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The Kulm Facies of the Montagne Noire (Mississippian, southern France)

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ABSTRACT. The Kulm facies of the Montagne Noire formed in a foreland basin south of the French Massif Central. During the preorogenic phase (Tournaisian – early late Viséan) two major facies domains can be differentiated in the Montagne Noire. The Mont Peyroux Succession represents more distal environments with an almost continuous stratigraphical record, which displays the development from a deeper-water carbonate platform to a starved basin facies, which is followed by the onset of calciturbidite deposition. The contemporaneous Ecailles Succession, only found in exotic blocks, represents the proximal environments with important stratigraphical gaps. The synorogenic phase of the basin (early late Viséan – Serpukhovian?) is characterized by flysch deposits, which contain in the later stages large exotic blocks indicating the final collapse of a mixed-siliciclastic carbonate shelf system. Differences in the Kulm sequence of the Carboniferous foreland basin of southern France (Montagne Noire, Mouthoumet Massif and Pyrénées) are due to different local palaeotopographies and distances to platform areas and sediment sources in the preorogenic sedimentation, and the timing of the onset of the synorogenic sedimentation and the migration of the depocentre from east to west. Striking similarities in respect to the overall facies, but also to the development of particular facies during a particular time slice exist to the succession of the Rhenish Kulm Basin, especially its north-western part; e.g. dark shales with phosphatic nodules during the Lower Alum Shale Event or the interruption of the bedded chert deposition by deeper water carbonates during the latest Tournaisian – earliest Viséan.

KEYWORDS: Mississippian, stratigraphy, sea-level, basin dynamic, palaeogeography, Rhenish Massif, Massif Central

1. Introduction

With the beginning of geological and stratigraphical research in Western Europe in the early 19th century, two main marine facies realms have been identified in the lower Carboniferous (Mississippian) strata based on specific lithologies and organic content. The *Carboniferous Limestone* or *Kohlenkalk* represents the shallow-water platform facies and was first identified in the British Isles and Southern Belgium. The *Kulm* is equivalent of the deeper water, basinal facies of the German Rhenohercynian Basin (Fig. 1). Both names are still widely in use and especially the *Kulm* has been exported outside its regional and stratigraphical context.

One of these examples is found in southwest France. Here, south of the Massif Central, the remnants of a Mississippian foreland basin are exposed in the Montagne Noire, the Mouthoumet Massif and the Pyrénées (Fig. 1). The best-exposed and most complete succession is found in the Montagne Noire

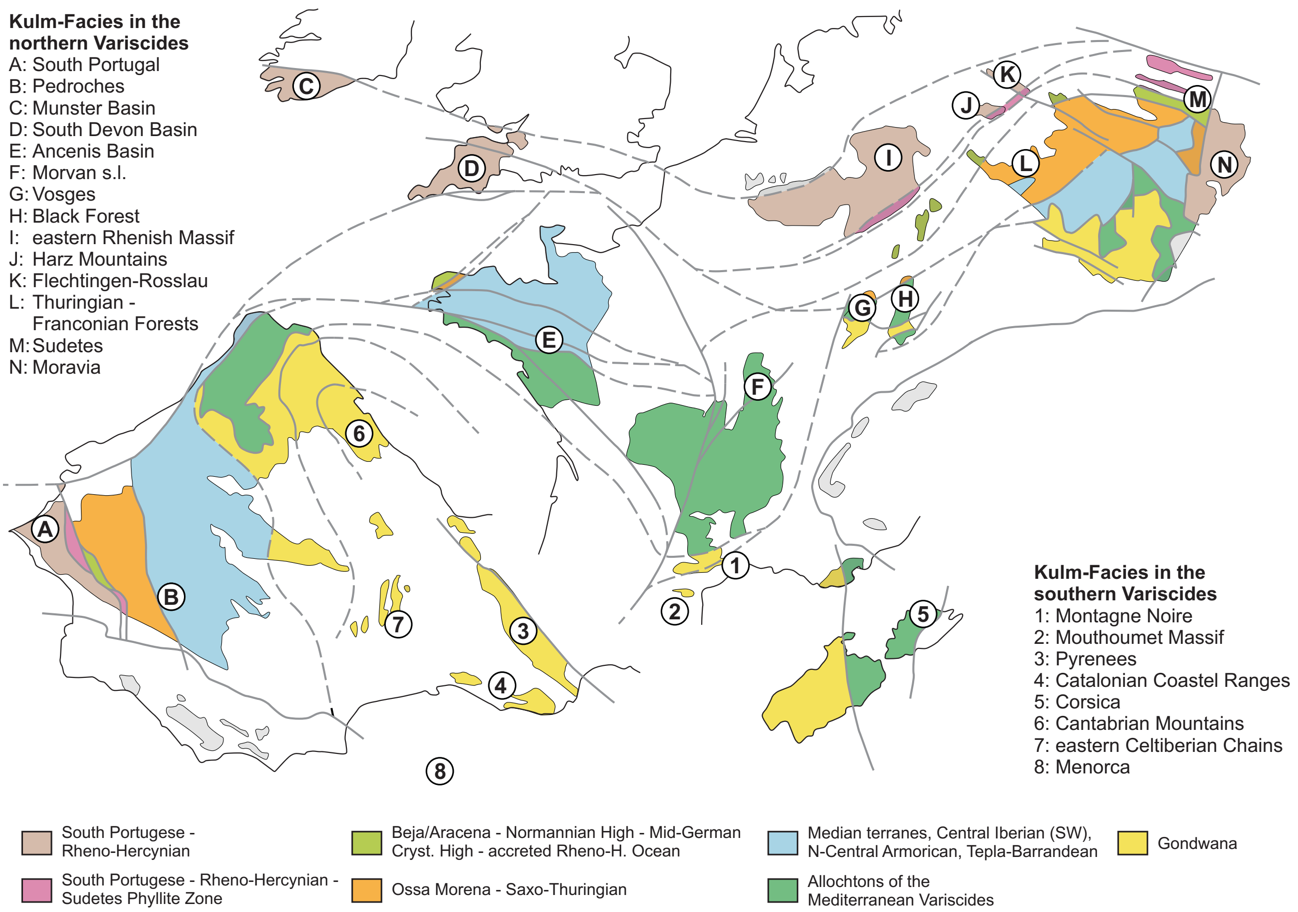

Figure 1. Localisation of the main outcrops of Kulm Facies in the framework of Variscan Europe. The attribution of the regions 5-6 in the southern Variscides is disputable. Kulm deposits in Variscan massifs included in Alpine mountain chains (e.g. Betic Cordillera) have been omitted except for the Pyrénées. The division into large tectonic units is from Franke (2014).

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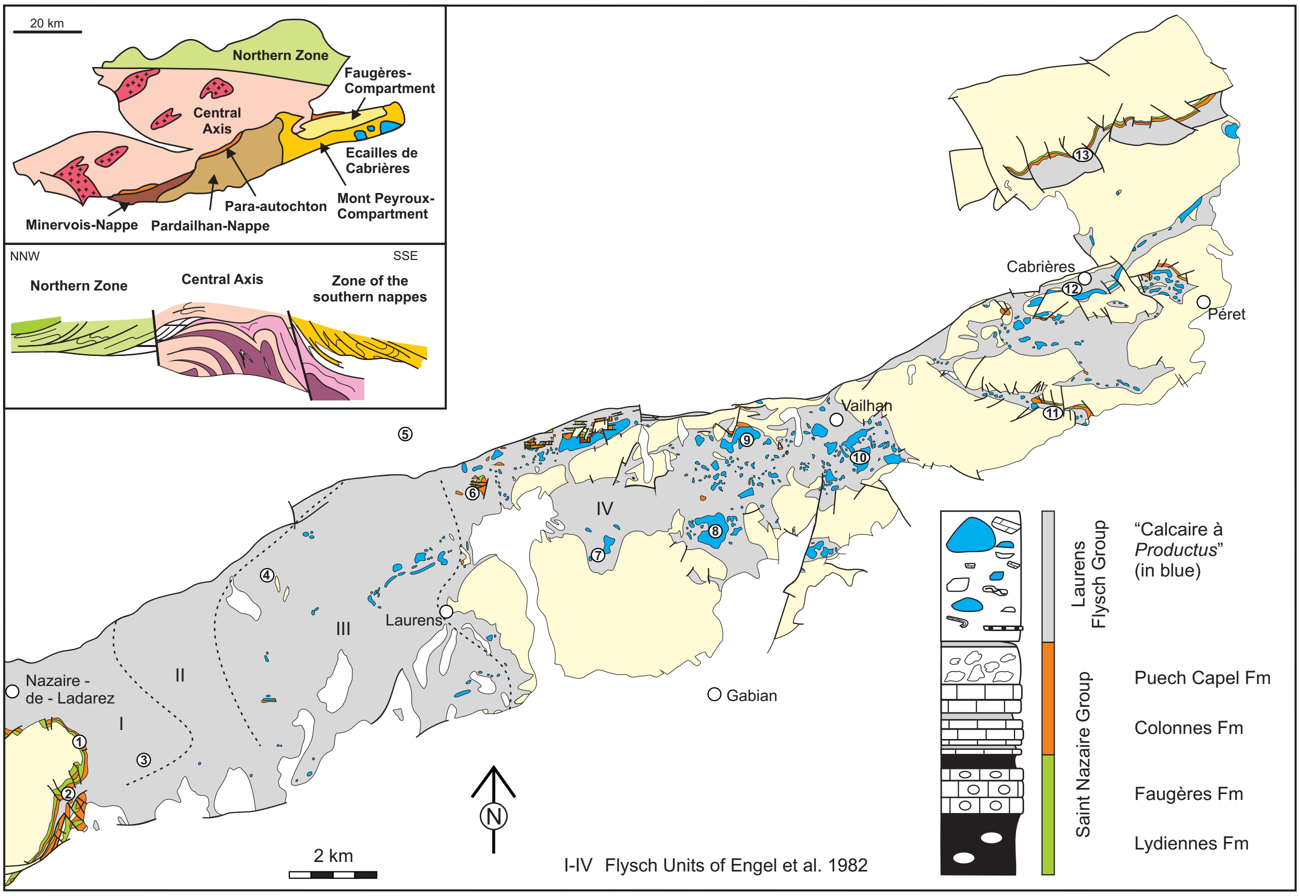

Figure 2. Geological map of the Mississippian Kulm deposits in the southeastern Montagne Noire (Mont Peyroux and Ecailles de Cabrières units, after Engel et al., 1982) and the main localities mentioned in the text. From West to East: 1. Puech de la Suque, 2. Puech Capel, 3. Barrac, 4. La Liquière, 5. Hill 243, 6. Le Pioch, 7. Roc du Cayla et Castelsec, 8. Les Pascales, 9. Roc de Murviel, 10. Roque de Redonde, 11. La Serre (GSSP, D/C boundary), 12. Cabrières, 13. Pic de Vissou (older name Pic de Bissous). The Ordovician to Devonian rocks of the Mont Peyroux-Compartment are coloured in light yellow. Small insets show the main structural units of the Montagne Noire and the complex tectonic deformation (modified from Demange, 1994). Note the doming of the Central Axial zone in the cross-section.

(Figs 1, 2). It is the aim of the paper to summarize the currently available data on the Kulm Facies of that region, to discuss a depositional model, to place the succession into the larger regional context of Southern France and to propose a correlation with the classical Rhenish Kulm Facies.

In France the term *Culm* or *Culm Facies* has become a synonym for *flysch* deposits of Upper Palaeozoic age (e.g. Perret, 1993). This use is certainly influenced by Pruvost (1956) who defined *Culm* as alternation of marine conglomerates, sandstones and mudstones, respectively shales of ‘Dinantian’ age. Thus the French *Culm* is often only the equivalent to the Flysch or Kulm-Grauwacken (e.g. Schrader, 2000) of the traditional Rhenish Kulm sequence.

However, the entire Mississippian succession (preorogenic + synorogenic) of the Montagne Noire is far more similar in respect to facies and development of the depositional environment to the full suite of the *Rhenish Kulm* as implied by the restricted connotation of *Culm*. Thus *Kulm* is applied herein to clearly mark the differences to the French *Culm*.

The assignment of a Carboniferous age to rocks in the south-eastern Montagne Noire goes back to de Serre (1847) who recognized the brachiopod genus *Productus*, which would become important for the local stratigraphical nomenclature. In the mid-1880’s *Culm* was introduced when describing and comparing the Carboniferous rocks and fossils of the Montagne Noire with other regions (Bergeron, 1887; Frech, 1887; Zeiler in de Rouville, 1887). However at that time, only the Viséan stage was recognized and it was up to Bergeron (1898) to show the presence of Tournaisian strata. Detailed lithostratigraphical and biostratigraphical descriptions of the *Culm* succession were provided by Böhm (1935), but he advocated for a hiatus during the entire Tournaisian time. He also presented comparisons with time-equivalent successions in Central and Southern Europe, mostly from a biostratigraphical view, but facies similarities were sometimes indicated. The recognition of synorogenic gravitational transport within the upper part of the Mississippian succession of the Montagne Noire (Engel et al., 1978, 1982) can be seen as a milestone in the understanding of the complicate structures and their temporal and spatial developments. It considerably altered the older models including those of Gèze et al. (1952), Maurel (1966), Arthaud (1970), and Vachard (1974, 1977).

Engel et al. (1982) provided the first correlation between formations from the Montagne Noire and the Rhenish Kulm Basin. Feist & Flajs (1987) and Lethiers & Feist (1991) added more details for specific time slices to this comparison. The decision (Paproth et al., 1991) to define the base of the Carboniferous in the La Serre section (global stratotype section and point, GSSP) has been a stimulus for the study of this time interval in the Montagne Noire from the mid-1980’s onward. Recent work on the Carboniferous ammonoids (Korn & Feist, 2007) provided an improved biostratigraphical and also lithostratigraphical scheme for the preorogenic phase and thus allows detailed comparisons to other basins. New lithostratigraphical and biostratigraphical data for late Mississippian exotic blocks within the flysch were provided by Poty et al. (2002), Aretz (2002 a, b), Vachard & Aretz (2004) and Pille (2008).

2. Geological Setting

The Montagne Noire forms the southern margin of the Precambrian-Palaeozoic French Massif Central. Towards the south and southeast, rocks of intramontane post-Variscan basins and the Cainozoic Languedoc Basin unconformably cover it. The Montagne Noire itself is characterized by a complex polyphased Variscan deformation and syntectonic metamorphism (e.g. Franke et al., 2011; Chardon et al., 2015), and is one of the rare areas south of the Variscan suture, which has not been incorporated into Alpine orogenies (Feist & Flajs, 1987).

The Montagne Noire is divided into three major zones based on lithological, metamorphical and structural arguments (Fig. 2): (a) the northern thrust zone consisting of Cambro-Ordovician rocks, (b) the Central axial zone mainly comprising medium- to high-grade metamorphic rocks of the basement (gneiss and migmatites surrounded by micaschists), which form an anticlinal structure ("doming"), and (c) the southern nappes zone. The latter consists of several south-facing, recumbent folded nappes with Precambrian to Mississippian strata (Fig. 2). The structural situation in this pile of nappes is relatively complicated (Arthaud, 1970), but in general only the inverted limbs of the nappes are preserved and those have in later stages of the Variscan deformation been refolded (see discussion in Engel et al., 1982). A different tectonic style is preserved in the "Ecailles de Cabrières" (Fig. 2), which are gravitational displaced klippen-like slabs and blocks of various ages. The origin of the nappes is thought to be north of their current positions and the "Ecaillles de Cabrières" being the most northern elements (Engel et al., 1982). This traditional model has been recently disputed (e.g. Chardon et al., 2014, 2015). However, to avoid confusion, the Roquessels Fault is used in this work to separate a southern Mont Peyroux-Compartment and a northern Faugères-Compartment. In the view of Engel et al. (1982) those compartments are two individual nappes (Faugères and Mont Peyroux nappes), whereas they belong to the same nappe (Faugères-Nappe) according to Chardon et al. (2015).

3. Succession

Mississippian strata only occur in the Para-autochthon, the Faugères-Compartment and the Mont Peyroux-Compartment including the "Ecailles de Cabrières" (Fig. 1).

Outcrops in the Para-autochthon are scarce. The succession of the Faugères-Compartment is lithologically relatively monotonous and mainly consists of shales. In contrast to this monotony is the Carboniferous succession of the Mont Peyroux-Compartment. Outcrops are numerous and a variegated suite of mainly sedimentary rocks occurs.

Taking mainly into account the Mont Peyroux-Compartment, its preorogenic sedimentation, Tournaisian to early late Viséan in age, shows the differentiation in at least two larger distinctive palaeogeographical domains (Fig. 3): (a) the Mont Peyroux Succession and (b) the Ecailles Succession. The Mont Peyroux Succession represents more distal environments, whereas the

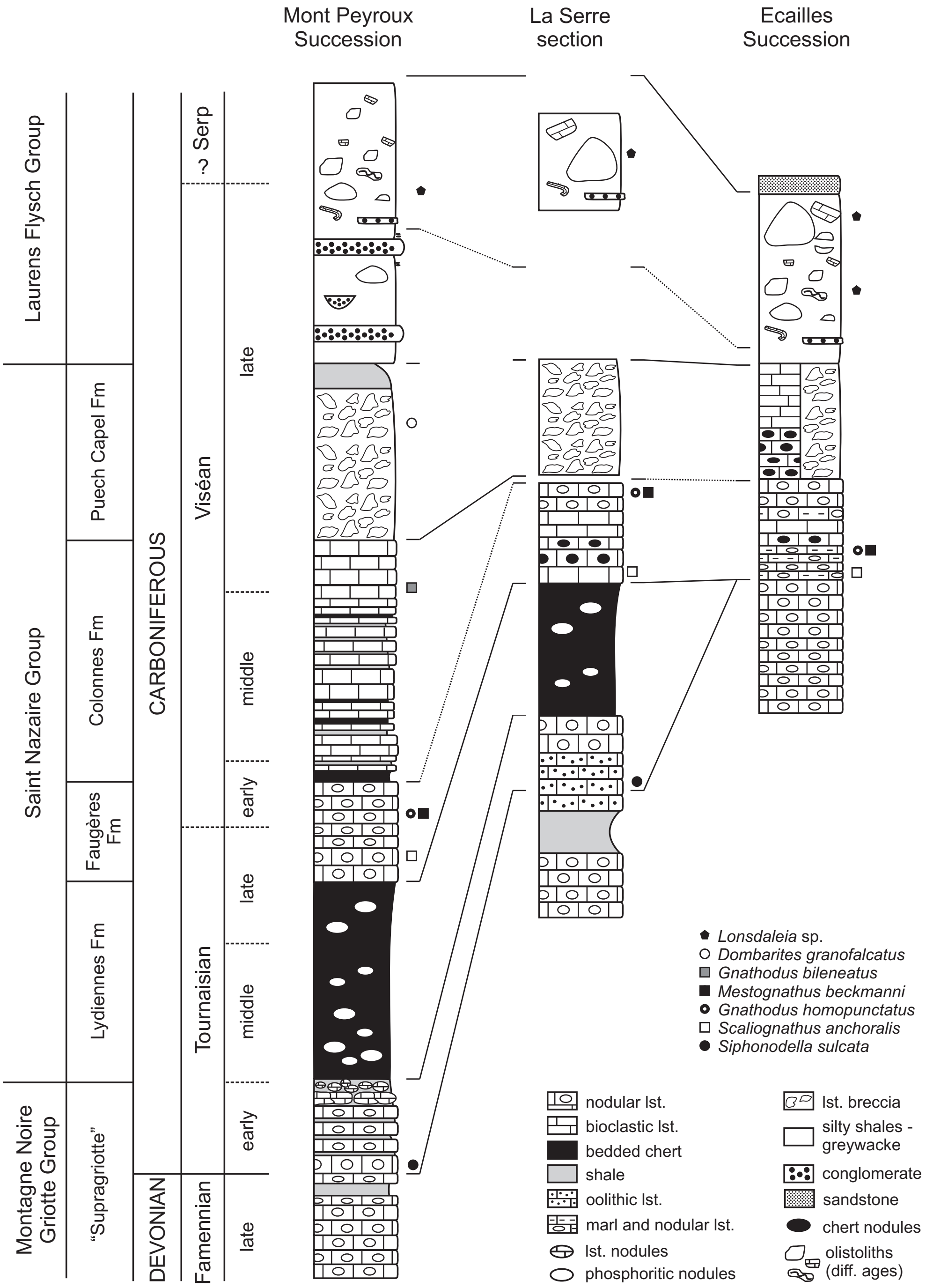

Figure 3. Lithological logs (not to scale) of the Mont Peyroux Succession based on outcrops in the Puech de la Suque area, the La Serre Section, and the Ecailles Succession and stratigraphical correlation between the three depositional models. Lithostratigraphy is according to Korn & Feist (2007). The approximate positions of some biostratigraphical markers are indicated.

Ecailles Succession contains more proximal settings and has in some respects similarities to a carbonate platform facies of *Kohlenkalk*-style. These two successions can be partly correlated with the sedimentological models of Vachard (1977); Mont Peyroux Succession: Mont Peyroux-Bissous (old name for Vissou) model, Vieussan-Caragnas model, and parts of the La Serre & Bande de Roquessels model; Ecailles Succession: Cabrières model and parts of the La Serre & Bande de Roquessels model.

These marked palaeogeographical differences are not seen in the synorogenic phase, late Viséan – Serpukhovian time. However, this does not imply a homogeneous flysch facies for the entire area at that time. Facies changes still persist on very different scales.

3.1. Preorogenic phase

3.1.1. Mont Peyroux Succession

The Mount Peyroux Succession characterizes the outcrops along the western and northern border of the Mont Peyroux-Compartment, including the displaced blocks in the Pic de Vissou area (Fig. 2), which belong to the "Ecailles de Cabrières". The Succession is divided into two lithostratigraphical groups (Fig. 3); Montagne Noire Griotte Group and Saint Nazaire Group (Korn & Feist, 2007). The reference sections Puech de la Suque and Puech Capel (Fig. 2) are situated few kilometres SSE of Saint Nazaire-de-Ladarez.

Montagne Noire Griotte Group

The vast majority of the often iron-stained nodular (cephalopod) limestones, which characterize this group, are Famennian in age (e.g. Girard et al., 2013). Only the topmost unit of the group, the upper part of the "supragriottes" of Boyer et al. (1974) and Lethiers & Feist (1991) is Tournaisian in age. This upper part consists of about 3 m of medium- to thick-bedded nodular limestone (Fig. 4), which succeeds few decimetres of dark shales. The latter is thought to be the equivalent to the Rhenish Hangenberg (black) shales (Feist & Flajs, 1987).

However, the first bed above the shale is still Devonian in age (Kaiser, 2005), whereas the appearance of *Siphonodella sulcata* in the second limestone bed above the shale (bed 12) (Boyer et al., 1974; Kaiser, 2005, Kaiser et al., 2016) indicates a position above the Devonian/Carboniferous boundary. The limestone unit itself consists of light to dark grey nodular limestone beds with thin argillaceous intercalations. Weathering often results in yellowish, rarely reddish colours. The shale content increases up-section, and likewise compact beds become dissociated and limestone nodules in an argillaceous matrix characterise the upper part of this unit. The boundary with the succeeding Saint Nazaire Group is drawn above the last occurrence of limestone nodules (Fig. 3).

Kaiser (2005) noted differences in older assignments of individual beds to particular conodont biozones. However Korn & Feist (2007) reported the presence of all five conodont zones representing the Hangenberg Limestone in the Rhenish successions (upper *praesulcata* – *sandbergi* Conodont biozones) from the uppermost part of the Montagne Noire Griotte Group. Their ammonoid faunas from this interval were of latest Devonian (below the dark shales) and early Tournaisian ages, thus corroborating the conodont data, and establishing a Tournaisian age for the topmost beds of the "supragriottes".

Saint Nazaire Group

The Saint Nazaire Group comprises four formations (Korn & Feist, 2007). These are in ascending order: Lydiennes Formation (Fm), Faugères Fm, Colonnes Fm, and Puech Capel Fm. The naming of the Lydiennes and Colonne formations sensu Korn & Feist (2007) do not respect the recommendations of the stratigraphic code. They are kept herein since a new naming requires a detailed stratigraphic revision of the entire Mississippian succession south of the Massif Central, which is beyond the scope of this review.

Lydiennes Formation

The name of this formation arises from the black siliceous sedimentary rocks ("lydites"), which make up most of the up to 30 m-thick formation in its stratotype section Puech de la Suque (Fig. 5). Individual bed thickness of these bedded cherts are generally in the size range of 2-10 cm. Traditionally, these rocks are described as radiolarian cherts (*cum. lit*) based on their rich radiolarian content (Deflandre, 1946; Gourmelon, 1987).

Figure 4. Light nodular limestone of the "supragriottes", Montagne Noire Griotte Group. Puech de la Suque section. Hammer length is 29 cm. Stratigraphic top to the left.

Figure 5. Typical outcrop of the Lydiennes Formation with bedded cherts and nodules. Puech de la Suque section. Width of the figure is about 30 cm. Stratigraphic top to the left.

However a detailed modern petrographical study is lacking and it seems reasonable to assume that diverse rock types, as homogeneous or spiculitic cherts, can be expected, as known from comparable contemporaneous facies (Gursky, 1996; Randon & Caridroit, 2008). Some detritic siliciclastic grains and sponge spicules in the lowermost beds of the "lydiennes" (Gèze, 1949) support this possibility. Thin layers of blackish shales often form the interbeds between the cherts. Some strongly weathered light greenish-greyish coloured mm-thin beds may represent metabentonite interbeds or silicified tuffs.

Characteristic for the succession is the presence of phosphatic nodules, up to 6 cm in diameter. Korn & Feist (2007) report the nodules from the basal part, whereas previous authors (e.g. Böhm, 1935; Engel et al., 1982) indicate a less restricted distribution. These nodules have become famous for containing permineralized plant fragments belonging to more than 30 taxa (Decombeix et al., 2006). Beside plants (e.g. Meyer-Berthaud, 1984; Galtier et al., 1988) the nodules also contain radiolarians (see above), cephalopods (Delépine, 1935; Böhm, 1935; Korn & Feist, 2007) and arthropods (Delépine, 1935; Böhm, 1935; Rolfe, 1985). Early phosphatogenesis during diagenesis, probably around the water–sediment interface (Trappe, 1998) might explain the good preservation of the fossils within the nodules. However, fossils are not only restricted to the nodules, they also occur in the surrounding matrix, e.g. compressions of plant remains (Galtier et al., 1987).

Böhm (1935) concluded an early Viséan age for the Lydiennes Fm, thus contributing to a lasting debate on a possible unconformity between upper Devonian and Viséan strata in southern France (see discussion in Boyer et al., 1968; 1974). Coudray et al. (1979), Engel et al. (1982) and Lethiers & Feist (1991) reported from the succeeding Faugères Fm latest Tournaisian – early Viséan conodonts (from the *anchoralis* biozone onward), thus contradicting the assignment of Böhm (1935). The revised ammonoid data of Korn & Feist (2007) clearly show that the Lydiennes Fm does not contain any latest Tournaisian or early Viséan elements. Based on comparisons with European and North African faunas, these authors conclude a "middle" Tournaisian age for the ammonoid fauna of the Lydiennes Fm. Hence the Lydiennes Fm comprises the stratigraphical interval above the *sandbergi* Conodont biozone and below the *anchoralis* Conodont biozone ("middle" to "late" Tournaisian).

Faugères Formation

Limestones now divided into the Faugères and Colonnes formations as well as stratigraphical names are often combined and/or mixed in the older literature (Böhm, 1935; Gèze, 1949; Maurel, 1966; Mamet, 1968).

Böhm (1935) first described fossiliferous beds in the "Calcaire de Faugères" located 2.5 km S-SE of Faugères (Fig. 2). Vachard (1974, 1977) introduced and named for that locality the term "limestones of hill 243", subsequently named Faugères Fm (Engel et al., 1982; Korn & Feist, 2007). Engel et al. (1982) mentioned good outcrops at the nearby locality "Le Pioch", 1.75 km SW of Roquessels. However, the type locality of the Faugères Formation is situated at Mont Mou, 1 km S of Faugères (Korn & Feist, 2007).

The Faugères Fm comprises an interval dominated by red, pink or yellowish nodular limestones. Shales of variegated colours and carbonate content can be intercalated. Thus, a broad suite of variations from massive nodular limestones to calcareous shales and marls with limestones nodules can be observed in individual or among several outcrops. Average thickness of the formation is about 10 m, the exposures in the reference section at Puech de la Suque are discontinuous.

Based on foraminifers Vachard (1977) concluded an early Viséan age (V1b) for the Faugères Formation, but the fauna did not contain many characteristic elements. Coudray et al. (1979), Engel et al. (1982) and Lethiers & Feist (1991) reported from the lower two metres of the Faugères Fm *Scaliognathus anchoralis*, *Doliognathus latus*, and *Gnathodus pseudosemiglaber* and up-section *Gnathodus praebilineatus*, *Mestognathus beckmanni*, and *Gnathodus homopunctatus*. According to these conodont data the Tournaisian/Viséan boundary can be placed within the formation. Korn & Feist (2007) reported the ammonoid genera *Merocanites*, *Ammonellipsites*, *Dzhaprakoceras*, and *Winchelloceras*, which only indicate a latest Tournaisian age. However, Lethiers & Feist (1991) reported *Merocanites* and *Ammonellipsites* from the upper part of the formation, which according to the conodont data is Viséan in age (Korn & Feist, 2007). Thus, an uncertainty remains for the exact position of the Tournaisian/Viséan boundary, but it seems to be reasonable to place it within the formation.

Colonnes Formation

The Colonnes Fm is a 30 to 50 m-thick package of fine-grained, often graded, micritic and bioclastic limestone beds alternating with light grey to light green bedded cherts and yellowish-brownish shales (Fig. 6). The limestones clearly dominate the formation; bedded cherts and shales are restricted to its lower half. Vachard (1977) and Engel et al. (1982) mentioned substantial local facies variations, including some thin limestone breccias. The latter could easily be recognized by the high ratio clast size/bed thickness.

Figure 6. Bedded fine-grained limestones interpreted as calciturbidites of the Colonnes Formation. Puech de la Suque section. Vertical thickness of the figure is about 60 cm.

Most limestone beds are 5-20 cm-thick. Typical sedimentary structures are gradation, concentration of lithoclasts in the lower part of individual beds, parallel lamination in the upper part of individual beds, and planar bed bases. However, individual beds can attain up to 2 m thickness and clasts up to 1 m (Engel et al., 1982). Most of the beds of the Colonnes Formation are assigned to calciturbidites deposited in a distal position to the source area. However, at Coumiac, oolitic grainstones and alternating wackestones and packstones rich in sponge spicules are the main limestone facies types in this formation (Vachard, 1977).

The formation is very poor in macrofossils. Microfossils are scarce, but more common, and seem to be restricted to distinctive beds. Calcareous microfossils (Vachard, 1974, 1977) indicate a range from the late early Viséan ("V2a") to the early late Viséan ("V3bα"). Ziegler (1959) reported the conodont *Gnathodus bilineatus* from the upper part of the formation.

In the Para-autochthon and the Faugères-Compartment the formation comprises light bedded cherts, grey, yellowish and green shales, metabentonites, and very few thin limestone beds.

Puech Capel Formation

Korn & Feist (2007) introduced a two-fold subdivision of the Puech Capel Formation. The lower part consists of up to 100 m of dark silty shales comprising abundant limestone blocks of variable size, having partly the aspect of a limestone breccia with siliciclastic matrix ("shistes troués" of Engel et al., 1982). Locally, slumping can be observed. According to Korn & Feist (2007) it represents an olistostrome-like coarse debris flow deposits incorporating pluri-decimetric blocks of shallow-water carbonates. The upper part of the formation is up to 20 m-thick and consists of greenish shales with marly, nodular limestone beds. The latter are 5-20 cm-thick. Korn & Feist (2007) noted the resemblance of these nodular limestones with the lowermost Tournaisian Griotte facies. Thus the term "third griotte" is used in this context (the Faugères Fm being the second). The ammonoid data of Korn & Feist (2007) (*Dombarites granofalcatus*, *Irinoceras* sp. A) point to a latest Viséan age for this part of the succession.

Up-section follows a unit of green shales with marly intercalations (= Landeyran shales of Böhm, 1935), which contains a probably latest Viséan ammonoid fauna (Korn & Feist, 2007). The thickness of this unit is not well-known due its transitional lithological character to the overlying Laurens Flysch Group. Apparently Korn & Feist (2007) did not include it into the Puech Capel Fm, and did not formalise this unit in their lithostratigraphical scheme. It might be envisaged to include this unit as a third member within the Puech Capel Fm.

However, the Puech Capel Fm and the Landeyran Shales of Böhm indicate the change in the overall tectonic regime and link to the deposits of the synorogenic phase.

3.1.2. Ecailles Succession

The Ecailles Succession is restricted to the Mississippian strata documented in exotic blocks found in the flysch deposits. These blocks are abundant in the central and eastern part of the Mont Peyroux-Compartment. In general the succession represents more proximal settings, and stratigraphical gaps are more common than in the Mont Peyroux Succession. Moreover, the olistolitic nature of the exotic blocks often prevents the preservation of long stratigraphical sections.

Characteristic for the Ecailles Succession (Fig. 3) is the onset of Carboniferous deposition in the late Tournaisian. The hiatus is of variable duration, but always comprises the interval latest Famennian to "middle" Tournaisian.

Above a thin basal conglomerate a variegated package of dominantly reddish- brownish nodular limestones, marls and siltstones-mudstones were deposited. Biostratigraphical dating (Engel et al., 1982) shows the presence of taxa from the *anchoralis* and *homopunctatus* Conodont biozones (*S. anchoralis*, *Do. latus*, *Po. bischoffi*, *Gn. texanus*, *Gn. homopunctatus*, *M. beckmanni*). Thus, these deposits can be correlated on lithostratigraphical and biostratigraphical grounds with the Faugères Fm in the Mont Peyroux Succession. The onset of sedimentation at this stratigraphical interval might be correlated with a global sea-level highstand in the latest Tournaisian (Avins Event, Poty, 2007).

Pale and locally reddish bioclastic limestones sometimes with chert nodules follow up-section. Dolomitization may be locally intense. They are thought to represent platform carbonates (Engel et al., 1982). Vachard (1977) differentiated in the Valuzières area two units: the lower "les bancs de dessus" and the upper "les calcaires à chailles". Based on calcareous microfossils he attributed mainly middle Viséan ages to both units, "V2b" and "V3a". Only the topmost reddish limestones were placed into the earliest late Viséan ("V3bα"). In the same stratigraphical context, Poty et al. (2002) and Aretz (2002b) used the term "Colonnes limestones" for the pale limestones below the Roque Redonde Fm in the Roc de Murviel section. Some sections (e.g. in Engel et al., 1982) show the development of a carbonate breccia on top of a thinner limestone horizon above the Faugères Fm, but not much is known about their composition and age.

Engel et al. (1982) speculated that the limestones above the Faugères Fm belong to the same carbonate platform, which was the source area for the calciturbidites of the Colonnes Fm. The latter is the temporal equivalent in the Mont Peyroux Succession.

3.1.3. La Serre section

The La Serre section is unique for the Montagne Noire (Figs 2, 3, 7). A shallow-water facies (biodetrital oolites) characterizes the latest Famennian and earliest Tournaisian without any hiatus. It is in this facies, where the GSSP for the D/C boundary was placed (Paproth et al., 1991; Fig. 7). Due to problems with the index taxon (*Siphonodella sulcata*) and the facies of the stratotype section, the base of the Carboniferous is currently being revised and will likely be moved away from the La Serre section (e.g. Kaiser, 2005, 2009; Kaiser & Corradini, 2011; Aretz, 2014; Becker et al., 2016).

The oolites are topped by yellowish nodular limestone in alternation with marls, with a topmost bed of oolithic limestones. Feist & Flajs (1987) used the term "upper Griotte Member" for this lithostratigraphical unit. It can easily be correlated with the "supragriottes" of the Mont Peyroux Succession. Up-section follows a package of dark marls turning into black mudstones and shales and bedded cherts with a few phosphatic nodules. This facies has strong similarities with the Lydiennes Fm, and it also contains well-preserved plant remains. The Lydiennes Fm at La Serre is thinner than in the Mont Peyroux Succession. This can be at least partly explained by reworking, as evidenced by bedded chert pebbles in the lowermost beds of the succeeding Faugères Fm.

The Faugères Fm at La Serre is lithologically comparable to other sections. It has to remain uncertain if deposition of the Faugères Fm at La Serre started earlier, as possibly indicated by a higher entry of *S. anchoralis* (Feist & Flajs, 1987). Feist & Flajs (1987) interpreted the following brecciated and cherty limestones as slope deposits.

Hence, the La Serre section forms the transition between the Ecailles and Mont Peyroux successions.

3.2. Synorogenic phase

The onset of the synorogenic sedimentation is well delineated in many outcrops by alternations of shales, greywackes, sandstones or conglomerates. However, in some outcrops, such as the Roc de Murviel (Poty et al., 2002; Aretz, 2002b), the carbonate

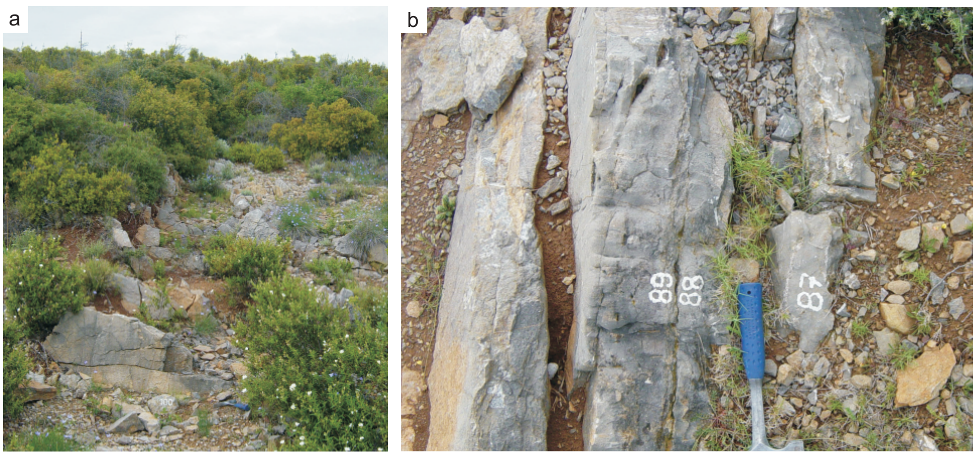

Figure 7. GSSP of the Devonian/Carboniferous boundary at La Serre. (a) The trench in May 2008 seen from up-section. (b) The boundary interval. The boundary is currently placed between beds 88 (Devonian) and 89 (Carboniferous).

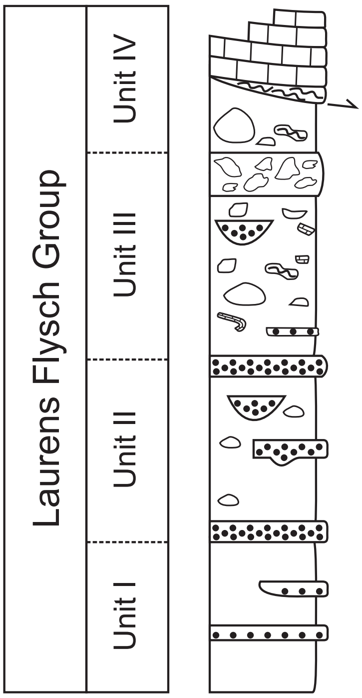

Figure 8. Idealized composition of the Laurens Flysch Group succession based on Engel et al. (1982). For legend see Fig. 3.

sedimentation continues without any siliciclastic input. It seems reasonable to assume a position for these outcrops outside the flysch context by the time of their deposition.

Laurens Flysch Group

Korn & Feist (2007) coined the name Laurens Flysch Group (Fig. 8) for the deposits of the synorogenic phase. A further formalized subdivision was not done. However, possibilities to divide the flysch deposits or parts of it have been presented by Vachard (1977), Engel et al. (1982), and Poty et al. (2002).

The synorogenic and allochthonous nature of the deposits summarized in this group has been noted and described by Engel et al. (1978, 1982). Flysch deposits of Mississippian age are widely known in the south-eastern Montagne Noire. In the Para-autochthon, they are represented by shales with few centimetres-thick intercalations of cross-stratified and parallel-laminated greywacke. In the Faugères-Compartment the amount of greywacke attains up to 50%, with individual bed thickness varying between few millimetres to 20 cm. The greywackes show internal sedimentological structures typically associated with turbidites.

Figure 10. Heavily deformed flysch deposits east of La Liquière. Note the difference between the brittle deformation of sandstones and conglomerates and the ductile behaviour of the shales. Laurens Flysch Group. Unit III. Field of view is about 3 m wide.

Large parts of the Mont Peyroux-Compartment consist of strata attributed to the Laurens Flysch Group. Based on Engel et al. (1982) a thickness of at least 4-5 km can be estimated. The succession is lithologically variegated and comprises: (a) shales with fine-grained greywacke intercalations (Figs 9, 10), (b)

Figure 9. Alternation of fine-grained and coarse-grained flysch deposits in the Barrac Valley. Stratigraphic top to the right. Laurens Flysch Group. Unit I. Field of view is about 4 m wide.

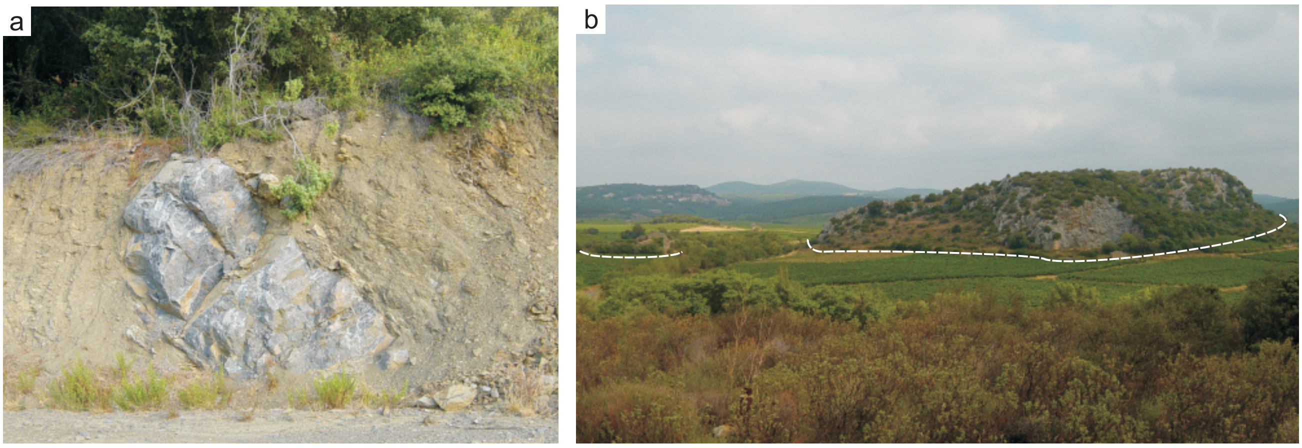

Figure 11. Exotic blocks in the flysch matrix. A. cubic metre-sized limestone block east of Vailhan. B. large blocks forming entire mountains, dashed lines indicate the approximate contact between the block and surrounding matrix. Small block (width 50 m) on the left is the Castelsec Quarry, the large block (width 400 m) to right is Roc du Cayla.

mixed sandy limestone – carbonated greywacke beds, (c) thick greywackes – conglomeratic greywackes with Bouma-sequences (Figs 9, 10), (d) coarse conglomerates, (e) pebbly mudstones, (f) calciturbidites, (g) resedimented blocks and olistostromes, (h) slumps, large debris flows with isolated slabs of basinal clastics and exotic blocks, (i) exotic blocks of Mississippian platform carbonates ("Calcaire à *Productus*") (Fig. 11) and exotic blocks of pre-flysch age ("Ecailles de Cabrières"). Based on the spatial and temporal distribution of these main lithologies, four units ("Unit I – IV") (Figs 2, 8) could be differentiated. Conglomerate bands define the boundaries between these units.

The base of the flysch ("Unit I") is found in the western parts of the Mont Peyroux-Compartment, the younger units appear towards the east. "Unit IV" attains the largest areal extent and characterizes the central and eastern parts of the Mont Peyroux-Compartment. It has to be noted that the medium size of the clasts incorporated into the flysch increases towards the top of the succession. Thus the exotic blocks or "Ecailles de Cabrières" can be interpreted as the largest clasts. The Ecailles Succession of the preorogenic phase is only known from these exotic blocks.

Biostratigraphical dating of the flysch succession is relatively complicated. Korn & Feist (2007) give a latest Viséan age for the base of the flysch, and speculate that the basal 1100 m-thick "unit I" was deposited in the short interval of one ammonoid biozone. Maximum and minimum ages for the flysch can also be obtained from the fossils found in the exotic blocks. The "upper Viséan" carbonates (Figs 11, 12) have traditionally been named "Calcaire à *Productus*" (see Böhm, 1935). Based on lithological criteria Poty et al. (2002) (Fig. 12) introduced for these carbonates two formations: Roque Redonde Fm and Roc de Murviel Fm. Pille (2008) differentiated more formations, which correspond mostly to biozones and not to lithological consistent units. Biostratigraphical dates (Poty et al., 2002; Aretz, 2002a, b; Poty & Hecker, 2003; Vachard & Aretz, 2004) indicate a late Viséan age (latest Asbian?-Brigantian) for the Roque Redonde Fm, and early Serpukhovian for the Roc de Murviel Fm. Pille (2008) proposed a different age model for the "Calcaire à *Productus*" with the youngest deposits at the Brigantian/Serpukhovian boundary. A recent study (Vachard et al., submitted) dates the "Calcaire à *Productus*" as Mikhailovian to Tarusian, and thus confirms the previous general age. However, the precise dates for individual sections and blocks change. This questions the lithostratigraphical subdivision of Poty et al. (2002) and the influence of the different facies (Poty et al., 2002; Aretz, 2002b; Vachard et al., submitted) may be more important for stratigraphy than previously thought.

Facies analyses of these formations (Aretz, 2002a, b; Poty et al., 2002; Aretz & Herbig, 2003; Aretz et al., 2007; Ernst et al., 2015) show a broad range of different platform facies. Microbial-dominated facies is very abundant and contributed to the formation of different types of reefs. Somewhat less abundant is bioclastic facies, but again a broad range of mainly shallow-water platform facies was documented. Outcrops such as Les Pascales (Aretz, 2002b) clearly show that carbonate sedimentation coexisted with finer-grained siliciclastics in the original platform settings. Thus, not all shales can be directly attributed to deeper water basinal (flysch) deposits.

Feist & Galtier (1985) reported from siltstones of a possible cyclothem in the Cabrières area (Figs 2, 3) a flora attributed to the Namurian A. These deposits might represent the youngest elements of the flysch deposits, although a precise correlation with the marine organisms has so far not been achieved.

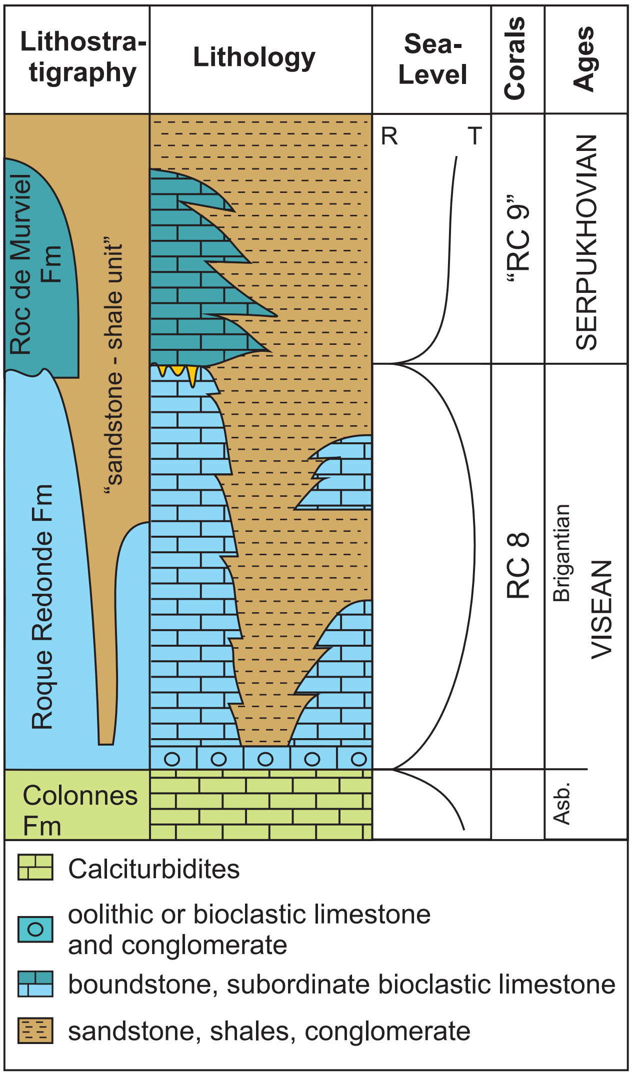

Figure 12. Overview on the litho- and biostratigraphy of the late Viséan – early Serpukhovian "Calcaire à *Productus*". R- Regression; T –Transgression. Modified from Poty et al. (2002).

4. Depositional setting

4.1. Local Scale

The Kulm deposits of the Montagne Noire developed in different depositional environments in time and space. Minor facies changes reflect slight differences in the position to sediment sources and small-scale sea-level fluctuations, common at least from the Middle Viséan onwards, as seen in the Belgian platform successions (Hance et al., 2001; Poty et al. 2014).

During most of the Mississippian, deposition in the areas of the Para-Autochthone and the Faugères-Compartment took place in distal basinal environments. The general shallowing trend and increasing instabilities of the basin in the synorogenic phase are seen in lithologically more variegated upper parts of these successions. In this context it has to be reminded that the preorogenic distances of the three structural units may have been in the order of tens of kilometres.

Mont-Peyroux-Compartment: With the exception of the La Serre section, early Tournaisian sedimentation took place on an outer deeper water carbonate platform (“supragriottes”). Characteristic is a very low, but continuous sedimentation rate during the lower Tournaisian, which results in the presence of several conodont biozones in 3 m of rock thickness. The La Serre section represents a shallow-water marine environment, which may either have been in inner platform settings or on an interbasinal high. The olistolitic nature of the section does not allow a more precise reconstruction. Deposits of the Lydiennes Fm represent a basin plain environment with very low sediment input, very likely a starved basin facies with low oxygen to anoxic conditions indicated by the dark colours and the relatively organic-rich rocks. The transition into that facies was gradual, as evidenced by the progressive dissociation of the nodular limestone beds and the increase of shale interbeds in the uppermost Montagne Noire Griotte Group. This scenario has to be put in context with the important global sea-level rise at the end of the early Tournaisian (Lower Alum Shale Event, Siegmund et al., 2002), which leads to the characteristic formation of dark shales with phosphatic nodules. A further important sea-level highstand (Avins Event, Poty, 2007) is connected to an extensive transgression in the late Tournaisian, and thus deposition of the Faugères Fm starts in the Ecailles Succession concordant on late Devonian rocks. The onset of carbonate sedimentation (nodular limestones of the Faugères Fm) in the Mont Peyroux Succession started slightly later, and corresponds to an important sea-level drop just below the Tournaisian/Viséan Boundary, which resulted in a hiatus of the earliest Viséan in the platform successions (e.g. Hance et al., 2001; Poty et al, 2014). Thus, this sea-level drop opened for a short time the window for carbonate production and deposition, and it could be equivalent to the lowstand system tracts and beginning transgressive system tracts of sequence 5 of Hance et al. (2001). Then, the general transgressive trend of the early Viséan time closed the window for carbonate production again. Thus, much of the early Viséan and probably middle Viséan are characterized by bedded chert sedimentation on a basin plain environments, but now under oxic conditions as indicated by the light rock colours. Its gradual replacement by calciturbidites (Colonnes Fm) indicates a shallowing and proximity to the slope. Shallowing continues throughout the entire Colonnes Fm, as seen e.g. in the increasing grain sizes of the individual beds. Contemporaneous deposits in the Ecailles Succession are thought to represent a shallow-water carbonate platform, which can be interpreted as the source area for the calciturbidites (Engel et al., 1982). In the Mont Peyroux area the Puech Capel Fm already shows instabilities within the entire basin. Debris flows start to become abundant. The temporal equivalents in more shallow water are thought to correspond to the basal Roque Redonde Fm.

The synorogenic sedimentation starts in late Viséan and continues into early Serpukhovian times. Decreasing water depths, at least partly resulting from the huge sediment supply, can be postulated for the flysch basin based on the “grain size” of the elements incorporated into the flysch matrix. However, for the individual section, the relative position to submarine canyons and resulting fans mainly determines the lithological composition, especially in units I-III. Small-sized carbonate platforms and reefs surrounded by siliciclastics formed in inner and middle platform positions. Finally, the entire platform system collapsed and huge exotic blocks were transported and deposited in the uppermost unit of the flysch. This is the final stage of basin-filling episode in the Montagne Noire and at the end of this basin fill trend; water depth was very shallow. This is seen in mud cracks in the fine-grained siliciclastics surrounding the exotic blocks in the easternmost Mont Peyroux-Compartment. The sandstones and siltstones containing the Namurian A flora may indicate a deltaic setting and could be interpreted as the transition into a molasse-typed sedimentation pattern in Serpukhovian times.

Engel et al. (1982) speculated about the migration of the flysch depocentre within the Montagne Noire, but convincing arguments are only obtained for the entire basin in Southern France.

Overall, the Kulm Facies of the Montagne Noire represents the underfilled stage of the basin evolution. However, there are distinctive differences in accumulation rates. The Tournaisian rate is the lowest, with less than 1 m/Ma, this rate increases in the early – early late Viséan to 5-6 m/Ma. Sediment supply greatly increases in the late Viséan and depending on the estimated thickness and duration of the flysch sedimentation, the accumulation rate is 500-1500 m/Ma. When adding the thickness reduction due to the compaction, the differences in the numbers between the different time slices are even higher. The transition into the overfilled phase may also be found in the youngest deposits in the eastern Mont Peyroux-Compartment. Remnants of the overfilled stage may also be found in the continental basin of upper Pennsylvanian age at Graissesac or Neffiez. However, volumetrically, these basins are insignificant.

4.2. Regional Scale

The Montagne Noire is only a small fraction of the Kulm succession in parts of southern France (Mouthoumet Massif and Pyrenees; Schulze, 1982; Delvolvé et al., 1993, Perret, 1993), which all developed in the same foreland basin. The preorogenic sedimentation seems to be relatively homogeneous throughout the entire region, although local stratigraphical names and units are in use. Differences within the succession can be best explained with differences (a) in the local palaeotopography of the basin and (b) in the distances to platform areas and sediment sources. Sections in the Pyrénées, e.g. Barousse area (Perret, 1993; Randon & Caridroit, 2008), well illustrate these differences. They show a very similar lithological composition, but the individual thicknesses are lower, and a thick interval of Viséan calciturbidites is lacking. Thus, these sections possibly represent a slightly deeper facies with more distance to sediment sources and platform areas.

Marked differences exist in the onset of the synorogenic sedimentation and the migration of the depocentre from east to west (Delvolvé et al, 1993), which corresponds to the closure of the foreland basin south of the Massif Central, from east to west in the collision scenario between Armorica and Gondwana. The Montagne Noire represents one of the oldest flysch deposits in southern France. However, in consequence of the revised biostratigraphical dates of the exotic blocks in the Montagne Noire (Poty et al., 2002; Vachard et al., submitted), the temporal differences are less marked then currently postulated.

The western continuation of the Southern France Kulm basin may be found in northern Spain in the Cantabrian Mountains.

5. Comparison to the Rhenish Kulm

The Rhenish Kulm and the succession in the Montagne Noire both developed in a foreland basin and earlier workers noted already similarities in respect to facies and biostratigraphical ages. However, Engel et al. (1982) presented the first attempt at a more detailed comparison in making references to Rhenish formations. In the correlation attempted herein (Fig. 13), traditional and the corresponding new names of Korn (2003, 2006) for the Rhenish succession will be given.

	Montagne Noire	Rhenish Kulm
Laurens Flysch Group		Kulm-Grauwacken/ Dainrode Formation
Saint Nazaire Group	Puech Capel Fm	?
	middle and upper Colonnes Fm	Kulm-Plattenkalk/ Herdingen-Fm
	lower Colonnes Fm	Kieselige Übergansgschichten/ Bromberg Fm
	Faugères Fm	late Tournaisian-early Viséan limestones at Drewer
	Lydiennes Fm without phosphatic nodules	Kulm-Lydite/ Hardt-Member
	Lydiennes Fm with phosphatic nodules	Liegende Alaunschiefer/ Kahlenberg-Member
upper “supragriottes” Montagne Noire Griotte Group		Hangenberg-Kalk

Figure 13. Attempted correlation for the Kulm succession of the Montagne Noire and the Rhenish Kulm (Formation names for the Rhenish Kulm after Korn 2003, 2006).

It is evident that an exact mirror of the northern foreland basin cannot be expected in the South. Thus, not all characteristic Rhenish lithostratigrapic units such as the Posidonienschiefer/ Dieken Fm can be found in the Montagne Noire. The larger size and thus larger lithological variability of the Rhenish Kulm Basin has also to be taken into consideration.

The upper Montagne Noire Griotte Group can be well correlated with the Hangenberg-Kalk. In consequence of the Lower Alum Shale Event in both regions dark shales with phosphatic nodules and later bedded cherts were deposited, although shales are less abundant in the Montagne Noire. In Germany a division into Liegende Alaunschiefer/Kahlenberg-Member and Kulm-Lydite/Hardt-Member exists. This subdivision has not been undertaken in the Montagne Noire, but it seems to be reasonable that the distribution of phosphatic nodules within the Lydiennes Fm may allow a further subdivision. Equivalents of the Faugères Fm in the Rhenish Kulm are somewhat difficult to recognize. One possible correlation would be the “Erdbach Kalke”/Kattensiepen-Member but the palaeotopographic context is not comparable since these limestones only formed on top of a Devonian reef in the Breitbach-Erdbrach area. However, limestones of latest Tournaisian - early Viséan age are also known from other areas of the Rhenish Kulm; e.g. Richrath-Kalk/Member. As evidently seen in the Drewer Quarry, their deposition is connected to intrabasinal highs, and thus such a scenario seems to be likely for the Montagne Noire as well. The Rhenish equivalent to the lowermost part of the Colonnes Fm with the presence of bedded cherts is found in the Kieselige Übergansgschichten/ Bromberg Fm, but most of the Colonnes Fm can be correlated with the Kulm-Plattenkalk/Herdringen Fm. The Puech Capel Fm is difficult to place, but the younger Laurens Flysch Group can be easily correlated with the Kulm-Grauwacken/Dainrode Fm. In Germany, the depocentre migrated towards the outer side of the orogeny (e.g. Schrader, 2000). This outward migration may help to the elucidate original palaeogeographical positions between the different displaced tectonic units forming the Kulm Basin of Southern France; especially those in the Pyrénées (e.g. Arize Massif, Axial Zone) and the Corbières (e.g. Mouthoumet Massif) that were incorporated in the Alpine Orogeny. However, one important difference in the geodynamic setting is the absence of a large-scale shelf collapse in the Rhenish Kulm Basin; the Dainrode Fm lacks the abundance of exotic blocks known in Southern France.

Summing up, the succession in the Montagne Noire has considerable similarities to the succession of the northwestern Rhenish Kulm Basin. In this setting, outer platform and basin environments characterize much of the succession, but a nearby carbonate platform supplies at least, at distinctive time, material re-sedimented in calciturbidites. The basin was then progressively and relatively rapidly filled with the erosional products of the rising Variscan Orogen.

6. Conclusions

The Mississippian succession of the Montagne Noire shares many similarities with the classical Rhenish Kulm. To avoid confusion with the French usage of *Culm*, the term *Kulm* is used herein to combine the mainly deeper water facies of the preorogenic (Tournaisian – early late Viséan) and synorogenic phases (early late Viséan – Serpukhovian?) of the Mississippian-aged succession in the Montagne Noire. The Kulm succession of the Montagne Noire formed in a foreland basin south of the Massif Central. The extension of this basin goes far beyond the Montagne Noire and comprises at least most of the Mississippian strata in the Corbières and the Pyrénées. This larger basin was filled from east to west. Thus, the Montagne Noire comprises one of the oldest flysch successions in the region.

Kulm deposits in the Montagne Noire are known in three tectonic units: the Para-autochthon, the Faugères-Compartment and the Mont Peyroux-Compartment. The first two units are characterised by little variegated shale-dominated successions. The succession of the Mont Peyroux-Compartment shows distinctive spatial and temporal differentiations in lithology and (bio)facies. Within the preorogenic phase two successions can be differentiated. The deeper environments, thus those with the most similarities to the Rhenish Kulm, are found in the Mont Peyroux Succession. This succession is mostly present along the northern and western margins of the Mont Peyroux-Compartment. Two lithostratigraphical groups are differentiated. Only the uppermost part of the older Montagne Noire Griotte Group is early Tournaisian in age and represents the continuation of the deeper water carbonate sedimentation in the outer parts of the platform across the D/C boundary. The following Saint Nazaire Group starts with the Lower Alum Shale Event and can be divided into four formations. The Lydiennes Fm and the base of the Colonnes Fm are characterized by bedded cherts indicating a starved basin environment. Rock colours indicate that these environments were dysoxic to anoxic during Tournaisian times and oxic in Viséan times. The nodular limestones of the Faugères Fm are sandwiched in-between, and their sedimentation may be associated with the regressive scenario after the Avins Event. Calciturbidites comprise most part of the Colonnes Fm. The Puech Capel Fm already transfers to the highly dynamic sedimentation patterns of the synorogenic phase. The Ecailles Succession is only known from exotic blocks incorporated into the flysch deposits. It represents the shallow-water environments of a supposed carbonate platform, and thus may have in part *Kohlenkalk*-character. There, deposition of nodular carbonates started with the Avins Event in the latest Tournaisian conformably on Famennian strata. The transition between the two successions is found in the La Serre section.

The synorogenic phase is lithostratigraphically combined in the Laurens Flysch Group. The flysch deposits can be divided into four units. Lithological composition of individual sections largely depends on their positions to sediment sources and fans. However, an increase of the “grain size” incorporated into the flysch matrix can be observed up-section. The youngest unit comprises the largest exotic blocks and corresponds to the collapse of the nearby shelf system and is the final basin fill. The exotic blocks allow the reconstruction of a mixed carbonate – siliciclastic shelf system.

Lithostratigraphical and biostratigraphical correlations with the formations of the Rhenish Kulm result in the postulation that the depositional environment for the Montagne Noire is similar to that of the north-western Rhenish Kulm Basin.

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8. References

Aretz, M., 2002a. Rugose corals and associated carbonate microfossils from the Brigantian (Mississippian) of Castelsec (Montagne Noire, Southern France). Geobios, 35, 187-200.

Aretz, M., 2002b. Habitatanalyse und Riffbildungspotential kolonialer rugoser Korallen im Unterkarbon (Mississippium) von Westeuropa. Kölner Forum für Geologie und Paläontologie, 10, 1-155.

Aretz, M., 2014. Redefining the Devonian–Carboniferous boundary: An overview of problems and possible solutions. In: Rocha, R., Pais, J., Kullberg, J.C. & Finney, S. (eds), STRATI 2013. Springer, Cham, Springer Geology, 227-231.

Aretz, M. & Herbig, H.-G., 2003. Contribution of rugose corals to Late Viséan and Serpukhovian bioconstructions in the Montagne Noire (Southern France). In Ahr, W.M., Harris, P.M., Morgan, W.A. & Somerville, I.D. (eds), Permo-Carboniferous Carbonate Platforms and Reefs. Society for Economic Palaeontologists and Mineralogists Special Publication 78, and American Association of Petroleum Geologists Memoir 83, 119-132.

Aretz, M., Pille, L. & Vachard, D., 2007. Serpukhovian microbes-coral reef, southern France. In Vennin, E., Aretz, M., Boulvain, F. & Munnecke, A. (eds), Facies from Palaeozoic reefs and bioaccumulations. Mémoires du Muséum d´histoire Naturelle de Paris, 198, 253-255.

Arthaud, F., 1970. Étude tectonique et microtectonique de deux domaines hercyniens: les nappes de la Montagne Noire (France) et l'anticlinorium de l'Iglesiente (Sardaigne). Publications de l'Université des Sciences et Techniques du Languedoc (Ustela), Série Géologie structurale, 1, 1-175.

Becker, R.T., Kaiser, S. & Aretz, M., 2016 (in press). Review of chrono-, litho- and biostratigraphy around the global Hangenberg Crisis and Devonian-Carboniferous boundary. In Becker, R.T., Königshof, P. & Brett, C. (eds), Devonian climate, sea level and evolutionary events. Geological Society of London, Special Publications, 423. doi.org/10.1144/SP423.10.

Bergeron, J., 1887. Étude paléontologique et stratigraphique des terrains anciens de la Montagne Noire. Bulletin de la Société géologique de France, 3ème série, 15, 373-382.

Bergeron, J., 1898. Étude du versant méridional de la Montagne Noire. Bulletin de la Société géologique de France, 3ème série, 26, 472-487.

Böhm, R., 1935. Étude sur les faunes du Dévonien supérieur et Carbonifère de la Montagne Noire. Thèse Doctorat, Université de Montpellier, Imprimerie Charité, Montpellier, 203 p.

Boyer, F., Krylatov, S., Le Fèvre, J. & Stoppel, D. 1968. Le Dévonien supérieur et la limite Dévono-Carbonifère en Montagne Noire (France). Bulletin du Centre des recherches de Pau-SNPA, 2 (1), 5-33.

Boyer, F., Krytlatov, S. & Stoppel, D., 1974. Sur le problème de l'existence d'une lacune sous les lydiennes à nodules phosphatés du Dinantien des Pyrénées et de la Montagne Noire (France, Espagne). Geologisches Jahrbuch Reihe, B9, 1-60.

Chardon, D., Roques, D. & Aretz, M. 2014. Revised "nappe" tectonics in the Southern French Massif Central: Orogen-parallel transtensional stretching during wildflysch sedimentation. RST Pau 2014, 182.

Chardon, D., Roques, D. & Aretz, M. 2015. Kinematic reappraisal of nappe tectonics and late orogenic sedimentation in the Southern French Massif Central. Géologie de la France, 1, 35-36.

Coudray, J., Feist, R., Galtier, J. & Michel, D., 1979. Nouvelles précisions sur l'âge et le paléoenvironnement des lydiennes à nodules phosphatés du Mont Peyroux (Montagne Noire) et de leur encaissant carbonaté. 7e Réunion annuelle des Sciences de la Terre, Lyon 79, Société géologique de France, 132.

Decombeix, A.-L., Galtier, J. & Meyer-Berthaud, B., 2006. *Faironia difasciculata*, a new gymnosperm from the Early Carboniferous (Mississippian) of Montagne Noire, France. Review of Palaeobotany and Palynology, 142/3, 79-92.

Deflandre, G., 1946. Radiolaires et Hystrichosphaerides du Carbonifère de la Montagne Noire. Comptes rendus hebdomadaires des séances de l'Académie des Sciences, 223, 515-517.

Delépine, G., 1935. Contribution à l'étude de la faune du Dinantien des Pyrénées. Première partie. Goniatites et crustacés des nodules phosphatés de l´Ariège. Bulletin de la Société géologique de France, 5ème série, 5, 171-189.

Delvolvé, J.J., Souquet, P., Vachard, D., Perret, M.-F. & Aguirre, P., 1993. Caractérisation d'un bassin d'avant-pays dans le Carbonifère des Pyrénées : faciès, chronologie de la tectonique synsédimentaire. Comptes rendus de l'Académie des Sciences, *série II,* 316/7, 959-966.

Demange M., 1994. Antevariscan evolution of the Montagne Noire (France): from a passive margin to a foreland basin. Comptes rendus de l'Académie des Sciences, série II, 318, 921-933.

Engel, W., Feist, R. & Franke, W., 1978. Synorogenic gravitational transport in the Carboniferous of the Montagne Noire (S-France). Zeitschrift der Deutschen Geologischen Gesellschaft, 129, 461-472.

Engel, W. Feist, R. & Franke, W., 1982. Le Carbonifère anté-stéphanien de la Montagne Noire: rapports entre mise en place des nappes et sédimentation. Bulletin du B.R.G.M., section 1, 4, 341-389.

Ernst, A., Wyse Jackson, P. & Aretz, M., 2015. Bryozoan fauna from the Mississippian (Visean) of Roque Redonde (Montagne Noire, southern France). Geodiversitas, 37/2, 151-213.

Feist, R. & Flajs, G., 1987. Devonian and Carboniferous of the south-eastern Montagne Noire – Guidebook. International Union of Geological Sciences, Commission on Stratigraphy, working group on the Devonian/Carboniferous boundary., 91 p.

Feist, R. & Galtier, J., 1985. Découverte de flores d'âge namurien probable dans le flysch à olistolithes de Cabrières (Hérault). Implication sur la durée de la sédimentation synorogénique dans la Montagne Noire (France méridionale). Comptes rendus de l'Académie des Sciences, série II, 300, 207-210.

Franke, W., 2014. Topography of the Variscan orogen in Europe: failed–not collapsed. International Journal of Earth Sciences, 103/5, 1471-1499.

Franke, W., Doublier, M.P., Klama, K., Potel, S. & Wemmer, K., 2011. Hot metamorphic core complex in a cold foreland. International Journal of Earth Sciences, 100/4, 753-785.

Frech, F., 1887. Die paläozoischen Bildungen von Cabrières (Languedoc). Zeitschrift der Deutschen Geologischen Gesellschaft, 39, 360-487.

Galtier, J., Feist, R., Meyer-Berthaud, B., Rex, G. & Rowe, N.P., 1987. Découverte d'une flore en compression dans les niveaux à lydiennes du Tournaisien de la Montagne Noire (Hérault, France). Comptes rendus de l'Académie des Sciences, série II, 305, 647-651.

Galtier, J., Meyer-Berthaud, B. & Rowe, N.P., 1988. Tournaisian plants from the «Lydiennes» Formation of the Montagne Noire (France). Courier Forschungsinstitut Senckenberg, 100, 109-117.

Gèze, B., 1949. Études géologiques de la Montagne Noire et des Cévennes méridionales. Mémoires de la Société géologique de France, 62, 1-215.

Gèze, B., de Sitter, L.U. & Trümpy, R., 1952. Sur le sens de déversement des nappes de la Montagne Noire. Bulletin de la Société géologique de France, série 6, 2, 491-533.

Girard, C., Cornée, J.-J., Corradini, C., Fravalo, A. & Feist, R., 2013. Palaeoenvironmental changes at Col de Tribes (Montagne Noire, France), a reference section for the Famennian of north Gondwana-related areas. Geological Magazine, 151/5, 864-884.

Gourmelon, F., 1987. Les radiolaires tournaisiens des nodules phosphatés de la Montagne Noire et des Pyrénées centrales: systématique, biostratigraphie, paléobiogéographie. Biostratigraphie du Paléozoïque, 6, 1-172.

Gursky, H.-J., 1996. Siliceous rocks of the Culm Basin, Germany. In Strogen, P., Somerville, I.D. & Jones, G.L. (eds), Recent advances in Lower Carboniferous geology. Geological Society of London, Special Publications, 104, 303–314

Hance, L., Poty, E. & Devuyst, F.X., 2001. Stratigraphie séquentielle du Dinantien type (Belgique) et corrélation avec le Nord de la France (Boulonnais, Avesnois). Bulletin de la Société géologique de France, 172, 411-426.

Kaiser, S.I., 2005. Mass extinctions, climatic and oceanographic changes at the Devonian-Carboniferous boundary. PhD Thesis, Ruhr-Universität Bochum, 156 p.

Kaiser, S. I., 2009. The Devonian/Carboniferous boundary stratotype section (La Serre, France) revisited. Newsletters on Stratigraphy, 43/2, 195-205.

Kaiser, S. I. & Corradini, C., 2011. The early siphonodellids (Conodonta, Late Devonian-Early Carboniferous): overview and taxonomic state. Neues Jahrbuch für Geologie und Paläontologie, Abhandlungen, 261, 19–35.

Kaiser, S.L., Aretz, M. & Becker, R.T., 2016 (in press). The global Hangenberg Crisis (Devonian-Carboniferous transition) – review of a first order mass extinction. In Becker, R.T., Königshof, P. & Brett, C. (eds), Devonian climate, sea level and evolutionary events. Geological Society of London, Special Publications, 423. doi.org/10.1144/SP423.9.

Korn, D., 2003. Die Formationen der Kulm-Fazies im Rheinischen Schiefergebirge. In Amler M.R.W. & Gereke, M. (eds) Karbon-Korrelationstabelle (KKT), Senckenbergiana lethaea, 83, 236-242.

Korn, D., 2006. Lithostratigraphische Neugliederung der Kulm-Sedimentgesteine im Rheinischen Schiefergebirge. In Amler M.R.W. & Stoppel, D. (eds), Stratigraphie von Deutschland VI. Unterkarbon (Mississippium). Schriftenreihe der Deutschen Gesellschaft für Geowissenschaften, 41, 379-383.

Korn, D. & Feist, R., 2007. Early Carboniferous ammonoid faunas and stratigraphy of the Montagne Noire (France). Fossil Record, 10, 99-124.
Lethiers, F. & Feist, R., 1991. Ostracodes, stratigraphie et bathymétrie du passage Dévonien–Carbonifère au Viséen Inférieur en Montagne Noire (France). Geobios, 24, 71-104.
Mamet, B., 1968. Sur les microfaciès calcaires du Viséen de la Montagne Noire (France). Revue de Micropaléontologie, 11, 121-136.
Maurel, M., 1966. Études géologiques sur le Dévonien et le Carbonifère inférieur du versant méridional de la Montagne Noire. Thèse Doctorat, Université de Montpellier, 194 p.
Meyer-Berthaud, B., 1984. Les axes de Lycophytes à structure anatomique conservée du Carbonifère basal (Tournaisien) de la Montagne Noire: *Trabicaulis* gen. nov. et *Landeyrodendron* gen. nov. Palaeontographica, 190B, 1-36.
Paproth, E., Feist, R. & Flajs, G., 1991. Decision on the Devonian-Carboniferous boundary stratotype. Episodes, 14/4, 331-336.
Perret, M.F., 1993. Recherches micropaléontologiques et biostratigraphiques (conodontes, foraminifères) dans le Carbonifère pyrénéen. Strata, série 2, 21, 1-597.
Pille, L., 2008. Foraminifères et algues calcaires du Mississippien supérieur (Viséen supérieur-Serpukhovien): rôles biostratigraphique, paléoécologique et paléogéographique aux échelles locale, régionale et mondiale. Thèse Doctorat, Université de Lille, 320 p. + 255 p. + 150 p.
Poty, E., 2007. The Avins event: a remarkable worldwide spread of corals at the end of the Tournaisian (Lower Carboniferous). In Hubmann, B. & Piller W.E. (eds), Fossil corals and sponges. Schriftenreihe der Erdwissenschaftlichen Kommission der Österreichischen Akademie der Wissenschaften, 17, 231-250.
Poty, E., Aretz, M. & Barchy, L., 2002. Stratigraphie et sédimentologie des « Calcaires à *Productus* » du Carbonifère inférieur de la Montagne Noire (Massif Central, France). Comptes Rendus Geoscience, 334, 843-848.
Poty, E., Aretz, M. & Hance, L., 2014. Belgian substages as a basis for an international chronostratigraphic division of the Tournaisian and Viséan. Geological Magazine, 151, 229-243.
Poty, E. & Hecker, M.R., 2003. Parallel evolution in European rugose corals of the genus *Lonsdaleia* McCoy, 1849 (Lower Carboniferous). Bulletin de l'Institut Royal des Sciences Naturelles de Belgique, Sciences de la Terre, 73, 109-135.
Pruvost, P., 1956. Lexique stratigraphique international, vol. 1, Europe, fasc. 4: France, Pays-Bas, Luxembourg. C.N.R.S., Paris, 231 p.
Randon, C. & Caridroit M., 2008. Age and origin of Mississippian lydites: examples from the Pyrénées, southern France. In Aretz, M., Herbig, H.-G. & Somerville, I. (eds), Carboniferous Platforms and Basins. Geological Journal, 43, 261-278.
Rolfe, W.D.I., 1985. Form and function in Thylacocephala, Conchyliocarida and Concavicarida (?Crustacea): a problem of interpretation. Transactions of the Royal Society of Edinburgh, 76, 391-399.
Rouville, P.G., de, 1887. Monographie géologique de la commune de Cabrières. Imprimerie Boehm, Montpellier, 62 p. + 7 p.
Schrader, S., 2000. Die sedimentär-geodynamische Entwicklung eines variszischen Vorlandbeckens: Fazies- und Beckenanalyse im Rhenohercynischen Turbiditbecken (Spätes Viseum, cd III). Kölner Forum für Geologie und Paläontologie, 5, 1-104.
Schulze, H., 1982. Deckenbau und Flysch-Sedimentation im Variszikum des Massivs von Mouthoumet (Süd-Frankreich). PhD Thesis. University of Göttingen, 117 p.
Serres, M. de, 1847. Note sur la découverte du genre des Productus, dans les formations carbonifères de Roujan ou de Neffiez (Hérault). Académie des Sciences et Lettres de Montpellier, Mémoires de la Section des Sciences, 1, 65-67.
Siegmund, H., Trappe, J., Oschmann, W., 2002. Sequence stratigraphic and genetic aspects of the Tournaisian "Liegender Alaunschiefer". Geologische Rundschau, 91, 934-949.
Trappe J., 1998. Phanerozoic phosphorite depositional systems: a dynamic model for a sedimentary resource system. Springer, Berlin, Lecture notes in Earth Sciences, 76, 257 p.
Vachard, D., 1974. Contribution à l'étude stratigraphique et micropaléontologique (algues et foraminifères) du Dévonien-Carbonifère inférieur de la partie orientale du versant méridional de la Montagne Noire (Hérault, France). Thèse Doctorat en Sciences, Université Paris VI, 408 p.
Vachard, D., 1977. Étude stratigraphique et micropaléontologique (algues et foraminifères) du Viséen de la Montagne Noire (Hérault, France). Mémoires de l'Institut Géologique de l'Université de Louvain, 29, 111-195.
Vachard, D. & Aretz, M., 2004. Algae, pseudoalgae and cyanobacteria from the Earliest Serpukhovian (Early Carboniferous) of La Serre (Montagne Noire, France). Geobios, 37, 643-666.
Vachard, D., Cózar, P., Aretz, M. & Izart, A., submitted. Late Viséan – early Serpukhovian foraminifers in the Montagne Noire (France). Geobios.
Ziegler, W., 1959. Conodonten aus Devon und Karbon Südwesteuropas und Bemerkungen zur bretonischen Faltung (Montagne Noire, Massiv v. Mouthoumet, Span. Pyrenäen). Neues Jahrbuch für Geologie und Paläontologie, Monatshefte, 1959, 289-309.

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