The Col de Braus (Maritime Alps, SE France): an Historical Geological Locality with High Geoheritage Value

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The Col de Braus (Maritime Alps, SE France): an historical geological locality with high geoheritage value

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Abstract

The Col de Braus section (Maritime Alps, SE France) offers a continuous and beautiful exposure of the Jurassic–Cretaceous Provençal succession and the lower part of the Alpine Foreland Basin succession, over a total thickness of about 1200 m. This stratigraphic succession is the result of a long geological history, corresponding to a time span of about 130 Myr, and records different stages of the evolution of the paleo-European passive margin of the Alpine Tethys and the subsequent development of the Alpine Foreland Basin. The Col de Braus section represents a classic locality for the geology of the Maritime Alps and of the SE France in general, known since the late XVIII century, and is here individuated as a highly significant geological heritage, due to its multiple aspects of interests going far beyond scientific value. A geological itinerary along the Col de Braus section is also proposed. It is entirely developed along a main road in a beautiful Mediterranean upland landscape, and is enjoyable by both specialists and neophytes thanks to the multiple levels of reading offered by the selected outcrops.

Keywords

Geological heritage, Mesozoic, Provençal Domain, Col de Braus, Maritime Alps, SE France

Introduction

In SE France, the high mountains of the Alps and the Subalpine Ranges to one side, and the dry plateaus of Provence to the other, offer ideal conditions to observe superb exposures of stratigraphic successions. This region is placed at the external edge of the Western Alps, where limited tectonic overprint allowed good preservation of primary characters of sedimentary rocks. This is one of the regions where, in the XIX century, the bases of modern stratigraphy have been established by renowned naturalists as Alcide d'Orbigny and Henri Coquand. Different Cretaceous stages are indeed named after SE France localities (Berriasian, from Berrias; Barremian, from Barrême; Aptian, from Apt; Cavelier and Roger 1980).

This important geoheritage has been recently valorized with creation of geoparks in the areas of greater geological and naturalistic value (Hobléa 2014). In the Alpes de Haute-Provence department, the Geopark of Haute-Provence was recently labelled by the UNESCO (2004). On the other hand, the Réserve Naturelle Géologique de Haute Provence, created in 1984, represents the largest European Natural Reserve of geological purpose. It extends over about 2300 km^2 in the Castellane–Digne area (Guiomar 2009, 2013; Pagès 2009; Guiomar et al. 2010; Venzal 2012). It is visited by a great number of people every year, thanks to the high variety of geological heritage it offers, often valorized in situ with adequate protection structures (e.g., ichthyosaur skeletons, sirenian bones, and the famous "ammonite slab" (Dommergues and Guiomar

2011)). However, although much work has been done and is currently in progress, the inventory of the geological heritage of SE France is still partial and many of the pieces composing this huge patrimony have not yet been described in this connection.

On the western side of the Col de Braus pass, in the southern Maritime Alps, the Jurassic–Cretaceous Provençal succession and the lower part of the Alpine Foreland Basin succession are exposed over about 1200 m in a continuous stratigraphic section, recording about 130 Myr of geological history from Middle Jurassic to Paleogene. This section represents a classic locality for the geology of the Maritime Alps and of SE France in general, which has been studied for more than 200 years and still attracts the attention of geologists. The Col de Braus section is fully entitled to be considered an important geological heritage, due to its high scientific, educational and geohistorical value, coming along a series of additional values spacing from aesthetic factors to historical interest. However, though this locality has been cited in dozens of scientific works, its geoheritage importance has not been pointed out yet. The aim of this paper is twofold:

- to bring out the Col de Braus section as an outstanding geological heritage, due to its multiple factors of interest going far beyond mere scientific aspects;
- to propose a geological itinerary along this section, in which highly significant outcrops illustrate the main geological events recorded in the stratigraphic succession and offer different levels of reading, resulting therefore enjoyable by both specialists and non-specialists.

Geological setting

The study area is located in SE France (Département des Alpes-Maritimes) and belongs to the Southern Subalpine Ranges (Nice Arc; Gèze 1963), which derive from folding and thrusting of Mesozoic sediments deposited on the paleo-European passive margin of the Alpine Tethys and Cenozoic sediments of the Alpine Foreland Basin (Fig. 1a,b).

This area is part of the southeastern margin of the Alpine External Domain (Provençal Domain; Fig. 1a). The stratigraphic succession of this domain rests on a crystalline basement, currently cropping out in the Argentera and Tanneron Massifs, and starts with thick Upper Carboniferous–Permian continental successions, followed by Lower Triassic siliciclastic coastal deposits, Middle Triassic peritidal carbonates, and Upper Triassic evaporites. In the Early Jurassic, the paleo-European margin differentiated into a platform domain (Provençal) and a basinal domain (Dauphinois), as a result of extensional tectonics related to the opening of the Alpine Tethys (Dardeau 1988). In the Provençal Domain, after a period of emersion which included most of the Early Jurassic, Middle Jurassic–Berriasian sedimentation occurred in a carbonate platform environment. Subsequently, in the Nice Arc area, Valanginian tectonism resulted in platform drowning (Debelmas and Kerckhove 1980), followed by deposition of a condensed, open-marine shelfal succession (Hauterivian–early Cenomanian *p.p.*), showing important lateral variations related to synsedimentary tectonics (Pasquini, et al. 2004; Decarlis and Lualdi 2008; Bersac et al. 2010). After definitive 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 hiatus spanning the latest Cretaceous–middle Eocene. Above, the Alpine Foreland Basin succession starts with continental to coastal deposits (*Microcodium* Formation), followed by the ramp deposits of middle Eocene Nummulitic Limestone, the hemipelagic upper Eocene *Globigerina* Marl and the upper Eocene–lower Oligocene turbidite succession of the Grès d’Annot (Ford et al 1999; Sinclair 1997).

Historical and geohistorical importance of the Col de Braus area

The Col de Braus connects the valleys of the Paillon and Bevera rivers in the southern Maritime Alps, close to the city of Nice. As the legend goes, the pass owes its name to a lieutenant of Hercules, who there defeated one of the Ligurian tribes fighting the mythological hero on its way back from Spain (e.g., Salvetti 1925; Desbiolles 1939; Ginesy 1974). The Col de Braus has been also fancifully indicated by someone as the way followed by the Carthaginian general Hannibal during its crossing of the Alps (Alberti 1728). Apart from legends, this pass has represented since ancient times an important way of communication between the Provence coast and the internal regions of NW Italy, through the Roja valley and the Colle di Tenda pass (the so-called “salt road”). After a series of improvement works accomplished over several centuries, the road passing through the Col de Braus and the Colle di Tenda became a strategic communication artery of the Kingdom of Sardinia, connecting the capital Turin to the port of Nice (before the annexation of this city to France, in 1860). Also Thomas Jefferson, principal author of the American Declaration of Independence and third president of the United States of America, traveled through the Col de Braus in 1787, as he writes in his memoirs (Jefferson 1787). Moreover, this area had a privileged geographic position at the join between the Italian and the French “Rivieras”, which in the XIX century were largely frequented by wealthy European tourists. Among them, many naturalists were included (e.g., Horace-Bénédict de Saussure, Thomas Allan, William Buckland, Henry Thomas De La Beche, and Roderick Impey Murchison, in company of Charles Lyell), as we know from their firsthand accounts (de Saussure 1796; Allan 1818; Buckland 1829; De La Beche 1829; Murchison 1849). This fact was determinant for the “fortune” of the Col de Braus section, which has been renown and actively studied since the early XIX century.

The first references to the Col de Braus stratigraphic succession date back to the late XVIII (Sulzer 1780; Beaumont 1795; Fig. 2; Anonymous 1797) and early XIX century (e.g., Wilson and Riddell 1809; Omalius d’Halloy 1810; Foderé 1821; Risso 1826; Buckland 1829; Zuccagni-Orlandini 1835; Sismonda 1841, 1848; Perez 1847), either as part of actual scientific works or in the form of naturalistic notes in travel reports. Since then, the Col de Braus has become a “classic” locality for the geology of the Maritime Alps, and has been cited by numerous authors throughout late XIX and XX centuries (e.g., Bellardi 1852; Caméré 1877; de la Harpe 1877; Hébert 1877; Potier 1877; Fallot 1885; Kilian and Reboul 1908; Boussac 1912; Lanteaume 1968; Campredon 1972; Demay 1984). In recent years, stratigraphic and sedimentological studies have been particularly focused on Lower Cretaceous condensed deposits (Pasquini et al. 2004; Decarlis and Lualdi 2008; Barale et al. 2013). Moreover, the abundant fossil content of the Lower Cretaceous succession has largely attracted the interest of paleontologists. As an example, detailed studies on the upper Barremian deposits cropping out at Clarissia, near Saint Laurent, contributed to establishing a total of 3 new ammonite genera, and 10 new species (Delanoy 1990, 1992; Bert and Delanoy 2000; Bert et al. 2006). The Lower Barremian deposits of Saint Laurent also furnished an exceptionally preserved specimen (1.16 m long) of the giant heteromorphic ammonite *Moutoniceras nodosum*, known before only by fragments (Delanoy et al. 1991).

General features of the Col de Braus section

The Col de Braus section is located on the western side of the homonymous pass (Fig. 3), and is comprised in the Menton–Nice sheet of the Geological Map of France at 1:50,000 (Gèze et al. 1968). A more detailed representation of the Col de Braus area has been recently given by Barale et al. (in press). The section is limited at its base by a thrust (Touët de l'Escarène Thrust; Barale et al. in press), and exposes about 1200 m of stratigraphic succession, recording the evolution of the passive margin of the Alpine Tethys and the subsequent development of the Alpine Foreland Basin. It can be subdivided in four intervals (Fig. 4):

- Middle Jurassic–Berriasian succession (>300 m; Lanteaume 1968). Carbonate platform succession, mainly made up of dolostones and dolomitic limestones in the lower interval (Bathonian–Callovian), followed by a limestone succession showing a general regressive trend from Oxfordian outer-platform bioclastic limestones to Berriasian inner-platform peritidal sediments (Cime de la Graye Limestone; Barale et al. in press). At the top of Berriasian limestones, a mineralized hard ground marks the drowning of the carbonate platform.
- Hauterivian–lower Cenomanian p.p. succession (60–70 m; Lanteaume 1968; Demay 1984; Barale et al. in press). Condensed succession, rich in authigenic minerals (Clarissia Formation, early Hauterivian p.p.–early Aptian p.p.; Grès Verts, early Aptian p.p.–early Cenomanian p.p.), deposited in an open-marine shelfal environment under the influence of oceanic currents (Delamette 1988; Parize et al. 2005; Decarlis and Lualdi 2008). At the top, a dm-thick glauconitic bed corresponds to the early Cenomanian drowning of the shelf.
- Upper Cretaceous succession (>700 m; Conard and Manivit 1979; Barale et al. in press). Hemipelagic sediments, starting with the early Cenomanian p.p.–late Cenomanian Saint Laurent Marl, followed by limestone–marl alternations (Mont Auri Limestone; Turonian–late Coniacian p.p.), and by a thick marly succession (Caire de Braus Marl; late Coniacian p.p.–middle Campanian). At the top, a regional discontinuity surface corresponds to an important hiatus (middle Campanian–middle Eocene), related to prolonged subaerial exposure during the first stages of Alpine collision.
- Alpine Foreland Basin succession (40–50 m; Lanteaume 1968; Campredon 1972; Varrone and Clari 2003). It starts with a m-thick, laterally discontinuous interval of continental to coastal deposits (*Microcodium* Formation; Lutetian?–early Bartonian), followed by mixed carbonate–siliciclastic ramp sediments (Nummulitic Limestone; Bartonian p.p.) and by the hemipelagic *Globigerina* Marl (late Bartonian p.p.–Priabonian).

Such a lithological variety is reflected by an articulated geomorphologic asset. Different stratigraphic intervals have indeed diverse responses to the action of morphogenetic agents, according to their mechanic and chemical characteristics. Massive Middle Jurassic–Berriasian carbonates give rise to a deeply incised gorge where the Ruisseau de Redebraus river runs encased between hundred-metres-high cliffs. The passage to the less-competent lithotypes of Cretaceous succession (marly limestones and marls), near the village of Saint Laurent, corresponds to a sharp morphological change (Fig. 3). They form indeed a gently sloping mountainside, covered by vegetation, which is crowned by a 15–20 metres-high cliff, made up of the more competent rocks of the lower part of Alpine Foreland Basin succession (*Microcodium* Formation and Nummulitic Limestone). The latter, cropping out at the core of a km-scale, open syncline (Col de Braus syncline), constitutes the backbone of a gutter-shaped plateau, slightly inclined toward the south, extending over several km^2 around the Col de Braus. In the southern part of the plateau, the easily erodible *Globigerina* Marl gives rise to a badland landscape.

Geological itinerary

The proposed itinerary is entirely developed along the D2204 county road, starting a little way upstream of the village of Touët de l'Escarène and ending near the Col de Braus pass (Fig. 5). This area is comprised in the topographic map at 1:25,000 of the French National Geographic Institute Top 25 IGN–3741 ET. The Col de Braus section can be easily reached by car from Nice, which is about 22 km distant, following the D2204 road itself (Fig. 1b). The itinerary, articulated in 5 stops (plus the optional stops 5b and 5c, complementary to stop 5a), is 6.5 km long for about 400 m of height difference (from stop 1 to stop 5a). For this reason, it can be covered even on foot and it is practicable all year long due to the low altitude and the mild climate of the region, resulting in the absence of snow cover during virtually all winter. The itinerary is immersed in a beautiful Mediterranean upland landscape, with olive tree cultivations in the lower part and maquis shrubland with small woods of pines and holm oaks in the upper part. Different panoramic viewpoint are present all along D2204 road.

The following description of the geological features of different stops enters into a scientific detail which is adequate for fruition at a university-student level. However, the same itinerary and stops are also eligible for educational/divulgative purposes, by selecting the themes of most immediate communicability and by explaining them in a simpler way using a non-technical language.

Stop 1

The first stop is located in correspondence of a hairpin bend, 500 m upstream of Touët de l'Escarène. On the road cut, crowned by olive trees, Upper Cretaceous marl-limestone alternations crop out (Caire de Braus Marl). They are folded by m-scale chevron folds, cut by low-angle faults (Fig. 6a,b). This outcrop shows a highly-deformed rock volume just below the Touët de l'Escarène Thrust (TET; Barale et al. in press), which overthrusts on it the Jurassic succession constituting the base of the Col de Braus section. The deformation of this rock volume is directly related to the thrust shearing: folds and low-angle faults are in fact kinematically consistent with the TET sense of shearing (Fig. 6b).

Stop 2

The second stop corresponds to two small panoramic lay-bys on the right side of D2204, overlooking the Ruisseau de Redebraus gorge. In this point the road is cut in the rock, with a sheer drop to the gorge below. This place, once called "Rocca Tagliata" ("cut rock", in Italian), caught the attention of ancient travelers who gave suggestive descriptions of it (e.g., Beaumont 1785, see also Fig. 2; Brockedon 1829; Gioffredo 1839), and suggested to Alberti (1728) the speculation about the passage of Hannibal, who according to ancient authors had to cut his way in the rock during his crossing of the Alps.

From this point, one can enjoy an amazing view on the thick Middle Jurassic–Berriasian carbonate platform succession, which constitutes the high cliffs on both sides of the gorge (Fig. 7a). Moving toward Saint Laurent, the upper part of this succession is continuously exposed on the road cut. It consists of massive bioclastic–oncoidal–ooidal packstones, grainstones and rudstones, containing thick-shelled bivalves, nerineid gastropods, colonial corals (Fig. 7b), crinoids, echinoids, and calcareous algae. Both sedimentological and paleontological characters document a high-energy, shallow-water platform environment in a warm, tropical sea. The carbonate platform succession ends with Berriasian inner-platform limestones (Dardeau and Pascal 1982; Barale et al. in press), cropping out at the entrance of Saint Laurent and organized in dm-thick, shallowing-upward peritidal cycles. In the upper part of the cycles, supratidal facies show diverse evidence of subaerial exposure as desiccation pores (Fig. 7c), mud cracks, and reddened intraclasts.

Stop 3

At Saint Laurent, on the basement of an ancient chapel now become a private house, the highly condensed Barremian succession, corresponding to the upper part of the Clarissia Formation, crops out (Fig. 8a). It is represented by a phosphate- and glaucony-rich, bioclastic–lithoclastic conglomerate bed, 30–50 cm thick, showing a reddish-brown colour, composed of limestone intraclasts, ammonites, belemnites, and other bioclasts (Fig. 8b,c). Clasts are commonly impregnated and encrusted by authigenic minerals (phosphates, F-oxides, glaucony). Ammonites are invariably reworked, as documented by the marked compositional, textural, and color contrast between the internal mould and the encasing sediment (Fig. 8d). This conglomerate, attributed to late Barremian (Delanoy 1992; Barale et al. in press), deposited in an open-marine shelf, swept by oceanic currents and episodic storms responsible for repeated sediment reworking (Pasquini et al. 2004; Decarlis and Lualdi 2008). Reworking resulted in continue removal of fine sediments and progressive concentration of larger grains (bioclasts and lithoclasts), which were impregnated and encrusted by authigenic minerals during periods of exposure at the seafloor. The abundance of phosphates (as grains and clast impregnations or coatings) documents particular environmental conditions, i.e. high organic productivity related to the upwelling of nutrient-rich deep waters along the continental margin (Decarlis and Lualdi 2008), as it is observed today in areas of strong upwelling, e.g. off the coasts of Chile and Peru or SW Africa.

The conglomerate rests on a mineralized hard ground, developed on top of late Hauterivian marly limestones (Fig. 8b,c). The hard ground corresponds to a period of non-sedimentation spanning the latest Hauterivian–lower Barremian, which caused prolonged exposure of the sediments at the seafloor, resulting in their early lithification and encrustation by authigenic minerals. A framework of cm-wide, firm-ground bioturbation galleries extends for several decimeters from the hard ground surface in the underlying bed. Galleries are surrounded by a cm-thick, brownish to yellowish halo, deriving from incipient phosphatization of the gallery-wall sediment during exposure at the seafloor. The gallery system shows a polyphase fill: the upper part is filled up by the conglomerate material constituting the above bed, whereas the lower part contains a dark-green, glaucony-rich sediment. This sediment can be correlated with a thin interval of glauconitic limestones (late Hauterivian p.p.–early Barremian), preserved below upper Barremian conglomerates in the close Clarissia locality, where a slightly less condensed succession crops out (Delanoy 1992; Barale et al. in press). This shows how, in correspondence of discontinuity surfaces, bioturbation galleries can act as effective traps for sediments that otherwise would have leave no trace on the local stratigraphic record (cf. Bromley et al. 2009; Wetzel et al. 2014).

The upper Barremian conglomerate is followed by a bed of glauconitic limestone, representing the top of the Clarissia Formation (early Aptian; Delanoy 1992; Barale et al. in press), and by the glaucony-rich marls of the lower interval of the Grès Verts. The entire Barremian stage, corresponding to a time span of about 4.5 Myr, is thus represented by an extremely reduced succession, less than 1 m thick. By way of comparison, the Upper Cretaceous succession, deposited in a time frame a little more than quadruple (about 20 Myr, from early Cenomanian to middle Campanian), is several-hundred times thicker (more than 700 m)!

Stop 4

At Saint Laurent, deviating for a few metres from D2204 on a lateral road, it is possible to observe the limit between the Grès Verts (early Aptian p.p.–early Cenomanian p.p) and the overlying Saint Laurent Marl (early

Cenomanian p.p–late Cenomanian). The limit corresponds to a gully, deriving from preferential erosion of Saint Laurent Marl, and is made even more striking by the pronounced color contrast between the two units (Fig. 9a). The upper part of the Grès Verts, cropping out for some metres all along the lateral road, is mainly composed of thick-bedded hybrid glauconitic arenites and glauconarenites. They show unusual colors, varying from brilliant dark-green on fresh surfaces to blackish green or brown on weathered ones, which are due to the abundant presence of glaucony grains. These glaucony-rich sediments deposited in an outer-shelf environment, with a low sedimentation rate and under the action of oceanic and/or storm-related currents (Pasquini et al. 2004; Parize et al 2005; Decarlis and Lualdi 2008).

The top of the Grès Verts is represented by a dm-thick interval of highly bioturbated, glaucony-rich calcareous marl and marly limestones (Fig. 9b), very rich in fossils: ammonites, belemnites, echinoids, bivalves, shark teeth, and brachiopods. Internal moulds of *Puzosia* sp. ammonite macroconchs, 50–60 cm in diameter, are also common (Fig. 9c). On the Saint Laurent outcrop, some of the external moulds of these large ammonites are still visible, whereas the internal moulds have been removed by erosion. The deposition of this thin interval corresponds to the drowning of the Provençal shelf in the early Cenomanian, due to a concurrence of eustatic and tectonic factors (Pasquini et al. 2004; Barale et al. 2013). The overlying Saint Laurent Marl consists of light-gray marls with thin marly limestone interbeds, containing ammonite moulds, belemnites, echinoids, and brachiopods, resulting from hemipelagic sedimentation in slope environment.

Stop 5a

Leaving Saint Laurent, the road climbs up the mountainside with a series of tight hairpin bends that recross the limit between Grès Verts and Saint Laurent Marl observed at stop 4, before entering and crossing the entire Upper Cretaceous succession. This is a monotonous succession of marls and marly limestones, about 700 m thick, which resulted from hemipelagic sedimentation in slope and basinal environment (e.g., Götz et al. 2008). Looking at the road walls, it is possible to note that the building stones consist almost exclusively of coarse-grained, bioclastic-lithic arenites, containing large *Nummulites* and other macrofossils (bivalves, gastropods). These rocks derive from a small quarry opened in the lower part of the Nummulitic Limestone along D2204, not far from the Col de Braus (the same facies will be observed in situ at stop 5b).

Stop 5a can be reached with a five-minute hike on an easily walkable dirt track, closed to traffic, detaching from D2204 (Fig. 5). Next to Source de Pissaour spring, the northern side of Mont Brec offers a panoramic view of the lower part of the Alpine Foreland Basin succession, resting on the Upper Cretaceous Caire de Braus Marl (Fig. 10). The latter is cut at the top by a regional discontinuity surface, corresponding to a considerable stratigraphic gap (middle Campanian–middle Eocene), which records a prolonged subaerial exposure of the Mesozoic succession during the first stages of Alpine collision. The discontinuity surface is followed by a 5–6-m-thick interval of conglomerates, mainly made up of marly limestone clasts deriving from the underlying Upper Cretaceous succession, with thin marl interbeds. This interval corresponds to the lower member of *Microcodium* Formation, which has been deposited in a continental environment (Varrone and Clari 2003), and is followed by the shallow-marine deposits of the Nummulitic Limestone related to later marine transgression.

The *Microcodium* Formation (Lutetian?–early Bartonian) consists of lenticular bodies of continental and coastal deposits, whose distribution and lateral variations have been strongly controlled by the articulate paleotopography deriving from the uplift and subearial erosion of the Mesozoic substrate (Fig. 11). This unit deposited in depressed sectors (incised valleys), whereas it did not in more elevated interfluvial zones, where the Nummulitic Limestone rests directly on the Mesozoic substrate (Varrone and Clari 2003). The following two stops will show different situations in which *Microcodium* Formation is not present (stop 5c), or only the coastal deposits of its upper member are (stop 5b).

The Source de Pissaour represents a didactic example of contact spring. The fractured and karstified Nummulitic Limestone, cropping out at the core of the Col de Braus syncline, constitutes a bowl-shaped aquifer, limited at its base by the much less permeable Upper Cretaceous marls. The spring corresponds to the altimetrically lowest point of intersection between the topographic surface and the impermeable aquifer base, thus acting as the aquifer “overflow”.

Stop 5b

This outcrop is located in the eastern part of the Col de Braus syncline (Crête de Montauri), along an easily walkable dirt track, closed to traffic, reachable with a short deviation from D2204 (Fig. 5). Resting on the Upper Cretaceous Caire de Braus Marl, the Alpine Foreland Basin succession starts with a 2,5 m-thick interval of medium- to coarse-grained, thick-bedded, whitish quartzarenites, with erosional base, clay chips, and trough cross-stratification, locally containing cm-thick conglomerate beds (Fig. 12a,b). These deposits belong to the upper member of *Microcodium* Formation and have been interpreted as deposits of barrier island, i.e. coast-parallel sandy bodies representing the seaward edge of coastal lagoons (Varrone and Clari 2003). Trough cross-stratification derives from the migration of large bedforms (dunes). Above, the middle Eocene Nummulitic Limestone starts with a few metres of coarse-grained, quartz-rich and fossil-poor lithoarenites, containing thin conglomerate beds. They are followed by thick-bedded, medium- to coarse-grained, bioclastic–lithic arenites, with larger benthic foraminifera (*Nummulites, Assilina, Discocyclina;* Fig. 12c), gastropods, bivalves, echinoderms, and carbonized wood fragments. These sediments have been deposited in the inner part of a mixed carbonate–siliciclastic ramp. The heterozoan association, dominated by larger benthic foraminifera and mollusks (foramol facies), indicates temperate climatic conditions (James 1997). On the way back, it is possible to observe along the trackside a continuous, nearly along-bed exposure of this stratigraphic interval.

Stop 5c

The last stop is situated in the northern part of the Col de Braus syncline, at the base of the Rocher de Pianastan cliff. It can be reached by an easily walkable dirt track, closed to traffic, and requires a short off-trail hike on a gentle shrubby slope in the last part (Fig. 13a). In this locality, the *Microcodium* Formation is not present and the Nummulitic Limestone rests directly on the Upper Cretaceous succession (Fig. 13b,c; Fig. 11). The discontinuity surface separating the two intervals is pitted by numerous bivalve borings (*Gastrochænolites*) (Fig. 13d). They appear as circular holes, up to 7–8 mm in diameter, with a cylindrical or ampoule-shaped vertical section, and penetrate for a few centimetres in the Upper Cretaceous marly limestones. Bivalve borings document that, before deposition of Nummulitic Limestone, the already lithified Upper Cretaceous sediments were exposed in a littoral environment, where they constituted a hard substrate colonized by boring organisms. *Gastrochænolites*-making bivalves live indeed on rocky substrates in the first few metres under sea surface (e.g., Bromley 1994; Hillgärtner 1998).

Discussion and conclusions

In the last years, different methods for quantitative evaluation of geosites and geomorphosites have been proposed, in which the intrinsic *scientific value* of the site is combined with a large spectrum of *additional values*, going from cultural interest to aesthetic relevance. The sum of scientific and additional values defines the *global value* of the geosite (e.g., Grandgirard 1999; Wimbledon et al. 2000; Pereira et al. 2007; Reynard et al. 2007; Bollati et al. 2012, 2014; Fassoulas et al. 2012). The proposed methods differ considerably from one to another, depending on the diverse criteria utilized and on the relative importance accorded to each, largely conditioned by the finality of geosite assessment (e.g., site protection vs. touristic exploitation; Reynard et al. 2007; Pereira and Pereira 2010).

The main aspects defining the geoheritage value of the Col de Braus section are discussed below, following the criteria most commonly utilized in the literature for geosite assessment.

- The *scientific value* results from different parameters including representativeness, integrity, rarity and geodiversity (e.g., Grandgirard 1999; Wimbledon et al. 2000; Lugon and Reynard 2003; Pereira et al 2007 ;Reynard et al. 2007; Bollati et al. 2012, 2014; Fassoulas et al. 2012). The Col de Braus is a unique geological locality in the Maritime Alps due to the exceptional exposure of the Middle Jurassic–Cretaceous Provençal succession and the perfect accessibility of the entire stratigraphic section. It also offers a large geodiversity in terms of sedimentary facies and processes. The uniqueness of this situation is evidenced by the number of papers that cited this locality in the last decades, regarding different facets of sedimentary geology as stratigraphy and biostratigraphy (Lanteaume 1968; Campredon 1972; Conard 1978; Conard & Manivit 1979; Demay 1984; Götz et al. 2008), sedimentology (Pasquini et al. 2004; Decarlis and Lualdi 2008; Barale et al. 2013), and paleontology (Delanoy 1990, 1992; Delanoy et al. 1991; Thomel 1992; Bert and Delanoy 2000; Bert et al. 2006).
- The *geohistorical value*, i.e., the importance of the site in the history of geological researches, has been either considered to be part of the scientific value (Pereira et al 2007; Bollati et al. 2012, 2014) or of the cultural value (Lugon and Reynard 2003; Reynard et al. 2007). The study area has an elevated geohistorical value, as it has been object of scientific interest for more than two centuries, being also studied by renowned geologists as William Buckland or Angelo Sismonda.
- The *educational value*, or *educational exemplarity*, is part of the scientific value according to Pereira et al. (2007) and Bollati et al. (2012, 2014) whereas it is an additional or independent value following Serrano Cañadas and Gonzales Trueba (2005) and Reynard et al. (2007). By reason of its geodiversity and favorable outcropping conditions, the Col de Braus section is ideal for didactic purposes regarding different aspects of sedimentary geology. Actually, this locality was regularly visited in the past by the students of the Geology course of Torino University.
- The *ecological value*, i.e. the role of geological elements in the development of specific biological communities, has been listed among the additional values (e.g., Reynard 2007; Pereira et al. 2007; Pereira and Pereira 2010; Fassoulas et al. 2012) or as a part of the scientific value (Bollati et al. 2012, 2014). The area surrounding the studied section supports a complex ecosystem, with many faunal and floristic particularities including species endemic of the Maritime Alps, and has been included in a «Zone Naturelle d'intérêt écologique, faunistique et floristique» [Natural site of ecologic, faunal and floristic interest] (ZNIEFF 930020139 Mont Farghet - Col de Braus; Michaud et al. 2014).

- The additional *aesthetic value* is a subjective criterion, largely influenced by personal evaluations (e.g., Lugon and Reynard 2003; Reynard et al. 2007; Pereira et al. 2007; Bollati et al. 2012; Fassoulas et al. 2012). However, the study area can be reasonably given a high score under this aspect, as it is immersed in an amazing Mediterranean upland landscape, with a rough and varied morphology. Moreover, the Col de Braus road is greatly panoramic and presents many remarkable viewpoints.
- The additional *cultural value* represents the most heterogeneous class, comprehending a large range of possible components (e.g., Reynard et al. 2007; Bollati et al. 2012). The Col de Braus road has an *historical value* deriving from its role of important way of communication utilized since ancient times ("salt road"), and traveled also by historical personalities (Thomas Jefferson). Furthermore, the Col de Braus plateau was theatre of different military episodes: fightings between the armies of France and Kingdom of Sardinia at the end of XVIII century, and between Americans and Germans during World War II (Klingbeil 2005). The cultural value is also defined by *folkloristic aspects* related to legends and myths (e.g., Reynard et al. 2007; Fassoulas et al. 2012; Necheş 2013): the mentioned tales about Hercules and Hannibal fall into this category.
- The *potential for use* is commonly evaluated in addition to the global value of geosites. It refers to the potentiality of site fruition by the public, and takes into account various elements as accessibility, presence of services, visibility of geological features, and the general tourist attractiveness of the area (e.g., Pereira and Pereira 2010; Bollati et al. 2012, 2014; Fassoulas et al. 2012). The Col de Braus section has a good accessibility, as it is entirely developed along a county road, and can be reached in short time by car from the city of Nice. The section can be also reached from Nice by train, following the highly panoramic Nice–Sospel–Tende railroad (Touët de l'Escarène rail station is about 1.3 km from the starting point of the proposed itinerary). Accommodation facilities are present in the nearby localities (Sospel, l'Escarène, Lucéram). Moreover, the mild climate of the region and the relatively low altitude allow the visit of this site all year long. This part of the Maritime Alps is largely visited by tourists, and is close to famous tourist localities of Côte d'Azur to one side (Menton, Monte Carlo, Nice, Antibes) and to the Mercantour National Park to the other. In addition, the Col de Braus road is part of the "Route du Baroque nisso-ligure", a cultural–touristic itinerary aimed at discover the rich patrimony of baroque architecture of the eastern Maritime Alps. Lastly, the practice of sport and leisure activities has been recognized to increase the potential for use of a locality (e.g., Bollati et al. 2014): in the study area, canyoning is practiced in the Ruisseau de Redebraus gorge, incised in the Middle Jurassic–Berriasian succession (Fiorina and Jourdan 2007). Furthermore, the Col de Braus road is largely frequented by cyclists and motorcyclists and hosted, over the years, several stages of Tour de France and Giro d'Italia (the two most important cyclistic competitions in the world), and of the automobilistic race Monte Carlo Rally.

In conclusion, the Col de Braus section matches several of the criteria commonly utilized in the literature for geosite–geomorphosite assessment, thus having full rights to be recognized as a remarkable geological heritage. The touristic fortune of the close Réserve Naturelle Géologique de Haute-Provence and Geopark of Haute-Provence (Guiomar 2009, 2013; Pagès 2009; Guiomar et al. 2010; Venzal 2012), distant only 80 km from Col de Braus as the crow flies, testifies the high geotouristic potential of a region — the SE France — in which terrific exposures of geological elements occur in a magnificent and largely preserved landscape, and come along an efficient network of communication routes and accommodation services deriving from a wellestablished touristic vocation. Far from hypothesize a similar geotouristic development for the Col de Braus area, given the limited extension and the lesser overall spectacularity, its valorization and protection would be desirable by reason of its undeniable geoheritage value. At present, the Col de Braus section does not belong to any protected area (although it is at the borders of the Mercantour National Park) and is therefore exposed to different kinds of threats, including indiscriminate collection of rocks and fossils.

The proposed itinerary offers a unique opportunity to travel through 130 Myr of geological history, following the evolution of a portion of the Alpine Tethys passive margin and the subsequent development of the Alpine Foreland Basin, touching a variety of sedimentary environments and climatic conditions, from tropical carbonate platforms to temperate shallow-water ramps. The selected outcrops offer multiple levels of reading, and can be therefore interesting to both neophytes and academic geologists. The great variety of lithotypes exposed along the stratigraphic section, containing abundant macrofossils and commonly showing vivid color contrasts, constitute an additional value capable of capturing the attention of even the least experienced observer. Discontinuity surfaces and condensed deposits introduce the concepts of sedimentary gap and sedimentation rate, contributing to get an idea of the different processes that preside over "materialization" of geological time. On the other hand, abrupt lateral variations occurring within the same stratigraphic interval clearly bring out the role of paleotopography in controlling sedimentary processes.

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Figure captions

Fig.1 (a) Geological setting. The framed area is enlarged in (b). (b) Geographic location of the Col de Braus section with respect to the city of Nice. The framed area corresponds to Fig. 5.

Fig.2 Artistic representation of the western side of the Col de Braus and its road, by Beaumont (1795). In the left foreground, the place known as "Rocca Tagliata" ("cut rock", in Italian), where the road is directly cut in the Jurassic succession with a sheer drop on the Ruisseau de Redebraus gorge

Fig.3 Panoramic view of the Col de Braus section, from Albaretta locality (see position of shooting point in Fig. 5)

Fig.4 Schematic stratigraphic column of the Col de Braus section (numbers refer to position of proposed stops). In the right column, sedimentation conditions of the different stratigraphic intervals are indicated, together with correlation between main discontinuity surfaces and regional geological events

Fig.5 Geological map of the Col de Braus area, showing the proposed itinerary and stops (for stop 5c, see Fig. 13a). The inset represents an enlargement of the Saint Laurent sector (stops 3–4). The shooting point of the image in Fig. 3 is also shown. Modified from Barale *et al.* (in press)

Fig.6 Stop1, Touët de l'Escarène. (a) Highly-deformed volume of Upper Cretaceous marl-limestone alternations (Caire de Braus Marl), showing chevron folds cut by low-angle faults, situated below the Touët de l'Escarène Thrust (TET). (b) Line-drawing of the outcrop in (a); the TET sense of shearing is indicated

Fig.7 Stop2, Ruisseau de Redebraus gorge. (a) Panoramic view of the gorge, from the Rochers de Saint Sauveur. The star indicates the position of Stop 2. (b) Weathered surface of Upper Jurassic limestones, showing branching colonial corals, near Saint Laurent. (c) Desiccation pores in supratidal facies of the Cime de la Graye Limestone; Saint Laurent

Fig.8 Stop3, Saint Laurent. (a) General view of the outcrop; the framed portion is enlarged in (b) and (c). (b), (c) Condensed deposits in the upper part of the Clarissia Formation ((b) field image, (c) line-drawing): upper Barremian bioclastic–lithoclastic conglomerate, lying on a mineralized hard ground (HG) on top of late Hauterivian marly limestones (HL). Note the framework of bioturbation galleries, showing a polyphase filling (*c*, bioclastic–lithoclastic conglomerate; *g*, glaucony-rich sediment). The conglomerate bed is followed by a bed of glauconitic limestone, and by glaucony-rich marls representing the base of the Grès Verts (GV). (d) Cross section of a lytoceratid ammonite shell in the upper Barremian conglomerate; note the compositional difference between internal mould and encasing sediment, indicative of reworking

Fig.9 Stop4, Saint Laurent. (a) General view of the outcrop; note the color contrast between the dark-green Grès Verts (foreground) and the light grey Saint Laurent Marl (background). (b) Particular of the bioturbated glauconitic calcareous marls at the top of the Grès Verts; note the dark-green, submillimetric glaucony grains. (c) Large macroconch specimen of *Puzosia* sp. in the calcareous marl at the top of the Grès Verts

Fig.10 Stop5a: panoramic view of the Source de Pissaour outcrop, with the lower part of the Alpine Foreland Basin succession resting on the discontinuity surface on top of the Upper Cretaceous succession (CB, Caire de Braus Marl; MF, *Microcodium* Formation; NL, Nummulitic Limestone)

Fig.11 Scheme of the stratigraphic relationships among Upper Cretaceous succession, *Microcodium* Formation, and Nummulitic Limestone (redrawn from Varrone and Clari 2003). Relative positions of stops 5a to 5c are indicated

Fig.12 Stop5b, Crête de Montauri. (a) The quartzarenites of the upper member of the *Microcodium* Formation (MF), and the lower part of the Nummulitic Limestone (NL), lying on the Upper Cretaceous Caire de Braus Marl (CB); encircled rule for scale is 1 m high. (b) Trough cross-stratification in the quartzarenites of upper member of the *Microcodium* Formation (c) Bioclastic–lithic arenite, rich in larger benthic foraminifera (*Nummulites*), in the lower interval of the Nummulitic Limestone

Fig.13 Stop5c, Rocher de Pianastan. (a) Geological map of the northern part of Col de Braus syncline, showing the position of stop 5c. For abbreviations of lithostratigraphic units, see Fig.5. (b) Panoramic view of the Rocher de Pianastan; stars delimitate the part of the outcrop most suitable for observation. (c) Discontinuity surface separating the Nummulitic Limestone (NL) from the underlying Caire de Braus Marl (CB); encircled hammer for scale. (d) Particular of the discontinuity surface: the top of the light-coloured Caire de Braus Marl, pitted by ampoule-shaped *Gastrocheanolites* borings, is covered by dark-coloured lithoarenites with rare *Nummulites* (arrowed), representing the base of the Nummulitic Limestone

Figure 1

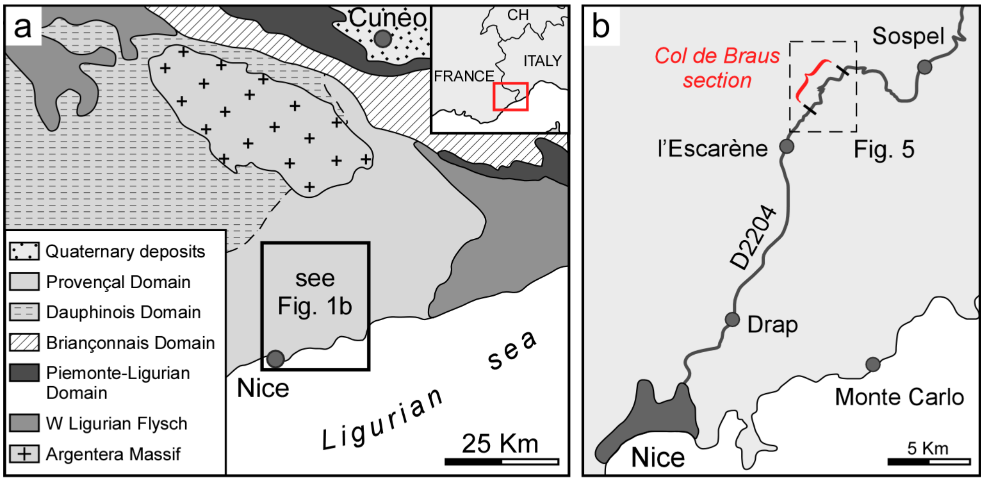


Figure 2

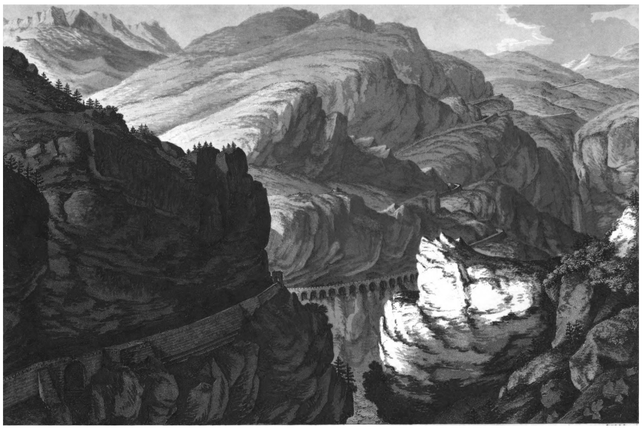


Figure 3

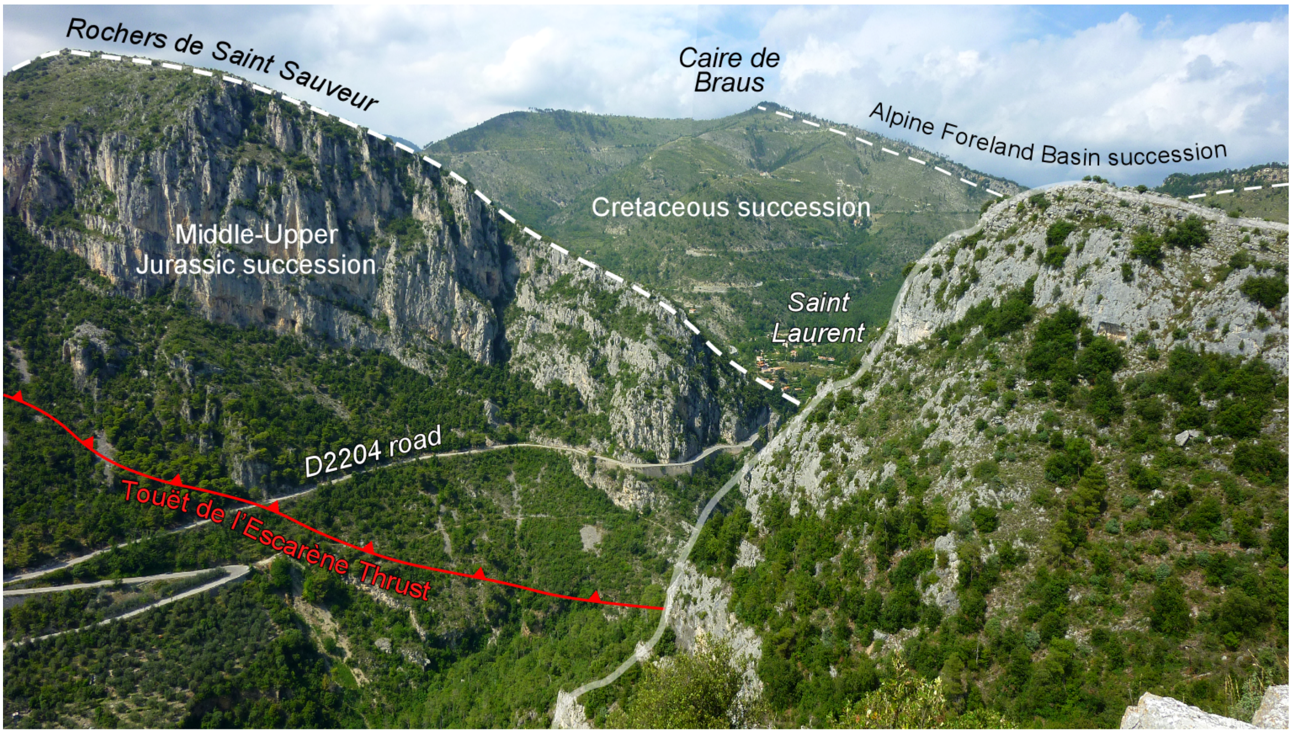
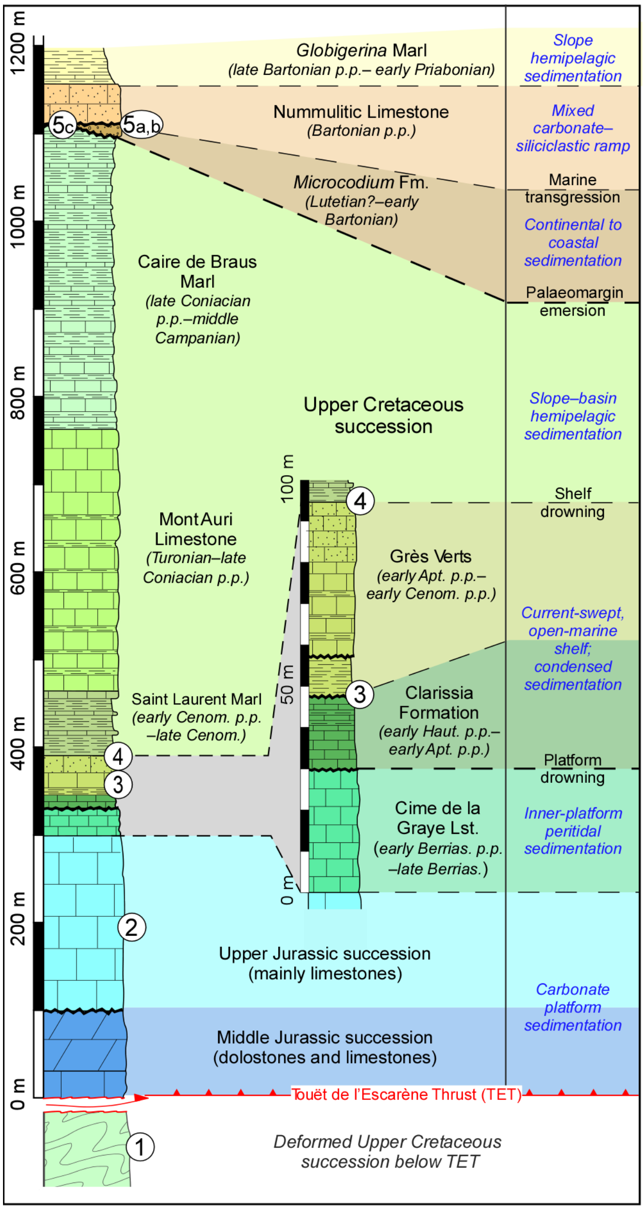
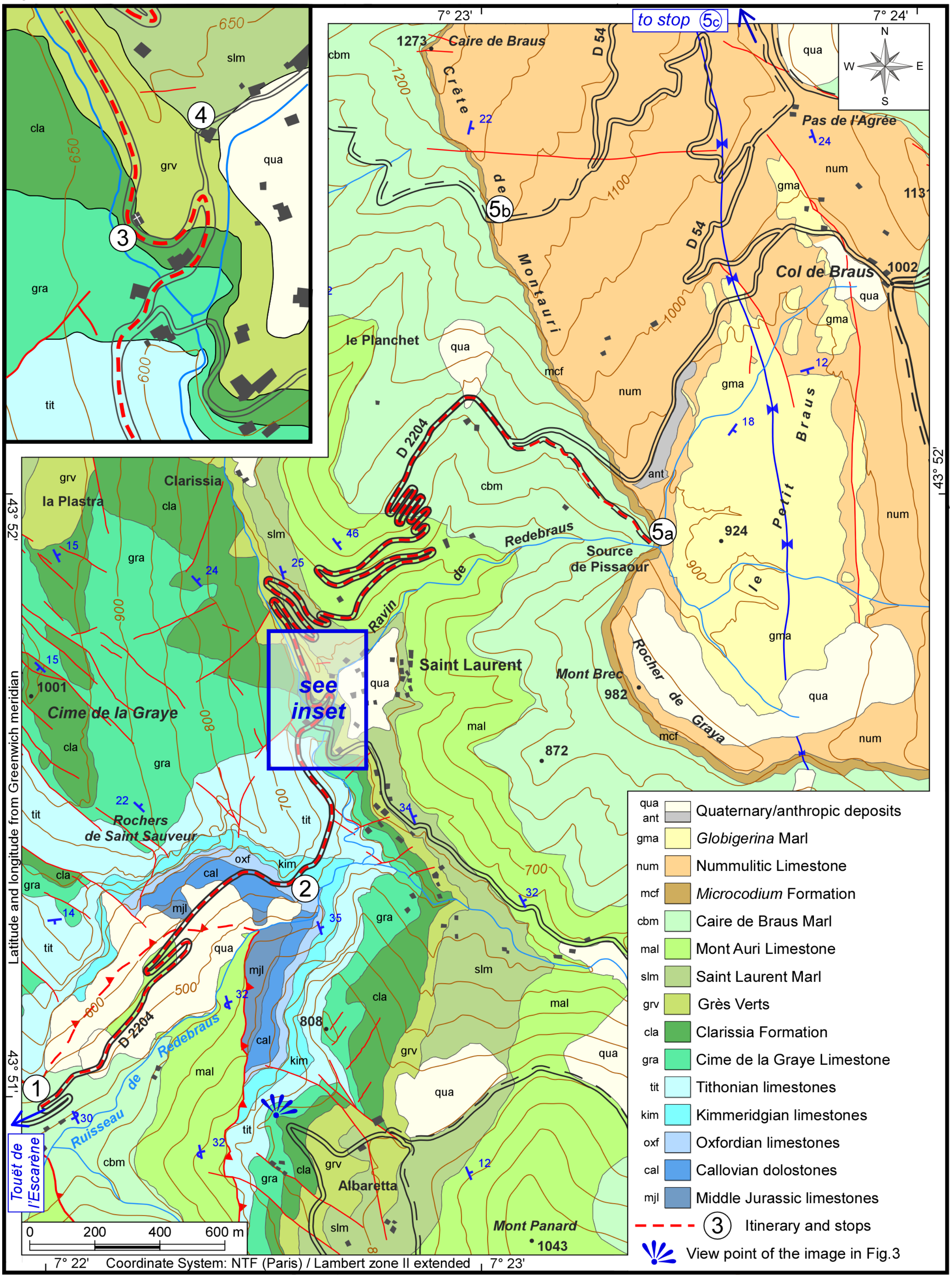


Figure 4



1200 m
1000 m
800 m
600 m
400 m
200 m
0 m
Globigerina Marl
(late Bartonian p.p.– early Priabonian)
Slope hemipelagic sedimentation
Nummulitic Limestone
(Bartonian p.p.)
Mixed carbonate–siliciclastic ramp
5c
5a,b
Microcodium Fm.
(Lutetian?–early Bartonian)
Marine transgression
Continental to coastal sedimentation
Palaeomargin emersion
Caire de Braus Marl
(late Coniacian p.p.–middle Campanian)
Upper Cretaceous succession
Slope–basin hemipelagic sedimentation
100 m
50 m
0 m
4
Shelf drowning
Mont Auri Limestone
(Turonian–late Coniacian p.p.)
Grès Verts
(early Apt. p.p.– early Cenom. p.p.)
Current-swept, open-marine shelf; condensed sedimentation
3
Clarissia Formation
(early Haut. p.p.– early Apt. p.p.)
Saint Laurent Marl
(early Cenom. p.p. –late Cenom.)
Platform drowning
Cime de la Graye Lst.
(early Berrias. p.p. –late Berrias.)
Inner-platform peritidal sedimentation
2
Upper Jurassic succession
(mainly limestones)
Carbonate platform sedimentation
Middle Jurassic succession
(dolostones and limestones)
Touët de l'Escarène Thrust (TET)
1
Deformed Upper Cretaceous succession below TET

Figure 5



to stop 5c
7° 23'
7° 24'
7° 22'
43° 52'
43° 51'
N
S
W
E
Caire de Braus
1273
Crête de Montauri
Pas de l'Agrée
Col de Braus
1002
D 54
D 2204
le Planchet
Redebraus
Source de Pissaour
Ravin de Redebraus
Saint Laurent
Mont Brec
982
872
924
Rocher de Graya
le Petit Braus
Clarissia
la Plastra
Cime de la Graye
1001
Rochers de Saint Sauveur
see inset
808
Albaretta
Mont Panard
1043
Ruisseau de Redebraus
Touët de l'Escarène
Latitude and longitude from Greenwich meridian
Coordinate System: NTF (Paris) / Lambert zone II extended
0
200
400
600 m
qua
ant
Quaternary/anthropic deposits
gma
Globigerina Marl
num
Nummulitic Limestone
mcf
Microcodium Formation
cbm
Caire de Braus Marl
mal
Mont Auri Limestone
slm
Saint Laurent Marl
grv
Grès Verts
cla
Clarissia Formation
gra
Cime de la Graye Limestone
tit
Tithonian limestones
kim
Kimmeridgian limestones
oxf
Oxfordian limestones
cal
Callovian dolostones
mjl
Middle Jurassic limestones
3
Itinerary and stops
View point of the image in Fig.3

Figure 6

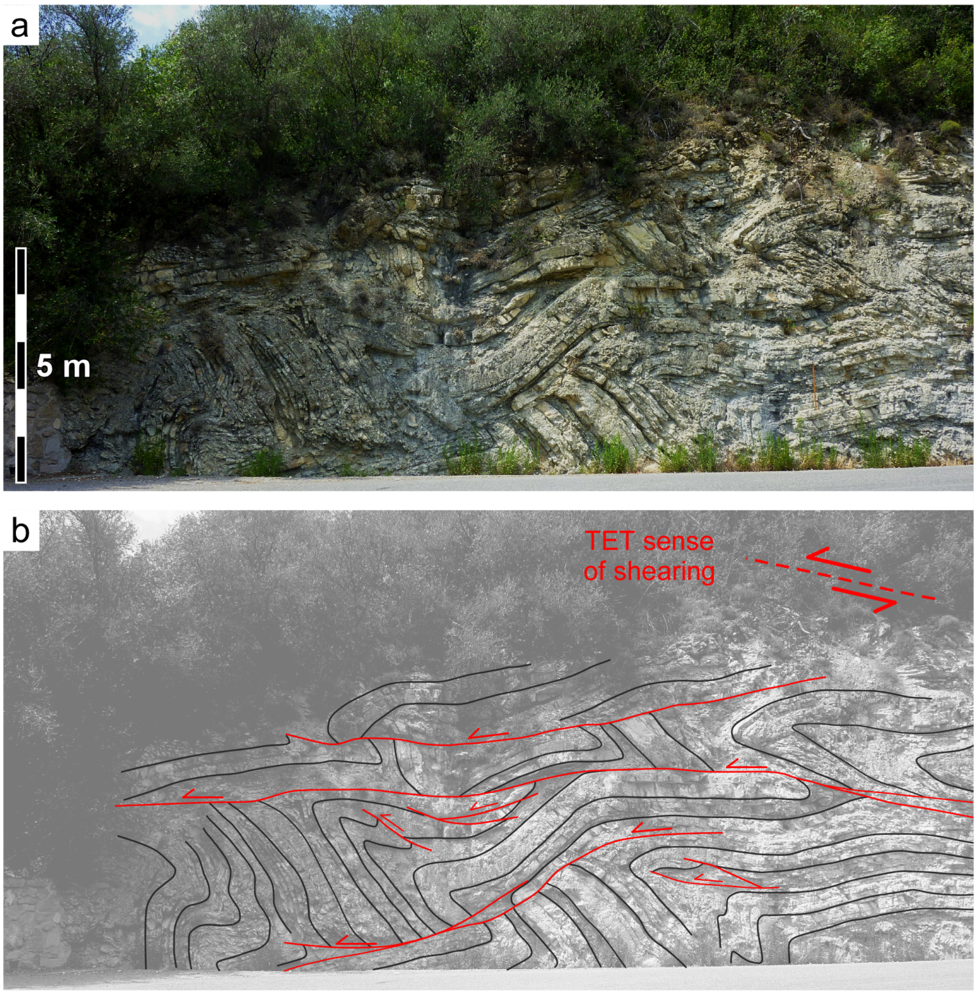


Figure 7

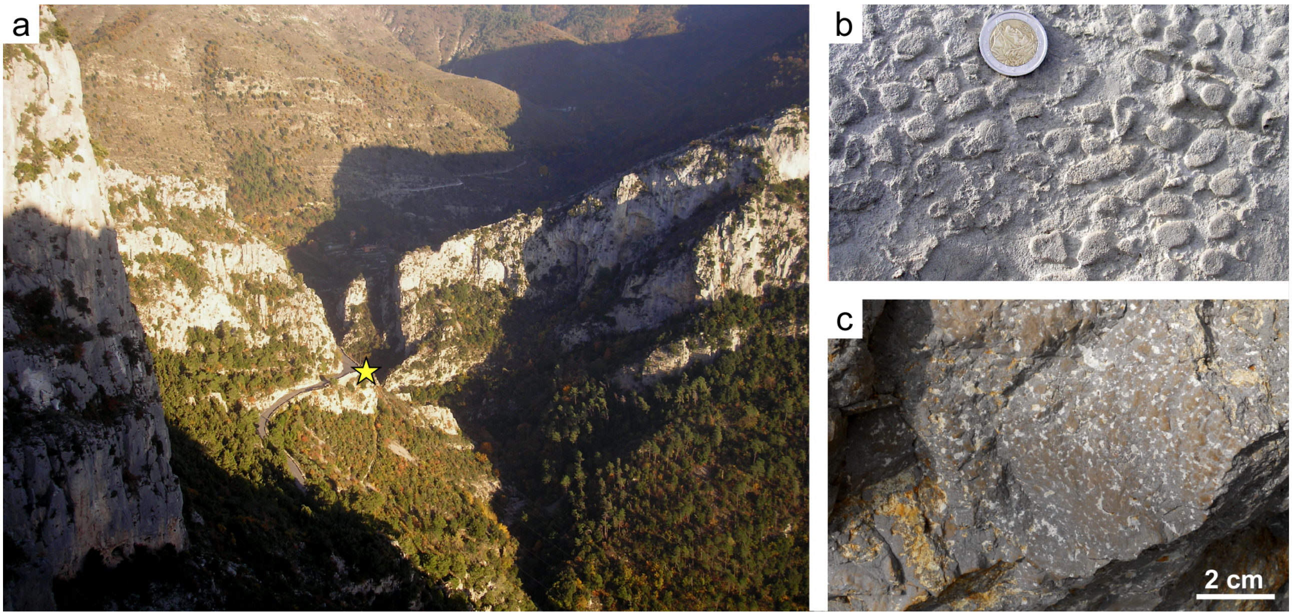


Figure 8

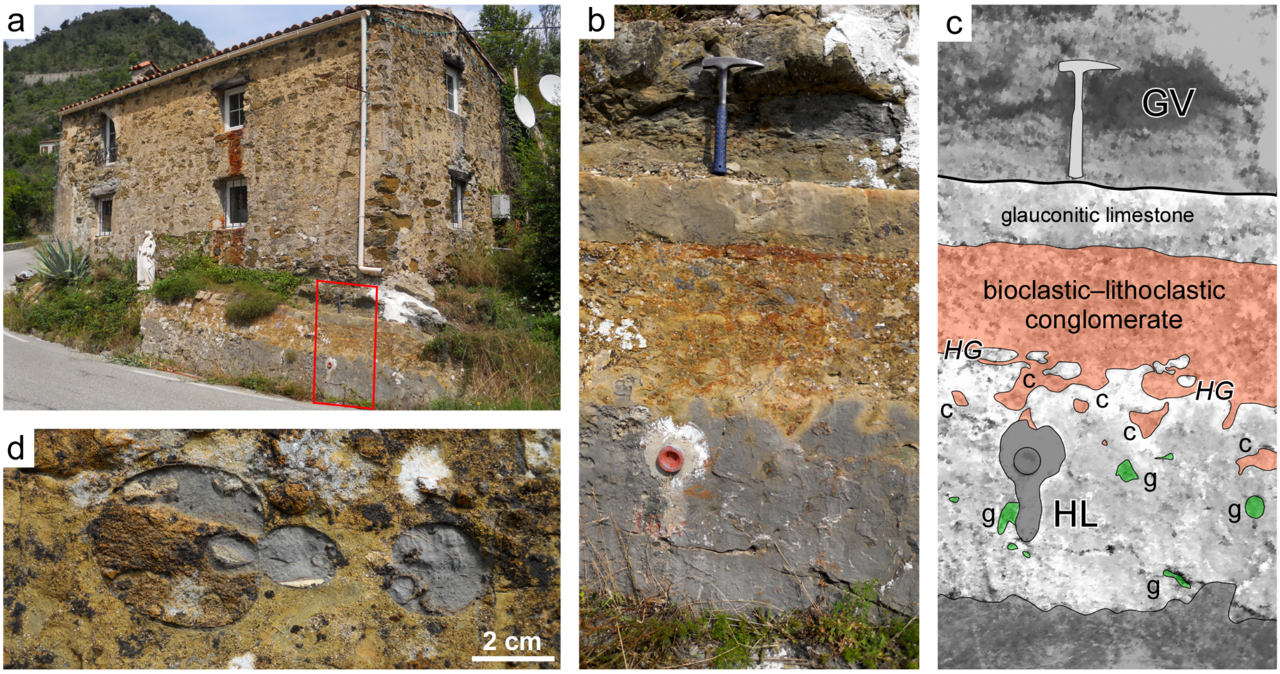


Figure 9

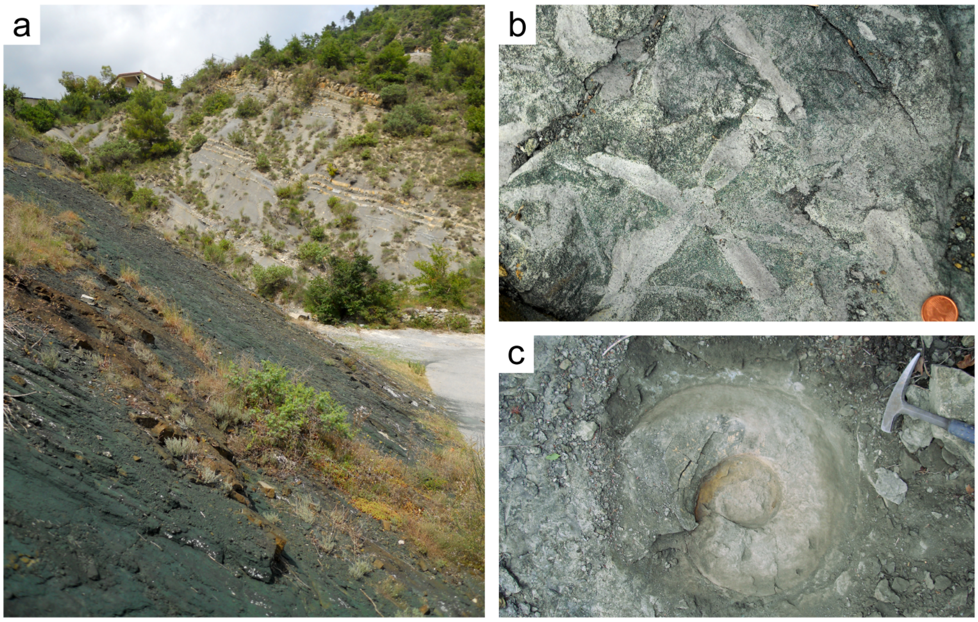


Figure 10

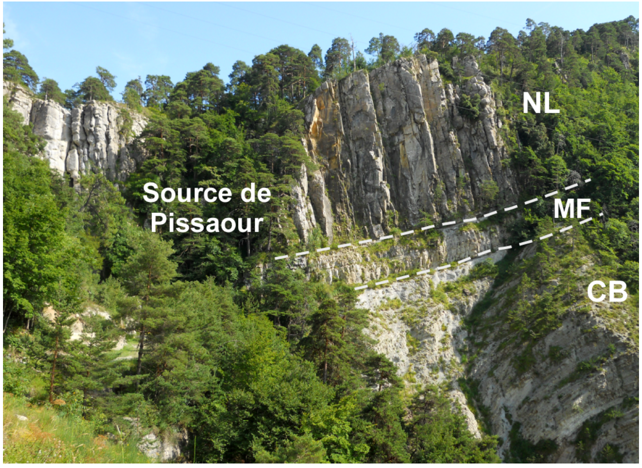


Figure 11

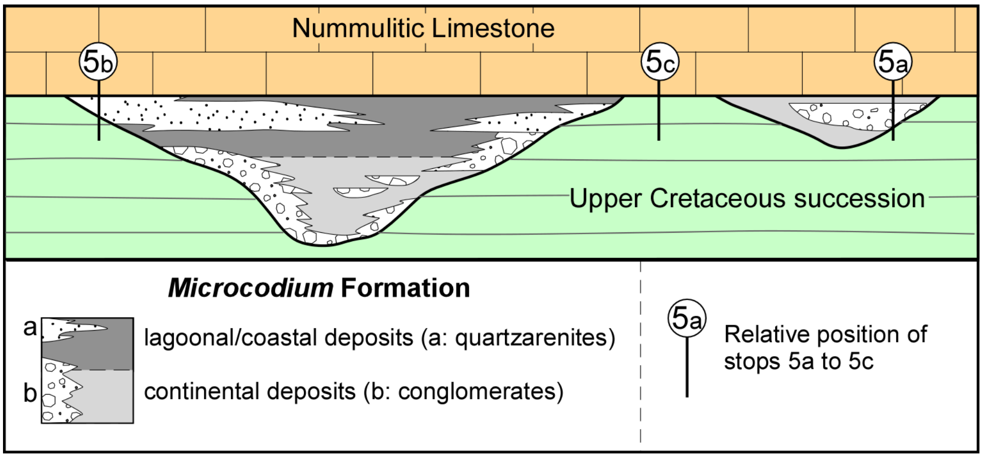


Figure 12

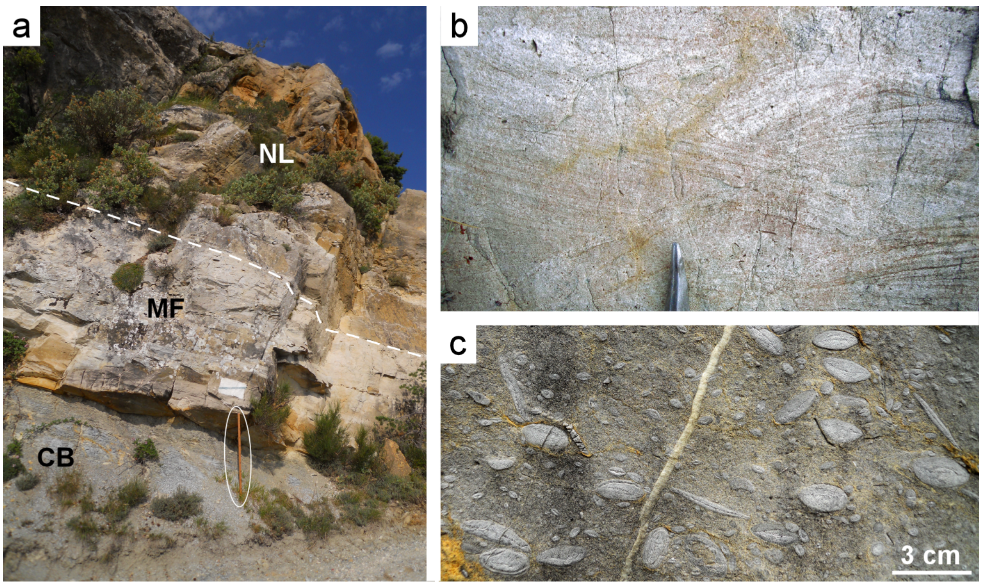
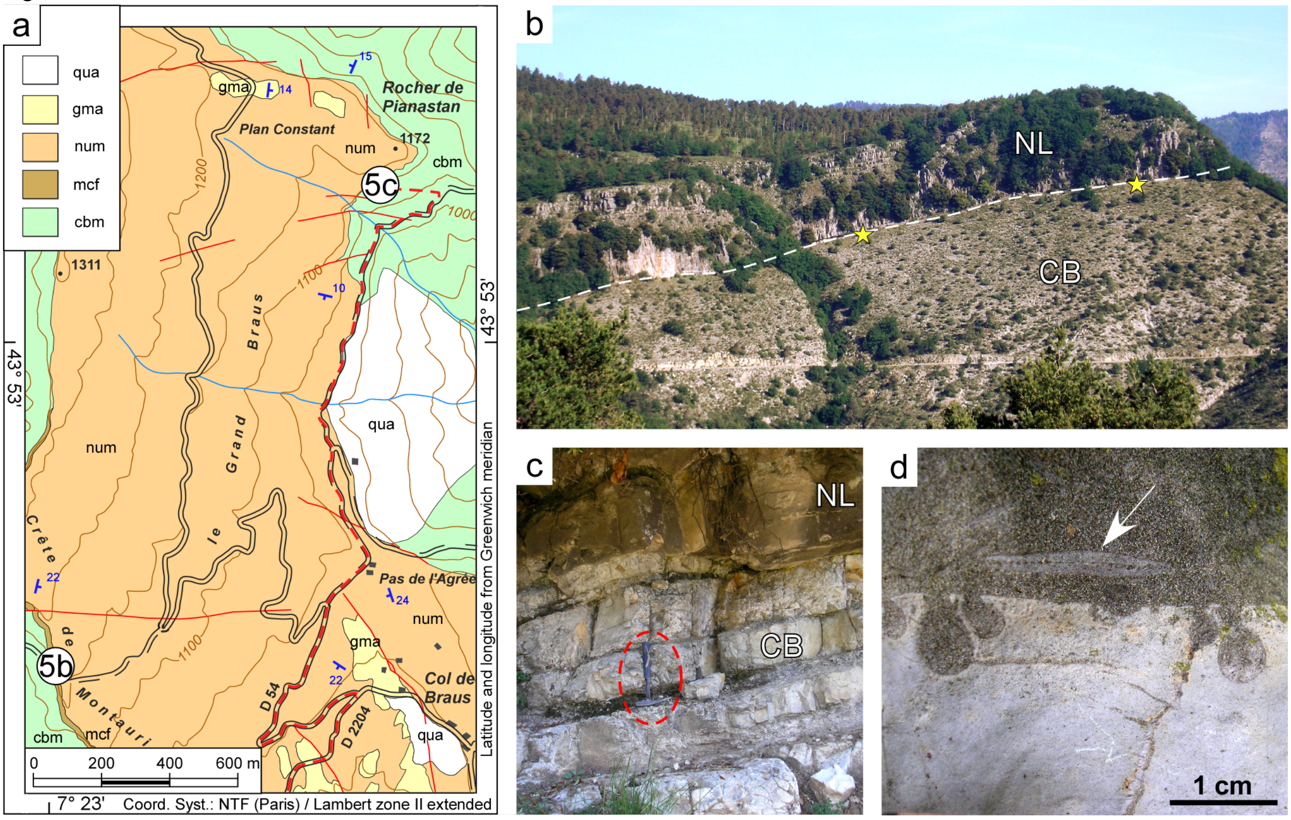


Figure 13


a
qua
gma
num
mcf
cbm
Rocher de Pianastan
Plan Constant
1172
5c
1311
le Grand Braus
Crête de Montauri
5b
Pas de l'Agrée
Col de Braus
D 54
D 2204
0 200 400 600 m
7° 23'
43° 53'
Coord. Syst.: NTF (Paris) / Lambert zone II extended
Latitude and longitude from Greenwich meridian
b
NL
CB
c
NL
CB
d
1 cm