Mississippian (middle Tournaisian-late Serpukhovian) lithostratigraphic and tectonosedimentary units of the southeastern Montagne Noire (Hérault, France)

Unités lithostratigraphiques et tectono-sédimentaires du Mississippien (Tournaisien moyen-Serpoukhovien supérieur) du Sud-Est de la Montagne Noire (Hérault, France)

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Abstract

The tectonosedimentary and lithostratigraphic units of the Mont Peyroux nappe and Cabrières klippes, in the southeastern Montagne Noire, are revised. The Mont Peyroux nappe displays two Mississippian groups: Saint-Nazaire-de-Ladarez and Barrac. The Saint-Nazaire-de-Ladarez Group includes the traditional formations of Lydiennes, Faugères and Colonnes. The Barrac Group (new group) encompasses the Puech Capel Fm (with two new members: Puech Capel Mb and Landeyran Barn Mb), and the new Barrac and Fabrègues formations. The Puech Capel Mb corresponds to a period of erosion, reworking, and debris flow deposition in the basin, linked to a major tectonic event; hence, the distinction between two groups is made here. The Barrac Fm, overturned and normal, with classical Bouma turbidites, and without carbonate olistoliths, ends west of the Fabrègues Formation, bearing a few latest Viséan to Serpukhovian olistoliths. The Cabrières klippes contain numerous Ordovician, Silurian, Devonian and Mississippian klippes and olistoliths included in a detrital unit (formerly Flysch-units III-IV or Laurens Flysch Group); they are re-named here as the Laurens-Cabrières Group, and subdivided into three new complexes: the Laurens Complex, Roquessels Complex and Vailhan-Cabrières Complex. The Laurens Complex is not yet subdivided into formations. The Roquessels Complex shows characteristically the new Coteau de Bergue Fm and the Lentilles de la route D13 informal unit (including the former grauwacke de Roquessels). The Vailhan-Cabrières Complex is composed of three klippes: Vissou, La Serre and Tourière-Escandolgue -Mougno (TEM), and various disseminated smaller olistoliths, which are Early Ordovician to late Serpukhovian (Protvian) in age. The Vissou klippe probably corresponds to a fragment of the overturned limb of the Mont Peyroux nappe, because it exposes the traditional inverse succession of the Saint-Nazaire-de-Ladarez Group, followed by the equivalent of the Puech Capel Mb, with carbonate slumps and sandy turbidites. In the La Serre klippe, a new La Serre East Fm is described as the unique formation of Montagne Noire with late Tournaisian-early Viséan shallow carbonates. In the Vailhan-Cabrières Complex, several formations are defined or redefined in the Mississippian klippes and olistoliths: Tourière Fm (former secondes griottes), Combe Rolland Fm (former bancs de dessus), Valuzières Fm (former calcaires du sommet 224-Valuzières), Oolites of Roc de Murviel Fm, Roque Redonde Fm, Roc de Murviel Fm, and La Serre de Péret Fm. The four latter formations correspond to the former Calcaires à Productus. The Laurens-Cabrières Group in Cabrières is relatively distinct, and exhibits possible prodeltaic units within the poudingue à dragées (candy conglomerates), sandstone with "Namurian A" terrestrial plants fragments, and Phillipsia sandstones, designated here as the Mougno-Les Batailles informal unit. Some carbonate units associated with these prodeltaic deposits, such as the Spanish Scarf and other "bioherms of Cabrières", seem to be affected by small displacements (Escandolgue, Japhet). Palaeogeographic and tectonic implications lead to the structural hypothesis of a Mont Peyroux-Cabrières unit, including together the Mont Peyroux nappe and the Cabrières klippes, which initially was thrust and deposited in the Axial Zone, and then glided southward to its current location.

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Résumé

*Le Sud-Est de la Montagne Noire (Hérault, Occitanie) comporte classiquement deux grandes unités tectoniques, la nappe du Mont Peyroux et les klippes (écailles) de Cabrières. Ces deux unités se composent de différents ensembles tectono-sédimentaires et lithostratigraphiques du Mississippien (= Carbonifère inférieur), du Tournaisien moyen au Serpoukhovien supérieur, dont la révision fait l'objet de ce travail. La nappe du Mont Peyroux comporte les deux groupes lithostratigraphiques mississippiens de Saint-Nazaire-de-Ladarez et de Barrac. Le premier réunit les formations classiques des Lydiennes, de Faugères et des Colonnes. Le Groupe de Barrac, créé ici, se compose des formations du Puech Capel, de Barrac et de Fabrègues (ces deux dernières unités étant nouvelles). La Formation du Puech Capel est émendée et divisée en deux membres, Puech Capel et Grange de Landeyran. Le membre du Puech Capel correspond à une période d'érosion, de remaniement et de coulées de débris dans le bassin, liée à un important événement tectonique. La Formation de Barrac (*Flysch-unit I*), une série inverse et normale de turbidites de Bouma, dépourvue d'olistolithe calcaire, passe vers l'Est, en continuité, à la Formation de Fabrègues (*Flysch-unit II*) qui est un flysch, en série normale, dans lequel sont disséminés des olistolithes calcaires viséens supérieurs et serpoukhoviens, datés pour la première fois. Les anciennes « écailles de Cabrières » de la littérature reçoivent ici le nom de Groupe de Laurens-Cabrières. Celui-ci se compose de klippes et d'olistolithes ordoviciens, siluriens, dévoniens et mississippiens, insérés dans une unité détritique autrefois appelée* Flysch-units III-IV *ou Laurens Flysch Group. Le Groupe de Laurens-Cabrières est divisé en trois nouveaux complexes lithostratigraphiques, le Complexe de Laurens, le Complexe de Roquessels et le Complexe de Vailhan-Cabrières. Le Complexe de Laurens n'est pas divisé en formations, par contre le Complexe de Roquessels inclut, en plus des formations classiques du Groupe de Saint-Nazaire-de-Ladarez, la nouvelle Formation du Coteau de Bergue et l'unité informelle des Lentilles de la route D13 (dont une partie fut décrite autrefois sous le nom de grauwacke de Roquessels). Le Complexe de Vailhan-Cabrières comporte les grandes klippes de Vissou, de La Serre et de Tourière-Escandolgue-Mougno (TEM), ainsi que de plus petites klippes et des olistolithes dont l'âge s'échelonne de l'Ordovicien inférieur au Serpoukhovien supérieur. Dans la klippe de Vissou, où les séries sont très semblables à celles du flanc inverse de la nappe du Mont Peyroux, la succession classique du Groupe de Saint-Nazaire-de-Ladarez est suivie par un équivalent du Membre de Puech Capel montrant des slumps carbonatés et des grès turbiditiques. Dans la klippe de La Serre, la Formation de La Serre-Est est créée, comme étant l'unique ensemble de Montagne Noire qui comporte des dépôts peu profonds du Tournaisien supérieur et du Viséen inférieur non resédimentés. Dans le Complexe de Vailhan-Cabrières, dans les klippes et olistolithes mississippiens, sont définies et redéfinies les formations de Tourière (ex secondes griottes), Combe Rolland (ex bancs de dessus), Valuzières (ex calcaires du sommet 224-Valuzières), Oolithes du Roc de Murviel, Roque Redonde, Roc de Murviel et de Serre de Péret. Les quatre dernières formations furent appelées calcaires à Productus. Autour de Cabrières, le Groupe de Laurens-Cabrières montre des tendances prodeltaïques, avec ses « poudingues à dragées », ses grès à végétaux du « Namurien A » et ses grès à* Phillipsia*, regroupés ici dans l'unité informelle de Mougno-Les Batailles. Des unités carbonatées associées à ces dépôts prodeltaïques, telles que « l'Écharpe à l'espagnole » et les « biohermes de Cabrières », semblent n'avoir subi que de courts déplacements depuis leurs lieux d'origine (Escandolgue et Japhet). Les implications paléogéographiques et tectoniques, tirées de cette révision stratigraphique, conduisent à reconstituer une unité initiale Mont Peyroux-Cabrières (comprenant la future nappe du Mont Peyroux et les futures klippes de Cabrières), d'abord charriée et deposée sur la Zone Axiale, avant d'avoir glissé vers le Sud jusqu'à sa position actuelle.*

1. Introduction

The Montagne Noire is a Palaeozoic massif situated in the south of France (Fig. 1A), which was subdivided by *J. Bergeron* (1887a, 1889) into three major geological units: 1) the northern slope or Northern Zone; 2) the metamorphic Axial Zone or Central Axis; and 3) the southern slope (Fig. 1B).

The northern slope is composed of Cambrian and Ordovician (and locally Silurian) tectonic slices, transported towards the south-east and affected by low grade metamorphism. The Axial Zone contains micaschist, orthogneiss dated at 550 Ma and 470-450 Ma (Matte *et al*., 1998; Roger *et al*., 2004; Lin *et al*., 2016), migmatites dated at 333-326 Ma (Faure *et al*., 2010) and 333-316 Ma (Franke *et al*., 2011), and eclogite (Demange, 1985; Faure *et al.,* 2014; Doublier *et al*., 2015), which is dated from 357 to 350 Ma (Faure *et al*., 2014), and consequently are Tournaisian in age, according to the radiometric data of V. Davydov *et al.* (2010, 2012; Table 1).

Six superposed tectonic units constitute the southern slope of the Montagne Noire (B. Gèze, 1949; Arthaud, 1970; Franke *et al*., 2011; Fig. 1B-C): 1) the anchizonal Para-autochthon, which was considered for a long time as the lowermost cover of the Axial Zone. Nevertheless, it shows locally deeper deposits, the schists X (*schistes X*) composed of (ascending order): black meta-cherts, greenish slates with limestones, dark shales and greywackes, which are probably Carboniferous in age (Vignard, 1976; Franke *et al*., 2011), and possibly represent nappes initially located north of the Axial Zone (Franke, written communication, September 2017); 2) the Faugères nappe, which contains both normal and overturned limbs; 3) the Mont Peyroux nappe only preserved by its overturned limb; 4) the Pardailhan nappe, also overturned; 5) the Minervois nappe, which is probably a western, lateral equivalent of the Mont Peyroux nappe (Arthaud, 1970); and 6) the Cabrières klippes composed of Early Ordovician through Late Mississippian klippes and olistoliths of sedimentary rocks (with rare Ordovician volcanic rocks) reworked in siliciclastic detrital sediments (B. Gèze, 1949; Engel *et al.,* 1978, 1982) (Fig. 1B-C).

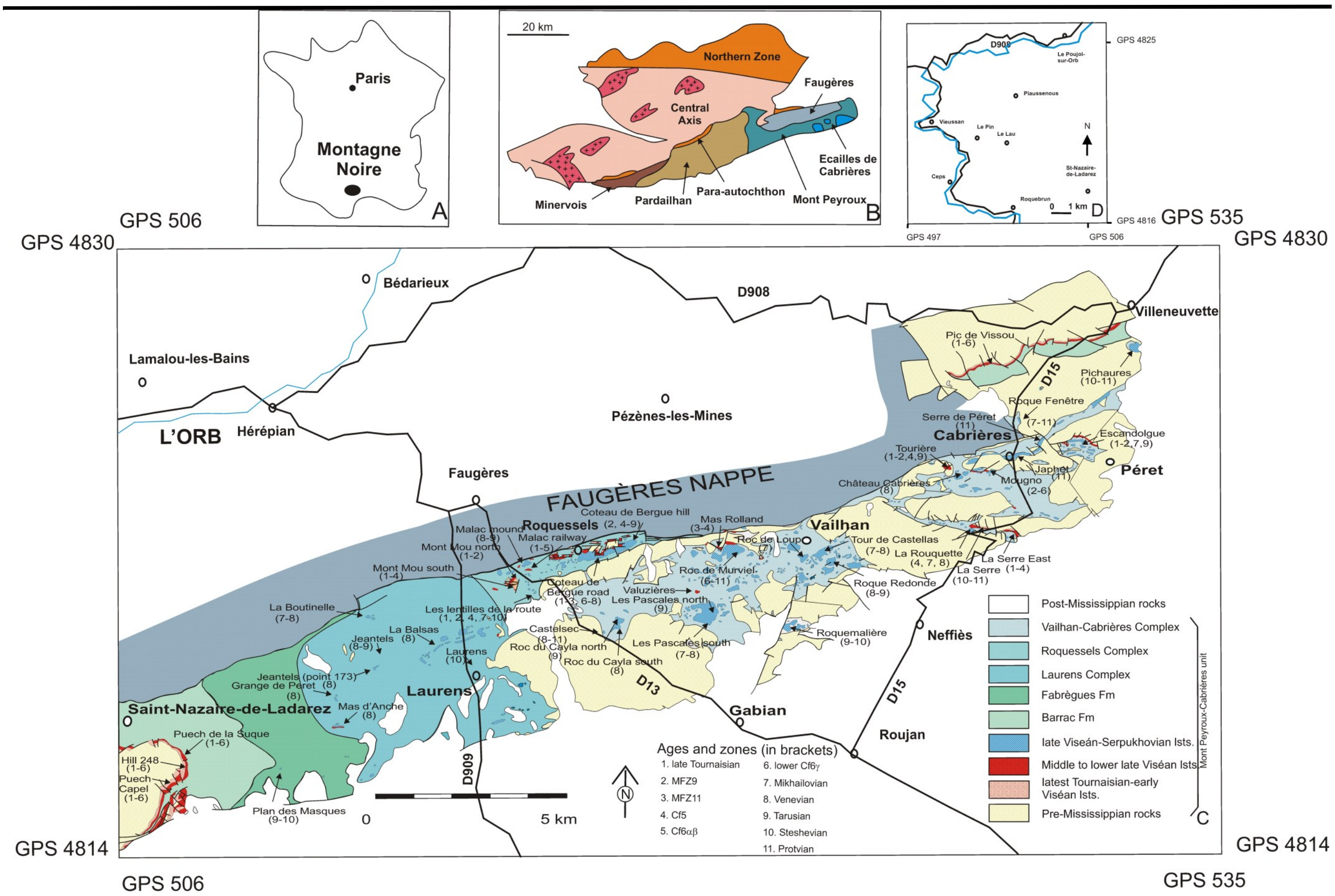

Figure 1. A. Location of the Montagne Noire in southern France. B. Structural units in the Montagne Noire. C. Location map of the sections, outcrops, and biostratigraphic age determinations in the Mont Peyroux nappe and the Cabrières klippes. D. Sketch map with the location of sections and photos in the Faugères nappe.

***Figure 1**. A. Localisation de la Montagne Noire dans le Sud de la France. B. Unités structurales majeures de la Montagne Noire. C. Carte de localisation et de datation biostratigraphique des coupes et des affleurements de la nappe du Mont Peyroux et des écailles de Cabrières. D. Schéma de localisation des coupes et des photos de la nappe de Faugères mentionnées dans le texte.*

Since the publications of B. Gèze *et al.* (1952) and F. Arthaud (1970), it is generally agreed that the nappes were transported towards southerly directions, although later tectono-metamorphic overprint has destroyed all shear criteria. In the Cabrières klippes, brittle faulting reveals transport towards the south (Franke, oral communication, June 2017). As the emplacement type (thrust or gravity) of the former *écailles de Cabrières* is often a matter of debate, the term Cabrières klippe *sensu lato* is used in this paper. When a thrust is indicated, the term klippe *sensu stricto* should be used, whereas if gravity is only involved, the term olistolith should be used (see discussion in section 7.3).

D. Vachard (1977) subdivided the southeastern Montagne Noire into five tectonosedimentary units: Cabrières, La Serre, Roquessels band, Mont Peyroux-Vissou, and Vieussan-Caragnas, because of their distinct lithostratigraphic successions and depositional environments during the Devonian and Carboniferous, and because of their different degrees of cleavage development.

In this paper, we try to define more precisely the different groups, complexes, formations, members, and other tectonosedimentary units, in order to characterize undisputable geological units in a region, the interpretation of which remains actively discussed. All these units were successively considered as (1) autochthonous; i.e., all formed *in situ* (authors of 19th Century; Denizot, 1956, 1962; Maurel, 1956, 1966a); (2) then, the first recumbent major fold (*nappe*) in France was described in the Pic de Vissou (Bergeron, 1899, p. 766); (3) in contrast, B. Gèze (1949) and F. Arthaud (1970) interpreted almost all the units as allochthonous; however, with a discussion on the displacement direction: all nappes coming from the south according to B. Gèze (1949); from the north, according to B. Gèze *et al.* (1952), M. Mattauer and F. Proust (1963), F. Arthaud (1970), W. Engel *et al.* (1978, 1982), P. Matte (2001), and W. Franke *et al.* (2011); or from an indeterminate direction by D. Chardon *et al.* (2015). In order to achieve additional criteria to prove if these units are allochthonous or autochthonous, we tried successively to give a more precise biostratigraphy (Vachard et al., 2016a, 2016b, and unpublished data); to characterize the palaeoenvironments and palaeobathymetry of deposition (Cózar *et al*., 2017); and to revise lithostratigraphically the main tectonostratigraphic units (this work).

The aims of this paper are: (1) to revise the tectonosedimentary units of the southeastern Montagne Noire, mainly focused on the Mont Peyroux nappe and Cabrières klippes; (2) to revise their previous lithostratigraphic subdivisions; and (3) to describe new groups, formations and members based on new biostratigraphic data and new field studies (Cózar *et al*., 2017), as a pre-requisite to a palaeogeographic reconstruction of the southern slope of the Montagne Noire prior to the Variscan orogeny.

2. Geologic and stratigraphic setting

The Palaeozoic strata of the Montagne Noire were actively investigated during the 19 and 20th centuries. These pioneer studies culminated with the regional syntheses of B. Gèze (1949) and F. Arthaud (1970). The Mississippian (formerly Early Carboniferous) sediments were mostly studied by R. Böhm (1935), M. Maurel (1956, 1957, 1966a, 1966b), B. Mamet (1968), D. Vachard (1973, 1974a, 1974b, 1977), W. Engel *et al.* (1978, 1982), G. Flajs and R. Feist (1988), and more recently by D. Korn and R. Feist (2007), L. Pille (2008), D. Vachard *et al.* (2016a, 2016b, and unpublished data), M. Aretz (2016), and P. Cózar *et al.* (2017). In the Montagne Noire, almost complete Palaeozoic series have been progressively recognized:

The Cambrian succession, composed of sandstone, shale and limestone, is well developed in the northern slope, Saint-Ponais Para-autochthon, and in the Pardailhan nappe of the southern slope (Álvaro, 2002; Devaere *et al.*, 2013).

Lower Ordovician clastic shelf sediments composed mainly of monotonous sandstone-shale alternations, with some quartzitic sandstones (Noffke and Nitsch, 1994), are described everywhere, whereas Upper Ordovician volcano-detrital rocks, limestones and shales with brachiopods and trilobites only crop out in some areas of the Cabrières klippes (Vizcaïno *et al.*, 2001; Álvaro *et al.*, 2016).

Silurian black shales with graptolites are locally present in the Mont Peyroux nappe and Cabrières klippes (Feist and Schönlaub, 1974; Álvaro *et al.*, 2016).

The lowermost Devonian strata are composed of marine quartzite followed by bioclastic limestones that are often dolomitized (Mont Peyroux nappe and Cabrières klippes, where they compose the Devonian *causses*).

The Middle Devonian is differentiated into relatively deep -water crinoidal limestones (tops of Mont Peyroux and Pic de Vissou) and shallow reefal limestone (Causse de Laurens quarry).

The Late Devonian shows everywhere nodular limestones with ammonoids (*infragriottes*, *vraies griottes* and *supragriottes*), recently re-studied by A. Préat *et al.* (1999) and C. Girard *et al.* (2014); rarely, it contains shales, black shales and lydites with tentaculitoids (Vachard, 1974b).

The international Devonian/Carboniferous boundary was defined in La Serre klippe, where the early Tournaisian is represented by grainstones with large ooids and a few supragriotte limestones (Feist and Flajs, 1987a; Flajs and Feist, 1988; Vachard, 1988; Feist *et al.,* 2000). Nevertheless, this D/C boundary has been criticized for a long time (e.g., Legrand-Blain and Vachard, 2005; Pille, 2008; Kaiser, 2009; Richards, 2013).

The Mississippian succession is revised here in the different tectonosedimentary units of the southern slope of the Montagne Noire, from west to east (Fig. 1C), and from the middle Tournaisian to late Serpukhovian (Tables 1, 2).

The stratigraphic scale used in this paper (Table 1) correlates different Mississippian foraminiferal biozones used in Belgium and North France (Poty *et al.*, 2006), the British Isles (Conil *et al.*, 1980), the Russian Platform and the Urals (Hecker, 2002; Kulagina *et al.*, 2003; Davydov et al., 2012). The two Viséan/Serpukhovian boundaries (the traditional and that used in Davydov *et al.* (2012), based on the first occurrence of the conodont *Lochriea ziegleri* within the Venevian) have been indicated in Table 1, because this boundary is not yet ratified by the Subcommission of

France-Belgium			British Isles		Mamet	Russian Platform		2012	
Arnsb.	MFZ 16	not defined	Arnsbergian	Cf7	19	Zapaltjubian	SERPU-KHOVIAN	SERPU-KHOVIAN	323.2 Ma
						Protvian			
Pe.	MFZ 15		Pendleian	upper Cf6δ	16s-18	Steshevian			
Warnantian		V3c sup.	Brigantian			Tarusian			
	MFZ 14	V3c inf.		lower Cf6δ	16i	Venevian	VISÉAN	VISÉAN	330.9 Ma
						Mikhailovian			
		V3bγ	Asbian	Cf6γ2					
				Cf6γ1	15				
	MFZ 13	V3bβ		Cf6β	12-14	Aleksian			
		V3bα		Cf6α					
Livian	MFZ 12	V3a V2b	Holkerian	Cf5		Tulian			
						Bobrikovian			
Moliniacian	MFZ 11	V2a	Arundian	Cf4δ					
				Cf4γ		Radaevian			
	MFZ 10	V1b		Cf4β	11				
	MFZ 9	V1a		Cf4α2	10	Elkhovian			346.7 Ma
Ivorian	MFZ 8	Tn3	Chadian	Cf4α1	9	Kosvian	upper TOURNAISIAN		
	MFZ 7								
	MFZ 6		Courceyan	Cf3		Cherepetian			
	MFZ 5	Tn2		Cf2	8				
Hastarian	MFZ 4	Tn1		Cf1	7	Upian	lower TOURNAISIAN		
	MFZ 3								
	MFZ 2				pre-7				
	MFZ 1					Malevian			358.9 Ma
"Strunian"	DFZ 8					Zavolgian	Late DEVONIAN		
	DFZ 7	Fa2d		Df3	6				
	DFZ 6				5				
	DFZ 5								

Table 1. Chrono- and biostratigraphic table used in this work. Arnsb. = Arnsbergian; Cf = Carboniferous foraminifers; DFZ = Devonian foraminiferal zones; i = lower; Ma = milion years; MFZ = Mississippian foraminiferal zones; Pe. = Pendleian; s = upper; Tn = Tournaisian, V = Viséan. France-Belgium according to E. Poty *et al.* (2006); England according to R. Conil *et al.* (1980); B. Mamet according to B. Mamet (1974); Russian Platform according to M. Hecker (2002); E. Kulagina *et al.* (2003); and V. Davydov *et al.* (2010); 2012 from V. Davydov *et al.* (2012). Radiometric ages according to V. Davydov *et al.* (2012).

***Tableau 1.** Tableau comparatif des échelles chrono- et biostratigraphique utilisées dans ce travail. Arnsb. = Arnsbergien; Cf = foraminifères carbonifères; DFZ = zones de foraminifères du Dévonien; i = inférieur; Ma = millions d'années; MFZ = zones de foraminifères du Mississippien; Pe. = Pendléien. s = supérieur; Tn = Tournaisien, V = Viséen. France-Belgium d'après E. Poty* et al. *(2006); England d'après R. Conil* et al. *(1980); B. Mamet d'après B. Mamet (1974); Russian Platform d'après M. Hecker (2002), E. Kulagina* et al. *(2003) et V. Davydov* et al. *(2010); 2012 d'après V. Davydov* et al. *(2012). Âges radiométriques d'après V. Davydov* et al. *(2012).*

Carboniferous Stratigraphy. In the Montagne Noire, we used both biozonal schemes: first, the British Isles zones from Tournaisian to Mid-Viséan and, then, the Russian zones from the late Viséan to Serpukhovian (Vachard *et al*., 2016a, 2016b; Cózar *et al.,* 2017).

3. Material and methods

This study is based on almost 50 years of field investigation and analysis of rock samples (1969-2017), during which about 7,500 thin sections and polished slabs have been examined, brought together during numerous field trips and collections sampling tours. Preliminary results of this study have been published by D. Vachard *et al.* (2016a, 2016b, and unpublished data) and P. Cózar *et al.* (2017).

In this revision of the lithostratigraphic units, as primordial elements of the geological investigation of our team, the International Code of Stratigraphy has been followed (Salvator, 1994; in particular, sections 3.B.5 and 5.E-F), especially to describe or redescribe the Mississippian groups, complexes, formations, and members. In these descriptions, our analytical procedure has been as follows: (1) Type locality; (2) Type section; (3) Lithology; (4) Boundaries; (5) References; (6) Remarks; (7) Biostratigraphy; (8) Chronostratigraphy; (9) Tectonics; (10) Regional variations; and (11) Division into formations and/or members.

Stratigraphic terminology has also followed the recommendations of D. Owen (2009). The microfacies and environments were analyzed according to the methods and nomenclatures compiled by E. Flügel (2004). For the spelling of the locality names, we generally used the current indications of the French topographic maps IGN 1/25,000; nevertheless, it must be noticed that B. Gèze (1979, p. 89) has previously highlighted the numerous differences between the spellings of the current topographic IGN map Bédarieux 1/25,000 and those of the traditional geological literature. Coordinates of outcrops are written in UTM as in the IGN topographic maps.

Correlation between previous and new groups and formations are indicated in Table 2.

4. Faugères nappe

In this study, the Faugères nappe (Fig. 1C, D) has not been accurately studied, because the biostratigraphic data in this unit remain uncertain, even if a generalized Mississippian age is assumed for most parts of its succession. The stratigraphy of the Faugères nappe (Caragnas, Le Pin, and Le Lau), and of northern schistosed parts of Mont Peyroux nappe (Vieussan, Moulin de Grais, and Ceps; Alabouvette *et al.,* 1985), now attributed to Faugères nappe (Franke *et al.,* 2011), is probably partially decipherable based on the Vieussan-Caragnas succession (Vachard, 1974b, 1977), where lydites are overlain by a complex of limestones, calci-schists and schists (Fig. 2A) with a higher degree of schistosity and recrystallization, and then by a flysch. The upper part of the “blue calci-schists with small carbonate pebbles” of D. Vachard (1974b), when dissolved, probably correspond to the *schistes troués* in the sense of W. Engel *et al.* (1982) and D. Korn and R. Feist (2007) (see section 5.2.1.1). These blue calci-schists with carbonate lenses possibly represent debris flows (Engel *et al*., 1982). The main outcrop of *schistes troués* is located in Moulin de Grais (near Vieussan village) along the D 14 road (x = 499.5, y = 4820; Fig. 2B). However, the Vieussan-Caragnas unit has been occasionally disputed, because: 1) it belongs to two different nappes according to F. Arthaud (1970) and B. Alabouvette *et al.* (1985), Mont Peyroux nappe for Vieussan and Faugères nappe for Caragnas; or both would be part of the same Faugères nappe for W. Franke *et al.* (2011, fig. 2); 2) two different degrees of schistosity and perhaps lithological successions initially distinct are present (see later); 3) both contain crinoids in their black limestones and shales, and rare Viséan foraminifers (Vachard, 1974b; Vachard *et al.,* unpublished data) in Ceps and Vieussan (Moulin de Grais, Fig. 2A). In the Ceps section along the Orb river (x = 499.3, y = 4818), from the middle part of the section *Valvulinella lata* is recorded. The genus can be present from the Tournaisian (MFZ6 in Poty *et al*., 2006), although the species was used by D. Vachard (1974b) to identify the early Viséan in the Montagne Noire. In higher levels of the section, the occurrence of *Globoendothyra* together with *Eoparastaffella* and *Spinobrunsiina* confirms this early Viséan age. In the Moulin de Grais section along the D14 road (x = 499.4, y = 4820.1), *Omphalotis minima* and *Globoendothyra antoninae* have been found. These taxa confirm a Viséan age, most probably the upper part of the early Viséan (MFZ11), where *O. minima* is first recorded.

The flyschs of Faugères nappe are constituted of thick turbiditic sandstone, in Faugères along the D909 road (x = 514.9, 4821; Fig. 2C), and alternations of turbiditic siltstone and shale in Plaussenous (x = 502.2, y = 4821.4; Engel *et al.,* 1982; Fig. 2D). These flyschs were deposited in

Tectonostratigraphic unit	Group (this paper)	Formation (Fm) and Complex (Co) (this paper)	Member (this paper)	Previous Group	Previous Formation
Mont Peyroux nappe, Vissou klippe, and Laurens-Cabrières basin	Laurens-Cabrières	Vailhan-Cabrières Co		Laurens-Flysch	Flysch-unit IV
		Laurens Co			Flysch-unit III
	Barrac	Fabrègues Fm			Flysch-unit II
		Barrac Fm			Flysch-unit I
		Puech Capel Fm	Landeyran Barn Puech Capel		Puech Capel
	Saint-Nazaire-de-Ladarez	Colonnes Fm		Saint-Nazaire	Colonnes
		Faugères Fm			Faugères
		Lydiennes Fm			Lydiennes
		Supragriottes Fm		Montagne Noire Griotte	Supragriottes
Roquessels klippe		Roquessels Co with the five Fm below:			
		Lentilles de la route D13			
		Coteau de Bergue Fm			
		Colonnes Fm			
		Faugères Fm			
		Lydiennes Fm			
La Serre klippe		Mas de la Rouquette unit			
		La Serre East Fm			
		Faugères Fm			
		Lydiennes Fm			
Vailhan-Cabrières klippes		La Serre de Péret Fm			Calcaires à Productus
		Roc de Murviel Fm			
		Roque Redonde Fm			
		Oolites of Roc de Murviel Fm			
		Valuzières Fm			
		Combe Rolland Fm			
		Tourière Fm			

Table 2. Stratigraphic table with new names of this paper and previous names from D. Korn and R. Feist (2007). The biostratigraphic and chronostratigraphic correlations between tectonostratigraphic units are shown in Figure 22.

Tableau 2. *Tableau stratigraphique avec la nouvelle nomenclature utilisée dans cette étude et l’ancienne nomenclature de D. Korn and R. Feist (2007). Les corrélations biostratigraphiques et chronostratigraphiques entre les unités tectonostratigraphiques sont indiquées sur la Figure 22.*

a deep, sandy turbiditic fan and a hemipelagic basin plain, respectively. These two types may alternate with each other, although the siltstones and shales mostly occur at the base of the flysch, above the *schistes troués*. They may represent overbank fines, as in the Mont Peyroux flysch or distal turbidites, but the small grain-size, typical of the Faugères nappe, does not permit to identification of proximal overbank deposits (Franke, written communication, September 2017).

Furthermore, hummocky cross stratification (HCS) was discovered in the track from Le Pin to Plaussenous (x = 501.5, y = 4821; Fig. 2E, F). These HCS are characterized by low angle lamina dips and intersections, and present laminations draped on a hummocky surface. The HCS can exist either in platform as tempestite deposits between fair weather wave base and storm wave base (maximum depth 100 m; Peters and Loss, 2012) or in a channel cut in the basin slope associated with turbidites and storm wave modification to form HCS (Walker, 1984, p. 151, 154). The second interpretation seems to be likely in the Faugères nappe.

Figure 2. Outcrops of the schistosed units (Faugères nappe *sensu lato*). A. Alternation of micritic limestone and calci-schist (early Viséan) in Vieussan (Moulin de Grais) (limestone bed thickness = 10 cm). B. Debris flow with limestone pebbles in *schistes troués* in Vieussan (Moulin de Grais). C. Flysch of Faugères nappe, composed of thick turbiditic sandstone along the road D909, north of Laurens (sandstone bed thickness = 50 cm). D. Flysch of Faugères nappe composed of alternations of turbidite siltstone and shale, in the trail from Plaussenous to Le Pin (siltstone bed thickness = 25 cm). E-F. Platform sandstone with hummocky cross stratification (underlined) in the trail from Plaussenous to Le Pin, located north of a sheath fold (*pli en fourreau*) (sandstone bed thickness = 50 cm).

Figure 2. *Affleurements des unités schistosées du versant sud (nappe de Faugères au sens large). A. Alternances de calcaires micritiques et de calcschistes (Viséen inférieur) à Vieussan (Moulin de Grais) (épaisseur des bancs calcaires = 10 cm). B. Coulée de débris à galets calcaires dans les schistes troués de Vieussan (Moulin de Grais). C. Flysch de la nappe de Faugères, constitué de grès turbiditiques épais, le long de la D909 au Nord de Laurens (épaisseur des bancs de grès = 50 cm). D. Flysch de la nappe de Faugères composé d'alternances de siltites, d'argilites turbiditiques et d'argiles, sur la piste de Plaussenous au Pin (épaisseur des bancs de siltites = 25 cm). E-F. Grès de plate-forme à stratifications en hummock (soulignées), sur la piste de Plaussenous au Pin, au Nord du pli en fourreau (épaisseur des bancs de grès = 50 cm).*

5. Mont Peyroux nappe

The Mississippian formations of the Mont Peyroux nappe (Figs. 1B-C, 3A-G, 4A, 5A-C, 6A-D, 7A-B, 8A-C, 13F-G) have been re-described by D. Korn and R. Feist (2007), with the following units, from base to top: Lydiennes, Faugères, Colonnes and Puech Capel formations (all included within the Saint-Nazaire Group). In the Cabrières klippes, D. Korn and R. Feist (2007) additionally described the Laurens Flysch Group. The composition and nomenclature of these units are revised in this paper.

5.1. Saint-Nazaire-de-Ladarez Group (emend.)

Type locality: Trails from Puech de la Suque (Fig. 3A) to Concous-le-Haut, via Puech Capel (map 1/50,000: Saint-Chinian).

Type section: Northern border of the trails, from x = 507.5, y = 4815 to x = 508, y = 4816.25.

Lithology: See the descriptions of the Lydiennes, Faugères, and Colonnes formations (sections 5.1.1, 5.1.2, 5.1.3, respectively).

Boundaries: Lower boundary: normal contact at the base of the Lydiennes with the supragriotte limestones; upper boundary: normal contact of the top of the Colonnes Fm with the Barrac Group.

References: R. Böhm (1935, 1936); F. Boyer *et al.* (1968); D. Vachard (1973, 1974b, 1977); W. Engel *et al.,* 1982; R. Feist (1985); R. Feist and G. Flajs (1987b); G. Flajs and R. Feist (1988); D. Korn and R. Feist (2007); M. Aretz (2016); P. Cózar *et al.* (2017).

Remarks: We provide some modifications to the status of this group:

1) Change of name: Saint-Nazaire is in reality a big city in Bretagne (western France), not the eponymous small village in Occitanie (southern France); as a consequence, the group is re-designated here under its complete name: Saint-Nazaire-de-Ladarez Group.

2) Change of rank: The Saint-Nazaire-de-Ladarez Group was initially described as a formation by R. Feist (1985), R. Feist and G. Flajs (1987b), and G. Flajs and R. Feist (1988). We adopt here the status of Group suggested by D. Korn and R. Feist (2007) and M. Aretz (2016).

3) Change of composition: The Puech Capel Fm, which is readily associated with the latest Viséan-Serpukhovian flysch sedimentation, is considered here as part of the new Barrac Group.

Biostratigraphy: The main data come from ammonoids, conodonts and foraminifers. Although they were actively well studied, the radiolaria and terrestrial plants play a subordinate biostratigraphic role.

Chronostratigraphy: Middle Tournaisian Cf2 (Tn2) to late Viséan lower Cf6γ.

Tectonics: Overturned limb of the Mont Peyroux nappe.

Regional variations: This group is present in the Mont Peyroux nappe (synform of Roquebrun), Vissou klippe and Roquessels Complex. It is absent from the Laurens-Cabrières Group, although some black chert pebbles are reworked in the *poudingues à dragées* (candy conglomerates) in the Mougno-Les Batailles informal unit (see section 6.2.8).

Division into formations: The following formations are described:

- Lydiennes Fm;
- Faugères Fm;
- Colonnes Fm.

Figure 3. Outcrops of the Mont Peyroux nappe. A. Puech de la Suque (PS) and hill 248, photographied from the trail of Puech Capel. B. Debris flow with limestone boulders in a vineyard close to Puech Redon ruins. Hammer for scale = 33 cm. C. Debris flow with a block of carbonate breccia ("third griottes" of Korn and Feist, 2007) topped by a laminar, partly dolomitized calciturbidite (reverse dip), in Puech Capel trail. Scale = 5 cm. D. Detail view of the block of 3C showing rounded and subquadratic extraclasts of different sizes (bed thickness = 10 cm). E. Debris flow with breccoid limestone (Br) and sandstones (Sa) in the trail at the bottom of hill 248 (reverse dip). F. Detailed view of the breccoid limestone of 3E showing rounded, relatively isodiametric extraclasts. Scale = 5 cm. G. Debris flow with a small block of carbonate breccia from the Colonnes Fm, South of Saint-Nazaire-de-Ladarez.

***Figure 3.** Affleurements de la nappe du Mont Peyroux. A. Puech de la Suque (PS) et colline 248, photographiée depuis la piste au pied du Puech Capel. B. Coulée de débris avec des blocs calcaires dans un vignoble proche des ruines de Puech Redon. Le marteau mesure 33 cm. C. Coulée de debris avec un bloc de calcaire bréchique (« troisièmes griottes » de Korn et Feist, 2007) surmonté d'une calciturbidite laminée et partiellement dolomitisée, en pendage inverse sur la piste du Puech Capel. Échelle = 5 cm. D. Vue de détail du calcaire bréchique de 3C montrant des extraclastes arrondis et subquadratiques de tailles différentes (épaisseur du banc = 10 cm). E. Coulée de débris avec un calcaire bréchique (Br) et des grès (Sa) sur la piste au pied de la colline 248 (« troisièmes griottes », pendage inverse). F. Vue de détail du calcaire de 3E montrant des extraclastes subarrondis de taille relativement homogène. Échelle = 5 cm. G. Coulée de débris à brèche carbonatée provenant de la Formation des Colonnes, au Sud de Saint-Nazaire-de-Ladarez.*

5.1.1. Lydiennes Formation

Type locality: Puech de la Suque.

Type section: In a curve of the trail (x = 508, y = 4816.25), in the ancient small quarry, where the phosphatic nodules were once commercially exploited, and which is now partly hidden by bushes.

Lithology: It is composed of centimetric to decimetric, black radiolarian chert beds with a reverse north-west dip. At the type locality, it is about 22 m thick (Michel, 1981), or approximately 30 m (Korn and Feist, 2007), or even 35 m (Maurel, 1966a). Phosphatic nodules, present in the upper part of the formation, contain terrestrial plants and ammonoids.

Boundaries: Normal or slightly faulted contacts with the underlying supragriottes and the overlying Faugères Fm.

References: P. de Rouville (1868); P. Levat (1898); H. Théron (1899); J. Bergeron (1899); L. Cayeux (1929, 1939); J. Blayac *et al.* (1935a, 1935b); G. Delépine (1935); R. Böhm (1935); E. Genson (1937); G. Deflandre (1946, 1973); B. Gèze (1947, 1949); G. Denizot (1962); M. Maurel (1966a, 1966b); R. Racionero (1967); F. Boyer *et al.* (1968); Galtier (1970); D. Vachard (1973, 1974b, 1977); S. Krylatov and G. Termier (1978); J. Coudray *et al.* (1979); D. Michel (1981); S. Crilat (1981); W. Engel *et al.* (1982); W.D.I. Rolfe (1985); J. Galtier *et al.* (1988); W. Rowe and J. Galtier (1989, 1990); D. Korn and R. Feist (2007); L. Pille (2008); M. Aretz (2016); P. Cózar *et al.* (2017).

Remarks: The phosphatic nodules of the Pyrenees and Montagne Noire were first mentioned by P. Levat (1898). As early as 1899, the abbot H. Théron, Cabrières' priest, published some fossil plants and ammonoids of the Pic de Vissou. Other pioneer works about the lydiennes have been summarized by D. Vachard (1974b) and D. Korn and R. Feist (2007).

For a long time, the origin of the silica, carbon and phosphate remained relatively questionable, up to the modern reconstructions involving coastal upwelling currents. The assemblages of radiolarian microfaunas with floated terrestrial plant fragments, within the lydites as well as the nodules, were also paradoxical. D. Michel (1981) described in detail the lithology and the geochemistry of the lydiennes and associated shales and phosphatic minerals. He concluded that they were deposited in slope and basin environments. This reconstruction was confirmed by geochemical arguments (Cózar *et al.,* 2017).

Biostratigraphy: Based on the ammonoid assemblages, an early Viséan age was proposed by R. Böhm (1935, 1936) and G. Delépine (1937). D. Vachard (1973, 1974b, 1977) speculated on a late Tournaisian Tn3c (= Cf4α1) to early Viséan V1a (= Cf4α2) age because of his reinterpretation of R. Böhm's ammonoids, and his interpretation of a V1b (= Cf4β) age for the overlying Faugères Fm. Then, a middle Tournaisian (Tn 2 = Cf2) age of the Lydiennes Fm was indicated by W. Engel *et al.* (1982), who dated the underlying supragriottes as Tn1b (by the conodont *Siphonodella lobata*), and the overlying Faugères Fm as

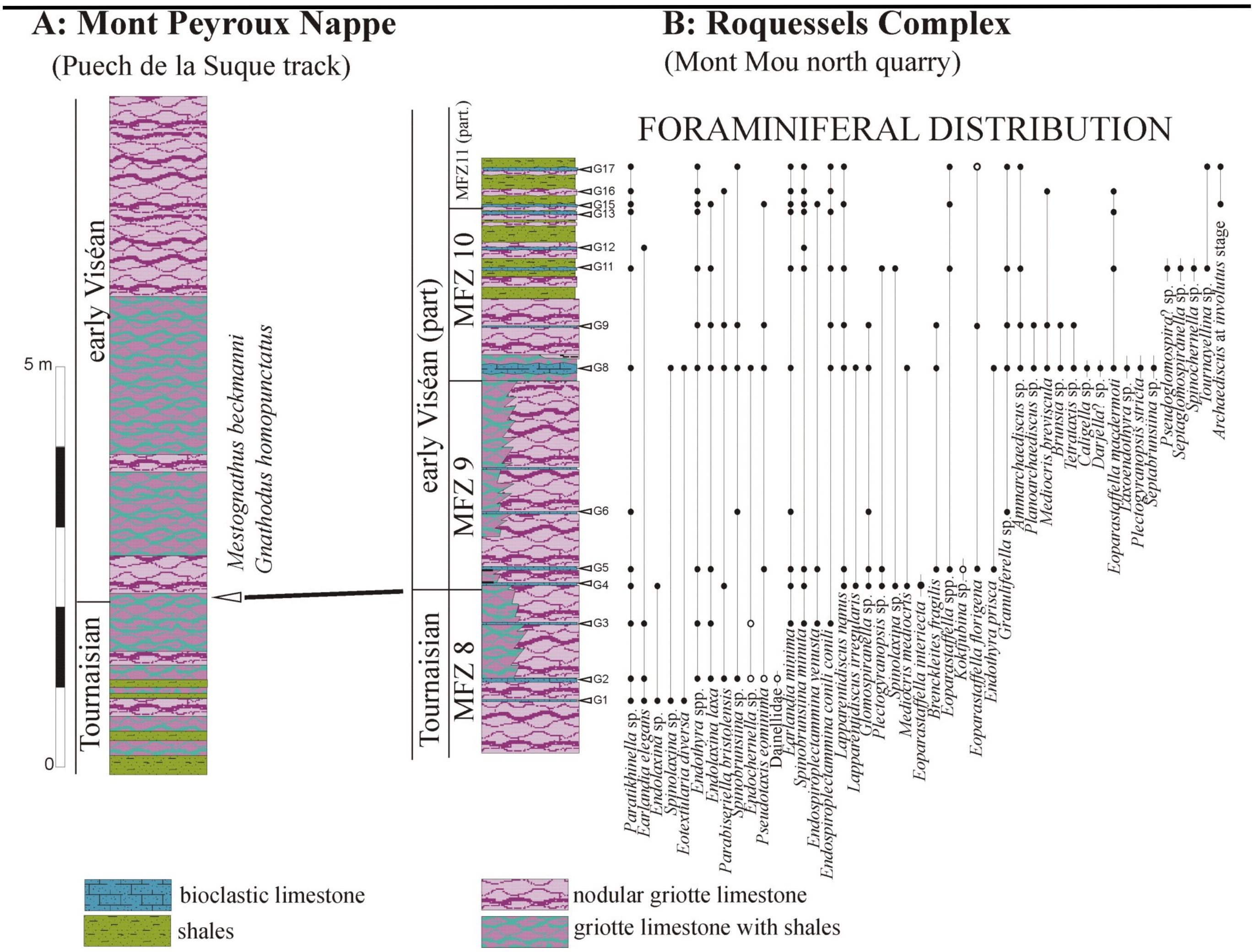

Figure 4. Stratigraphical columns of the Faugères Fm, with the proposed location of the Tournaisian-Viséan boundary based on conodonts (according to Cózar *et al.*, 2017, fig. 4 modified). A. Puech de la Suque (Mont Peyroux nappe). B. Mont Mou northern quarry (Roquessels Complex), with G1 to G17 corresponding to the intercalated grainstones (Vachard, 1974b, 1977; Cózar *et al.*, 2017).

Figure 4. *Colonnes stratigraphiques de la Formation de Faugères, avec proposition d'une limite Tournaisien-Viséen fondée sur les conodontes (d'après Cózar* et al.*, 2017, fig. 4 modifiée). A. Puech de la Suque (nappe du Mont Peyroux). B. carrière au Nord du Mont Mou (Complexe de Roquessels) avec intercalations des bancs de grainstones G1 à G17 (Vachard, 1974b, 1977; Cózar* et al.*, 2017).*

Tn3c based on the conodonts *Polygnathus communis carina* and *Scaliognathus anchoralis*. The recent revision of R. Böhm's ammonoids by D. Korn and R. Feist (2007) gave a middle to early late Tournaisian age (= Tn2-Tn3a = Cf2-Cf3 = MFZ5-MFZ7). On the other hand, the phosphatic nodules contain well-studied permineralized plant remains (Rowe and Galtier, 1989, 1990 and references therein), and the black chert was intensively studied for its radiolarian assemblages (Deflandre, 1946, 1973).

Chronostratigraphy: Middle to early late Tournaisian.

Tectonics: The formation is everywhere folded in accordion-like fashion.

Regional variations: The formation is 10 m thick in Pic de Vissou, where it was also exploited for its phosphatic nodules. The apparently thickest outcrop of the formation is in the trail of Concous-le-Haut (Maurel, 1966a, fig. 16), but, to our knowledge, was never accurately described. The Lydiennes Fm is 20 m thick in Coumiac-Les Granges (Maurel, 1966a). In La Serre klippe, some atypical, very small phosphatic nodules contain quartz grains and sponge spicules (Böhm, 1935; Cayeux, 1939; B. Gèze, 1947, 1949; D. Vachard, 1974b; Krylatov and Termier, 1978), and are located at the top of a shaly series (Michel, 1981; Cózar *et al.*, 2017, fig. 3).

Division into members: According to the descriptions of R. Böhm (1935) and F. Boyer *et al.* (1968), there are possibly three lithologies, which could correspond to three members in this formation, from bottom to top: 1) transition with the underlying supragriottes; 2) chert without nodules; 3) chert with phosphatic nodules. Nevertheless, this observation at Puech de la Suque cannot be currently extended to all of the outcrops.

5.1.2. Faugères Formation

See the detailed analysis of this formation in the Roquessels Complex (section 6.1.2.2). In the Mont Peyroux nappe, this formation, ca. 8 m thick, is known in Puech de la Suque (Fig. 4A), Puech Capel, Concous-le-Haut, Coumiac-Les Granges, Ferme de Libes, and Laurenque (Denizot, 1962; Maurel, 1966a; D. Vachard, 1973, 1974b; Michel, 1981). It is a pink nodular limestone with common, oxidized, irregular surfaces rich in siliciclastic material, composed of pure micrites with globochaetaceans, calcisphaeroids, rare unilocular foraminifers, rare radiolarians, gastropods, ammonoids and ostracods (Vachard, 1974b).

In Puech Capel, D. Michel (1981) has described nodular limestones in the lower part (4 m) and breccoid limestones

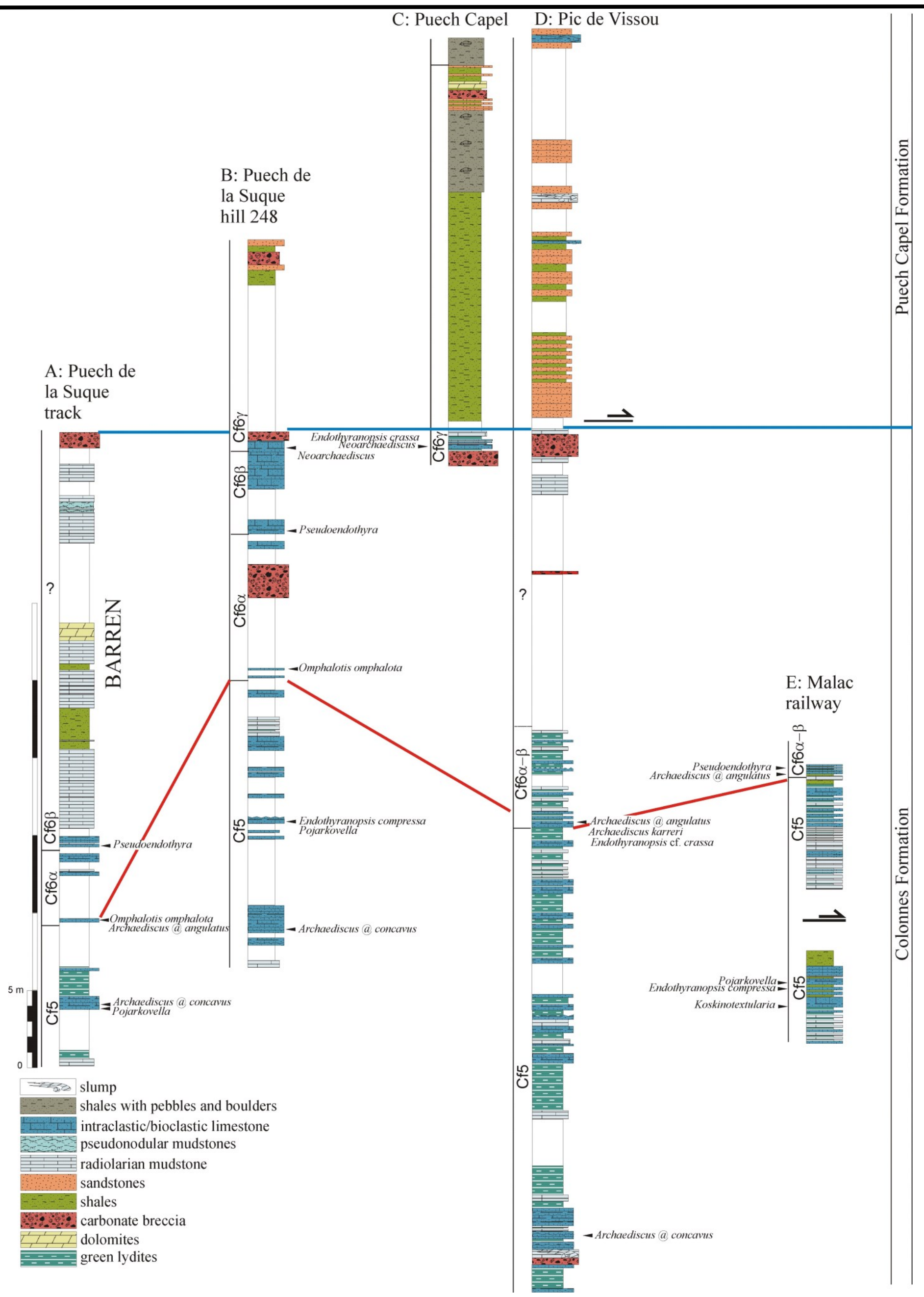

Figure 5. Stratigraphic sections of the Colonnes and Puech Capel formations (modified from Cózar *et al*., 2017, fig. 7). A. Puech de la Suque trail. B. Puech de la Suque-hill 248. C. In the bottom of Puech Capel. D. Pic de Vissou klippe. E. Malac railway trench (Roquessels Complex).

***Figure 5.** Colonnes stratigraphiques des formations des Colonnes et du Puech Capel (modifiées d'après Cózar* et al.*, 2017, fig. 7). A. Piste du Puech de la Suque. B. Colline 248. C. Au pied du Puech Capel. D. Écaille du Pic de Vissou. E. Tranchée du chemin de fer de Malac (Complexe de Roquessels).*

in the upper part (6 m) of the formation. To explain this field observation, J. Coudray and D. Michel (1981) experimented on the fabric of the nodular limestone. They demonstrated that this structure was formed by the alternation of thin limestone and shale gliding on a low slope. Both structure types, breccoid and nodular, depend on two factors: clay content and friction on the limestone surfaces. The fissurization and clay penetration producing the breccoid structure is observed in the case of a thick limestone bed and a thin shale. The pinching and shear, producing the nodular limestone, is observed in the case of a thin limestone and a thick shale. Another hypothesis is that there was chemical compaction and pressure dissolution during the diagenesis of the fabric of the nodules (Tucker and Wright, 1990, p. 360). Uncompacted hard limestone can alternate with fissile limestone and claystone showing dissolution seams. This would be the result of episodic subseafloor cementation.

In Puech de la Suque, the Faugères Fm is 5-9 m thick. The *Scaliognathus anchoralis* conodont Zone (latest Tournaisian) was recorded in its lowermost part, whereas *Mestognathus beckmanni* and *Gnathodus homopunctatus*, found in its uppermost part (Coudray *et al*., 1979; Engel *et al.,* 1982; Lethiers and Feist, 1991; Fig. 4A), unquestionably indicate the earliest Viséan, because *G. homopunctatus* appears less than one metre above the base of the type Viséan in Belgium (Conil *et al*., 1991; Poty *et al*., 2006), as well as in the GSSP stratotype in China (Devuyst *et al*., 2003).

5.1.3. Colonnes Formation

See the detailed analysis of this formation in the sections 6.1.2.3 and 6.1.3.1.2 of this paper. In the Mont Peyroux nappe, the lower contact with the Faugères Fm is normal but generally covered, whereas the normal upper contact with the Puech Capel Fm of the Barrac Group is easily observable and well marked.

In the Puech de la Suque trail (Vachard, 1973, 1974b; Lethiers and Feist, 1991; Cózar *et al*., 2017; Fig. 5A), the formation, ca. 40 m thick, is mainly composed of pale grey lime mudstone, well-stratified in beds from 10 to 50 cm thick. They contain rare radiolarians, sponge spicules and ostracods. In the lower part, greenish to creamy chert levels (*lydiennes vertes*) are commonly interbedded with fine- to medium-grained dark grey to brown limestone beds (Andrieux and Matte, 1963; Michel, 1981; Crilat, 1981). Destructive dolomitization occurs in the upper part of the succession; and at the top of the Colonnes Fm, two metres of carbonate breccia are observed everywhere (Figs. 5A-D, 6A-D). Sedimentary structures are not observed in the green lydites and lime mudstones; in contrast, the fine- to medium-grained beds exhibit common parallel- and cross-laminations, as well as finning-upward sequences (Cózar *et al*., 2017).

In the hill 248 section, located 500 m SW of the Puech de Suque trail section (Fig. 3A), the formation, 35 m thick, is composed of more bioclastic/intraclastic packstone/ grainstone (Fig. 5B).

At the top of the Mont Mou section, the Faugères Fm is overlain by a few alternations of limestone and lydite beds, which contain rare MFZ10/11 (= Cf4β/δ) foraminifers, *Glomodiscus* sp. These alternations might correspond to the lowermost part of the calcareo-siliceous succession (4 m) described by D. Michel (1981) in Puech de la Suque, with green and grey siliceous limestone, green shale and green and black lydite. The topmost alternations of Mont Mou may also correspond to the *jaspes supérieurs* (4.50 m thick) of S. Krylatov and G. Termier (1978) and S. Crilat (1981).

On the other hand, rare MFZ11 (= Cf4γ-δ) limestone pebbles with *Uralodiscus rotundus*, *Eotextularia diversa* and *Eoparastaffella simplex*, reworked in the Puech Capel Fm, between Puech Capel and Concous-le-Bas, have been published (Vachard, 1973, 1974b, 1977; Pille, 2008). Unfortunately, this small outcrop, probably covered in the meantime, has not been relocated during this study.

In Puech de la Suque, the base of the Colonnes Fm, although only separated by a few metres from the Faugères Fm (and by only 10 cm in Pic de Vissou), already belongs to the foraminiferal Cf5 biozone (middle Viséan; Fig. 5D), as demonstrated by the occurrence of the foraminifer genera *Pojarkovella*, *Archaediscus* (at *concavus* stage and transitional to *angulatus* stage), *Endothyranopsis*, and *Koskinotextularia*. At the same locality, the early late Viséan Cf6α-β is recorded in bioclastic beds located 13 m from the base (Vachard *et al.,* unpublished data). Foraminifers of the Cf6α-β have been also found in the upper part of the sections in Coumiac-Les Granges and Pic de Vissou (Fig. 5D). D. Vachard (1973, 1974b) identified *Koskinobigenerina prisca* in the upper levels of Pic de Vissou and *Climacammina antiqua* in Coumiac-Les Granges. This latter taxon is misinterpreted, and probably corresponds also to *K. prisca*, because it is now well known that *Climacammina* only appears in Cf6δ (Conil *et al*., 1991; Cózar and Somerville, 2004). Moreover, this biozone Cf6δ, which, formerly, constituted the uppermost part of the Viséan, is currently assigned to the earliest Serpukhovian (Vachard *et al*., 2016b). These records of *Koskinobigenerina*, and additional discovery of foraminifers (Vachard *et al.,* unpublished data), indicate that the Colonnes Fm in Pic de Vissou, Puech de la Suque track, hill 248, Puech Capel (Cózar *et al.,* 2017; Fig. 5A-D), and Coumiac-Les Granges, seems to achieve synchronously the lower part of the Cf6γ (Vachard *et al*., unpublished data), which therefore constitutes the youngest age of the carbonate substrate of the flyschs of the Montagne Noire.

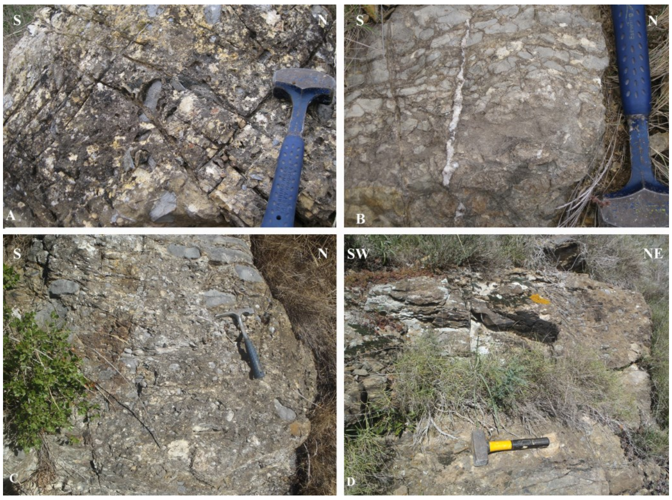

Figure 6. Calcareous breccias at the top of the Colonnes Fm in the Mont Peyroux nappe (according to Cózar *et al*., 2017, fig. 10 slightly modified). A. Breccia of Puech Capel section. B. Breccia of hill 248 section. C. Breccia at the top of Puech de la Suque section. D. Breccia at the top of Pic de Vissou section (length of the hammer in A-B = 27.5 cm; C-D = 28 cm long).

Figure 6. *Brèches calcaires au sommet de la Formation des Colonnes de la nappe du Mont Peyroux (d'après Cózar* et al*., 2017, fig. 10 légèrement modifiée). A. Brèche du Puech Capel. B. Brèche de la colline 248. C. Brèche au sommet de la section du Puech de la Suque. D. Brèche au sommet de la section du Pic de Vissou (longueur du marteau en A-B = 27.5 cm et en C-D = 28 cm).*

5.2. Barrac Group (new group)

Type locality: The Roquebrun synform (Puech Capel, Landeyran valley, and Barrac valley). See the location of the Flysch-unit I of Engel *et al*. (1982, fig. 9).

Type section: A type section is defined for each formation.

Lithology: The Puech Capel Member displays 20 m-thick-green shales; thin debris flows with limestone pebbles, sandy turbidites and thin lenses of breccias ("third-griottes" of Korn and Feist, 2007), and thick debris flows with limestone boulders (Figs. 3B-C, 5B-C). Then, the Landeyran Barn Mb exposes shale with rare ammonoids; and finally, the Barrac (= Flysch-unit I of Engel *et al*., 1982) and Fabrègues (= Flysch-unit II of the same authors) formations display alternations of turbiditic sandstone and shale. Rare carbonate olistoliths are included in the Fabrègues Fm.

Boundaries: The lower contact of the Puech Capel Mb with the Colonnes Fm, and the upper contact of the Fabrègues Fm with the Laurens-Cabrières Group, are sedimentary.

References: W. Engel *et al.* (1982); D. Korn and R. Feist (2007); M. Aretz (2016).

Remarks: This group is composed of classical turbidites and debris flows with scarce carbonate boulders and pebbles.

Biostratigraphy: D. Korn and R. Feist (2007) used goniatites for dating the Puech Capel and Barrac formations. On the other hand, P. Cózar *et al.* (2017) used foraminifers for the age determination of olistoliths in the Fabrègues Fm.

Chronostratigraphy: The chronostratigraphy is defined for each formation; from the Puech Capel Mb, which is latest Viséan, to the olistoliths of the Fabrègues Fm, which are late Mikhailovian to Serpukhovian.

Tectonics: Overturned limb of the Mont Peyroux nappe, for the Puech Capel Member and the Landeyran Barn Member, and overturned and normal limbs of a B1 fold described by W. Engel *et al.* (1978, 1982), for the Barrac Fm. In contrast, the Fabrègues Fm, also allochthonous, corresponds to the normal limb of the Mont Peyroux nappe, with an eastward dip.

Regional variations: See W. Engel *et al.* (1982, figs. 5, 9).

Division into formations:

Puech Capel Fm;

Barrac Fm;

Fabrègues Fm.

5.2.1. Puech Capel Formation (emend. herein)

This formation is subdivided here into two members:

- Puech Capel Member;
- Landeyran Barn Member.

The formation is not redefined here, because we have followed its description by D. Korn and R. Feist (2007); only two new members are described.

5.2.1.1. Puech Capel Member

Type locality: On the trail, between Puech de la Suque and Puech Capel (x = 507.7, y = 4815.5). Hence, the locality was initially named *Entre-deux-Puechs* (i.e., between two hills; Vachard, 1973, 1974b, 1977).

Type section: From Puech de la Suque to Concous-le-Bas village; starting on the trail where the type locality of the Lydiennes Fm described earlier is exposed, and continuing on the ancient path, on the left of the trail.

Lithology: The Puech Capel Formation, as defined by D. Korn and R. Feist (2007), was theoretically composed of 100 m of very coarse debris flow deposits with up to pluri-decimetric boulders and cobbles, followed by 20 m of greenish shales interbedded with thin nodular limestones (Fig. 3C-F). Nevertheless, the succession includes only, in its lower part, 20 m of greenish shale, thin sandstone, and thin debris flows with elongate blocks of carbonate breccias, occasionally with a cap of laminated and partly dolomitized calciturbidite (Fig. 3C-D). The apparent "nodules" are really composed of a mixture of limestones from older formations (see below, top of the hill 248 section), and thus, should be considered as parts of carbonate breccias. Furthermore, these carbonate breccias present everywhere a sharp lateral contact with the shales, and represent blocks that slid along the slope. This succession rests directly on the last limestone beds of the Colonnes Fm in the trail of Puech Capel (Fig. 5C). Higher up, 100 m-thick-debris flows with some boulders and pebbles of the Colonnes Fm, have been recorded in the slope of the Puech Capel hill and an adjacent vineyard (Fig. 3B).

At hill 248, above the uppermost levels of the Colonnes Fm, 10 metres of greenish shales (almost entirely covered) and four metres of channelized debris flow with limestone pebbles ("third griottes"; Korn and Feist, 2007) are interbedded with laminated turbiditic sandstones (Figs. 3E-F, 5B). The microfacies show lithoclasts of mudstones with rare ostracods and spicules (possibly from the Colonnes Fm), and of wackestone-packstone with peloids, spicules and crinoids. This latter contains the unique late Viséan foraminifers discovered in this formation, and mentioned hereafter.

South of Saint-Nazaire de Ladarez (x = 505.9, y = 4816.9), close to the wastewater treatment plant and lonely tomb, a debris flow shows some boulders of carbonate breccias similar to those that are known at the top of the Colonnes Fm (Fig. 3G).

Boundaries: The lower contact with the Colonnes Fm is sedimentary but well marked; the upper contact with the Landeyran Barn Mb is sedimentary and transitional.

References: D. Vachard (1974b, 1977); F. Lethiers and R. Feist (1991); D. Korn and R. Feist (2007); M. Aretz (2016); P. Cózar *et al.* (2017).

Remarks: This member is interpreted as a debris flow with pebbles and boulders of calciturbidites of the Colonnes Fm and flagstones of "third griottes". This debris flow can be followed from Concous and Puech Capel to the D136 road south of Saint-Nazaire de Ladarez. The so-called third griottes of D. Korn and R. Feist (2007) are carbonate breccias resedimented in this debris flow. This member records an important tectonic change in the basin (Aretz, 2016).

The Puech Capel Formation was equated with the *schistes troués* (shales with holes) by W. Engel *et al.* (1982) and D. Korn and R. Feist (2007), the type locality of which is situated in the Caragnas Massif (de Rouville, 1886), an outcrop of the Faugères nappe close to the village of Cabrières. In the Caragnas Massif, 20 metres of shales with some scattered and sparsely distributed limestone boulders are visible; there, this metamorphosed formation is difficult to interpret sedimentologically. Nevertheless, in other areas such as Moulin de Grais and Le Pin and Le Lau, these *schistes troués* correspond possibly to a debris flow with micritic limestone boulders (Fig. 2B). As a consequence, this comparison between the Puech Capel Mb and *schistes troués* is possible, but needs precise dating to be justified.

Biostratigraphy: Based on the conodont *Gnathodus bilineatus* and the ammonoids *Dombarites granofalcatus* and *Irinoceras* sp., the upper part of the Puech Capel Formation (here the Landeyran Barn Member) was assigned to the *Arnsbergites-Neoglyphioceras* ammonoid Zone (Korn and Feist, 2007). This latter zone is correlated with the early Brigantian P1b-d zones in Britain, and the Goβ in Germany (Sevastopulo and Barham, 2014). In the debris flow of the Puech Capel Mb, the foraminiferal assemblages have only been encountered in the boulders of the older Faugères and Colonnes formations. The occurrence of *Neoarchaediscus*, in samples from the top of hill 248, suggests at least the Cf6γ zone (Fig. 5B) at the base, and Venevian at the top.

Chronostratigraphy: This member is dated as Mikhailovian (Fig. 5C) at the base and Venevian at the top.

Tectonics: The Puech Capel Formation and its equivalents probably record the first major episode of the maximal phases of the Variscan orogeny in the Montagne Noire. It is possible to speculate that: (1) the carbonate breccias at the top of the Colonnes Fm, (2) the Puech Capel Fm in South Mont Peyroux nappe and (3) the *schistes troués* in Faugères nappe, all correspond to an important tectonic change in the basin, which is less registered in the northern platform (see later). W. Franke *et al.* (2011, p. 779) suggested that this debris flow resulted from the emersion and erosion of the basin sediments, and their reworking. The boulders came from the Colonnes Fm for Mont Peyroux nappe and another possible basinal limestone for Faugères nappe. The Devonian and Mississippian series of Mont Peyroux and Faugères nappes were originally deposited over the Axial Zone (Arthaud, 1970; Vachard, 1974b), or farther north (Franke *et al*., 2011). The northern and southern faults, at the limits of a pull-apart basin located in this zone (Franke *et al.,* 2011, fig. 31), may be responsible for these debris flows that could flow from the northern fault high towards the South in the Mont Peyroux unit and from the southern fault high towards the North in the Faugères unit. This interpretation may also explain the differences of lithology of the boulders in each unit.

Regional variations: The Puech Capel Mb can correspond to the numerous slumps observed in Pic de Vissou in association with detrital turbidites, in the flysch succession above the Colonnes Fm (Fig. 5D).

5.2.1.2. Landeyran Barn Member (new member)

Type locality: As indicated by R. Böhm (1935, p. 143, pl. 10, fig. 2), this unit was initially defined near a ruined barn named *Grange de Landeyran*. In contrast, another formation, almost a homonym, the Early Ordovician Landeyran Fm, is defined after the Landeyran creek valley (Vizcaïno *et al*., 2001).

Type section: Grange de Landeyran (see Böhm, 1935).

Lithology: Dark coloured shales with rare ammonoids.

Boundaries: Normal and continuous with the Puech Capel Mb and the Barrac Fm.

References: R. Böhm (1935); W. Engel *et al.* (1982)

Remarks: This lower part of the flysch of the Mont Peyroux nappe was initially considered as the upper part of the Puech Capel Fm by D. Korn and R. Feist (2007). We follow this suggestion, but we distinguish formally these two units, which differ lithologically and structurally.

Biostratigraphy: Fossiliferous beds of the flysch of the Mont Peyroux nappe were described by R. Böhm (1935) as the *schistes du Landeyran*, and rare ammonoids were identified by this author as *Goniatites subcircularis* and *Sagittoceras* sp. These taxa were re-interpreted by D. Korn and R. Feist (2007) as *Neoglyphioceras* sp. and *Ferganoceras* sp., respectively, and assigned to the latest Viséan *Lusitanoceras-Lyrogoniatites* Zone, correlated with the Goγ of the German zonal scheme or the P2b zone (late Brigantian) in Britain according to G. Sevastopulo and M. Barham (2014).

Chronostratigraphy: Venevian-Tarusian.

Tectonics: Overturned limb of the Mont Peyroux nappe.

Regional variation: Work in progress.

5.2.2. Barrac Formation (new formation)

Type locality: Barrac creek (see Andrieux and Matte, 1963, p. 171) and D136 road (x = 509.5, y = 4816).

Type section: *Ibidem*.

Lithology: Alternation of conglomerate with white quartz and black lydite pebbles, graded sandstone (Tab sequences of Bouma, 1962) and shale with turbiditic sequences stacked in fining upward sequences (0.5-1 m; Fig. 7A-B). These decimetric sequences are recorded in the turbidites along the road D136 close to La Vertu. They correspond to turbidites from the sandy fan retrograding by an increase of tectonic subsidence along a fault (Mutti, 1992, fig. 37).

Boundaries: The boundary between the Barrac Fm and the Fabrègues Fm is a sedimentary contact, with a normal eastern dip. F. Arthaud in B. Alabouvette *et al.* (1985) drew a thrust east of this contact. However, there is no evidence in the field, where only a change of dips, due to a fold B1 described by W. Engel *et al.* (1978, 1982), is observable.

References: J. Andrieux and P. Matte (1963); D. Vachard (1974b); W. Engel *et al.* (1978, 1982); B. Alabouvette *et al.* (1985); M. Aretz (2016).

Remarks: In the Barrac valley, there are alternations of homogeneous or graded sandstone (Tab sequences of Bouma, 1962), microconglomerate with normal or inverse grading, and fine sandstone, siltstone with current ripples and shale (Tcde sequences). In the Pic de Vissou, a nearly 60 m thick succession, composed predominantly of shales and sandstones (turbidites), is followed by an interval with numerous carbonate slumps and sandy turbidite olistoliths (Fig. 7C-D). This facies was deposited on a slope.

Biostratigraphy: The Barrac Fm contains goniatites belonging to the *Lyrogoniatites* Zone (Korn and Feist, 2007).

Chronostratigraphy: Latest Viséan-early Serpukhovian.

Tectonics: Overturned and normal limbs of the Mont Peyroux nappe.

Regional variations: This allochthonous flysch is 500 to 1000 m thick according to the literature. It was described in detail by J. Andrieux and P. Matte (1963) and W. Engel *et al.* (1978, 1982).

Division into members: No subdivisions.

Figure 7. Barrac Fm (or Flysch-unit I). A. Alternations of homogeneous or graded sandstone (Tab, Bouma, 1962), microconglomerate with normal grading and fine sandstone, and siltstone with current ripples and shale (Tcde); these facies are stacked in a decimetric or metric thinning and fining upward sequence (scale bar = 0.5 m) in Barrac creek valley. B. Microconglomerates (MC) passing by graded bedding (Gr) to sandstone (Sa) upward (thickness of the bed = 0.5 m) in Barrac creek valley. C. Slump in radiolarian mudstones in the flysch (scale bar = 20 cm) in Pic de Vissou slope. D. Slump of radiolarian mudstones and sandy turbidites (thickness of the mudstone bed = 30 cm) in Pic de Vissou slope.

Figure 7. *Formation de Barrac (ou Flysch-unit I). A. Alternances de grès homogènes ou granoclassés (séquence Tab de Bouma, 1962), de microconglomérats à granoclassement normal et grès fins, et de siltites à rides de courant et argilites (Tcde). Ces faciès sont empilés dans des séquences décimétriques ou métriques, strato- et granodécroissantes vers le haut (barre d'échelle = 0, 5 m), affleurant dans la vallée du ruisseau de Barrac. B. Microconglomérats (MC) passant vers le haut, par granoclassement (Gr) à des grès (Sa; épaisseur du banc = 0, 5 m), dans la vallée du ruisseau de Barrac. C. Slump de mudstone à radiolaires dans le flysch (barre d'échelle = 20 cm) sur la pente du Pic de Vissou. D. Slump de mudstone à radiolaires et turbidites sableuses (épaisseur du banc de mudstone = 30 cm) sur la pente du Pic de Vissou.*

5.2.3. Fabrègues Formation (new formation)

Type locality: The area called Bois de Fabrègues (Fabrègues Wood), between Laurens and Saint-Nazaire-de-Ladarez.

Type section: Along the road D136, in the curve located NE of Sicard (x = 510, y = 4817.25) and Fabrègues.

Lithology: Alternation of fine sandstone (Ta sequence), siltstone with wavy (Tcde sequence) and lenticular ripples and shale with turbiditic sequences stacked in fining and coarsening upward sequences (0.5-1 m thick), and conglomerate lenses with white quartz and black lydite pebbles (Le Montimbert, East of Barrac, and Fabrègues) (Fig. 8A-C). They correspond respectively to thin and fine overbank deposits of channel, and to channel deposits (Mutti, 1977). This deposit is more proximal than the turbidites from the Barrac Fm (Engel *et al*., 1978, 1982). This formation contains calciturbidite lenses (cm- to dm-thick rudites) within the siltstone, with diverse intraclasts (ooidal, micropelletoidal and from micritic limestones), lithoclasts (metamorphic rocks), bioclasts (foraminifers, tabulate corals, bryozoans, and crinoids), and quartz. This formation passes laterally into a disorganized zone with small limestone olistoliths between Le Montimbert and Plan des Masques (map of Engel *et al.,* 1982; Fig. 1). A lateral passage between the channel and levee zone and the slope zone can explain the presence of the olistoliths.

Boundaries: A first boundary is located between the normal eastern dip of the Barrac Fm (former Flysch-unit I) and the normal eastern dip of the Fabrègues Fm (former Flysch-unit II). A second boundary, located between the Fabrègues Fm and the basin of Laurens-Cabrières, has been drawn as a thrust on the Saint-Chinian map by F. Arthaud in B. Alabouvette *et al.* (1985). W. Engel *et al.* (1978, 1982) did not consider the thrusts in their map, because they suggested a transitional sedimentary continuity between the different units called here Barrac Fm, Fabrègues Fm, and Laurens Complex.

References: J. Andrieux and P. Matte (1963); D. Vachard (1974b); W. Engel *et al.* (1978, 1982); B. Alabouvette *et al.* (1985); M. Aretz (2016).

Remarks: The former units I and II of Engel *et al.* (1982) are interpreted as two distinct tectonosedimentary units, the Barrac and Fabrègues formations, because of their different lithologies in a deep-sea fan (see later), for example, the succession from Puech Capel up to the D136 compared to that from Le Montimbert to the East.

Biostratigraphy: Some calciturbidites provide the foraminifer *Janischewskina gibshmanae*, which is at least Tarusian. The limestone olistoliths from the disorganized zone of the Fabrègues Fm, located in the trail North of Plan des Masques (x = 510.1, y = 4816; see the map of Engel *et al.,* 1982), show foraminifers dated as Tarusian-Steshevian (early Serpukhovian).

Chronostratigraphy: Early Serpukhovian.

Tectonics: Normal limb of a B1 fold that transforms the reverse limb in a normal limb of the Mont Peyroux nappe.

Regional variation: Work in progress.

Division into members: No subdivisions.

6. Laurens-Cabrières basin

During the late Viséan-Serpukhovian (Mikhailovian-Protvian), the Laurens-Cabrières basin contained a detrital group, the Laurens-Cabrières Group, which can be subdivided into three complexes, in the sense of the International Stratigraphic Guide (Salvador, 1994; 5.C.8): (1) the Laurens Complex (= Flysch-unit III of Engel *et al*., 1982; Autochthonous (Viséan?) of A. Préat *et al*., 1999; eponymic Laurens Flysch Group of D. Korn and R. Feist, 2007; and western part of the autochthonous Cabrières Unit of M. Faure *et al*., 2010); (2) the Roquessels Complex (= Roquessels band of Vachard, 1974b, 1977, and Cózar *et al*., 2017 = part of the Flysch-unit IV of Engel *et al*., 1982), and (3) the Vailhan-Cabrières Complex (= Flysch-unit IV of

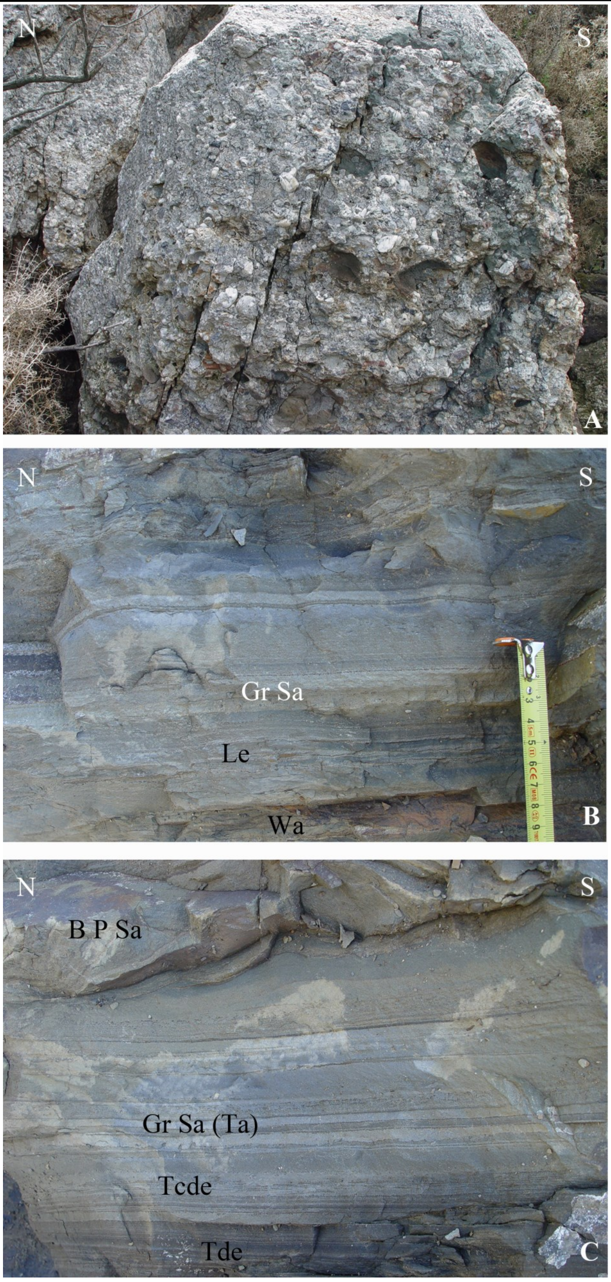

Figure 8. The Fabrègues Fm (Flysch-unit II). A. Conglomerate located on the hill at the south of La Liquière, close to the intersection between D136 and D154. The conglomerate contains pebbles of white quartz and black chert in a sandy matrix; they have a composition similar to those from Le Montimbert at the base of the flysch (thickness of the bed = 1 m). B. From base to top, fining and thinning sequence composed of alternations of wavy siltstone (Wa) and shale (Tcde) passing upward to alternations of lenticular siltstone and shale (Le), then a new fining sequence with a coarse sandstone grading into a fine sandstone (Gr Sa). C. Turbidites composed of a decimetric coarsening and thickening upward sequence with, from base to top: alternations of laminated siltstone and shale (Tde), alternations of wavy siltstone with ripples and shale (Tcde), thin fine or silty sandstone (Gr Sa, Ta) and sandstone with ball- and-pillow structure (B P Sa). B and C are located North of Le Montimbert, in the road D136.

***Figure 8.** Formation de Fabrègues (Flysch-unit II). A. Conglomérat situé sur la colline au Sud de La Liquière, près de l'intersection des routes D136 et D154. Il contient des galets de quartz blancs et de jaspes noirs dans une matrice sableuse. Il a donc une composition semblable à ceux du Montimbert à la base du flysch (épaisseur du banc = 1 m). B. De la base au sommet, se succèdent une séquence strato- et granodécroissante constituée d'alternances de siltites ondulées (Wa) et d'argilites (Tcde) passant vers le haut à des alternances de siltites lenticulaires et d'argilites (Le), puis une séquence granodécroissante, avec un grès grossier passant à un grès fin (Gr Sa). C. Turbidites constituées de séquences décimétriques, grano- et stratocroissantes vers le haut, avec, de la base au sommet, des alternances de siltites laminées et d'argilites (Tde), des alternances de siltites ondulées à rides et des argilites (Tcde), des grès fins ou silteux (Gr Sa, Ta) et des grès avec des séismites balls and pillows (B P Sa). B et C sont situés au Nord du Montimbert sur la route D136.*

Engel *et al*., 1982 with the exception of the Roquessels Complex = eastern part of Laurens Flysch Group *sensu lato*; central and eastern part of the autochthonous Cabrières Unit of M. Faure *et al*., 2010, except for the Vissou klippe). This allochthonous basin, which was an autochthonous foreland basin during its formation on the Axial Zone, was thrust together with the Mont Peyroux nappe southwards to its present location (see section 7.3).

6.1. Laurens-Cabrières Group (new Group)

Type locality: Because of the diversity of the olistoliths and olistostromes reworked in this group, it is difficult to indicate a type locality. Nevertheless, the central part of the Laurens-Cabrières area, between Vailhan and Mas Rolland, is probably the most representative region.

Type section: The transect N-S from Mas Rolland and in the direction of Gabian.

Lithology: All the Palaeozoic olistoliths, from the Early Ordovician to the late Serpukhovian, are conspicuous in the Laurens-Cabrières Group: (1) the typical olistoliths of the Vailhan-Cabrières Complex (i.e., from the Tourière, Combe Rolland and Valuzières formations); and (2) the Saint-Nazaire-de-Ladarez Group typical olistoliths (i.e., from the Lydiennes, Faugères and Colonnes formations). These latter are only present in the Roquessels Complex, west of the line Mas Rolland-Valuzières.

Boundaries: The western boundary is the limit with the Fabrègues Fm. The northern limit is the Roquessels fault and the Faugères nappe outcrops. The southern and eastern boundaries are the transgressive contacts with the post-Palaeozoic series.

References: M. de Serres (1847); J. Fournet and M. Graff (1849); J. Fournet (1850, 1854); P. de Rouville (1876); J. Bergeron (1889, 1898, 1899, 1900a, 1900b, 1912); R. Böhm (1935); B. Gèze (1949); M. Maurel (1966a); B. Mamet (1968); D. Vachard (1974b, 1977); W. Engel *et al.* (1982); M. Aretz (2002a, 2016); D. Korn and R. Feist (2007); L. Pille (2008); L. Pille and D. Vachard (2011); D. Vachard *et al.* (2016a, 2016b).

Remarks. A long time ago, M. de Serres (1847), J. Fournet and M. Graff (1849), and J. Fournet (1850, 1854) described some lenses with productid brachiopods near the disused Laurens railway station, and established their Early Carboniferous age. As early as 1876, most of these Early Carboniferous *îlots* (= islets, small islands) were indicated in the map of P. de Rouville (1876). Then, the siliciclastic series, in which are included these carbonate lenses, were described and compared with the Culm of Germany (de Rouville, 1886; Bergeron, 1889, 1898, 1899, 1900 a, 1900b, 1912; B. Gèze, 1949; D. Vachard, 1974b; Aretz, 2016).

As redefined herafter, the Laurens-Cabrières Group corresponds more or less to the *calcaires à Productus* of the authors, in the Laurens, Gabian, Vailhan, and Cabrières areas. This group corresponds only partially to the Laurens Flysch Group of D. Korn and R. Feist (2007) and M. Aretz (2016), because we excluded the Flysch-units I and II from the new Laurens-Cabrières Group. As the International

Code of Stratigraphy indicates (Article 5.F.3, p. 41) that "(…) "flysch" should be avoided for formally named lithostratigraphical units", the name Laurens Flysch Group is modified here into Laurens-Cabrières Group, and re-defined.

Biostratigraphy: Some data on the ages of several carbonate olistoliths have already been published (Vachard *et al.,* 2016b). Additional data are in preparation (Vachard *et al.*, unpublished data).

Chronostratigraphy: Mikhailovian to Protvian.

Tectonics: The Mont Peyroux nappe and this basin were thrusted together southwards in their present location (see discussion later).

Regional variations: The detrital units of the group were well described (Engel *et al*., 1982). It is possible that more prodeltaic sediments exist around the village of Cabrières, within the Mougno-Les Batailles informal unit (see section 6.2.8).

Division into complexes:

Laurens Complex;

Roquessels Complex;

Vailhan-Cabrières Complex.

6.1.1. Laurens Complex (new complex)

Type locality: The initial reference, about the Laurens-Group and this Laurens Complex, was an outcrop near the railway station of Laurens (Fournet, 1847). W. Engel *et al.* (1982) described a lens with platform sandstone and limestone in the railway trench just SE of the crossing with the D136, but this latter likely differs from that of J. Fournet. Another locality, Les Jeantels, is proposed for this Laurens Complex.

Type section: Les Jeantels (x = 513.3, y = 4820.5).

Lithology: Complex with the Laurens-Cabrières Group, rare Lower Ordovician shaly olistoliths close to La Liquière, and abundant Viséan and Serpukhovian limestone olistoliths close to Laurens. This complex shows blocks in mudstone matrix, slumps, and calciturbidites (rudites) with diverse intraclasts (ooidal, micropelletoidal and micritic limestones), lithoclasts (metamorphic rocks, sandstone, and shale), bioclasts (foraminifers, tabulate corals, bryozoans, and crinoids), and quartz.

Boundaries: The contacts with the Fabrègues Formation, the Roquessels Complex and the Vailhan-Cabrières Complex are currently poorly defined.

References: M. de Serres (1847); J. Fournet and M. Graff (1849); J. Fournet (1850, 1854); B. Gèze (1949); M. Maurel (1966a); W. Engel *et al.* (1982); M. Aretz (2002a, 2016); D. Korn and R. Feist (2007).

Remarks: See the study of the Flysch-unit III of Engel *et al.* (1982).

Biostratigraphy: Some data on the ages of several carbonate olistoliths have already been published (Vachard *et al*., 2016b). The biostratigraphy of the calciturbidites is not clear, and the scarce elements, such as the incertae sedis algae *Praedonezella cespeformis* and *Zidella*, possibly indicate a Venevian age.

Chronostratigraphy: The olistoliths from this formation were dated Mikhailovian and Venevian (La Boutinelle), Venevian (La Balsas), Venevian and Tarusian (Les Jeantels), and Steshevian (Laurens station).

Tectonics: See the Flysch-unit III of W. Engel *et al.* (1982). On the other hand, the western part of this formation was linked to the Faugères nappe by some authors (Arthaud, 1970, fig. 22; Préat *et al*., 1999, fig. 1; Faure *et al*., 2010, fig. 2). However, this facies does not exist in the Faugères nappe.

Regional variations: No variations.

Division into formations: No divisions.

6.1.2. Roquessels Complex

This name is introduced herein to replace the term Roquessels band, previously used in the literature, because the word band has another meaning in the International Stratigraphic Code. D. Vachard (1974b, 1977) first defined this tectonosedimentary unit of the Roquessels band, because this area of the Cabrières klipppes *sensu* B. Gèze (1949) displayed a sedimentation of type Mont Peyroux and a stronger flow schistosity than the true Cabrières klippes. F. Arthaud (1970) already considered the outcrops of the Roquessels area as an individualized tectonic unit limited by a basal thrust. In contrast, R. Feist in M.-F. Perret (1990) and D. Korn and R. Feist (2007) did not distinguish the Roquessels Complex from the Mont Peyroux nappe, whereas W. Engel *et al.* (1982) and M. Aretz (2016) included it in the Flysch-unit IV, which is designated here as the Vailhan-Cabrières Complex.

The Roquessels Complex has a northern limit constituted by the Roquessels fault, and it is limited to the south by large Early Ordovician olistoliths (south and west of Montesquieu). The eastern and western limits are more disputable, because the Roquessels Complex laterally passes gradually into the eastern part of the Laurens Complex. Nevertheless, it seems to be logical to separate the Roquessels Complex from the Laurens and Vailhan-Cabrières complexes, because the Roquessels Complex contains many olistoliths of Mont Peyroux type, which are absent from the Laurens and Vailhan -Cabrières complexes. The Roquessels Complex contains the following formations: Lydiennes Fm, Faugères Fm, Colonnes Fm, Coteau de Bergue Fm, and the formations reworked in the *Lentilles de la route* D13 informal unit (Figs. 9-12).

6.1.2.1. Lydiennes Formation

In the Roquessels Complex, this formation mainly crops out in the Mont Mou (the type locality of the Faugères Fm), where it was mapped (Böhm, 1935; B. Gèze, 1949) as a syncline or synform over the flysch of the Laurens-Cabrières Group. Its approximate thickness is 10-15 m. The Lydiennes Fm has been also found as blocks (4 to 6 m in diameter) in the base of the sections of the Coteau de Bergue road, in the hills near the Coteau de Bergue, in the Malac railway trench, and as boulders in the *Lentilles de la route* D13 (Vachard, 1974b; Pille, 2008; Cózar *et al*., 2017).

Figure 9. Faugères Fm in Mont Mou. A. General view of Mont Mou. B. Lower part of the northern quarry, with the grainstone levels G1 to G7 (hammer = 28 cm long). C. Assymetric ripples (R) above G8. D. Shales interbedded with nodular limestones in the upper part of the quarry, G16 (hammer = 33 cm long).

Figure 9. *Formation de Faugères dans sa localité type du Mont Mou. A. Vue générale du Mont Mou avec indication de l'emplacement de la carrière nord (flèche). B. Partie inférieure de la carrière nord avec emplacement des niveaux de grainstones de G1 à G7 (le marteau mesure 28 cm de long). C. Rides asymétriques (R) au-dessus de G8. D. Argilites intercalées dans les calcaires noduleux de la partie supérieure de la carrière, G16 (le marteau a 33 cm de long).*

6.1.2.2. Faugères Formation (emend.)

Type locality: Mont Mou (= colline 246 = cote 246 = Le Pioch = cote 243 = hill 243; x = 516.6, y = 4821.3), designated by R. Böhm (1935).

Type section: The north quarry (x = 516.6, y = 4821.3) in a small hill within a vineyard, 2.5 km SSE of Faugères (Fig. 9A), on the left of the road D13 from Gabian to Faugères. In this hill, it is possible to recognize (1) the Lydiennes Fm, at the boundary with the vineyard, (2) the Faugères Fm, in two small quarries on the slope of the hill, and (3) the possible base of the Colonnes Fm in the small wood at the top of the hill.

Lithology: This formation is mostly composed of reddish-pinkish, ferruginized, nodular micrites. In Mont Mou, these nodular limestones are interbedded with grey to pale purple limestone levels (mostly grainstones, abbreviated and numbered G1 to G9 (Vachard, 1974b, 1977) or to G17 (Cózar *et al*., 2017; Figs. 4B, 9B-D). The grainstone levels are usually centimetric, rarely decimetric such as G8, finely granular, with an irregular and wavy base and top. The lithology of these grainstones is described by Cózar *et al.* (2017). Their components are mainly calcisphaeroids, uni- and multilocular foraminifers, ostracods, and crinoids; with subordinate kamaenaceans, bryozoans, molluscs, trilobites, and, rarely, small lithoclasts and quartz grains.

Boundaries: The lower contact with the lydites is well marked; the upper boundary with the lower part of the Colonnes Fm is probably more transitional, even if it is difficult to observe this everywhere.

References: R. Böhm (1935); B. Gèze (1949); M. Maurel (1956, 1966a); B. Mamet (1968); D. Vachard (1973, 1974b, 1977); J. Coudray *et al.* (1979); S. Crilat (1981); W. Engel *et al.* (1982); G. Flajs and R. Feist (1988); D. Korn and R. Feist (2007); P. Cózar *et al.* (2017).

Remarks: The old name of the formation is maintained here, even if the type locality does not belong to the Faugères nappe, and is located at the boundary of the Faugères, Roquessels, and Laurens administrative territories. M. Aretz (2016, fig. 2) located, in his map, an outcrop number 5 called Hill 243, and an outcrop 6 called Le Pioch; both are synonyms in the traditional literature and correspond to his locality number 6. Similarly, D. Korn and R. Feist (2007, fig. 1) have erroneously emplaced the Mont Mou in the Faugères nappe.

Nodular limestones and grainstones can be interpreted as outermost ramp or basinal hemipelagic limestones and calciturbidites, respectively (Cózar *et al*., 2017).

Biostratigraphy: The nodular limestone contains poor assemblages, mostly composed of parathuramminid foraminifers, calcispheroids, and globochaetaceans. The grainstones contain more diversified assemblages. The grainstones G1 to G8 yielded foraminifers, which indicate only the Tournaisian/Viséan (MFZ8/9) boundary interval, because of the absence of the best markers, *Eoparastaffellina* and *Eoparastaffella* (Fig. 4B). Nevertheless, the Tournaisian/Viséan (MFZ8/MFZ9) boundary in Mont Mou is probably located between G3 and G4, due to the first occurrence of the foraminifer *Lapparentidiscus* (Vachard *et al*., unpublished data; Fig. 4B); i.e., in a rather similar position as the Tournaisian-Viséan boundary indicated at the Puech de la Suque-section B by conodonts (Lethiers and Feist, 1991). In higher grainstone levels, the early Viséan MFZ10 and lower part of the MFZ11 zones are recognized (Vachard *et al*., unpublished data). D. Vachard (1974b, 1977) assigned the entire formation to the V1b (= Cf4β), because of the occurrence of the foraminifer *Planoarchaediscus* in Mont Mou. On the other hand, B. Mamet (1968) recorded primitive *Eostaffella*, *Permodiscus* and *Propermodiscus* at the same locality. These taxa characterize the upper Cf4α2, Cf4β and/or Cf4γ–δ in the Belgian stratotypes (Conil *et al*., 1991; Poty *et al*., 2006).

Chronostratigraphy: The recent revision of the ammonoids of the Faugères Fm has only provided late Tournaisian genera (Korn and Feist, 2007). However, due to the occurrence of the conodont *Scaliognathus anchoralis* Zone (latest Tournaisian) from the base of the formation, it is possible to infer that the Faugères Fm encompasses the latest Tournaisian and the entire early Viséan. *Scaliognathus anchoralis* has been also found in the Malac railway trench (Engel *et al*., 1982, p. 367).

Tectonics: The contacts with the underlying Lydiennes and overlying Colonnes are horizontal and sedimentary.

Regional variations: The formation is better exposed in the Roquessels Complex (where its maximum thickness is 12 m in the northern quarry of Mont Mou) than in the Mont Peyroux nappe. Moreover, Mont Mou is the single locality, where the nodular limestones alternate with relatively numerous, thin grainstone levels. Nevertheless, the southern quarry (x = 516.5, y = 4821.1) of Mont Mou, which contains similar thickness of nodular limestones as the northern quarry, displays a lesser amount of grainstone beds, mostly concentrated in the upper part of this quarry. In the Roquessels Complex, outside of Mont Mou, small coeval outcrops (Coteau de Bergue road and Coteau de Bergue hill) exhibit only one or two grainstone beds. The grainstone levels are even apparently absent in the Malac railway trench, and in the *Lentilles de la route* D13, as well as in the outcrops of the Mont Peyroux nappe.

Division into members: No subdivisions.

6.1.2.3. Colonnes Formation

Small outcrops of this formation (principally described here in the Mont Peyroux and Vissou chapters), exist in the Roquessels Complex; especially in Mont Mou, the Malac railway trench (Figs. 5E, 10A-C), the *Lentilles de la route* D13 (Fig. 10D), and the Coteau de Bergue road and hill sections (Fig. 11), as olistoliths displaying very incomplete successions. The longest succession is observed in the Malac railway trench section (Maurel, 1956; D. Vachard, 1974b, 1977; Cózar *et al*., 2017; Figs. 5E, 10A-C). There, a composite succession can be inferred from two sections (6 m and 8 m thick, respectively), separated by faults. These Colonnes of Malac are more comparable to those of Pic de Vissou than those of Puech de la Suque (Figs. 5A-E, 13F-G), because they are composed of numerous intraclastic-bioclastic limestones interbedded with greenish lydites, and medium- to coarse-grained limestones are more common than in the overturned limb of the Mont Peyroux nappe (Cózar *et al*., 2017).

Figure 10. Outcrops of the Roquessels Complex. A. Colonnes Fm in the Malac railway trench, which is 8 m deep. B. Contact between the Colonnes Fm (bottom, with the hammer = 28 cm long) with the overlying shales of the Laurens-Cabrières Group (top), in the Malac railway trench. C. Mud mound olistolith belonging to the Coteau de Bergue Fm in the Malac railway trench. D. Megabreccia and debris flows in the *Lentilles de la route* D13.

Figure 10. *Affleurements du Complexe de Roquessels. A. Formation des Colonnes dans la tranchée du chemin de fer de Malac dont la profondeur est de 8 m. B. Contact entre les Colonnes (longueur du marteau, 28 cm) avec les argilites sus-jacentes du Groupe de Laurens -Cabrières, dans la tranchée du chemin de fer de Malac. C. Olistotithe constitué par un mud mound appartenant à la Formation du Coteau de Bergue, dans la tranchée du chemin de fer de Malac. D. Méga-brèche et coulée de débris des Lentilles de la route D13.*

6.1.2.4. Coteau de Bergue Formation (new formation)

Type locality: Right border of road D136 (to Fos) and adjacent hills (Coteau de Bergue).

Type section: Coteau de Bergue (x = 519.5, y = 4822.4).

Lithology: This formation, about 45 m thick, is composed of massive to roughly bedded dark grey limestones, slightly better stratified in the upper part of the formation, in beds approximately 0.5 m thick (Fig. 11). Limestones are mostly micrites, micropeloidal matrix- or cement-supported, and rarely, have cementstone and peloidal textures. The microfacies is affected by a weak flow schistosity. The cyanobacteria *Ortonellopsis* is the principal constituent, in association with kamaenaceans, aoujgaliaceans, foraminifers, fenestellid bryozoans, brachiopods, ostracods, and crinoids. Large stromatactis occasionally occurs in the middle and upper parts of the formation. Micritization is common in the upper better bedded levels. At the top of the formation, a carbonate breccia is recognized (Cózar *et al*., 2017; Fig. 11).

Boundaries: The lower contact, with the Colonnes Fm is probably faulted, and the upper contact is the boundary of the olistolith with the Laurens-Cabrières Group.

References: B. Gèze (1949, fig. 82); D. Vachard (1974b, 1977); P. Cózar *et al.* (2017, fig. 12).

Remarks: Those limestones are interpreted as microbial mounds, with isolated, floated material (dasycladales, foraminifers; Cózar *et al*., 2017). Because of the large stromatactis, paucity of micritization processes by endolithic, photic algae, and abundance of cyanobacteria, these mounds were probably growing mostly in dysphotic conditions (Bridges *et al*., 1995; Cózar *et al*., 2006, 2017), or even in aphotic conditions. The breccias situated at the top may be considered as the capping beds of the mounds (Cózar *et al*., 2017). They differ by their Tarusian age from the carbonate breccias that predate the Puech Capel Mb in the Mont Peyroux nappe.

Biostratigraphy: The lower samples of the mounds contain Cf6α-β foraminifers: *Archaediscus* ex gr. *karreri*, *Vissariotaxis* sp., and *Omphalotis omphalota*. Then, the lower Cf6γ is characterized by *Cribrospira panderi* and *Endothyranopsis crassa*, whereas the upper Cf6γ-lower Cf6δ (= Mikhailovian-Venevian) are characterized by *Janischewskina* sp. and *Howchinia gibba*. The upper part of the succession is assigned to the earliest Serpukhovian (Tarusian) due to *Janischewskina gibshmanae* and *Biseriella* spp.

Chronostratigraphy: Late Viséan to earliest Serpukhovian.

Tectonics: Resedimented carbonate build-ups.

Regional variations: The upper part of this formation is obvious in the Malac railway trench (x = 516.5, y = 4821.9; Fig. 10C, see later).

Division into members: No subdivisions.

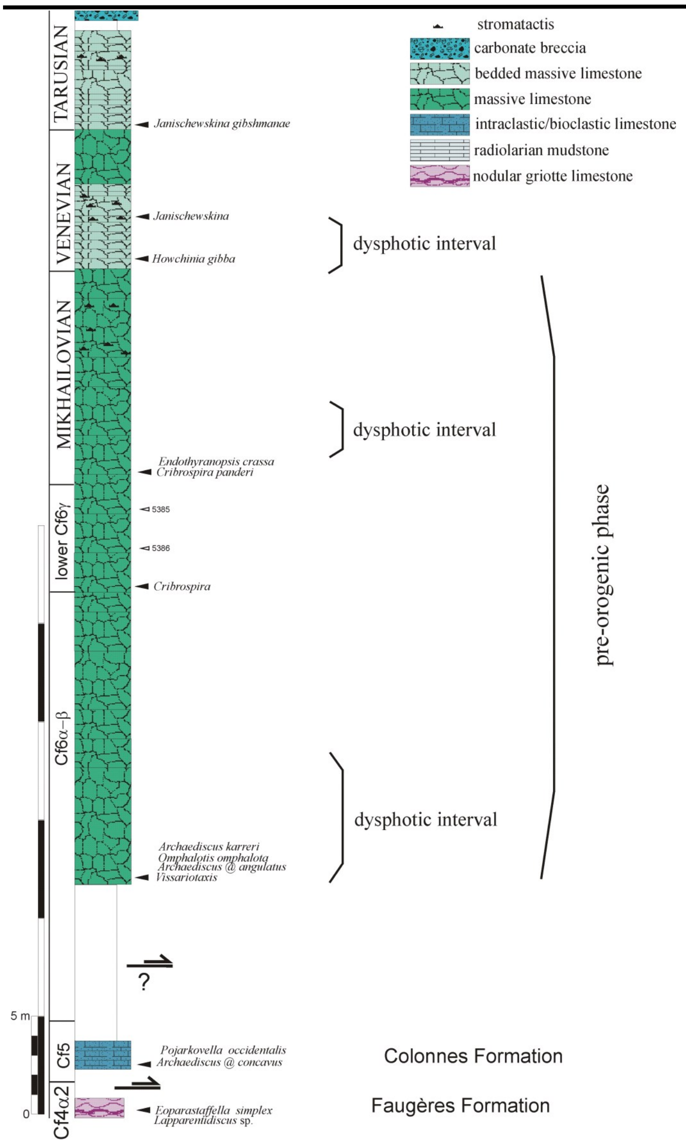

Figure 11. Coteau de Bergue Fm type section (according to Cózar *et al.*, 2017, fig. 12 slightly modified).

***Figure 11.** Section type de la Formation du Coteau de Bergue (d'après Cózar* et al.*, 2017, fig. 12 légèrement modifiée).*

6.1.2.5. *Lentilles de la route D13* (partly, *Grauwacke de Roquessels*)

Type locality: The D13 road (Faugères-Gabian) area, from Malac to Roquessels.

Type section: Left border of the D13 road, from the Malac bridge to the Roquessels crossing.

Lithology: Megabreccia composed of numerous small and large olistoliths, slumps, fragments of turbidites, pebbles, boulders, and carbonate breccias (Figs. 10D, 12).

Boundaries: This megabreccia is included in the Roquessels Complex. Its cartographic limits are those of the map of W. Engel *et al.* (1982), from the D13 road to Coteau de Bergue.

References: J. Bergeron (1899 and 1900a, p. 655-656; 1900b, p. 29); J. Vidal (1952); R. Racionero (1967); F. Arthaud (1970); D. Vachard (1974a, 1974b, 1977); W. Engel *et al.* (1978, 1982, fig. 7); L. Pille (2008); L. Pille and D. Vachard (2011); P. Cózar *et al.* (2017).

Remarks: Brachiopods (*Spirifer tornacensis* and *Productus semireticulatus*) were described from this formation, at the end of the 19th Century (Bergeron, 1899). The first mention of this formation as *grauwacke de Roquessels* was made by J. Vidal (1952) (see Racionero (1967) and Vachard (1974b), and references therein). This name was re-used by F. Arthaud (1970, fig. 25), and then was forgotten. Some carbonate lenses (probable slumps and boulders) were mentioned by D. Vachard (1974b) along the road, near the *embranchement* (crossing) of Roquessels. D. Vachard (1977) introduced the name *Lentilles de la route*. Due to the correction of the D13 road profile, the outcrop is currently very conspicuous between the Malac railway bridge and the crossing to Roquessels. It includes a great mixture of boulders and cobbles coming from numerous formations present in the Roquessels Complex: Lydiennes, Faugères, and Coteau de Bergue, but also from Oolites of Roc de Murviel, Roque Redonde and Roc de Murviel, which are more typical of the Vailhan-Cabrières Complex. Geographically, and probably also palaeogeographically, this megabreccia, and the Roquessels Complex in general, are probably the key sector of the southeastern Montagne Noire, because of the different origins of olistoliths and Coteau de Bergue new formation formed by a microbial mound contemporaneous with the Colonnes Fm.

Biostratigraphy: Dated by foraminifers from limestone olistoliths (see Cózar *et al.*, 2017). Numerous brachiopods have been also found (see Racionero, 1967).

Chronostratigraphy: Boulders in the megabreccia include the Lydiennes Fm, Colonnes Fm (dolomitized and silicified limestone), and late Viséan to early Serpukhovian limestones.

Tectonics: Olistostrome within the Roquessels Complex (due to the arguments indicated earlier), previously mapped in the Vailhan-Cabrières Complex (Engel *et al.*, 1982).

Regional variations: No variations.

Division into members: No subdivisions.

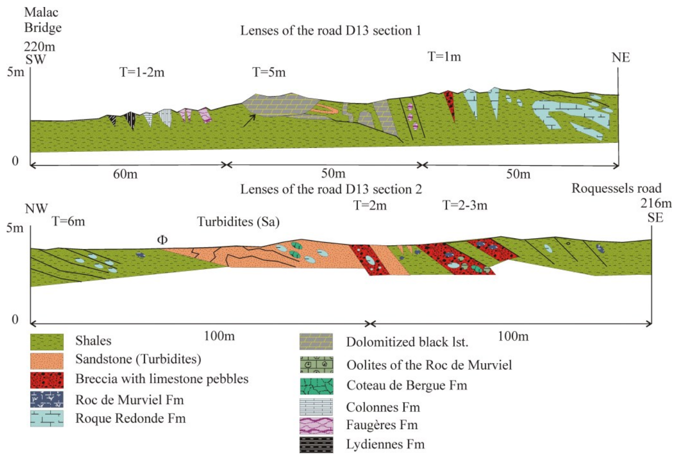

Figure 12. Scheme of the *Lentilles de la route* D13, from the Malac bridge to the Roquessels crossing.

***Figure 12.** Schéma des Lentilles de la route D13, du pont de Malac à l'embranchement de Roquessels.*

6.1.3. Vailhan-Cabrières Complex

The Vailhan-Cabrières Complex corresponds to the central and eastern parts of the Flysch-unit IV of Engel *et al.*

(1982) and is composed of different klippes: Vissou klippe (overturned limb of Mont Peyroux nappe); La Serre klippe (normal limb of the Mont Peyroux nappe), and olistoliths, coming from the normal limb of Mont Peyroux, which have been described by J. Bergeron (1898, 1900a, 1900b); B. Gèze (1949); M. Maurel (1966a); F. Arthaud (1970); D. Vachard (1974a, 1974b, 1977); W. Engel *et al.* (1982, fig. 7); R. Feist and J. Galtier (1985); L. Pille (2008); L. Pille and D. Vachard (2011); and P. Cózar *et al.* (2017). They are mainly composed of:

- Lower Ordovician large olistoliths.
- Lower Devonian dolomitized hills (the *causses dévoniens* = Devonian carbonate hills), often with mineralized barytine and copper.
- Other Devonian outcrops (Les Batailles, Le Cauquillou, Pitrous creek, Japhet (pars), and Mougno (pars)), with, successively, Lower Devonian limestone with silicified corals, Givetian crinoidal limestones, Frasnian black shales with pyritized ammonoids, black lydites with styliolinids, and griotte limestone (early Famennian to early late Famennian).
- A Devonian and late Tournaisian-early Viséan klippe in Tourière, Escandolgue and Mougno (TEM), the series of which is probably partly reworked in the olistoliths of Combe Rolland.
- A middle Viséan series in Valuzières.
- Various small, late Viséan-early Serpukhovian carbonate build-ups; e.g., on the slopes of Tourière and Les Batailles (Bergeron, 1899, text-fig. 2, lens number 7; Vachard, 1974a, 1974b, 1977; Ernst and Vachard, 2017); slopes of Valuzières and Les Mentaresses (Vachard, 1974b); in Les Pichaures and Roque Fenêtre (this study); and in Castelsec.
- Medium-sized olistoliths, Mikhailovian-Tarusian in age: Les Pascales, Roc du Cayla, and Roquemalière.
- Some larger, resedimented carbonate build-ups, such as *l'Echarpe à l'espagnole* (the Spanish scarf) (de Rouville, 1886, 1887; Bergeron, 1898, 1899; B. Gèze, 1949) with the outcrops in Boyne creek, the early late Serpukhovian (Protvian) of Japhet-bridge, and the La Serre de Péret hill outcrops (Aretz, 2002a; Pille, 2008; Vachard *et al.,* 2016a, 2016b).
- These resedimented carbonate build-ups are re-deposited in the Laurens-Cabrières Group which is, in Cabrières, locally richer in terrestrial plants than the other detrital units (Barrac Fm, Fabrègues Fm, and Laurens Complex). As a consequence, the Laurens-Cabrières Group is sometimes considered deltaic (Aretz, 2016) or prodeltaic (Ernst and Vachard, 2017) in Cabrières (see section 6.2.8). Nevertheless, it is likely that these deltaic sectors represent olistoliths in the flysch of the Laurens-Cabrières Group.

6.1.3.1. Vissou klippe

Many authors admit currently that this unit represents a klippe detached from the Mont Peyroux nappe (Vachard, 1974b, 1977; Engel *et al*., 1982; Feist and Klapper, 1985). The re-studied succession of the Vissou klippe includes the following formations:

Figure 13. The Colonnes Fm at the type locality of Pic de Vissou and Puech de La Suque trail (according to Cózar *et al.,* 2017, fig. 9 modified). A. General view of Pic de Vissou with its overturned succession: the thick upper cliff is composed of Middle Devonian limestones; the first bushy area corresponds to the Devonian griottes and supragriottes and to the Lydiennes Fm; the lower cliff is the type locality of de Rouville (the section of Fig. 5D is measured in the left side of this lower cliff); the flysch, equivalent to the Puech Capel Member, is observed in the bushy slope of the hill. B. Channel with laminated limestone and olistolith at the section base in Vissou. C. Parallel and oblique laminated limestone at 4-5 m from the base in Vissou; thickness of the bed = 0.5 m. D. Slump and block at 2 m from the section base in Vissou. E. Alternation of laminated grey limestone and ochreous chert at 21 m in Vissou; thickness of the limestone = 0.5 m. F. Radiolarian mudstones (cliff = 6 m thick) in Puech de la Suque trail. G. Detail of the base of the Colonnes Fm, with alternating mudstones (m), cherty beds (ch) and bioclastic calciturbidites (b), in Puech de la Suque trail (hammer = 28 cm long).

Figure 13. *La Formation des Colonnes dans sa localité type du Pic de Vissou et sur le chemin du Puech de la Suque (selon Cózar* et al.*, 2017, fig. 9 modifiée). A. Vue générale du Pic de Vissou. La série étant inverse, on trouve successivement, à partir du sommet, une épaisse falaise supérieure composée de calcaires du Dévonien moyen, puis une zone boisée qui correspond aux griottes dévoniennes et aux lydiennes, puis une falaise inférieure qui est la localité type des Colonnes de de Rouville (la coupe de la Fig. 5D a été levée à gauche de cette falaise inférieure); puis un flysch, équivalent du Membre de Puech Capel, s'observe sur la pente boisée inférieure. B. Chenal avec calcaires laminés et olistolithe à la base de la coupe du Pic de Vissou. C. Calcaires à laminations parallèles et obliques à 4-5 m de la base de la coupe du Pic de Vissou (épaisseur du banc = 0,5 m). D. Slump et bloc à 2 m de la base de la coupe du Pic de Vissou. E. Alternances de calcaires gris laminés et cherts ocres (épaisseur du calcaire = 0, 5 m) à 21 m sur la coupe de Vissou. F. Mudstones à radiolaires (la falaise est haute de 6 m) sur le chemin du Puech de la Suque. G. Détail de la base des Colonnes, avec des alternances de mudstones (m), de bancs de jaspes (ch) et de calciturbidites bioclastiques (b) sur le chemin du Puech de la Suque (la longueur du marteau est de 28 cm).*

6.1.3.1.1. Lydiennes and Faugères formations

See Mont Peyroux nappe and Roquessels Complex chapters (sections 5.1.1 and 6.1.2.1). The lydiennes of Pic de Vissou have been mentioned for a long time in the literature (de Rouville, 1868).

6.1.3.1.2. Colonnes Formation

Type locality: Southern slope of the Pic de Vissou; the lower cliff, very visible from the northern exit of Cabrières (de Rouville, 1887, p. 15: "*nous avons donné à cette série d'assises le nom de système des colonnes*" (we gave to this succession the name of "columns' system")).

Type section: The cliff located to the east of the top of 480 (as suggested by de Rouville, 1887), and its lateral equivalents between Vissou and Vissounel (more easily accessible nowadays). The sampling was done in the cliff close to the track which goes down from the delta-plane runway of Pic de Vissou (Figs. 5D, 13A-E).

Lithology: This formation is 25 m thick in Pic de Vissou (Cózar *et al.,* 2017; Fig. 13A) and is composed of calciturbidites, hemipelagic limestone and chert (Fig. 13B-E). The lower part presents slumps and blocks (Fig. 13B-D), and thick limestones with parallel and oblique laminations (Fig. 13C). These limestones are packstone and wackestone with foraminifers, sponge spicules, and lithoclasts, which consist of many graded beds corresponding to the amalgamated sequences Ta of A. Bouma (1962). The mid-part contains grainstone, packstone and wackestone with foraminifers and lithoclasts. The upper part is mainly covered, but shows a carbonate breccia (Fig. 6D).

Boundaries: The lower contact with the Faugères Fm is sedimentary and the upper contact with the equivalent of the Puech Capel Mb in Vissou-Vissounel is faulted (Fig. 5D).

References: P. de Rouville (1868, 1884, 1887); P. de Rouville and A. Delage (1892); J. Bergeron (1899, 1900a); B. Gèze (1949, 1979); M. Maurel (1966 a, 1966b); D. Vachard (1974b, 1977); S. Crilat (1981); R. Feist and G. Klapper (1985); D. Korn and R. Feist (2007); P. Cózar *et al.* (2017).

Remarks: In 1887, P. de Rouville has named *colonnes*, the alternation of limestone and lydite previously described by him (de Rouville, 1868; as "shaly limestones and lydites"). P. De Rouville and A. Delage (1892) named it *assise des colonnes*. The name *calcaires à colonnes du Pic de Bissous* is also mentioned (Gèze (1979, p. 17).

Biostratigraphy: The lower part of the succession is assigned to the middle Viséan (Cf5), and the upper part to the lowermost late Viséan (Cf6α-β) by foraminifers (Cózar *et al*., 2017; Vachard *et al*., unpublished data). Levels attributed to the Cf6γ or younger are only recorded in flysch slumps. Nevertheless, D. Vachard (1974b) recorded *Koskinobigenerina* in the younger levels, although in the biostratigraphic revision of the sections, such a taxon has been only recorded from the slumped beds in the overlying flysch (Vachard *et al*., unpublished data). The same problem exists in the Mont Peyroux nappe (see earlier: section 5.1.4).

Chronostratigraphy: Middle-early late Viséan.

Tectonics: Originally located in an equivalent of the overturned limb of the Mont Peyroux nappe.

Regional variations: Perhaps, this series partly corresponds also to the *partie inférieure des schistes et calcaires à* Productus semireticulatus *du Pic de Bissous* (lower part of shales and limestones with *Productus semireticulatus* of Bissous Peak) of B. Mamet (1968). According to S. Crilat (1981), this latter is situated in the lower part of the flysch of Vissou. However, in this case, its dating, as V2a-V2b (= Cf4γ-Cf5) by B. Mamet (1968), would be largely misinterpreted.

Division into members: No subdivisions.

6.1.3.1.3. Informal flysch unit on the slope of Vissou-Vissounel

See discussion in Barrac Fm (section 5.2.2). The flysch succession in Pic de Vissou contains carbonate and sandy turbidite slumps (Fig. 7C-D), blocks of sandy turbidite, and a conglomerate channel with white quartz veins and black lydite, in Dauterribes close to D15. This facies was deposited on the slope and came from the hinge of the Mont Peyroux recumbent fold (Engel *et al.,* 1982). This unit probably corresponds to the Puech Capel Mb (see section 5.2.1), but with deposits located higher on the slope with more slumps. The upper part of the flysch looks like the Puech Capel Mb sedimentation, but with disorganized sandy turbidites. This flysch does not present limestone blocks dated as latest Viséan and Serpukhovian.

6.1.3.1.4. Resedimented build-ups near Vissou

South of the Pic de Vissou, Les Pichaures are two small olistoliths located above the base of a larger Ordovician olistolith (x = 532.1, y = 4827.8). They contain an alternation of limestone with corals and shale in normal series dated as Steshevian in the lower olistolith, and microbial limestone dated as Venevian in the upper olistolith.

Other small carbonate olistoliths, located south of the Vissou thrust and possibly pushed up at the front of the Vissou klippe, were found at the base of an Ordovician outcrop. They are located between Roque Fenêtre and the car park of the Pic de Vissou trail close to the bridge and a vineyard (x = 529.4, y = 4825.75). They are dated Mikhailovian, Venevian and Protvian, and are comparable to the olistoliths of the Laurens-Cabrières Group growing on the upper slope, and belonging to the Roque Redonde and Roc de Murviel formations (see later, sections 6.2.5 and 6.2.6).

6.1.3.2. La Serre klippe

This unit is a narrow, oblique, SE-NW oriented klippe, sandwiched between Devonian klippes and siliciclastic units. It is famous, because it exhibits the Devonian/Carboniferous GSSP boundary. East of the D/C stratotype, a stratigraphical succession, distinct from that at Mont Peyroux, is recorded, even if it is strongly faulted, and that numerous repeated parts have been recognized. Overlying the Devonian/Carboniferous boundary interval, the succession starts with a few black lydites, traditionally considered as equivalent of the Lydiennes Fm. Higher up, there is a lithostratigraphical combination of local formations and of formations recorded in other parts of the Vailhan-

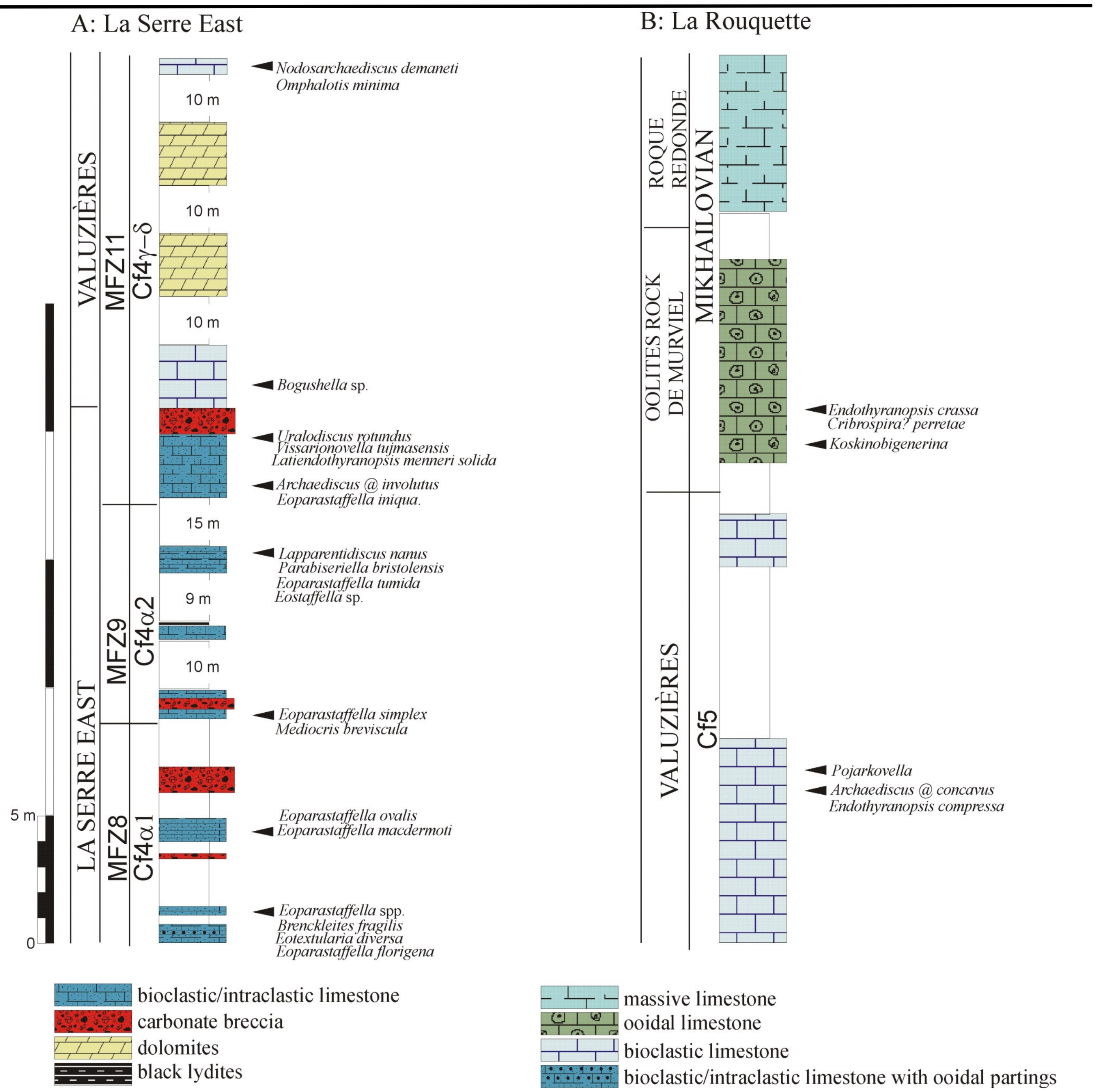

Figure 14. Sections in the La Serre klippe (according to Cózar *et al*., 2017, fig. 14 slightly modified). A. La Serre East Fm type section. B. Unamed series of outcrops near La Rouquette house.

Figure 14. *Coupes dans l'écaille de La Serre (d'après Cózar* et al.*, 2017, fig. 14 légèrement modifiée). A. Localité type de la Formation de La Serre-Est. B. Unité informelle proche du mas de La Rouquette.*

Cabrières Complex (Fig. 14A-B). The Mississippian succession of La Serre klippe is composed, from bottom to top, of: (1) the uppermost beds of the D/C stratotype; (2) Lydiennes (not observed); (3) La Serre East Fm (new formation); (4) an unnamed series which includes some equivalents of units described later (sections 6.23, 6.24, 6.25, and 6.2.6): Valuzières, Oolites of Roc de Murviel, Calcaires stratiformes de Vailhan and Roc de Murviel (this latter is only represented in the La Serre Vineyard section).

6.1.3.2.1. Lydiennes Formation?

The lydiennes of La Serre have been described by L. Cayeux (1939, pl. 4, fig. 12); B. Gèze (1947, 1949); D. Michel (1981); and W. Engel *et al*. (1982). The outcrop mentioned by L. Cayeux (1939) as "Combe de la Serre" is unknown in the literature, and, currently, there are no exposures of those lydiennes in La Serre. They were nonetheless studied by D. Michel (1981) after the digging of a trench by a power shovel. Their thickness is 7-8 m and their lithology is composed of an alternation of black lydite and shale (Cózar *et al*., 2017, fig. 3).

6.1.3.2.2. La Serre East Formation (new formation)

Type locality: Southeastern exposures of the La Serre hill.

Type section: East of the D/C stratotype (x = 529.5, y = 4822.5).

Lithology: This formation, approximately 32 m thick, is composed of well-bedded pale grey bioclastic limestones and carbonate breccias, with frequent covered intervals

(Cózar *et al*., 2017). Rarely, chert bands and chert nodules have been observed. Despite the poor exposures of this limestone, it can be defined as a formation, because its lithological features are sufficiently distinct from coeval limestones (Fig. 14A). Microfacies are mainly fine- to medium-grained, laminated grainstone with fining upward sequences, and well-sorted, poorly packed, fragmented components. Locally, breccias contain centimetric-elongated clasts as well as chert clasts (either from true lydiennes or from chert nodules also found in the formation) (Fig. 14A).

Boundaries: Both contacts are inconspicuous. The base is covered, and probably faulted because it is located less than 20 m from the late/latest Famennian supragriottes. As a consequence, the earliest Tournaisian beds of the D/C stratotype, as well as the middle Tournaisian lydiennes are probably absent due to faults. Furthermore, lateral to this base, a limestone block attributed to the middle Viséan, 4 m thick, has been found, confirming the intense faulting.

References: W. Engel *et al.* (1982); P. Cózar *et al.* (2017).

Remark: These accumulations are interpreted as proximal to distal tempestites on a middle platform (Cózar *et al.,* 2017). The brecciated levels have been sedimentarily or tectonically produced.

Biostratigraphy: The lower 5 metres of the section are latest Tournaisian Cf4α1 in age, based on primitive *Eoparastaffella* sp. The upper 30 metres contain *Eoparastaffella simplex*, *Mediocris breviscula* and *Eostaffella* sp., and are earliest Viséan MFZ9 (= Cf4α2) in age. On the other hand, W. Engel *et al.* (1982, fig. 6) have dated, by conodonts, bioclastic limestones with chert as late Tournaisian, and nodular limestones (not seen by us) as early Viséan. In contrast, one isolated outcrop of this formation contains species of the foraminifers *Archaediscus* and *Pirletidiscus*, which indicate the uppermost Cf4δ (Vachard *et al.,* unpublished data).

Chronostratigraphy: Latest Tournaisian and late early Viséan.

Tectonics: La Serre hill shows a normal dip southwards and is a klippe that comes from the normal limb of the Mont Peyroux nappe. The lower and upper boundaries of the La Serre East Fm are currently inconspicuous (see, however, the old field observations of Engel *et al*., 1982, fig. 6). The lower contact is probably with the equivalents of the Lydiennes Fm on one side, and the Valuzières Fm on another side.

Regional variations: No variations due to the covered area and the sporadic outcrops.

6.1.3.2.3. Other carbonate outcrops near the Mas de La Rouquette

Discontinuous outcrops composed of 40 m of massive bioclastic limestones and dolomites, in beds up to 3-4 m thick, as well as carbonate breccias previously included in the log of the platform facies (Engel *et al*., 1982, fig. 6), have been found in La Serre. Chert nodules are common in the limestones. The upper part of this series is coarsely bedded, with metric beds (Fig. 14B). Close to La Rouquette house (x = 528.5, y = 4822.5), 15 metres of this limestone are also exposed.

These carbonates are proximal storm deposits on a mid-ramp, which seem to be similar to other sedimentary units of the Vailhan-Cabrières Complex: Valuzières, Oolites of Roc de Murviel, and Roque Redonde (Cózar et *al*., 2017, fig. 14). They contain, indeed: (1) MFZ11 (Cf4γ/δ foraminifers: *Archaediscus* at *involutus* stage, *Omphalotis minima*, *Uralodiscus rotundus*, and *Vissarionovella tujmasensis*; (2) middle Viséan foraminifers: *Archaediscus* at *concavus* stage transitional to the *angulatus* stage, *Endothyranopsis compressa* transitional to *E. crassa*, and *Lituotubella magna*; (3) in outcrops close to La Rouquette, the middle Viséan assemblage shows *Pojarkovella nibelis*, *P. occidentalis*, *P.* spp., *Koskinotextularia* sp., and *Mirifica intermedia* (Vachard *et al*., unpublished data). It is noted that this latter outcrop was dated as V3bβ (= Cf6β) by W. Engel *et al.* (1982; fig. 6), and included in the upper part of the section in La Serre. The foraminiferal assemblages recorded by us in those levels do not contain any late Viséan foraminifers. The misinterpreted V3bβ dating of W. Engel *et al.* (1982) is probably due to the presence of large *Eoparastaffella iniqua* confused by these authors with a *Pseudoendothyra*. Furthermore, the currently covered parts of the succession were considered as breccias by W. Engel *et al.* (1982), even if no Cf6γ breccias were seen in La Serre by our team. In addition, the thick oolitic interval in this upper part is probably resedimented in the flysch, because it contains late Viséan (Mikhailovian) foraminiferal and algal assemblages, similar to those recorded in the Roque Redonde Fm and the Roc de Murviel Fm, or in some olistoliths of the *Lentilles de la route* D13 (Vachard *et al.,* 2016a, 2016b; Cózar *et al*., 2017).

The La Serre Vineyard section, formed by microbial limestone rich in algae and corals (Vachard and Aretz, 2004), ends the sedimentation in La Serre during the Steshevian and Protvian (Vachard *et al*., 2016b). La Serre Vineyard and Roc de Murviel contain similar endemic rugose corals of the subgenus *Lonsdaleia* (*Serraephyllum*) (Poty and Hecker, 2003).

6.2. Other formations of the Vailhan-Cabrières Complex

This Complex contains typical formations, resedimented in the basin, from late Tournaisian to late Serpukhovian, and located now in diverse klippes and olistoliths: Tourière, Combe Roland, Valuzières, Oolites of Roc de Murviel, Roque Redonde, Roc de Murviel and La Serre de Péret.

6.2.1. Tourière Formation (new formation)

Type locality: Tourière hill near Cabrières; a klippe, which displays a normal dip towards the South-East at the North and towards North-East at the South (Fig. 15A).

Type section: Southern slope of Tourière, from SSE of the top of 281 to the trough (*abreuvoir*: x = 527.6, y = 4842.5) (Engel *et al*., 1982; Figs. 15A, 16A).

Lithology: The formation, ca. 10 m thick, is located in a klippe of Cabrières that encompasses the three hills of Tourière, Escandolgue, and Mougno (Figs. 15A-C, 16A-B, 17A-B). It was also found in olistoliths of Combe Rolland and Valuzières-sommet 223, north of Gabian (Figs. 16A-B, 17C-D). It is a typically red nodular limestone, ammonoid-bearing, with thin partings of reddish and greenish shales between the nodules. Because of this lithology, the limestone was for a long time confused with the early Famennian *vraies griottes*. It was distinguished under the name of *secondes griottes* by D. Vachard (1974b, 1977). Microfacies are ferruginous mudstones, with calcisphaeroids, foraminifers, solitary rugose corals, fenestellid bryozoans, brachiopods, molluscs, ostracods, trilobites, crinoids, and negligible quartz grain percentages.

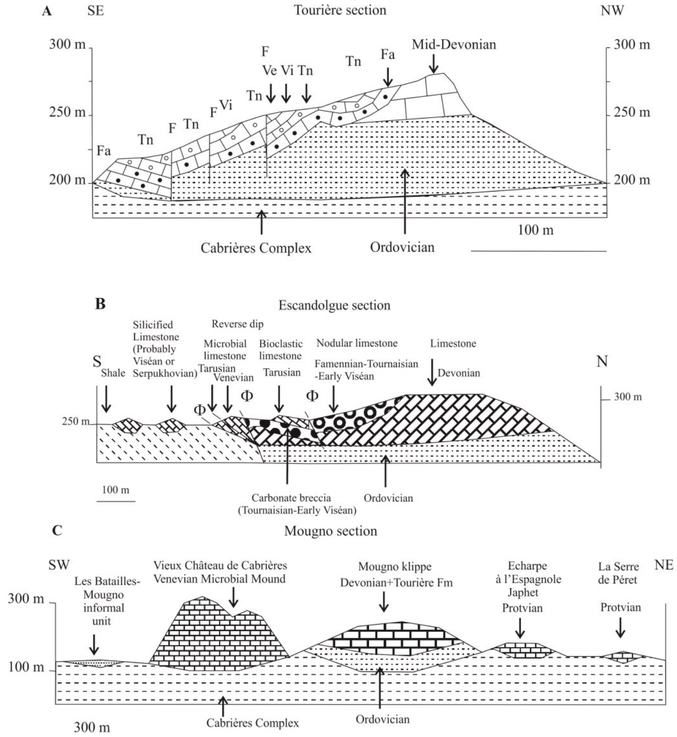

Figure 15. Sections in the Tourière hill (A), Escandolgue hill (B), and Mougno hill (C). F: Fault, Φ: Thrust, Fa: Famennian, Tn: Tournaisian, Vi: Early Viséan, and Ve: Venevian.

***Figure 15.** Coupes dans les collines de Tourière (A), de l'Escandolgue (B) et de Mougno (C). F: Faille, Φ: Chevauchement, Fa: Famennien, Tn: Tournaisien, Vi: Viséen inférieur, Ve: Venevien.*

Boundaries: The lower boundary is a stratigraphic transgressive contact with the late early Famennian (= lower supragriottes = DFZ3; Engel *et al.,* 1982, pl. 3, fig. 6). The upper boundary is transitional with the Combe Rolland Fm (Figs. 16A, 17D).

References: P. de Rouville (1884); J. Bergeron (1899); B. Gèze (1949, fig. 84); M. Maurel (1957, 1966a); D. Vachard (1973, 1974b, 1977); W. Engel *et al.* (1982); P. Cózar *et al.* (2017, figs. 17-18).

Remarks: Consistent with the rules of the International Stratigraphic Code, the name Tourière Formation is proposed here to replace the name *secondes griottes* (Vachard, 1973, 1974b, 1977). M. Maurel (1957, 1966a) did not give a type locality; D. Vachard emphasized the *secondes griottes* of Combe Rolland (Fig. 17C) but did not formally designate it as the type locality. Hence, we select here Tourière as type locality.

The Tourière Fm is the oldest Mississippian unit in the Vailhan-Cabrières Complex, where the lydites are absent. In contrast, these oldest Mississippian strata of the Vissou klippe are the Lydiennes derived from an overturned limb of one of the several folds of the Mont Peyroux nappe; those of La Serre klippe are the shallow limestones of the La Serre East Fm.

Biostratigraphy: The conodonts and ammonoids recorded at the different outcrops (Maurel, 1957; Remack-Petitot, 1960; Hoffmann, 1969; Engel *et al.*, 1982) were considered as V2a (= Cf4δ) by D. Vachard (1973, 1974b). However, new samples collected in the Tourière section only contain foraminifers assigned to the latest Tournaisian (MFZ8 = Cf4 α1) (e.g., *Eoparastaffellina* spp. and *Parabiseriella bristolensis*), similar to those described by D. Vachard (1973, 1974b), and the transition into the Viséan could not be characterized by foraminifers (Vachard *et al.*, unpublished data). However, Engel *et al.* (1982) identified the base of the Viséan by means of conodonts (*G. homopunctatus* and *M. beckmanni*) at 6 m above the base of the formation in Tourière, 3.5 m above the base in Escandolgue, and 1 m above the base in the Valuzières section.

The Tourière Fm ranges from the latest Tournaisian (MFZ8 = Cf4α1) to possibly the earliest Viséan (MFZ9 = Cf4 α2). Its upper part is MFZ11 (= Cf4γ), in Combe Rolland, contains the foraminifers *Archaediscus* at *involutus* stage and transitional to the *concavus* stage. Nevertheless, MFZ10 (= Cf4β) assemblages have not been recognized in between.

Chronostratigraphy: Latest Tournaisian to latest early Viséan.

Tectonics: All the outcrops of this formation are resedimented. Nevertheless, the lower boundary seems to be a normal contact with the *vraies griottes*, and in Valuzières-sommet 223, the contact is normal with the Combe Rolland Fm.

Regional variations: This formation crops out in the different hills of TEM (Tourière, Escandolgue, and Mougno) a composite klippe (Fig. 15A-C), but the gap between Tournaisian and Famennian is more important in Escandolgue (up to the former ds IIβ) than in Tourière (up to ds IIIα) (Engel *et al.*, 1982, fig. 6), probably due to sedimentation in different compartments at the basin border. The olistolith of Combe Rolland measures only 2.50 m in thickness (Fig. 17C).

Division into members: No subdivisions.

6.2.2. Combe Rolland Formation (new formation)

Type locality: Combe Rolland, south of Mas Rolland and at the foot of the Roc de Murviel.

Type section: Along the road D146, at the bottom of the Roc de Murviel (x = 523.1, y = 4822) (Cózar *et al.*, 2017, fig. 18C; Fig. 17C).

Lithology: Pale grey to pink massive to thickly bedded limestone (Cózar *et al*., 2017), 1.40-4.00 m thick, composed of bioclastic mudstones, and more rarely wackestones, with iron remobilization, common quartz grains, rare foraminifers, sponge spicules, gastropods, bivalves, brachiopods, fenestellid bryozoans, ostracods, trilobites, and crinoids.

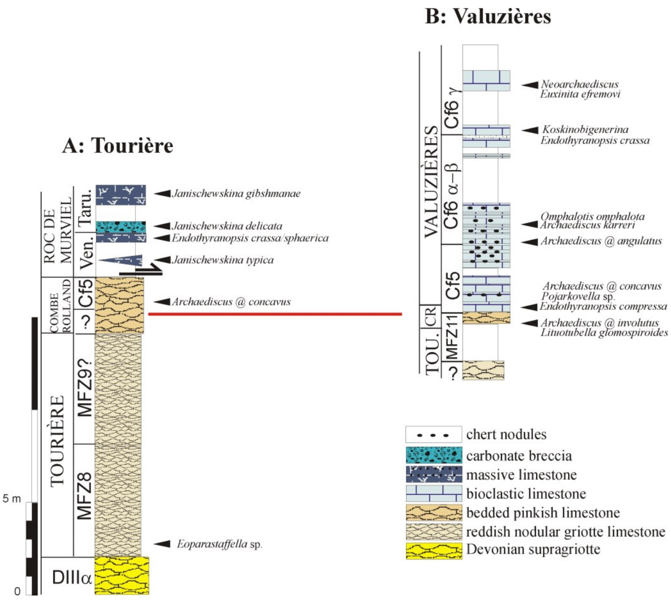

Figure 16. Stratigraphic columns of two olistoliths of the Vailhan-Cabrières Complex (according to Cózar *et al*., 2017, fig. 17 slightly modified). A. Tourière (type section) with the Tourière and Combe Rolland formations, in probable fault contact with the Laurens-Cabrières Group, containing resedimented carbonate lenses of the Roc de Murviel Fm. B. Valuzières section (type section in Valuzières-sommet 223), with poor outcrops of the Tourière and Combe Rolland formations, and the Valuzières Fm.

Abbreviations: CR = Combe Rolland; Taru. = Tarusian; Tou. = Tourière; Ven. = Venevian.

Figure 16. *Colonnes stratigraphiques du Complexe de Vailhan-Cabrières (selon Cózar* et al., *2017, fig. 17 légèrement modifiée). A. Coupe de Tourière (localité type) avec les formations de Tourière et de Combe Rolland, en contact probablement faillé avec le Groupe de Laurens-Cabrières, renfermant localement des lentilles carbonatées olistolithisées appartenant à la Formation du Roc de Murviel. B. Coupe de Valuzières (dans la localité type de Valuzières-sommet 223), avec des affleurements incomplets des formations de Tourière et de Combe Rolland, et un beau développement de la Formation de Valuzières.*

Abréviations: CR = Combe Rolland; Taru. = Tarussien; Tou. = Tourière; Ven. = Venevien.

Boundaries: In Valuzières-sommet 223, the lower contact with the Tourière Fm, and the upper contact with the Valuzières Fm are normal. The upper contact in Tourière is normal and transitional (Cózar *et al*., 2017; Fig. 17D).

References: P. de Rouville (1894, p. 44-45); B. Gèze (1949, fig. 83); M. Maurel (1966a, p. 65-66); D. Vachard (1973, 1974b, 1977); P. Cózar *et al.* (2017).

Remarks: Initially, D. Vachard (1973, 1974b, 1977) considered these limestone beds as the top of the carbonate sedimentation preserved *in situ* in his Cabrières unit; hence, the name of *bancs de dessus* (i.e., uppermost beds); nevertheless, he indicated also their presence between the *secondes griottes* and the *calcaires du sommet 224-Valuzières* (here Tourière Fm and Valuzières Fm, respectively). As for the *secondes griottes* and Tourière Fm, Combe Rolland Fm replaces herein the informal name of *bancs de dessus*.

Biostratigraphy: The foraminifers recorded by D. Vachard (1973, 1974b, 1977) were assigned to the V2b (= lower half of Cf5). This age is confirmed by new samples from Combe Rolland, Valuzières and Tourière with *Archaediscus* at *concavus* stage and transitional forms to the *angulatus* stage.

Chronostratigraphy: Late early Viséan-early middle Viséan.

Tectonics: The formation is: (1) *in situ* at the top of the Tourière Fm, in the klippes of Cabrières (Cózar *et al.*, 2017; Fig. 15A); (2) resedimented at the Laurens-Cabrières Group in the type locality (Cózar *et al*., 2017; Fig. 17C); and (3) part of an overturned series at Valuzières-sommet 223 (Cózar *et al*., 2017; Fig. 16B).

Regional variations: No variations.

Figure 17. The Tourière and Combe Rolland new formations (according to Cózar *et al*., 2017, fig. 18 slightly modified). A. Nodular griotte limestones of the Tourière type locality (length of the hammer = 25.5 cm). B. Tourière Fm in the Mougno-Cabrières section (length of the hammer = 28 cm). C. Reddish nodular olistolite of the Tourière Fm (left) and well-bedded, pale grey limestone of the Combe Rolland Fm at the Combe Rolland section (length of the hammer at the centre of the picture = 27.5 cm). D. Well-bedded, pale grey limestone of the Combe Rolland at the Tourière section (thickness of the two beds = 1.2 m).

Figure 17. *Nouvelles formations de Tourière et de Combe Rolland (d'après Cózar* et al., *2017, fig. 18 légèrement modifiée). A. Calcaires griottes noduleux de la localité type de Tourière (longueur du marteau = 25, 5 cm). B. Formation de Tourière dans la coupe de Mougno-Cabrières (longueur du marteau = 28 cm). C. Olistolithe noduleux rougeâtre de la Formation de Tourière (à gauche) et calcaire compact gris clair de la Formation de Combe Rolland dans la coupe de Combe Rolland (longueur du marteau au centre de la photo = 27, 5 cm). D. Calcaires stratifiés gris clair de Combe Rolland dans la coupe de Tourière (épaisseur des deux bancs = 1, 2 m).*

6.2.3. Valuzières Formation

Type locality: Hill 223, located left of the road D146 (coming from Gabian) and south of the Valuzières house (x = 521.3, y = 4821). The succession is overturned, with from top to bottom: Tourière Fm, Combe Rolland Fm, and Valuzières Fm (Fig. 16B). This succession, which was for a long time considered as Devonian in age (B. Gèze, 1949, p. 148; Maurel, 1966a, p. 38), is resedimented in the detrital Laurens-Cabrières Group.

Type section: The northern slope of the hill from the top to the contact with the flysch of the Laurens-Cabrières Group. This hill is currently covered by bushes and small trees and barely accessible.

Lithology: Dark grey, well-bedded, bioclastic limestones with common chert nodules in the lower half of the formation. Its thickness is less than 15 m. It is overlain by the Laurens-Cabrières Group, which exhibits some olistoliths of *Productus* limestone-type (Vachard, 1974b, 1977). Microfacies are fine-grained packstone and grainstone, medium-grained in the upper part of the formation, with strongly fragmented bioclasts. The dominant components, in the lower half of the formation, are kamaenaceans, calcisphaeroids, foraminifers, crinoids, and small micritic intraclasts. In the upper half, intraclasts are larger in size, and the calcisphaeroids and kamaenaceans become rare. Subordinate components are ooids, dasycladales, brachiopods, bryozoans, and ostracods.

Boundaries: Normal, horizontal contacts with the Combe Rolland Fm and the Laurens-Cabrières Group.

References: D. Vachard (1973, 1974b, 1977); W. Engel *et al*. (1982); L. Pille (2008); P. Cózar *et al.* (2017, fig. 17).

Remarks: This facies was deposited in a middle platform as proximal storm deposits between the FWWB (fair weather wave base) and the SWB (storm weather wave base). In contrast to the Colonnes Fm of the Mont Peyroux nappe, the Valuzières Fm is devoid of Cf6γ carbonate breccia at the top.

Biostratigraphy: The lower part of the formation is middle Viséan in age, based on the foraminifers *Archaediscus* at *concavus* stage and transitonal to *angulatus* stage, *Pojarkovella nibelis*, *P. occidentalis*, *Mirifica intermedia*, *Endothyranopsis compressa* and *Koskinotextularia* sp. The middle part of the formation contains late Viséan foraminifers, such as *Archaediscus* ex gr. *karreri*, *A.* at *angulatus* stage, and *Omphalotis omphalota*, the acmes of which are considered as early Asbian in age. The upper beds show early late Asbian (lower Cf6γ) foraminifers, with *Protoinsolentitheca fundamenta*, *Endothyranopsis crassa*, *Pseudoendothyra* spp., and primitive *Neoarchaediscus* sp.

Chronostratigraphy: Middle and early late Viséan.

Tectonics: The series in this hill is overturned; the upper contact (topographically lower) is probably a faulted contact flysch on flysch.

Regional variations: In La Serre klippe, equivalents are known near La Rouquette (Cózar *et al*., 2017 and see earlier: Fig. 14B).

6.2.4. Oolites of Roc de Murviel Fm (new formation)

Type locality: Roc de Murviel.

Type section: Base of the cliff.

Lithology: A key horizon of oolitic limestone (3 m).

Boundaries: Sedimentary, normal, lower, lateral and upper contacts with the Valuzières Fm, Roque Redonde Fm, and Roc de Murviel Fm, respectively.

References: M. Aretz (2002a, fig. 17); E. Poty and M. Hecker (2003, fig. 2); D. Vachard *et al.* (2016a, 2016b); P. Cózar *et al.* (2017).

Remarks: The key oolitic horizon corresponds to wave-dominated, high-energy, shallow-water environments in ooidal shoreline sandbodies (Flügel, 2004; Cózar *et al.*, 2017). It was described as the “microconglomeratic base of the Roque Redonde Fm” by M. Aretz (2002a, fig. 17) and as “oolithic, bioclastic and conglomeratic limestones” by E. Poty and M. Hecker (2003, fig. 2). In these two latter studies, this limestone is resting on ca. 12 m of calciturbidites of the *Calcaire à Colonnes*. We have not seen this Colonnes Fm in Roc de Murviel, where only 3 m of Roque Redonde Fm are visible below the Oolites.

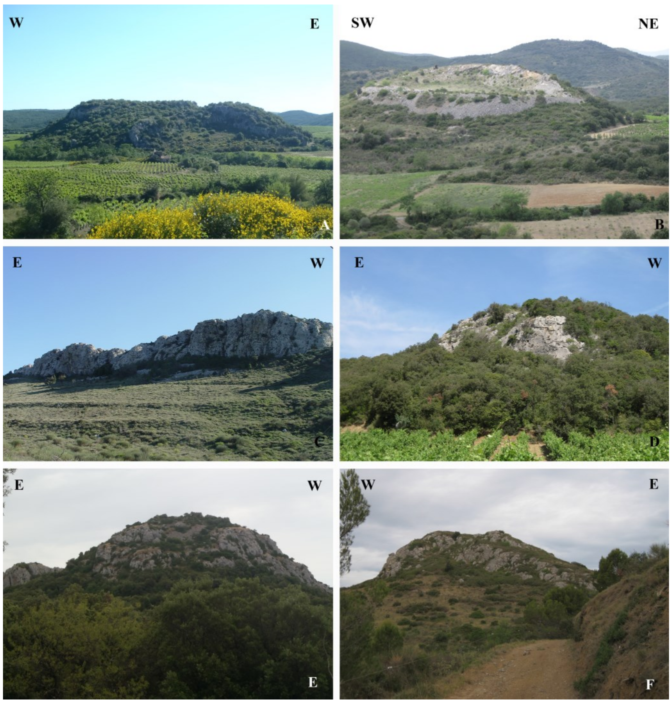

Figure 18. Important outcrops of the Vailhan-Cabrières Complex (location in Fig. 1C). A. Roc du Cayla. B. Roque Redonde. C. Roc de Murviel (top cliff and slope). D. Les Pascales north. E. Château-Cabrières (= Vieux-Château). F. Roquemalière.

Figure 18. *Affleurements importants du Complexe de Vailhan-Cabrières (leur emplacement est indiqué sur la Fig. 1C). A. Roc du Cayla. B. Roque Redonde. C. Roc de Murviel (pente herbue et falaise du sommet). D. Les Pascales-Nord. E. Château-Cabrières (= Vieux-Château). F. Roquemalière.*

Biostratigraphy: The foraminifers *Bradyina rotula* and *Cribrospira*? *perretae.* characterize the Mikhailovian in the type locality, but the oolites of Tourière are Venevian due to the occurrence of *Janischewskina typica*.

Chronostratigraphy: Mikhailovian-Venevian.

Tectonics: Sedimentary unit in a large olistolith.

Regional variations: See the paragraphs devoted to La Serre klippe (section 6.1.3.2) and *Lentilles de la route* D13 (section 6.1.2.5). A Venevian oolitic limestone (two metres thick) has been found (Cózar *et al*., 2017) above the Tourière Fm in Tourière (Fig. 15A). The olistoliths dated V3bβ by Vachard (1974a) in the slopes of Mougno, Tourière and Mentaresses hills, and at the bottom of the hill 223-Valuzières, belong to this formation. This latter boulder, reworked in the Laurens-Cabrières Group of Valuzières, shows that, if the Oolites of Roc de Murviel are currently absent in this locality, they were probably originally present, and then eroded and redeposited in the flysch.

Division into members: No subdivisions.

6.2.5. Roque Redonde Formation (emend.)

Type locality: Roque Redonde hill (203 m), 500 m southeast of the village of Vailhan (x = 524.9, y = 4821.75).

Type section: Access trail to the disused quarry in the top of Roque Redonde hill (Fig. 18B).

Lithology: The formation, 70 m thick in Roque Redonde and 35 m in Roc de Murviel, is composed of thick beds of microbial limestones, with or without large stromatactis, and bioclastic limestones with corals. In Roc de Murviel (Figs. 18C, 19B, 20A), the Roque Redonde Fm shows 40 metres of thick-bedded microbial limestone developed on the outer platform or upper part of the slope, in predominantly dysphotic conditions, and more photic environments on the upper part of the outer platform.

Boundaries: The lower contact with the Laurens-Cabrières Group is tectonic. No subaerial exposure or palaeokarst (as proposed Poty *et al.* (2002), Aretz (2002a), and Poty and Hecker (2003)) as the upper boundary of the Roque Redonde Fm has been recognized in the type locality. In Roc de Murviel, the lower contact with the Oolites de Murviel, and the upper contact with the Roc de Murviel Fm, are sedimentary and normal.

References: B. Gèze (1949, 1979); E. Poty *et al.* (2002); L. Pille (2008); L. Pille and D. Vachard (2011); A. Ernst *et al.* (2015); D. Vachard *et al.* (2016 a, 2016b).

Remarks: The microbial limestones are representative of microbial mounds developed in the outer platform or upper part of the slope, in predominantly dysphotic conditions, and more photic environments in the upper part of the formation on the outer platform. There is no carbonate breccia at this level.

E. Poty *et al.* (2002) considered the Roque Redonde Fm as subdivided into two “facies”, the Cayla facies and the Castelsec facies. This notion of “facies”, which in reality corresponds more to the old use of “horizon” by the Russian geologists, is not used here because: (1) Castelsec is either part of the Vailhan-Cabrières Complex or part of the Laurens Complex, because it is located in an area where no other olistoliths of Cabrières-type are present; (2) Roc du Cayla (Fig. 18A) is also difficult to assign to both complexes, and could belong also to the Roquessels Complex, as a highest element of the Coteau de Bergue Fm; (3) the Cayla and Castelsec outcrops are not homogeneous olistoliths but are composed of several blocks (Vachard *et al.,* 2016b); 4) both “facies” differ in age from the Roque Redonde Fm (Vachard *et al.,* 2016a, 2016b) and are coeval with the Murviel Fm.

Biostratigraphy: See D. Vachard *et al.* (2016b). The oldest part of the Roque Redonde Fm, in Roc de Murviel, contains *Vissariotaxis*, *Euxinita* and *Archaediscus* at *angulatus* stage, which allow assignment to the lower Cf6γ. The foraminifers *Bradyina rotula* and *Cribrospira*? *perretae* characterize the Mikhailovian.

Chronostratigraphy: The formation starts in the Aleksian in the Roc de Murviel section (3 m in the lower part of this section); then, it is Mikhailovian in age, when it is a lateral equivalent of the three metres of the Oolites of Roc de Murviel; and finally, it is Venevian-Tarusian at its type locality (Vachard *et al*., 2016b).

Tectonics: Resedimented sedimentary pile.

Regional variations: Variations have already been indicated by D. Vachard *et al.* (2016a, 2016b) and P. Cózar *et al.* (2017). Some limestones located near the Roque Redonde hill, on the road to Vailhan, might correspond to the *Calcaires stratiformes de Vailhan* (Mamet, 1968; Cózar *et al*., 2017), which cannot be a name with priority for the formation, because their type locality was not defined by B. Mamet; they contain, at the base, rich Mikhailovian foraminiferal assemblages: *Bradyina rotula*, *Pseudoendothyra kremenkensis*, *Cribrospira baliamadeni*, and *Haplophragmina beschevensis*. Near Vailhan, the Venevian is recorded in the upper part of the Tour du Castellas section, where *Howchinia gibba* and *Biseriella delicata* have been recorded (Cózar *et al*., 2017). Other coeval outcrops are La Boutinelle and Les Pascales south (Vachard *et al*., 2016a, 2016b; Cózar *et al*., 2017; Figs. 1, 18D, 19C-D, 20B). The Tour du Castellas (Fig. 19A), Château-Vailhan east, lower part of Roc de Murviel section (Figs. 19B, 20C), Les Pascales south (Fig. 19C), and upper part of La Boutinelle (Fig. 19D) are other representatives of the Roque Redonde Fm (Vachard *et al*., 2016a, 2016b; Cózar *et al*., 2017, fig. 20), which, as a consequence, corresponds to the main development of the *calcaires à Productus*. Furthermore, other microbial mounds, such as the hill 199 close to Mont Mou (Vachard, 1974b, 1977), as well as Vieux-Château (Fig. 18E) and Saint-Rome, in Cabrières, may be considered as olistoliths of the Roque Redonde Fm.

Division into members: No subdivisions.

6.2.6. Roc de Murviel Formation (emend.)

Type locality: Roc de Murviel (286 m; x = 522.1, y = 4822.1); a large olistolith included in the Laurens-Cabrières Group; right of the road D146, coming from Gabian (Fig. 18C).

Type section: Upper cliff of Roc de Murviel (Figs. 18C, 20C).

Lithology: This formation is composed of dark grey well-bedded limestones, rich in bioclasts, and interbedded with shales. These well-bedded limestones contain microbial limestones, coral rich intervals, and bioclastic limestones. They were deposited in the outer platform or upper part of the slope, in dysphotic and photic conditions.

Boundaries: In continuity above the Roque Redonde Fm, and included in the Laurens-Cabrières Group.

References: E. Poty *et al.* (2002); M. Aretz (2002a); E. Poty and M. Hecker (2003); L. Pille (2008), D. Vachard *et al.* (2016a, 2016b); P. Cózar *et al.* (2017).

Remarks: The type-section, nearly 25 m thick, was described by E. Poty *et al.* (2002).

Biostratigraphy: See D. Vachard *et al.* (2016a, 2016b) and P. Cózar *et al.* (2017).

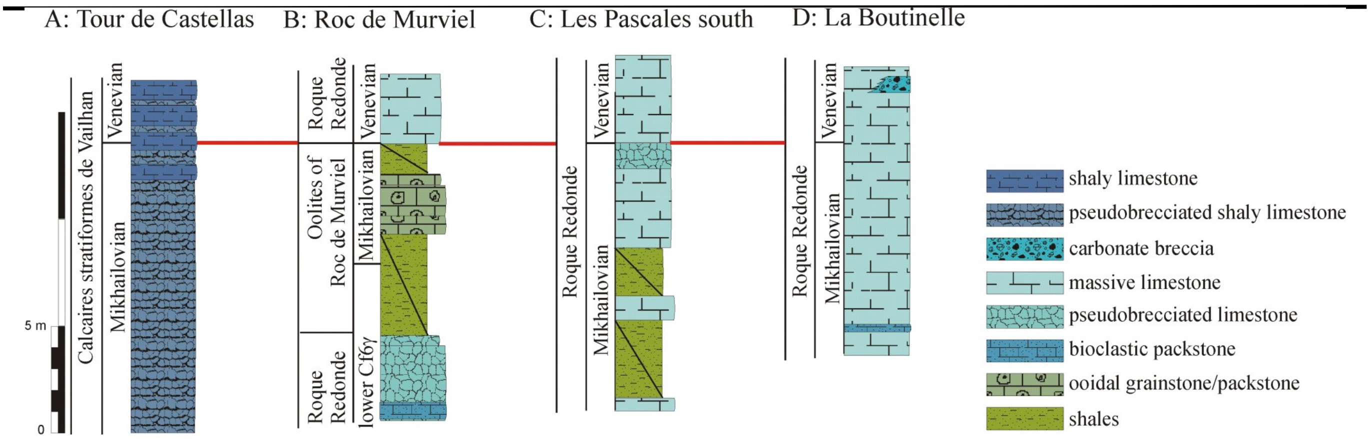

Figure 19. Lower part of the Roque Redonde Fm and *Calcaires stratiformes de Vailhan* (according to Cózar *et al.*, 2017, fig. 20 slightly modified). A. Tour du Castellas. B. Roc de Murviel. C. Les Pascales south (A, B and C in the Vailhan-Cabrières Complex). D. La Boutinelle (Laurens Complex).

Figure 19. *Partie inférieure de la Formation de Roque Redonde et des Calcaires stratiformes de Vailhan (selon Cózar* et al., *2017, fig. 20 légèrement modifiée). A. Tour du Castellas. B. Roc de Murviel. C. Les Pascales-Sud (A, B et C sont des olistolithes du Complexe de Vailhan-Cabrières). D. La Boutinelle (olistolithe du Complexe de Laurens).*

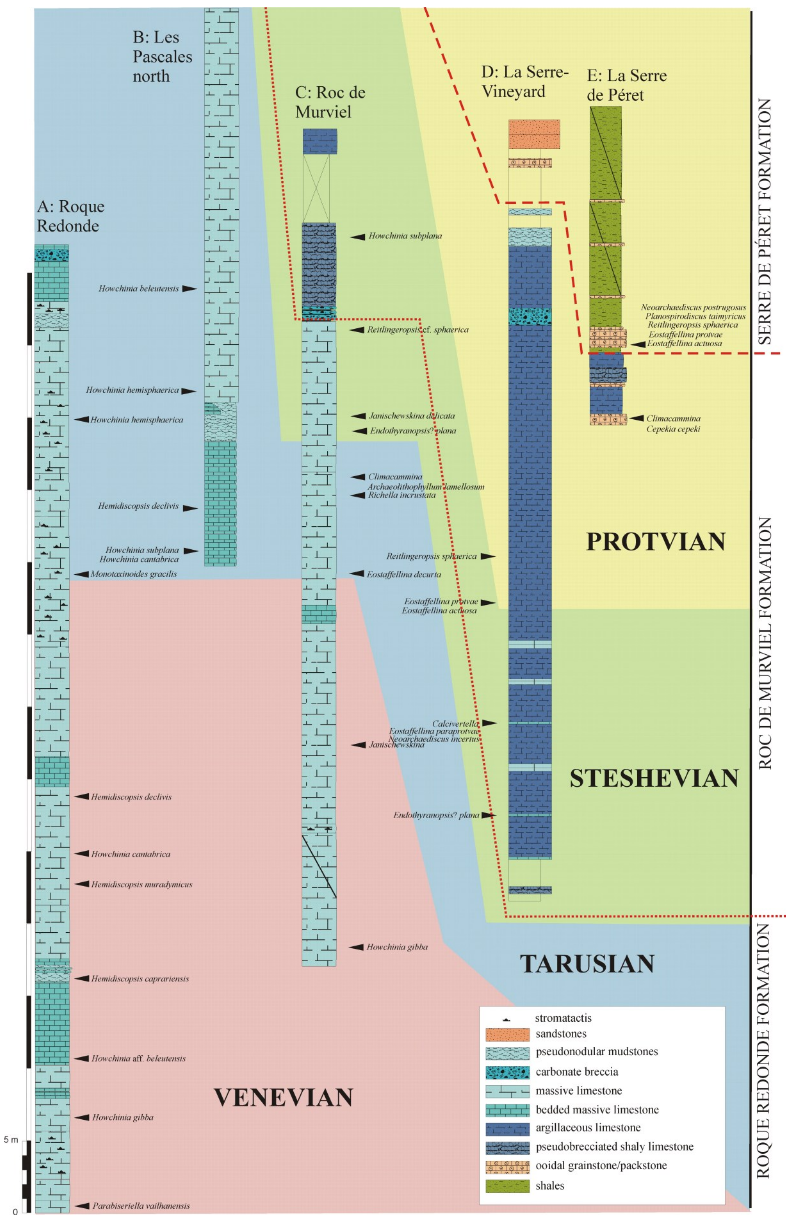

Figure 20. Main sections of the outcrops of Roque Redonde, Les Pascales north, Roc de Murviel, La Serre Vineyard, and La Serre de Péret; from the Venevian upward.

Figure 20. *Coupes principales des affleurements de Roque Redonde, Les Pascales-Nord, Roc de Murviel, La Serre Vineyard et La Serre de Péret, du Vénévien au Protvien.*

Chronostratigraphy: Tarusian-Protvian. The palaeokarst described by E. Poty *et al.* (2002) is therefore located within the early Serpukhovian, at the Tarusian-Steshevian boundary.

Tectonics: Large olistolith in the Vailhan-Cabrières Complex.

Regional variations: The best outcrop of the Roc de Murviel Fm is likely the small quarry of Castelsec (x = 518.9, y = 4820), where (1) the Venevian is recorded with *Rectoendothyra japhetensis* and *Janischewskina minuscularia* in the lower part, whereas (2) in the upper part, the successive occurrences of *Janischewskina delicata*, *Eostaffellina decurta* and *Eostaffellina actuosa* allow the recognition of the Tarusian, Steshevian and Protvian substages. In Castelsec, the rugose coral fauna (Aretz, 2002b) and the algal microflora (Pille and Vachard, 2011) are also very rich. Roquemalière (formerly Roquemaillère) (x = 523.6, y = 4819.9; Fig. 18F) (see Vachard, 1974b, 1977 and Pille and Vachard, 2011) is dated as Tarusian (microbial limestone) in the lower part and Steshevian (bedded limestone) in the upper part. The La Serre Vineyard section (Vachard and Aretz, 2004) is dated Steshevian-Protvian (Vachard, 2016a, 2016b; Fig. 20D).

6.2.7. La Serre de Péret Formation (new formation)

Type locality: La Serre de Péret hill, E of Cabrières.

Type section: The path to the top of the hill, which starts from the road in La Serre de Péret that goes from the village of Cabrières towards the Pioch Farrus mine (x = 530.2, y = 4825.1). The limestone beds are only observed crossing the bushes, because in the path it is possible to see the shales and sandstones only. In the asphalt road, it is only possible to see the limestones of the Roc de Murviel Fm described by M. Aretz (2002a) and L. Pille (2008).

Lithology: This succession, 15 m thick approximately, is mainly composed by green shales and very thin sandstones (locally with terrestrial plant fragments), as well as rare, well-bedded limestones (Fig. 20E). Facies are ooidal grainstones, with common parallel and cross lamination, moderately sorted, and additional intraclasts, bioclasts (crinoids, foraminifers, brachiopods, bryozoans, dasycladales), and quartz grains. There is a mixture of normal radial, irregular and superficial ooids, poorly sorted, and of varied sizes (as well as the bioclasts). The superficial ooids are only present in the upper samples; they are small and associated with numerous quartz grains.

Boundaries: Lower contact with the Roc de Murviel Fm (see Aretz, 2002a), and upper contact not observed at the top of the hill.

References: M. Aretz (2002a); M. Aretz and H.-G. Herbig (2003); L. Pille (2008); L. Pille and D. Vachard (2011); D. Vachard *et al.* (2016a, 2016b); P. Cózar *et al.* (2017).

Remarks: A mixture of ooid types is typically recorded in low-energy, peritidal shoals (Flügel, 2004). The shales yield common plants remnants, such as those described by R. Feist and J. Galtier (1985), and suggest shallow environments on the platform (deltaic for M. Aretz, 2016; or prodeltaic for Ernst and Vachard, 2017); even if these shaly deposits may also be resedimented in the flysch.

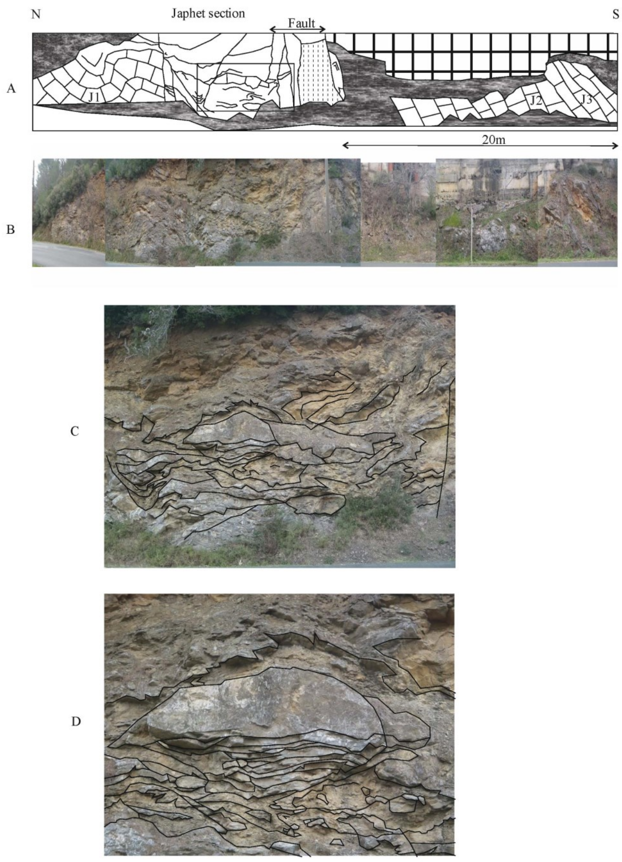

Figure 21. Japhet-bridge outcrop (belonging to the Roc de Murviel Fm, in Cabrières). A-B. Sketches and photos of the Japhet section with folding and faults (J1, J2, J3 = samples collected in 2016). C-D. Close up of the middle part of the section with typical Riedel shears, associated with the bedding-parallel shear planes. The lenticular limestone in the centre of Figure 21C-D is probably a small microbial mound. The dasycladale grainstones, which are visible around these microbial mouds, are interpreted as storm or current accumulations between the microbial mounds.

Figure 21. *Affleurement du pont sur la Boyne, à la retombée de la colline de Japhet, à la sortie SE du village de Cabrières. Ces calcaires appartiennent à la Formation du Roc de Murviel. A-B. Schémas et photos de la coupe de Japhet montrant les failles et les plissements (J1, J2 et J3 sont des échantillons récoltés en 2016). C-D. Vues détaillées de la partie moyenne de la coupe avec des cisaillements de Riedel typiques, associés avec des plans de cisaillement parallèles. La lentille calcaire au centre de la Figure 21C-D est probablement un monticule microbien. Les grainstones à dasycladales, qui correspondent aux dépôts grenus qui entourent ce monticule microbien, sont interprétés ici comme des accumulations de courant ou de tempête.*

Biostratigraphy: The formation is assigned to the Protvian with foraminiferal assemblages similar to the upper part of the Murviel Fm, except for the first occurrence of *Neoarchaediscus postrugosus* and *Planospirodiscus* aff. *taimyricus*.

Chronostratigraphy: Early late Serpukhovian (Protvian). This formation is currently the youngest formation encountered in the Cabrières area (Vachard *et al.,* 2016a, 2016b).

Tectonics: The La Serre de Péret Fm constitutes probably the uppermost part of the *Echarpe à l'espagnole* of P. de Rouville (1887) and B. Gèze (1949, fig. 86); i.e., this large outcrop of limestone, which is drawn on numerous maps, north of the TEM (Tourière-Escandolgue-Mougno) hills. In the lower beds of the La Serre de Péret and Japhet hills, this *Écharpe à l'espagnole* is mostly composed of limestone belonging to the Roc de Murviel Fm.

Regional variations: The upper part of the La Serre Vineyard section dated Protvian belongs to this formation (Fig. 20D).

Division into members: No subdivisions.

6.2.8. Mougno-Les Batailles informal unit

Type locality: Valley between Mougno and Les Batailles hills.

Type section: Paths along the Mougno-Cabrières and surrounding vineyards (see Vachard, 1974b, 1977).

Lithology: Greenish argilites and ochreous sandstones, with some local lithologies, often mentioned in the literature of the 19th century and the beginning of the 20th century (e.g., de Rouville, 1886; Bergeron, 1887b, 1900b), are present in Cabrières: *poudingue à dragées* (channelized conglomerates with ellipsoidal pebbles of white quartz and black lydites), sandstone with plant fragments, and sandy limestone with trilobites ("*Phillipsia*") and crinoids (de Rouville, 1886; Bergeron, 1887b, 1900b; von Gaertner, 1937). Some lenticular limestones seem to be preserved more or less *in situ* in this siliciclastic unit (see section 6.2.9).

Boundaries: This formation is interpreted here as deposited during the end of the filling of the basin, probably between Lower-Middle Devonian hills, such as Les Batailles, and composite Devonian-Mississippian olistoliths such as the TEM. The contacts could therefore be sedimentary, even if they have been removed by faults.

References: J. Bergeron (1898, 1900a, 1900b); B. Gèze (1949); M. Maurel (1966a); D. Vachard (1974b, 1977); R. Feist and J. Galtier (1985); L. Pille and D. Vachard (2011).

Remarks: The palaeoenvironments could be deltaic with marine and continental influences west of Mougno, and developed at the end of basin filling.

Biostratigraphy: A Namurian A age (i.e., late Serpukhovian *sensu lato*) was based on the terrestrial plants *Mesocalamites* and *Alloiopteris* (Feist and Galtier, 1985). Foraminifers and bryozoans, in the carbonate olistoliths of the slopes of Tourière and Les Batailles, indicate the local biozones G and H of the early Serpukhovian (Vachard *et al*., 2016a, 2016b; Ernst and Vachard, 2017).

Chronostratigraphy: Early Serpukhovian-early late Serpukhovian.

Tectonics: A part of the Laurens-Cabrières basin shallower than the other detrital units of the southern slope of the Montagne Noire.

Regional variations: The platform sandstones located at the Laurens station described by W. Engel *et al.* (1982) can be a regional variation of this facies.

Division into members: No subdivisions.

6.2.9. Questions on the boundstones of Cabrières

It is suggested in this study that *in situ* microbial mounds exist at Escandolgue, a hill in the Cabrières area. The Escandolgue hill (called La Boissière by B. Gèze, 1949, 1979), which is part of the TEM (Tourière-Escandolgue-Mougno) klippe, corresponds to an Ordovician, Devonian and Mississippian succession with a normal dip southward and a tectonic zone constituted of normal, folded and reverse blocks. A section (x = 531, y = 4825.25), although affected by faults, displays a relatively complete succession, from North to South, with: (1) the Devonian limestones; (2) Tourière Fm with a normal dip southward; (3) Venevian-Tarusian limestone with corals, with a normal dip northward; (4) a carbonate breccia with limestone pebbles dated late Tournaisian and early Viséan; and (5) Tarusian and Venevian microbial limestone, with a reverse dip northward (Fig. 15B). There are two parts in this section: the bordering tectonic zone and the supposed *in situ* zone with silicified lenses in the south. At the top of another olistolith (Ordovician and Devonian), in the South of Escandolgue, there are siliceous limestone lenses in shale (x = 531, y = 4825) that could not be dated yet. These lenses can be *in situ* microbial mounds growing at the top of the olistoliths after their gliding. In contrast, this area cannot be interpreted as a tectonic window, because these outcrops are located at the top of the olistolith. It is possibly the unique regional outcrop of mounds preserved *in situ*. The silicification can be linked with these hot flows that produced barite ores in Lower Devonian strata. The same lenses in shale are observable on the Japhet-Escandolgue track north of La Roussignole mine (x = 530.3, y = 4824.5). They contain decimetric shells of gigantoproductin brachiopods, latest Viséan-Serpukhovian in age (Legrand-Blain, written communication, September 2017).

Other "reefal" units near Cabrières, named *alignements de récifs* (reef alignments; Maurel, 1966a) or *biohermes de Cabrières* (Cabrières bioherm; Mamet, 1968) in the literature, even if they are not really preserved *in situ,* have probably been displaced over only short distances. These sub-in-place units are: (1) small, late Viséan-early Serpukhovian carbonate lenses on the slopes of Tourière and Les Batailles hills (Bergeron, 1899, text-fig. 2, lens number 7; Vachard, 1974a, 1974b, 1977; Ernst and Vachard, 2017); (2) some larger, resedimented, carbonate build-ups (Fig. 15C) such as *l'Écharpe à l'espagnole* (the Spanish scarf) (de Rouville, 1886, 1887; Bergeron, 1898, 1899; B. Gèze, 1949) including the outcrops in Boyne creek, the early late Serpukhovian (Protvian) of the Japhet-bridge in the road D124E2, and the La Serre de Péret hill lower outcrops (Aretz, 2002a; Pille, 2008; Vachard *et al*., 2016a, 2016b).

The Japhet-bridge outcrop, in the road D124E2, near the bridge on the Boyne creek, is affected by B1 and B2 folds (according to the terminology of Engel *et al*., 1982) and faults. A bedding-parallel shear has transformed a bedded sequence into layers of tectonic lenses (Fig. 21A-D). There are typical Riedel shears associated with the bedding-parallel shear planes. The dip of the Riedels clearly indicates a southward transport direction (Franke, oral communication, June 2017). As a consequence, this olistolith was not initially located on the the top of Mougno or another hill of the TEM, but on another palaeorelief situated to the North. Three other remarks can be made about this outcrop: (1) Some of the beds of Japhet-bridge are grainstone with a very rich dasycladale microflora (Vachard, 1974b, 1977; Mamet and Roux, 1975; Pille, 2008; Pille and Vachard, 2011; Vachard *et al*., 2016a; Fig. 21A, D); the age of which was successively interpreted as V3bγ (Vachard 1974b, 1977), biozone 16i (Mamet and Roux, 1975), Brigantian (Pille, 2008; Pille and Vachard, 2011), and late early- to early late Serpukhovian (Vachard *et al*., 2016a, 2016b). (2) Other beds of Japhet hill, on the same road (x = 529.4, y = 4824.5; Fig. 21A), displayed thick Protvian microbial limestones with *Eostaffellina*, which have indicated definitively the age of the dasycladale assemblages (Vachard *et al*., 2016b). (3) It is worth mentioning that one of the foraminiferal markers associated with these dasycladales, *Rectoendothyra japhetensis*, has its range correctly indicated by Vachard *et al.* (2016b, fig. 15), but erroneously indicated in fig. 13 of the same paper.

Finally, the alternations and shallow limestones and shallow siliciclastic series in Cabrières become well characterized with the La Serre de Péret Fm.

7. Discussion

7.1. Preorogenic and synorogenic stratigraphic synthesis

Our stratigraphic results are summarized in Fig. 22 and the palaeosections with facies distribution in Fig. 23 for preorogenic facies (i.e., older than the flysch facies) and Fig. 24 for synorogenic facies (i.e., contemporaneous with the flysch facies).

At La Serre hill, an incomplete succession contains a well-characterized carbonate La Serre East Fm (latest Tournaisian Cf4α1 up to the late early Viséan Cf4γ-δ; MFZ8 to MFZ11, with an apparent gap for the Cf4β, MFZ10), and an apparently incomplete succession principally composed of formations of the Vailhan-Cabrières Complex: Valuzières Fm, Oolites of Roc de Murviel Fm, Roc Redonde, Roc de Murviel, and La Serre de Péret.

In the Cabrières area, and in general in the Vailhan-Cabrières Complex, the succession is represented by the Tourière Fm (latest Tournaisian Cf4α1 up to the uppermost early Viséan Cf4γ-δ, MFZ8 to MFZ11, with a possible hiatus for the Cf4β, MFZ10), Combe Rolland Fm (latest early Viséan Cf4γ-δ up to middle Viséan Cf5, MFZ11 to MFZ12), and Valuzières Fm (middle Viséan Cf5 up to the lower part of the late Viséan Cf6α-β; i.e., MFZ12 to MFZ13). Above the Valuzières Fm, different formations and informal units are laterally equivalent: Roque Redonde, Oolites of Roc de Murviel, *Calcaires stratiformes de Vailhan*, and Roc de Murviel (Fig. 22). La Serre de Péret Fm, which is Protvian in age, constitutes the uppermost part of the sedimentation in Cabrières.

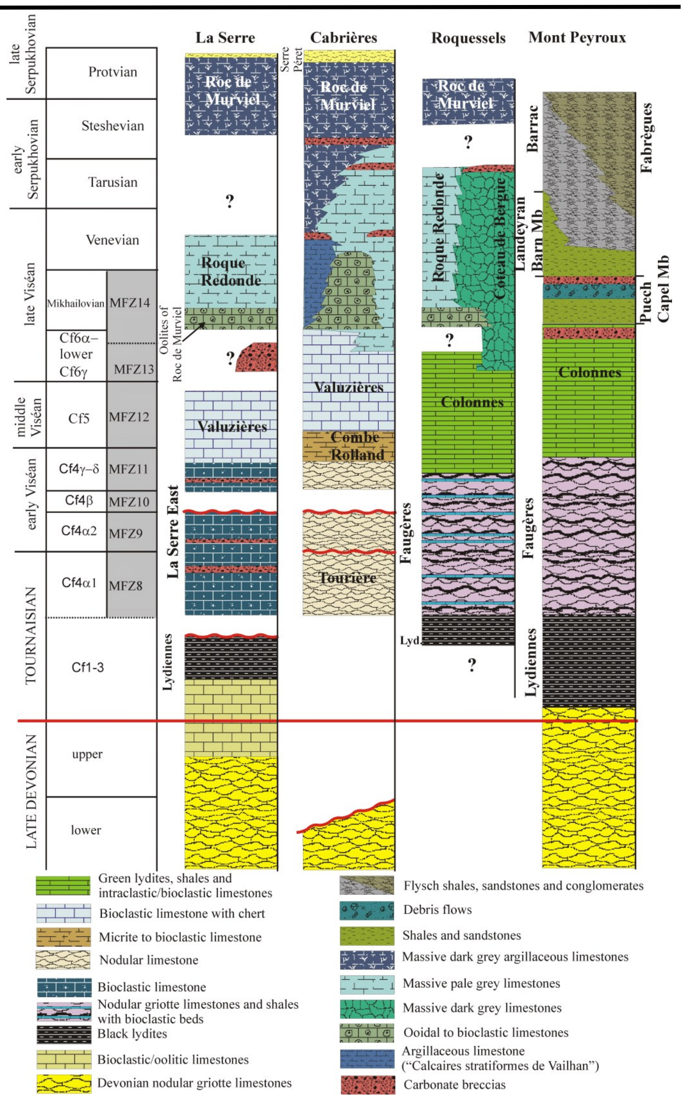

Figure 22. Comparative stratigraphical data of the different tectonosedimentary units of the Mont Peyroux nappe and Cabrières klippes, with the different formations revised and/or proposed in this work (according to Cózar *et al*., 2017, fig. 2 modified). The zones in the left column in the grey box are those of Poty *et al*. (2006), which are not used in this paper.

***Figure 22**. Comparaison des données stratigraphiques de différentes unités tectono-sédimentaires de la nappe du Mont Peyroux et des écailles de Cabrières, avec les différentes formations révisées ou proposées dans ce travail (selon Cózar* et al.*, 2017, fig. 2 modifiée). Les zones de Poty* et al. *(2006), figurant dans la colonne en grisé, n'ont pas été utilisées dans ce travail.*

The succession in the Mont Peyroux nappe is characterized by the Lydiennes Fm (middle Tournaisian, foraminiferal zones Cf2-Cf3), Faugères Fm (latest Tournaisian, Cf4α1 zone and entire early Viséan, Cf4γ zone; MFZ8 to MFZ11 zones) and Colonnes Fm (middle Viséan, Cf5 zone up to mid late Viséan, lower Cf6γ, and questionably from the top of the early Viséan, Cf4δ zone, in outcrops such as in Mont Mou or Puech de la Suque; MFZ11 to MFZ12).

The Pic de Vissou klippe is an equivalent of the overturned limb of the Mont Peyroux nappe, but it exhibits a flysch that presents more carbonate slumps and sandy olistoliths than the Puech Capel Member of the Barrac Group, which is a more siliceous flysch. Both successions were probably deposited on different parts of the continental slope.

In the Roquessels Complex, in addition to these formations of the Mont Peyroux nappe, the typical Coteau de Bergue Fm is described (late Viséan Cf6α-β up to the Tarusian), whereas parts of the formations of the Vailhan-Cabrières Complex were also found, from Mikhailovian to Protvian. The Roquessels Complex represents, therefore, the palaeogeographical transitional zone between the Cabrières klippes and the Mont Peyroux nappe (Figs. 22, 23).

In the Mont Peyroux nappe and Roquessels Complex, the Saint-Nazaire-de-Ladarez Group probably, during all the period, was deposited on an outer ramp and/or continental slope, whereas the Barrac Group corresponds more or less to a basinal deep-sea fan (Figs. 22, 23). The shallower rocks in this unit are represented by the Coteau de Bergue Fm, the microbial mounds of which were probably mostly developed in aphotic to dysphotic conditions in outermost platform environments. Except for this Coteau de Bergue Fm, the shallow ramps of the Mont Peyroux nappe and Roquessels Complex can be only reconstructed thanks to the calciturbidites of the Faugères and Colonnes formations, and some olistoliths of the *Lentilles de la route* D13, flysch of Pic de Vissou, and Puech Capel Fm, with their slumps, boulders and debrites.

The shallow-water platform is better represented in the La Serre klippe, with limestones of the Valuzières Fm, which were deposited on inner- and mid ramps. Microbial mound and intermound facies, which are present in the Roque Redonde and Roc de Murviel formations, are representative of shallower environments than those of the Coteau de Bergue mounds, and interpreted to have been developed in the mid- to outer ramp.

During the middle Viséan and early late Viséan, the deepest-water depositional environments in the Mont Peyroux nappe and Roquessels Complex were dominated by widespread turbidites on the margin of the platform and slope. Nevertheless, in the Roquessels Complex, the development of the microbial mounds of the Coteau de Bergue Fm started in the lower Cf6α-β zone.

During the upper Cf6γ-lowermost Cf6δ (Mikhailovian), ooidal shoals were widespread on the platform from the La Serre klippe, Cabrières area and Roquessels Complex, although laterally, the mounds of the Coteau de Bergue Fm and Roque Redonde Fm continued to grow (Cózar *et al.*, 2017). No carbonate breccias of this age are known on the platform (Figs. 22, 23). However, a thick carbonate breccia was seen in the La Serre klippe by Engel *et al.* (1982), and a carbonate breccia that reworked late Tournaisian and early Viséan limestones was seen in Escandolgue hill by our team (Fig. 22). In the basin (Fig. 23), the Mont Peyroux unit presents a carbonate breccia at the top of the Colonnes Fm (Cf6γ) and a debris flow in the Puech Capel Mb (Mikhailovian) (Fig. 22). The Faugères unit, including the Ceps area, shows the *schistes troués*, which probably correspond to a coeval debris flow (Fig. 23).

During the Venevian, five turbidite facies (Fig. 24A) were deposited in the basin: slope facies (Pic de Vissou and Puech Capel Mb) with slumps and debris flows formed in a basin with strong marginal tectonic uplift (Mutti, 1985, fig. 12), channel-detached sandy lobes and silty-clayey lobes from Faugères nappe during stage I, retroceding channel-attached sandy lobes (Barrac Fm) during stage II, and channels and levees facies (Fabrègues Fm) during stage III, all deposited in elongate basins of thrust belts (Mutti, 1985, figs. 4-11). These different stages of growth of turbidite systems in an elongate basin correspond to a decrease in the volume of gravity flows and a rise of sea level for Mutti (1985). Stage I was deposited during the lowstand system tract (LST), stage II during the transgressive system tract (TST) and the type III during the highstand system tract (HST). This sequence can correspond to the late Viséan-early Serpukhovian sequence with eustatic and tectonic control, channels and levees facies (Fabrègues Fm), retroceding sandy lobes (Barrac Fm), sandy lobes (Faugères nappe) and silty-clayey lobes (Para-autochthon). During the Venevian and Serpukhovian, the microbial mounds grew in the upper part of the slope or platform (Fig. 24A). During the late Serpukhovian, the olistoliths and klippes glided in the basin (Fig. 24B, C).

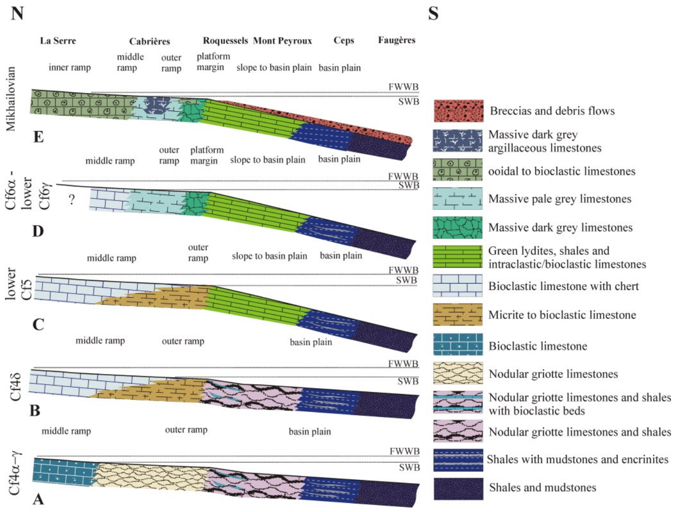

Figure 23. Facies distribution and evolution of the ramp from the latest Tournaisian up to the Mikhailovian during pre-orogenic time. SWB = storm wave base, FWWB = fair weather wave base.

Figure 23. *Répartition des faciès et évolution de la rampe du Tournaisien supérieur au Mikhailovien, pendant la phase préorogénique. SWB = limite des vagues de tempête, FWWB = limite des vagues de beau temps.*

7.2. Unresolved problems

The classical interpretation of overturned and normal limbs of the Mont Peyroux nappe, of the 1/50,000 geological maps, is confirmed herein. Moreover, the Fabrègues Fm (= former Flysch-unit II) is interpreted to belong also to the normal limb of the Mont Peyroux nappe because of dip and flysch facies. The basin, from Laurens to Cabrières, is considered as filled with olistoliths or elements of the substrate coming from the erosion of an overturned limb of the Mont Peyroux nappe (Vissou klippe and Roquessels Complex), and the normal limb of the Mont Peyroux nappe (La Serre, TEM, Devonian *causses* klippes and olistoliths). The reverse or normal dip of the olistoliths and klippes cannot be an argument to indicate that they belong to the overturned or normal limb of the Mont Peyroux nappe, only the location in the paleogeographic section can help with this reconstruction (see later).

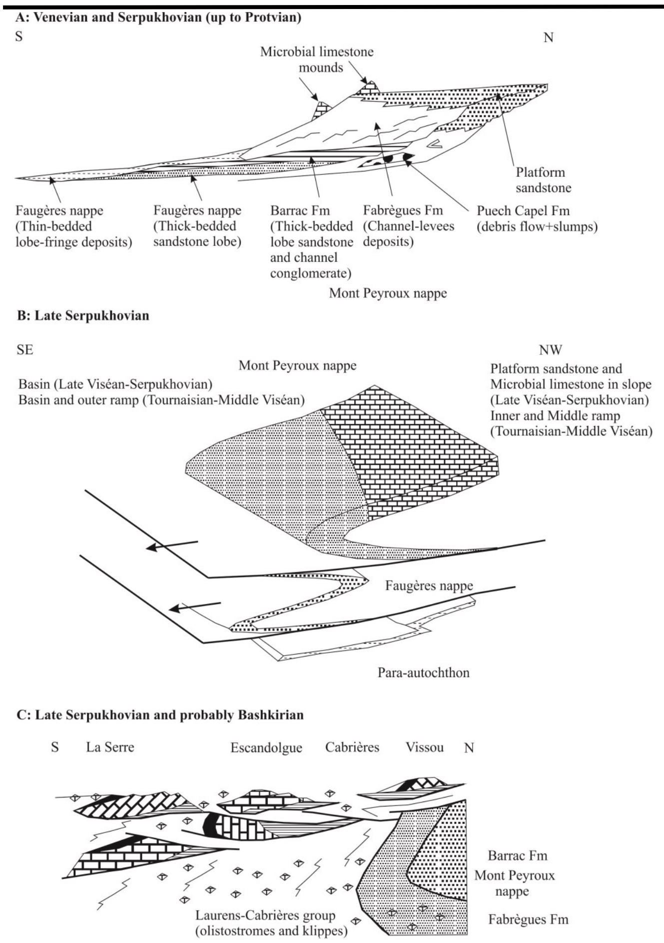

Figure 24. Facies distribution of flyschs. A. During the latest Viséan-late Serpukhovian (up to Protvian), i.e., the syn-orogenic time, nappes gliding (scheme drawn after turbiditic sequence from Hecho Group (Mutti, 1985, 1992)). B. During the late Serpukhovian (i.e., nappe and olistolith gliding) (after Engel *et al*., 1982, modified). C. During the late Serpukhovian and probably Bashkirian in the Vailhan-Cabrières Complex.

Figure 24. *Répartition des faciès des flyschs. A. Pendant le Viséen terminal et le Serpoukhovien inférieur et supérieur (jusqu'au Protvien), c'est-à-dire durant la phase synorogénique et le glissement des nappes (schéma inspiré de la séquence turbiditique du Groupe d'Hecho décrite par Mutti (1985, 1992)). B. Pendant le Serpoukhovien supérieur (glissement des nappes et des écailles) (d'après Engel* et al. *(1982), modifié). C. Pendant le Serpoukhovien supérieur et probablement le Bashkirien, dans le Complexe de Vailhan-Cabrières.*

The La Serre klippe, after the data in W.Engel *et al.* (1982) and P. Cózar *et al.* (2017), probably constitutes a more puzzling palaeogeographic problem. La Serre was a deeper platform area during the Devonian, with griottes limestone deposits; it becomes shallower during the Mississippian. This change probably began as early as the earliest Tournaisian, with the ooid sedimentation of the oldest Mississippian beds of the D/C GSSP stratotype. This change is interpreted as episodic, since the earliest Tournaisian ooid beds are followed by possible equivalents of the Lydiennes Fm. According to W. Franke (written communication, September, 2007), the same oolites are present at the D/C boundary in the Rhenish Massif (Germany), and most probably correspond to a glacio-eustatic drop of sea level. A lower Tournaisian glacial event is indeed suggested by J. Kalvoda (1999), and such a glacioeustatic fall of sea level could also explain the gap of sedimention in the TEM klippe of Cabrières (with the absence of supragriottes and lydites). The La Serre restructuring on a shallow platform becomes definitive during the late Tournaisian. The La Serre-East Fm is the only shallow late Tournaisian-early Viséan formation known in the Montagne Noire. It could be a lateral equivalent of the Faugères Fm, and hence, the source, or a lateral equivalent of this latter, of the calciturbidites/grainstones recorded in Mont Mou. As these latter are absent in the Mont Peyroux nappe, it is possible to suggest that, palaeogeographically, the proximal/distal location of the succession of tectonosedimentary units of the Montagne Noire, from North to South (Figs. 22, 23), during the deposition of the Faugères Fm, remained: La Serre klippe/Vailhan-Cabrières Complex source area/Roquessels Complex/Mont Peyroux nappe (with Vissou)/Faugères nappe (with Caragnas, Vieussan and Ceps) (Cózar *et al*., 2017). The La Serre area remained a platform with shallow-water deposits during Mississippian time, with the unnamed series close to La Rouquette. These shallower series of La Serre are recorded up to the Protvian, with the La Serre Vineyard section, rich in algae (Vachard and Aretz, 2014), which is the equivalent of the Roc de Murviel Fm and La Serre de Péret Fm. There is no direct evidence of the location of the La Serre source area to the south of the Montagne Noire during the Mississippian, despite the old hypothesis that the limestone olistoliths were derived from the south (B. Gèze, 1949) and the geological individuality of La Serre compared to the other klippes and olistoliths of Cabrières, which came from the north. Moreover, and unfortunately, no seismic sections exist between the Montagne Noire and Mouthoumet.

Concerning the problem of allochthony versus autochthony, the majority of the late Viséan-Serpukhovian limestone lenses of the Laurens-Cabrières Group (i.e., the *calcaires à Productus*) are olistoliths; in the Laurens Complex (work in progress) with Malac mound and colline 199 near Mont Mou; Roquessels Complex with the Coteau de Bergue Fm; and Vailhan-Cabrières Complex, including from west to east, Roc du Cayla and Castelsec, the Roque Redonde Fm and Roc de Murviel Fm type-localities, numerous small blocks around the village of Vailhan (e.g., Chardon *et al*., 2015, fig. 3; Aretz, 2016, fig. 11), Les Mentaresses and Les Pascales, Spanish Scarf, and the Escandolgue microbial limestones, La Serre Vineyard series, and La Serre de Péret Fm.

However, despite this better-known litho- and biostratigraphy, some major problems remain, such as:

1) the dating of the emplacement of the Faugères nappe;
2) the dating of the emplacement of the Mont Peyroux nappe (D1-folding) must postdate the youngest age (Late Serpukhovian) found in olistoliths and calciturbidites of the Barrac and Fabrègues formations and Laurens Complex which were involved in D1-folding. This emplacement is probably post-Protvian due to the resedimentation of Protvian mounds;
3) the dating of the filling of the Laurens-Cabrières basin and of the incoming of all the olistoliths, which are currently well dated, from Early Ordovician to late Serpukhovian (Protvian);
4) the scenario of the Variscan orogenesis, from the

Protvian (youngest olistoliths dated) to the disconformable, Gzhelian (formerly Stephanian), intra-montane, coal and molassic deposits;

5) the dating of the structural inversion of the La Serre klippe, passing from deep-sea sedimentation during the Devonian (Vachard, 1974; Engel *et al.,* 1982) to shallow-sea sedimentation during the Mississippian (Cózar *et al*., 2017);

6) how to maintain the growth of microbial mounds on the slope up to the late Serpukhovian after the gliding of the Mont Peyroux nappe during the Serpukhovian? However, the gliding of the nappe during the late Serpukhovian can explain the growth of microbial mounds up to the Protvian;

7) the siliciclastic sedimentation of the flysch only presents a few direct ages, and, for the moment, we are faced with the problem of three or four tectonic units (Faugères nappe, overturned limb of Mont Peyroux nappe; normal limb of the Mont Peyroux nappe and one to three complexes), which all begin at the end of the lower Cf6γ, and all contain carbonate olistoliths as old as Mikhailovian and up to the Protvian. Normally, the ages of these siliciclastic complexes would be different, to permit the emplacement and erosion of the different nappes. As a consequence, it is currently impossible to understand how these different units could have been emplaced;

8) the emplacement of small olistoliths and klippes (Ordovician, Silurian, Devonian and Mississippian) in the Cabrières basin probably occurred in many phases (Figs. 25, 26) because some olistoliths are located in the basin between the klippes and others are at the tops of these latter (Pichaures and car park at the beginning of the Vissou trail close to Roque Fenêtre, Escandolgue) or on the slopes of the olistoliths (Japhet and La Serre de Péret close to Mougno, and La Serre Vineyard in La Serre hill);

9) the sedimentation of microbial mounds *in situ* at the tops of olistoliths or klippes after their coming during the late Serpukhovian is difficult to prove, but can be considered in the case of the mounds south of Escandolgue, which are in place at the top of the olistolith (Figs. 25, 26).

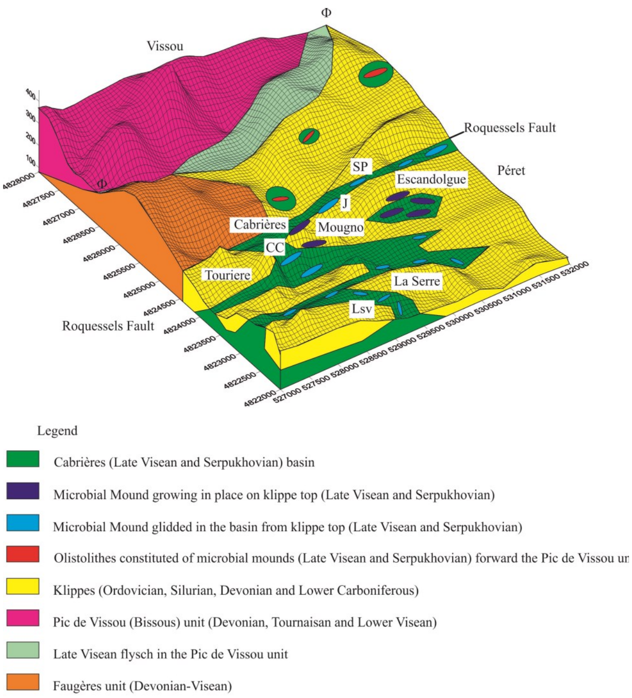

Figure 25. Wireframe image around Cabrières, built with Surfer software®, after the topographic and geological maps of Lodève and Pézenas. CC. Château de Cabrières; Φ. Thrust; J. Japhet; Lsv. La Serre Vineyard; SP. Serre de Péret.

Figure 25. *Modèle 3D aux alentours du village de Cabrières, construit avec le logiciel Surfer®, à partir des cartes géologiques et topographiques de Lodève et de Pézenas. CC. Château de Cabrières; Φ. Chevauchement; J. Japhet; Lsv. Vignoble de La Serre; SP. Serre de Péret.*

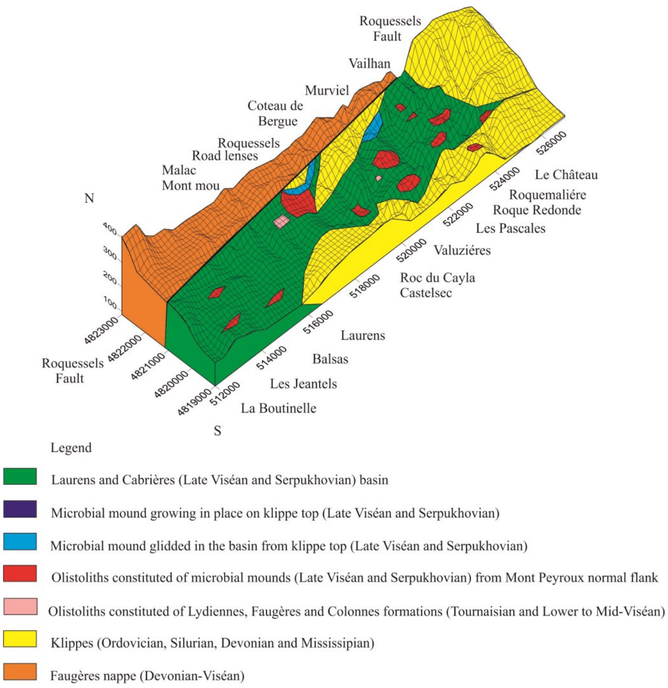

Figure 26. Wireframe image from Laurens to Vailhan, built with Surfer software®, after the topographic and geological maps of Saint Chinian, Lodève and Pézenas.

Figure 26. *Modèle 3D de la région située entre Laurens et Vailhan construit avec le logiciel Surfer®, à partir des cartes géologiques et topographiques de Saint Chinian, de Lodève et de Pézenas.*

7.3. Tectonic and geodynamic implications

We present here some wire frame images built from topographic and geological maps around Cabrières, and from Laurens to Vailhan, with Surfer ® software (Figs. 25, 26). These figures show the diverse locations of microbial mounds in the basin or on the back or side of olistoliths. Some of them come from the normal flank of the Mont Peyroux nappe, others may have grown at the top of klippes after their gliding or may have glided on the flank of klippes after growing on the top. We can therefore regard them as formed at the top of klippes. Fig. 27A-B shows two tectonic sections in the western part (Mont Peyroux and Faugères nappes) and the eastern part of the basin (from Vissou to La Serre) after the geological maps Saint Chinian, Lodève and Pézenas. The Faugères and Mont Peyroux nappes are tectonic nappes thrust during the D1 phase (Engel *et al*., 1978, 1982; Franke *et al*., 2011). This Laurens-Cabrières basin, linked with the Mont Peyroux nappe, is filled with small and large olistoliths and klippes (Pic de Vissou, La

Serre and TEM). The problem is to find tectonic arguments between thrust and gliding, to say if they are tectonic klippes or large olistoliths in the Cabrières area. Previously, arguments, such as basal planing visible in the Pic de Vissou, Tourière, Escandolgue and La Serre, were used for a tectonic origin. It is, however, noteworthy that many authors working in the Montagne Noire (e.g., Franke *et al*., 2011; Álvaro *et al*., 2016) used the term klippe, which is probably more neutral than slice or large olistolith, as long as the tectonosedimentary origin of the unit is not elucidated.

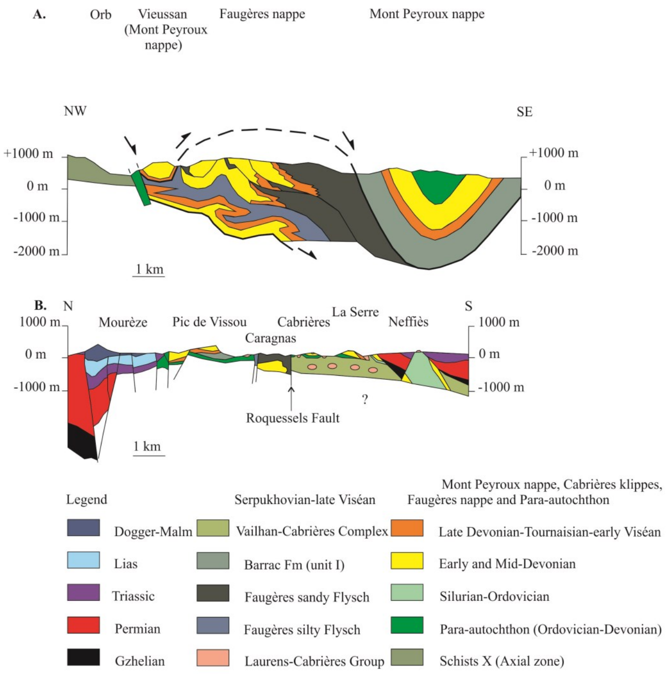

Figure 27. A. Section across the Orb valley (Para-autochtonous zone) and the Faugères and Mont Peyroux nappes, after the Saint-Chinian geological map (Arthaud in Alabouvette *et al*., 1985) and maps and sections of W. Franke *et al.* (2011) and M.-P. Doublier *et al.* (2015). B. Section across the Lodève Permian basin, Mourèze, Pic de Vissou, Cabrières, La Serre and Neffiès Permian basin, after the Lodève geological map (Feist in Alabouvette *et al.,* 1982) and Pézenas geological map (Feist in Berger *et al*., 1981).

Figure 27. *A. Coupe à travers la vallée de l'Orb (Para-autochtone) et les nappes de Faugères et du Mont Peyroux, d'après la carte géo-logique de Saint-Chinian (Arthaud in Alabouvette* et al.*, 1985) et les cartes et coupes de W. Franke* et al. *(2011) et M.-P. Doublier* et al. *(2015). B. Coupe à travers le bassin permien de Lodève, Mourèze, Pic de Vissou, Cabrières, La Serre et le bassin permien de Neffiès, d'après les cartes géologiques de Lodève (Feist in Alabouvette* et al.*, 1982) et de Pézenas (Feist in Berger* et al.*, 1981).*

As a consequence, the timing of the tectonosedimentary events, during the Variscan orogeny in the Montagne Noire, is complicated and rapid; hence, we suggest the following scenario:

1. the initial location of the units are more or less similar to the schemes of F. Arthaud (1970), D. Vachard (1974b), and W. Engel *et al.* (1982), except for the location of La Serre (north of the Cabrières klippes). This unit, deep during the Devonian, became shallow during the Mississippian. Several explanations are possible: (1) a possible glacioeustatic shoaling; (2) northernmost (correlatively shallowest) location on the ramp prior to the synorogenic phases (Cózar *et al.,* 2017); (3) tectonic vertical faulting, from a graben to a horst, or another similar, local tectonic event; (4) travel from west to east of the La Serre klippe, for example, in relation with strike -slip fault activity; (5) distinct origin from the normal limb of the Mont Peyroux nappe (Engel *et al*., 1982); such as, for example, a location on an intermediary seamount or even an independent origin from a platform located to the south of the Cabrières area;
2. the Faugères nappe is folded during a period difficult to be determined, because the real age interpretations are almost totally absent in this nappe. Nevertheless, an early Viséan age for some pre-flysch sediments of these areas has been proposed (Vachard *et al.,* unpublished data);
3. the flysch of the Fabrègues Fm belongs to the normal limb of the Mont Peyroux nappe;
4. the Mont Peyroux nappe, which is a recumbent fold, comes from the north probably during the late Serpukhovian;
5. in the Laurens-Cabrières basin, linked with the Mont Peyroux nappe, the resedimentation of various elements of the normal limb of Mont Peyroux nappe started just before (olistoliths in Laurens Complex) and probably after (olistoliths in Cabrières Complex) this emplacement of the Mont Peyroux nappe. In Cabrières, as they came from North to South and are superposed (see B. Gèze, 1949), La Serre, TEM, the Devonian *causses*, the Ordovician olistoliths, and Vissou klippe were successively thrusted or resedimented in the Laurens-Cabrières basin. In the Combe Rolland area, Valuzières (initially overturned, or being secondarily refolded after its resedimentation); Devonian *causses*; and Ordovician-Silurian olistoliths were probably successively resedimented. Due to the presence of such klippes and olistoliths only to the south of the Roquessels fault, we suggest that a Roquessels palaeofault was already active during this epoch. The southern limit of this Laurens-Cabrières basin remains totally unknown in the absence of published geoseismic profiles. Fig. 27B shows South of La Serre the extension of the Cabrières basin thanks to ancient petroleum boreholes in Neffiès.

The Roquessels fault has several periods of activity, being a normal fault affecting the Triassic in Clermont-l'Hérault (Fig. 27B), but reactivating a possible earlier subhorizontal thrust (see Engel *et al*., 1982, fig. 4 and p. 342). The activity of the Roquessels palaeofault, and/or other faults around the olistoliths, can explain other instabilities and redeposition of the mud mounds, shallow platforms und subreefal deposits; namely, the *calcaires à Productus* of the Laurens-Cabrières Group, and the Coteau de Bergue, Roque Redonde, Oolites of Roc de Murviel, and Roc de Murviel formations. These latter probably covered the active faults bordering the basin (such as the Coteau de Bergue on the palaeofault of Roquessels), Roque Redonde microbial limestones, and olistoliths of the Fabrègues Fm; the shallowest being on the top of the large olistoliths, such as the Devonian *causses* of Laurens, Gabian, Vailhan, and Cabrières. These shallowest platform elements are the *Calcaires stratiformes de Vailhan*, Murviel, Roquemalière, Castelsec, debrites of the Lentilles *de la route* D13, Oolites of Roc de Murviel, La Serre Vineyard, and La Serre de Péret Fm. As a consequence, the different coeval assemblages of the *calcaires à Productus* allow us to reconstruct almost in continuity the outer platform and slope, where these microbial mounds were built (Fig. 24A) in the Laurens-Cabrières basin, from the Mikhailovian to the Protvian. No inner and mid-platforms have been identified during this time.

6. W. Franke *et al.* (2011) speculated that, after the emplacement of nappes in the Axial Zone during a phase D1, all the structural levels presented a phase D2 of extension and exhumation, a phase D3 of refolding (phase B2 of Engel *et al*., 1982), and then a phase post-D3 of dextral transtension. After W. Franke (written communication, June 2017), as the flyschs are included in the Faugères and Mont Peyroux nappes, the phase D1 postdates the youngest flysch sediments (i.e., the Barrac and Fabrègues formations, and at least the basal part of Laurens-Cabrières). As the younger olistoliths dated by our team are early Serpukhovian in the Fabrègues Fm and late Serpukhovian in the Vailhan-Cabrières Complex, it is possible to deduce that this phase D1 should correspond to at least the Serpukhovian/Bashkirian limit (323 Ma) and, at most, to the Bashkirian-Moscovian limit (315 Ma). During D1, these nappes were located on the Axial Zone, or farther north. Their current location in the southern Montagne Noire was probably achieved as early as the D2 phase. Two solutions are possible: 1) the Mont Peyroux nappe was deposited on the Axial Zone and then glided southward in a basin that received nappe and olistoliths in the Laurens-Cabrières basin before D2, if the primary Roquessels fault was produced during D2); 2) the Mont Peyroux-Cabrières unit containing the Mont Peyroux nappe and the Cabrières klippes (Laurens, Roquessels and Cabrières complexes) glided and was deposited in the Axial Zone and then glided southwards during D2 or possibly later, by gravity sliding on the southern flank of the rising Axial Zone (the *sur-déversement* of Arthaud) during D3. As the metamorphism affected the nappes and flysch (see the metamorphism maps of Franke *et al*., 2011), and even, slightly, some olistostromes of the Roquessels Complex, such as the Malac railway trench and Coteau de Bergue), with an increase from North to South, the second solution is the most probable. The age of the high pressure-low temperature event (eclogite) of the Axial Zone was dated 357 to 350 Ma (Faure *et al*., 2014) corresponding to Tournaisian. Younger dates from as 315 to 308 Ma found also in the eclogites postdates migmatization (Faure *et al*., 2014). Furthermore, W. Franke *et al.* (2011) and M.-P. Doublier *et al.* (2015) indicated that the onset of high temperature and low pressure metamorphism in Montagne Noire at 333 Ma corresponded to a heat rising in the Axial Zone during the genesis of a dextral-transpressional pinched pull-apart dome. This metamorphism continued from 315 to 308 Ma. The metamorphism at 333 Ma is coeval with our Cf6γ biostratigraphic datum (Pointon *et al*., 2015), when generalized debris flows began to affect the basins in the Mont Peyroux and Faugères nappes. The metamorphism at 315 Ma (i.e., Bashkirian-Moscovian boundary; Davydov *et al.,* 2010, 2012) postdates the end of marine sedimentation in the Protvian (325 Ma; Richards, 2013) and the Serpukhovian-Bashkirian boundary (323 Ma, Davydov *et al*., 2010, 2012) by 10-12 Ma. This metamorphism was controlled by exhumation of the Axial Zone (Doublier *et al*., 2015) in two stages: stage 1 from 316 Ma to 300 Ma, exhumation into the upper crust controlled by dextral shear zone and stage 2 (300 Ma), final exhumation by extension with formation of the Graissessac and Lodève basins;

7. in contrast, nothing is known sedimentologically about the history of the Montagne Noire from the resedimentation of the Protvian olistoliths to the deposition of the intramontane Gzhelian coalfields. Nevertheless, Franke *et al.* (2011) emphasized in this period the following tectonic phases: the stacking of nappes over a rising pull-apart dome, *sur-déversement*, emplacement of klippes, and the final compression;

8. concerning the palaeobiogeography, it is worth noting, that, based on the dasycladales *Eovelebitella*, so abundant in the Montagne Noire, Vachard *et al.* (2006) have deduced that the Montagne Noire belongs to a Palaeoprovince with *Eovelebitella*, which extended to the Betic Cordillera and Balearic islands on one side, and to the Carnic Alps, on the other side. The Eastern Pyrenees belong to this Province with *Eovelebitella* (Sanz-López *et al*., 2005), as well as the core of the Picos de Europa unit in the Cantabrian Mountains (unpublished data). Hence, it is possible to conclude that an eastern part of the Pyrenees is linked with the Montagne Noire, when the other parts were independently linked with the Cantabrian Mountains. Nevertheless, the palaeogeography is possibly more complicated, with the Cantabrian Mountains located west of the Pyrenees and Montagne Noire; this latter being located north of the Pyrenees. Both regions share many foraminiferal taxa (Cózar *et al*., unpublished data). With the compression of the Variscan front, it is possible to invert the Spanish zones, those originally located in the north now being in the south.

8. Conclusions

1. The middle-late Tournaisian black radiolarian chert of the Lydiennes Fm, are known in several units (Faugères nappe, Mont Peyroux nappe, Roquessels Complex, Vissou klippe, and La Serre klippe) but are absent from the other Cabrières klippes, where the late Tournaisian rests upon the lower late Famennian supragriottes.

2. Latest Tournaisian-early Viséan and rare other Viséan nodular limestones are a continuation of the typical Devonian griottes and supragriottes, and the last representatives of the griotte sedimentation in the Montagne Noire, with the Faugères and Tourière formations, respectively. In contrast, the third griottes are carbonate breccia and/or elements of debris flows and do not correspond to griotte limestones. The La Serre klippe can be distinguished from the all late Tournaisian

deposits by the La Serre East Fm, deposited on a shallow platform.

3. The middle-late Viséan limestone sedimentation is represented by the Colonnes and Valuzières formations, from the outer- and mid-platform, respectively.

4. After that, there begins everywhere a siliciclastic sedimentation of flysch-type, including limestone olistoliths; especially, in the easternmost area. Considered as homogeneous by many authors, these flyschs constitute four to six different geographical units from west to east. Except for the previously described Puech Capel Fm, several formal names for these units are introduced in this paper: Barrac Group, Landeyran Barn Member, Barrac Formation, Fabrègues Formation, and Laurens-Cabrières Group.

5. The carbonate olistoliths reworked in these siliciclastic units characterize three complexes: Laurens, Roquessels, and Vailhan-Cabrières. The carbonate olistoliths generally record short intervals of time. However, some fragments of carbonate sedimentary piles can be described as formations; during a period from Mikhailovian to Protvian, these formations are: Roque Redonde Fm, Oolites of Roc de Murviel Fm, Roc de Murviel Fm, and La Serre de Péret Fm. However, it is generally difficult to use cartographically these latter "formations". The study of the facies of carbonate olistoliths allows us to reconstruct the sedimentation of microbial mounds under diverse conditions (aphotic, dysphotic and photic) on the slope of the basin between channels feeding the flysch or outer platform.

6. The succession from the middle Tournaisian up to the late Serpukhovian, studied within the pre-orogenic context of the southern Montagne Noire, confirms the incoming of the nappes and olistoliths from the north, and the existence of distinct tectonostratigraphic units corresponding to the odyssey of these units.

7. The Mont Peyroux nappe, the Pic de Vissou klippe and the Roquessels Complex display the deepest deposits during the whole Mississippian, whereas the La Serre and other Cabrières klippes show the shallowest deposits.

8. The La Serre area during the Mississippian shows the shallowest series (outer inner ramp) of the Montagne Noire. The La Serre East Fm is the unique, shallow late Tournaisian-early Viséan formation. These shallower series of La Serre are recorded up to the Protvian, with unnamed series near La Rouquette and La Serre Vineyard.

9. Palaeogeographically, the succession of the tectonosedimentary units from North to South, during the Early Carboniferous, is: La Serre klippe/Cabrières klippes source area/Roquessels Complex/Mont Peyroux nappe (including Vissou) overturned limb/normal limb of Mont Peyroux nappe (with Fabrègues Fm)/Faugères nappe (from Vieussan to Caragnas).

10. Our new age determinations (Vachard *et al*., 2016a, 2016b, and unpublished data) lead us to question the chronological order of the great tectonic and geodynamic episodes of the Variscan orogenesis in the Montagne Noire; i.e., the emplacement of the Faugères nappe; the emplacement of the Mont Peyroux nappe; and the timing of the diverse stages of resedimentation. The emplacements of the Mont-Peyroux and Faugères nappes, and the development of the Laurens-Cabrières basin, are currently difficult to constrain chronologically.

11. The beginning of the large siliciclastic series probably constitutes a major tectonic event at the end of the Cf6γ; even if it can only indirectly dated by the reworked or intercalated carbonate olistoliths.

12. The flysch sedimentation needs some additional age determinations. However, the flyschs of the Faugères and Mont Peyroux nappes must have been deposited in elongate basins of thrust belts and organized in a sequence with a LST (Faugères flysch), TST (Barrac Fm) and a HST (Fabrègues Fm) corresponding to the late Viséan-early Serpukhovian sequence, which was controlled by tectonics of the foreland basin.

13. The more probable tectonic solution includes a Mont Peyroux-Cabrières unit containing the Mont Peyroux nappe and the Cabrières klippes (Laurens, Roquessels and Cabrières complexes) that glided and was deposited in the Axial Zone and then glided southwards to its current location.

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