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

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Abstract

The 1:10,000 geological map here presented extends over about 32 Km^2 around the Col de Braus pass in the Maritime Alps (SE France). This area attracted the attention of geologists since the late XVIII century due to superb exposures of the Jurassic–Cretaceous Provençal succession, and has become a classic geological locality continuously studied until the present day. In this area, Early Cretaceous synsedimentary tectonics is evidenced by important lateral thickness and facies variations. This sector is presently placed at the western termination of a large structural domain extending from the westernmost Ligurian Alps into the French-Italian Maritime Alps, thus representing a key-area to understand the structural setting of this part of the Western Alps.

Keywords:

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

1. Introduction and geological setting

The Col de Braus area, in the Nice inland (Maritime Alps, SE France), represents a key-sector for the geology of SE France, as confirmed by the long history of the geological researches that there have been carried out over more than two centuries (see Chapter 3). 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 Tethys. In the Paleogene, the study area became part of the Alpine Foreland Basin that developed in front of the Alpine chain after the first stages of continental collision between 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

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

The map area is located at the transition between two structural domains, the Nice Arc and the Roya Arc (Bulard *et al*., 1975; Gèze, 1963; Perez, 1975) showing different trends of major folds and thrusts (see structural scheme in the Map). The Nice Arc shows variably orientated folds and thrusts, trending NNW-SSE in the western part and E-W to NE-SW in 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; 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

Maritime Alps and bounded toward the north by the Argentera Massif. This domain, showing NNW–SSE to N–S fold trends, has been the target of detailed geological survey in the last 15 years by a research group of the Italian National Research Council (Istituto di Geoscienze e Georisorse) and Torino University (Earth Science Department). The related results have been only partly published (Piana et al., 2014; d'Atri et al., in press). The Col de Braus area is located at the western termination of this domain and will be therefore important in the definition of its western boundary, which is possibly identifiable in the 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 Nummulitic Limestone.

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;

Sismonda, 1848; Sulzer, 1780), and has soon become a “classic” locality for the geology of the Maritime Alps (e.g., Boussac, 1912; Caméré, 1877; Demay, 1984; Fallot, 1885; Gignoux & Moret, 1937; Hébert, 1877; Kilian & Reboul, 1908; Lanteaume, 1968; Potier, 1877). In the past decade, detailed stratigraphic and sedimentological analyses have focused on glaucony- and phosphate-rich Lower Cretaceous condensed deposits (Barale, d’Atri and Martire, 2013; Decarlis & Lualdi, 2008; Pasquini et al., 2004, and discussion by Parize *et al.*, 2005; Pasquini and Vercesi, 1999). Different paleontological studies have 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, & Selebran, 1991). The Upper Cretaceous succession of the Col de Braus section was also the subject of detailed biostratigraphic analyses ofplanktonic foraminifera and calcareous nannofossils (Conard, 1978; Conard & Manivit, 1979), palynofacies (Götz, Feist-Burkhardt, & Ruckwied, 2008), and ammonites (Thomel, 1992).

3. Methods

The geological map is drawn at 1:10,000 scale and covers an area of approximately 32 km^2. Data were collected through original fieldwork, stored in a GIS database (Coordinate system: NTF (Paris)/Lambert zone II extended) and represented on a vector topographic map, which has been completely redrawn on the SCAN 25® EDR map (1:25,000 scale) of 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).

4. Structural setting

The main structural feature of the mapped area is the SW-vergent Rocca Serra–Ongrand 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, characterized by a metre-thick shear zone with intense cataclastic deformation, which in 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 structural domains. Its footwall domain is deformed by hectometre- to kilometre-scale, NNW–SSE trending, WSW-vergent open to tight flexural folds, involving the Upper Cretaceous and the Alpine Foreland Basin successions (l'Escarène and Mortisson synclines, l'Escarène anticline), with highly inclined axial surfaces and axes gently plunging toward SSE. The ROT hangingwall domain is instead characterized by a kilometre-scale, NNW–SSE trending open syncline (Col de Braus syncline), affecting the Jurassic-Cretaceous and the Alpine Foreland Basin successions on both sides of the Col de Braus.

On the western limb of this syncline, just above the ROT, the Jurassic-Lower Cretaceous succession is involved in a complex structure, known in the literature as "*Écaille intercutanée de la Graye de Touet*" [Graye de Touet intracutaneous wedge] (Gèze, 1963). This is a non-cylindrical structure, whose overall N170 strike is oblique to the strike of the ROT. In its middle part (Ruisseau de Redebraus valley), it is represented by a kilometre-scale fault-propagation fold affecting the Upper Cretaceous succession and related to the 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 onto the Upper Cretaceous succession cropping out near Touët de l'Escarène. The latter is characterized by development of drag fold sequences, kinematically consistent with the

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

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).

5.1. *Jurassic succession*

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

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 (shallow-water 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.

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).

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.

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 reddish-brown chert nodules, disposed in decimetre-spaced layers, give the rock a bedded appearance. Open-platform deposits. Thickness: 70–80 m.

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

5.2. *Lower Cretaceous succession*

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

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

Medium- to thick-bedded, light-gray to beige limestones, locally alternating with very thin beds of greenish marls and nodular mudstones with a greenish marly matrix. Limestone beds commonly have an erosional base and show the following internal lithofacies organization (shallowing-upward peritidal cycles; e.g., Wilson, 1975): bioclastic packstones/rudstones (2–10 cm); bioturbated, peloidal–bioclastic mudstones/wackestones (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). Decimetre-thick beds of bioclastic wackestones/packstones with *Clypeina jurassica* and miliolids are locally present (lagoonal sediments; Figure 2(d)). Thickness: 4–25 m.

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 ferruginous microstromatolites (Figure 2(e)), is covered by a centimetre-thick lag deposit made up of mineralized intraclasts and bioclasts (*Hypophylloceras ponticuli*, *Cymatoceras* sp., belemnites). Above, a thin stratigraphic interval (0–1 m), rich in mixed Fe-oxide–phosphate ooids is locally present (Barale *et al*., 2013). This interval is made up of bioturbated ooidal wackestones/packstones (Figure 2(f)), with reworked cephalopods (*Acanthodiscus* sp., *Lytoceras* sp., Phylloceratidae, *Cymatoceras* sp.), belemnites (*Duvalia* sp.), echinoderms, brachiopods, bivalves, and fish teeth. It is followed by medium-bedded glauconitic limestones (Figure 4(a)) and marly limestones, with *Duvalia* sp., *Cruasiceras cruasense* (Figure 5(a)), *Crioceratites* sp., *Cymatoceras* sp., passing upward to thin-bedded bioclastic mudstones and wackestones, with centimetre-thick marly interbeds, containing *Crioceratites* sp. (Figure 4(b)), *Toxaster* sp., and belemnites (4–20 m). At the top of this interval, a mineralized hard ground is present (HG2).

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

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.

The rest of the unit is made up of decimetre-thick beds of bioturbated glauconitic marly limestones, with ammonite molds (*Puzosia* sp.) and echinoids, associated with thick-bedded hybrid glauconitic arenites and glauconarenites, commonly bioturbated, with large-scale cross-stratification (Parize et al., 2005; Pasquini et al., 2004) and decimetre-sized, 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 Cenomanian (*saxbii* Subzone) ammonites (*Mantelliceras picteti* (Figure 5(g)), *M. mantelli*, *M. cantianum*, *M. tuberculatum*, large macroconchs of *Puzosia mayoriana* (Figure 4(c)), *Schloembachia* sp.), echinoids (*Protocardiaster* sp., *Camerogalerus* sp.), brachiopods, belemnites, bivalves, and lamniform selachian teeth (Figure 4(d)). This bed marks the drowning of the shelf.

5.3. *Upper Cretaceous succession*

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

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 and frequency increase toward the top of the unit. The fossil content in the lower part of the unit is abundant: ammonites (*Mantelliceras saxbii*, *Schloembachia subvarians*, *Puzosia mayoriana*, *Hypoturrilites* sp., *Turrilites costatus*, *Cunningtoniceras cunningtoni* (Figure 5(h)), *Acanthoceras rhotomagense*, *Eucalycoceras* sp., *Calycoceras* sp., *Newboldiceras* sp., Phylloceratinae), terebratulids, belemnites (*Neohibolites* sp.), echinoids (*Camerogalerus cylindricus*, *Holaster subglobosus*), and bivalves (*Inoceramus* sp.). Thickness: 60–80 m.

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

Marly limestones (planktonic-foraminifera mudstones and wackestones) with thin marl interbeds, passing toward the top to medium-bedded limestones (bioclastic wackestones 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 resedimented glauconitic lithoarenites and hybrid glauconitic arenites are present. These beds have an erosional base, locally followed by imbricated clay chips or by a centimetre-thick lag consisting of *Inoceramus* fragments, and show normal grading and parallel lamination. Thickness: 300 m.

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.

5.4. *Alpine Foreland Basin Succession*

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

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

Lenticular bodies, 0–15-m thick, including from base to top the following, laterally 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).

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

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

This unit consists of mixed siliciclastic-carbonate ramp deposits. Its base is represented bya 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.

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

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

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.

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 decimetre-thick, 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).

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 Nummulitic Limestone;

- 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.

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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Figure captions

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.

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

in the footwall of the Touët de l'Escarène Thrust, cropping out along the D2204 road near Touët de l'Escarène. (b) Bed of intraclast rudstone in the Middle Jurassic limestones, 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 Graye Limestone; Saint Laurent. (d) Bioclastic packstone rich in *Clypeina jurassica* fragments from the upper part of the Cime de la Graye Limestone; Roccaniera. Thin section photomicrograph, plane-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 ground HG1; Saint Laurent. The cavity is filled-up by a micritic sediment (S), giving rise to 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 Formation, showing the ellipsoidal mixed Fe-oxide–phosphate ooids; Cime de la Graye.

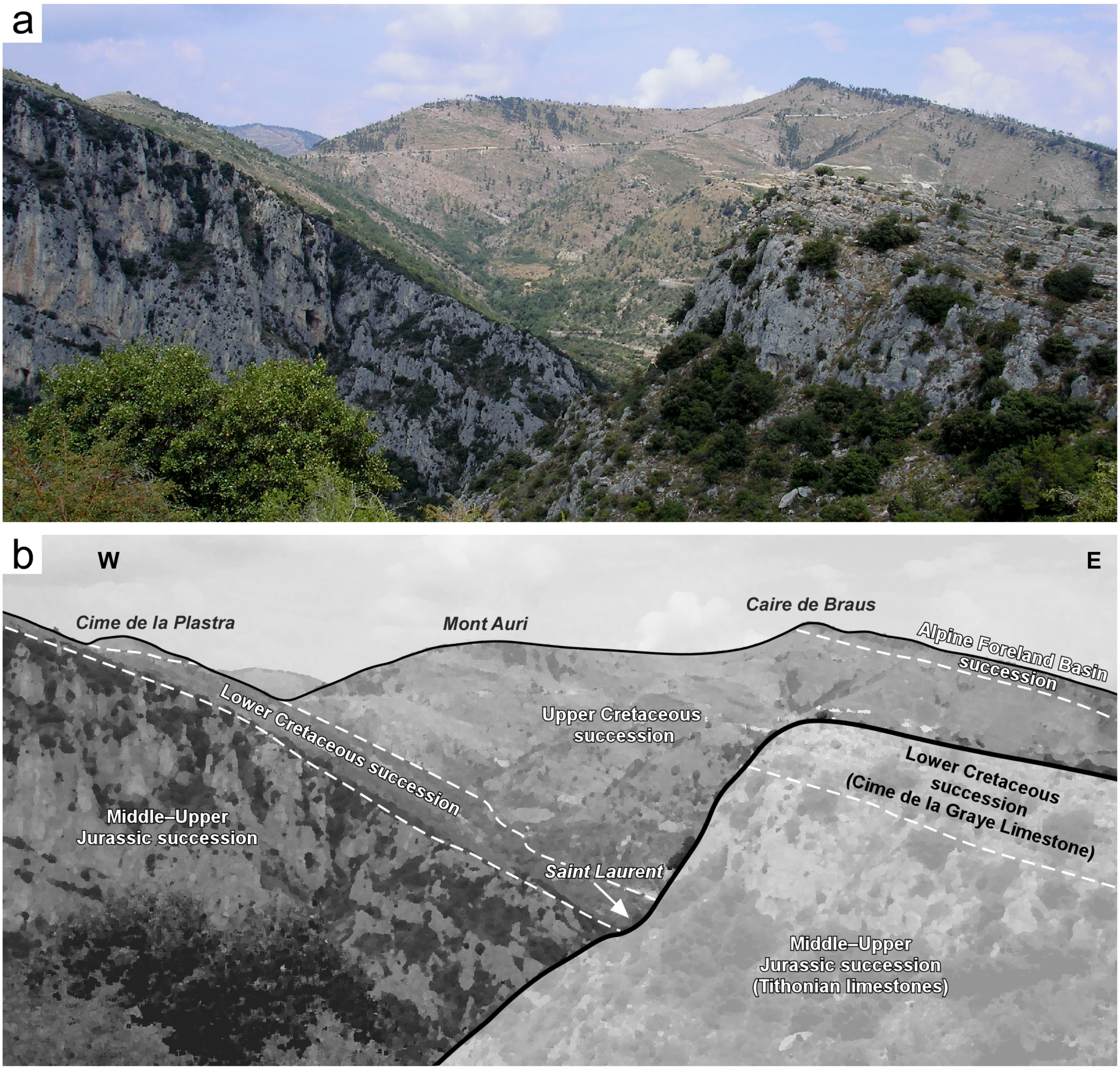
Figure 3. Correlative scheme showing the lateral variations of the Lower Cretaceous succession in the study area (stratigraphic sections: AL, Albaretta; SL, Saint Laurent; RN, Roccaniera; VP, Vallon du Parais). Stratigraphic sections have been aligned in correspondence of the base of the Saint Laurent 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.

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

in the Clarissia Formation, showing internal (to the left) and external (to the right) moulds of *Crioceratites* sp.; Cime de la Graye. (c) Large macroconch of *Puzosia* sp. in the 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 bed at the top of the Grès Verts (note the dark-green glaucony grains sticking out of the surface); Roccaniera. (e) Alternations of thin-bedded marly limestones and marls in the 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 the underlying Caire de Braus Marl (CBM), showing abundant *Gastrochaenolites* bivalve borings; Rocher de Pianastan.

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

Figure 1


a
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Cime de la Plastra
Mont Auri
Caire de Braus
Alpine Foreland Basin succession
Upper Cretaceous succession
Lower Cretaceous succession
Lower Cretaceous succession (Cime de la Graye Limestone)
Middle–Upper Jurassic succession
Saint Laurent
Middle–Upper Jurassic succession (Tithonian limestones)

Figure 2

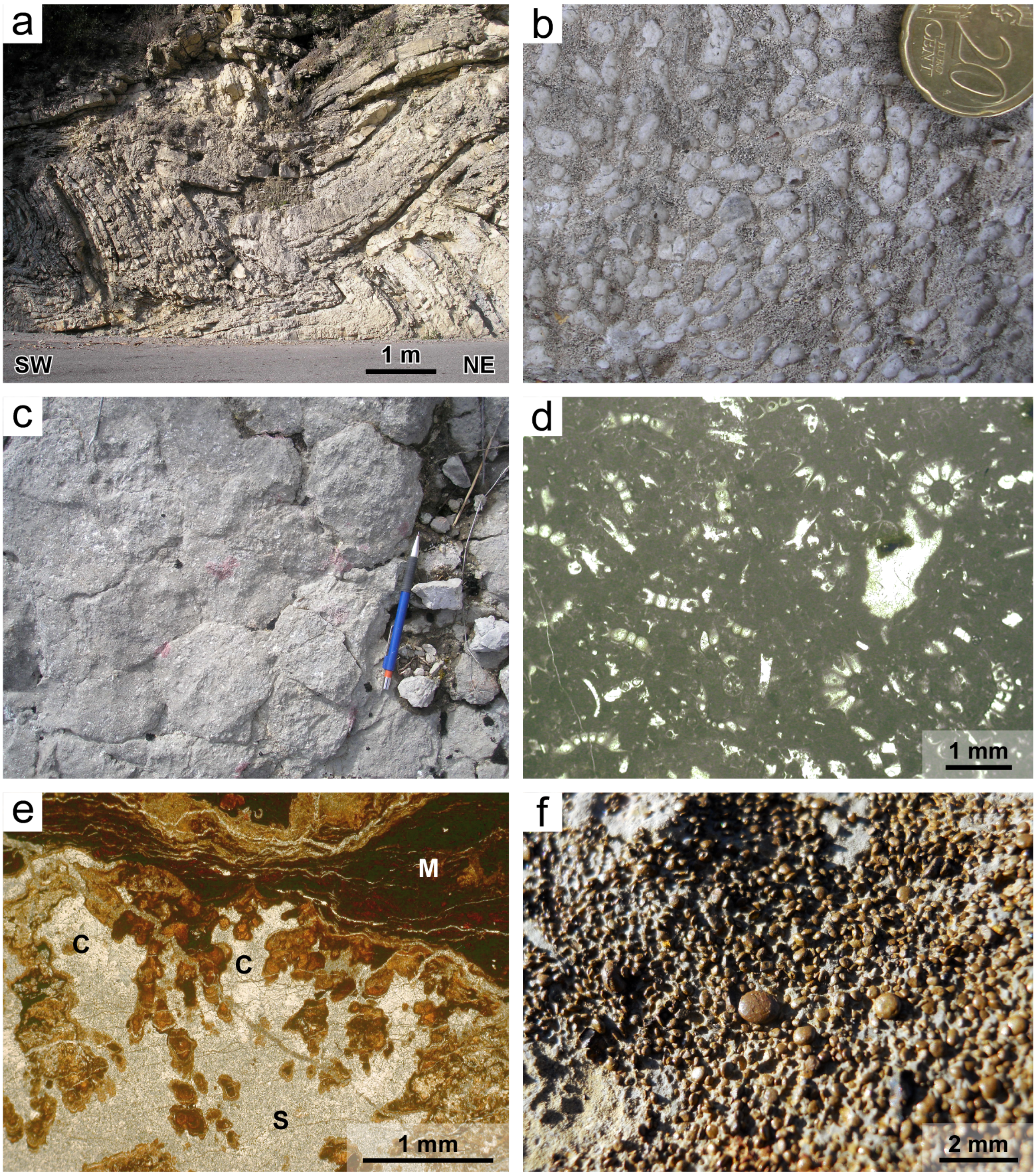
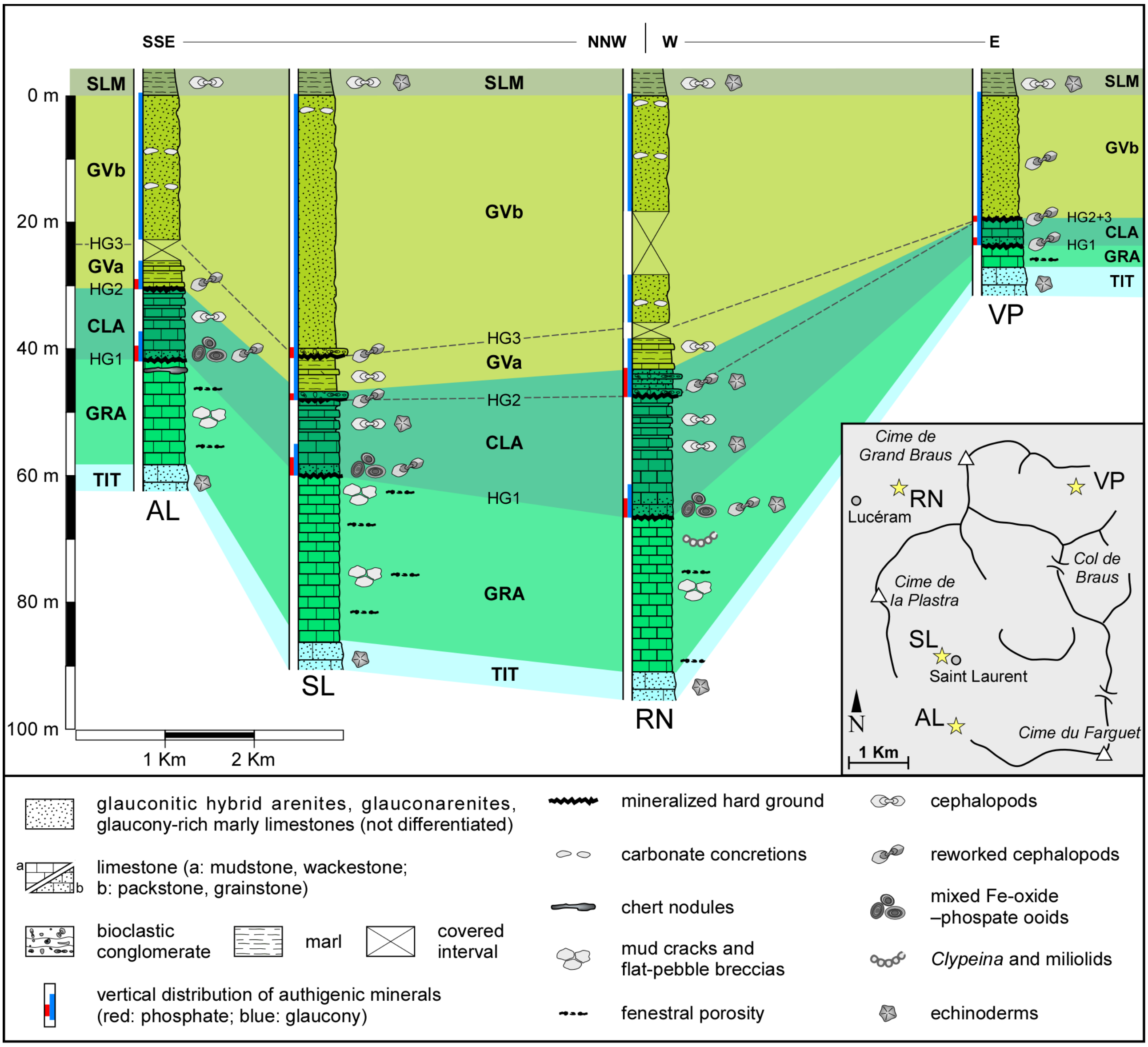


Figure 3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GRA
TIT
AL
SL
RN
VP
HG2+3
Cime de Grand Braus
RN
VP
Lucéram
Cime de la Plastra
Col de Braus
SL
Saint Laurent
N
AL
Cime du Farguet
1 Km
glauconitic hybrid arenites, glauconarenites, glaucony-rich marly limestones (not differentiated)
limestone (a: mudstone, wackestone; b: packstone, grainstone)
bioclastic conglomerate
marl
covered interval
vertical distribution of authigenic minerals (red: phosphate; blue: glaucony)
mineralized hard ground
carbonate concretions
chert nodules
mud cracks and flat-pebble breccias
fenestral porosity
cephalopods
reworked cephalopods
mixed Fe-oxide –phospate ooids
Clypeina and miliolids
echinoderms

Figure 4

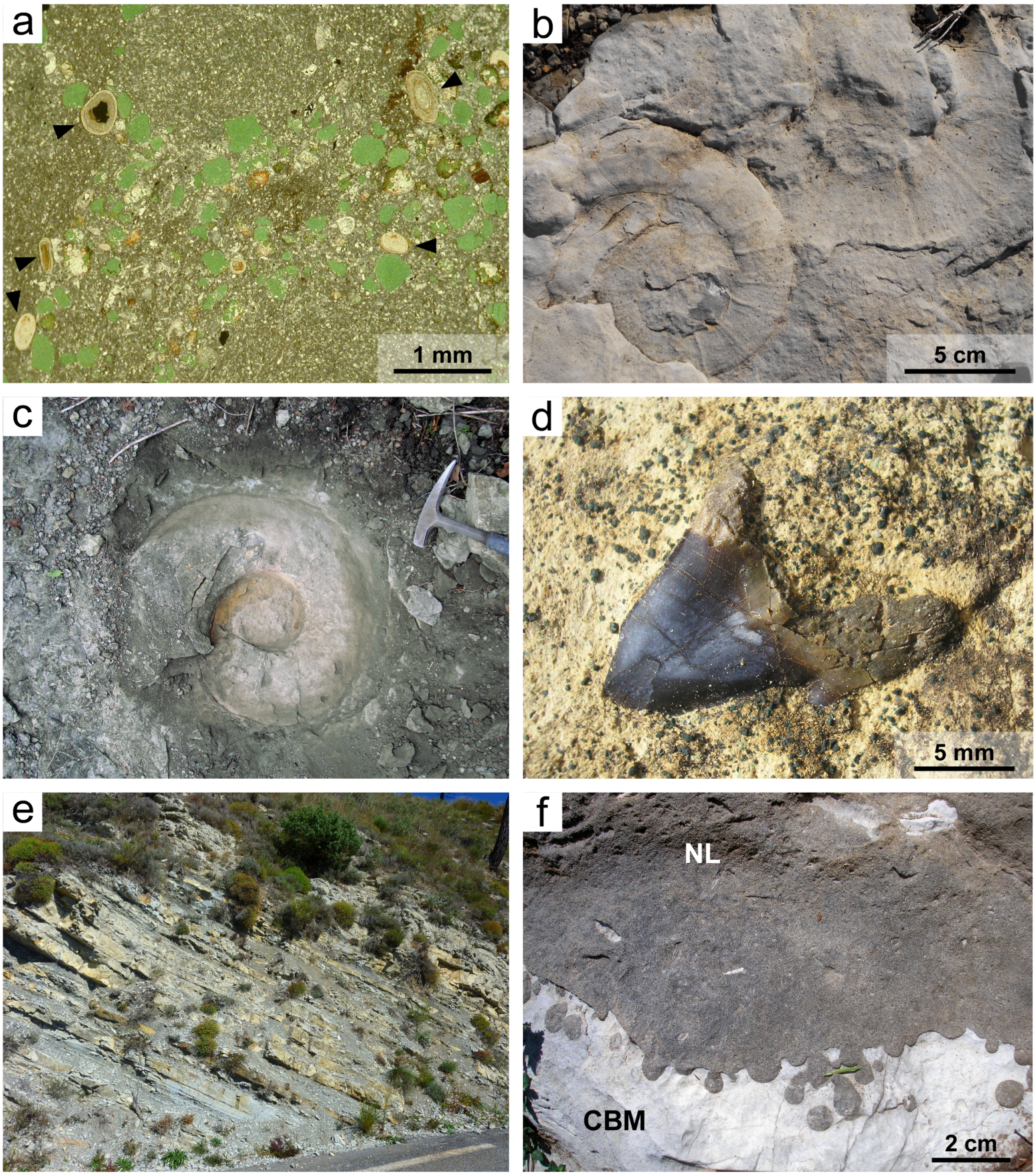

Figure 5