Rivista Italiana di Paleontologia e Stratigrafia
(*Research in Paleontology and Stratigraphy*)
vol. 123(3): 355-378. **November 2017**

STRATIGRAPHY, SEDIMENTOLOGY AND SYNDEPOSITIONAL TECTONICS OF THE JURASSIC-CRETACEOUS SUCCESSION AT THE TRANSITION BETWEEN PROVENÇAL AND DAUPHINOIS DOMAINS (MARITIME ALPS, NW ITALY)

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To cite this article: Barale L., Bertok C., d'Atri A., Martire L. & Piana F. (2017) - Stratigraphy, sedimentology and syndepositional tectonics of the Jurassic-Cretaceous succession at the transition between Provençal and Dauphinois domains (Maritime Alps, NW Italy). *Riv. It. Paleontol. Strat.*, 123(3): 355-378.

Keywords: syndepositional tectonics; palaeoescarpment; Jurassic-Cretaceous; Dauphinois Domain; Provençal Domain; Maritime Alps.

Abstract. The Provençal and Dauphinois Mesozoic successions cropping out at the southeastern margin of the Argentera Massif (Maritime Alps, NW Italy) were deposited at the transition between the Provençal platform and the Dauphinois basin, marked in the study area by a partly preserved Mesozoic palaeoescarpment. These successions show important lateral variations occurring over relatively short distances, probably related to syndepositional tectonics. Different stratigraphic intervals of the pelagic-hemipelagic Dauphinois succession contain resedimented deposits, made up of both intra- and extrabasinal material, which provide a twofold evidence of syndepositional tectonics indicating both tectonically-triggered gravitational processes and a tectonically-driven evolution of the source areas. Two stages of syndepositional tectonics have been recognized: the first in the earliest Cretaceous, which is related to the deposition of carbonate breccias in the Dauphinois succession and to hydrothermal dolomitization of the Middle Triassic-Jurassic Provençal carbonates, and the second in the Late Cretaceous, which triggered the deposition of different detrital lithozones in the Upper Cretaceous Puriac Limestone. The cited evidence indicates that syndepositional tectonics continued to influence the evolution of the Alpine Tethys European passive margin long after the Late Triassic-Early Jurassic syn-rift stage, which caused the differentiation between the Dauphinois basin and the Provençal platform.

Introduction

Syndepositional tectonics plays a major role in the evolution of modern passive continental margins, where high-resolution seismic methods and deep-drilling data allow detailed reconstruction of the geometries of faults and sedimentary bodies (e.g., Favre & Stampfli 1992; Karner & Driscoll 2000; Moulin et al. 2005; Péron-Pinvidic et al. 2007; Afilhado et al. 2008; Aslanian et al. 2009). Conversely, in fossil continental margins presently involved in orogenic chains, the direct observation of preserved palaeostructures is rare and the reconstruction of syndepositional tectonics commonly relies on the recognition of indirect evidence, both stratigraphic and sedimentologic. In the case of the Alpine Tethys European palaeomargin, currently incorporated in the Alpine orogen, the effects of Mesozoic syndepositional tectonics have been increasingly recognized in the last decades in several sectors of the Western Alpine chain, often revising previous interpretations that overestimated the role of Alpine deformation in generating complex geometries (e.g., Barféty & Gidon 1983, 1984; Dardeau & De Graciansky 1987; Dardeau 1988; Hibsch et al. 1992; Montenat et al. 1997, 2004; Claudel et al. 1997; Claudel & Dumont 1999; Bertok et al. 2011, 2012; Cardello & Mancktelow 2014).

The Mesozoic stratigraphic successions cropping out at the southeastern margin of the Argentera Crystalline Massif (Maritime Alps, NW Italy) were deposited on the Alpine Tethys European palaeomargin, at the transition between the Provençal platform and the Dauphinois basin. The present-day geological knowledge about these stratigraphic successions substantially derives from studies earlier than 1970, and is summarized in the Geological Map of the Argentera Massif at 1:50,000 (Malaroda

Received: November 09, 2016; accepted: June 27, 2017

1970, explanatory notes by Carraro et al. 1970). The study of the sedimentary successions on the Italian side of the Argentera Massif has been resumed in recent years by Bersezio et al. (2002), Barale et al. (2016a, b) and d'Atri et al. (2016).

Detailed stratigraphic and sedimentologic analyses show that syndepositional tectonics played a key-role in the evolution of this part of the European margin throughout the Mesozoic. The Provençal and Dauphinois successions are characterized by important lateral variations, occurring over relatively short distances. Moreover, different stratigraphic intervals of the pelagic-hemipelagic Dauphinois succession contain resedimented deposits, made up of both intrabasinal and extrabasinal material, which provide a twofold evidence of syndepositional tectonics both pointing to tectonically-triggered gravitational processes and documenting tectonically-driven changes in the source and dispersal of sediments.

The aim of this paper is twofold:

• to describe the Jurassic-Lower Cretaceous Provençal and Dauphinois stratigraphic successions, and the overlying Upper Cretaceous succession, cropping out at the southeastern margin of the Argentera Massif, providing new stratigraphic and sedimentologic interpretations based on original data;

• to document the multiple stratigraphic and sedimentologic evidence of syndepositional tectonics recorded in these successions, reconstructing the major phases of Mesozoic tectonic activity.

Methods

Geological mapping at 1:10,000 scale was performed to identify the main tectonic and lithostratigraphic units, and to reconstruct primary geometries and stratigraphic relationships. The resulting geological map was recently published at 1:25,000 scale by Barale et al. (2016a). Petrographic studies on 60 uncovered thin sections (30 µm thick) of the collected samples were carried out by optical microscopy and cathodoluminescence (CL) with the aim of characterizing the main microfacies. CL observations were carried out on polished thin sections using CITL 8200 mk3 equipment (operating conditions: 17 kV, 400 µA).

Geological setting

The study area is located at the southeastern margin of the Argentera Massif (Maritime Alps, NW Italy), between the Gesso and the upper Vermenagna valleys (Fig. 1). This sector is composed of a set of tectonic units, whose stratigraphic successions have been referred to the Dauphinois and Provençal palaeogeographic domains (d'Atri et al. 2016): the Entracque Unit, the Roaschia Unit, the Limone-Viozene Zone (LiVZ), and the Refrey Zone. They form a SE-NW trending narrow belt, comprised between the Argentera Massif to the SW and the more internal Briançonnais and Western Ligurian Flysch units to the NE (Fig. 1). The Italian side of the Argentera Massif and the adjoining sedimentary successions have been mapped at 1:50,000 by Malaroda (1970; explanatory notes by Carraro et al. 1970). More recently, Barale et al. (2016a) published a detailed map of the study area, which the reader is addressed to for all the cited toponyms and names of lithostratigraphic units.

The Dauphinois and Provençal domains represent the most internal part of the Alpine Tethys European palaeomargin, developed on continental crust. The two domains started to differentiate in the Early Jurassic, in response to the extensional tectonics related to the opening of the Alpine Tethys (e.g., Lemoine et al. 1986; Dardeau 1988; De Graciansky & Lemoine 1988). The stratigraphic successions of the study area (Carraro et al. 1970; Barale et al. 2016a) start with Permian continental siliciclastic deposits, which rest on the crystalline basement of the Argentera Massif, and are characterized by marked thickness changes, reaching a maximum thickness of up to 4000 meters (Faure-Muret 1955; Malaroda 1999). They are followed by Lower Triassic coastal siliciclastic deposits (Valette du Sabion quartzarenites) and Middle Triassic peritidal carbonates (Mont Agnelet Formation). Upper Triassic-Lower Jurassic deposits consist of a thin stratigraphic interval, commonly involved in tectonic slicing. This interval is present in the Roaschia Unit and in the northern part of the Entracque Unit, whereas it is absent in the southern part of the Entracque Unit (see Barale et al. 2016a). It consists of (Malaroda 1957; Carraro et al. 1970; Barale et al. 2016a): red and green shales (Bec Matlas shales, Late Triassic); fine grained limestones and dolomitic limestones, locally with algal lamination, containing beds of flat pebble breccias and bivalve coquinas (Monte Servatun Formation, Rhaetian-Hettangian); bioclastic packstones and wackestones with abundant echinoderm fragments, cephalopods and bivalves (Costa Balmera Limestone, Sinemurian). These units indicate a progressive

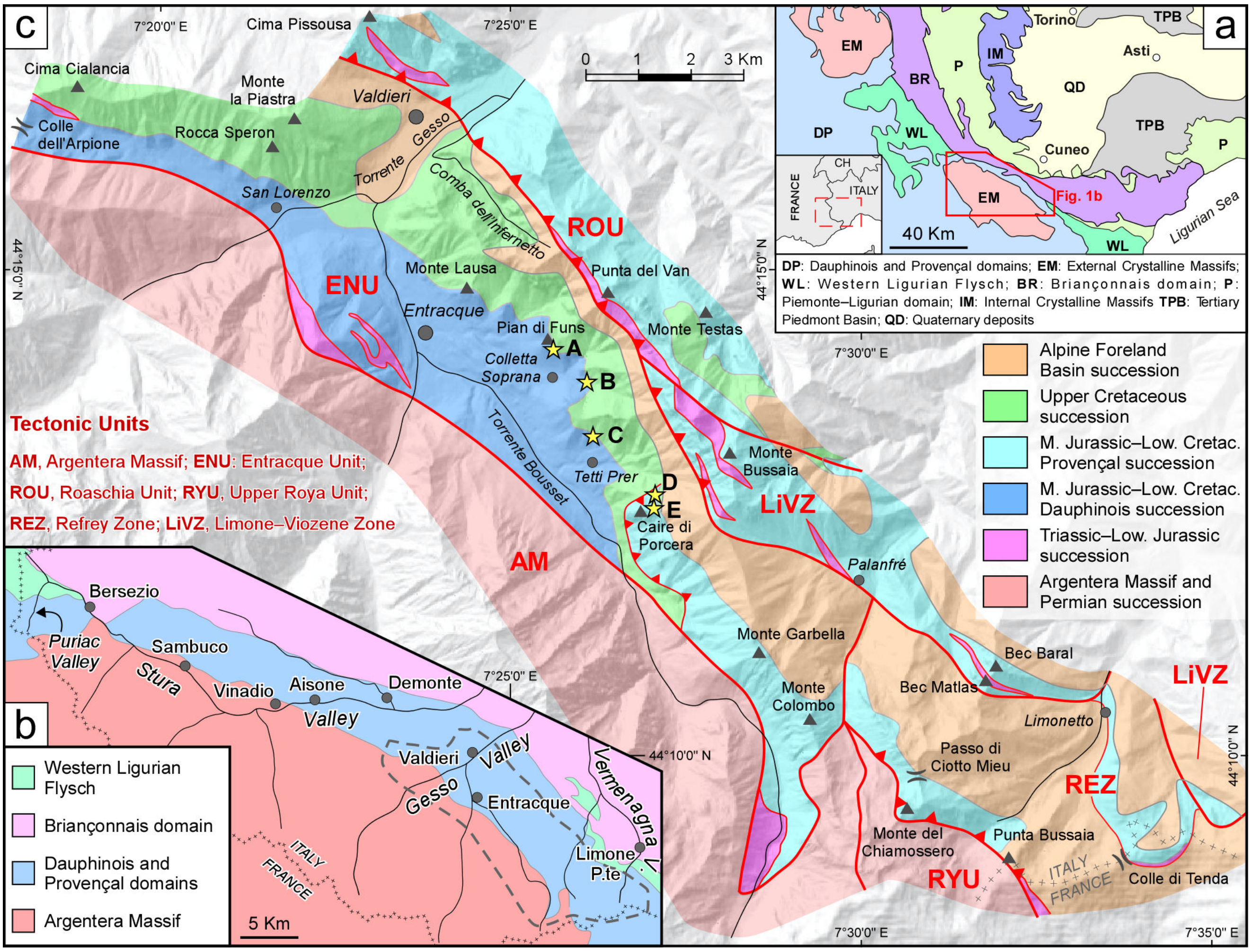

Fig. 1 - a) Schematic geographical and geological map of the SW Alps. The red polygon indicates the position of Fig. 1b. b) Geological scheme of the northeastern side of the Argentera Massif (Stura and Gesso Valleys). The dashed line indicates the study area. c) Geological scheme of the study area, modified from Barale et al. (2016a). The stars indicate the location of the five logs (A, B, C, D, E) of Fig. 4. Hillshade: Sfumo_Europa_WM, Arpa Piemonte (http://webgis.arpa.piemonte.it/ags101free/rest/services/topografia_dati_di_base/Sfumo_Europa_WM/MapServer).

shift from a continental sedimentation (Bec Matlas shales), to inner platform-lagoonal (Monte Servatun Formation) and then to frankly marine, open platform environments (Costa Balmera Limestone).

Starting from Early Jurassic, this area differentiated into two distinct sedimentation domains. To the north, the Dauphinois Domain evolved as a subsiding basin, while, to the south, the Provençal Domain remained a platform area where shallow-water sedimentation lasted until the Early Cretaceous. The transition between Dauphinois and Provençal successions is presently located near Caire di Porcera, a few kilometres south of Entracque. This transition, previously considered as a tectonic contact of Alpine age (Carraro et al. 1970), has been recently interpreted as a preserved palaeomorphological feature, i.e. a palaeoescarpment resulting from the erosional remodelling of a submarine Early-Middle Jurassic fault scarp, and progressively covered by slope deposits during the Middle-Late Jurassic (Barale et al. 2016a; d'Atri et al. 2016). In the study area, the Middle Triassic-lowermost Cretaceous Provençal platform carbonates locally show an intense dolomitization, related to a large-scale and deep-rooted hydrothermal system active in the Provençal sector of the European palaeomargin during the latest Berriasian-Valanginian (Barale et al. 2013, 2016b).

During the late Early Cretaceous, the drowning of the Provençal platform led to a relative facies homogenization between the two domains, as suggested by the common stratigraphic evolution, even if characterized by important thickness variations, documented by the deposition of the Marne Nere and Puriac Limestone.

The top of the Mesozoic successions is truncated by a regional discontinuity surface, corresponding to an important hiatus (latest Cretaceous-middle Eocene) due to a prolonged subaerial exposure related to a significant uplift of the Mesozoic European margin during the first stages of Alpine collision (Crampton & Allen 1995). The collision led to the development of the Alpine Foreland Basin, where a middle Eocene-lower Oligocene succession was unconformably deposited, in response to the increasing flexural subsidence (Sinclair 1997; Ford et al. 1999). This succession starts with laterally discontinuous continental to coastal deposits (*Microcodium* Formation; Faure-Muret & Fallot 1954; Varrone & Clari 2003), followed by the middle Eocene Nummulitic Limestone ramp deposits, the upper Eocene hemipelagic *Globigerina* Marl and the upper Eocene-lower Oligocene turbidite succession of the Annot Sandstone (Sinclair 1997; Ford et al. 1999).

Since the Eocene, the palaeo-European continental margin has been progressively involved in the ongoing formation of the Alpine belt (e.g., Dumont et al. 2012). The studied stratigraphic successions underwent three main deformation events which are well recorded at a regional scale: a first, southwestward brittle-ductile thrusting and superposed foldings, followed by northeastward, backvergent folding, in turn followed by southward brittle thrusting and flexural folding (d'Atri et al. 2016, and reference therein). The regional structural setting was achieved in the frame of a transpressional regime, as indicated by the presence of a post-Oligocene NW-SE Alpine transcurrent shear zone (Limone Viozene Zone) which extends for several kilometres from the Western Ligurian Alps to the study area (Piana et al. 2009; d'Atri et al. 2016). In this context, despite the large amount of finite deformation, strain partitioning allowed preservation of most of the primary stratigraphic features and geometrical relationships (Piana et al. 2009, 2014).

The Mesozoic sedimentary rocks of the study area show, in general, a rather high degree of recrystallization; data on the thermal history of these successions are lacking; however, an anchizonal metamorphism can be inferred by extrapolating the data from the adjoining upper Roya Valley (Piana et al. 2014). Due to the scarcity and the general bad preservation of fossils, the chronostratigraphic attribution of most of the lithostratigraphic units is based on regional correlations with better preserved stratigraphic successions of nearby areas. Only locally, the palaeontological and biostratigraphic study of a few but significant fossiliferous intervals has provided direct age information.

Jurassic-Lower Cretaceous Provençal succession

Garbella Limestone (Middle? Jurassic-Berriasian?)

The Garbella Limestone is a 200-300 metres thick massive limestone succession, only locally showing an ill-defined bedding, with decimetre-thick beds. In the southern sector of the study area (southern Entracque Unit and Refrey Zone) the Garbella Limestone is mainly composed of bioclastic packstones, floatstones, and rudstones, locally associated with coral boundstones (Fig. 3a, b). Fossils are represented by colonial and solitary corals, nerineid gastropods (*Ptygmatis pseudobruntrutana*; Campanino Sturani (1963) also signaled *Nerinea* sp., *Phaneroptyxis moreana*, and *Cryptoplocus* cf. *subpyramidalis*), rudists (Diceratidae), stromatoporoids, echinoderm fragments, benthic foraminifera (Textularidae, Valvulinidae). Beds of oncoidal rudstones, peloidal wackestones and oolitic grainstones are locally present. In the upper part of the unit, a common lithofacies is represented by peloidal-bioclastic mudstones-wackestones with dasycladacean algae (*Clypeina* sp.). In the Roaschia Unit, and in the tectonic slices of Provençal succession presently incorporated in the LiVZ (Bec Matlas-Bec Baral), the above described lithofacies are limited to the upper part (some tens of metres?) of the Garbella Limestone, whereas the lower part is generally formed by bioclastic wackestones/packstones, with abundant crinoid ossicles, along with rare gastropods, bivalves, corals, stromatoporoids and red algae.

The top of the Garbella Limestone is commonly represented by a thin stratigraphic interval (some metres thick) of fenestral and laminated mudstones, locally interbedded with thin layers of greenish clays, associated with flat pebble breccias and oolitic grainstones to packstones. Beds of nerineid gastropod coquina are also present, in which shells are locally completely dissolved and the resulting voids are filled up with a whitish to greenish silty/marly sediment (Fig. 3c); microstalactitic

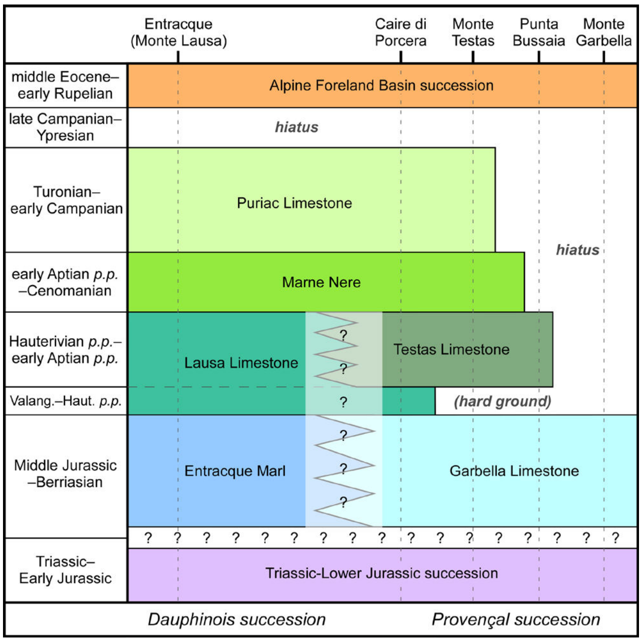

Fig. 2 - Simplified scheme of the stratigraphic relationships between Provençal and Dauphinois successions in the study area. Thicknesses of the rectangles representing lithostratigraphic units are not proportional to their stratigraphic thicknesses nor to time spans.

cements locally predate the sediment infill. At Punta del Van, a grainstone bed composed of subrounded to angular intraclasts, coated grains, benthic foraminifera (*Trocholina* sp.), and abundant ammonite shells is present (Fig. 3d, e). Intraclasts are formed by mudstones, locally with *Clypeina* sp. fragments (Fig. 3e), and peloidal grainstones. Locally (Monte Colombo, Passo Ciotto Mieu), beds of bioclastic mudstone-wackestone with Porocharaceae gyrogonites and stems (sp. aff. *Porochara fusca*), ostracods, and gastropods are also present (Fig. 3f).

The Garbella Limestone is affected for its entire thickness by important phenomena of hydrothermal dolomitization, which locally completely overprinted the primary characters of the rock (Barale et al. 2013, 2016b).

Interpretation. The Garbella Limestone represents a carbonate platform succession and it is mainly formed, in the southern part of the study area, by reefal, peri-reefal, and bioclastic shoal facies (coral-stromatoporoid boundstones, bioclastic rudstones/floatstones and packstones), associated with lagoonal facies (peloidal-*Clypeina* wackestones). Conversely, the succession of the Roaschia unit, dominated by crinoid-rich wackestones/packstones, has been probably deposited on a middle-outer carbonate ramp, possibly evolving into a rimmed platform only toward the top of the unit, where reefal-peri-reefal facies are locally found.

The facies association of the uppermost interval of the Garbella Limestone indicates an inner platform, peritidal environment, in which intertidal/supratidal facies prevail, as indicated by the multiple evidence of periodical emersion: fenestrae, flat pebble breccias, dissolution of aragonitic gastropod shells (probably due to meteoric diagenesis), microstalactitic cements, and nodular fabrics (interpreted to form in peritidal settings as a consequence of bioturbation and periodical desiccation, coupled with early cementation; e.g., Mojon & Strasser 1987). Charophyte-rich beds resulted from deposition in a coastal lagoon environment. The fossil association, dominated by Porocharaceae, indicate a restricted, brackish-water environment (Mojon 1989, 2002). The ammonite-bearing grainstone bed, intercalated within the peritidal facies, can be interpreted as a storm-related, washover deposit, mainly formed by intraclasts (*Clypeina* mudstones) and loose grains ripped out from shallow-water sectors of the platform. The presence and local accumulation of stranded pelagic bioclasts (ammonite shells) in storm-related beds within peritidal or coastal deposits, although unusual, is reported in the literature (e.g., Daber 1968; Stricklin & Smith 1973; Septfontaine 1985; Palma et al. 2013).

The Garbella Limestone has been generically attributed by previous authors to the Middle-Upper Jurassic (Carraro et al. 1970). However, the Middle Jurassic age of the lower part of this unit is only supposed, as it is not supported by biostratigraphic data. The stratigraphic distribution of gastropod species found in the upper part of the unit indicates a Late Jurassic age: *Ptygmatis pseudobruntrutana* is present in the Kimmeridgian-Tithonian (Wieczorek 1998), and *Phaneroptyxis moreana* in the Oxfordian-Tithonian (Sirna & Mastroianni 1993).

A Berriasian age can be speculated for the uppermost interval of the unit, represented by peritidal deposits, based on the correlation with the successions of the southern part of the Maritime Alps (Nice Arc), where the Middle-Upper Jurassic platform carbonates are followed by an interval of peritidal and lagoonal sediments of lower-middle Berriasian age (Lanteaume 1968; Dardeau & Pascal 1982; Barale et al. 2016c). This attribution is consistent with the presence of charophyte remains attributed to *Porochara fusca*, as this species has a large

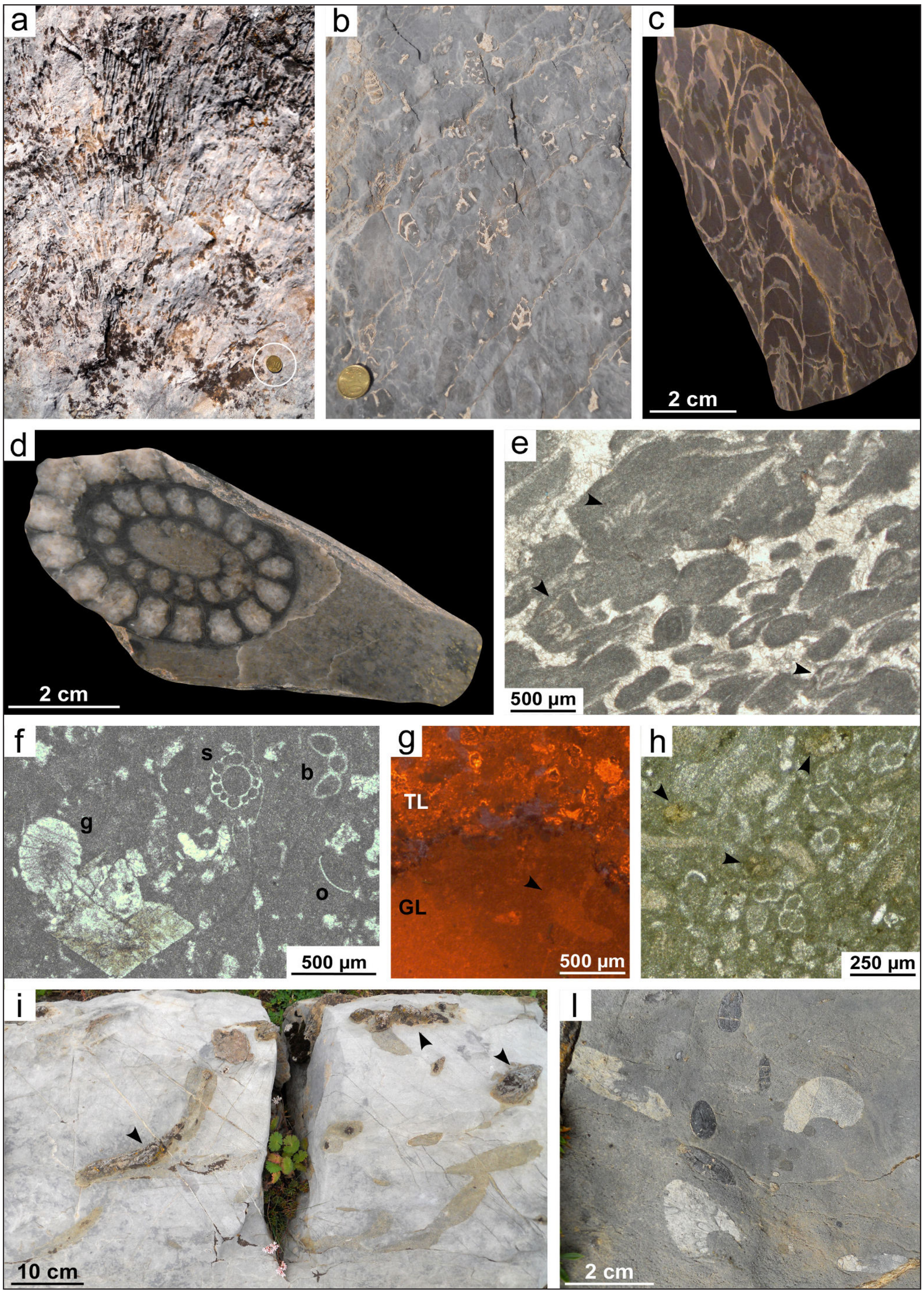

Fig. 3 - Jurassic-Lower Cretaceous Provençal succession. a) Garbella Limestone: coral boundstone affected by selective dolomitization of the matrix (encircled coin for scale). Vallone degli Alberghi, Palanfré. b) Garbella Limestone: bioclastic rudstone with dolomitized nerineid gastropods. Monte del Chiamossero. c) Nerineid gastropod coquina from the top interval of the Garbella Limestone. Voids, derived from the dissolution of gastropod shells, are filled by a yellowish marly sediment. Monte Testas. d) Ammonite shell in a grainstone composed of platform-derived intraclasts and loose grains, from the upper interval of the Garbella Limestone. Punta del Van. e) Thin section photomicrograph (plane light) of the grainstone in (d), mostly composed of mudstone intraclasts, some of which contain *Clypeina* fragments (arrow tips). f) Thin section photomicrograph (plane light) of a bioclastic wackestone with Porocharaceae remains (g: gyrogonite, s: stem, b: branchlet) from the upper interval of the Garbella Limestone; an ostracod shell (o) is also visible. Note the brown, euhedral dolomite crystal growing on the matrix. Monte Colombo. g) Cathodoluminescence photomicrograph of the discontinuity surface separating the Garbella Limestone (GL) from the Testas Limestone (TL), encrusted by phosphates (lilac-blue luminescence) and Fe-oxyhydroxides (non luminescent). The arrow tip indicates a probable sponge boring. Monte Testas. h) Testas Limestone: thin section photomicrograph (plane light) of a bioclastic packstone with echinoderm fragments, planktonic foraminifera (*Hedbergella* sp.), and phosphatic grains (arrow tips). Punta del Van. i) Cross-section of a bioturbated bed of Testas Limestone, showing *Thalassinoides* burrows filled with a crinoid-rich packstone. Silicified nodules are locally developed along the burrows (arrow tips). Monte Testas. l) Detail of the bioclastic-lithoclastic conglomerate interval in the upper part of the Testas Limestone, containing reworked ammonite moulds and belemnite rostra. Punta del Van.

stratigraphic distribution spanning the Bathonian-Berriasian (Mojon 1989; Schudack 1993; Pereira et al. 2003).

Testas Limestone (Hauterivian p.p.?-early Aptian p.p.?)

In the northern sector of the study area (Roaschia Unit) the Testas Limestone overlies a hard ground surface developed at the top of the Garbella Limestone (Fig. 2), commonly mineralized and patchily coated by a millimetre-thick crust of phosphates and Fe-oxyhydroxides (Fig. 3g) and locally colonized by large serpulids (10-15 centimetres long and 3-4 millimetres in diameter). Above, a few metres of bioclastic, crinoid-rich, wackestones and packstones are present (Fig. 3h), containing planktonic foraminifera (*Hedbergella* sp.), fragments of large tube worms, ammonite moulds, and partly silicified belemnite rostra, locally iso-oriented. These deposits are bioturbated (*Thalassinoides*) and contain decimetre-sized silicified nodules, commonly developed along burrows (Fig. 3i); phosphates are present as millimetre-sized grains, as filling of foraminifera chambers, and as impregnations on minor discontinuity surfaces. In the upper part of the unit, a bioclastic-lithoclastic conglomerate interval, 100-120 cm thick, is present, with phosphatized lithoclasts, belemnites, reworked ammonite moulds (*Barremites* sp. and *Melchiorites* sp., figured in Barale 2014) and solitary corals (Fig. 3l). The conglomerate lies on a mineralized hard ground, coated by Fe-oxides and phosphates, and characterized by the presence of decimetre-long fractures and burrows.

In the southern sector of the study area, the Testas Limestone consists of a thin interval (0-2 metres) of marly limestones containing abundant segmented belemnites and echinoderm fragments. This interval is only locally present (Carraro et al. 1970; Barale et al. 2016a), lying on the dolomitized Jurassic succession (Punta Bussaia), or on the thin interval of pebbly limestones attributed to the lower member of the Lausa Limestone (Caire di Porcera, Monte del Chiamossero).

Interpretation. The Testas Limestone can be interpreted as the result of pelagic sedimentation, in an open- marine shelf environment. The basal discontinuity surface, represented in the Roaschia Unit by a mineralized hard ground, marks the drowning of the Jurassic-Berriasian platform (Garbella Limestone). The presence of repeated discontinuity surfaces and the abundance of phosphates indicate the condensed character of this unit. Condensation was probably related to sediment winnowing by bottom currents, whose action is also confirmed by the local iso-orientation of belemnite rostra on bedding surfaces. The lateral thickness variations of these deposits can be attributed to a palaeotopographic control, with sediment deposition limited to more depressed sectors of the shelf.

The Testas Limestone probably has an Early Cretaceous age as it is comprised between the Middle? Jurassic-Berriasian? Garbella Limestone and the early Aptian p.p.-Cenomanian Marne Nere. For this unit, a Hauterivian p.p.-early Aptian p.p. age is proposed, by comparison with the condensed Lower Cretaceous successions of the southeastern Maritime Alps. In this area, after drowning of the Jurassic-Berriasian carbonate platform, a condensed open-marine succession deposited in the early Hauterivian p.p.-early Aptian p.p., until a switch to marly sedimentation during the early Aptian (Bigot et al. 1967; Lanteaume 1968, 1990; Pasquini et al. 2004; Barale et al. 2016c).

Bioclastic-lithoclastic conglomerates in the upper part of the Testas Limestone can be correlated with analogous deposits occurring in the Lower Cretaceous successions of the southeastern Maritime Alps, corresponding to an important Barremian condensation episode and representing a reliable key interval in this region (e.g., Faure-Muret 1955; Bigot et al. 1967; Lanteaume 1968, 1990; Delanoy 1992; Pasquini et al. 2004; Barale et al. 2016c). A Barremian age is consistent with the presence of reworked *Melchiorites* sp. and *Barremites* sp., as the first genus has a Barremian-early Albian stratigraphic distribution, and the second is Barremian (Wright et al. 1996).

Jurassic-Lower Cretaceous Dauphinois succession

The Jurassic-Lower Cretaceous Dauphinois succession of the Entracque area (Fig. 1) has been previously subdivided by Carraro et al. (1970) and Malaroda (1970) into two units, namely:

- a lower marly unit (300-400 m), with breccia beds at the top, basically correlated to the Middle-Upper Jurassic “Terre Nere” of the classic Dauphinois succession;

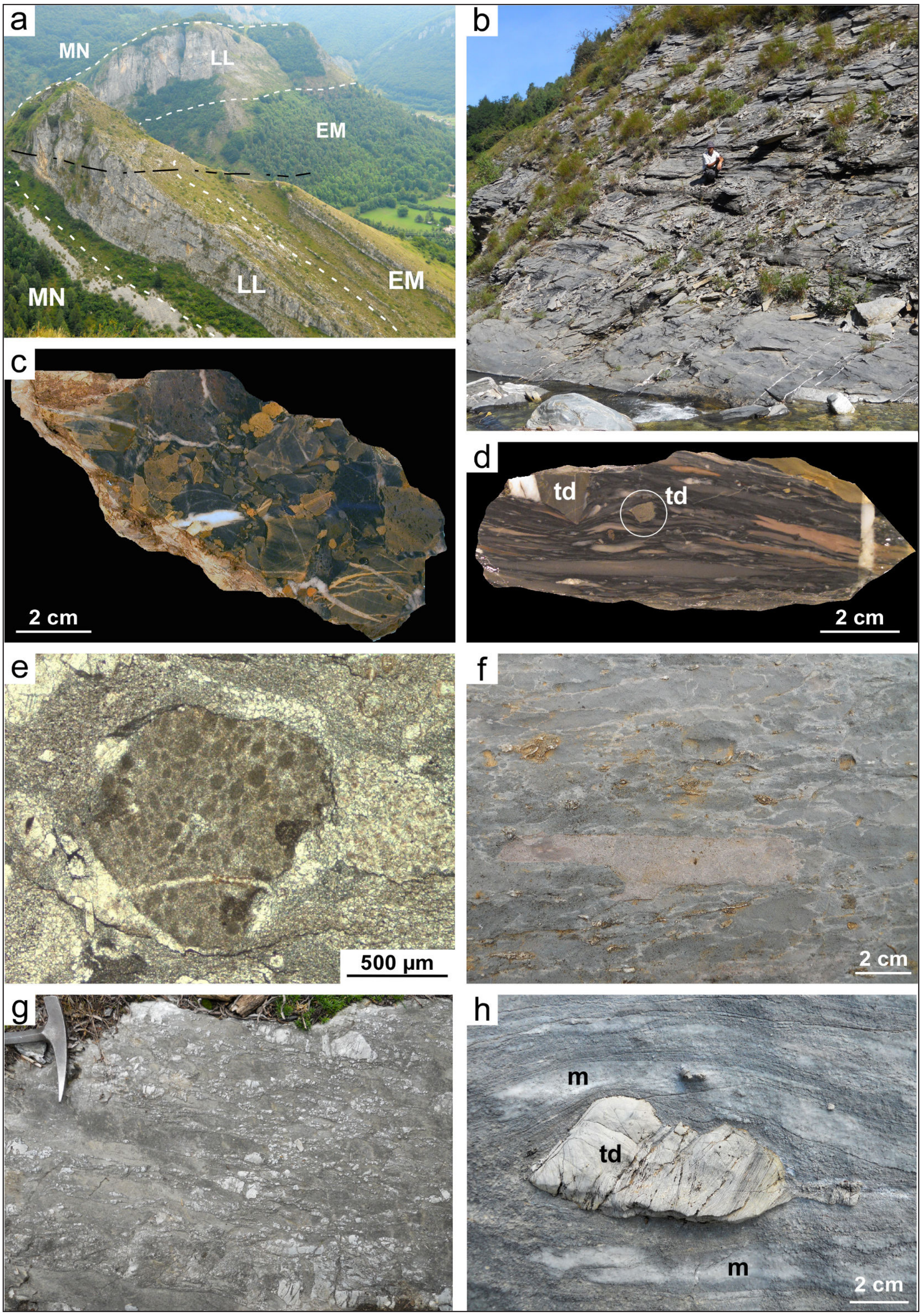

Fig. 4 - Jurassic-Lower Cretaceous Dauphinois succession. a) Panoramic view of Monte Stramondin (foreground) and Pian dei Funs (background), taken from Monte Lausa. The image shows the Entracque Marl (EM), Lausa Limestone (LL) and Marne Nere (MN) units folded in the Monte Lausa-Monte La Piastra anticline (the image is roughly perpendicular to the axial plane, whose trace is indicated by the black dashed line). b) Dark shales in the lower interval of the Entracque Marl, cropping out along the Bousset River southeast of Entracque. c) Hand sample of breccia from the upper interval of the Entracque Marl, mainly composed of dolostone clasts from the Middle Triassic Mont Agnelet Formation. Bec Cavallera, near Tetti Prer. d) Hand sample of breccia from the upper interval of the Entracque Marl, with stretched mudstone clasts and angular clasts of Middle Triassic dolostones (Mont Agnelet Formation; td). Monte Stramondin. e) Clast of peloidal packstone in a breccia bed of the upper interval of the Entracque Marl. Monte Viver, southeast of Entracque. f) Breccia bed in the lower interval of the Lausa Limestone, mainly composed of grey and pinkish mudstone clasts. Monte Stramondin. g) Breccia bed with clasts of coarsely crystalline dolostone in the lower interval of the Lausa Limestone. Tetti Tancias, near Colletta Soprana. h) Breccia bed in the lower interval of the Lausa Limestone, with a clast of Middle Triassic dolostone (Mont Agnelet Formation; td) surrounded by stretched mudstone clasts (m). Caire dell'Uglia, near Colletta Soprana.

• an upper limestone unit, with breccia beds at the base, corresponding, according to these authors, to the Upper Jurassic "Barre Tithonique" and the Lower Cretaceous "Neocomiano a Cefalopodi".

In this paper, the distinction between a lower marly unit (Entracque Marl) and an upper calcareous unit (Lausa Limestone) is maintained (Fig. 2, 4a), but a different chronostratigraphic attribution is proposed for the two intervals (see below).

Entracque Marl (Middle? Jurassic-Berriasian?)

The Entracque Marl consists of a marly-shaly succession, whose thickness can be estimated at some hundred metres, with some uncertainty owing to poor exposure and tectonic deformation.

This unit mainly consists of dark grey marls, calcareous marls and shales (Fig. 4b), with rare thin beds of bioclastic mudstones and wackestones containing echinoderm fragments, bivalve shells, and other bioclasts. The upper part (uppermost 100 metres) is characterized by the presence of breccia beds, a few centimetres to a few decimetres thick. Breccia beds become more and more abundant toward the top; the interbedded marly intervals progressively decrease in thickness and eventually disappear marking the transition to the overlying Lausa Limestone. Breccias are generally clast-supported, with subrounded to subangular clasts (Fig. 4c, d), millimetre-sized in the lower part of the breccia interval, up to centimetre-sized in the upper part. Larger clasts (10-15 cm) have been observed in outcrops close to the Caire di Porcera palaeoescarpment (south of Tetti Prer). Clasts are composed of:

• finely to medium crystalline dolostones, macroscopically showing a gray or beige colour; some of these clasts are crossed by calcite veins which end at the edge of the clast without continuing in the matrix;

• ooidal-peloidal grainstones, peloidal packstones (Fig. 4e), and bioclastic wackestones;

• grayish or pinkish mudstones (Fig. 4d), appearing in thin section as a rather homogeneous microspar mosaic, with rare recrystallized bioclasts.

The first two lithotypes prevail in the lower part of the breccia interval, whereas mudstone clasts largely prevail in the upper part. Rare rounded grains of polycrystalline quartz are also presents. Bioclasts are mainly represented by echinoderm fragments, benthic foraminifera and belemnite rostra.

Interpretation. The Entracque Marl is the result of an essentially hemipelagic sedimentation; breccia beds in the upper interval indicate an increasing importance of resedimentation processes toward the top of the unit. Carbonate breccias of Tithonian age are widespread in the pelagic successions of the Dauphinois Basin and have been interpreted as deep-water depositional lobes derived from gravity flow originated by the mobilization of slope sediments (e.g., Courjault et al. 2011; Ferry et al. 2015). The carbonate breccias observed in the Entracque sector likely represent a more proximal equivalent, which deposited close to the margin of the Provençal platform.

Macroscopic and petrographic characters of the finely to medium crystalline dolostone clasts indicate a probable origin from the erosion of the Middle Triassic Mont Agnelet Formation. Clasts of ooidal-peloidal grainstones and peloidal packstones could derive from Middle Jurassic-lowermost Cretaceous, early-lithified platform deposits of the Provençal domain, or from the Middle Triassic-Early Jurassic succession, in which similar facies are present (Carraro et al. 1970). Polycrystalline quartz grains may derive from the Lower Triassic Valette du Sabion quartzarenites, or from the crystalline basement (clasts of crystalline rocks in these beds have been actually reported by Carraro et al. 1970). The origin of grayish and pinkish mudstone clasts is more problematic, as similar facies are not known in the coeval Provençal sediments nor in the pre-Jurassic succession. These are probably intraformational clasts derived from redeposition of consolidated or semi-consolidated slope sediments. Breccia beds rich in mudstone clasts can be thus interpreted as the result of debris flows representing the downslope transformation of slope sediment slumpings (e.g., Colacicchi & Baldanza 1986; Tucker & Wright 1990).

Lausa Limestone (Valanginian?-early Aptian p.p.)

The Lausa Limestone is an essentially calcareous unit, reaching a maximum thickness of 50-60 metres (Fig. 4a, 5). The lower interval of this unit is mostly composed of polymictic, clast-supported carbonate breccias, showing an ill-defined, dm-thick bedding, locally alternating with fine grained limestones. Clasts are subangular to

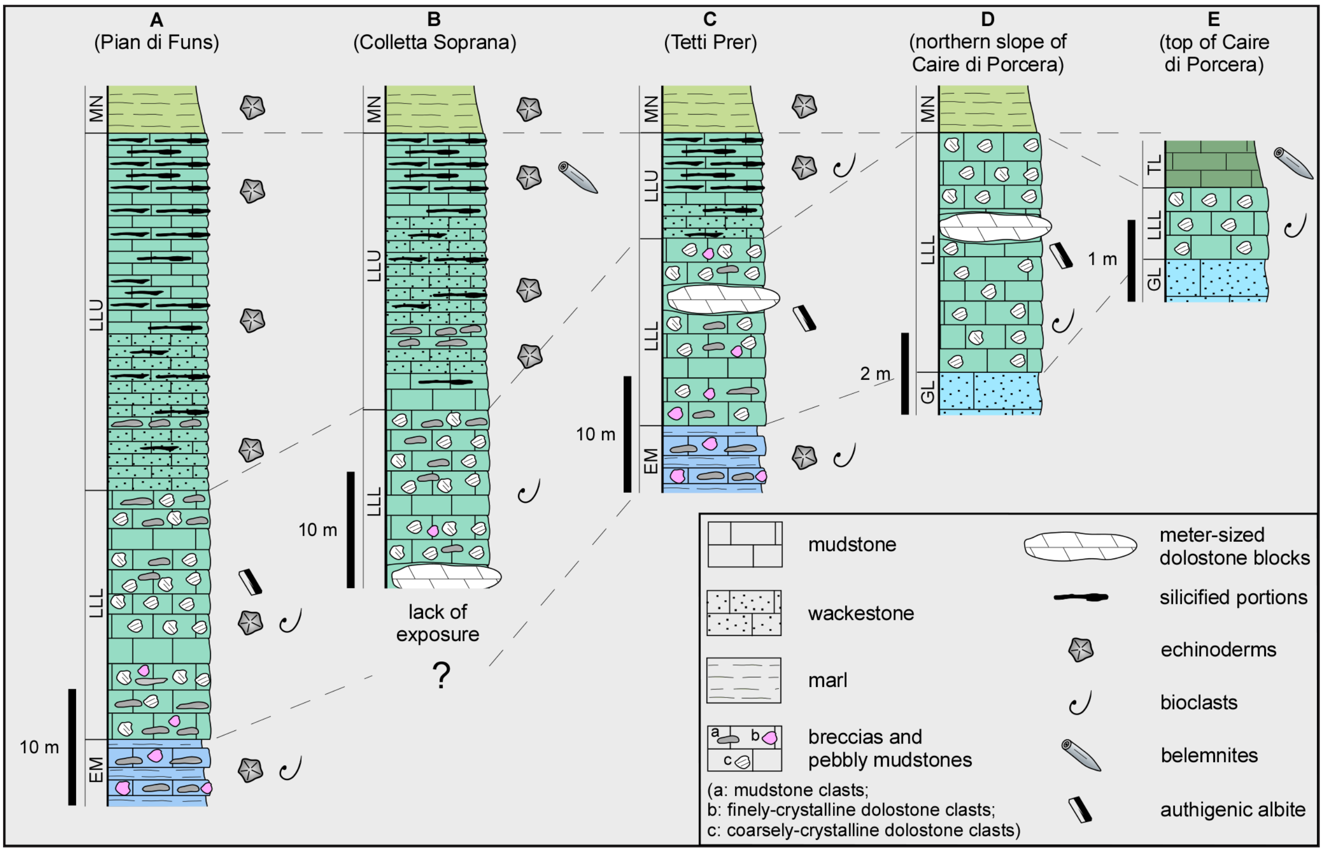

Fig. 5 - Schematic logs of the Lausa Limestone south of Entracque. Log A refers to the southern side of Pian dei Funs, log B to the lower Pautafol Valley (near Colletta Soprana), log C to the southern side of Caire dell'Uglia (near Tetti Prer), log D to the northern slope of Caire di Porcera and log D to the top of Caire di Porcera (see position of localities in Fig. 1). EM: Entracque Marl; LLL: Lausa Limestone, lower interval; LLU: Lausa Limestone, upper interval; MN: Marne Nere; GL: Garbella Limestone; TL: Testas Limestone. The location of the five logs is indicated in Fig. 1c. Please note the variation of the vertical scale among logs A-C, log D, and log E.

subrounded, vary in size from some millimetres to a few decimetres, and are composed of grayish or pinkish mudstones (Fig. 4f), coarsely crystalline dolostones (Fig. 4g) and subordinate finely to medium crystalline dolostones (Fig. 4h). The matrix is a mudstone, commonly recrystallized to a microspar-pseudospar mosaic, containing echinoderm fragments and other recrystallized bioclasts. Mudstone and finely crystalline dolostone clasts are analogous to those observed in the underlying Entracque Marl. Coarsely crystalline dolostone clasts have a whitish colour and are composed of subhedral to euhedral dolomite crystals, commonly showing sweeping extinction and characterized by a homogeneous, orange-red cathodoluminescence.

Close to the Caire di Porcera palaeoescarpment (Tetti Prer, Colletta Soprana), metre-sized masses of dolostones are locally present, whose colour (yellow on fresh surfaces and brown on weathered ones) and differential weathering make them stand out from the encasing limestone (Fig. 6a, b). These masses consist of coarsely to very coarsely crystalline, subhedral to euhedral dolomite crystals, commonly showing sweeping extinction. Concentrations of Fe-oxides along crystal boundaries and cleavage planes are probably responsible for the yellow-brown colour of the rock.

A thin stratigraphic interval (a few metres thick), is locally present on the northern side of Caire di Porcera (Fig. 5), where it rests on the palaeoslope surface connecting the Provençal Platform to the Dauphinois basin (Barale et al. 2016a; d'Atri et al. 2016). It consists of decimetre-thick beds of pebbly mudstones with scattered clasts of white dolostone. Clasts range in size from a few millimetres to some decimetres; rare metre-sized blocks are also present (Fig. 6c, d). They consist of subhedral to euhedral dolomite crystals, commonly showing sweeping extinction and characterized by a homogeneous, orange-red cathodoluminescence (Fig. 6e, f). This interval is locally overlain by belemnite-

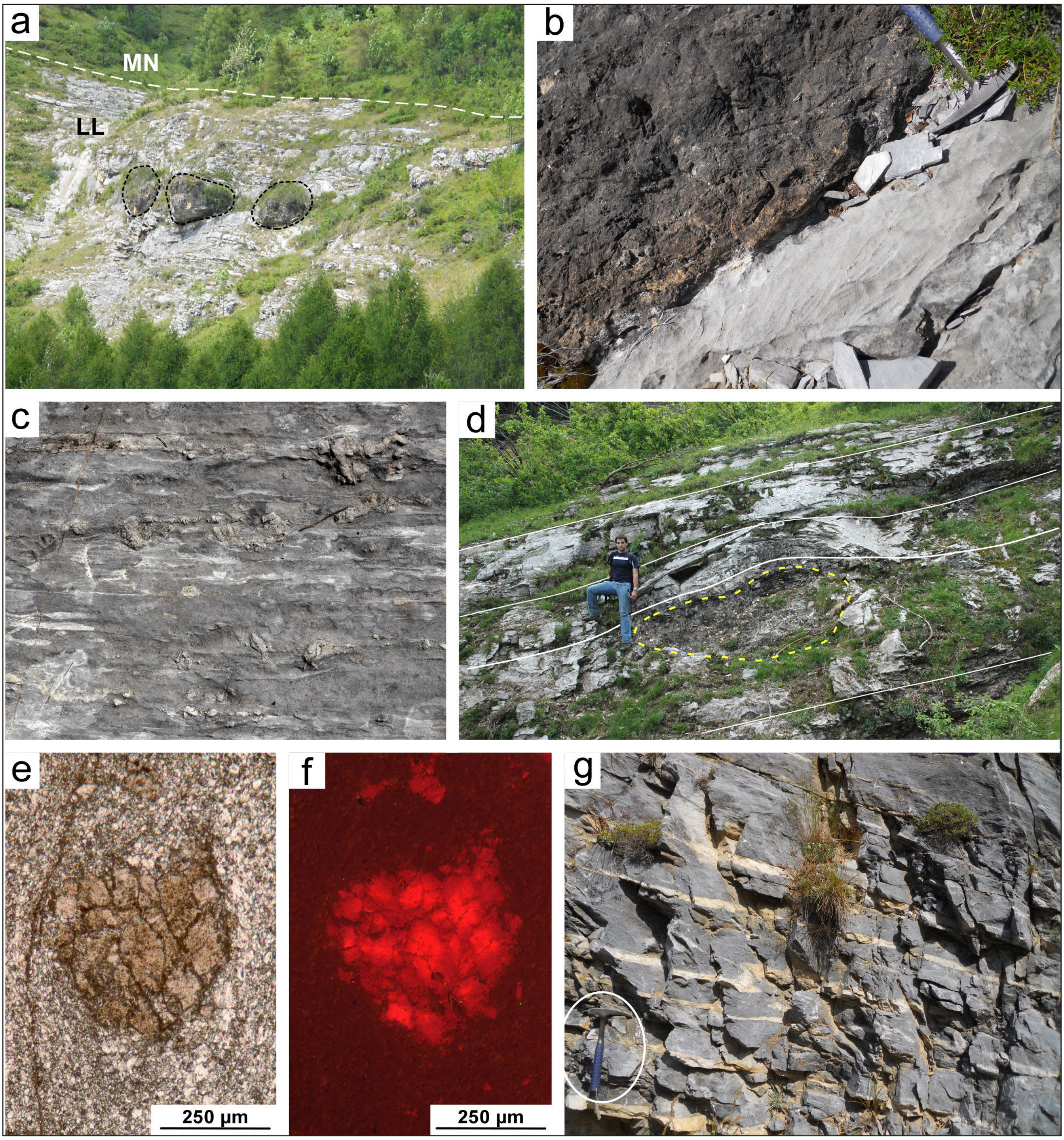

Fig. 6 - Lausa Limestone. a) Metre-sized masses of brown dolostone (black dashed lines) in the lower interval of the Lausa Limestone at Tetti Prer (LL: Lausa Limestone; MN: Marne Nere). b) Detail of the contact between one of the masses of brown dolostone in (a) and the encasing limestone. c) Clasts of coarsely crystalline dolostone in the pebbly mudstones cropping out on the northern side of Caire di Porcera. d) Metre-sized block of coarsely crystalline dolostone (dashed line) within the pebbly mudstone interval cropping out on the northern side of Caire di Porcera (white lines indicate the bedding). e), f) Millimetre-sized clast of coarsely crystalline dolostone in the pebbly mudstones cropping out on the northern side of Caire di Porcera (thin section photomicrographs; e, plane light; f, cathodoluminescence). g) Bioclastic mudstones with cm-thick, white-coloured silicified portions in the upper interval of the Lausa Limestone (encircled hammer for scale). Tetti Tancias, near Colletta Soprana.

bearing marly limestones of the Hauterivian p.p.?-lower Aptian p.p.? Testas Limestone, or directly by the lower Aptian p.p.-Cenomanian Marne Nere unit (see below).

The upper interval of the Lausa Limestone is made up of thin to medium bedded grey micritic limestones and crinoid-rich wackestones. They contain abundant bedding-parallel silicified portions, some centimetre thick and up to a few metres wide, with highly irregular shape on plan view, showing a white, grey or brownish colour on weathered surfaces (Fig. 6g). Carbonate breccia beds, 10-20 cm thick and entirely composed of centimetre-sized mudstone clasts, are locally present. This interval is about 30-40 metres thick near Entracque (Monte Lausa, Pian di Funs), and progressively thins out toward the south (Fig. 5). The boundary between the Lausa Limestone and the overlying Marne Nere is very sharp, though no unconformity can be recognized between the two units.

Interpretation. The lower interval of the Lausa Limestone is the result of repeated resedimentation events, indicating a relative instability of the marginal sectors of the basin. Breccia beds are very similar to those of the underlying Entracque Marl, and the same considerations can be made as to the origin of limestone and finely crystalline dolostone clasts. On the other hand, the coarsely crystalline dolostone clasts, which do not occur in the Entracque Marl, are strongly comparable, from a macroscopic and petrographic point of view, to the dolomitized Garbella Limestone of the Provençal succession, and probably derived from their erosion.

One of the most intriguing features of this breccia interval is represented by the metre-sized dolostone masses observed at Tetti Prer and Colletta Soprana, some of which (Tetti Prer) have been mapped as "carnieules" by Malaroda (1970). These masses are here interpreted as dolostone blocks, derived from the dolomitized Garbella Limestone. Indeed, the petrographic characteristic of the dolostone masses are very similar to those of the hydrothermal Provençal dolostones and smaller dolostone clasts of dolomitized Garbella Limestone are present in the same stratigraphic interval as the large dolostone masses. In conclusion, the lower breccia interval of the Lausa Limestone contains abundant clasts derived from the dolomitized Provençal succession and varying in size from millimetre-sized grains to metre-sized blocks. They probably derive from rockfall processes, possibly triggered by seismic events, affecting the dolomitized rocks exposed on unstable surfaces. Polymictic breccias containing both extraformational dolostone clasts and intraformational mudstone clasts probably derived from the redeposition, by debris flow processes, of semi-consolidated, fine-grained slope sediments containing dolostone clasts.

The pebbly mudstones which locally overlie the Garbella Limestone are interpreted as slope deposits draping the Caire di Porcera palaeoslope, laterally equivalent to the breccia beds in the lower interval of the Lausa Limestone (Fig. 5), deposited in the adjoining Dauphinois basin. The upper interval of the Lausa Limestone marks the recovery of a pelagic sedimentation, only rarely interrupted by resedimentation events resulting in the deposition of thin breccia beds.

Chronostratigraphic attribution of Entracque Marl and Lausa Limestone

The transition between the Entracque Marl and the Lausa Limestone corresponds to a sharp change in the composition of carbonate breccias. Clasts of coarsely crystalline dolostones, interpreted as dolomitized Garbella Limestone, abound in the lower part of the Lausa Limestone, whereas they are not present in the upper interval of the Entracque Marl. The breccia beds in the lower interval of the Lausa Limestone are here interpreted as laterally equivalent to the thin interval of pebbly mudstones which locally overlie the Garbella Limestone on the Caire di Porcera palaeoslope. This pebbly mudstone interval overlies the Middle? Jurassic-Berriasian? Garbella Limestone and is in turn overlain by the Hauterivian p.p.?-early Aptian? Testas Limestone (Fig. 2). Thus, a Valanginian?-Hauterivian p.p.? age is inferred for it and for the laterally equivalent breccias which compose the base of the Lausa Limestone; a Berriasian? age is proposed for the top of the underlying Entracque Marl. The carbonate-rich unit known as "Barre Tithonique" (Gignoux and Moret 1938) in the typical Dauphinois succession and dated to the upper Kimmeridgian-lowermost Berriasian (e.g., Debrand-Passard et al. 1984; Séguret et al. 2001; Courjault et al. 2011; with references therein), is therefore not present. In the Puriac Valley, about 40 km towards WNW from the study area (see Fig. 1b), the "Barre Tithonique" is represented by about 50 metres of Kimmeridgian fine-grained limestones, and a few metres of Tithonian carbonate breccias and fine-grained limestones (Sturani 1962). This unit becomes progressively thinner towards the east (i.e., towards the study area), whereas it grows thicker westward, i.e., towards the centre of the Dauphinois Basin (Sturani 1962; Dardeau 1983). This could be interpreted as a lateral pinchout of the whole unit towards the margin of the