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The Meso-Cenozoic stratigraphic succession of the Col de Braus area (Maritime Alps, SE France)

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UNIVERSITÀ DEGLI STUDI DI TORINO

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- The Meso-Cenozoic stratigraphic succession of the Col de Braus area (Maritime
 Alps, SE France)
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14 Abstract

15 The 1:10,000 geological map here presented extends over about 32 Km² around the Col 16 de Braus pass in the Maritime Alps (SE France). This area attracted the attention of 17 geologists since the late XVIII century due to superb exposures of the Jurassic-18 Cretaceous Provençal succession, and has become a classic geological locality 19 continuously studied until the present day. In this area, Early Cretaceous synsedimentary 20 tectonics is evidenced by important lateral thickness and facies variations. This sector is 21 presently placed at the western termination of a large structural domain extending from the 22 westernmost Ligurian Alps into the French-Italian Maritime Alps, thus representing a key-23 area to understand the structural setting of this part of the Western Alps.

24

25 Keywords:

26 Provençal Domain; Mesozoic; Nice Arc; Col de Braus; Maritime Alps; SE France

27

1. Introduction and geological setting

29 The Col de Braus area, in the Nice inland (Maritime Alps, SE France), represents a key-30 sector for the geology of SE France, as confirmed by the long history of the geological 31 researches that there have been carried out over more than two centuries (see Chapter 3). 32 It corresponds to the southeastern sector of the Alpine External Domain (Dauphinois Domain) that was part, during the Mesozoic, of the European passive margin of the Alpine 33 34 Tethys. In the Paleogene, the study area became part of the Alpine Foreland Basin that 35 developed in front of the Alpine chain after the first stages of continental collision between 36 Europe and Adria (Crampton & Allen, 1995).

The stratigraphic succession unconformably rests on a crystalline basement, currently cropping out in the Argentera Massif, and starts with a thick Upper Carboniferous–Permian continental succession, followed by Lower Triassic siliciclastic coastal deposits, Middle 40 Triassic peritidal carbonates, and Upper Triassic evaporites, related to the early stages of 41 the Alpine Tethys rifting. In the Early Jurassic, the European margin differentiated into a 42 platform domain (Provençal) and a basinal domain (Dauphinois), as a result of extensional 43 tectonics during the Alpine Tethys rifting (Dardeau 1988). In the Provencal Domain, after a period of emersion which included most of the Early Jurassic, Middle-Late Jurassic 44 45 sedimentation occurred in a carbonate platform environment (Lanteaume, 1968). 46 Valanginian tectonics resulted in the drowning of the carbonate platform (Debelmas & Kerckhove 1980), followed by the deposition, in the study area, of Hauterivian-lower 47 48 Cenomanian p.p. condensed, open-marine shelfal deposits, showing important lateral 49 variations related to synsedimentary tectonics (Pasquini, Lualdi, & Vercesi, 2004; Decarlis 50 & Lualdi 2008). After shelf drowning in the early Cenomanian, a thick hemipelagic 51 succession deposited (early Cenomanian p.p.-Campanian). The top of the Mesozoic 52 succession is truncated by a regional unconformity corresponding to a latest Cretaceous-53 middle Eocene hiatus. Above, the Alpine Foreland Basin succession starts with laterally 54 discontinuous continental to coastal deposits (Microcodium Formation, Faure-Muret & 55 Fallot 1954), followed by the middle Eocene ramp Nummulitic Limestone, the hemipelagic 56 upper Eocene Globigerina Marl and the upper Eocene-lower Oligocene Grès d'Annot 57 turbidite succession (Ford, Lickhorish, & Kuznir, 1999; Sinclair, 1997).

58 The map area is located at the transition between two structural domains, the Nice Arc and 59 the Roya Arc (Bulard et al., 1975; Gèze, 1963; Perez, 1975) showing different trends of 60 major folds and thrusts (see structural scheme in the Map). The Nice Arc shows variably 61 orientated folds and thrusts, trending NNW-SSE in the western part and E-W to NE-SW in 62 the southern and southeastern part (Bulard et al., 1975; Gèze, 1963; Perez, 1975). The Roya Arc is the westernmost part of a larger structural domain (Roya-Argentina Unit; 63 64 Piana et al., 2014; d'Atri, Piana, Barale, Bertok, & Martire, in press), extending from the westernmost Ligurian Alps (Nervia-upper Argentina valleys) to the eastern part of the 65

Maritime Alps and bounded toward the north by the Argentera Massif. This domain, 66 67 showing NNW-SSE to N-S fold trends, has been the target of detailed geological survey 68 in the last 15 years by a research group of the Italian National Research Council (Istituto di 69 Geoscienze e Georisorse) and Torino University (Earth Science Department). The related 70 results have been only partly published (Piana et al., 2014; d'Atri et al., in press). The Col 71 de Braus area is located at the western termination of this domain and will be therefore 72 important in the definition of its western boundary, which is possibly identifiable in the 73 Rocca Serra–Ongrand Thrust (ROT; Guardia, Ivaldi, Dubar, Guglielmi, & Perez, 1996).

The map is focused on a small area surrounding the Col de Braus pass, which was previously mapped in the Menton–Nice sheet of the Geological Map of France at 1:50,000 (Gèze, Lanteaume, Peyre, & Vernet, 1968). The large representation scale of the presented map (1:10,000) allowed detailed mapping of geological features, in particular:

- the lateral variations of Lower Cretaceous lithostratigraphic units, particularly significant
in this area;

the distribution of laterally discontinuous continental deposits at the base of the Alpine
 Foreland Basin succession (*Microcodium* Formation), which were not represented in
 previous maps; and

- the sites with the newly recognized cold-water colonial corals at the top of the NummuliticLimestone.

85

86 2. Geohistorical and scientific significance of the Col de Braus area

On the western side of the Col de Braus, the Jurassic–Cretaceous Provençal succession and the lower part of the Eocene Alpine Foreland Basin succession are continuously exposed in a natural stratigraphic section over a thickness of about 1200 m (Figure 1(a), (b)). This section has been firstly mentioned during the late 18th–early 19th century (Beaumont, 1795; Buckland, 1829; Omalius d'Halloy, 1810; Perez, 1847; Risso, 1826;

92 Sismonda, 1848; Sulzer, 1780), and has soon become a "classic" locality for the geology 93 of the Maritime Alps (e.g., Boussac, 1912; Caméré, 1877; Demay, 1984; Fallot, 1885; 94 Gignoux & Moret, 1937; Hébert, 1877; Kilian & Reboul, 1908; Lanteaume, 1968; Potier, 95 1877). In the past decade, detailed stratigraphic and sedimentological analyses have 96 focused on glaucony- and phosphate-rich Lower Cretaceous condensed deposits (Barale, 97 d'Atri and Martire, 2013; Decarlis & Lualdi, 2008; Pasquini et al., 2004, and discussion by 98 Parize et al., 2005; Pasquini and Vercesi, 1999). Different paleontological studies have 99 been dedicated to the fossil-rich Barremian deposits cropping out near Saint Laurent (Bert and Delanoy, 2000; Bert et al., 2006; Delanoy, 1990, 1992; Delanoy, Magnin, Selebran, & 100 101 Selebran, 1991). The Upper Cretaceous succession of the Col de Braus section was also the subject of detailed biostratigraphic analyses of planktonic for a minifera and calcareous 102 103 nannofossils (Conard, 1978; Conard & Manivit, 1979), palynofacies (Götz, Feist-Burkhardt, 104 & Ruckwied, 2008), and ammonites (Thomel, 1992).

105

106 **3. Methods**

107 The geological map is drawn at 1:10,000 scale and covers an area of approximately 32 108 km². Data were collected through original fieldwork, stored in a GIS database (Coordinate 109 system: NTF (Paris)/Lambert zone II extended) and represented on a vector topographic 110 map, which has been completely redrawn on the SCAN 25[®] EDR map (1:25,000 scale) of 111 the French National Geographic Institute (IGN).

Names of lithostratigraphic units already existing in the literature have been utilized (Alpine Foreland Basin units, and the Grès Verts of the Cretaceous succession). The other Cretaceous units, for which no names existed in the literature, have been newly named after study area localities. Jurassic units have been not renamed, due to their limited extension in the study area, and are referred to using a lithological term preceded by their age (e.g., Callovian dolostones). 118

119 **4. Structural setting**

120 The main structural feature of the mapped area is the SW-vergent Rocca Serra-Ongrand 121 Thrust (ROT; Guardia et al., 1996) also known as Rocca Serra-Touët de l'Escarène Thrust (Bulard et al., 1975). This is a NW-SE-striking, low-angle reverse fault, 122 123 characterized by a metre-thick shear zone with intense cataclastic deformation, which in 124 the study area runs almost entirely within the Upper Cretaceous succession and has scarce morphological evidence. The ROT crosses the whole map area, dividing it in two 125 structural domains. Its footwall domain is deformed by hectometre- to kilometre-scale, 126 127 NNW-SSE trending, WSW-vergent open to tight flexural folds, involving the Upper Cretaceous and the Alpine Foreland Basin successions (l'Escarène and Mortisson 128 129 synclines, l'Escarène anticline), with highly inclined axial surfaces and axes gently 130 plunging toward SSE. The ROT hangingwall domain is instead characterized by a 131 kilometre-scale, NNW-SSE trending open syncline (Col de Braus syncline), affecting the 132 Jurassic-Cretaceous and the Alpine Foreland Basin successions on both sides of the Col 133 de Braus.

On the western limb of this syncline, just above the ROT, the Jurassic-Lower Cretaceous 134 succession is involved in a complex structure, known in the literature as "Écaille 135 intercutanée de la Graye de Touet" [Graye de Touet intracutaneous wedge] (Gèze, 1963). 136 This is a non-cylindrical structure, whose overall N170 strike is oblique to the strike of the 137 138 ROT. In its middle part (Ruisseau de Redebraus valley), it is represented by a kilometre-139 scale fault-propagation fold affecting the Upper Cretaceous succession and related to the 140 propagation of a blind thrust (Touët de l'Escarène Thrust, TET; section C–C' in the Map) that causes the local superposition of the Jurassic succession of the Cime de la Graye 141 onto the Upper Cretaceous succession cropping out near Touët de l'Escarène. The latter 142 is characterized by development of drag fold sequences, kinematically consistent with the 143

144 TET sense of shearing (Figure 2(a)). Toward the north (Roccaniera), the TET evolves as a 145 faulted anticline with a highly inclined axial surface and hectometre-scale slices of 146 Jurassic-Lower Cretaceous succession in its core (see section A–A' in the Map), whereas 147 toward the south it merges in the ROT.

148

149 **5. Stratigraphy**

The description of lithostratigraphic units focuses oneasily observable field characters, i.e. lithology and macrofossil content. References given beside unit names refer to the age attribution, whereas unit descriptions, if not otherwise specified, are based on original data fully reported in Barale (2010).

154

155 **5.1.** Jurassic succession

156 It consists of a 300-metres-thick carbonate platform succession, mainly cropping out in the
157 Ruisseau de Redebraus valley, downstream of Saint Laurent.

158

159 5.1.1. Middle Jurassic limestones (Bajocian–Bathonian; Gèze et al., 1968)

Medium- to thick-bedded limestones (packstones/grainstones and rudstones with oncoids, ooids, bioclasts and intraclasts), locally showing a selective dolomitization of the matrix (Figure 2(b)), alternating with medium- to coarsely-crystalline dolostone beds (shallowwater carbonate platform deposits). In the study area, only the uppermost part of this unit crops out (about 20 m thick, referred to the Bathonian; Decarlis, 2005), due to its basal truncation by the TET.

166

167 5.1.2. Callovian dolostones (Callovian; Dardeau, 1983)

Light brown to beige, medium- to coarsely-crystalline dolostones (locally sucrosic),, in decimetre-thick beds; no fossils or internal structures are preserved (carbonate platform deposits). This unit, about 80 m thick, is cut at the top by an unconformity which
corresponds to a hiatus spanning the latest Callovian–early Oxfordian (Dardeau & Thierry,
1976).

173

174 5.1.3. Oxfordian limestones (middle–late Oxfordian; Dardeau & Thierry, 1976)

Brown to dark grey, thin- to medium-bedded limestones (bioclastic mudstones to wackestones and minor bioclastic packstones), with belemnites, crinoids, bivalves, gastropods, ammonites, solitary corals, and benthonic foraminifera (outer open-platform deposits). Thickness: 40–50 m.

179

5.1.4. *Kimmeridgian limestones (Kimmeridgian–Tithonian p.p.; Dardeau & Thierry, 1976)*Light brown, massive limestones (bioclastic wackestones to packstones and grainstones,
bioclastic rudstones), showing a grey colour on weathered surfaces. Abundant reddishbrown chert nodules, disposed in decimetre-spaced layers, give the rock a bedded
appearance. Open-platform deposits. Thickness: 70–80 m.

185

186 5.1.5. Tithonian limestones (Tithonian p.p.–early Berriasian p.p.; Dardeau & Thierry, 1976) 187 Light-grey massive limestones, consisting of bioclastic-oncoidal-ooidal packstones, grainstones and rudstones, locally passing to coral boundstones. The abundant fossil 188 content consists of nerineid gastropods, thick-shelled bivalves, corals, echinoderm 189 190 fragments, calcareous red and green algae, benthic foraminifera. The uppermost metres 191 are mainly composed of crinoid-rich grainstones. At the top of the unit, a decimetre-thick 192 conglomerate bed with rounded, centimetre-sized reddish intraclasts in a Fe-oxide-rich 193 packstone matrix with millimetre-sized authigenic quartz crystals, is probably referable to 194 an emersion episode. Shallow-water carbonate platform deposits. Thickness: 80 m.

195

196 **5.2.** Lower Cretaceous succession

197 It consists of a peritidal succession (Cime de la Graye Limestone), followed by open-198 marine shelfal deposits characterized by low sedimentation rates (Grès Verts, Clarissia 199 Formation), and shows important lateral variations (Figure 3) related to synsedimentary 200 tectonics (e.g., Decarlis & Lualdi, 2008; Montenat, Hibsch, Perrier, Pascaud, & de Bretizel, 201 1997; Pasquini et al., 2004). On the eastern side of the Col de Braus ridge (Cime de 202 Ventabren, Vallon du Parais), the thickness of the Cime de la Grave Limestone and the Clarissia Formation is reduced to a few metres each. Therefore, they have been 203 204 represented as a unique cartographic unit on the map.

205

206 5.2.1. Cime de la Graye Limestone (early Berriasian p.p.–late Berriasian; Dardeau & 207 Pascal, 1982)

208 Medium- to thick-bedded, light-gray to beige limestones, locally alternating with very thin 209 beds of greenish marls and nodular mudstones with a greenish marly matrix. Limestone 210 beds commonly have an erosional base and show the following internal lithofacies 211 organization (shallowing-upward peritidal cycles; e.g., Wilson, 1975): bioclastic 212 packstones/rudstones (2–10 cm); bioturbated, peloidal-bioclastic mudstones/wackestones 213 (20–100 cm); laminated mudstones with fenestral porosity, millimetre-sized black pebbles, and mud cracks (Figure 2(c)), locally passing to flat-pebble breccias (10-40 cm). 214 Decimetre-thick beds of bioclastic wackestones/packstones with Clypeina jurassica and 215 216 miliolids are locally present (lagoonal sediments; Figure 2(d)). Thickness: 4–25 m.

217

5.2.2. Clarissia Formation (early Hauterivian p.p.–early Aptian p.p.; Barale, 2010; Delanoy,
1992)

This unit rests on a mineralized hard ground (HG1) developed on top of the underlying Cime de la Graye Limestone.The hard ground, locally encrusted by serpulids and 222 ferruginous microstromatolites (Figure 2(e)), is covered by a centimetre-thick lag deposit 223 made up of mineralized intraclasts and bioclasts (Hypophylloceras ponticuli, Cymatoceras 224 sp., belemnites). Above, a thin stratigraphic interval (0-1 m), rich in mixed Fe-oxidephosphate ooids is locally present (Barale et al., 2013). This interval is made up of 225 226 bioturbated ooidal wackestones/packstones (Figure 2(f)), with reworked cephalopods (Acanthodiscus sp., Lytoceras sp., Phylloceratidae, Cymatoceras sp.), belemnites 227 228 (Duvalia sp.), echinoderms, brachiopods, bivalves, and fish teeth. It is followed by medium-bedded glauconitic limestones (Figure 4(a)) and marly limestones, with Duvalia 229 230 sp., Cruasiceras cruasense (Figure 5(a)), Crioceratites sp., Cymatoceras sp., passing 231 upward to thin-bedded bioclastic mudstones and wackestones, with centimetre-thick marly 232 interbeds, containing *Crioceratites* sp. (Figure 4(b)), *Toxaster* sp., and belemnites (4–20) 233 m). At the top of this interval, a mineralized hard ground is present (HG2).

234 In the northwestern sector (Clarissia, Roccaniera), HG2 is followed by a condensed interval made up of glauconitic-phosphatic limestones (120-140 cm, with Moutoniceras 235 sp. and belemnites), bioclastic-lithoclastic conglomerates (50-60 cm), and glauconitic 236 limestones (50-60 cm). The conglomerates are made up of reworked bioclasts and 237 238 centimetre-sized, angular to subrounded limestone intraclasts, commonly phosphatized or 239 impregnated by Fe-oxydes. The reworked bioclasts include ammonites (Barremites difficilis, Macroscaphites sp., Hypophylloceras ponticuli, Pseudohaploceras matheroni, 240 Pachyhemihoplites contei, P. dardeaui, Martelites sp., Gassendiceras alpinum, Peirescites 241 242 sp., Heinzia sayni, Gerhardtia provincialis, G. sp., Coronites darsi, Kotetishvilia 243 sauvageaui, Hemihoplites feraudianus, H. astarte, H. soulieri, H. sp., Emericiceras sp., 244 Imerites giraudi, Heteroceras baylei, H. emerici, Argvethites sp., Audoliceras sp., Camereiceras sp., Lytoceras sp.) (Figure 5(b-f)), belemnites, nautiloids (Cymatoceras 245 sp.), brachiopods, gastropods, bryozoans, and wood fragments. This interval shows 246 important lateral variations: at Saint Laurent it is represented by a 40-50-cm-thick 247

bioclastic–lithoclastic conglomerate bed, followed by a 15–20-cm-thick bed of glauconitic
limestone; in the eastern and southern sectors (Albaretta, Vallon du Parais) it reduces to a
centimetre-thick bioclastic–lithoclastic lag resting on HG2.

251

5.2.3. Grès Verts (early Aptian p.p.–early Cenomanian p.p; Thomel & Lanteaume, 1967;
Thomel, 1992)

In the western sector, this unit starts with a 8–10-metre-thick alternation of glaucony-rich dark marls and marly limestones, with ammonites (*Lithancylus* sp.) and nautiloids (*Paracymatoceras* sp.). At the top of this interval, a mineralized hard ground (HG3) is followed by a decimetre-thick bioclastic–lithoclastic conglomerate bed. In the eastern sector (Vallon du Parais), this interval is not present and the Grès Verts is lying on a polygenic hard ground (HG2+HG3), developed at the top of the Clarissia Formation and followed by a centimetre-thick bioclastic–lithoclastic lag.

261 The rest of the unit is made up of decimetre-thick beds of bioturbated glauconitic marly 262 limestones, with ammonite molds (Puzosia sp.) and echinoids, associated with thickbedded hybrid glauconitic arenites and glauconarenites, commonly bioturbated, with large-263 264 scale cross-stratification (Parize et al., 2005; Pasquini et al., 2004) and decimetre-sized, 265 brownish carbonate concretions (20-40 m). At the top, a decimetre-thick bed of bioturbated, fossil- and glaucony-rich calcareous marl is present It contains early 266 267 Cenomanian (saxbii Subzone) ammonites (Mantelliceras picteti (Figure 5(g)), M. mantelli, 268 *M. cantianum*, *M. tuberculatum*, large macroconchs of *Puzosia mayoriana* (Figure 4(c)), 269 Schloembachia sp.), echinoids (Protocardiaster sp., Camerogalerus sp.), brachiopods, 270 belemnites, bivalves, and lamniform selachian teeth (Figure 4(d)). This bed marks the 271 drowning of the shelf.

272

273 5.3. Upper Cretaceous succession

It consists of a thick deep water hemipelagic succession of marls and marl–limestonealternations.

276

5.3.1. Saint Laurent Marl (early Cenomanian p.p.–late Cenomanian; Conard, 1978;
Thomel, 1992)

Gray, clayey-silty marls, with decimetre-thick marly limestone interbeds whose thickness 279 280 and frequency increase toward the top of the unit. The fossil content in the lower part of 281 the unit is abundant: ammonites (Mantelliceras saxbii, Schloembachia subvarians, Puzosia mayoriana, Hypoturrilites sp., Turrilites costatus, Cunningtoniceras cunningtoni 282 283 (Figure 5(h)), Acanthoceras rhotomagense, Eucalycoceras sp., Calycoceras sp., Newboldiceras sp., Phylloceratinae), terebratulids, belemnites (Neohibolites sp.), 284 echinoids (Camerogalerus cylindricus, Holaster subglobosus), and bivalves (Inoceramus 285 286 sp.). Thickness: 60-80 m.

287

288 5.3.2. Mont Auri Limestone (Turonian–late Coniacian p.p.; Conard & Manivit, 1979)

Marly limestones (planktonic-foraminifera mudstones and wackestones) with thin marl 289 290 interbeds, passing toward the top to medium-bedded limestones (bioclastic wackestones 291 and packstones), with echinoids (Micraster sp., Holaster sp.) and bivalves (Inoceramus sp.). In the upper part, grey-coloured chert nodules, and thin- to medium-bedded 292 resedimented glauconitic lithoarenites and hybrid glauconitic arenites are present. These 293 294 beds have an erosional base, locally followed by imbricated clay chips or by a centimetrethick lag consisting of Inoceramus fragments, and show normal grading and parallel 295 296 lamination. Thickness: 300 m.

297

5.3.3. Caire de Braus Marl (late Coniacian p.p.-middle Campanian; Conard & Manivit,
1979)

Alternation of medium- to thick-bedded marls and marly limestones (Figure 4(e)), commonly bioturbated (*Zoophycos*), with *Inoceramus* sp., echinoids, planktonic foraminifera and rare ammonite molds. In the uppermost 100 metres, thin resedimented beds of bioclastic packstones with planktonic foraminifera and glaucony are present, showing erosional base, normal grading and parallel lamination. Thickness: 350 m.

305

306 **5.4.** Alpine Foreland Basin Succession

307 It is represented in the study area by the *Microcodium* Formation, the Nummulitic
308 Limestone and the *Globigerina* Marl, cropping out in the core of the Col de Braus,
309 l'Escarène and Mortisson synclines.

310

311 5.4.1. *Microcodium Formation (Lutetian? –early Bartonian; Varrone & Clari, 2003)*

312 Lenticular bodies, 0–15-m thick, including from base to top the following, laterally
313 discontinuous, facies and facies associations:

- polygenic, clast-supported conglomerates, with marly limestone and limestone clasts
(locally encrusted by *Microcodium*) mainly derived from the underlying Upper Cretaceous
succession, with arenitic or marly matrix with *Microcodium* fragments (S Col de Braus
syncline; l'Escarène; Blanchières) (alluvial fan–fluvial deposits);

- silty marls, containing decimetre-thick, lens-shaped bodies of clast-supported
conglomerates and decimetre-thick beds of quartz-rich arenites with reworked glaucony
grains (NE l'Escarène syncline; Mont Brec) (alluvial plain sediments with channellized
fluvial deposits);

- medium- to coarse-grained, thick-bedded quartzarenites, with erosional base, clay chips,
and trough cross-stratification, locally containing centimetre-thick conglomerate beds (SW
Col de Braus syncline). *Ophiomorpha* burrows are locally preserved as hypichnia at the
base of this interval (coastal deposits).

326 The *Microcodium* Formation unit represents the infilling of an incised valley system during 327 the first stage of the Alpine Foreland Basin development (Varrone & Clari, 2003).

328

329 5.4.2. Nummulitic Limestone (Bartonian p.p.; Varrone & Clari, 2003)

This unit consists of mixed siliciclastic-carbonate ramp deposits. Its base is represented by a transgressive erosional surface, locally covered by a centimetre- to decimetre-thick conglomerate lag and developed on the *Microcodium* Formation or directly on top of the Upper Cretaceous succession. In the latter case, it consists of a polygenic discontinuity surface, pitted by abundant *Gastrochænolites* bivalve borings (Figure 4(f)). From base to top, the following facies and facies associations are present:

- thick- to very thick-bedded, medium- to coarse-grained quartzarenites showing an
erosional base and normal gradation, grading upward to medium- to fine-grained
bioclastic–lithic arenites, with larger benthic foraminifera (*Nummulites*), ostreids, echinoids
and rare solitary corals (inner- to middle-ramp deposits);

- medium-bedded, medium- to fine-grained allochemic sandstones and siltstones, with
 Nummulites, bivalves, gastropods, solitary corals, echinoids, scaphopods, and *Teredolites* bored wood fragments, passing upward to an alternation of intensely bioturbated, fine grained allochemic sandstones and calcareous marls (outer ramp deposits).

In the Col de Braus syncline, the top of the unit is represented by a decimetre-thick interval of fine-grained, glaucony-bearing hybrid arenite, locally containing cold-water colonial corals (whose study is currently in progress). This interval marks the drowning of the ramp.

347

348 5.4.3. Globigerina Marl (late Bartonian p.p.–Priabonian; Varrone, 2004)

349 Dark-grey deep water hemipelagic silty marls, light-gray to yellowish on the weathered 350 surface, with abundant planktonic foraminifera and rare bivalves, showing centimetre- to 351 decimetre-thick bedding, commonly obliterated by intense bioturbation. 352

353 5.5. Quaternary deposits

The detailed study of Quaternary deposits is out of the scope of this work, therefore they will be only listed as they appear on the map. They have been subdivided into five large groups: anthropic deposits; undifferentiated alluvial deposits; slope and talus debris; cemented talus breccias; landslide accumulations.

358

359 6. Lucéram arsenic mine

At Roccaniera, near Lucéram, an arsenic mineralization was exploited during the XIX– early XX centuries (Caméré, 1877; Lacroix, 1897; Orcel, 1918). The mineralization affects the Grès Verts and the lower part of the Saint Laurent Marl and consists of decimetrethick, nearly bed-parallel veins, filled-up by calcite, orpiment, realgar, barite and fluorite (Féraud, 1970). It also yelded specimens of talmessite, a rare arsenate mineral (Mari & Mari, 1982).

366

367 7. Conclusions

The 1:10,000 Geological Map of the Col de Braus area gives a detailed representation of a sector of great scientific relevance, which also represents a historical locality for SE France geology. This map constitutes a useful complementary document to address specific features regarding both stratigraphic and structural issues of lively geological interest, namely:

- the stratigraphy and sedimentology of Lower Cretaceous condensed deposits, which
have been the focus of various publications in the last years (e.g., Barale *et al.*, 2013;
Decarlis & Lualdi, 2008; Pasquini *et al.*, 2004);

- the distribution of laterally discontinuous continental deposits at the base of the Eocene
Alpine Foreland Basin succession (*Microcodium* Formation), as well as the position of the

outcrops with newly-reported colonial cold-water corals at the top of the NummuliticLimestone;

the structural setting of an area located at the western termination of a large structural
 domain, extending across the Ligurian and the Maritime Alps, which has been the object of
 a pluriannual detailed work of structural and stratigraphic analysis.

383

384 Software

The compilation of the geological map, including the preparation of the topographic base, was done using QuantumGis 2.0 Dufour. The final layout of the map, the geologic sections, the tectonic sketch map, and the figures have been prepared and assembled using ACD[®] Canvas12.

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569 Figure captions

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Figure 1. Panoramic view (a) and explanatory sketch (b) of the Col de Braus stratigraphic succession exposed on the northern side of the Ruisseau de Redebraus valley (background); in the foreground, the transition from the Tithonian limestones to the Cime de la Graye Limestone cropping out near Albaretta, on the southern side of the same valley. Image taken from Albaretta locality (43°50'56.3" N; 7°22'37.5" E), looking northwards.

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Figure 2. Field and thin section features of the stratigraphic succession in the Col de Brausarea. (a) Chevron drag folds in the in the marl-limestone alternations (Caire de Braus Marl)

580 in the footwall of the Touët de l'Escarène Thrust, cropping out along the D2204 road near 581 Touët de l'Escarène. (b) Bed of intraclast rudstone in the Middle Jurassic limestones. 582 showing a selective dolomitization of the matrix; Rochers de Saint Sauveur. (c) Bedding surface with mud cracks in the upper part of the Cime de la Grave Limestone; Saint 583 Laurent. (d) Bioclastic packstone rich in Clypeina jurassica fragments from the upper part 584 of the Cime de la Grave Limestone; Roccaniera. Thin section photomicrograph, plane-585 586 polarized light. (e) Ferruginous microstromatolites hanging from the roof of a small cavity within the mineralized crust (M, mainly made up of Fe-oxyhydroxides) coating the hard 587 ground HG1; Saint Laurent. The cavity is filled-up by a micritic sediment (S), giving rise to 588 589 a geopetal structure plugged by later calcite cement (C). Thin section photomicrograph, plane-polarized light. (f) Weathered bedding surface of the basal deposits of the Clarissia 590 591 Formation, showing the ellipsoidal mixed Fe-oxide–phosphate ooids; Cime de la Graye.

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Figure 3. Correlative scheme showing the lateral variations of the Lower Cretaceous succession in the study area (stratigraphic sections: AL, Albaretta; SL, Saint Laurent; RN, Roccaniera; VP, Vallon du Parais). Stratigraphic sections have been aligned in correspondence of the base of the Saint Laurent Marl. Abbreviations of lithostratigraphic units: TIT, Tithonian limestones; GRA, Cime de la Graye Limestone; CLA, Clarissia Formation; GV, Grès Verts (GVa, lower interval; GVb, upper interval); SLM, Saint Laurent Marl.

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Figure 4. Field and thin section features of the stratigraphic succession in the Col de Braus area. (a) Bioturbated, glauconitic bioclastic packstone in the lower part of the Clarissia Formation (Roccaniera), showing brilliant-green glaucony grains and some phosphatic ooids (arrow points); the glaucony-poor portions correspond to burrows. Thin section photomicrograph, plane-polarized light. (b) Bedding surface of a bioclastic wackestone bed 606 in the Clarissia Formation, showing internal (to the left) and external (to the right) moulds 607 of Crioceratites sp.; Cime de la Grave. (c) Large macroconch of Puzosia sp. in the 608 bioturbated, glaucony-rich calcareous marl at the top of the Grès Verts; Saint Laurent. (d) Lamniform selachian tooth on a weathered surface of the glaucony-rich calcareous marly 609 610 bed at the top of the Grès Verts (note the dark-green glaucony grains sticking out of the 611 surface); Roccaniera. (e) Alternations of thin-bedded marly limestones and marls in the 612 lower part of the Caire de Braus Marl, cropping out along the D2204 road north of Saint Laurent. (f) Polygenic discontinuity surface separating the Nummulitic Limestone (NL) from 613 614 the underlying Caire de Braus Marl (CBM), showing abundant Gastrochaenolites bivalve 615 borings; Rocher de Pianastan.

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617 Figure 5. Ammonites from the Cretaceous succession of the Col de Braus area. (a) 618 Cruasiceras cruasense (lower part of the Clarissia Formation, eastern side of Cime de la Grave). (b-f) reworked ammonites from the bioclastic-lithoclastic conglomerates in the 619 620 upper part of the Clarissia Formation, Clarissia (b, Gassendiceras alpinum; c, Hemihoplites feraudianus; d. Pachyhemihoplites contei; e. Kotetishvilia sauvageaui; f. 621 Argvethites sp.). (g) Mantelliceras picteti (top bed of the Grès Verts, Saint Laurent). (h) 622 623 Cunningtoniceras cunningtoni (Saint Laurent Marl, Villatalla). Scale bars: a-b, 5 cm; c-h, 1 624 cm. Arrows in (a), (d), (e), and (f) point to the last septal suture.

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Figure 1



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665 Figure 5



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