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Revised holostratigraphy of the Tithonian-Berriasian transition at Tré Maroua (Le Saix, Hautes-Alpes, SE France): Study of a rejected Berriasian GSSP candidate

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Key words: stratigraphy, calpionellids, saccocomids, Tithonian, Berriasian, lithoclasts, erosion, debris flows, turbidites, Vocontian Trough.

Abstract. The study of the Tithonian and lower Berriasian succession of Le Saix (Hautes-Alpes, France) has made it possible to better characterize the lithological succession at a former Berriasian GSSP candidate, its set of microfacies, the stratigraphic ranges of the main groups of marine plankton and therefore the calpionellid and saccocomid biozonations. On the lithological level, the Tithonian strata are characterized by thick-bedded breccias representing debris flows and related calciturbidites, whereas the Berriasian strata are typically white limestones. The lower part of the Berriasian is comprised of scattered intercalations of thin-bedded breccias and calciturbitides (including cryptic mud calciturbidites). In thin sections, the white limestones display mud- to wackestone textures and their allochems are mostly tiny bioclasts (*e.g.*, radiolarians, calpionellids, saccocomids). Calciturbidites have wacke- to grainstone textures and their allochems are mostly pseudointraclasts and extraclasts, comprising various bioclasts and some ooids. Mud turbidites are made of micrograinstones some yielding almost exclusively well-sorted calpionellids, which were previously erroneously interpreted as the signature of “explosions” or “blooms” of *Calpionella alpina*. Breccias are mostly lithoclastic floatstones with a matrix similar to that of the calciturbidites. Their lithoclasts are either extraclasts *sensu stricto*, *i.e.*, material derived from updip shallow-water areas, or pseudointraclasts representing reworked subautochthonous material, *i.e.*, mud- and wackestone lithoclasts with radiolarians, saccocomids and/or calpionellids. Radiolarians are common over the whole studied interval. Saccocomids are part of the dominating biota reported from the lower and lower upper Tithonian interval whereas calpionellids replace them in the uppermost Tithonian to lower Berriasian interval. Minor planktonic groups comprise calcareous dinoflagellates and *Globochaete alpina*; *Iranopsis* nov. group is also present. Intervals with saccocomid sections characteristic of zones 4–5 and zone 6 are respectively ascribed here to the lower Tithonian (4–5) and the lower upper Tithonian (6). The biozonation of the calpionellid group *sensu lato* allows identification of i) the Boneti Subzone of the chitinoidellids, ii) the Crassicollaria Zone, more specifically its Tintinnopsella-Intermedia (A1), Intermedia-Alpina (A2) and Brevis-Massutiniana (A3) subzones, and iii) the Alpina Zone, with its Alpina-Parvula (B1) and its Alpina-Remaniella (B2) subzones. On the basis of biostratigraphical and sedimentological data, most zonal boundaries prove to be hiatal, located at the erosional base of breccia or turbidite layers whereas the Tithonian/Berriasian stage boundary appears to be located at a strike-slip fault plane in the Tré Maroua section.

INTRODUCTION

The Vocontian Trough, located in the southeastern part of France (Fig. 1), is mainly filled with Mesozoic argillaceous and calcareous sedimentary deposits later affected by Alpine thrust faulting and large curvature folding. The deposits of the Tithonian-Berriasian transition consist of thick-bedded sedimentary breccia and calciturbidite layers followed by white limestones with intercalations of breccia and calciturbites and then by alternations of marls and

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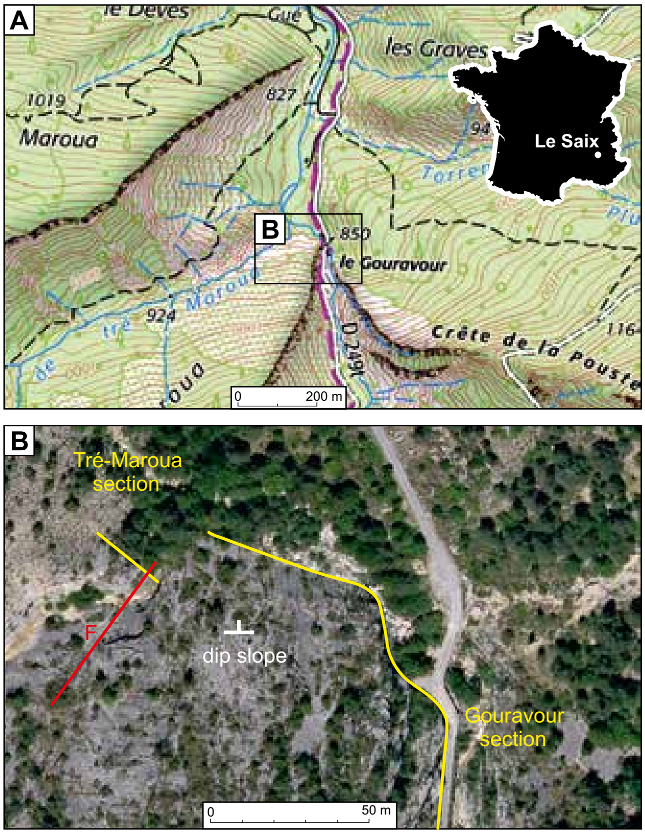


Fig. 1. Topographic map of the Le Saix area (A) and locations of the sections studied (B)

thin-bedded white limestones, *i.e.*, the "calcaires blancs" facies. The latter contains numerous and well-preserved calpionellids, *i.e.*, unilocular unicellular microfossils that have long attracted the attention of micropaleontologists and biostratigraphers. From these upper Tithonian to lower Berriasian series, Remane (1963) established the first preliminary biozonation based on this microfossil group. He first defined three zones: i) the Crassicollaria Zone (A), subdivided into three subzones (aff. intermedia, Intermedia-Alpina and Brevis-Massutiniana), ii) the Alpina Zone (B), and iii) the Tintinnopsella Zone (C). From the same basin, Le Hégarat and Remane (1968) defined the Calpionellopsis Zone (D) of the upper Berriasian. In turn, from southern Spain and Sicily, Italy, Catalano and Liguori (1971) and Allemann *et al.* (1971) defined the Calpionellites Zone (E) of the lower Valanginian. In the aftermath, Remane (1971) published a fairly precise sketch of the evolutionary trends within the group and his first more advanced calpionellid biozonation with five biozones (A to E), spanning the upper Tithonian to lower Valanginian interval. Again, from the Betic Ranges in southern Spain, Énay and Geyssant (1975) supplemented this biozonation with a Chitinoidella Zone for the lower/upper Tithonian boundary. Subsequently, from the western Carpathians, Borza (1984) subdivided the latter into two subzones, *i.e.*, a lower Dobeni Subzone and an upper Boneti Subzone. This Boneti Subzone of the Chitinoidella Zone had already been identified in the Vocontian Trough (*e.g.*, Cecca *et al.*, 1989). As a result of this work, the biozones and distributions of the calpionellid representatives in the upper Tithonian – lower Valanginian series of the Vocontian Trough are supposedly well-known whereas those of other groups of pelagic microfauna, in particular the calcareous dinoflagellates and sections of saccocomids, are still little or not studied. In order to help fill these analytical gaps and to better characterize the lithological succession, microfacies, saccocomid and calpionellid biozones, and the ranges of the other fossil groups around this stage transition, we undertook a new revision of the Tré Maroua section and a description of the nearby Gouravour section, the composite of which spans the interval of interest.

The Tré Maroua section was presented by the former Berriasian Working Group as a candidate for the Berriasian GSSP (Wimbledon *et al.*, 2019, 2020b; Granier *et al.*, 2020a, b). A detailed sedimentological and biostratigraphic survey demonstrates that the section does not meet at least four of the five "geological requirements for a GSSP" (see Remane *et al.*, 1996; Granier *et al.*, 2020b): 1) "exposure over an adequate thickness", 2) "continuous sedimentation", 3) sufficient "rate of sedimentation", and 4) "absence of synsedimentary and tectonic disturbances". As a result, the International Subcommission of the Cretaceous Stratigraphy rejected the section proposed as the Berriasian GSSP. This new revision addresses sedimentological, micropaleontological and stratigraphical side issues. In particular, the present paper includes a dating of the interval between the alleged boundary breccia and the Tré Maroua fault.

STUDIED SECTIONS

Both the Gouravour and the Tré Maroua sections are located some 500 m south of the village of Le Saix, Hautes-Alpes (Fig. 1), in an area located southwestern corner of the geological map at 1 : 50,000 scale of Gap (Gidon, 1971). The lower part of the composite section, the Gouravour section (60 m, Fig. 2), is sited on the left bank of the Maraize stream (GPS coordinates: 44°27'56.6"N 5°49'45.5"E – 44°28'00.4"N 5°49'42.0"E). The upper part of the composite section, the Tré Maroua section (15 m, Figs. 3, 4), is slightly downstream (GPS coordinates: 44°27'59.7"N 5°49'41.2"E – 44°28'00.3"N 5°49'40.4"E) and passes through a small waterfall near the junction of the Maraize stream with the Tré Maroua stream, one of the small tributaries of the Maraize stream. The initial publication of the Tré Maroua

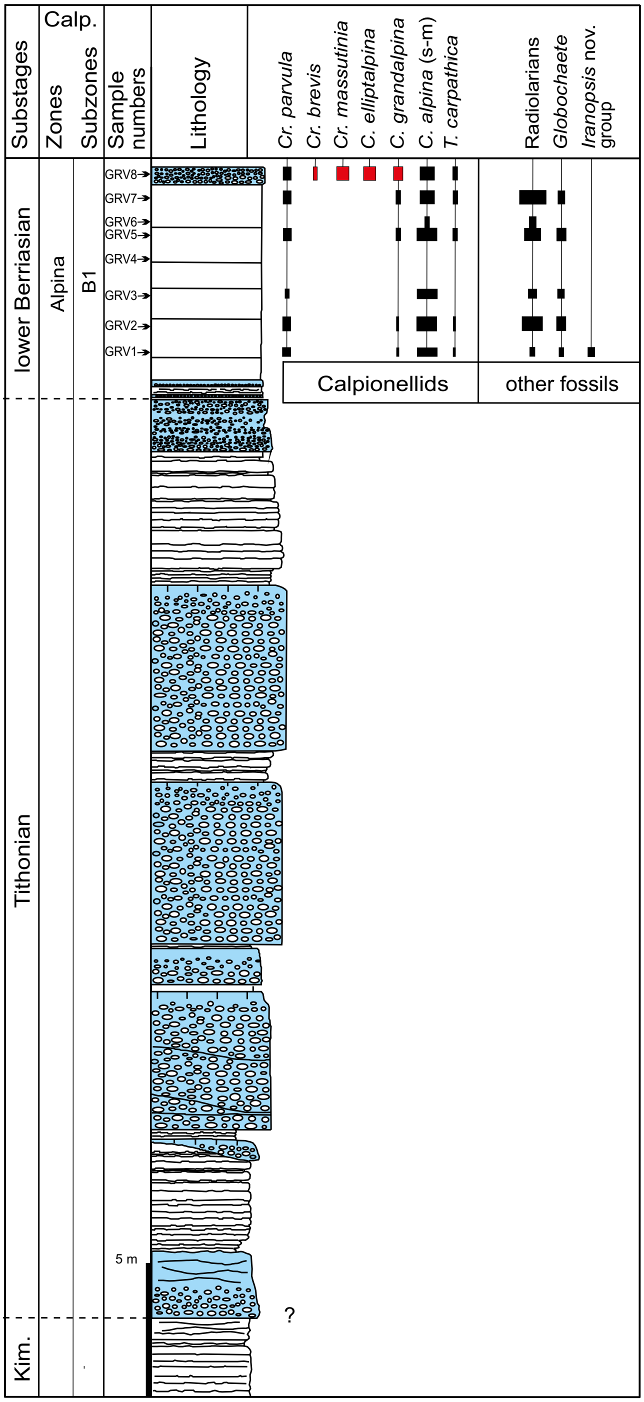


Fig. 2. Gouravour log displaying the lithological succession, the stratigraphic distribution of the main microfossil groups of the lower Berriasian, the calpionellid biozones, and the main reworked neritic elements

The red color in the distribution columns corresponds to reworked material. Mud- and wackestones in white color (autochthonous sediments); pack-, grain-, float- and rudstones in blue color (allochthonous sediments). Kimmeridgian/Tithonian boundary in the Gouravour section is traditionally set at the base of first breccia (see Ferry, 2017)

section (Wimbledon *et al.*, 2019, 2020c, fig. 4) did not report any fault. The Tré Maroua strike-slip fault (at the waterfall) was first documented by our group (Granier *et al.*, 2020b; https://youtu.be/aO-2R29gaMw, http://paleopolis.rediris.es/cg/20/01/TMF.mp4 or http://paleopolis.rediris.es/cg/20/01/TMF.avi) a few months before a new contribution of the former Berriasian Working Group (Wimbledon *et al.*, 2020b, Fig. 5) and that of another group of researchers (Grabowski *et al.*, 2022).

MATERIAL AND METHODS

The Tré Maroua section was sampled twice, first with labels ranging from TM16 to TM27 (first visit on 2019/07/24 by the first author, B.R.C.G.), a numbering which corresponds to that of Wimbledon *et al.* (2019, 2020b) when we were able to identify their pluggings, and second with labels ranging from 30 to 73 (second visit on 2019/10/03 by the third author, S.F.). During this second visit, another eight samples labelled from GRV1 to GRV8 were picked from the uppermost part of the Gouravour section, and both the Gouravour and Tré Maroua sections were fully (re-)logged with a Jacob's staff. The rock samples were cut and the derived slabs scrupulously examined in search for mud turbidites, grainy turbidites and debris flows. In addition, sets of thin sections were prepared to validate the identification of mud turbidites, identify the source of the lithoclasts (subautochthonous or allochthonous), and study the microfossil contents. All in all, more than 50 thin sections were prepared (44 for Tré Maroua and 8 for Gouravour). Compared to Granier *et al.* (2020b), we provide crucial information regarding the accurate location of the Tithonian/Berriasian boundary as defined by the primary proxy of the former Berriasian Working Group, *i.e.*, the base of an "acme" of *Calpionella alpina* Lorenz. We also provide information on the interval between the Tré Maroua fault and the erosional base of the first sedimentary breccia found about one meter above it (sample 50).

BIOZONES OF PELAGIC MICROORGANISMS

SACCOCOMID BIOZONES

For practical reasons, saccocomid sections have been named on the basis of their geometric shapes (Benzaggagh *et al.*, 2015a) as follows: 2Ax.act.br: biaxis with acute branches; 2Ax.brd.br: biaxis with broad branches; /ptd.bs: (...) and pointed basis; /psd-rtg.ax.tp: (...) and pseudo-rectangular axial tip; /elg.ax.tp: (...) and elongated axial tip; /rd.ax.tp: (...) and rounded axial tip; /shr.ax.pt: (...) and short

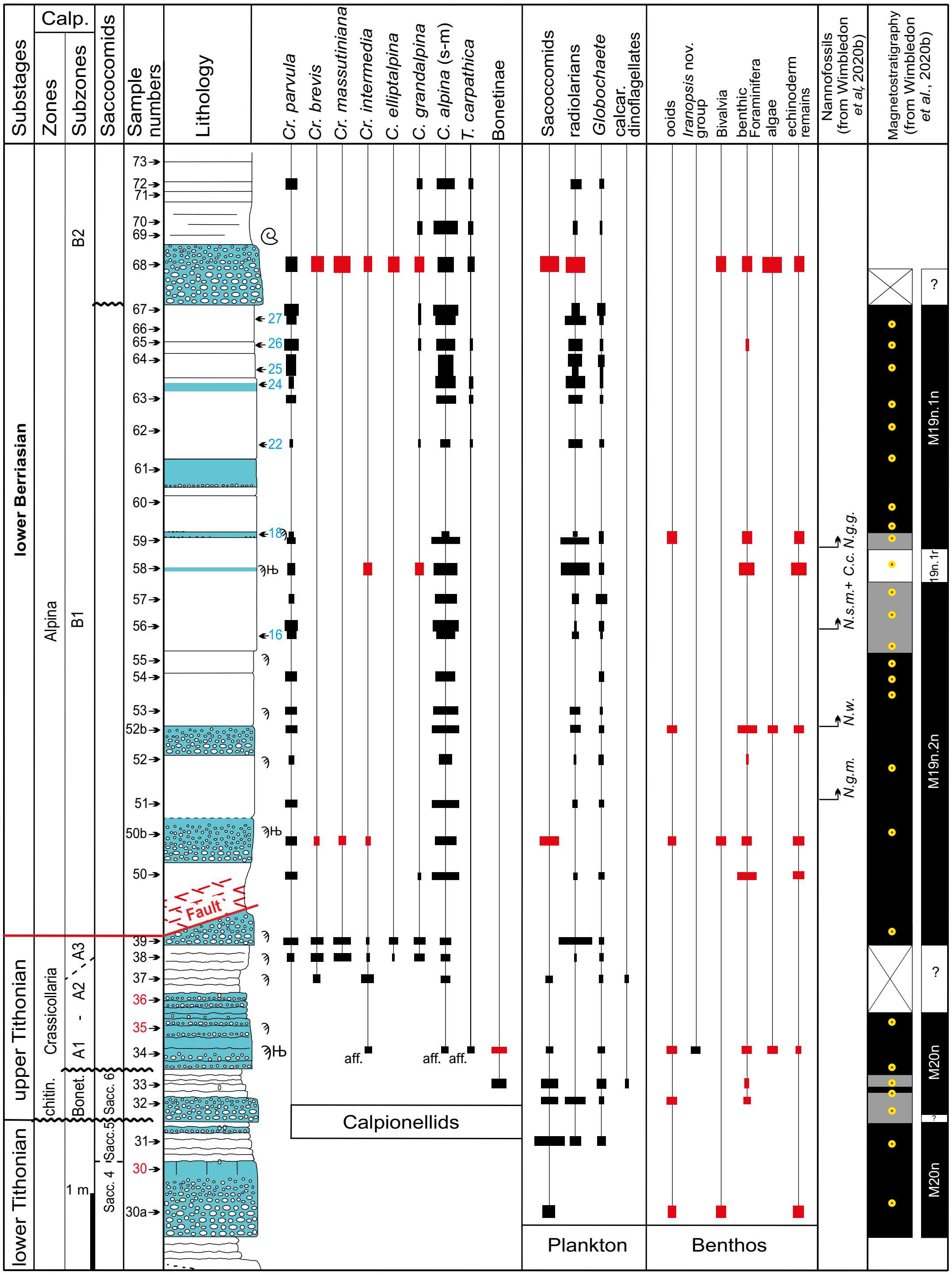


Fig. 3. Tré Maroua log displaying the lithological succession, the stratigraphic distribution of the main microfossil groups of the Tithonian – lower Berriasian, both the calpionellid and saccocomid biozones, and the main reworked neritic elements

There are no thin sections for the red sample numbers (30, 35, 36). Nannofossils from Wimbledon *et al.* (2020b): *N.g.m.* – *Nannoconus globulus minor*; N.w. – *Nannoconus wintereri*; *N.s.m.* – *Nannoconus steinmannii minor*; *C.c.* – *Cruciellipsis cuvillieri*; *N.g.g.* – *Nannoconus globulus globulus*. Magnetostratigraphy from Wimbledon *et al.* (2020b): yellow dots = pluggings. The blue labels TM16 to TM27 (on the right side of the log) correspond to our new sampling following Wimbledon's original numbering (2019, 2020b). The red color in the distribution columns corresponds to reworked material. Ƕ – belemnite rostrum, ℈ – *Aptychus*. Other captions as in Figure 2

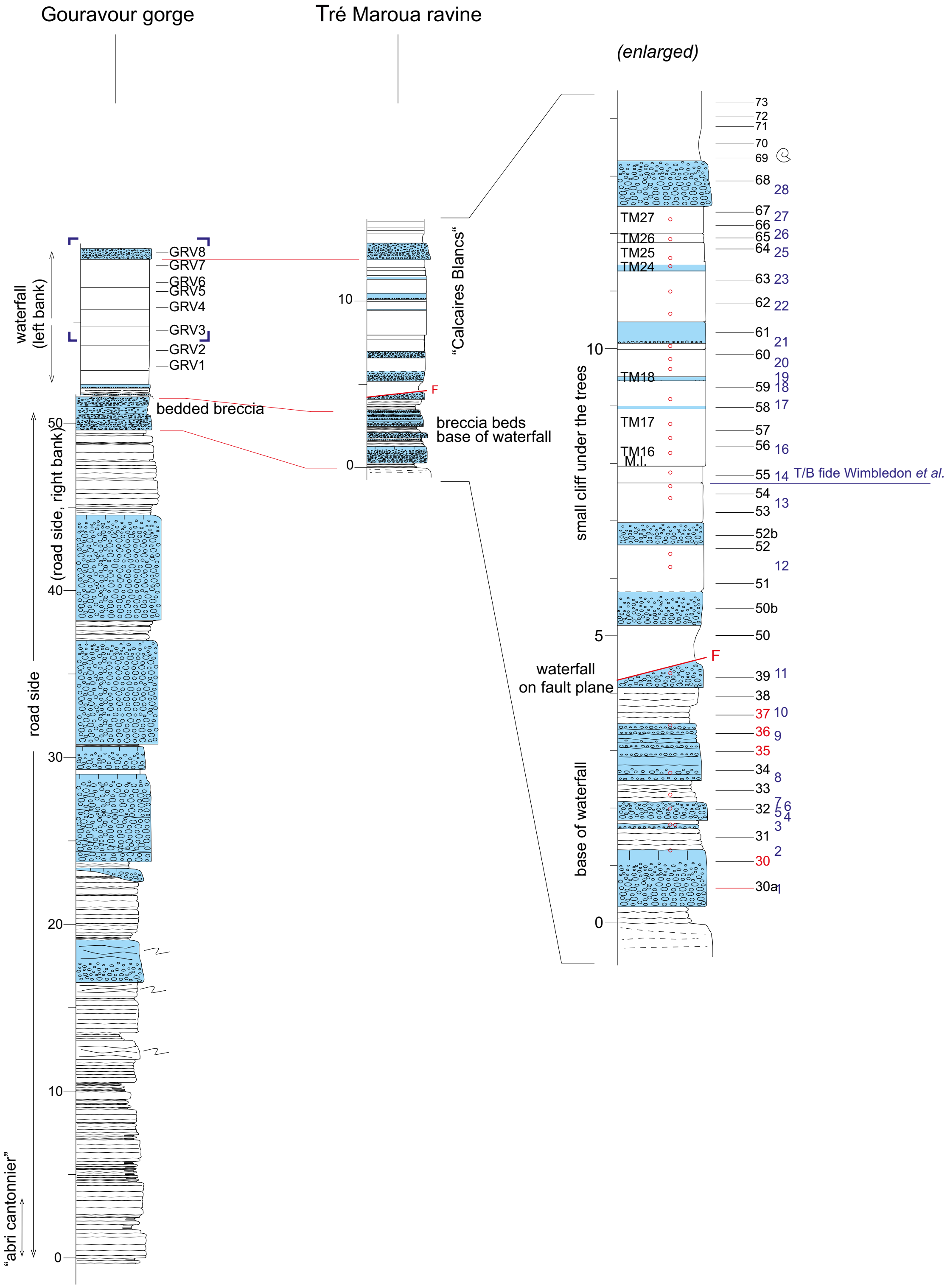


Fig. 4. Correlation of the Gouravour and Tré Maroua sections (at the same scale)

Same captions as in Figures 2 and 3. The blue labels (on the right side of the third – enlarged – log) correspond to Wimbledon's samples (2019, 2020b)

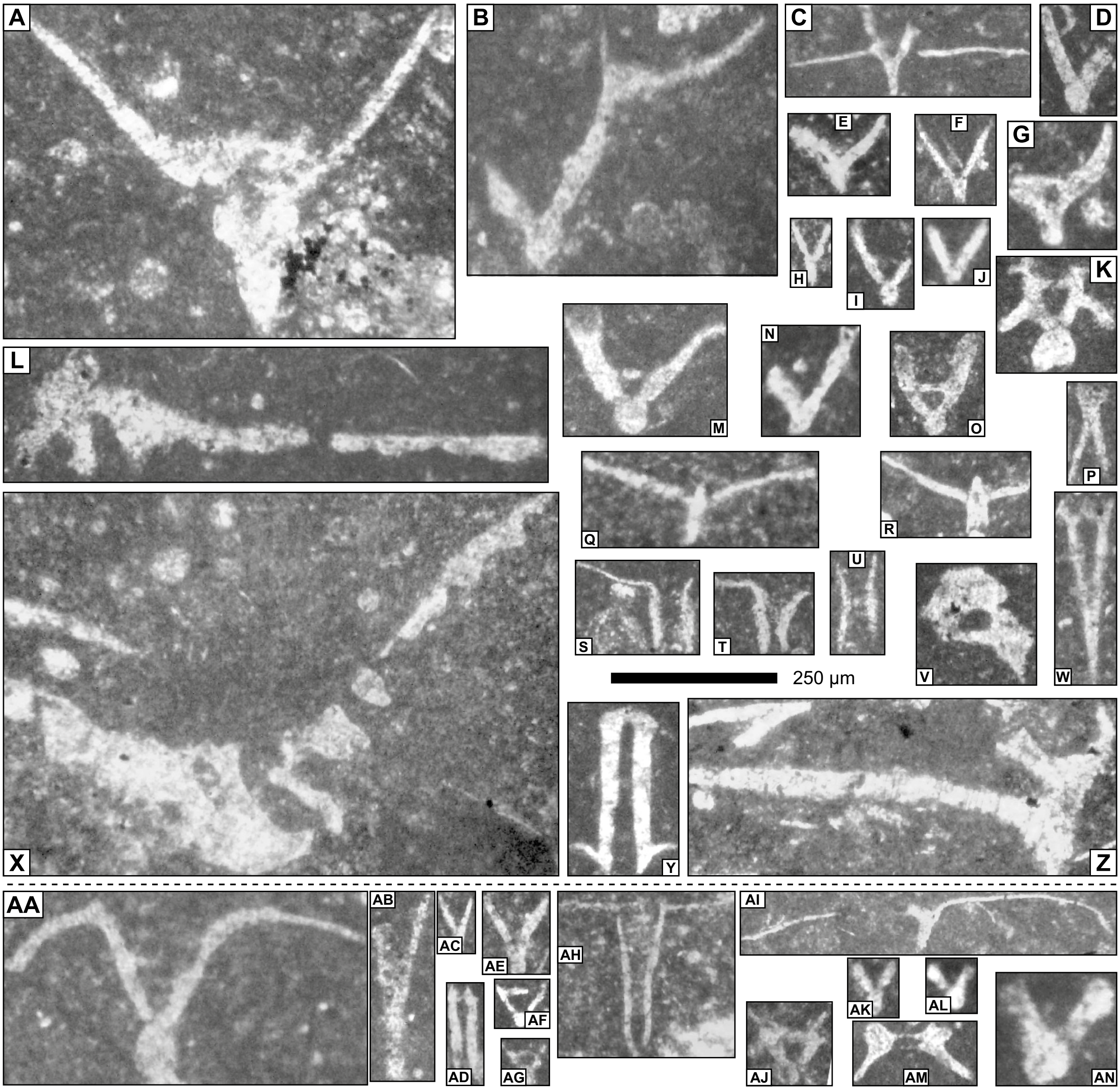


Fig. 5. Sections of skeletal elements of Tithonian saccocomids from the Tré Maroua section

A, Z. 2Ax.act.br/ptd.bs (large specimens); **B, N.** 2Ax.brd.br/psd-rtg.ax.tp (B, large specimen); **C.** 3Ax.act.br/2lat.apd; **D, I.** 2Ax.brd.br/rd.ax.tp; **E, F.** 2Ax. act. br/psd-rtg.ax.tp; **G, K, M, O.** brd.2Ax/trg.cvt; **H.** 2Ax.act.br/elg.ax.tp; **J.** 2Ax.act.br/shr.ax.pt; **L.** irg.Hd; **P.** elg.Tt; **Q, R.** tn.Wg/shr.ax.tp; **S, T.** 2prl.Br/elg.tp; **U.** 2prl.Br/smpl.tp; **V.** flt.psd-hxg.Hd/2lat.apd; **W.** 3Ax.brd.br; **X.** srd.Wg/tk.ts; **Y.** elg.ml.Tt/tn.flt.crw; **AA, AK, AL, AN.** 2Ax.brd.br/rd.ax.tp (AA, large specimen); **AB.** 3Ax.brd.br; **AC, AE.** 2Ax.act.br/elg.ax.tp; **AD.** 2prl.Br/smpl.tp; **AF, AG, AJ.** brd.2Ax/trg.cvt; **AH.** 2prl.Br/elg.tp; **AI.** 3Ax.act.br/2lat.apd; **AM.** brd.ml.Tt/tn.flt. crw. All photomicrographs with the same scale: scale bar = 250 µm.

All samples from the Tré Maroua section: A–Z: lower Tithonian, saccocomid zones 4 (30a) and 5 (31); AA–AN: upper Tithonian, saccocomid zone 6 (31–33). A, D–Q, S–W, AD: sample 31; B, C, R, X–Z: sample 30a; AA, AC, AE, AH–AK, AM: sample 32; AB, AF, AG, AL, AN: sample 33

axial tip; brd.2Ax/trg.cvt: broad biaxis with triangular cavity; 2tn.prl.Br: two thin parallel branches; 2prl.Br: two parallel branches; /smpl.tp: (...) with simple tips; /elg.tp: (...) with elongated tips; 3Ax.brd.br: triaxis with broad branches; 3Ax.act.br/2lat.apd: triaxis with acute branchs and two lateral appendices; srd.Wg/tk.ts: serrated wings with thick test;

tn.Wg/shr.ax.tp: thin wings with short axial tip; elg.Tt: elongated tooth; brd.ml.Tt/tn.flt.crw: broad molar tooth with thin and flat crown; elg.ml.Tt/tn.flt.crw: elongated molar tooth with thin and flat crown; flt.psd-hxg.Hd/2lat.apd: flattened pseudo-hexagonal head with two lateral appendices; irg.Hd: irregular head.

Saccocomid zones 4–5

Samples 30a and 31 are characterized by a saccocomid assemblage dominated by sections of large and massive shapes corresponding to the types: srd.Wg/tk.ts (Fig. 5X); irg.Hd (Fig. 5L); 2Ax.act.br/ptd.bs, large specimens (Fig. 5A, Z); flt.psd-hxg.Hd/2lat.apd (Fig. 5V); tn.Wg/shr.ax.tp (Fig. 5Q, R); brd.2Ax/trg.cvt (Fig. 5G, K, M, O); 2prl.Br/elg.tp (Fig. 5S, T); and 3Ax.act.br/2lat.apd (Fig. 5C). Additionally, it commonly includes the types: 2Ax.act.br (Fig. 5E, F, H–J); 2Ax.brd.br (Fig. 5B, D, N); 3Ax.brd.br (Fig. 5W); elg.Tt (Fig. 5P); 2prl.Br/smpl.tp (Fig. 5U); and elg.ml.Tt/tn.flt.crw (Fig. 5Y). These assemblages are characteristic of the lower Tithonian. Sample 30a with massive sections points to the saccocomid zone 4, equivalent to the Darwini Zone of the ammonites whereas sample 31 with less massive sections points to the saccocomid zone 5, equivalent to the Fallauxi Zone (Benzaggagh *et al.*, 2015a).

Saccocomid zone 6

Samples 32 to 34 are characterized by an assemblage of sections of smaller saccocomids, that are smaller in size and the tests of which are thinner. The assemblage is dominated by sections (including biaxial sections) of the following types: 2Ax.brd.br (Fig. 5AA, AK, AL, AN); 2Ax.act.br (Fig. 5AC, AE); brd.2Ax/trg.cvt (Fig. 5AF, AG, AJ); 3Ax.brd.br (Fig. 5AB); 2prl.Br/elg.tp (Fig. AH); 2prl.Br/smpl.tp (Fig. 5AD); brd.ml.Tt/tn.flt.crw (Fig. 5AM); and 3Ax.act.br/2lat.apd (Fig. 5AI). This assemblage is characteristic of the transition from the lower to upper Tithonian. It corresponds to the saccocomid zone 6, equivalent to the Ponti Zone and, *pro parte*, to the Microcanthum Zone (Benzaggagh *et al.*, 2015a).

CHITINOIDELLID ZONE (BONETI SUBZONE)

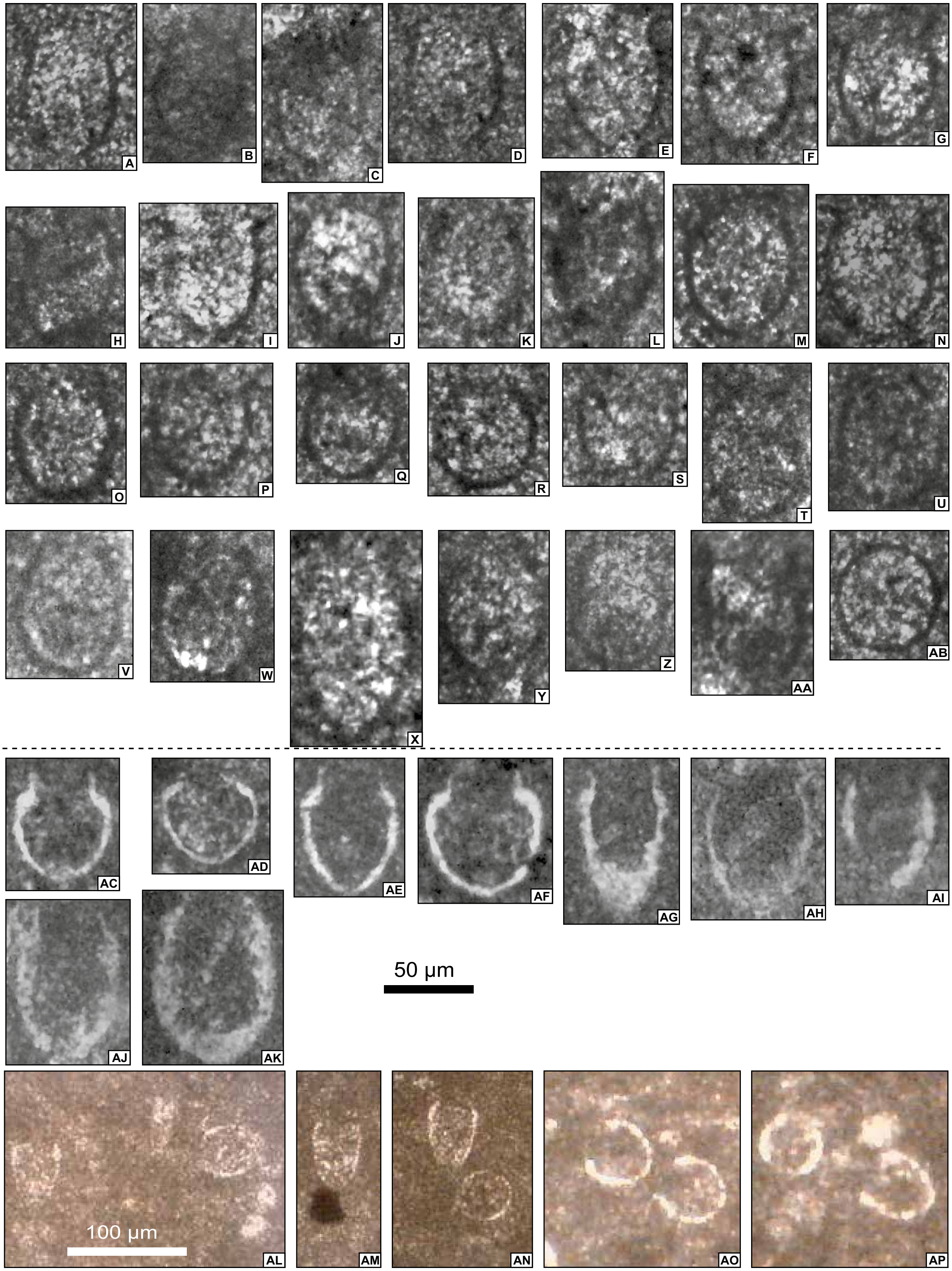
Only the Boneti Subzone of the lower part of the upper Tithonian has been characterized in the Tré Maroua section. Bonetinae have been identified in only two samples (33 and 34). The Boneti Subzone is characterized by a rich assemblage made of species exclusively ascribed to the subfamily Bonetinae Benzaggagh, 2021, with *Bonetilla boneti* (Doben) (Fig. 6A–D), *B. germanica* Benzaggagh (Fig. 6E–L), *B. lehegarati* Benzaggagh (Fig. 6M, N), *B. miniboneti* Benzaggagh (Fig. 6O–S), *B. popi* (Sallouhi *et al.*) (Fig. 6X), *B. sphaerica* Benzaggagh (Fig. 6T–W), *Furrazolaia cristobalensis* (Furrazola-Bermúdez) (Fig. 6Y, Z), *F.* sp. (Fig. 6AA), and various cross sections of Bonetinae (Fig. 6AB). Note that most of these species are here (?) mentioned for the first time for the Vocontian Trough. The first record of the Bonetinae Subzone was from Ardèche (Cecca *et al.*, 1989).

CALPIONELLID ZONES

Crassicollaria Zone (zone A)

This zone is characterized by the dominance of species of the genus *Crassicollaria*, mainly from the base of the subzone A2. It also contains *Calpionella alpina* and rare *Tintinnopsella* of small size (*Tintinnopsella pseudocarpathica* Benzaggagh *et al.*, 2012).

- **Tintinnopsella-Intermedia Subzone (subzone A1):** In layer 34 (a breccia), the calpionellid assemblage is dominated by *Tintinnopsella* aff. *carpathica* (Murgeanu & Filipescu), *Crassicollaria* aff. *intermedia* Durand Delga, *Calpionella* aff. *alpina* Lorenz (small size), and rare *Tintinnopsella remanei* Borza. This suggests that it be ascribed to the lower part of the Crassicollaria Zone (zone A), *i.e.*, the Tintinnopsella-Intermedia Subzone (A1). In addition, the micropaleontological assemblage comprises some *Colomisphaera fortis* (Nagy), *Col. tenuis* (Nagy), *Iranopsis* nov. group and radiolarians. Another thin section from the same layer was probably cut in a lithoclast because the facies is rather homogeneous and displays chitinoidellid sections (Fig. 6A, D, I–S, AB).
- **Intermedia-Alpina Subzone (subzone A2):** In sample 37, the calpionellid assemblage is dominated by typical *Crassicollaria* spp., *i.e.*, *Cr. intermedia* Durand Delga, *Cr. brevis* Remane, *Cr. massutiniana* (Colom) and also includes *Calpionella alpina* Lorenz (rounded and small in size, with some elongated specimens). Therefore, the median part of the Crassicollaria Zone (zone A), *i.e.*, the Intermedia-Alpina Subzone (A2), is identified here. In addition, the micropaleontological assemblage comprises some *Colomisphaera fortis* (Nagy), *Col. lapidosa* Vogler, saccocomids, and *Globochaete alpina* Lombard. The relative abundance of *Crassicollaria brevis* Remane in level 37 suggests that it should correspond to the uppermost part of the Intermedia-Alpina Subzone.
- **Brevis-Massutiniana Subzone (subzone A3):** In samples 38 and 39, the calpionellid assemblage is dominated by *Crassicollaria brevis* Remane and *Cr. massutiniana* (Colom).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50 μm
100 μm
AL
AM
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AP

Fig. 6. A–AB. Chitinoidellid specimens of the Boneti Subzone of the chitinoidellid Zone from the Tré Maroua section: A–D. *Bonetilla boneti* (Doben); E–L. *Bonetilla germanica* Benzaggagh; M, N. *Bonetilla lehegarati* Benzaggagh; O–S. *Bonetilla miniboneti* Benzaggagh; T–W. *Bonetilla sphaerica* Benzaggagh, slightly elongated specimens; X. *Bonetilla popi* (Sallouhi *et al.*); Y, Z. *Furrazolaia cristobalensis* (Furrazola-Bermúdez); AA. *Furrazolaia* sp.; AB. Transverse section of a Bonetinae specimen. **AC–AP.** Calpionellids of the Alpina-Parvula Subzone of the Alpina Zone from the Tré Maroua (AC–AK) and Gouravour (AC) sections: AC–AE, AO, AP. *Calpionella alpina* Lorenz (small size), AD. rounded oval lorica, AE. elongated oval lorica; AF. *Calpionella alpina* Lorenz (medium size); AG, AL–AN. *Crassicollaria parvula* Remane; AH. *Tintinnopsella carpathica* (Murgeanu & Filipescu); AI. *Tintinnopsella pseudocarpathica* Benzaggagh *et al.*; AJ, AK. *Calpionella elliptalpina* Nagy (specimens reworked from the uppermost part of the Crassicollaria Zone)

Photomicrographs A–AK: black scale bar = 50 µm; AL–AP: white scale bar = 100 µm. All samples from the Tré Maroua section, except AC (from the lower Berriasian of the Gouravour section): A, D, I–S, AB: upper Tithonian, in a lithoclast of the Boneti Subzone reworked at the bottom of the Crassicolaria Zone (34); B, C, E–H, T–AA: upper Tithonian, Boneti Subzone (33); AA–AN: lower Berriasian, Alpina-Parvula Subzone (50b, 54, 58) and Alpina-Remaniella Subzone (68). A, D, I–S, AB: sample 34; B, C, E–H, T–AA: sample 33; AC: sample GRV2; AD: sample 54; AE: sample 58; AF: sample 50b; AG–AK: sample 68; AL–AP: sample 50

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Therefore, it is ascribed to the upper subzone of the Crassicollaria Zone (zone A), *i.e.*, the Brevis-Massutiniana Subzone (A3). In addition to *Cr. brevis* and *Cr. massutiniana*, it includes some *Cr. parvula* Remane, *Calpionella alpina* Lorenz (small and medium size), *C. elliptalpina* Nagy, *C. grandalpina* Nagy, and rare *Crassicollaria intermedia* Durand Delga. The particular abundance of *Calpionella elliptalpina* Nagy and the absence of saccocomids in level 39 suggest that it should be restricted to the upper interval of the Brevis-Massutiniana Subzone, *i.e.*, the Parvula-Elliptalpina interval (Benzaggagh, 2020).

Note that *Calpionella elliptalpina* Nagy has been cited in high stratigraphic levels of the Crassicollaria Zone (subzone A3) from remote localities of the Tethys realm, *e.g.*, the outer Rif of Morocco (Benzaggagh, Atrops, 1995a; Benzaggagh, 2000; Benzaggagh *et al.*, 2010), the Vocontian Trough (Remane, 1963; Le Hégarat, Remane, 1968), the Betic ranges of southeastern Spain (Tavera *et al.*, 1994; Pruner *et al.*, 2010), Poland (Kowal-Kasprzyk, 2018), Serbia (Petrova *et al.*, 2012), Hungary (Nagy, 1986), Romania (Borza, 1969; Pop, 1998), Bulgaria (Lakova, Petrova, 2013), and Turkey (Atasoy, 2017; Atasoy *et al.*, 2018).

Alpina Zone (zone B)

The Alpina Zone was originally defined by Remane (1963) as an abundance interval (*op. cit.*, p. 62: "la prédominance du genre *Calpionella*"). Accordingly, his followers have focused on identifying the base of the "acmé" of *Calpionella alpina*. It is worth remembering that the base of this biozone is not characterized by the first occurrence of the index fossil but the base of its first acme. However, Wimbledon's summary figure (Wimbledon *et al.*, 2011, Fig. 1) identifies not less than "three '*C. alpina*' explosions". As discussed further in this paper, this "explosion" concept is rather misleading (*e.g.*, some mud turbidites are made of well-sorted calpionellid intraclastic micrograinstones and this kind of dynamic accumulation is not related to any biological bloom). Nevertheless, the Alpina Zone (zone B) could alternatively be defined by: i) the presence of the eponymic species, commonly associated with frequent *Crassicollaria parvula* (at its lower part) and/or large *Tintinnopsella carpathica* and *Calpionella alpelliptica* (at its upper part), and ii) the disappearance of all *Crassicollaria* spp. except for the aforementioned species, *i.e.*, *Crassicollaria parvula*. In other words and to follow Remane's concept, the Alpina Zone (zone B) is characterized by the predominance of the genus *Calpionella* over the genus *Crassicollaria*. At Tré Maroua, this zone starts at least from the sample 50 (Fig. 6AL–AP) that was picked in the uncertainty interval of Granier *et al.* (2020b) for the stage boundary, *i.e.*, a one-meter interval between the basal erosional surface of the breccia 50b above it and the Tré Maroua fault below it. Initially Granier *et al.* (2020b) reported that the base of this zone falls at least at the bottom of breccia 50b, *i.e.*, some three meters below the location choice of the former BWG (Wimbledon *et al.*, 2020c). It is now assumed that the base of this zone most probably coincides with the fault plane. In contrast to the preceding Crassicollaria Zone (zone A), the Alpina Zone (zone B) is represented by a relatively thick series.

- **Alpina-Parvula Subzone (subzone B1):** The interval between samples 50 and 67 (including TM16 to TM26) is dominated by *Calpionella alpina* Lorenz, small to medium in size, with spherical (Fig. 6AD) or oval elongated lorica (Fig. 6AE). It also contains larger (*i.e.*, medium in size) specimens of *Calpionella alpina* Lorenz (Fig. 6AF, AO, AP). *Crassicollaria parvula* Remane (Fig. 6AL–AN) are still common, but there are no other *in situ Crassicollaria* species.
- **Alpina-Remaniella Subzone (subzone B2):** This subzone is still dominated by *Calpionella alpina* Lorenz and contains frequent *Crassicollaria parvula* Remane (Fig. 6AG). It starts with the first occurrence of the *Remaniella duranddelgai* Pop (Benzaggagh, Atrops, 1995b). This species, which is often rare in the levels of the Alpina Zone, has not been characterized in the section studied. However, the

reappearance of large specimens of *Calpionella alpina* ("*Calpionella grandalpina*") and the presence of frequent specimens of both *Tintinnopsella carpathica* (Murgeanu & Filipescu) (Fig. 6AH) and *T. pseudocarpathica* Benzaggagh *et al.* (Fig. 6AI) point to a relatively high stratigraphic position within the Alpina Zone for the samples ranging from 68 to 73. This interval, which presents similarities with series known from the outer Rif (Benzaggagh, Atrops, 1995b) and northern Tunisia (Ben Abdesselam-Mahdaoui *et al.*, 2011), is ascribed to the Alpina-Remaniella Subzone (subzone B2).

Tithonian calpionellids from the Crassicollaria Zone and Tithonian saccocomids are commonly found in pseudointraclasts of the Berriasian debris flows and calciturbidite levels. For instance, sample 50b contains *Crassicollaria brevis* Remane, *Cr. massutiniana* (Colom), and *Cr.intermedia* Durand Delga, whereas sample 68 contains the above three *Crassicollaria* species plus *Calpionella elliptalpina* Nagy (Fig. 6AJ, AK) and C*alpionella grandalpina* Nagy from the subzone A3 of the Crassicollaria Zone.

MACROFACIES AND MICROFACIES

The measured sections span two lithostratigraphic units: the "brèches tithoniennes" (Tithonian breccias) below and the "calcaires blancs" (white limestones) above. However, in detail, and as shown in the logs, there is no clear boundary between the two units: lime mudstone layers locally occur between conglomeratic beds of the Tithonian breccias and conglomeratic layers sporadically occur in the white limestones. That merely reflects the decreasing intensity of the resedimentation with debris flows and associated calciturbidites over the Tithonian-Berriasian interval. Only the dominant type of macrofacies justifies this prevailing subjective subdivision. The macrofacies of some samples have already been described in a previous paper (Granier *et al.*, 2020b), which focused on identifying conglomerates at the transition from the Tithonian to the Berriasian. Lithoclastic rudstone and grainstone facies form the mass of the debris flows (Granier *et al.*, 2020b, fig. 4) and associated grainy turbidites, whereas the "background facies" of the white limestones consists of mud- to wackestone facies with calpionellids, radiolarians and/or saccocomids. Besides these two main facies categories, the presence of a third facies, which is hardly detectable with a hand lens on the field (Granier *et al.*, 2020b, fig. 5), is fully revealed by thin sections under a standard microscope. It consists of the so-called mud turbidites or cryptoturbidites, *i.e.*, well-sorted micrograinstones with a very finely lithoclastic composition. In another section, at Le Chouet (Les Près, Drôme), similar microfacies have been inadequately identified as biopelmicrosparites or biopelsparites (Wimbledon *et al.*, 2013, fig. 8.2–4, 8.6). Most allochems that are less than 100 µm in diameter are not bioclasts or peloids but mostly small rounded pseudointraclasts, commonly consisting of a calpionellid lorica filled and coated by micritic mud (Fig. 7M). In turn, these cryptoturbidites can be reworked to form larger (millimeter to centimenter scale) pseudointraclasts (Granier *et al.*, 2020b, pl. 3, fig. A; Fig. 7P herein).

ALLOCHTHONOUS (EXTRACLASTIC) MATERIAL

Whereas pseudointraclasts are the larger ones (up to pluricentimetric) and have smooth subrounded shapes, the extraclasts are commonly smaller and more angular. Reworked sponges (Granier *et al.*, 2023, fig. 11N), bryozoans, algae, or microbial encrusters (Fig. 7J) and other larger remains may eventually be re-ascribed to this category. Material reworked from the shallow environments of a neighbouring platform edge comprise extraclasts (Figs. 8D, 9A), ooids (Figs. 5N, O, 9K), Bivalvia, bryozoans and serpulids (Fig. 9I), calcareous and siliceous sponges, sea urchin radioles and various echinoderm remains (Fig. 7K), calcareous algae and incertae sedis (Figs. 8D, 9A, B, among which are *Iberopora bodeuri* and *Thaumatoporella parvovesiculifera* Raineri: Fig. 9C, D), and foraminifers. The benthic foraminifers, mostly reworked from an updip shallow-water area, are the more diverse: Ataxophragmiids, Textulariids, Lenticulinids

→

Fig. 7. Microfacies and main pelagic microfossil groups of the Tithonian – lower Berriasian of the Tré Maroua (A–G, I) and Gouravour (H) sections, microfacies and microfossils of reworked lithoclasts (J–P), bioturbation (Q)

A. Pseudointraclast with a calpionellid wackestone facies (containing abundant *Calpionella alpina* Lorenz and common *Crassicollaria parvula* Remane); **B.** Saccocomid wackestone; **C.** Radiolarian wackestone; **D, E.** Radiolarian sections; **F, G.** Calcareous dinoflagellates. F. *Colomisphaera lapidosa* (Vogler), G. *Cadosina radiata* Vogler, **H.** *Iranopsis* nov. group; **I.** *Globochaete*, in the form of two joined pieces; **J.** Microbial *cayeuxia*-like encrusters; **K–M.** Grainstone facies of the calciturbidites (M with lithoclasts containing calpionellids – white arrows – of the Crassicollaria Zone); **N, O.** Concentric calcitic ooids; **P.** Pseudointraclast made of the calciturbitide facies; **Q.** Burrow in a mudstone facies.

Photomicrographs A–J and M–O: scale bar = 250 µm; K, L, P, Q: scale bar = 500 µm.

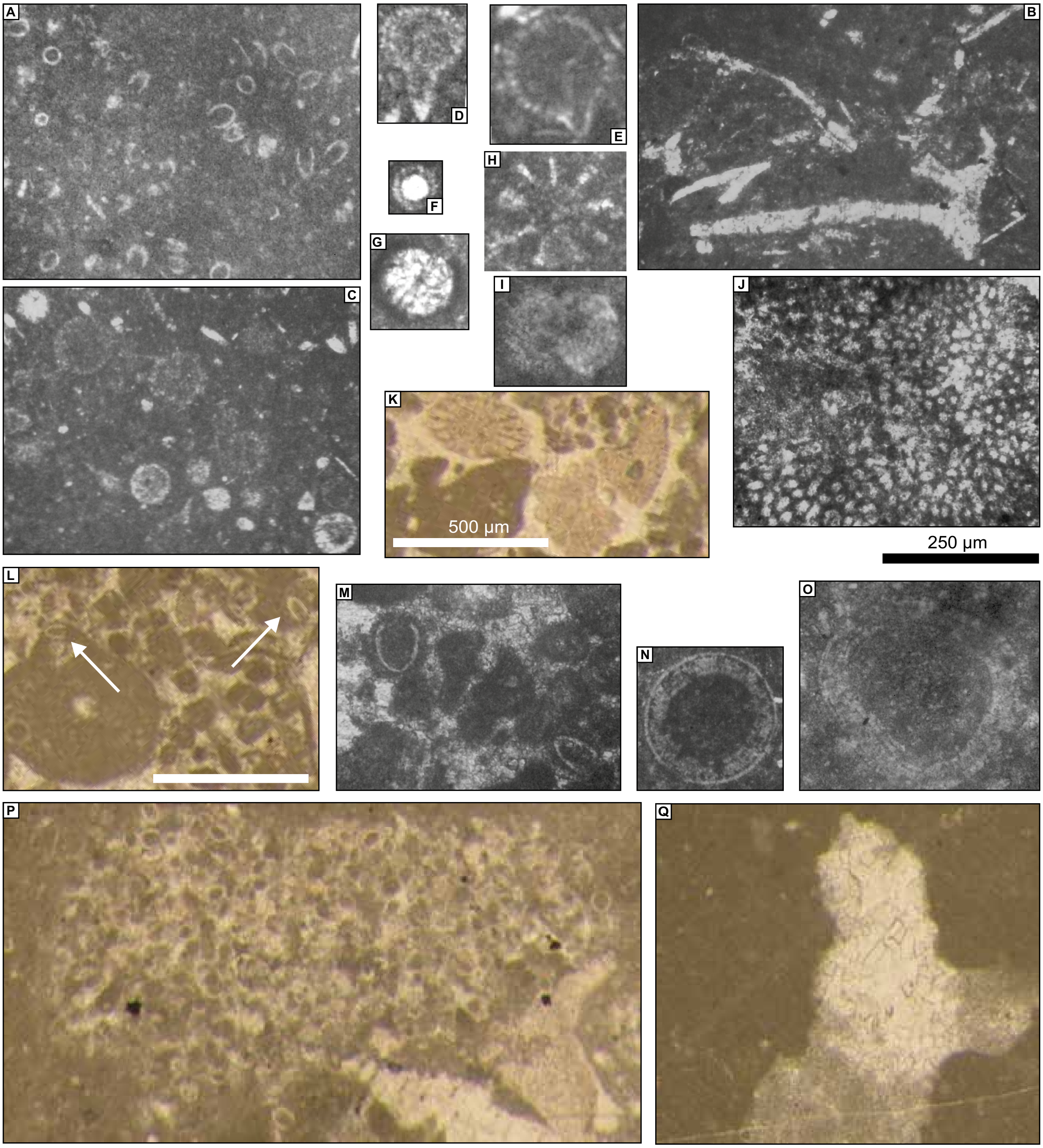
All samples from the Tré Maroua section, except H (from the lower Berriasian of the Gouravour section): B–E, N: lower Tithonian; I: upper Tithonian; A, J–M, O: lower Berriasian. A, J, O: sample 68; B: sample 30a; C–E, N: sample 32; F, G, I: sample 33; H: sample GRV2; K, L: sample 50b; M: sample 50; P: sample 58; Q: sample TM18

(Fig. 9L), Miliolids (Fig. 9M), *Ichnusella* sp. (Figs. 8C, E, 9J), *Coscinoconus* sp. (Fig. 9J), and *Mohlerina basiliensis* (Mohler) (Fig. 9H), as well as the *incertae sedis*: *Koskinobullina socialis* Cherchi & Schroeder (Fig. 9I), *Tubiphytes* sp. (Fig. 9F) and microbial encrusters (Fig. 7J).

Locally, the grains described above are floating in a matrix made of finer bioclasts, peloids and/or microlithoclasts.

AUTOCHTHONOUS AND (PSEUDOINTRACLASTIC) SUBAUTOCHTHONOUS MATERIAL

Mudstones and wackestones with saccocomids, calpionellids, calcareous dinoflagellates, and/or radiolarians correspond to the regular accumulation of pelagic material falling and accumulating on the sea bed. Besides the pelagic



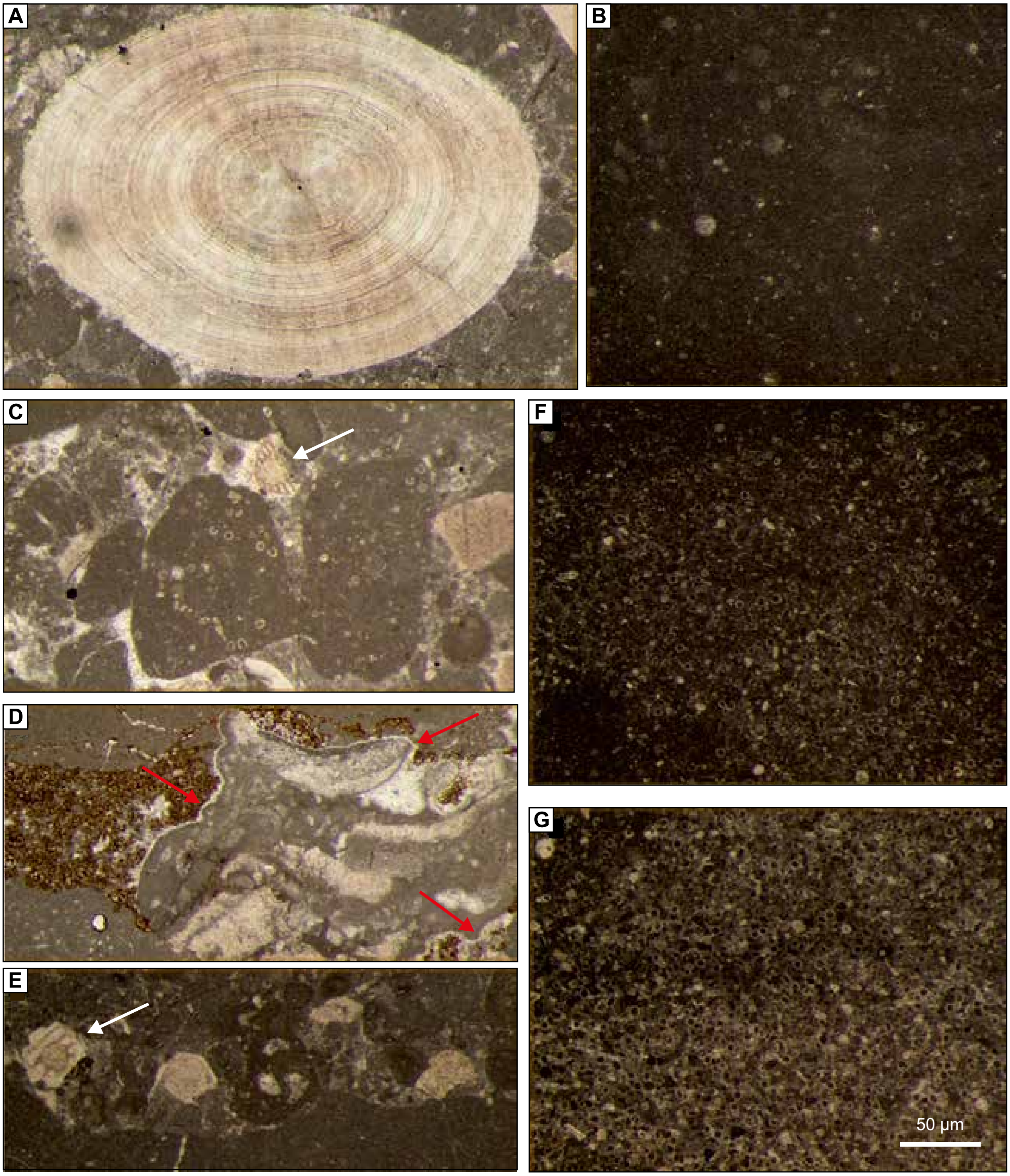


Fig. 8. A. Subtransverse section of a belemnite rostrum; **B, F, G.** Upward gradation from a mud turbidite to autochthonous mud; **C.** Pseudointraclasts and bioclasts in a coarse-grained turbidite interval (white arrow: *Ichnusella* sp.); **D.** Extraclast made of the red alga (?) *Ethelia* and microbial encrusters, with early marine palisadic cement (red arrows); **E.** Erosional surface (white arrow: *Ichnusella* sp.)

All photomicrographs with the same scale: scale bar on G = 500 µm. All samples from the Tré Maroua section: A, C: sample 58; B, E–G: sample 52b; D: sample 68

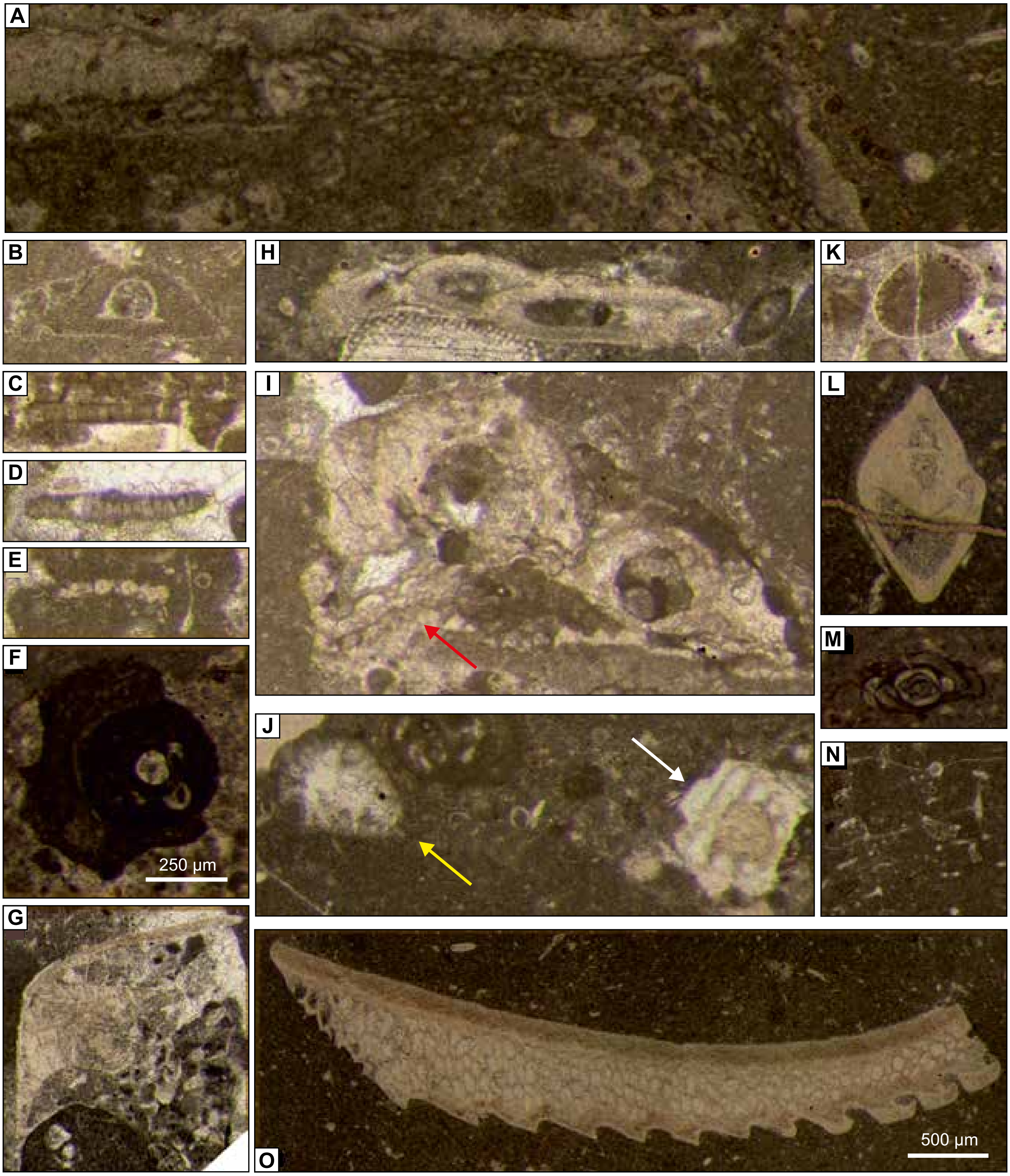


Fig. 9. A. Microbial (?) encrusters or *Pycnoporidium* sp.; **B.** *Iberopora bodeuri*; **C, D.** *Thaumatoporella parvovesiculifera* Raineri; **E.** *Globochaete* sp.; **F.** *Tubiphytes* sp.; **G.** Piece of ammonite jaw; **H.** *Mohlerina basiliensis* (Mohler); **I.** Extraclast with serpulids, bryozoans and *Koskinobullina socialis* Cherchi & Schroeder (red arrow); **J.** *Ichnusella* sp. (white arrow) and *Coscinoconus* sp. (yellow arrow); **K.** Concentric calcitic ooid; **L.** Lenticulinid; **M.** Miliolid; **N.** Network of siliceous sponge spicules; **O.** *Aptychus*

Photomicrographs A–F, H–M: scale bar on F = 250 µm; G, N, O: scale bar on O = 500 µm. All samples from the Tré Maroua section: A, F, M, N: sample 34; B, J: sample 52b; C: sample 50; D, K: sample 59; E, G–I: sample 58; L, O: sample 35 groups of microorganisms, the thin sections contain various subautochthonous and autochthonous bioclasts, either small (*e.g.*, sponge spicules: Fig. 9N) or larger ones [*e.g.*, ammonite upper: Fig. 9G, and lower (aptychii): Fig. 9O, jaws; and belemnite rostrums: Fig. 8A].

The mudstones and wackestones with planktonic microfossils are also commonly found within all breccias in the form of lithoclasts, which were labelled "extraclasts" in our preceding paper (Granier *et al.*, 2020b) because they did not result from an *in situ* deposition process but of a lateral dismantling of older strata and resulting deposition of the erosion products in our study site. A single breccia layer may contain saccocomid wackestone lithoclasts, calpionellid wackestone lithoclasts (Fig. 7K, M) and radiolarian wackestone lithoclasts. These lithoclasts are not intraclasts because they do not result from the *in situ* dismantling of the same and single layer but that of several discrete layers. Because they resemble the mudstones and wackestones, commonly with mud-supported fabrics, that form the background sedimentation and in order to differentiate them from the genuine extraclasts derived from the shallow-water areas, they are referred to here as "pseudointraclasts".

Chitinoidellids: Level 33 of the Tré Maroua section is rich in specimens of chitinoidellids (Fig. 6A–AB), *i.e.*, representatives of the subfamily Bonetinae (Benzaggagh, 2021). They also occur in level 34 in pseudointraclasts.

Calpionellids: The first specimens of calpionellids (*i.e.*, those with a hyaline test) are found in levels 34 (in a breccia) and 37 of the Tré Maroua section. They correspond to advanced morphotypes dominated by *Crassicollaria* spp. In levels 50 to 73, calpionellids are always present and often abundant. Their assemblages are largely dominated by *Calpionella alpina* Lorenz. Because the limited sampling interval of the Gouravour section (GRV1 to GRV8) roughly corresponds to the upper part of the Tré Maroua section from levels 52 and 68. Samples GRV1 to GRV8 also display this calpionellid assemblage dominated by *Calpionella alpina* Lorenz.

Saccocomids: In the Tré Maroua section, saccocomid sections are found in levels 30 to 34. In levels 30a to 31 (Figs. 5A–Z, 7B), they are dominated by large and massive forms (Fig. 5A, L, X, Z) whereas, in levels 32 to 37, they are dominated by smaller and less massive forms (Fig. 5AB–AN). With the notable exception of sample 50b, (some 2 meters above sample 37), and sample 68 (about 10 meters above sample 37), which both correspond to reworked material in breccia lithoclasts, the group is absent above sample 34. However, note that no petrographic thin section is available for samples 30, 35, 36.

Radiolarians: Present from near the base of the Tré Maroua section (Fig. 7C), numerous 2D radiolarian sections with a huge variety of shapes (Fig. 7D, E) are visible in our petrographic thin sections. There are local peaks of abundance, *e.g.*, in level 39 at the top of the Crassicollaria Zone (A3) and in levels 58 to 66 of the upper part of the Alpina-Parvula Subzone (B1). They also occur in samples GRV1 to GRV7 of the Gouravour section.

Calcareous dinoflagellates and *Globochaete*: Unlike the previous groups, these two fossil groups are rather rare and often missing in the two studied sections of the Vocontian basin compared to the series of the other Tethys basins, particularly those of North Africa [*e.g.*, Morocco (Benzaggagh, Atrops, 1996) and northern Tunisia (Benzaggagh *et al.*, 2015b)] or Eastern Europe (Borza, 1969, 1984). In the Tré Maroua section, calcareous dinoflagellates are represented by rare specimens of *Colomisphaera lapidosa* (Vogler) (Fig. 7F) and *Cadosina radiata* Vogler (Fig. 7G). A few scattered *Globochaete* specimens are found in thin sections of both the Tré Maroua (*e.g.*, Fig. 7I) and Gouravour sections.

Iranopsis n. group: This group was originally identified in the Berriasian – lower Valanginian strata of Alborz (NW Iran), where it is abundant, as "pièces de sclérites d'holothuries" (=pieces of holothurian sclerites, Benzaggagh *et al.*, 2012). The original mineralogy could have been silicon dioxide (silica) or unstable calcium carbonate (aragonite). This group occurs lower in the stratigraphic column, *i.e.*, in the upper Tithonian strata, at Tré Maroua, whereas it is recorded from the lower Berriasian strata of the Gouravour section. It is represented by rare specimens in both the Gouravour (GRV1: Fig. 7H) and Tré Maroua (34) thin sections.

EROSIONAL FEATURES

There is inherently no relationship between the thickness of a debris flow or a turbidite layer at a location and the amount of material that was eroded from this same location and that accumulated downdip. There is no relationship either between the depth of erosion at a location and the amount of material accumulated above the erosion surface at this same location.

In the Gouravour section, the thicknesses of the lower and upper Tithonian are estimated to be ~35 meters and ~2 meters, respectively. In the Tré Maroua section, the Dobeni Subzone of the chitinoidellids was not identified, suggesting that the lower part of saccocomid zone 6 could be missing. In other words, the uppermost lower Tithonian is probably missing. In turn, the upper Tithonian is anomalously thin compared to the lower Tithonian or the lowermost Berriasian (>>10 m). The subzones A1 and A2 of the Crassicollaria Zone (zone A) are identified respectively at level

34, which was sampled at the bottom of a median one-meter thick set of breccia, and at level 37.

In both sections, pseudointraclasts with upper Tithonian saccocomids or *Crassicolaria* spp. are found in Berriasian strata stratigraphically above and even considerably above the lithoclastic source layer, providing a metric to decametric scale evidence for the related lateral updip submarine erosion. Sample 50b in the Tré Maroua section contains lithoclasts with saccocomid remains from various saccocomid zones, more than 3 meters above sample 33 (ascribed to the saccocomid zone 6 and the Boneti Subzone of the chitinoidellids). Sample 58 in the Tré Maroua section contains *Crassicolaria* lithoclasts (Granier *et al.*, 2020b, pl. 3, figs. B, C), more than 5 meters above sample 39 (ascribed to the Crassicollaria subzone A3). Both samples, 68 in the Tré Maroua section and GRV8, its lateral equivalent, in the Gouravour section, contain calpionellid lithoclasts, especially from the Crassicollaria Zone (zone A), more than 9 meters above sample 39 (ascribed to the Crassicollaria subzone A3), and also saccocomid lithoclasts of various saccocomid zones, more than 10 meters above sample 34 (ascribed to the saccocomid zone 6 and of the Boneti Subzone of the chitinoidellids).

In a larger scale regional study, Courjault (2011) and Courjault *et al.* (2011) showed that the Vocontian Trough – the deepest part of the Subalpine Basin where some Tithonian/Berriasian boundary sections have been investigated – was at that time a morphologically complex basin partly filled in by large breccia lobes anchored on its slopes. Its deepest part, where the Tré Maroua section is located, presents a staircase morphology with terraces alternating with steeper slopes often robbed of their deposits to build small breccia lobes like the Céüse lobe (Ferry *et al.*, 2015; Ferry, 2017), a few kilometres northeast of the Le Saix area. Photographic panoramas of the “Tithonian cliff” in the region also illustrate complex depositional geometries with superimposed erosional surfaces, especially within the lower Tithonian breccias (Ferry, 2017). In such a geological context most sections of the Tithonian-Berriasian transition are stratigraphically non-continuous. They all must be scrutinized carefully not only because of possible large hiatuses due to synsedimentary gravity processes, but also because of small-scale biostratigraphic reworking through mud turbidites which are often hard to spot in the field.

CONCLUSION

The Tithonian – lower Berriasian successions of the Tré Maroua and Gouravour sections show pelagic assemblages with calpionellids, saccocomids and/or radiolarians quite similar to those known from other sectors of the Tethys realm, particularly those from the southwestern Tethys basins of North Africa. Only the *Iranopsis* n. group, which, to date, has never been reported from the coeval series of the southern Tethys margin, appears to be restricted to northern Tethys basins.

Our biostratigraphical analyses, combined with sedimentological analyses, suggest that most zonal boundaries (biozonal as well as some magnetozonal boundaries, *e.g.*, base M18r or base of M19n.20, see Granier *et al.*, 2020b, fig. 3.B) are hiatal, specifically meaning that they are more probably related to submarine erosion rather than to non-deposition episodes (Granier *et al.*, 2023). Wimbledon *et al.* (2020a) have clearly minimized the significance of sedimentological features such as breccia, turbidites, and related erosional phenomena (Granier *et al.*, 2023). Additionally, our calpionellid study suggests that the stage boundary between the Tithonian and the Berriasian (*i.e.*, the boundary between the Crassicollaria Zone below and the Calpionella Zone above) in the Tré Maroua section could match a fault plane (Granier *et al.*, 2020b), more than 3 meters below the boundary location proposed by the former Berriasian Working Group (Wimbledon *et al.*, 2020b, fig. 5). Therefore, it is not a stratigraphic boundary as expected but a tectonic boundary, another reason to reject this GSSP candidate.

The estimated depths of lateral (updip) erosion, the frequency of debris flows and turbidites, including cryptoturbidites, and the abundance of subautochthonous pseudointraclasts in the Tithonian – lower Berriasian interval, as well as the aberrantly reduced thickness of the upper Tithonian, document the paleotectonic instability of the area and even of a wider region in the Vocontian Trough. It is unlikely that a suitable Berriasian GSSP boundary meeting all requirements for identification of such a boundary could be found in a section recording so much sedimentary instability (Granier *et al.*, 2023). This is in contradiction with the expectations of the “Colloque sur la limite Jurassique/Crétacé” held in Lyon in 1973 (Flandrin *et al.*, 1975).

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