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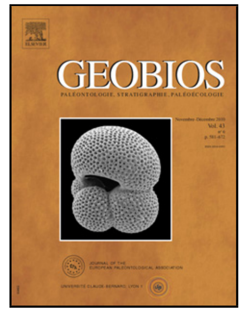

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Stratigraphy of the Haut Var Paleogene continental series (Northeastern Provence, France): new insight on the age of the 'Sables bleutés du Haut Var' Formation ✡

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Abstract

The age of the Paleogene deposits of the Haut Var (Provence, France) has been the subject of debate. Particularly, the 'Calcaire à Bithynies' and the 'Sables bleutés' units were ascribed either to the early Eocene or to the Oligocene. A stratigraphical clarification is required in order to precise the paleogeographical relationships of the Haut Var Paleogene sedimentary series with coeval deposits in the neighbouring southern Provence and Subalpine regions and other European domains. The study area is characterized by tectonically separated synclines and grabens filled in by continental Paleogene deposits. Detailed mapping and lithostratigraphical logging, sedimentological and microfacies analysis have been undertaken in order to provide a reliable stratigraphical framework. Biostratigraphical subdivisions were established based on five different fossil groups: mammals, charophytes, gastropods, ostracodes, and foraminifers. Accordingly, five formations are distinguished and dated: 'Calcaire à Microcodium' and 'Brèche à Microcodium' (Danian); 'Marnes à oeufs d'oiseaux' (Selandian(?)-earliest Ypresian); 'Sables bleutés du Haut Var' (early-late(?) Ypresian); and 'Bourdas conglomerates' (Rupelian). Particular emphasis is given to the study of the controversial 'Sables bleutés du Haut Var' Formation. As a result, correlations have been established between the different syncline and graben areas where Paleocene-Eocene and Oligocene deposits occur. Terrestrial deposits (carbonate paleosols and piedmont alluvial fans) took place during Paleocene times, while fluvial (cross-bedded sands) and lacustrine carbonate deposits developed in a foreland compressional intracontinental basin surrounded by emerged areas and tectonic highs during the early Ypresian. Paleoenvironmental and paleogeographical analysis strengthen the view that a relative isolation characterized the Haut Var area during the early Eocene, probably enhancing episodes of brackish water or evaporitic sedimentation and gastropod endemism. During the late Eocene Pyrenean-Provence tectonic phase, the E-W trending Haut Var overthrusts have been emplaced posteriorly to the deposition of the 'Sables bleutés du Haut Var' Fm. Finally, coarse alluvial fan and local lacustrine carbonate sedimentation occurred during the Oligocene in narrow N-S trending subsident extensional grabens associated with the N-S trending Barjols Triassic uplift.

Keywords:
Paleocene
Early Ypresian
Rupelian
'Sables bleutés du Haut Var' Formation
Carbonate microfacies
Provence
Pyrenean-Provence tectonics

1. Introduction

In Provence, the Paleogene is represented by continental deposits filling in graben and basinal areas (Fig. 1). The most widespread facies correspond to lacustrine, palustrine, fluviatile, and terrestrial environments (Cavelier et al., 1984; Durand and Nury, 1984). Paleogene deposits from Provence recorded significant climatic (Cojan and Moreau, 2006) and tectonic (Leleu, 2005; Leleu et al., 2009) events. During Paleocene, alluvial fans derived from the incipient Basse-Provence E-W trending tectonic structures (Lutaud, 1957) spread away into flood-plain areas. In the Basse-Provence region, the Pyrenean-Provence major compressive tectonic phase occurred during late Eocene times and was responsible for emplacement of the main overthrusts (Lacombe and Jolivet, 2005; Andreani et al., 2010; Espurt et al., 2012; Bestani et al., 2015). During the Oligocene, a distensive regime led to the opening of the main Manosque, Marseille and Aix-en-Provence grabens that were filled in either by coarse detritic or by carbonate and evaporitic facies (Gigot et al., 1977; Hippolyte et al., 1991).

In the Aix-en-Provence, Marseille and Manosque basins, the distinction between Paleocene, Eocene and Oligocene series has been the subject of a wide consensus (Cavelier et al., 1984; Durand and Nury, 1984) and correlations were established with the Languedoc (Alabouvette and Cavelier, 1984), the Pyrenean realm (Plaziat, 1984), and the southern Castellane subalpine grabens (Roux, 1974; Giannerini, 1980-1981). However, precisions are still required concerning the Paleogene stratigraphy of northeastern Provence (Haut Var regional area) that has been greatly debated (Ginsburg et al., 1967; Touraine, 1973a; Angelier and Aubouin, 1973; Durand, 1984; Philip, 2012, 2013; Plaziat, 2013a, 2013b). A clarification of this regional stratigraphy is needed for a better understanding of tectonic and paleogeographical questions, as well as for establishing correlations with other Paleogene basins. Likewise, clarification is also required concerning the respective age range of some fossil groups used as biomarkers in the Haut Var Paleogene continental facies, mainly gastropods (Lapparent, 1938a; Rey, 1966) *vs.* mammals (Ginsburg et al., 1967; Godinot, 1981).

The aim of this paper is to revisit the Paleogene stratigraphy of the Haut Var area and to shed light on the age of the conspicuous but controversial ‘Sables bleutés du Haut Var’ Formation. Hence, the new stratigraphical framework will lead to provide a better reconstruction of the paleoenvironmental and paleogeographical evolution of this area during the Paleogene and will contribute to highlight new perspectives for more accurate correlations with other Paleogene Provence and west European basins.

2. Geological setting and historical background

The Haut Var region represents the northern part of the French Var department, including the Barjols, Tavernes, Rians, Salernes and Aups administrative cantons (Fig. 1: insert). It appears as an intermediate geological domain located between the Basse-Provence fold and north verging thrust systems to the south, and the Alpine fold and south verging thrust front to the north. In the Haut Var area, the Paleogene extends in synclines and grabens bounded by normal faults or thrusts (Fig. 2). Paleogene strata overlie either conformably the Maastrichtian (Rognacian local stage) continental series, or unconformably cover the Lower Cretaceous-Jurassic basement.

The first synthetic approach about the stratigraphy of the Haut Var Paleogene series was due to Lapparent (1938b), while Mennessier (1959, 1970) mapped the Tavernes and Salernes geological sheets at the 1/50,000 scale. From 1966 to 1978, Touraine reported a number of stratigraphical observations, synthetized in two contributions (Touraine 1973a, 1976). The Ph.D. thesis of Angelier (1970) dealt mainly with the tectonics, but also provided precisions on the structure and stratigraphy of Paleogene synclines and grabens. Also Cornet (1973b), Cojan (1993) and Cojan et al. (2000) provided accurate data on the sedimentology and stratigraphy of Paleogene deposits. These different studies however led to numerous discrepancies concerning the Paleogene biostratigraphy and the tectonic interpretation of the Haut Var area.

Following the first attempt by Lapparent (1938b), Mennessier (1959) and Ginsburg and Mennessier (1967) subdivided the Haut Var Eocene based on mammal biostratigraphy. Indeed, mammalian fossils dating from the early Ypresian have been discovered in the 'Sables bleutés du Haut Var' Fm. Nevertheless, Touraine (1968a) claimed that the mammal specimens were reworked and established new subdivisions on the basis of gastropod associations (Rey, 1966) that he considered as early Oligocene in age. These different interpretations regarding the stratigraphy also resulted in discrepancies about the age of the Haut Var tectonic structures. Hence, the north-verging Sambuc-Pallières and Salernes overthrusts (Fig. 2), that rest on the 'Sables bleutés du Haut Var' Fm., were ascribed to the late Eocene Pyrenean-Provence phase by Lapparent (1938b) and Mennessier (1959), while for both Touraine (1969) and Angelier (1970) the emplacement of the north-verging overthrusts would be post-Rupelian and linked to the alpine compressive phases (Touraine, 1976).

3. Material and methods

Mapping of the Paleogene series was undertaken at the 1/12,500 scale. Stratigraphical sections have been logged at metre-scale or less when necessary. Samples were collected with a regular spacing in order to document their lithological and micropaleontological components.

Thin sections and polished slabs were prepared using standard methods in order to examine textures, cements, and lithoclastic and bioclastic components of limestones. Soft sediments were disaggregated in water and oxygen peroxide. The fine sediment was removed using 1.0 and 0.063 mm mesh sieves. Ostracodes and charophytes were hand picked under a light binocular stereoscopic microscope at ×40 magnification. Both macrofossils (vertebrates and gastropods) and microfossils (charophytes, ostracodes, foraminifers) have been used for establishing stratigraphic subdivisions.

The paleontological and sedimentological materials are archived at the CEREGE, Institut Pytheas, Aix-Marseille University, Campus Saint-Charles, Marseille. The Touraine collection, housed at the same address, has provided many interesting paleontological materials (especially gastropods) originating from the Haut Var Paleogene strata, that have been very useful for complementary data and comparisons.

4. Paleocene-Eocene

4.1. The Maastrichtian-Danian boundary

The Upper Cretaceous lithostratigraphical subdivisions of the Haut Var area have been established for a long time by Lapparent (1938b) and Angelier (1974) and ascribed to the Begudian-Rognacian local stages (middle Campanian-Maastrichtian). In most basins, the upper Maastrichtian deposits (upper Rognacian local stage) grade transitionnaly upwards into those of the Danian. The Rognacian generally ends with a reddish silty marl unit ('Ensemble marno-gréseux sommital' or 'Marnes terminales' *sensu* Angelier, 1974). Dinosaurian eggshells have been reported only from the lower part of this stratigraphical unit (Touraine, 1963; Angelier, 1974). Accordingly, in respect to the Arc syncline (Garcia and Vianey-Liaud, 2001; Cojan and Moreau, 2006), the K/Pg boundary could be located in the upper part of this reddish silty marls unit. Nevertheless, biostratigraphical and chemostratigraphical analysis are still needed for a more accurate determination of its precise location.

4.2. 'Calcaire à Microcodium' Formation

The upper reddish silty marls of the K/Pg transition are conformably overlain by the 'Calcaire à Microcodium" Fm. A first detailed attempt to describe the stratigraphy of this formation was made by Angelier (1974), while Cojan (1993) and Djurkovic-Colson (1996) have provided meaningful sedimentological data. In the southwestern border of the Rians syncline (L'Olivière, Bois des Taillades), the lower part of the formation consists of a 2 m-thick nodular mottled paleosol overlain by a 5 m-thick vadose calcrete characterized by silty and sandy limestone, with Microcodium fragments and fine (millimetre thick) irregular silica beds (Djurdjevic-Colson, 1996). Clay minerals (palygorskite associated with smectite and illite/smectite) have been identified in connection with these facies (Cornet, 1974; Cojan, 1993; Djurdjevic-Colson, 1996). This calcimorphic pedogenesis has been used as a regional key-marker event (Cojan, 1993). The 'Calcaire à Microcodium' Fm. widely extends in the Haut Var area, except in the Moissac, St Julien-le-Montagné and Ampus synclines where the formation is missing (Appendix B1).

In a first attempt, Lapparent (1938b) ascribed the 'Calcaire à Microcodium' to the Thanetian. However, according to Angelier (1974), Cojan (1993) and Djurdjevic-Colson (1996), it should be correlated with the Arc syncline 'Calcaire de Vitrolles' unit referred to the Danian (Westphal and Durand, 1990; Cojan et al., 2000; Leleu, 2005; Cojan and Moreau, 2006).

4.3.'Brèche à Microcodium' Formation

A well-known outcrop of this unit, defined by Angelier (1974), extends along the western Rians, Fenêtre des Vacons road, overlying the 'Calcaire à Microcodium' by means of a conspicuous discontinuity. It consists of 20 m-thick coarse breccias (including local Jurassic limestones elements) interbedded with red siltstones. Laterally, the 'Brèche à Microcodium' extends into the eastern part of the Rians syncline where it is well developed, and into the Montmeyan, Salernes, Pontevès and Bauduen synclines (Appendix B2).

To the north of the Rians syncline, a reddish gravelly breccia (including Microdium clasts and weathered quartz grains) overlies the 'Calcaire à Microcodium'. This peculiar facies ('Marnes graveleuses' *sensu* Angelier, 1974) constitutes a 1 to 3 m-thick, characteristic stratigraphical level that also occurs in the southern part of the La Mourotte syncline (Fig. 2; Angelier, 1971). By comparison with the Arc syncline, and given its close relationship with the underlying 'Calcaire à Microcodium', the 'Brèche à Microcodium' could be tentatively ascribed to the Danian.

4.4. "Marnes à oeufs d'oiseaux" Formation

This unit is widely developed and fossiliferous in the Rians syncline (Fig. 2) where it has been described by Lapparent (1938a), Angelier (1974), and Durand (1984). In the western part of the syncline, a 100 m-thick red marl-claystone-siltstone unit, attributed to sedimentation in a fluvial floodplain, conformably and gradually overlies the 'Brèche à Microcodium' Fm. Thin bird eggshells ascribed to the oospecies *Ornitholithus biroi* by Dughi and Sirugue (1962) occur in the middle part (St Maurin) of this unit. In the eastern Rians syncline, coarse conglomerates ('Poudingues des Touars' *sensu* Angelier, 1971) are present in the lower part of the formation, pinching out westwards (Appendix B3).

West of Rians (Bardouine locality), the upper part of the formation is formed by red claystones-fine sandstones-siltstones with interbeds of coarse sandstones, conglomerates and lenticular palustrine marls and limestones. According to Dughi and Sirugue (1962), and Angelier (1974), thick bird eggshells belonging to the *Ornitholithus arcuatus* oospecies occur in these facies.

The 'Marnes à oeufs d'oiseaux' Fm. spreads away in all basins of the study area, with only some variations of thickness and lithology such as, for instance, metre-thick interbeds of Microcodium-bearing paleosols or breccias in the Montmeyan, Salernes, Pontevès, and Moissac synclines. In the Salernes syncline (Les Cadenières), the uppermost part provides numerous and well preserved thick bird eggshell fragments. A particular emphasis must be placed on the occurrence of a rich charophyte association (Fig. 3; Appendix A1) of early to middle Thanetian age in the red gypsiferous marls that crop out at the middle part of the formation in the Moissac syncline (Fig. 2).

Stratigraphical correlations can be established with the Arc Basin where bird eggshells have been reported (Corroy and Touraine, 1961; Dughi and Sirugue, 1968), correlated with other biostratigraphical markers such as gastropods (Dughi and Sirugue, 1968; Durand and Nury, 1984) or charophytes (Feist-Castel, 1975). On the basis of the stratigraphical framework established in the Arc Basin (Dughi and Sirugue, 1968; Cojan et al., 2000; Buffetaut and Angst, 2014), the thick-shelled eggs (*O. arcuatus*) occur above the 'Calcaire de Saint-Marc' Fm., in red siltstones underlying a lacustrine unit ('Calcaire de Langesse' Fm.) that contains *Physa columnaris*, considered as early Ypresian in age (Dughi et al., 1969). In addition, according to Cojan et al. (2000), The 'Calcaire de Saint-Marc' Fm. could encompass the Paleocene Eocene thermal maximum (PETM), which occurred at the boundary between the Paleocene and Eocene. Therefore, *O. arcuatus* eggshells have been ascribed to the earliest Eocene. This dating is somewhat supported by the recent attribution of *O. arcuatus* eggshells from southern France to *Gastornis*, a giant bird which is known in Europe from the Selandian to the Lutetian (Buffetaut and Angst, 2014; Angst et al. 2015).

The stratigraphical interval of the thin-shelled eggs (*O. biroi*) is less well constrained than that of the thick ones. However, according to Dughi and Sirugue (1962, 1968), and referring to the Arc Basin, *O. biroi* would be present in the red siltstones underlying the 'Calcaire de Saint-Marc' Fm., considered as Thanetian in age in its lower part, yielding *Physa prisca* (Dughi and Sirugue, 1968), and recently referred to the Selandian by Leleu (2005), but without any biostratigraphical evidence.

Accordingly, in the Rians syncline the lower part of the 'Marnes à oeufs d'oiseaux' Fm. should be tentatively referred to the Selandian(?)-Thanetian and correlated with the marls underlying the 'Calcaire de Saint-Marc' Fm. in the Arc Basin, whereas the uppermost part could be ascribed to the earliest Ypresian and correlated to the red siltstones overlying the 'Calcaire de Saint Marc' Fm. Charophyte data suggest that the Paleocene-Eocene transition would be located within this formation (Feist-Castel, 1975), but it has not been identified in the Haut Var due to the lack of a stratigraphical equivalent of the 'Calcaire de Saint Marc' Fm. and moreover because no accurate biostratigraphical and/or chemostratigraphical data have been reported there so far.

4.5. 'Sables bleutés du Haut Var' Formation

Lapparent (1938) emphasized the great development of fluvial bluish micaceous sand deposits in the Haut Var synclines. He proposed the name of 'Sables bleutés' facies for these peculiar deposits. He indicated that the 'Sables bleutés' facies generally overlies a gastropod bearing lacustrine limestone unit that he named the 'Calcaire à Bithynies'. Both lithostratigraphical units were ascribed by Lapparent to the lower Eocene ('Sparnacian').

The same names were used by different authors (Ginsburg et al., 1967; Touraine, 1968a, 1971; Mennessier, 1970; Angelier, 1971; Cornet, 1973a), although they did not agree about the ages of these units. However, Touraine (1971) created the denomination of 'Sables bleutés' *lato sensu* Formation including two distinct facies: the fossiliferous *Bithynia* bearing limestones ('Calcaire à Bithynies'), and the bluish micaceous sand deposits ('Sables bleutés' *stricto sensu*).

Indeed, our stratigraphical investigations and mapping have shown that the 'Calcaire à Bithynies' is represented by carbonate lenses interfingered with the 'Sables bleutés' *stricto sensu* at different levels of the series (see below). Accordingly, taking into account this sedimentological feature, and in order to avoid any ambiguity of definitions, we propose to replace the name 'Sables bleutés' *lato sensu* by 'Sables bleutés du Haut Var' Formation, which includes two main facies: the 'Calcaire à Bithynies' and the 'Sables bleutés' *stricto sensu*.

4.5.1. 'Calcaire à Bithynies'

The 'Calcaire à Bithynies' is only represented in the western part of the Rians syncline and in the synclines of La Mourotte, Montmeyan and Bauduen. In the other areas it is missing and the 'Marnes à oeufs d'oiseaux' Fm. passes gradually upwards to the 'Sables bleutés' facies.

4.5.1.1. Les Toulons type-section

A well exposed section (Figs. 4(A), 5(A)) of the 'Calcaire à Bithynies' can be logged to the west of Rians village, near Les Toulons farm (43° 37' 20.1" N; 5° 42' 38. 1" E), with complementary observations along the limestone cliff between Les Toulons and Rians. Two lithological units have been distinguished, from the bottom to the top:

* **Unit I: *Bithynia* bearing sandy-marls**. It is a 1 to 1.5 m-thick greyish, sandy-marl bed that conformably overlies the red siltstones-sandstones of the 'Marnes à oeufs d'oiseaux' Fm. The sediment provides arenitic quartz grains, numerous gastropod shells (*Bithynia* sp.), charophyte gyrogonites, and ostracodes;
* **Unit II: *Bithynia* bearing limestones**:
    - <u>Lower part</u>: 1 m-thick of gastropod (*Bithynia* sp.)-ostracode-rich wackestone-floatstone yielding the foraminifer *Rosalina bractifera* Le Calvez;
    - <u>Middle part</u>: superimposition of 4 m-thick ternary sequences made up of clayed beds – laminated cherty limestones – peloidal wackestones-packstones (Fig. 6(G, H)) formed by a bioaccumulation of smooth ostracode carapaces (sometimes with valves still

articulated), *Bithynia* shells, scarce tiny bivalve shells (Sphaeriidae?), and charophytes (thalli and gyrogonites);

- Upper part: 1 m-thick fenestrate thrombolitic wackestones-floatstones, yielding gastropods (*Bithynia* sp.), very abundant smooth ostracode carapaces, scarce charophyte gyrogonites and thalli.

4.5.1.2. Lateral variations

The ‘Calcaire à Bithynies’ widely extends in the western part of the Rians syncline and pinches out eastwards, probably interfingered with the lowermost ‘Sables bleutés’ deposits in the vicinity of La Fabresse farm (see below, section 4.5.2.3.). In the northern part of the Montmeyan graben (Fig. 4(A): Saint-Maime section, Costebelle), Unit I yields quartz grains, fragments of gastropods (cf. *Bithyni*a sp.), and gypsum crystals. Unit II is formed of alternating laminated vuggy – carbonate and gypsum beds (suggesting evaporitic conditions) – grey clayed ligniteous beds bearing plant fragments, and laminated limestone beds (gastropod-ostracode-bearing peloidal-fenestrate packstones; Fig. 6(A, B, D)). Fish remains (Characidae) have been reported from the laminated limestone beds (Gaudant, 1980). Southward of St Maime (La Tour d’Enguerne), unit II displays *Bithynia* sp.-rich coquina layers (shells and opercula), while to the east of Montmeyan it yields well-preserved lumachellic deposits (Fig. 5(C)) from which gastropod species have been reported (Lapparent, 1938a; Touraine, 1966a; Rey, 1966). This biofacies extends southwards as far as the Bouche farm locality, near Fox-Amphoux.

In the La Mourotte syncline (Fig. 2), the ‘Calcaire à Bithynies’ conformably overlies alternating greyish sandy clays and coarse sands that correspond to the upper part of the ‘Marnes à oeufs d’oiseaux’ Fm. (Angelier, 1971). In the central part of the syncline, unit I is missing, and unit II (about 1 m-thick) is very fossiliferous, formed by superimposition of graded-bedded grainstone to floatstone centimetric beds, yielding abundant gastropods and ostracodes, oncolites, oolites, and extraclasts (Fig. 6(E, F)). Many gastropod species have been reported from this level (Touraine, 1966a; Angelier, 1971). To the north (near La Mourotte locality), unit II is formed by laminated limestones including foraminifers (*Rosalina bractifera*), gastropods, and well preserved casts of Characidae fishes (Gaudant, 1980).

In the Bauduen area, the ‘Calcaire à Bithynies’crops out in the western part of the syncline, to the north of Saint-Barthèlemy farm (Cornet, 1980; Fig. 4(A)). It was considered as stratigraphically located either at the upper part of the 'Sables bleutés' Fm. (Lapparent, 1938), or at its base (Cornet, 1978, 1980; Durand, 1984). Actually, a detailed mapping of the St Barthèlemy area (Fig. 4(B)) has shown that the 'Calcaire à Bithynies' occurs as limestone lenses interbedded at different levels in the lower part of the 'Sables bleutés' facies, some metres above its boundary with the 'Marnes à oeufs d'oiseaux' Fm. (Fig. 4(A): St Barthèlemy section). 'Calcaire à Bithynies' lenses are formed by sandy-micaceous packstone-wackestone beds (encompassing abundant *Bithynia sp.* shells or opercula, minute Sphaeriidae? bivalves, ostracodes, and charophytes; Fig. 6(C)) alternating with coarse and fine sands made up of quartz and micas. Thereby, in the Bauduen syncline, the 'Calcaire à Bithynies' occurs in a stratigraphical position that is different from its occurrence in the Rians, Montmeyan and La Mourotte areas, where it directly overlies the 'Marnes à oeufs d'oiseaux' Fm.

4.5.1.3. Stratigraphical interpretation

4.5.1.3.1. Biostratigraphical data

4.5.1.3.1.1. Historical background

Teilhard de Chardin and Lapparent (1933) mentioned in the 'Calcaire à Bithynies' of the Bauduen syncline, a rodent right half-mandible ascribed to *Paramys* cf. *lemoinei* Teilhard de Chardin 1922, emend. *Euromys* aff. *thaleri* (Michaux, 1964) *in* Escarguel (1999; Fig. 7(C)), characteristic of the lower Ypresian in the Paris basin. Besides, Lapparent (1938) described two new gastropod species, *Bithynia bauduensis* Lapp. and *Melania (Tarebia) cardinalis* Lapp., that he considered as characteristic of this lithological unit in the whole Haut Var area. However, this chronostratigraphical assignment was later questioned by Touraine (1966a; 1968a) and Rey (1966), on the basis of gastropods they collected in the 'Calcaire à Bithynies' and attributed to the lower Oligocene. Due to the discovery at Montmeyan and La Mourotte of specimens ascribed by Rey (1966) to *Potamides lamarcki* and *P. laurae* (species referred in Provence and in the Paris basin to the early (not earliest)-late Oligocene; Nury, 1988), Touraine (1971, 1976) ascribed the 'Calcaire à Bithynies' to the early Rupelian (Sannoisian local stage) and compared it to the same stratigraphical interval represented at the Butte Iouton area (near Beaucaire town, Gard department) by typical gastropod-rich layers, attributed for a long time to the early Rupelian (Roman, 1910), but more recently (Alabouvette and Cavelier, 1984) to the late Priabonian.

4.5.1.3.1.2. Discussion

Gastropods are abundant but relatively poorly preserved in the 'Calcaire à Bithynies'. Only gastropod *(Bithynia* sp*.)* shells are present in the lower sandy marls unit I (Fig. 7(D)). As mentioned above, they were considered by Lapparent (1938a) as belonging to a new species (*B. bauduensis*), while according to Rey (1966) they are close to *B. ugernensis* Roman from the Priabonian of the Butte Iouton. Other gastropods (preserved as external casts) occur in the unit II *Bithynia*-bearing limestones of Montmeyan (Fig. 7(E-J)) and La Mourotte (Fig. 7(K)) synclines. These gastropod casts have been ascribed to only one species [*Melania (Tarebia) cardinalis*] by Lapparent (1938a: fig. 9 and pl. I, fig. 13), whereas Rey (1966, 1967) identified among them various genera (e.g., *Potamides*, *Tympanotonos*, *Melanoides*, *Melanopsis*, *Brotia*) and species, but did not provide any paleontological description or illustration. We have retrieved the type locality of *Melania (Terebia) cardinalis* Lapparent; the gastropod-bearing bed is situated to the east of Montmeyan (Les Aubarèdes); it has provided a lot of shell casts (also present in the Touraine collection), all fitting well with Lapparent's species description (Fig. 7(E-J)). Touraine (1976: pl. I, fig. 1, and in collection) figured a shell cast from the same locality that he ascribed to *Potamides lamarcki*. However, it is worth mentioning that the shell cast is incomplete (peristomal aperture not fossilized), whereas the outer shell sculpture is similar to that of *Melania (Tarebia) cardinalis* type specimens figured by Lapparent (1938a).

Despite these unresolved complex and contradictory taxonomic questions, Rey (1966) and some authors after him (Touraine 1968a; Angelier 1970) maintained that the gastropod taxa present in the 'Calcaire à Bithynies' were characteristic of the Oligocene. Contrary to this conclusion, the results presented here show that typical Oligocene gastropod taxa are missing in this facies. Lapparent's systematic approach provides a specific singularity of the 'Calcaire à Bithynies' gastropod association, in better agreement with other biostratigraphical elements and with the peculiar paleogeographical isolation of the Haut Var area during the Paleogene that possibly enhanced the occurrence of endemic species.

In order to resolve the apparent biostratigraphical discrepancy (Oligocene *vs.* Eocene) between gastropods and mammals, Touraine (1966a) proposed that the rodent half-mandible of *Euromys* aff. *thaleri* in the Bauduen 'Calcaire à Bithynies' was reworked, disregarding any taphonomic features. However, the absence of any reworking indices on the rodent bone such as iron coating or abrasion traces on the surface of the half-mandible should be emphasized.

Moreover, teeth are still in place in their respective sockets (cf. Lapparent, 1938: figs. 10, 11; pl. I, fig. 14; Escarguel, 1999: pl. 5, fig. m; Fig. 7(C)). The texture of the limestone matrix of the half-mandible (*Bithynia* sp. opercula bearing wackestone) is very similar to those that characterize the 'Calcaire à Bithynies' lenses in the Bauduen (St Barthèlemy) area (Fig. 4). To sum up our opinion, the *Euromys* aff. *thaleri* half-mandible was buried and fossilized in soft lacustrine carbonate sediments, probably after a slight displacement from a neighbouring terrestrial biotope located a short distance from the 'Calcaire à Bithynies' deposits in the Bauduen area. Accordingly, we support the intrinsic biostratigraphical value of this mammal fossil as a biomarker of the Ypresian age of the 'Calcaire à Bithynies' lenses interbedded in the lower part of the 'Sables bleutés' facies in the Bauduen area. It is worth remembering here that the genus *Euromys* is restricted to the early to late Ypresian (Mammalian Paleogene levels MP7 to MP10) but that *Euromys thaleri* is only known from a few localities in the Paris Basin (Pourcy, Mutigny, Condé-en-Brie and Avenay) dated from the MP 8+9 (early to ?middle Ypresian) (Escarguel 1999).

4.5.1.3.1.3. Other biostratigraphical data

Dughi and Sirugue (1968) reported thick bird eggshells (*O. arcuatus*) in the lower sandy-marls (unit I) of Rians 'Calcaires à Bithynies' and attributed them to the early Ypresian. However, reworking of this fossil material from the underlying 'Marnes à oeufs d'oiseaux' Fm. cannot be totally excluded. In the same unit, Cornet (1973b) mentioned a charophyte association composed of several species (Appendix A2) characteristic of the early Eocene from both Languedoc and Aix-en-Provence Basins (Castel and Grambast 1969). In La Fabresse area, unit I provides a monospecific charophyte association of *Lamprothamnium priscum* that has no precise chronostratigraphical meaning, and was first reported in the early Eocene of the Corbières (France). This species (and the whole genus) constitutes a prominent biomarker of brackish water environment during the whole Cenozoic. West of Rians (Bardouine locality), unit II provides a charophyte assemblage characteristic of the early Ypresian (M. Feist, written comm.; list of taxa in Appendix A2).

The foraminifer *Rosalina bractifera* from the Rians and La Mourotte synclines (Fig. 7(A, B)) is particularly frequent in the Eocene strata of the Paris basin (Bignot, 1988). It was also reported by Poignant (1968) in the Rupelian of the Aquitaine basin, although later this occurrence was not confirmed by the same author (Poignant, 1982, 1995).

As shown by microfacies (Fig. 6), ostracodes are relatively abundant in the limestones (unit II) of the 'Calcaire à Bithynies', but devoid of any biostratigraphical interest. Soft sediments sampled in the lower part (unit I), next to the La Fabresse farm (Fig. 8(A)), have provided to Apostolescu and Dellenbach (1999) a heterochronous assemblage of ostracodes that these authors attributed to the Late Cretaceous, early Eocene and Chattian. These varied ages suggest reworking, and consequently poor chronostratigraphical interest. To sum up, other fossils provide contradictory results, but an early Eocene age is clearly indicated by the charophyte assemblage.

4.5.1.3.2. Field data

Sedimentary continuity and strict conformity of the 'Calcaire à Bithynies' upon the underlying 'Marnes à oeufs d'oiseaux' Fm. (Fig. 5(A)) is noteworthy for all localities where this stratigraphical setting occurs. In the Rians and Montmeyan areas, the uppermost levels of the 'Marnes à oeufs d'oiseaux' Fm. gradually evolves into the sandy marls of the Unit I, without any sedimentary gap or transgressive surface, as wrongly postulated by Touraine (1968). In the Bauduen syncline, the 'Calcaire à Bithynies' lenses pass gradually to the underlying lower micaceous sands of the 'Sables bleutés' facies (Fig. 4).

These results rebut the hypothesis of a stratigraphical gap of about 20 m.y. – including the late Ypresian, middle and late Eocene, and earliest Oligocene (early Rupelian) – that, according to Touraine (1971), would correspond to the 'Marnes à oeufs d'oiseaux'/'Calcaire à Bithynies' boundary. This gap would have been around 24 m.y. if the *Bithynia* bearing sandy marls (Unit I) were ascribed to the Chattian, as postulated by Apostolescu and Dellenbach (1999). As a consequence, with the absence of such a gap there is no need to propose the hypothesis of tectonic movements in the Rians and Salernes synclines (Touraine, 1969; Angelier, 1970) in order to explain a sedimentation break lasting from the late Thanetian until the early Oligocene.

Our study shows there is a slight diachronism of the 'Calcaire à Bithynies' corresponding basically to a lateral and coeval facies change with the lower part of the 'Sables bleutés' facies. Two stratigraphical patterns must be highlighted (Fig. 4): (*i*) direct superimposition of the 'Calcaire à Bithynies' on the 'Marnes à oeufs d'oiseaux' Fm. both in the Rians and Montmeyan synclines; and (*ii*) interbedding of 'Calcaire à Bithynies' carbonate lenses with the lower part of the ‘Sables bleutés’ facies in the Bauduen syncline. If the *Euromys* aff. *thaleri* half-mandible found in the ‘Calcaire à Bithynies’ at Bauduen is not reworked, as taphonomic features indicate, it would provide an early Ypresian age for the lower part of the ‘Sables bleutés du Haut Var’ Fm. This agrees with the mammalian association of Rians, also of early Ypresian age (Ginsburg et al., 1967; Godinot, 1981).

4.5.1.4. Paleoenvironmental interpretation

Sedimentary and paleontological data allow interpreting the ‘Calcaire à Bithynies’ facies as formed in freshwater to brackish environmental conditions that probably prevailed in areas protected from fluvial outlets. In the southwestern part of the Haut Var (Rians syncline) these conditions have contributed to enhance deposition of alternating shallow lacustrine carbonate *vs.* laminated clayey and cherty sediments and development of benthic lacustrine associations composed of gastropods, ostracodes, charophytes, and the epiphytic, euryhaline foraminifer *Rosalina bractifera* (Bignot, 1988). In the northwestern part of the Haut Var (Montmeyan, la Mourotte; Fig. 2), shallow brackish water conditions led to the deposition of alternating laminated carbonates, gypsum beds, ligniteous marls, and gastropod-bearing limestones. In La Mourotte and Bauduen areas, high-energy conditions (storms?) in a shallow water environment (shoreface?) prevailed and were responsible for the formation of lumachellic deposits. The ‘Calcaire à Bithynies’ is missing particularly in the eastern part of the Haut Var (Salernes, Pontevès areas; Fig. 2), where there was a permanent input of siliciclastic fluviatile sands during the stratigraphical interval of its deposition.

4.5.2. ‘Sables bleutés’ facies

4.5.2.1. Definition

The ‘Sables bleutés’ facies is represented by a relatively thick detrital sequence encompassing laminated or cross-bedded bluish-grey micaceous coarse to fine sands (dominant facies), coarse gravelous-conglomeratic beds and scarce silty-marl or carbonate (paleosols?) intercalations. This unit conformably overlies either the ‘Calcaire à Bithynies’ or the ‘Marnes à oeufs d’oiseaux’ Fm. (Figs. 4, 8). Compared to the ‘Calcaire à Bithynies’, the ‘Sables bleutés’ facies has a wider geographical extent in the Haut Var area. Southward, it fills in the Rians, Salernes and Ampus synclines (Fig. 2). Northward, the bluish micaceous sands occur as well in the Montmeyan, La Mourotte, Ginasservis, and Bauduen synclines, as in the footwalls of both Moissac and St Julien-le-Montagné overthrusts. In local areas (Saint Pons, La Méyère, Berne), close to Draguignan (Fig. 1), and near Esparron-de-Verdon (Fig. 2), bluish micaceous sandy beds have been ascribed to the lower Eocene (Lapparent, 1938b) without any biostratigraphical evidence.

4.5.2.2. Mineral composition

The bulk of the sands is composed of quartz and micas (muscovite and biotite), these latter amounting to 42% on average. According to Cornet (1976), the average composition of the heavy minerals fraction is: Garnet 50% to 25%; Staurotide 25 to 30%; Anatase 6 to 9%; Disthene 4%; Tourmaline 3 to 5%; Zircon 2 to 3%; Rutile 1 to 2%; Sphene 1 to 2%; Epidote 1%; Sillimanite 1%; and Chloritoid 1%. This mineralogical association is characteristic of the micaschist series that crop out in the metamorphic Hercynian Maures massif, located southeastward of the Haut Var area (Fig. 1). Accordingly, a southeastern origin is generally postulated for the detritic supply that built up the 'Sables bleutés' facies. In support of this assumption, it is worth noting a high proportion of coarse sands and the frequence of conglomeratic beds (yielding granite, metamorphic rocks and quartz pebbles) in the eastern part of the Haut Var (Salernes syncline).

4.5.2.3. Stratigraphical subdivisions of the "Sables bleutés" facies in the Rians syncline

Owing to poor outcropping, no section of the 'Sables bleutés' facies was logged until now in the Haut Var area. However, detailed observations and mapping, carried out in the Rians syncline, made it possible to provide a general stratigraphical overview of it.

Lower part. It is relatively well exposed to the east of Rians (Fig. 8(A)), between La Fabresse and La Neuve farms, and along the country lane of La Désidère farm. At la Fabresse, blue micaceous sands rest upon the 'Calcaire à Bithynies'. East of La Fabresse, the 'Calcaire à Bithynies' pinches out, which results in the direct superimposition of the 'Sables bleutés' facies on the 'Marnes à oeufs d'oiseaux' Fm. in the whole eastern part of the Rians syncline, with gradual and conformable transition between both units. South of La Fabresse, the 'Sables bleutés' facies contains the rich mammalian fauna of Rians (Ginsburg et al., 1967, Godinot, 1981). The fossiliferous bed (43° 36' 36. 5" N; 5° 47' 34. 7" E) is located roughly 160 m above the top of the

'Calcaire à Bithynies' (Fig. 8(A, B)). Pinkish sandy marls and fine laminated sandy and silty beds overlying the mammal fossil layer have provided an ostracode association (Touraine, 1968b). Eastwards, at 1.250 km (La Désidère; 43° 36' 20.87" N; 5° 48' 26.66" E; Fig. 8(A)) there are 10 m-thick grey or reddish micaceous sands overlain by 8 m-thick laminated silty beds of alternating grey, reddish or green colours that yielded a rich ostracode fauna (Fig. 9). The sequence is ended by a thin limestone bed (20 cm-thick) displaying a nodular and vuggy structure typical of palustrine paleosols. It is suggested that the peculiar La Désidère sequence may be correlated with the La Fabresse mammal and ostracode-bearing 'Sables bleutés' beds. Overlying the la Désidère limestone bed, about 150 m of poorly stratified medium to coarse bluish micaceous sands crop out in bad conditions. The thickness of the lower part of the 'Sables bleutés' facies is roughly estimated to be 275 m at the western Rians area.

Upper part. This part is poorly exposed, but displays some discontinuous exposures in the area east from Esparron (Font Couverte, Bois du Sault) and to the east of St Martin des Pallières (La Bastidette, Ballastière), along the footwall of the Pallières overthrust (Fig. 2). This part of the Formation consists here of about 150 m of laminar and cross-bedded coarse sands and conglomerate lenses (including pebbles of quartz, sandstone, metamorphic and igneous rocks), intensively weathered or covered by screes. Buffetaut et al. (2016) recently reported fragmentary vertebrate remains near Esparron (Font Couverte).

4.5.2.4. Lateral variations

Salernes syncline. The 'Sables bleutés' facies widely crops out in this area. Contrary to the assertion of Touraine (1969), it conformably overlies without any gap the 'Marnes à oeufs d'oiseaux' Fm. (Barbebelle, Les Esparus, La Cadenière) and is formed by cross-bedded bluish coarse micaceous sands, including numerous conglomeratic lenses (composed of quartz and metamorphick rock pebbles; Fig. 5(E, F)), and scarce fine sandy and silty beds (Les Esparus) yielding ostracodes. The 'Sables bleutés' facies have been cored by several drillings for bauxite exploration (Durand et Mennessier, 1964) showing a thickness of about 100 m that could be representing only a part of its total thickness.

Montmeyan syncline. The lower part of the 'Sables bleutés' facies crops out to the south of Quinson village (Saint Maime-Costebelle-La Bastide blanche areas), conformably resting on the 'Calcaire à Bithynies' (Fig. 4(A): St Maime section). It consists of 25 m of cross-bedded and fine-laminated bluish micaceous sands in which with a 1.5 m-thick laminated limestone lens interbedded 15 m above the boundary with the underlying 'Calcaire à Bithynies' facies. The lens is composed of gastropod (*Bithynia* sp.) coquinas, alternating with ostracode-rich wackestones (Fig. 6(A, B)). In the Montmeyan syncline, the 'Sables bleutés' facies does not exceed 50 m in thickness.

Bauduen syncline. Fine laminated bluish micaceous sands fill in the N-S trending, strongly dissymmetric Bauduen syncline (Lapparent, 1938b). Its western border displays a conformable transition between the 'Marnes à oeufs d'oiseaux' Fm. and the 'Sables bleutés' facies (Cornet, 1980), encompassing *Bithynia* sp.-rich limestone lenses interfingered with micaceous sandy beds in its lower part (see above, section 4.5.1.2., and Fig. 4(A, B)).

4.5.2.5. Stratigraphical interpretation

The 'Sables bleutés' facies was considered as early Eocene in age by Lapparent (1938b) and Ginsburg and Mennessier (1967), whereas it was ascribed to the Rupelian (Stampian local stage) by Touraine (1971, 1976) and Angelier (1971).

4.5.2.5.1. Biostratigraphical data

Vertebrates. According to Ginsburg et al. (1967), the Rians (La Fabresse) fossiliferous locality contains a diverse and well-preserved vertebrate fauna composed of teeth, jaws and various bones belonging to mammals, reptiles (turtles and crocodilians) and amphibians. Godinot (1981) documented that the Rians mammalian fauna is unbiased, diverse (about 30 species and 25 genera), and rich in small condylarth Louisinidae, a family known from the mid-Paleocene to the early Eocene of Europe (Hooker and Russell 2012). Ginsburg et al. (1967) have pointed out the affinity of the mammalian association with the assemblages collected in the Sparnacian facies of England, Belgium and especially the Paris Basin. According to Godinot (1981) the Rians mammalian association occurs, in terms of evolutionary trends, near the earliest Eocene MP7 (Dormaal reference-level, Belgium). The most recent evaluation by Marandat et al. (2012), considers also that the Rians mammalian fauna is Ypresian in age and located within the MP7/MP8+9 interval.

A taphonomic study of the 6 to 7 cm-thick vertebrate-bearing bed was carried out by Godinot (1979) who attributed it to deposition in a fluvial environment characterized by bioturbated and weathered red-brown marls and clays (riverbank deposits) and coarse or fine sands (channel deposits). Godinot concluded that there was no reworking of the vertebrate association, in contrast to Touraine's (1968a) assumption.

A second mammalian locality has been discovered in the 'Sables bleutés' of Salernes (Ginsburg and Mennessier, 1973). It yielded two phalanges belonging to a phenacodontid "condylarth", a mammalian family which is known from the late Paleocene through the middle Eocene in North America and Europe (Thewissen, 1990). A third vertebrate locality, recently discovered near Esparron (Font Couverte locality), yielded fragmentary remains of crocodiles, turtles, mammals, and possibly birds (Buffetaut et al. 2016); some elements (notably a crocodile vertebra and the turtle association) suggest an Eocene age.

Ostracodes. In the Rians syncline, Touraine (1972) mentioned an association of ostracodes (determination: G. Carbonnel), 2-4 m above the mammalian bed, and composed of *Hemicyprideis* aff. *genavensis* Oertli, *Neocyprideis* sp. aff. *N. rara* Goerlich *cerestei* Carbonnel, 1969, and *Cytheromorpha* nov.sp. According to Touraine, and despite the systematic uncertainty, this association would suggest an Oligocene age for the lower part of the 'Sables bleutés' facies in the Rians area which, indirectly, would support the reworking hypothesis of the lower Ypresian mammals in this stratigraphical unit. However, new sampling carried out in the La Fabresse mammal bed and in the La Désidère section (see section 4.5.2.3.) did not confirmed the Touraine's biostratigraphical attribution. Only juvenile ostracodes attributed to *Neocyprideis* sp. and *Cyprideis* sp. were found, whereas sandy sediments sampled at the lower part of the 'Sables bleutés', to the east of the Salernes syncline (Les Esparus), provided adult ostracode carapaces ascribed to *Candona* sp. and *Ilyocypris* sp. (Fig. 9). Unfortunately, no discriminant biostratigraphical data can be deduced from this micropaleontological association.

Spores and pollen. A palynological investigation of the 'Sables bleutés' facies was carried out in the central part of the Bauduen syncline (Cornet, 1973a) and provided a homogeneous palynological association investigated by J.J. Châteauneuf (Appendix A3). According to the latter author, palynological spectrum supports the mammalian data from Rians and indicates without ambiguity an early Eocene age.

Nannoplancton. Nury and Touraine (1972) reported from the lower part of the 'Sables bleutés' of Montmeyan (St Maime section) a nannoplancton assemblage (four species, determination Carla Müller, unfortunately not illustrated; Appendix A4) that they considered as autochtonous and ascribed to the early Rupelian. However, the autochtony of this nannoplancton assemblage can be questioned owing to the fluvial depositional setting of the “Sables bleutés” in the St Maime area (Fig. 5(D)). Moreover, three species of the nannoplancton assemblage have a large stratigraphical range including the early Eocene while only one of the species, *Transversopontis zigzag*, is of Oligocene age. Taking into account these contradictions, it seems difficult to draw any biostratigraphical conclusion from the results by Nury and Touraine (1972).

4.5.2.5.2. Field data

Touraine (1968a, 1968b) and Deschamps and Touraine (1969) interpreted the ‘Sables bleutés du Haut Var’ Fm. as a transgressive deposit overlying a lithological unit (named ‘Argilites ferrugineuses’) that they considered as an Oligocene paleosol deposit, unconformably resting on the ‘Marnes à oeufs d’oiseaux’ Fm. Moreover, an angular unconformity was postulated by Touraine (1969, 1971) to occur between the ‘Sables bleutés du Haut Var’ Fm. and the underlying Paleocene formations in some areas such as Salernes and the Pontevès-Sillans synclines. In Touraine’s hypothesis, the unconformity and the underlying paleosol were strong arguments supporting the Oligocene age of the ‘Sables bleutés’ facies since they were interpreted as representing an important stratigraphical gap related to a pre-Rupelian tectonic phase. The ‘Argilites ferrugineuses’ paleosol would correspond in their view to a long period of non-deposition and exposure.

Observations and mapping undertaken in the present study allow us to reject Touraine’s assumption. Indeed, in all the Haut Var synclines, the ‘Sables bleutés du Haut Var’ Fm. conformably and gradually overlies the underlying ‘Marnes à oeufs d’oiseaux’ Fm., without any paleosol intercalation. Contrary to the stratigraphical scheme of Touraine (1968a), in the western part of the Rians syncline (La Fabresse; Fig. 8) it does not exist any weathered red clay paleosol below the ‘Calcaire à Bithynies’, nor any transgressive and erosive conglomerates. In many areas (Montmeyan, Rians, Fox Amphoux, Salernes, etc., synclines) gastrolites and bird eggshell fragments still occur in the ‘Marnes à oeufs d’oiseaux’ Fm. just beneath the first deposits of the ‘Sables bleutés’ facies (e.g., Les Cadenières in the eastern part of the Salernes syncline).

The angular unconformity reported by Touraine (1969, 1971) between the ‘Sables bleutés’ facies and the underlying ‘Marnes à oeufs d’oiseaux’ Fm. in the Salernes and Pontevès-Sillans synclines has not been confirmed in any further study. For instance, in the southern border of the Salernes syncline (Les Esparus, Les Cadenières), the 'Sables bleutés' facies conformably overlies the 'Marnes à oeufs d'oiseaux' unit, both displaying the same 20° N dip (Fig. 5(F)).

4.5.2.6. Depositional environment

Since the studies of Lapparent (1938a, 1938b), most authors (Mennessier, 1959; Vogt-Di Poppa, 1968; Cornet, 1973a, 1977; Godinot, 1979) have concluded that the 'Sables bleutés' facies was of fluvial origin. Only Touraine (1973b, 1973c, 1976) related it with a marine environment. According to Vogt-Di Poppa (1968), the deposition of the micaceous sandy beds occurred as a result of large alluvial sheet floods and fluvial crevasse-splay processes. Indeed, new sedimentological investigations and mapping showed that this facies is linked to a fluvial system characterized by sandy deposits with channel cross-bedding that alternate with alluvial plain plane-beds (Fig. 5(D)). This interpretation is further supported by the paleontological content of the 'Sables bleutés'. Godinot (1979) showed that the vertebrate assemblage found in the lower part of the 'Sables bleutés' in the Rians syncline is composed of species living on riverbanks and along streams. The animals, belonging to different taxa and different environments (terrestrial and freshwater biotopes) have probably been transported *post-mortem*, mixed and concentrated by a fluvial flood in an oxbow pond. Afterwards, the bone remains were buried by riverine fine sand deposits. The ostracode association, composed of *Neocyprideis* sp., *Cyprideis* sp., *Candona* sp. and *Ilyocypris* sp., strengthens ecological conditions close to fresh- or brackish-water, compatible with a fluvial system encompassing lakes, ponds and lagoons with carbonate and evaporitic sedimentation ('Calcaire à Bithynies').

Otherwise, the homogeneous clay-mineralogy led Cornet (1973a, 1977) to claim deposition of the 'Sables bleutés' facies in a single alluvial sheet, spreading out on a flat paleosurface affecting the whole Haut Var area, which was secondarily broken up by tectonic movements and dissociated by erosion. Our data complement Cornet's conclusion. Instead of a flat paleosurface the 'Sables bleutés' facies would be rather deposited in a subsident foreland basin surrounded by incipient emergent paleostructures (Fig. 10) that afterwards evolved as northward or southward verging thrusts during the late Eocene Pyrenean-Provence compressional tectonic phase. The Durance High was inherited from the mid-Cretaceous paleogeography that led to the uplift of the so-called 'Bombement durancien' (Masse and Philip, 1976) on which bauxite formed. The Greoux High was postulated by Morabito (1967) as an Upper Cretaceous-

Eocene uplift, confirmed by deep petroleum drillings (Dubois and Curnelle, 1978). The Subalpine Land (the present Canjuers Jurassic plateau) was emerged as early as the Late Cretaceous (Lapparent, 1938; Kerckhove, 1978). The southern part of the foreland basin was probably bounded by the E-W trending Sambuc-Pallières and Bessillons-Salernes flexural fronts that acted as incipient paleostructures as early as the Maastrichtian and the Danian (Angelier, 1974). The main subsident foreland area would correspond to the Rians syncline where up to 400 m of micaceous sands and conglomerates settled in a narrow E-W trending depocenter located at the footwall of the Sambuc-Pallières thrust.

5. Oligocene

5.1. Location and historical background

In the Haut Var area, the Oligocene continental deposits are only represented in Bourdas, Plan d'Auron, Gigery, La Combe grabens, and locally in the Chargeaire, Pierrette, and Bellevue areas (Fig. 2). In contrast with the debate about the age of the 'Sables bleutés du Haut Var' Fm., a general consensus arose about the Oligocene age of these deposits (the Bourdas facies *sensu* Touraine, 1971). However, a discussion took place concerning their stratigraphic correlations with the 'Sables bleutés du Haut Var' Fm. Hence, according to Touraine (1971) and Angelier (1971), the Oligocene would present two coeval facies: the Bourdas facies and the Montmeyan facies (corresponding to the whole 'Sables bleutés' facies and 'Calcaire à Bithynies'), whereas Mennessier (1970) disagreed with this hypothesis and stated that the Bourdas and Montmeyan facies were diachronous. He assigned the first to the Oligocene, while the second would correspond to the lower Eocene. These results are discussed below.

5.2. The Oligocene series of the Bourdas graben

The sedimentary infilling of the Bourdas graben (Fig. 2) was successively ascribed to the Miocene (Lapparent, 1938), to the Fuvelian local stage (Campanian) by Mennessier and Modret (1965), and finally to the Sannoisian local stage (earliest Rupelian) by Touraine (1966b, 1974) and Angelier (1971). In order to complement these studies, we have logged two detailed sections (Fig. 11): a first one in the northern border of the graben (Les Olagniers area: 43° 39' 50.77'' N; 5° 54' 18. 49'' E, until southward the altitudinal point 442 m) and a second one at L'Américaine (43° 39' 07. 12'' N; 5° 54' 37. 68'' E), in the southwestern border.

5.2.1. Les Olagniers type-section

Unit I. It is formed by an argillaceous limestone bed unconformably resting on the Lower Cretaceous basement, passing upwards to coarse heterogeneous conglomerates (Fig. S1(A)) that contain a high proportion of pebbles and cobbles of local origin (Jurassic and Lower Cretaceous limestones), while quartz pebbles are relatively scarce.

Unit II. Formed by about 100 m-thick sandy marls and siltstones that contain in the upper part gastropod shell fragments and gypsum crystals occurring in poor outcropping conditions.

Unit III. Characterized by an alternation of gypsiferous and fossiliferous sandy marls, sandstones and finely laminated limestones (Fig. S1(B)). Fossil assemblages encompass gastropods, ostracodes (*Neocyprideis* sp.), and charophytes.

5.2.2. L'Américaine section

Unit I is represented by an alternation of conglomerates (similar to those of the Les Olagniers section), argillaceous limestones and fossiliferous limestone lenses containing gastropods and small bivalves (*Pisidium* sp.). Only the lower part of **Unit II** crops out in this section.

5.3. Lateral variations

5.3.1. La Combe half graben

At the eastern end of the Rians syncline, the Oligocene deposits extend in the narrow N-S trending La Combe half graben parallel to the western faulted border of the Barjols Triassic uplift (Fig. 2). Initially ascribed to the Danian (Lapparent, 1938), the deposits were later attributed to the Eocene (Mennessier, 1966), then to the Oligocene (Touraine, 1967b; Angelier, 1971).

The Oligocene deposits are represented by Unit I and the lower part of Unit II only (Fig. 11). In the soutwestern part of the half graben, Unit I unconformably rests on the 'Sables bleutés' facies while it lies on the Upper Cretaceous or Jurassic basement in the northwestern part (Angelier and Aubouin, 1976). A well exposed stratigraphical section crops out along the road D561 with complement along the old railway from Rians to Varages. Unit I is characterized by alternating beds of conglomerates and coarse red sandstones. Conglomeratic beds mainly encompass pebbles and cobbles made of Jurassic limestone (Fig. S1(C)) mixed with scarce pebbles of Triassic cargneules (Fig. S1(D)), quartz, and metamorphic rocks. Pebbles of gastropod-rich limestones ascribed to the Oligocene have been mentioned by Angelier (1971) at the upper part of the conglomeratic sequence.

At the Engaraude locality, close to the northeast flank of the La Combe half graben, the lower part of the conglomeratic sequence includes a limestone lens (Angelier, 1971; Angelier and Aubouin, 1973) that yields a rich gastropod association referred to as *Striatella* horizon, which was considered by Rey (1966) and Nury (1988) as characteristic of the earliest Rupelian. However, Touraine (1971) interpreted the Engaraude limestone lens as collapsed from a hypothetic '*Striatella* limestone' resting on the nearby Triassic Barjols tectonic unit. This interpretation cannot be supported since such limestone does not exist *in situ* in the eastern part of the Rians syncline.

The Engaraude gastropod-bearing limestone is located east of the Montmayon domain (43° 36' 28.37'' N; 5°55' 15.58'' E; alt. 450 m). It is represented by a 2 m-thick, 100 m-wide limestone lens conformably underlying the conglomeratic Unit I (Fig. 11) that laterally overlaps the Jurassic basement. The carbonate lens is formed by alternating gastropod-bearing wackestones-floatstones and vuggy carbonate crusts (Fig. S1(E, F)). Field data suggest shallow lacustrine-palustrine carbonate sedimentation followed by diagenetic processes leading to the formation of the Engaraude limestone, preceding the La Combe conglomerate deposition.

5.3.2. Gigery half graben

The Gigery half graben is located along the western Upper Jurassic-Triassic border of the Barjols Triassic uplift from which it is separated by a roughly N-S major fault (Fig. 2). The sedimentary infilling of the Gigery half graben was successively ascribed to the Danian (Lapparent, 1938), the Paleocene-early Eocene (Mennessier, 1966) and finally the Oligocene (Touraine, 1967b; Angelier, 1971). The Oligocene series overlies unconformably either on the Upper Jurassic basement in the northwestern part of the structure or on the uppermost Cretaceous one (Rognacian) in its southern part.

A detailed stratigraphical section can be studied in the northern part of the half graben, near the Gigery farm (Fig. 11). The lower part of the sequence displays lenticular beds of conglomerates alternating with coarse sandstone and red siltstone beds. These facies are referred to the Unit I of the Les Olagniers type-section. The conglomerates contain a high proportion of pebbles and cobbles of Jurassic limestone, with minor quartz pebbles. Some conglomerate beds contain reworked boulders of gastropod limestones (Fig. S2(B)) referred to by Angelier (1971) as the 'Calcaire à Striatelles' facies. The Unit I grades upwards to white-greenish marls probably corresponding to the lower part of the Unit II as observed in the Les Olagniers section. The upper part of the marly Unit II crops out poorly and forms the weathered and colluvium-covered topographic depression that extends to the east of the Gigery farm.

5.4. Stratigraphy

Gastropods are abundant in the limestone lenses linked to the conglomerates of the Bourdas and La Combe (Engaraude) areas. The gastropod association (Angelier, 1971; Touraine, 1967b and in collection; Philip, in collection; Appendix A5) is characteristic of the lowermost Rupelian, *Striatella* horizon, well represented in the Marseille Oligocene Basin (Nury, 1988). It is worth noting that the pebbles of gastropod-bearing limestone in the upper part of the La Combe or Gigery conglomerates contain the same fossils as the autochtonous carbonate lenses of Bourdas and La Combe areas (Angelier, 1971). Hence, they can be considered as reworked from underlying *Striatella*-bearing limestone deposits.

To sum up, our results confirm Mennessier's stratigraphical interpretation. No correlation can be established between the Bourdas facies and the Montmeyan facies (*sensu* Touraine, 1971), since they are diachronous. The gastropod association that characterizes the limestone lenses interbedded in the Bourdas conglomerates is biostratigraphically younger that those of the 'Calcaire à Bithynies'. The Bourdas limestone lenses belong to the early Oligocene. Their deposition and that of the coeval conglomerates occurred later than the 'Sables bleutés' facies, as attested in the La Combe half graben. Additionally, the Bourdas facies corresponds to a characteristic and well-dated conglomerate-dominant detrital series that can be assimilated to a stratigraphical formation of Oligocene (Rupelian) age in the Haut Var area.

6. Synthesis and conclusions

Our results allow to establish a new chronostratigraphical framework of the Haut Var Paleogene continental series and to make stratigraphical correlations at the regional scale (Fig. 12). The K/Pg boundary may lie in the red silty marls underlying the 'Calcaire à Microcodium' Fm. ascribed to the Danian (Vitrollian local stage). Alluvial fans ('Brèches à Microcodium' Fm.)

interbedded in the red siltstones of the upper Danian were originated during an incipient uplift affecting the southern part of the Haut Var area in relation with the northward verging Sainte-Victoire tectonic compressional system (Espurt et al., 2012). Later, the Selandian(?)-earliest Ypresian 'Marnes à oeufs d'oiseaux' Fm. transgressively spread out in all Haut Var synclines, resting either conformably on the 'Brèches à Microcodium', or unconformably on the Lower Cretaceous-Upper Jurassic basement.

Upward in the stratigraphic record, the 'Marnes à oeufs d'Oiseaux' Fm. is covered conformably either by the 'Calcaire à Bithynies' or the 'Sables bleutés' facies, without any gap or tectonism contrary to what was wrongly postulated by Touraine (1971, 1976) and Angelier (1971). New sedimentological investigations have shown the absence of any reworked mammalian remains in the 'Calcaire à Bithynies' and 'Sables bleutés' facies, which supports a lower Ypresian age for these units, as previously proposed by Teilhard de Chardin and Lapparent (1933), Ginsburg et al. (1967), Godinot (1981), and Escarguel (1999). New analysis or re-interpretation of previous data concerning charophytes, foraminifera, ostracodes and palynoflora agree with this chronostratigraphical conclusion. The gastropod association present in the 'Calcaire à Bithynies' dramatically differs from the one that characterizes the 'Calcaire à Striatelles' horizon, typical of the lower Oligocene in both the Haut Var and Basse Provence basins.

Our results confirm the existence of a major stratigraphical gap, corresponding to the Lutetian-Priabonian interval, in the Haut Var area. This supports Lapparent's (1938b) and Mennessier's (1959) interpretations that this period corresponded with the Pyrenean-Provence compressional tectonic phase that resulted in the folding of the Haut Var synclines and the emplacement of the main overthrusts on the 'Sables bleutés du Haut Var' Fm.

The Oligocene Bourdas conglomerate Fm. unconformably rests on different terms of the stratigraphical basement. Oligocene deposits occur in N-S trending grabens or half grabens linked to an Oligocene-early Miocene(?) extensional phase that contributed to the rising of the Barjols Triassic uplift. The deposits are characterized by the predominance of conglomerates associated to gastropod-bearing limestone lenses ascribed to the lower Oligocene *Striatella* horizon.

Sedimentological and paleoecological investigations have shown that the deposition of the 'Calcaire à Bithynies' corresponded to fresh- or brackish-water conditions while the 'Sables bleutés' facies was typical of a fluvial environment. Both sedimentary units were deposited in a roughly E-W trending compressional foreland basin surrounded by emerged areas and tectonic highs (Fig. 10). These paleogeographical features contributed to the relative isolation of the Haut Var area during early Ypresian times and probably enhanced episodes of brackish water or evaporitic sedimentation. Likewise, restricted paleoenvironmental conditions and relative biogeographical isolation could be invoked as responsible for the peculiar features shown by the Ypresian Haut Var gastropod associations. However, detailed systematic revision is needed in order to compare these latter with those of other coeval European sedimentary basins. Future studies will also need to concentrate on a chemostratigraphical framework of the 'Sables bleutés du Haut Var' Fm. established on the hyperthermal events that occurred during the early Eocene. Hence, isotope analysis of organic carbon could be especially useful to provide correlations with other early Eocene deposits from Southern France (Aix-en-Provence Basin, Corbieres and Minervois) or elsewhere.

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Appendices A-B. Supplementary information

Supplementary information (including additional data on the biostratigraphy [Appendix A] and on the regional stratigraphy [Appendix B], and supplementary material on the Oligocene field facies (Figs. S1, S2)) associated with this article can been found, in the online version, at:

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Figure captions

Fig. 1. Simplified geological-structural map of the Provence region, southeastern France (modified from Philip, 2012). Polygonal insert: Location of the study area.

Fig. 2. Geological-structural map of the Haut Var area with location of the studied Paleogene synclines and grabens.

Fig. 3. Charophytes from the 'Marnes à oeufs d'Oiseaux' Fm. in the Moissac syncline (Fig. 2), Terrelongue locality (Appendix A1). **A, B**. *Dughiella bacillaris* Feist, lateral view. **C**. *Microchara vestita* Feist, lateral view. **D-F**. *Harrisichara* cf. *meguerchensis* Mebrouk and Feist; D, lateral view; E, apical view; F, basal view. **G-K**. *Maedleriella* cf. *cristellata* Grambast; G-I, lateral views; J, apical view; K, basal view. Scale bar: 500 µm.

Fig. 4. **A**. Columnar sections of the 'Calcaire à Bithynies' and 'Sables bleutés' facies in the Rians, Montmeyan, and Bauduen synclines (location: Fig. 2). 1, Red silty-marl; 2, *Bithynia* bearing sandy-marl; 3, Laminated micaceous sand; 4, Sandstone; 5, Cross-bedded micaceous sand; 6, *Bithynia* bearing limestone; 7, Alternating laminated limestone, marly and gypsum beds; 8, Gastropod; 9, Bivalve; 10, Ostracode; 11, Foraminifer (*Rosalina bractifera*); 12, Charophyte; 13, Fenestrae (Bird's eyes); 14, Gypsum; 15, Chert. **B**. Geological map of the Saint-Barthélemy area (northwestern part of the Bauduen syncline; Fig. 2). 1, Hauterivian basement; 2, 'Calcaire à Microcodium' Fm.; 3, 'Marnes à oeufs d'oiseaux' Fm.; 4a, 'Sables bleutés' facies; 4b, 'Calcaire à Bithynies' (stratigraphical occurrence of *Euromys* aff. *thaleri*); 5, Quaternary.

Fig. 5. Typical outcrops and facies of the 'Calcaire à Bithynies' and 'Sables bleutés' facies. **A**. Les Toulons section of the 'Calcaire à Bithynies'; Unit I: *Bithynia* bearing sandy marls; Unit II: *Bithynia* bearing limestones; (1): gastropod (*Bithynia* sp.) ostracode-rich wackestones floatstones; (2): alternating fine clayed layers – laminated cherty limestones – peloidal wackestones packstones. Scale bar: 1 m. **B**. 'Calcaire à Bithynies', Costebelle (Montmeyan syncline); Unit I: *Bithynia* bearing sandy gypsiferous marls; Unit II: *Bithynia* bearing limestones; (1) alternating

laminated vuggy carbonate and marly gypsum beds; (2): gastropod-ostracode bearing peloidal-fenestrate packstones (Fig. 6(D)). **C**. Lumachellic bed showing casts of *Melania cardinalis* Lapparent from the ‘Calcaire à Bithynies’, Les Aubarèdes (Montmeyan syncline). Scale bar: 6 mm. **D**. Fine laminated cross-bedded micaceous sands from the lower part of the ‘Sables bleutés’ facies, Saint-Maime (Montmeyan syncline). **E**. Alternating medium including coarse micaceous sands and quartz-rich conglomerates with interbeds of lenticular intraformational reworked and weathered (red oxidized) coarse micaceous sandyclasts (arrows) from the ‘Sables bleutés’ facies, Les Arnauds (Salernes syncline). **F**. Alternating coarse micaceous sands and fining upward quartz-rich gravelly bed from the northeastward tectonic dip, ‘Sables bleutés’ facies, Pin Bernard area, Salernes village.

Fig. 6. Microfacies of the ‘Calcaire à Bithynies’. **A**. Alternating beds of *Bithynia* floatstone (bottom left) and ostracode packstone (upper right); limestone lens interbedded in the ‘Sables bleutés’ facies (Saint-Maime section, Fig. 4(A); Montmeyan syncline); pond environment. **B**. Graded bedded ostracode rich packstone; same Saint-Maime limestone lens. **C**. Bioclastic sandy micaceous packstone; St Barthèlemy area (Fig. 4(A, B)); Bauduen syncline; microfacies composed of tiny bivalve shell fragments mixed with gastropods (*Bithynia* shells), quartz grains and micas (arrows); high-energy shoreface(?), pond environment. **D**. Fenestrate peloidal packstone-grainstone; Costebelle (Montmeyan syncline); peloids formed by ostracode-rich mudstone; fenestrate porosity could be due to post-depositional desiccation; shallow pond environment. **E**. Ooid grainstone; La Neuve locality (La Mourotte syncline); nuclei formed by ostracode-bearing peloids; note scarce early meniscus calcitic cement between ooids (1), and grain dissolution (2); shoreface (vadose?) pond environment. **F**. Same microfacies; magnification of an ooid particle displaying three radially structured laminae; note external micritic coating and (vadose?) dissolution of the nucleus replaced by late drusy calcite. **G**. *Bithynia* sp. within a charophyte packstone; Les Toulons section; shallow lacustrine environment. **H**. Ostracode-charophyte packstone; Les Toulons section.

Fig. 7. Microfossils and fossils. **A**. *Rosalina bractifera* Le Calvez. Thin section of a specimen enclosed in a wackestone matrix; arrows indicate the inner septal flaps characteristic of the species; ‘Calcaire à Bithynies’, La Mourotte, Touraine collection. **B**. Same microfacies with

numerous gathered individuals of *Rosalina bractifera*. **C**. *Euromys* aff. *thaleri* (Michaux, 1964), half-mandible embedded in its original matrix (m) made of *Bithynia* sp. opercula-rich wackestone-packstone; type-specimen from the Lapparent collection, now housed in the Paleontological collections of the University of Montpellier; 'Calcaire à Bithynies', Bauduen. **D**. *Bithynia bauduensis* Lapparent; 'Calcaire à Bithynies' (Unit I), Bardouine locality (W of Rians Village). **E-J**. *Melania (Terebia) cardinalis* Lapparent, 1938a. Typical polymorphous shells showing irregularly nodulous transversal ribs, well pronounced suture and fine string between each whorl of spire; 'Calcaire à Bithynies', Montmeyan, Touraine collection. **K**. *Tympanotonos* sp.; 'Calcaire à Bithynies', La Neuve (La Mourotte syncline), Touraine collection (generic determination: R. Rey). **L-O**. Gastropods from the Oligocene Bourdas Fm., Bourdas locality; all forms from the Touraine collection.; L: *Neritina* sp.; M: *Viviparus soricinensis* Noulet; N: *Pseudamnicola angulifera* (Dunker); O: *Melanoides tourainei* (Rey). **P**. *Potamides laurae* Matheron; Oligocene; Engaraude limestone (La Combe half graben); Philip collection. **Q**. *Pisidium* sp.; Oligocene; Bourdas Fm.; L'Américaine (Bourdas graben); Philip collection.

Fig. 8. Geological map (**A**) and structural cross section (**B**) of the Rians syncline at the footwall of the Mont Major thrust (Fig. 2). 1: Upper Jurassic limestone; 2: Rognacian limestone-sandstone; 3: 'Calcaire à Microcodium' Fm.; 4: 'Marnes à oeufs d'oiseaux' Fm.; 5: 'Calcaire à Bithynies'; 6: 'Sables bleutés' facies (white star corresponds to the La Fabresse-La Neuve mammalian locality; Ginsburg et al., 1967); 7: Quaternary; E: scree; F_z: Alluvial deposits; X-X': location of the structural cross section.

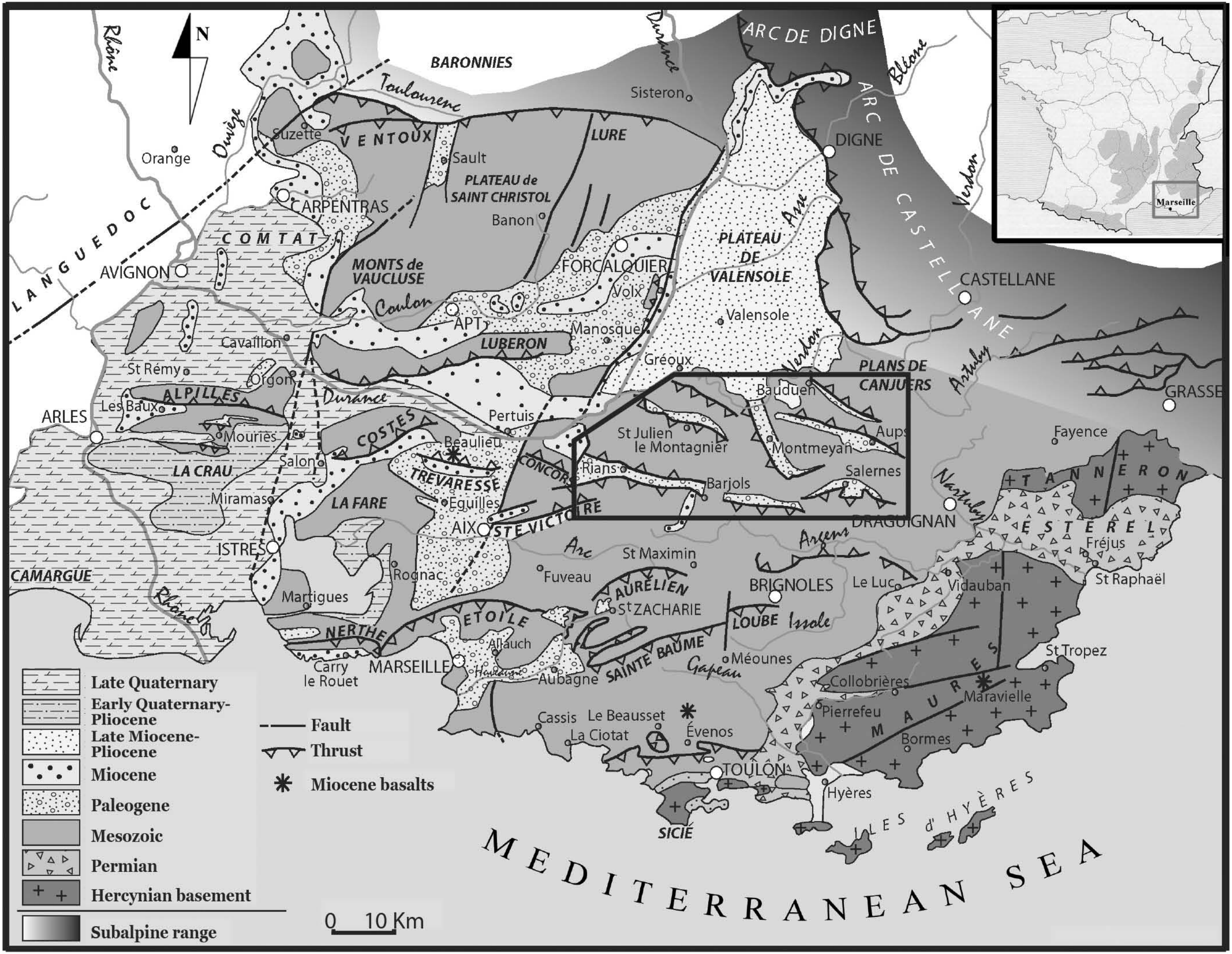
Fig. 9. Ostracodes from the 'Sables bleutés' facies (S: Shell; LV: Left valve; RV: Right valve). **A**. *Candona* sp., S, left side view; Var 1, Rians la Neuve. **B**. *Candona* sp., LV, side view; Var 4, Les Esparus (Salernes syncline). **C**. *Cyprideis* sp., S, right side view; Var 3, La Désidère (Rians syncline). **D**. *Cyprideis* sp., S, left side view; Var 3, La Désidère. **E**. *Cypridopsis* sp., S, left side view; Var 2, Bauduen (St Barthélemy). **F**. *Cypridopsis* sp., S, right side view; Var 2, Bauduen (St Barthélemy). **G**. *Ilyocypris* sp., RV, internal view; Var 4, Les Esparrus. **H**. *Ilyocypris* sp., LV, side view, adult form; Var 4, Les Esparrus. **I**. *Ilyocypris* sp., LV, side view, larval form; Var 4, Les Esparrus. **J**. *Neocyprideis* sp., S, right side view; Var 3, La Désidère. **K**. *Neocyprideis* sp., S, left

side view; Var 3, La Désidère. **L**. *Neocyprideis* sp., S, right side view; Var 3, La Désidère. Scale bar: 200 μm.

Fig. 10. Paleogeographical reconstruction of the lower Eocene Haut Var foreland basin. 1: Probably emerged areas; 2: Hypothetical maximum extent of the foreland basin; 3: Present outcrops of the 'Sables bleutés' facies; 4: Location of the 'Calcaire à Bithynies' facies; 5: Average thickness of the 'Sables bleutés' facies in the Rians-Salernes subsident axis; 6: Direction of detrital inputs; MDF: Middle Durance Fault. Localities: A, Ampus; B, Bauduen; Ba, Barjols; Bo, Bourdas; EV, Esparron-de-Verdon; FA, Fox-Amphoux; G, Greoux; Gi, Ginasservis; LM, La Mourotte; M, Montmeyan; Mo, Moissac; P, Pontevès; Q, Quinson; R, Rians; S, Salernes; Si, Sillans; SJM, St Julien-le-Montagné; V, Vinon.

Fig. 11. Columnar sections of the Oligocene Bourdas conglomerate Fm. in the Bourdas, La Combe-Engaraude, and Gigery areas (Fig. 2). 1: Conglomerate; 2: Sandstone; 3: Sandy-marl; 4: Argillaceous-sandy limestone; 5: Gastropod bearing limestone; D2: erosional unconformity (Fig. 12).

Fig. 12. Stratigraphical correlations of the Paleogene formations (chronostratigraphical subdivisions and geochronological ages after the Geologic Time Scale, 2012). Bracketed capital letters indicate stratigraphical location of prominent biomarkers: M, Mammals; B, Bird eggshells; G, Gastropods; C, Charophytes. D_1, D_2, D_3: main regional erosional unconformities. P.T: "Poudingues des Touars" unit. Stratigraphical gaps are shown by oblique lines.



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Banon
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AVIGNON
Volx
CASTELLANE
APT
Manosque
Valensole
Cavaillon
Gréoux
St Rémy
Orgon
Bauduen
GRASSE
Les Baux
Pertuis
ARLES
Mouriès
Beaulieu
St Julien le Montagnier
Montmeyan
Aups
Fayence
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Rians
Salernes
Barjols
Miramas
Eguilles
DRAGUIGNAN
AIX
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St Maximin
Fréjus
Fuveau
Rognac
St Raphaël
BRIGNOLES
Le Luc
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Martigues
St ZACHARIE
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Carry le Rouet
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Cassis
Le Beausset
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Durance
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Asse
Bléone
Verdon
Artuby
Nartuby
Argens
Arc
Issole
Gapeau
Huveaune
Marseille
Late Quaternary
Early Quaternary-Pliocene
Late Miocene-Pliocene
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Subalpine range
Fault
Thrust
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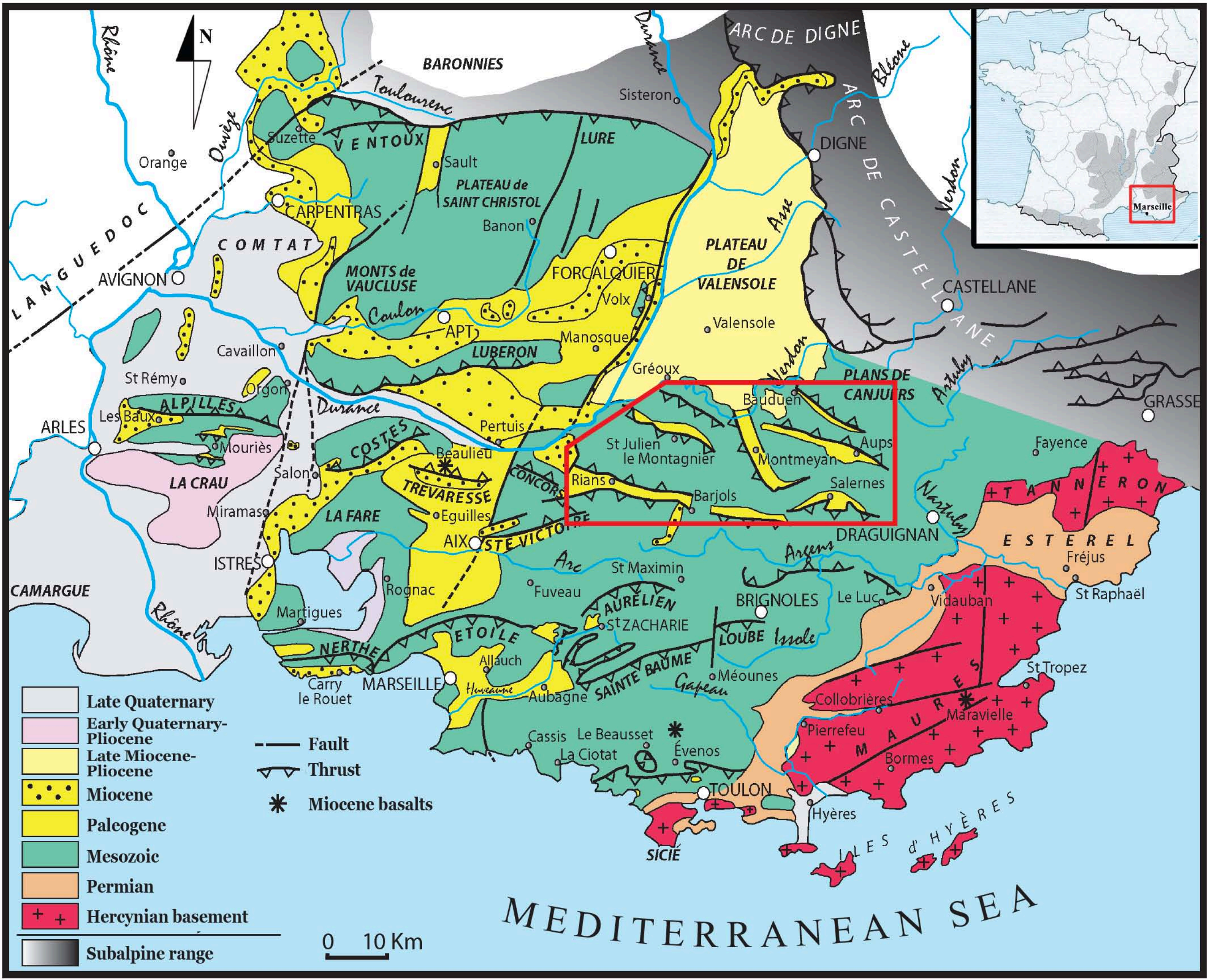

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Coulon
Arc
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Issole
Gapeau
Huveaune
Marseille
Late Quaternary
Early Quaternary-Pliocene
Late Miocene-Pliocene
Miocene
Paleogene
Mesozoic
Permian
Hercynian basement
Subalpine range
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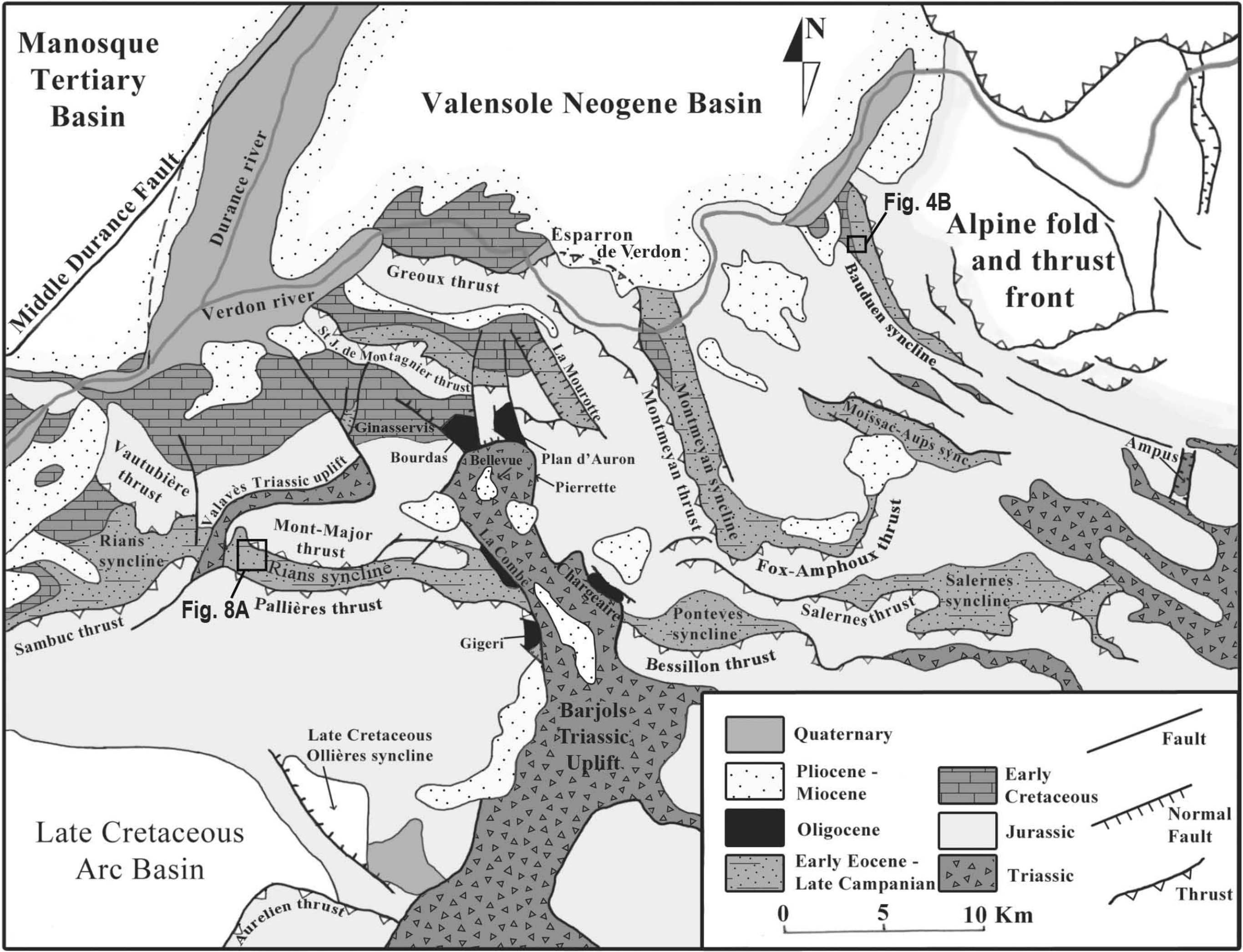

Manosque Tertiary Basin
Valensole Neogene Basin
N
Middle Durance Fault
Durance river
Verdon river
Esparron de Verdon
Greoux thrust
Fig. 4B
Alpine fold and thrust front
Bauduen syncline
St J. de Montagnier thrust
La Mourotte
Montmeyan thrust
Montmeyan syncline
Moissac-Aups sync
Ampus
Ginasservis
Bourdas
Bellevue
Plan d'Auron
Pierrette
Vautubière thrust
Valavès Triassic uplift
Mont-Major thrust
Rians syncline
Rians syncline
Fig. 8A
Pallières thrust
Sambuc thrust
La Combe
Chargeaire
Fox-Amphoux thrust
Salernes syncline
Salernes thrust
Ponteves syncline
Bessillon thrust
Gigeri
Barjols Triassic Uplift
Late Cretaceous Ollières syncline
Late Cretaceous Arc Basin
Aurelien thrust
Quaternary
Pliocene - Miocene
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Early Cretaceous
Jurassic
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Normal Fault
Thrust
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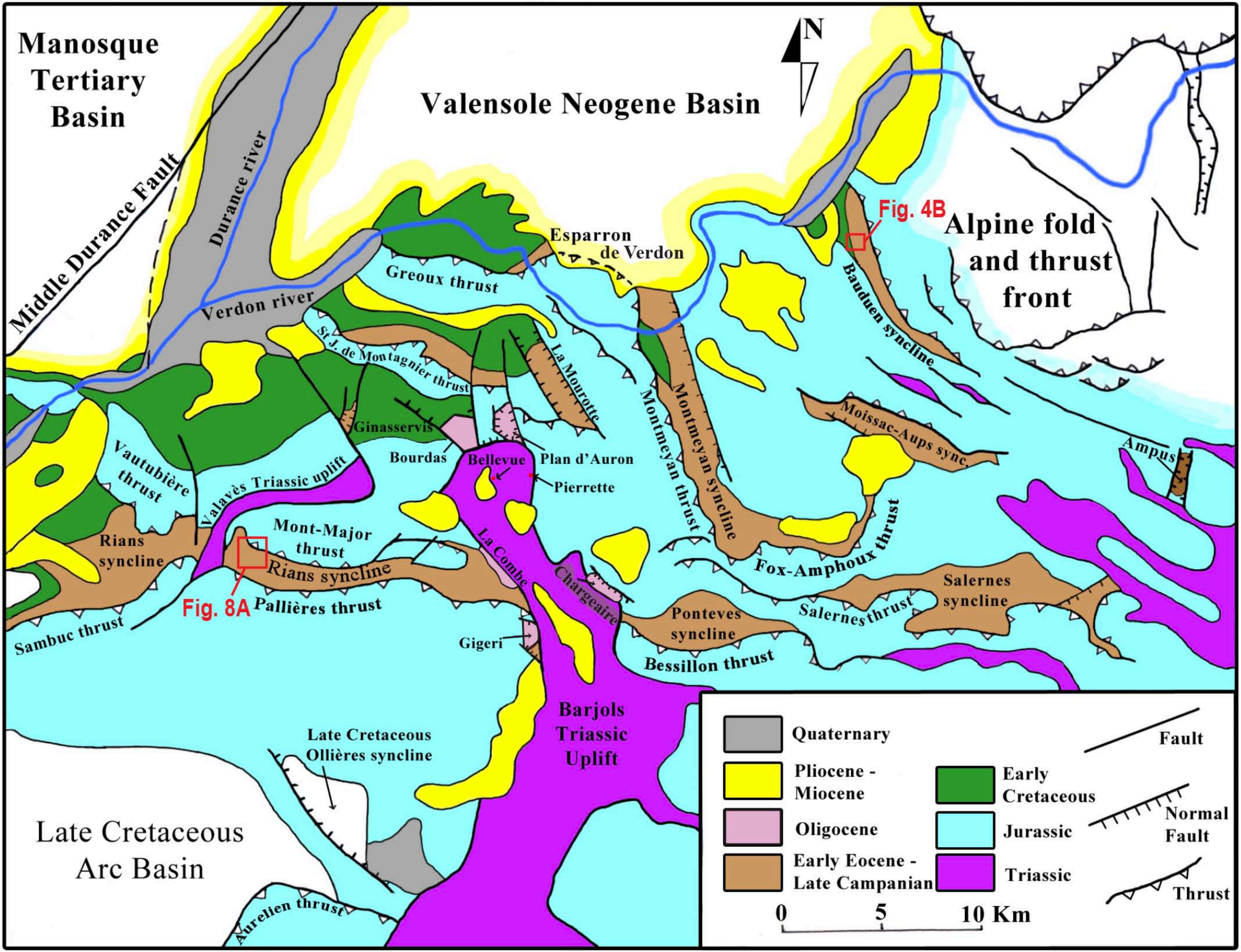

Manosque Tertiary Basin
Valensole Neogene Basin
N
Middle Durance Fault
Durance river
Verdon river
Esparron de Verdon
Greoux thrust
St J. de Montagnier thrust
La Mourotte
Montmeyan thrust
Montmeyan syncline
Bauduen syncline
Fig. 4B
Alpine fold and thrust front
Moissac-Aups sync.
Ampus
Ginasservis
Bourdas
Bellevue
Plan d'Auron
Pierrette
Vautubière thrust
Valavès Triassic uplift
Mont-Major thrust
Rians syncline
Rians syncline
Fig. 8A
Pallières thrust
Sambuc thrust
La Combe
Chargeaire
Gigeri
Fox-Amphoux thrust
Salernes syncline
Salernes thrust
Ponteves syncline
Bessillon thrust
Barjols Triassic Uplift
Late Cretaceous Ollières syncline
Late Cretaceous Arc Basin
Aurelien thrust
Quaternary
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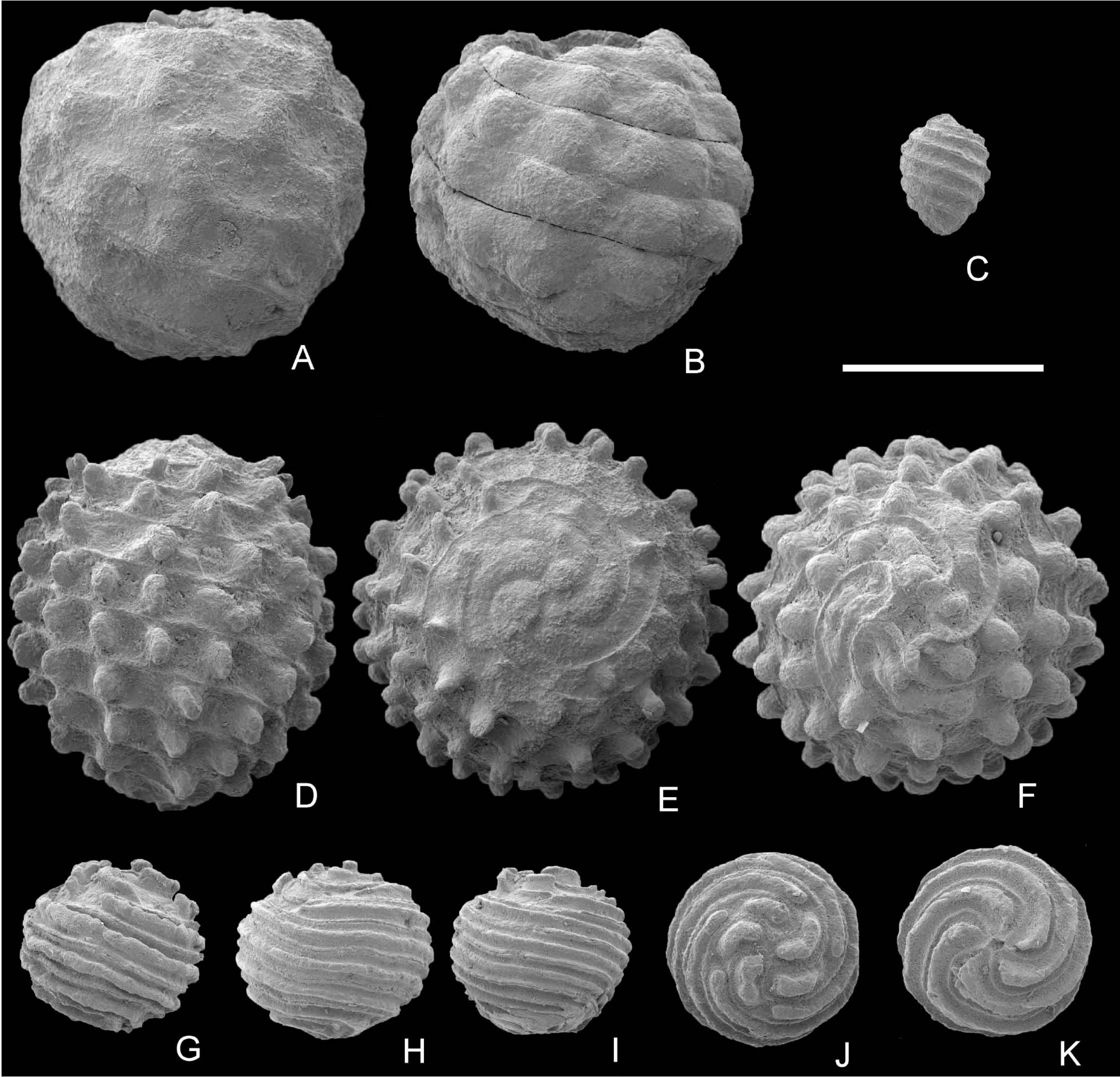
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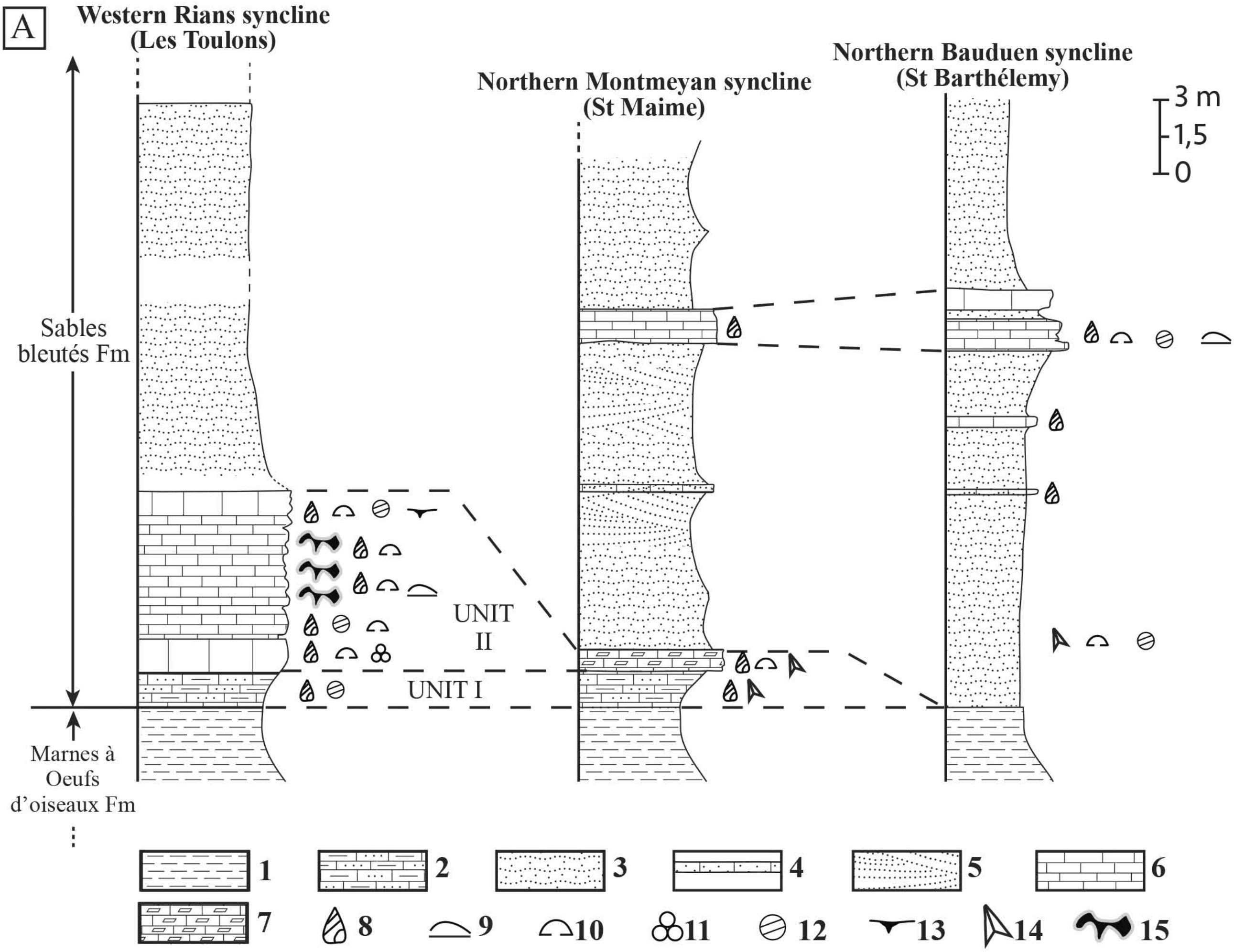
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(St Maime)
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UNIT II
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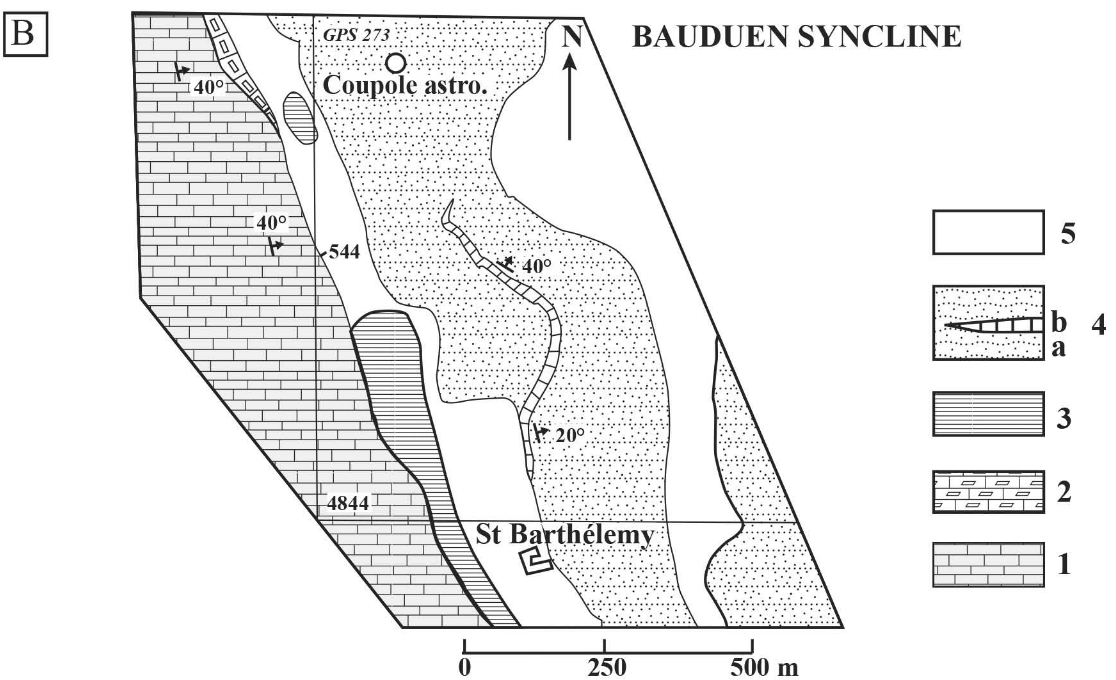
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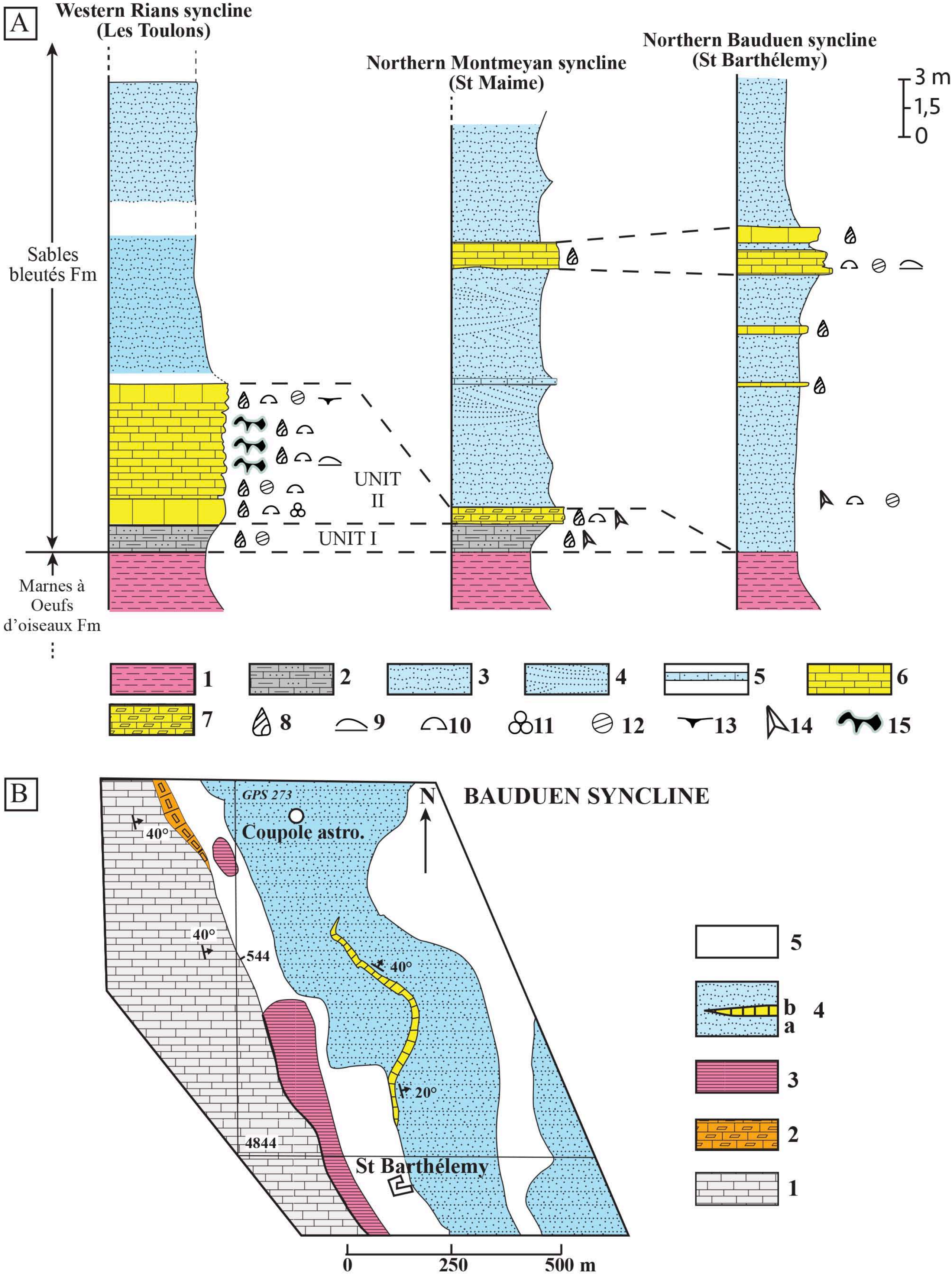

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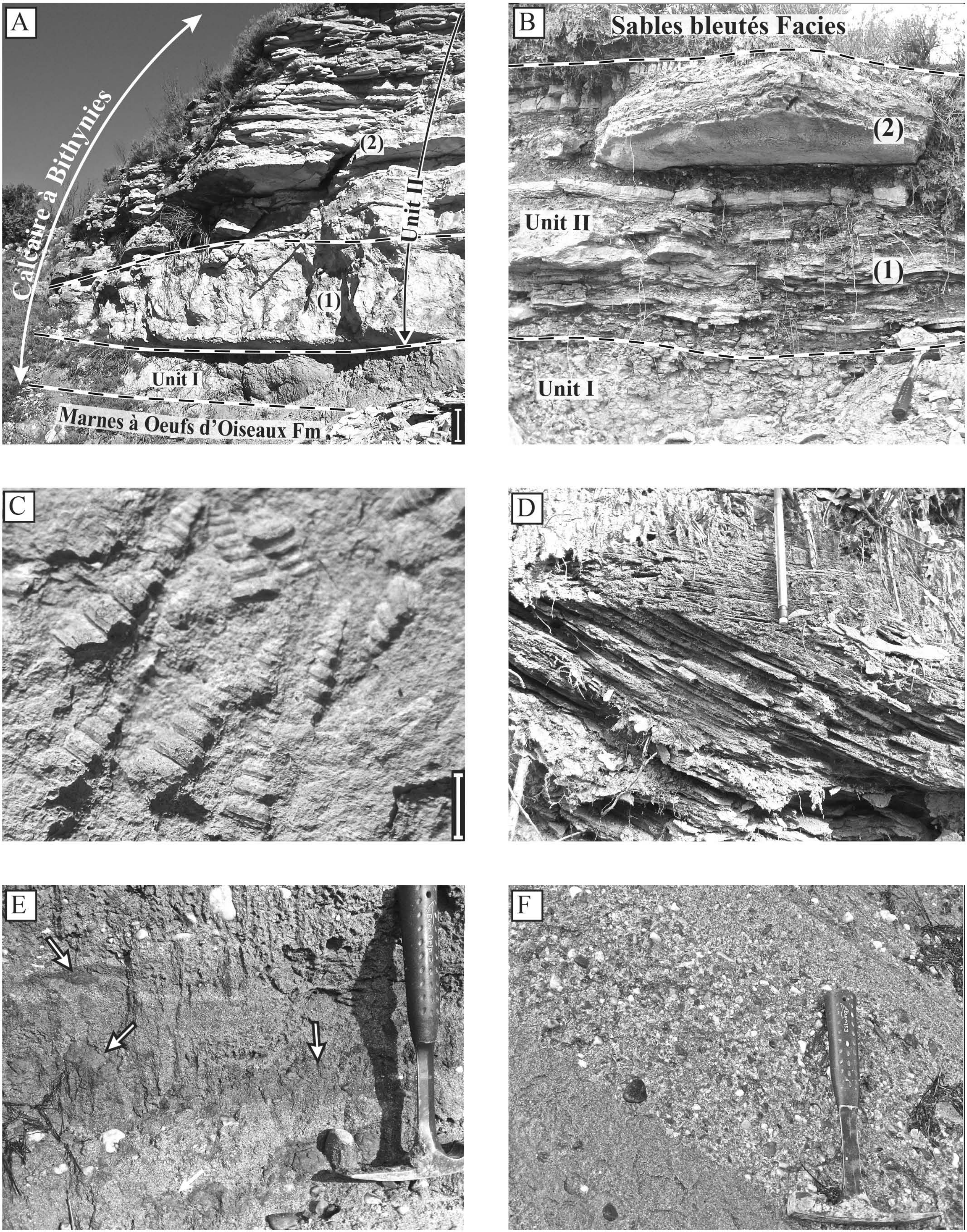
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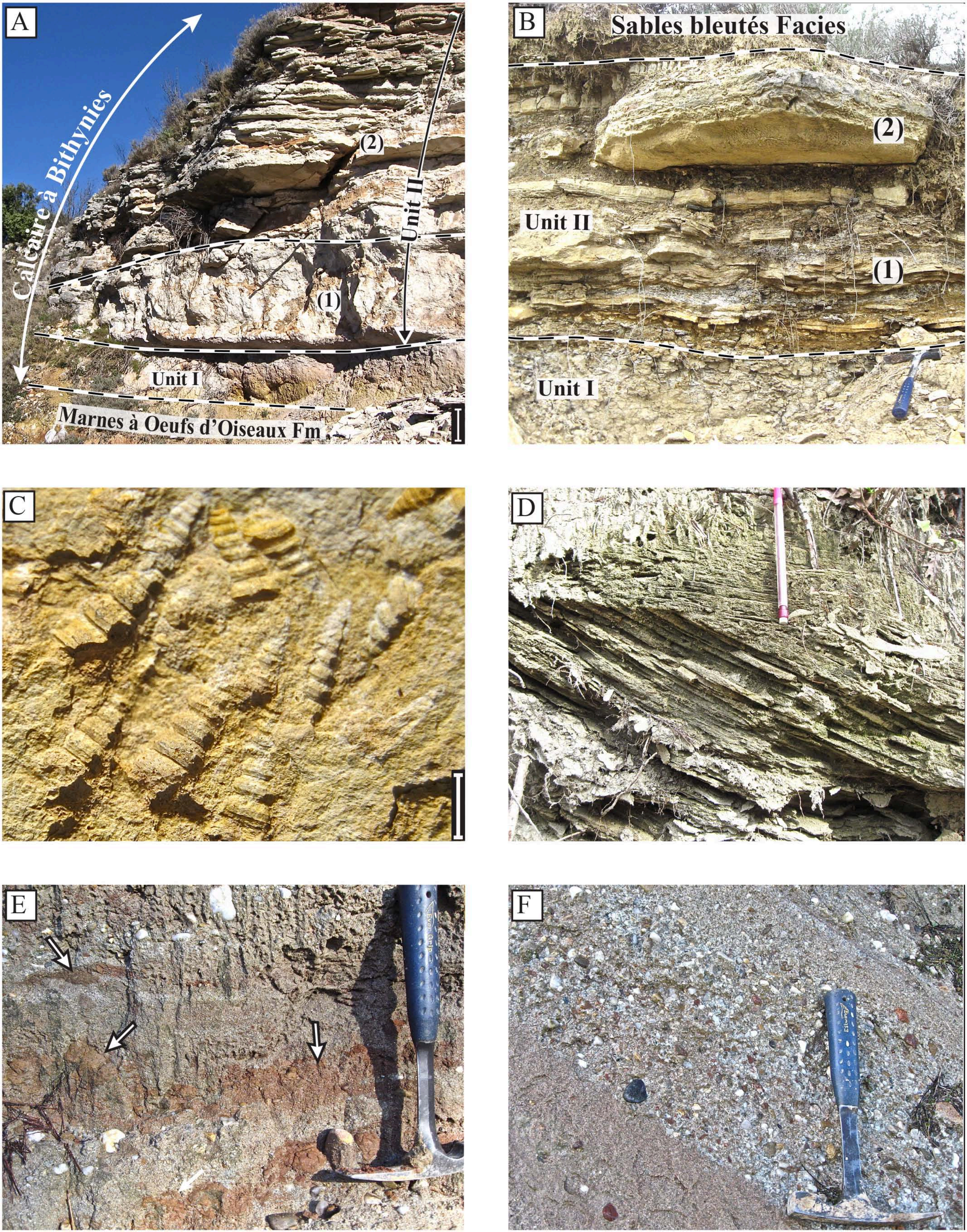
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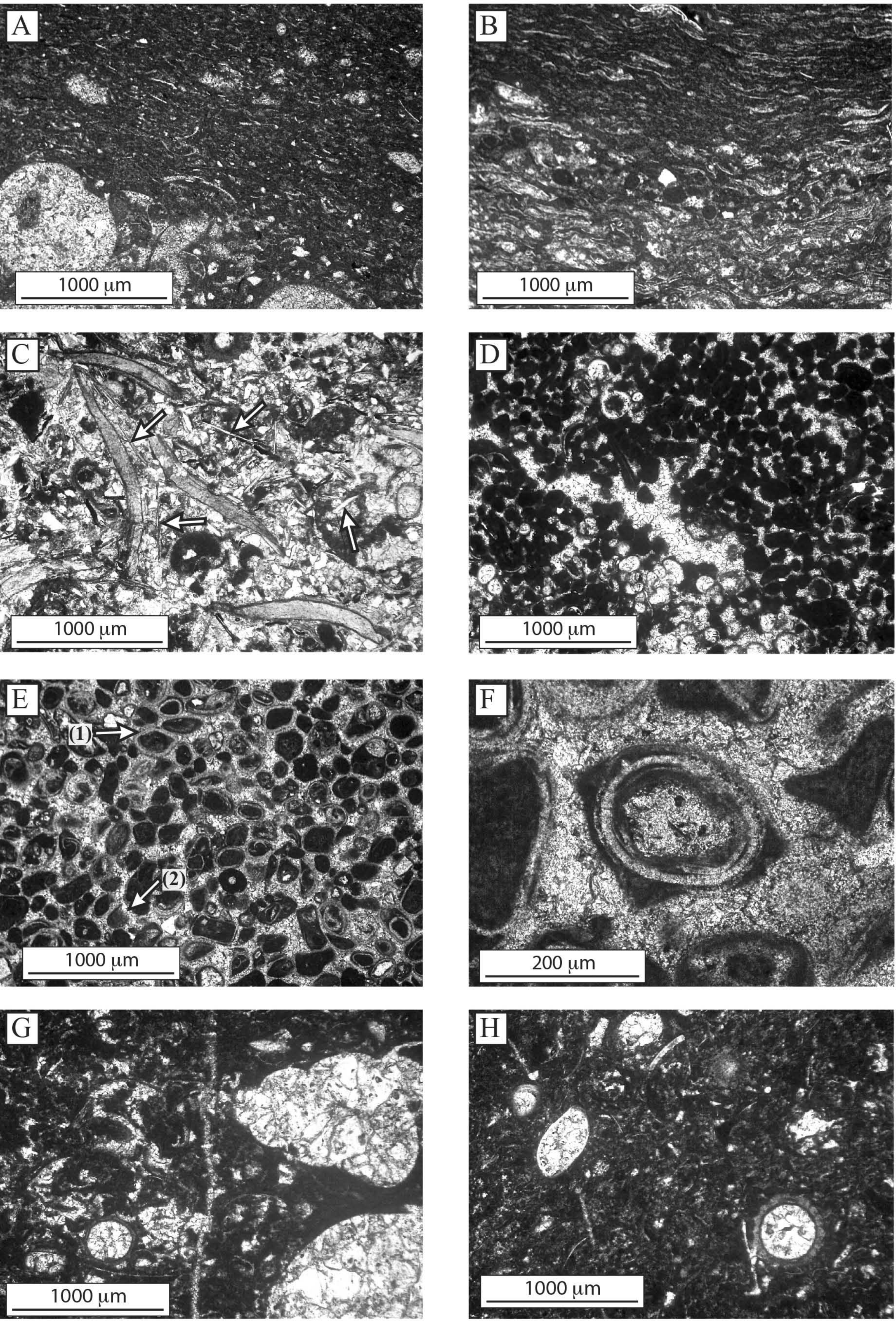
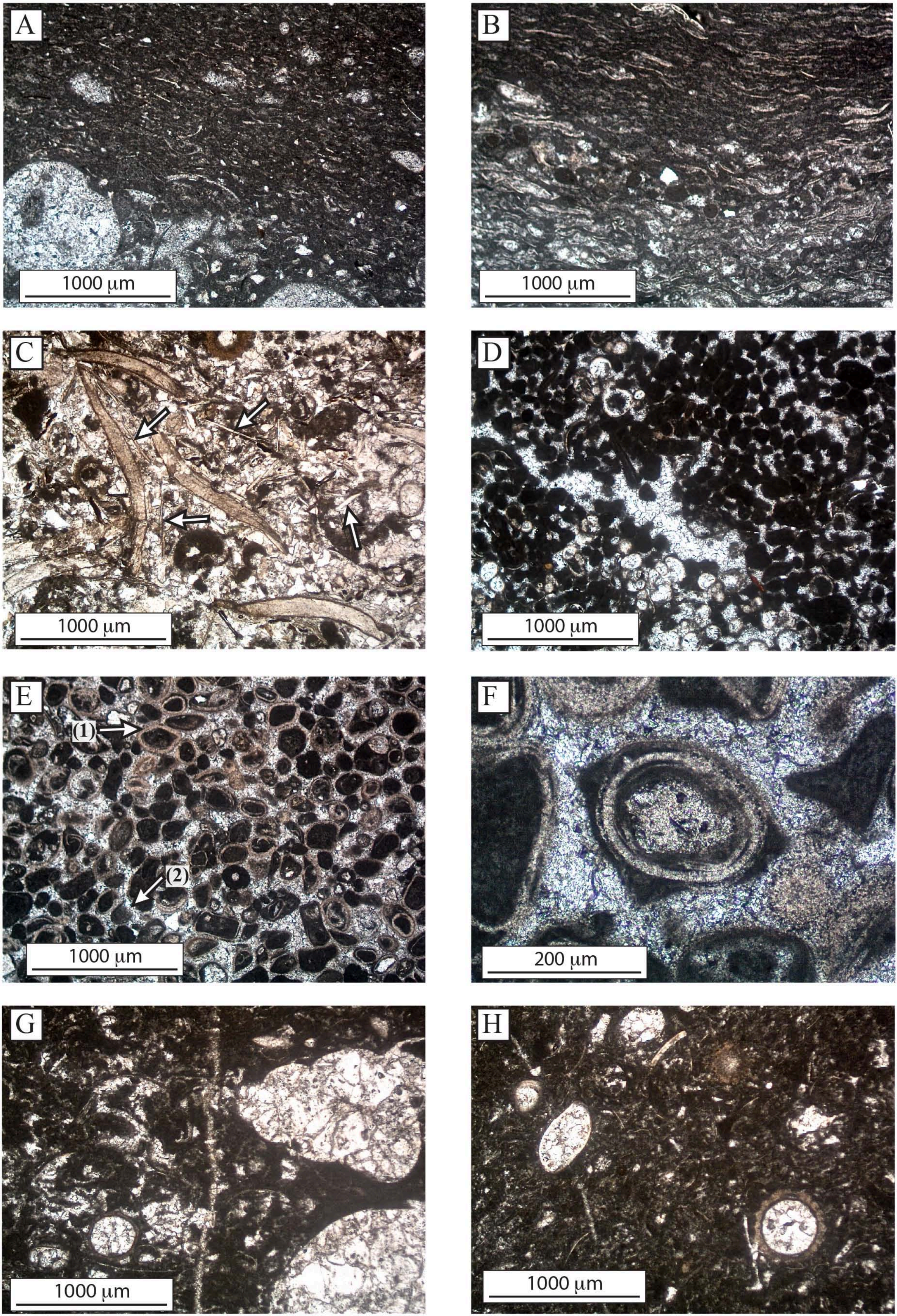
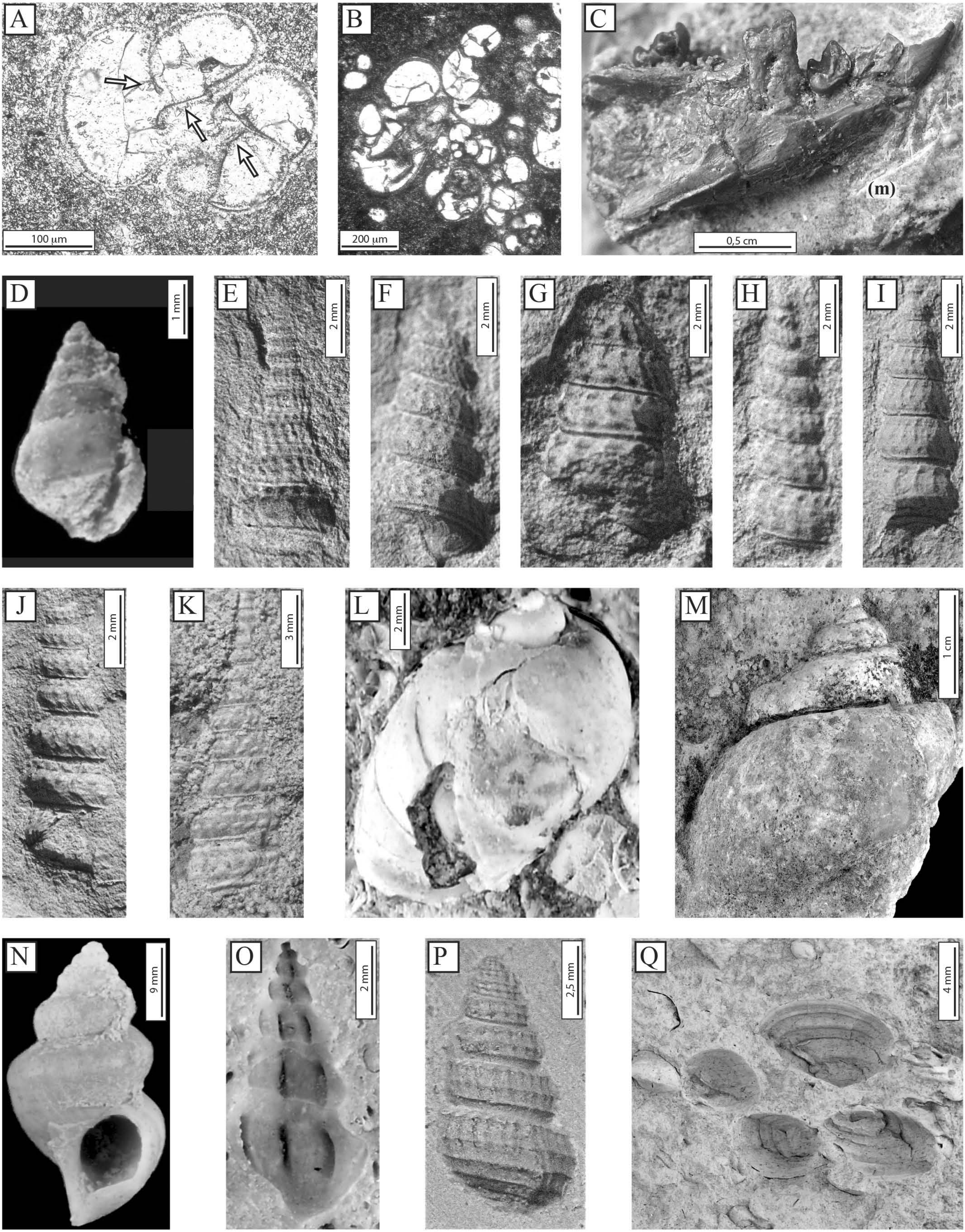
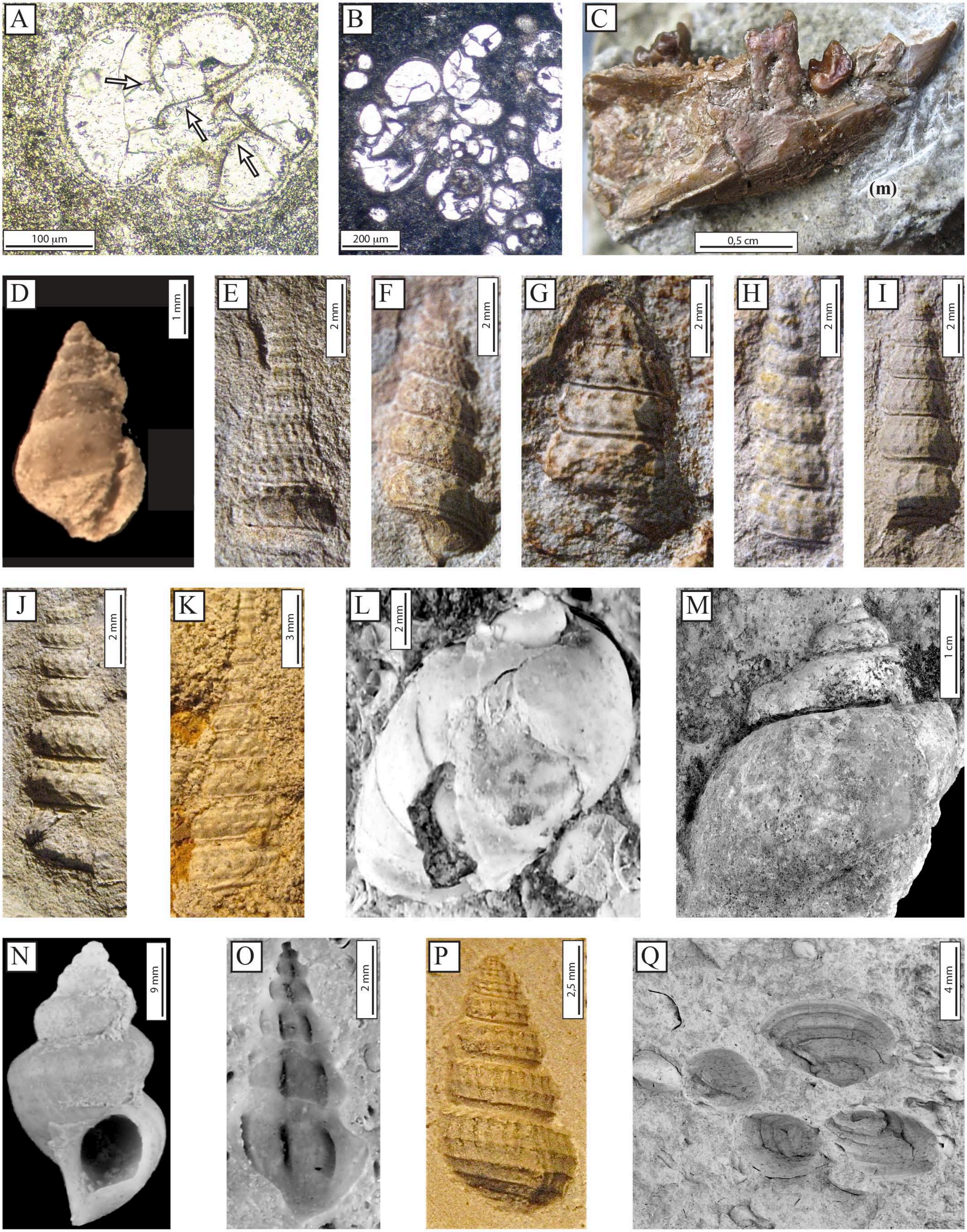
Unit I
C
D
E
F


A
1000 μm
B
1000 μm
C
1000 μm
D
1000 μm
E
(1)
(2)
1000 μm
F
200 μm
G
1000 μm
H
1000 μm

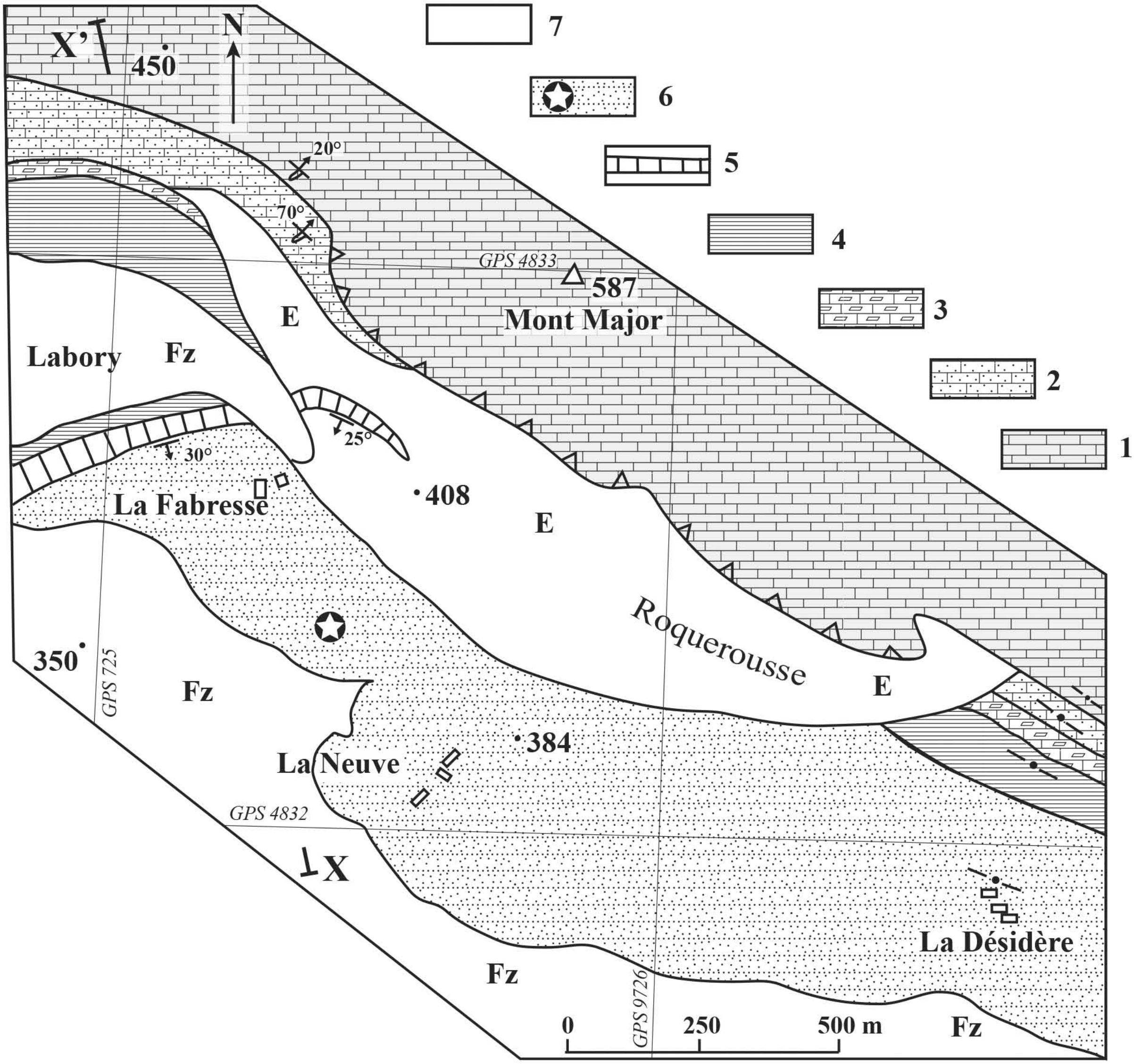

A
1000 μm
B
1000 μm
C
1000 μm
D
1000 μm
E
(1)
(2)
1000 μm
F
200 μm
G
1000 μm
H
1000 μm



A
100 µm
B
200 µm
C
(m)
0,5 cm
D
1 mm
E
2 mm
F
2 mm
G
2 mm
H
2 mm
I
2 mm
J
2 mm
K
3 mm
L
2 mm
M
1 cm
N
9 mm
O
2 mm
P
2,5 mm
Q
4 mm

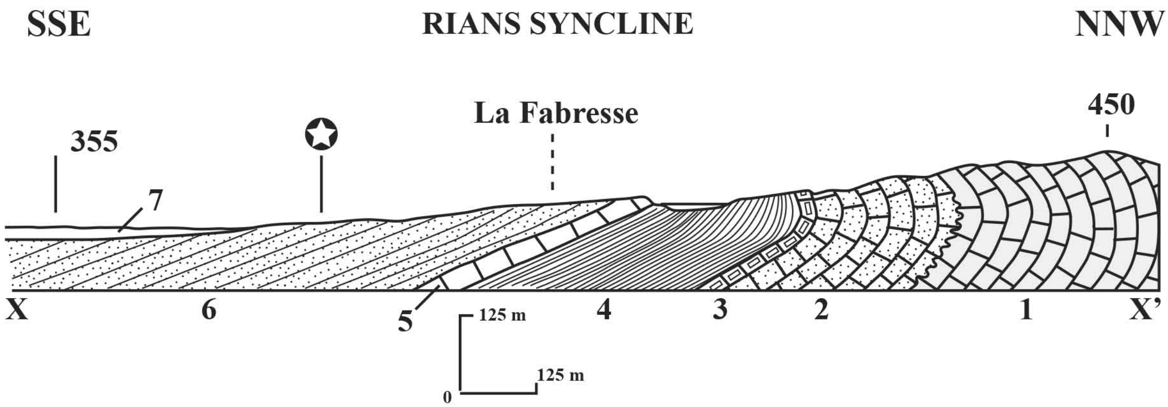

A
100 μm
B
200 μm
C
(m)
0,5 cm
D
1 mm
E
2 mm
F
2 mm
G
2 mm
H
2 mm
I
2 mm
J
2 mm
K
3 mm
L
2 mm
M
1 cm
N
9 mm
O
2 mm
P
2,5 mm
Q
4 mm

A

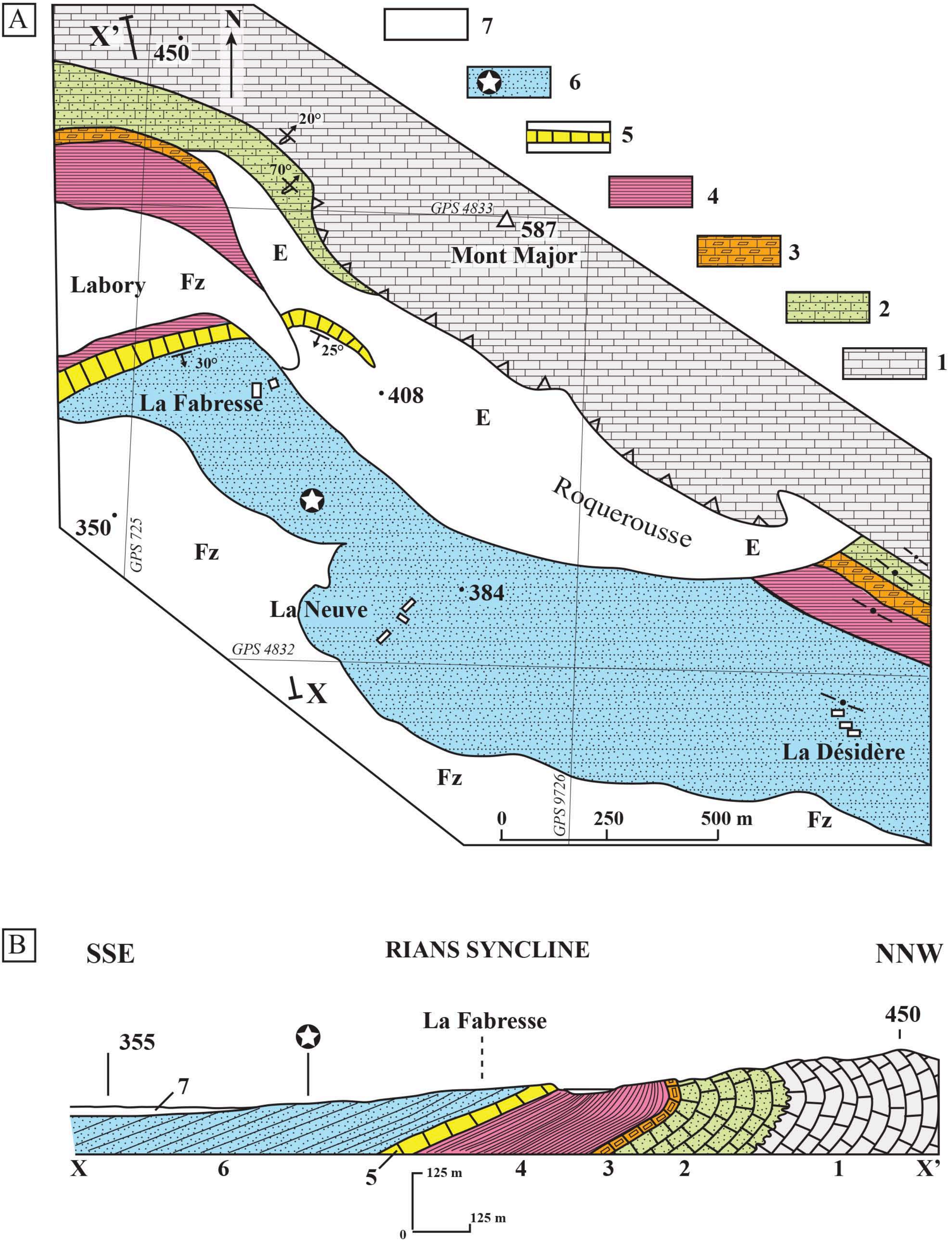


X'
450
N
7
6
5
4
3
2
1
20°
70°
GPS 4833
587
Mont Major
E
Labory
Fz
25°
30°
La Fabresse
408
E
Roquerousse
E
350
GPS 725
Fz
384
La Neuve
GPS 4832
X
La Désidère
Fz
GPS 9726
0
250
500 m
Fz

B



SSE
RIANS SYNCLINE
NNW
La Fabresse
450
355
7
X
6
5
4
3
2
1
X'
125 m
0
125 m


A
N
X'
450
7
6
5
4
3
2
1
20°
70°
GPS 4833
587
Mont Major
E
Labory
Fz
30°
25°
La Fabresse
408
E
Roquerousse
E
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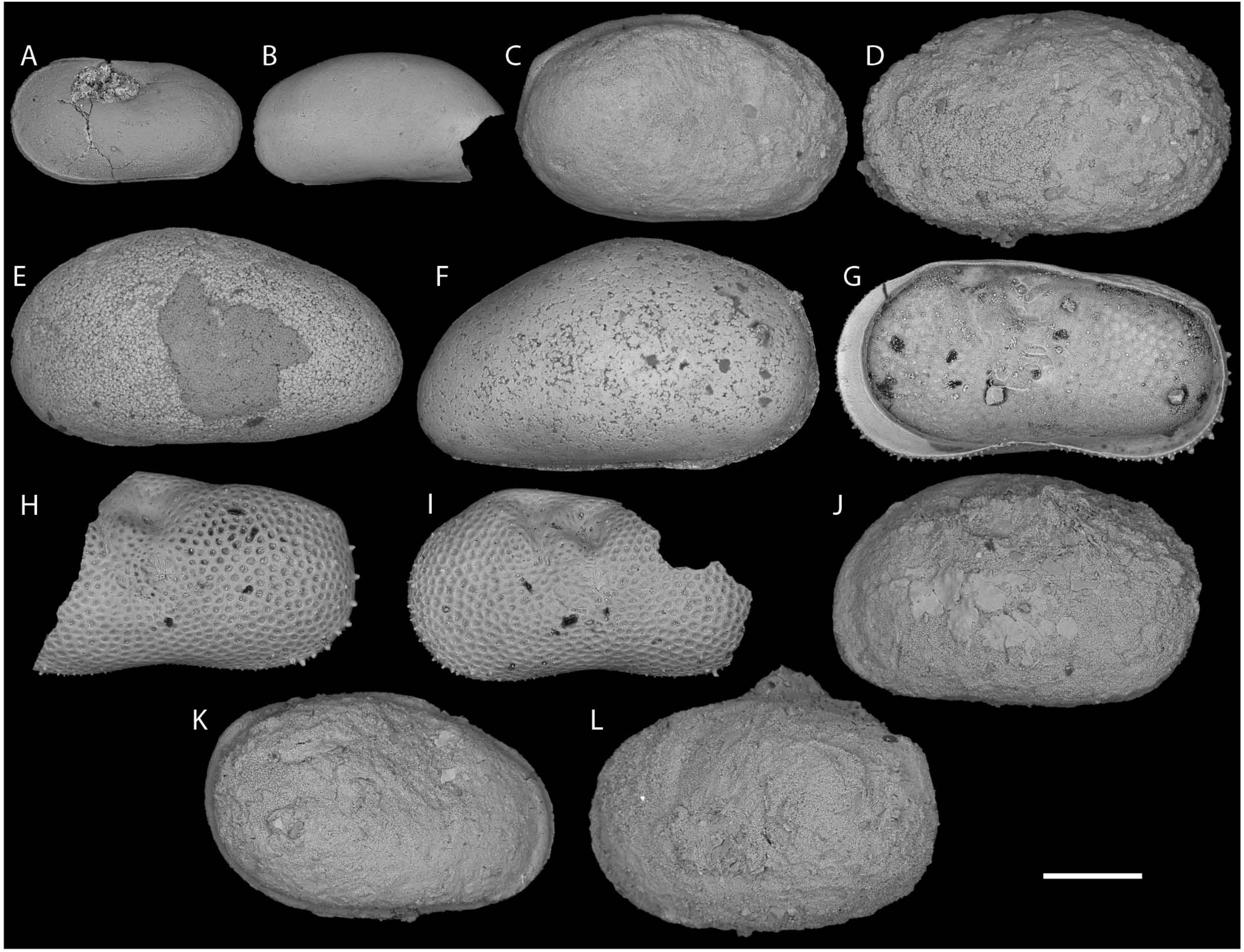
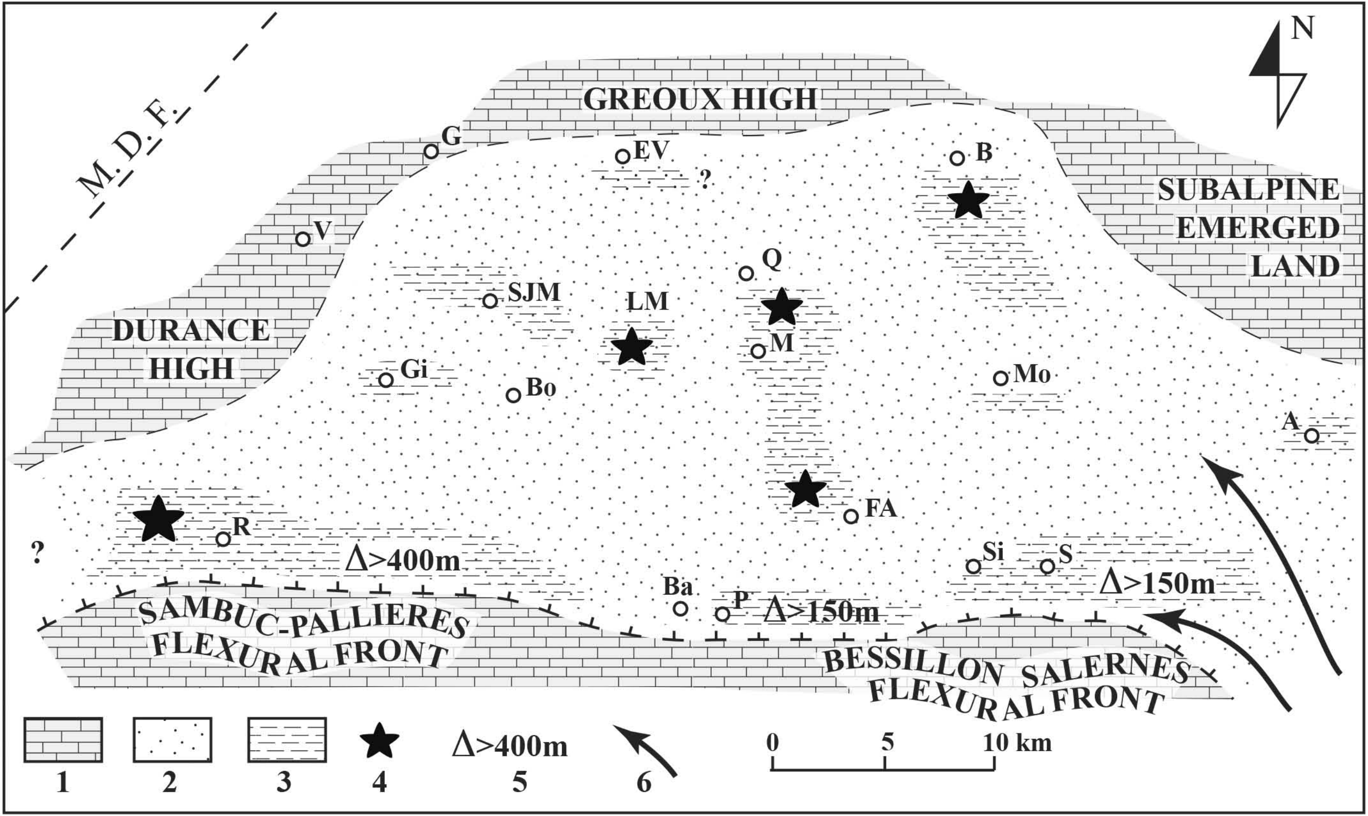
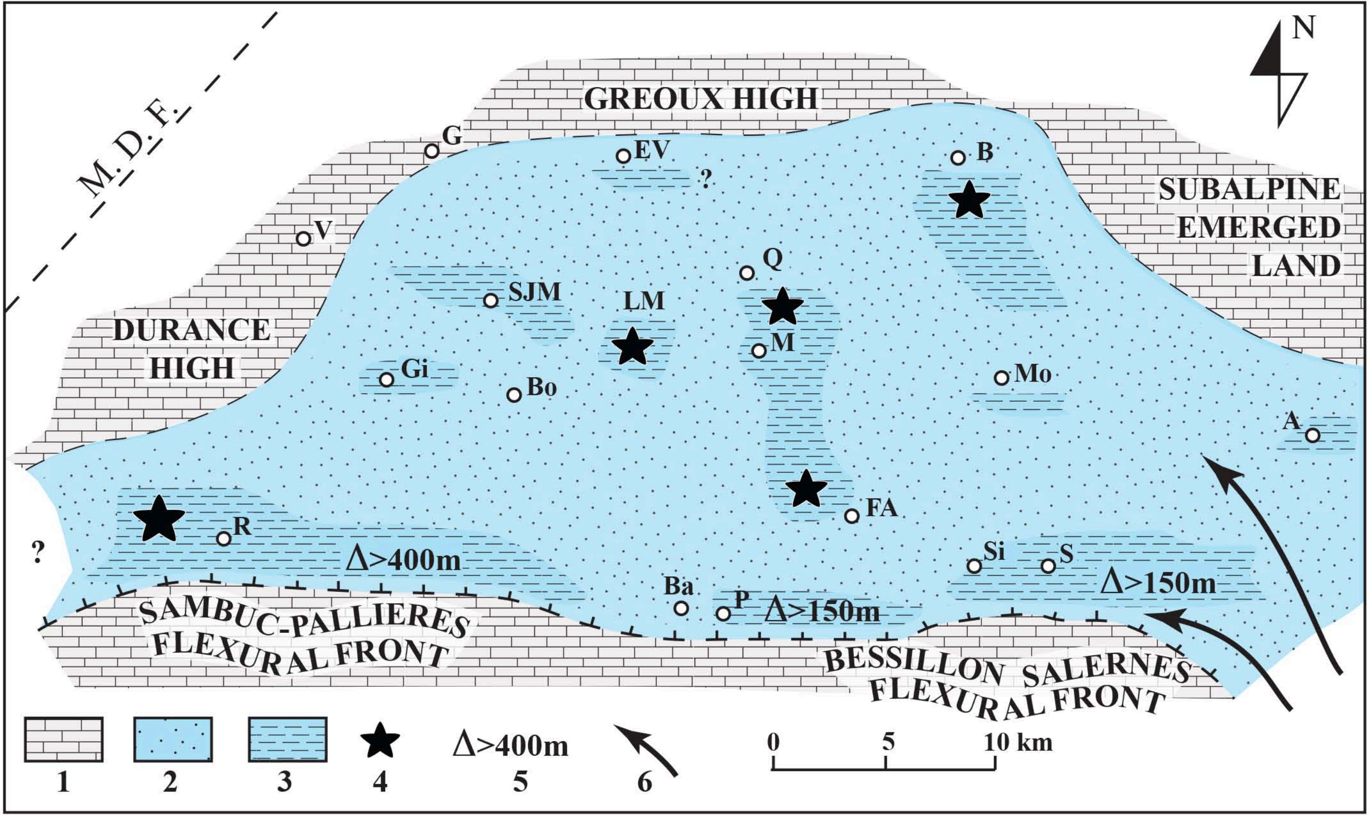
GPS 725
Fz
384
La Neuve
GPS 4832
X
La Désidère
Fz
GPS 9726
0
250
500 m
Fz
B
SSE
RIANS SYNCLINE
NNW
La Fabresse
450
355
7
X
6
5
4
3
2
1
X'
125 m
0
125 m

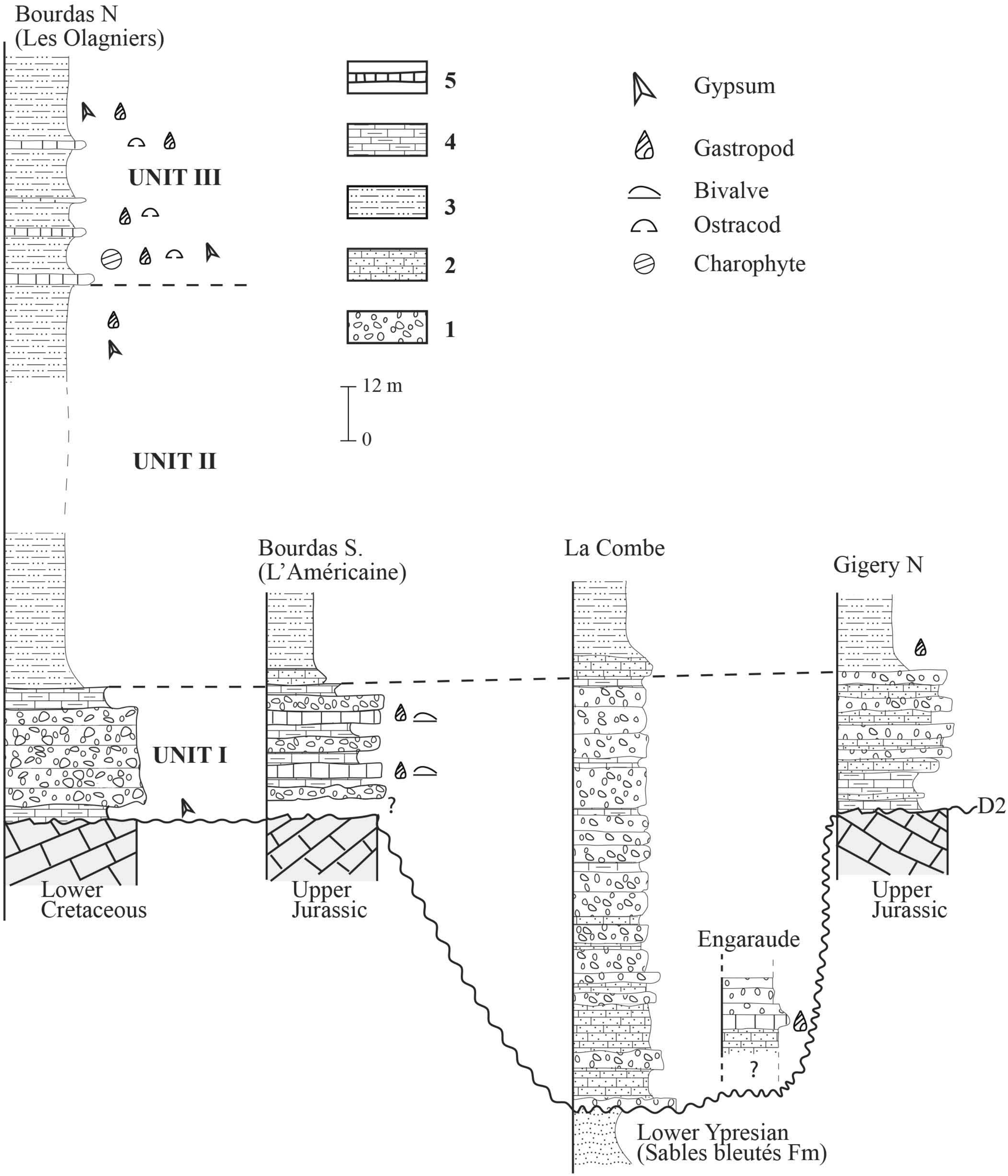

A
B
C
D
E
F
G
H
I
J
K
L

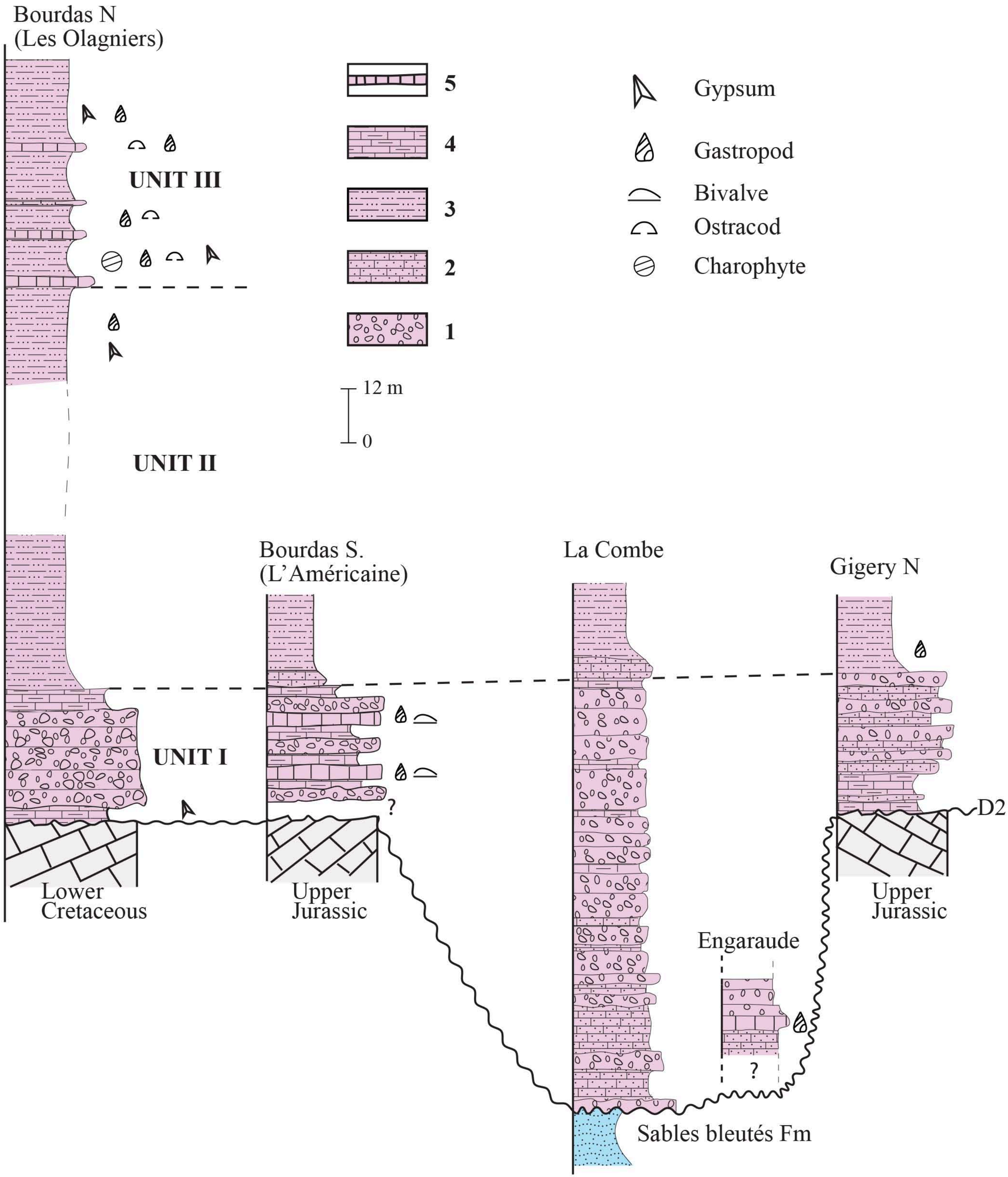


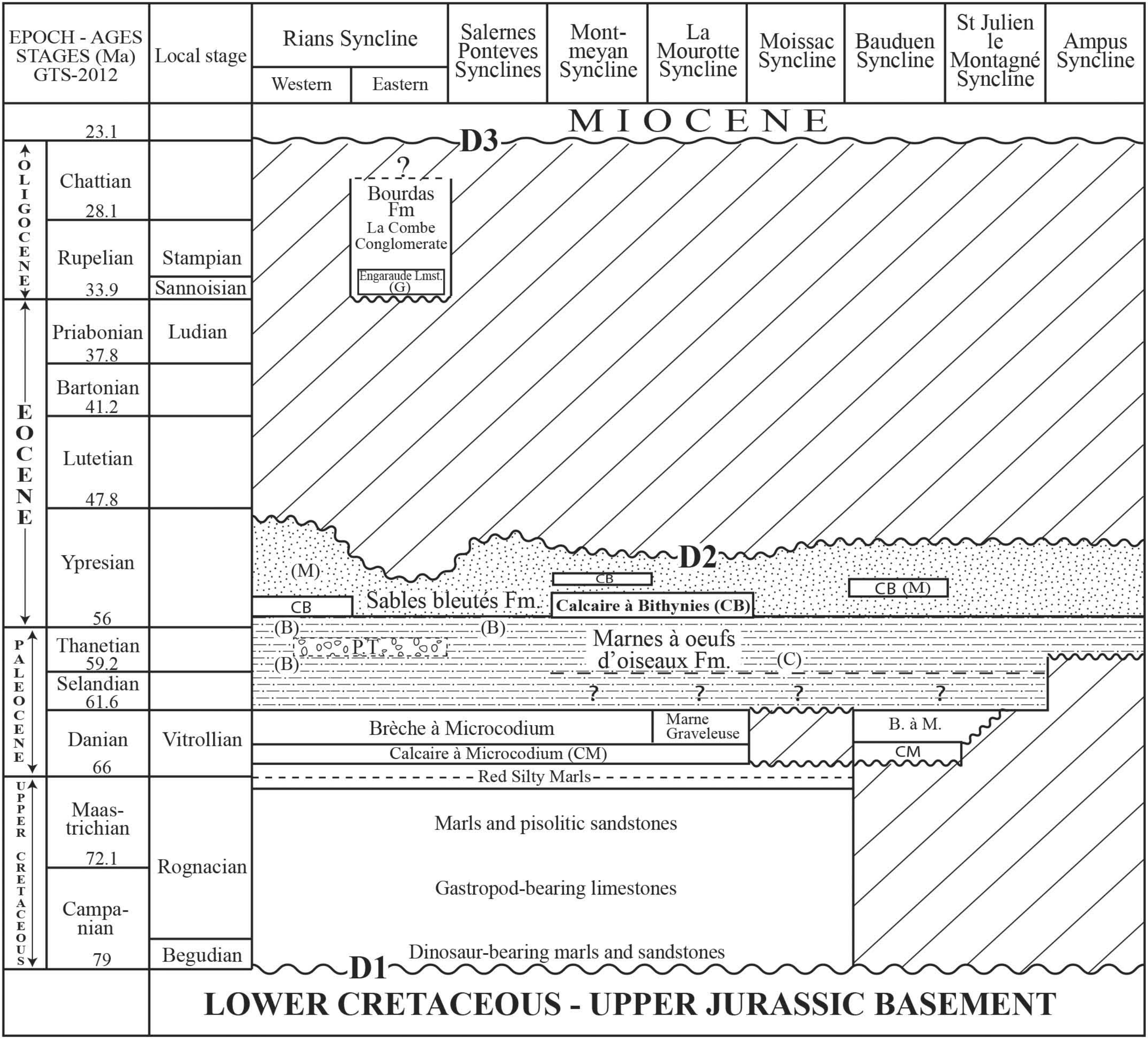
M. D. F.
GREOUX HIGH
N
G
EV
?
B
SUBALPINE
EMERGED
LAND
V
Q
SJM
LM
DURANCE
HIGH
M
Gi
Bo
Mo
A
FA
R
?
Δ>400m
Si
S
Δ>150m
Ba
P
Δ>150m
SAMBUC-PALLIERES
FLEXURAL FRONT
BESSILLON SALERNES
FLEXURAL FRONT
1
2
3
4
Δ>400m
5
6
0
5
10 km



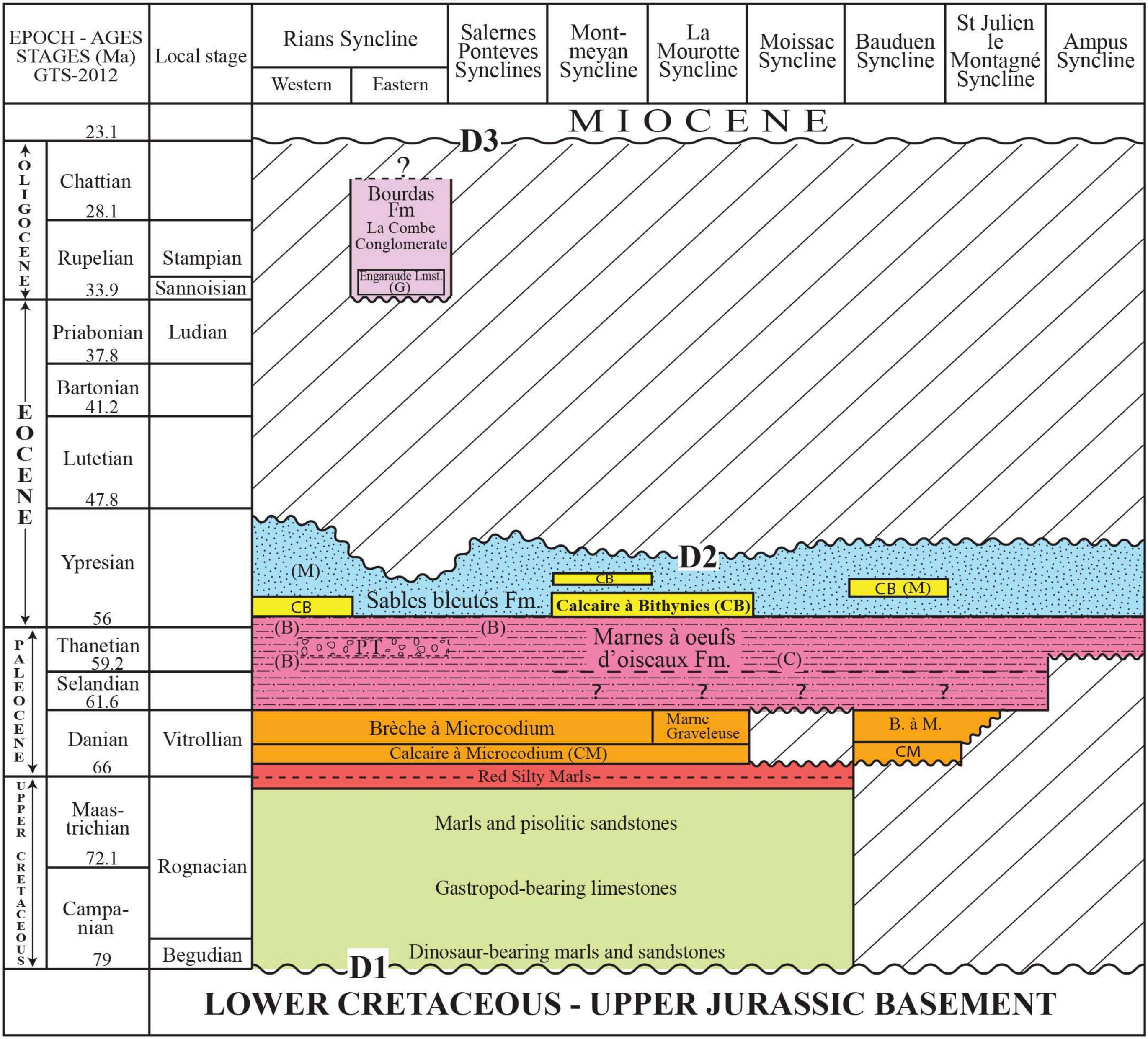
M. D. F.
GREOUX HIGH
G
EV
?
B
SUBALPINE
EMERGED
LAND
V
Q
SJM
LM
DURANCE
HIGH
M
Gi
Bo
Mo
A
FA
R
?
Δ>400m
Si
S
Δ>150m
Ba
P
Δ>150m
SAMBUC-PALLIERES
FLEXURAL FRONT
BESSILLON SALERNES
FLEXURAL FRONT
N
1
2
3
4
Δ>400m
5
6
0
5
10 km


Bourdas N
(Les Olagniers)
UNIT III
UNIT II
UNIT I
5
4
3
2
1
12 m
0
Gypsum
Gastropod
Bivalve
Ostracod
Charophyte
Bourdas S.
(L'Américaine)
La Combe
Gigery N
?
D2
Lower
Cretaceous
Upper
Jurassic
Upper
Jurassic
Engaraude
?
Lower Ypresian
(Sables bleutés Fm)


Bourdas N
(Les Olagniers)
UNIT III
UNIT II
UNIT I
5
4
3
2
1
12 m
0
Gypsum
Gastropod
Bivalve
Ostracod
Charophyte
Bourdas S.
(L'Américaine)
La Combe
Gigery N
?
D2
Lower
Cretaceous
Upper
Jurassic
Upper
Jurassic
Engaraude
?
Sables bleutés Fm



EPOCH - AGES STAGES (Ma) GTS-2012
Local stage
Rians Syncline
Western
Eastern
Salernes Ponteves Synclines
Mont-meyan Syncline
La Mourotte Syncline
Moissac Syncline
Bauduen Syncline
St Julien le Montagné Syncline
Ampus Syncline
MIOCENE
23.1
D3
OLIGOCENE
Chattian
28.1
Rupelian
Stampian
33.9
Sannoisian
?
Bourdas Fm
La Combe Conglomerate
Engaraude Lmst. (G)
EOCENE
Priabonian
Ludian
37.8
Bartonian
41.2
Lutetian
47.8
Ypresian
56
(M)
D2
CB
CB
Sables bleutés Fm.
Calcaire à Bithynies (CB)
CB (M)
PALEOCENE
Thanetian
59.2
Selandian
61.6
(B)
(B)
P.T.
(B)
Marnes à oeufs d'oiseaux Fm.
(C)
?
?
?
?
Danian
Vitrollian
66
Brèche à Microcodium
Marne Graveleuse
B. à M.
Calcaire à Microcodium (CM)
CM
Red Silty Marls
UPPER CRETACEOUS
Maas-trichian
72.1
Rognacian
Campa-nian
79
Begudian
Marls and pisolitic sandstones
Gastropod-bearing limestones
Dinosaur-bearing marls and sandstones
D1
LOWER CRETACEOUS - UPPER JURASSIC BASEMENT


EPOCH - AGES STAGES (Ma) GTS-2012
Local stage
Rians Syncline
Western
Eastern
Salernes Ponteves Synclines
Mont-meyan Syncline
La Mourotte Syncline
Moissac Syncline
Bauduen Syncline
St Julien le Montagné Syncline
Ampus Syncline
MIOCENE
23.1
D3
OLIGOCENE
Chattian
28.1
Rupelian
33.9
Stampian
Sannoisian
?
Bourdas Fm
La Combe Conglomerate
Engaraude Lmst. (G)
EOCENE
Priabonian
37.8
Ludian
Bartonian
41.2
Lutetian
47.8
Ypresian
56
D2
(M)
CB
CB
CB (M)
Sables bleutés Fm.
Calcaire à Bithynies (CB)
PALEOCENE
Thanetian
59.2
Selandian
61.6
Danian
66
Vitrollian
(B)
(B)
(B)
P.T.
Marnes à oeufs d'oiseaux Fm.
(C)
?
?
?
?
Brèche à Microcodium
Marne Graveleuse
B. à M.
Calcaire à Microcodium (CM)
CM
Red Silty Marls
UPPER CRETACEOUS
Maas-trichian
72.1
Campa-nian
79
Rognacian
Begudian
Marls and pisolitic sandstones
Gastropod-bearing limestones
Dinosaur-bearing marls and sandstones
D1
LOWER CRETACEOUS - UPPER JURASSIC BASEMENT