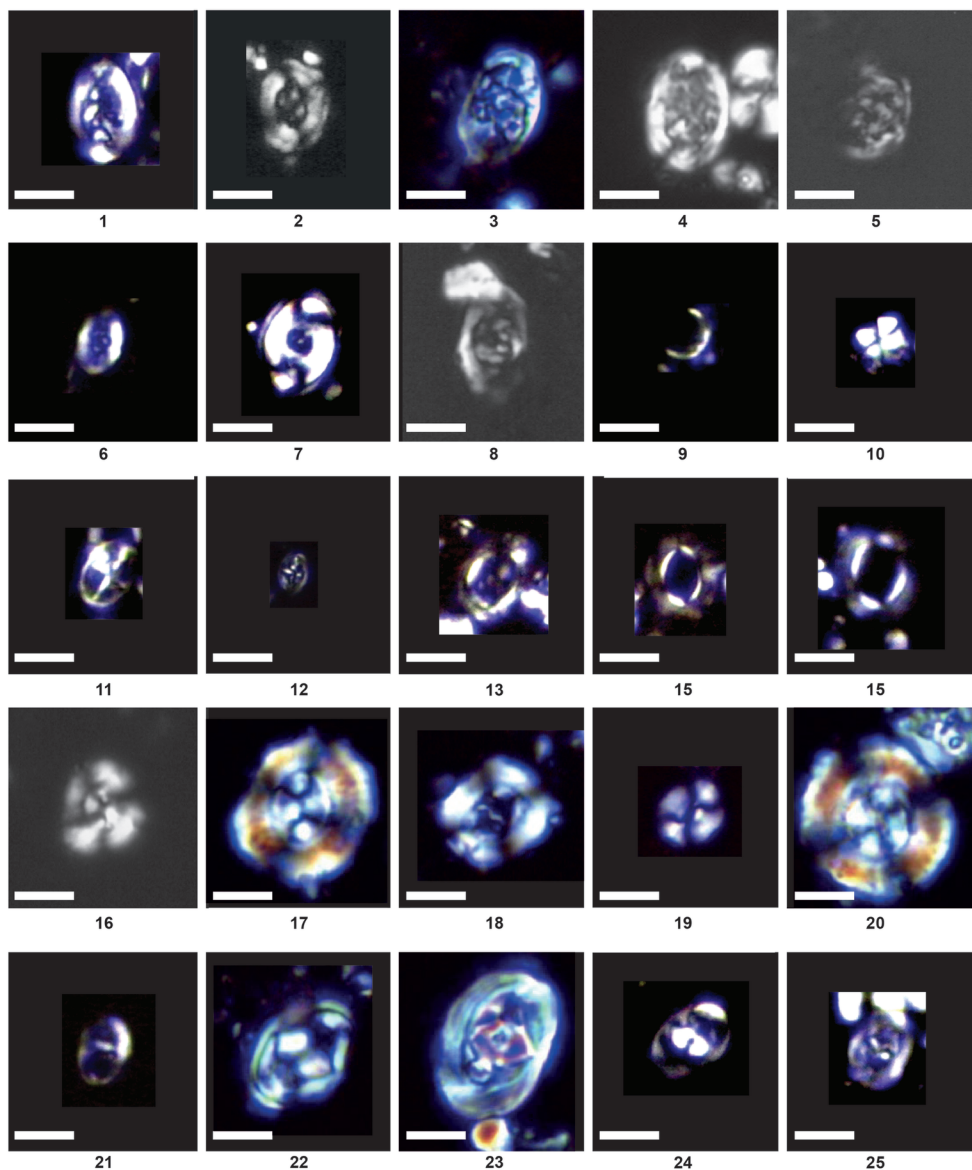


Figure 8

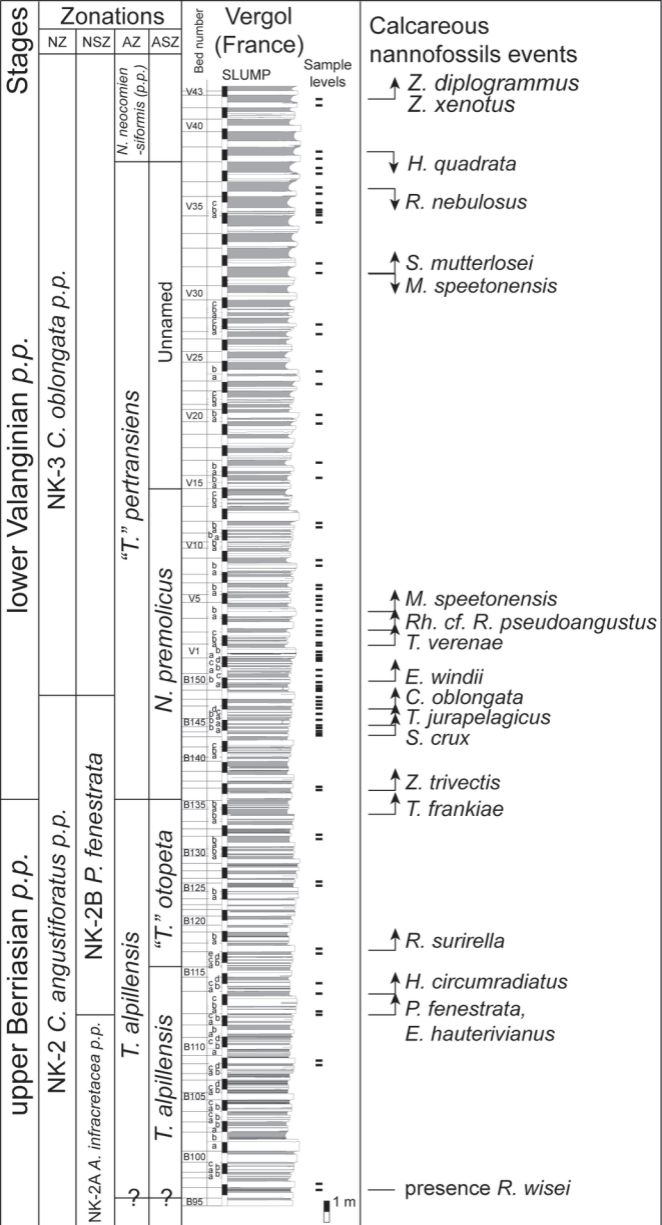


Figure 9 - 2 (1.5?) column fitting image

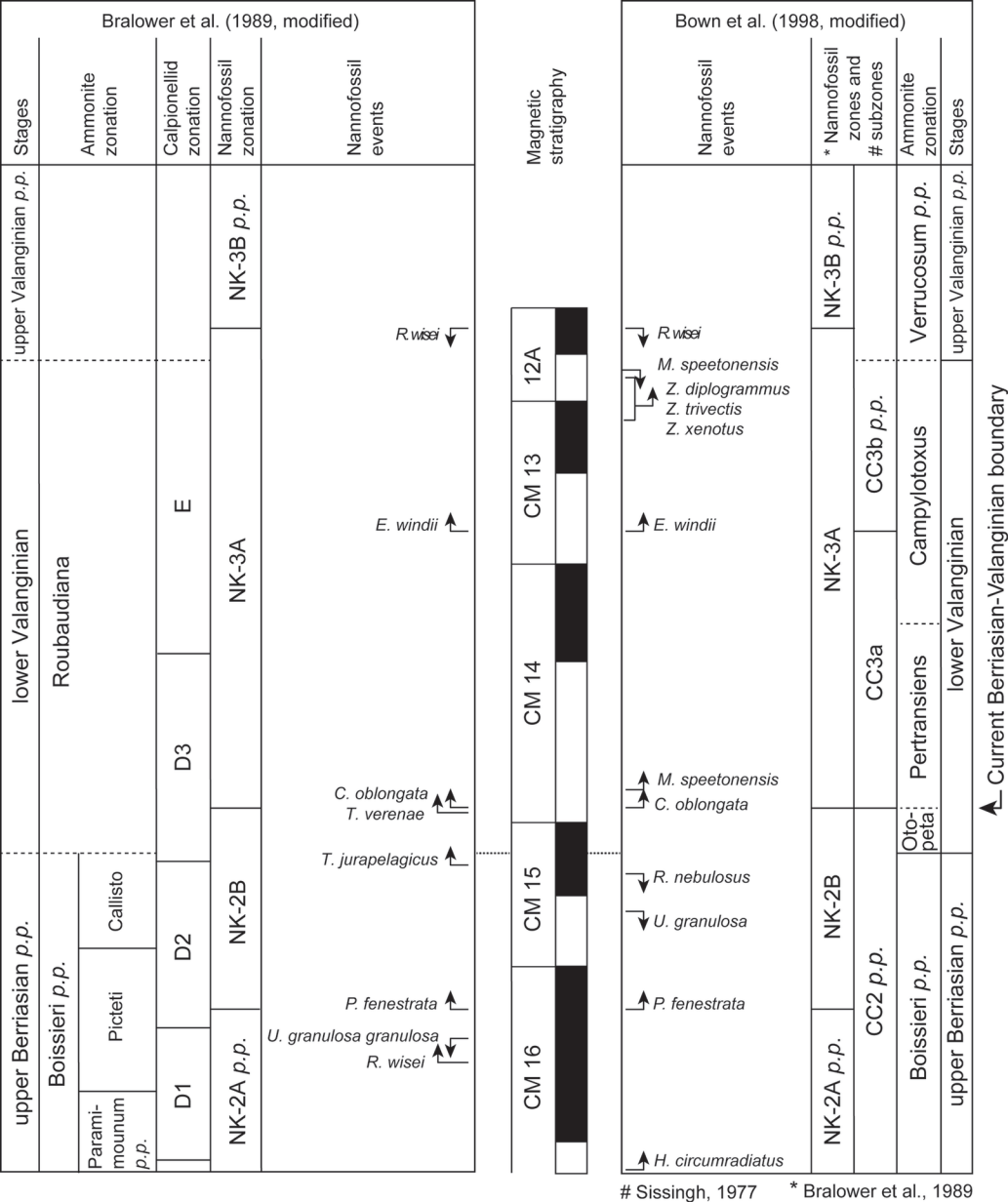


Figure 10 - 2 (1.5?) column fitting image

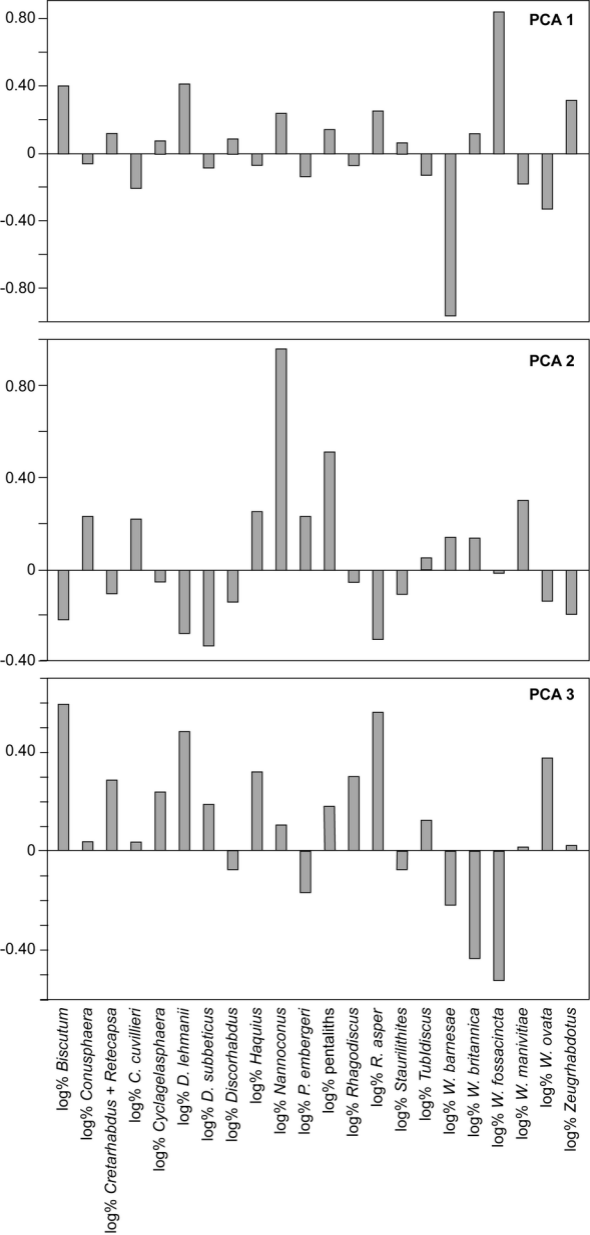


Figure 12 - 2 (1.5?) culumn fitting image

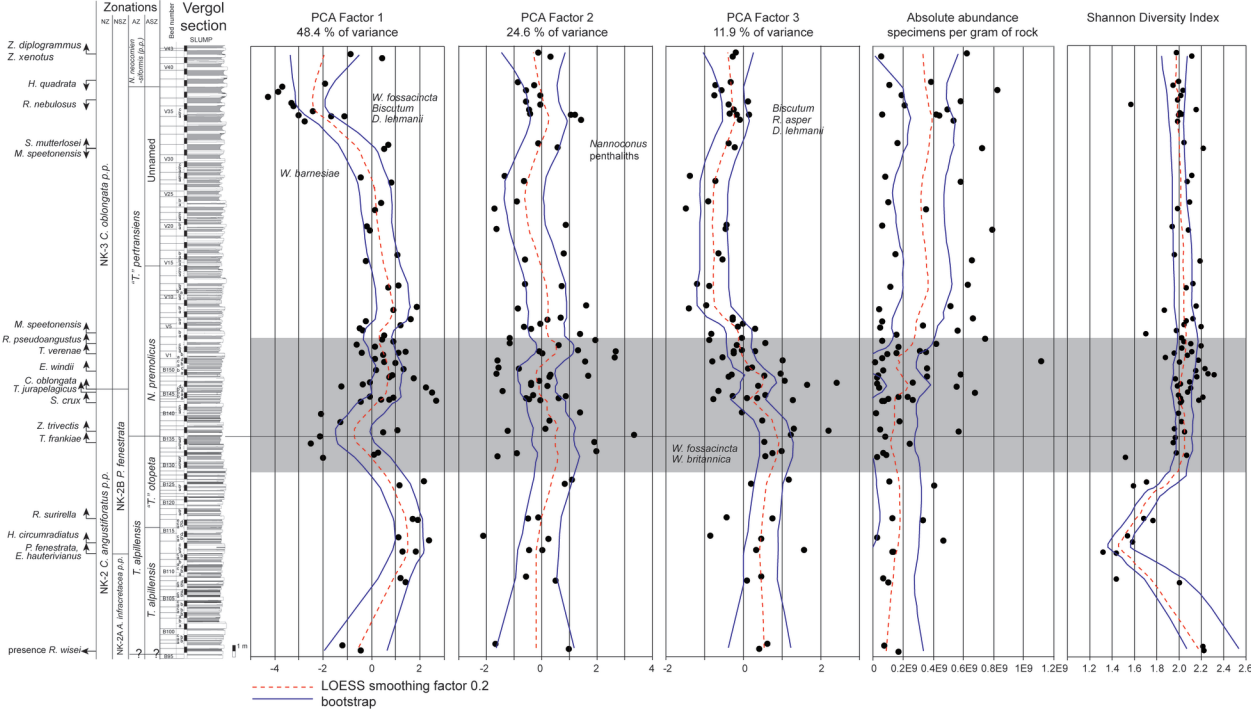


Figure 13 - 2 column fitting image

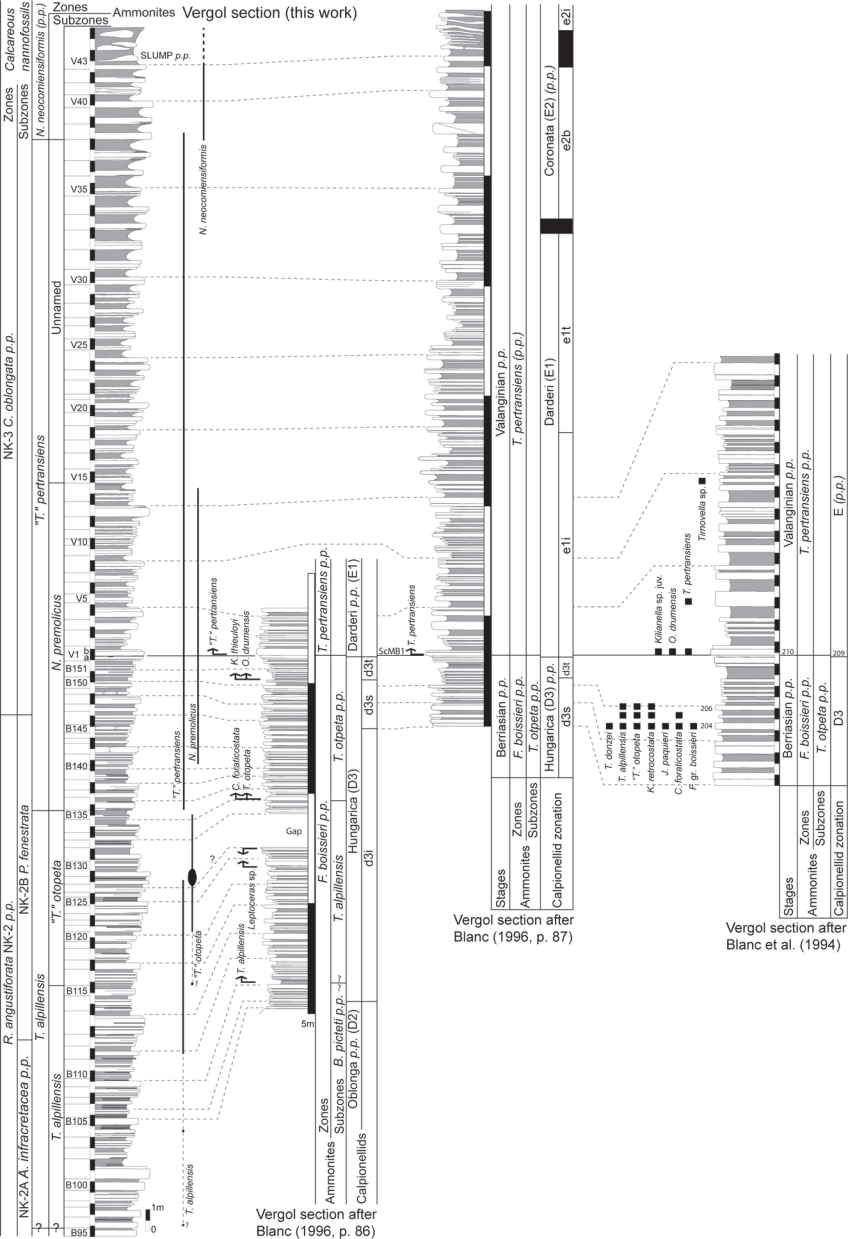


Figure 14 - 2 column fitting image

FSL N°	Beds	Height	PC1	PC2	PC3	Absolute abundance	Shannon index
766104	VGLV42M	52.4	-0.88876	-0.16341	-0.23431	612275892.35	1.98
766105	VGLV42L	52.1	0.40784	0.27441	-0.30588	51974566.73	2.11
766106	VGLV38M	49.9	-1.9623	-0.93438	-0.35984	378689937.51	2.00
766107	VGLV38L	49.6	-3.7149	-0.33023	-0.74866	106467776.50	1.95
766108	VGLV37M	49.2	-3.8977	-0.60758	-0.5981	815617563.21	2.04
766109	VGLV37L SO	48.7	-4.2917	-0.11727	-0.78242	188780478.11	2.01
766110	VGLV36M	48.2	-3.332	-0.62923	0.093401	571593058.64	1.99
766111	VGLV36L	47.9	-3.2505	-0.093962	-0.39868	207254082.03	1.57
766112	VGLV35CM	47.5	-2.4327	-0.50204	-0.2781	487144301.60	2.15
766113	VGL35CL	47.1	-3.0428	-0.48372	-0.37294	57163606.18	2.01
766114	VGLV35bM	47.05	-1.1546	1.1601	-0.20246	416396103.90	2.02
766115	VGLV35bL	47	-1.6756	1.0008	0.11902	436215817.51	2.00
766116	VGLV34M	46.55	-2.7876	1.3495	-0.11216	530310228.51	1.99
766117	VGLV32L	44.6	0.67638	-0.19063	-0.41348	158540290.12	2.04
766118	VGLV31M	44.2	0.4876	0.53482	-0.24213	711935180.58	2.21
766119	VGLV28CL	41.7	-0.46897	-1.4063	-1.4179	76680477.56	2.11
766120	VGLV27M	41.25	0.79659	-0.69001	-0.75384	575885115.95	2.08
766121	VGLV24BL	39.5	0.3632	-0.95008	-0.94396	100765563.72	2.09
766122	VGLV23M	38.9	0.11034	-1.769	-1.5035	347590004.67	1.99
766123	VGLV20BL	37.45	-0.23236	0.8031	-0.45179	60320420.83	1.94
766124	VGLV19M	37.1	-0.079354	-1.6751	-0.49789	781600598.35	2.09
766125	VGLV16M	35	1.0291	0.72761	-0.68006	144993894.99	1.96
766126	VGLV15BM	34.45	-0.25887	-0.66184	-0.57159	650474029.66	2.19
766127	VGLV12BM	32.3	1.0855	-0.67087	-1.2223	619421998.43	2.12
766128	VGLV12BL	32.15	0.65636	0.67806	-0.9177	110630713.29	2.08
766129	VGLV8M	30.5	1.8611	1.5415	-0.98388	505698531.67	2.15
766130	VGLV8BL	30.2	0.86981	-0.91457	-1.4268	35552632.51	1.87
766131	VGLV6M	29.4	1.6012	0.631	-0.30884	656049195.98	2.12
766132	VGLV6BL	29.2	-0.26369	0.13943	-0.29947	60053107.14	2.07
766133	VGLV5M	28.85	1.1836	-0.11725	-0.043246	323336076.48	2.05
766134	VGLV5L	28.6	-0.52721	-0.68171	-0.18006	45815608.59	2.20
766135	VGLV4BM	28.4	-0.37479	-0.42457	0.27768	552936910.80	1.98
766136	VGLV4BL	28	0.47688	1.3435	-0.86753	155865371.17	1.70
766137	VGLV3M	27.65	0.42686	-1.202	-0.059808	736651447.55	2.02
766138	VGLV3L	27.5	0.88578	1.8744	-0.9112	62070748.16	2.04
766139	VGLV2CM	27.2	-0.63838	-1.2099	0.53627	416875439.21	2.02
766140	VGLV2CL	27	0.11484	0.5374	-0.18907	167063656.11	2.11
766141	VGLV2BL	26.6	1.3855	1.2651	-0.077402	305245496.64	2.20
766142	VGLV1BM	26.5	-0.45128	-0.14975	0.28497	345525807.22	2.02
766143	VGLV1B-BIS L	26.45	1.0823	2.6233	-0.26701	154546488.91	2.11
766144	VGLV1BL	26.3	0.4507	-0.039556	-0.28315	89477593.21	1.96
766145	VGLV1a-L	26	0.095732	2.5804	-0.5562	60584553.51	2.08
766146	VGB151M	25.7	0.49776	-1.6628	0.98515	1103129228.13	1.88
766147	VGB151L	25.6	0.97157	1.5219	-0.83419	11537019.41	2.17
766148	VGB150M	25.1	1.2805	-1.6141	0.19345	355073938.41	2.00
766149	VGB150L	24.95	0.17283	-0.88622	0.086065	66899076.48	2.23
766150	VGB149M	24.55	0.83432	-1.6877	0.93609	571092634.58	2.14
766151	VGB149L	24.5	0.73259	0.25308	-0.33069	32435173.24	2.26
766152	VGB148M	24.4	0.71151	1.6388	0.51409	356403388.80	2.31
766153	VGB148L	24.3	1.7033	0.20623	-0.39497	24368552.47	2.15
766154	VGB147M	23.9	-0.099431	-0.13578	1.0376	260261008.17	1.97
766155	VGB147L	23.75	-0.4087	-0.43332	2.3806	26019296.61	2.10
766156	VGB146M	23.55	-1.2814	-0.44396	1.6143	548774362.07	2.01
766157	VGB146cL	23.45	2.2359	0.1505	0.36316	39870752.13	1.99
766158	VGB145M	23	2.477	-1.4766	-0.66355	665062702.62	2.11
766159	VGB145aL	22.65	-0.10042	-0.35232	0.53419	169200628.23	2.08
766160	VGB144M	22.6	0.87602	0.82649	-0.30087	223771326.71	2.00
766161	VGB144aL	22.45	0.38199	0.56869	0.33933	95977916.73	2.21
766162	VGB143Mb	22.4	-0.46837	-0.099021	1.2423	58857142.86	2.01
766162	VGB143M	22.4	0.71901	-0.62499	0.073419	260448754.28	2.18
766163	VGB143L	22.3	2.6414	-0.51588	-0.80128	70944936.77	2.01
766163a	VGB140M	21.2	-2.1028	1.3326	-0.059431	20824701.97	1.99
766163	VGB138M	20.5	-1.3357	0.23537	0.46249	171280575.54	2.01
766164	VGB137L	19.8	1.0582	0.063054	1.2862	47182230.52	1.95
766165	VGB136M	19.6	0.45256	-1.2942	2.1816	560819565.92	2.06
766165a	VGB135M	19.2	-2.1645	3.2834	1.1873	81856253.54	1.97
766165b	VGB134M	18.6	-2.5421	1.8457	0.50541	242016806.72	1.92
766165c	VGB132M	17.8	0.26031	1.9184	0.96108	64487133.02	1.98
766166	VGB132L	17.6	0.054453	-0.9556	0.71205	82415778.81	2.07
766167	VGB131M	17.4	-2.0494	-1.6728	0.52919	27304421.77	1.51
766168	VGB126L	15.3	2.1523	1.0326	1.1508	108320155.79	1.70
766169	VGB125M	15	1.1311	0.77353	0.15909	400252945.38	1.59
766170	VGB117L	12.1	1.6825	-0.19546	-0.46698	122601015.46	1.68
766171	VGB116M	12	1.8943	-0.55412	0.719	328325264.92	1.77
766172	VGB114L	10.5	1.0863	-2.1682	-0.89335	22719841.10	1.52
766173	VGB113CM	10.2	2.3311	0.19391	0.43687	462919221.19	1.58
766174	VGB113aL	9.25	1.2438	-0.027582	0.29168	125105351.88	1.31
766175	VGB112M	9.2	1.7901	-0.51305	1.5305	132603717.16	1.42
766176	VGB109L	6.9	1.1883	-0.63981	0.44175	66189175.63	1.42
766177	VGB108M	6.55	1.3749	0.45694	0.058989	96879653.39	2.00
766178	VGB97L	1.1	-1.2501	-1.7121	0.59468	69385118.39	2.21
766179	VGB96M	0.6	-0.45411	0.91482	0.38912	164951133.29	2.22