

Revision of the planktonic foraminiferal biostratigraphy of the Voiron Flysch (Chablais Prealps, Haute-Savoie, France)

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Abstract

The ages obtained from planktonic foraminiferal assemblages retrieved from two exposures in the Gurnigel Flysch and from the re-examination of similar material gathered by previous researchers from the Voiron Flysch reveal only minor discrepancies with previous studies based on nannofossil biostratigraphy. In contrast, major divergences between this work and previous studies on the Voiron Flysch also based on planktonic foraminifera have been identified. They are generally related to distinct approaches in species classification and the use of different zonal schemes. Based on our data, the age of the Voiron Flysch extends from the Early Eocene (planktonic foraminiferal zone P7) to the Middle Eocene (planktonic foraminiferal zone P12). Contrasting with claims made in earlier studies, no specimen of Late Eocene or Early Oligocene age has been observed in the revised material. However, we cannot exclude a younger age (possibly Late Eocene) for the upper portion of this flysch from which we did not revise any sample. Thus, more research and sampling are needed to resolve this question. The palaeogeographic origin of the Voiron-Wägital complex as well as the sedimentation history of these flyschs need now to be re-evaluated in light of this revised biostratigraphic data.

Keywords Biostratigraphy · Flysch · Palaeogene · Planktonic foraminifera · Valais domain · Voiron-Wägital complex

1 Introduction

The term “flysch” (e.g. Studer 1848; Wildi 1987; Homewood and Lateltin 1988) designates terrigenous sediments of Alpine basins that have been redeposited in the deep sea by gravity-flow processes during a period of convergence. Flysch deposits primarily consist of alternations of shales,

sandstones and conglomerates showing evidence of mass-flow transport (i.e. turbidites s.l., Mutti et al. 2009). They represent the last depositional stage in successive palaeogeographic domains before their subduction and subsequent accretion into a sedimentary accretionary prism (Kuenen and Carozzi 1953; Homewood and Lateltin 1988; Stampfli et al. 2002). Constraining the age of flysch units is thus critical for reconstructing the kinematics of orogenies (Stampfli et al. 2002; Stampfli and Hochard 2009; Handy et al. 2010).

Micro- and nannofossils are the most powerful tools for dating marine detrital sequences. This task is however greatly complicated due to the importance of reworking processes on the sea floor, which may incorporate material derived from older sediments in the flysch (e.g. Morel 1980; Mulder and Alexander 2001). The most appropriate dating technique consists in retrieving micro- and nannofossils from the pelagic beds interspersed in flysch successions (e.g. Ujetz 1996). Unfortunately, the preservation of hemipelagic layers is variable, and depends on the depositional environment. These layers are absent or rare in the amalgamated coarse-grained sandstones to conglomerates of channel settings, and can be confused with the

Electronic supplementary material

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fine-grained division of Bouma sequences (Te; Bouma 1962) in lobe settings (Mutti et al. 2003) commonly forming the bulk of flysch shales.

Initial attempts to date flysch deposits were based on larger benthic foraminifera (Pilloud 1936; Lombard 1940; Schaub 1951; Rigassi 1958; Cogulu 1961; Schaub et al. 1965). However, these organisms are mostly reworked from neighbouring carbonate platforms where they thrived during the Palaeogene (Scheibner and Speijer 2008). Calcareous nannofossils provided the first accurate biostratigraphic determinations in Alpine flyschs (Heckel 1968; Jan du Chêne et al. 1975; Van Stuijvenberg 1980). More recently, planktonic foraminifera biostratigraphy was also applied in the Voirons Flysch (Ujetz 1996; Frébourg 2006; Ospina-Ostios et al. 2013; Ospina-Ostios 2017).

The flyschs exposed in the Chablais and Swiss Prealps (Fig. 1) range in age from the Late Cretaceous to the Oligocene (Matter et al. 1980; Homewood and Caron 1982; Caron et al. 1989). As illustrated in Caron et al. (1989), the oldest flysch units are derived from the most internal palaeogeographic realms (e.g. the South-Penninic domain), and form the upper portion of the Prealpine nappes stack (e.g. the Gets nappe). By contrast, the youngest ones, known as the North Helvetic Flysch group (Menkveld-Gfeller et al., 2016), originate from more external domains (e.g. the inner portion of the North Alpine foreland basin),

and occur at the base of the nappe sequence. Determining the palaeogeographic origin of flyschs is fairly easy when such a succession occurs in stratigraphic continuity with pre-flysch deposits, as in the Briançonnais domain (Médianes Flysch, Caron et al. 1980; Brèche Flysch, Dall'Agnolo 2000). However, in the Chablais and Swiss Prealps, several flysch slices and nappes are indeed isolated from their substrate and, consequently, their palaeogeographic attribution largely depends on their inferred age.

This is the case of the Voirons Flysch, which forms the westernmost part of the former Gurnigel nappe, now called the Voirons-Wägital complex. This complex has long been considered as related to the Ultrahelvetic domain due to its low structural position (Lombard 1940; Trümpy 1960; Hsü and Schlanger 1971). In the late twentieth century, it was attributed to the South-Penninic domain based on micropalaeontological data and because of its petrographic resemblance with the Sarine nappe (Upper Prealps; Caron 1976; Caron et al. 1980; Van Stuijvenberg and Jan du Chêne 1980; Caron et al. 1989; Gasinski et al. 1997). In the past two decades, several researchers (Ujetz 1996; Coppo, 1999; Frébourg 2006; Ospina-Ostios et al. 2013, Ospina-Ostios 2017) found planktonic foraminiferal assemblages indicating a Middle Eocene to Early Oligocene age in the Voirons Flysch, which precludes a South-Penninic origin for this unit. Consequently, and corroborating the ideas of

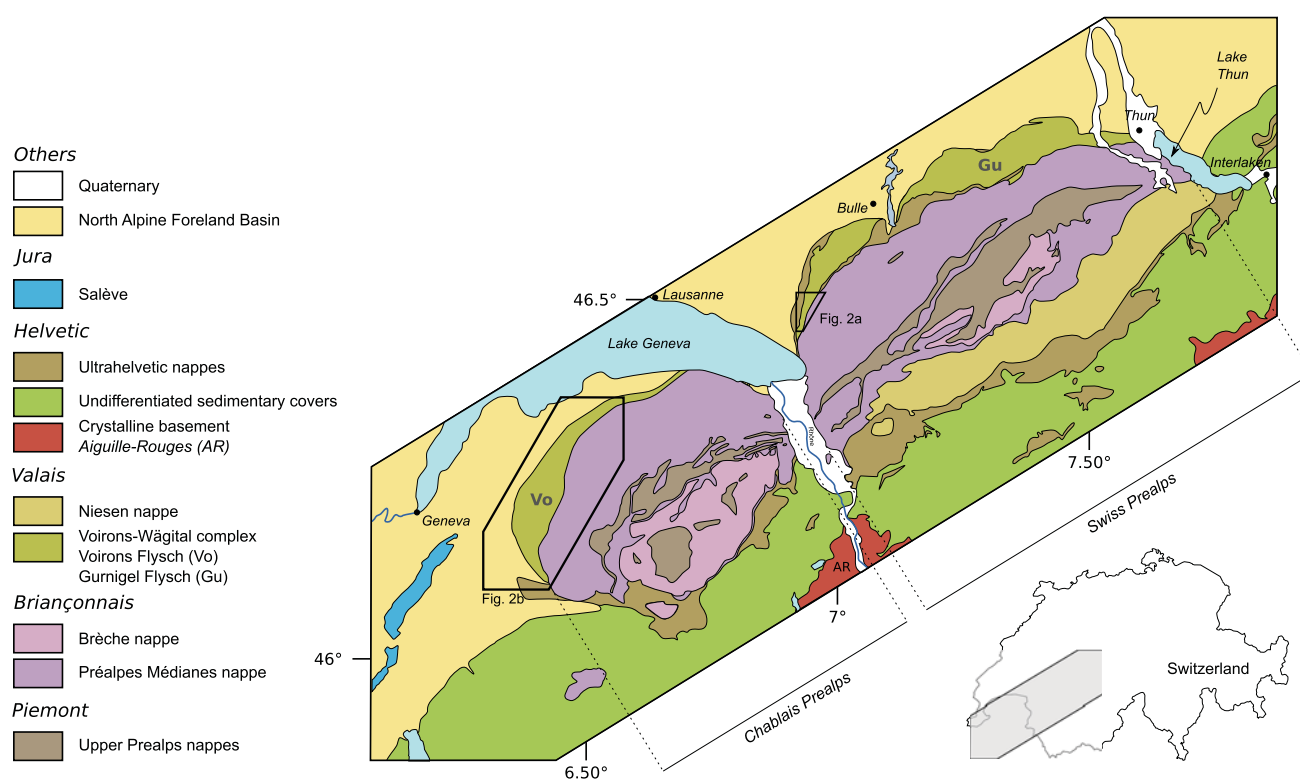


Fig. 1 Tectonic map of the Chablais and Swiss Prealps (SwissTopo 2008, modified) with the location of the western part of the Voirons-Wägital complex. The black boxes indicate the studied areas described in Fig. 2

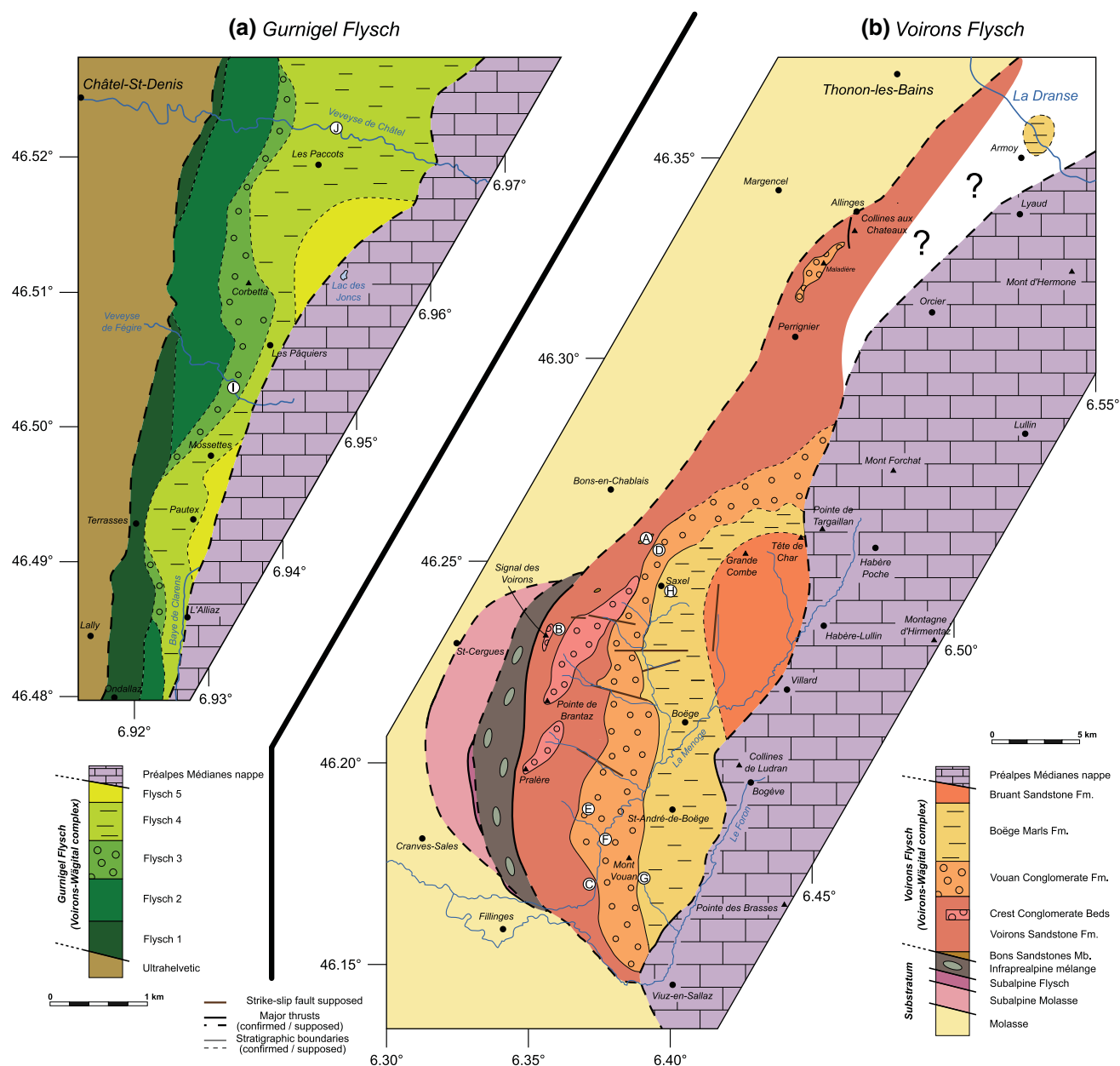


Fig. 2 Geologic map of the Gurnigel Flysch (Weidmann et al. 1976; Morel 1980, modified) and Voiron Flysch (Ragusa et al. 2017, modified) with the geographic location of the exposures where the studied or revised samples were collected (Table 1)

Schmid et al. (2005) as well as the conclusions of Trümpy (2006) for the easternmost part of the Voiron-Wägital complex (e.g. the Iberg Klippes), the Voiron Flysch was attributed to the Valais realm (Ospina-Ostios et al., 2013, Ragusa et al., 2017), which appears to agree better with its present-day low structural position but this is not the subject of the present paper.

The primary goal of this study was to apply planktonic foraminiferal biostratigraphy to exposures of the Voiron-Wägital complex in the western part of Switzerland to possibly confirm and substantiate the research made in the Voiron massif (Ujetz 1996; Coppo 1999; Frébourg 2006;

Ospina-Ostios et al. 2013, Ospina-Ostios 2017). However, our initial results from two outcrops in that area convinced us about the need of a thorough revision of the data from the Voiron Flysch, which is now the main aim of this paper.

2 Geological setting

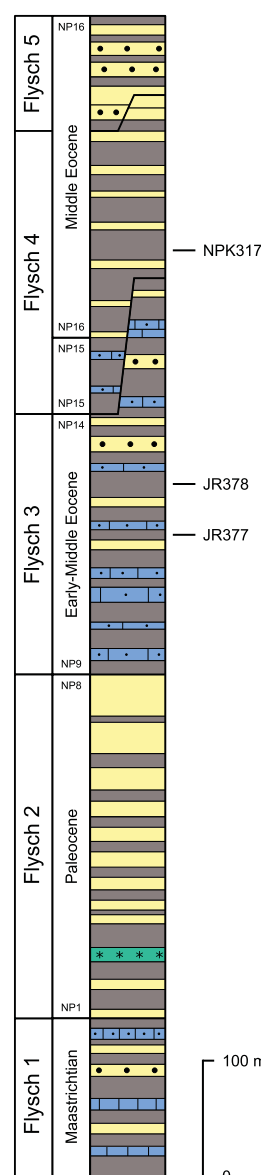
The Voiron-Wägital complex, which includes the Voiron, the Gurnigel, the Schlieren and the Wägital Flyschs (Fig. 1), forms moderate-elevation, commonly forest-

covered mountains (e.g. the Voirons, the Niremont) on the external edge of the Chablais and Swiss Prealps. This complex occurs near the base of the Prealpine nappe stack, between a complex zone comprising tectonic mélanges and Ultrahelvetic slices below and the Préalpes Médiannes nappe above (Figs. 1, 2), and consists of vertically stacked flysch successions generally forming a large synform with numerous internal folds (Weidmann et al. 1976; Morel 1980; Winkler 1983; Ospina-Ostios 2017). In this paper, we are only concerned with the Gurnigel and the Voirons Flyschs (Fig. 2a, b, respectively). The former encompasses a succession of five units (Flyschs 1–5; Fig. 3a), discriminated by subtle differences in lithology, that have been dated from the Maastrichtian to the Middle Eocene by calcareous nannofossil biostratigraphy (Fig. 3a, 4; Weidmann et al. 1976; Morel 1980). The latter includes four formations (from base to top, Fig. 3b): the Voirons Sandstone, the Vouan Conglomerate, the Boège Marl, and the Bruant Sandstone formations (Ragusa, 2015). Originally attributed to a time interval from the Danian to the Priabonian (nannofossil zones NP 2 to NP18; Fig. 5) based on coccolith and dinoflagellate assemblages (Jan du Chêne et al. 1975; Van Stuijvenberg 1980; Van Stuijvenberg and Jan du Chêne 1980), this flysch succession has more recently been dated to the Middle Eocene–Early Oligocene (Figs. 3b, 5; planktonic foraminiferal zones P13 to P20) based on planktonic foraminifera (Ujetz 1996; Coppo 1999; Frébourg 2006; Ospina-Ostios et al. 2013; Ospina-Ostios 2017). No nannofossils younger than the Priabonian has ever been found in these lithologies.

The selected outcrops are found in the southern part of the Gurnigel Flysch (Figs. 1, 2). Located to the SE of Châtel-St-Denis, in the Veveyse de Fégire gorges, the first section exposes the lower to middle Eocene Flysch 3 (Fig. 3a; Weidmann et al. 1976). The second outcrop is in the Veveyse de Châtel valley, to the N of Les Paccots, and comprises lithologies attributed to the middle Eocene Flysch 4 (Fig. 3a; Morel 1980). The revised samples from the Voirons massif have been borrowed from the collections of Lina Ospina-Ostios and Grégory Frébourg (samples LMO and GF, respectively), both of which are deposited at the Department of Earth Sciences of the University of Geneva. These samples represent all stratigraphic units from the Voirons Flysch, except for the Bruant Sandstone Fm (Fig. 2). GPS coordinates and stratigraphic attribution of these samples are given in Table 1.

The Schlieren Flysch (Winkler 1983, 1984) comprises a lithostratigraphic succession similar to that of the Gurnigel Flysch. Nannofossil biostratigraphy gave a Late Maastrichtian to late Ypresian age to this flysch (Late Maastrichtian to nannofossil zone NP14; Winkler 1984; Caron et al. 1989; Fig. 6). The Wägital Flysch (Winkler et al.

(a) Gurnigel Flysch



(b) Voirons Flysch

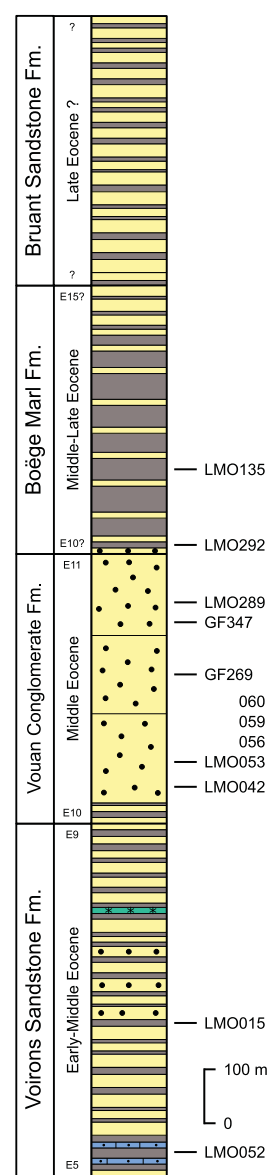


Fig. 3 Synthetic stratigraphic logs from the Gurnigel Flysch (Weidmann et al. 1976, modified) and Voirons Flysch with the position of the studied samples

1985) is roughly subdivided into three units, and extends from the Campanian to the Middle Eocene (Fig. 6).

3 Methods

In turbidites, the upper portions of thick shale beds have the highest probability to represent pelagic deposits (Mutti et al. 2003; Mulder and Alexander 2001). We thus looked for such layers in the selected exposures from the Gurnigel Flysch, and gathered ca. 500 g of material at depth with a

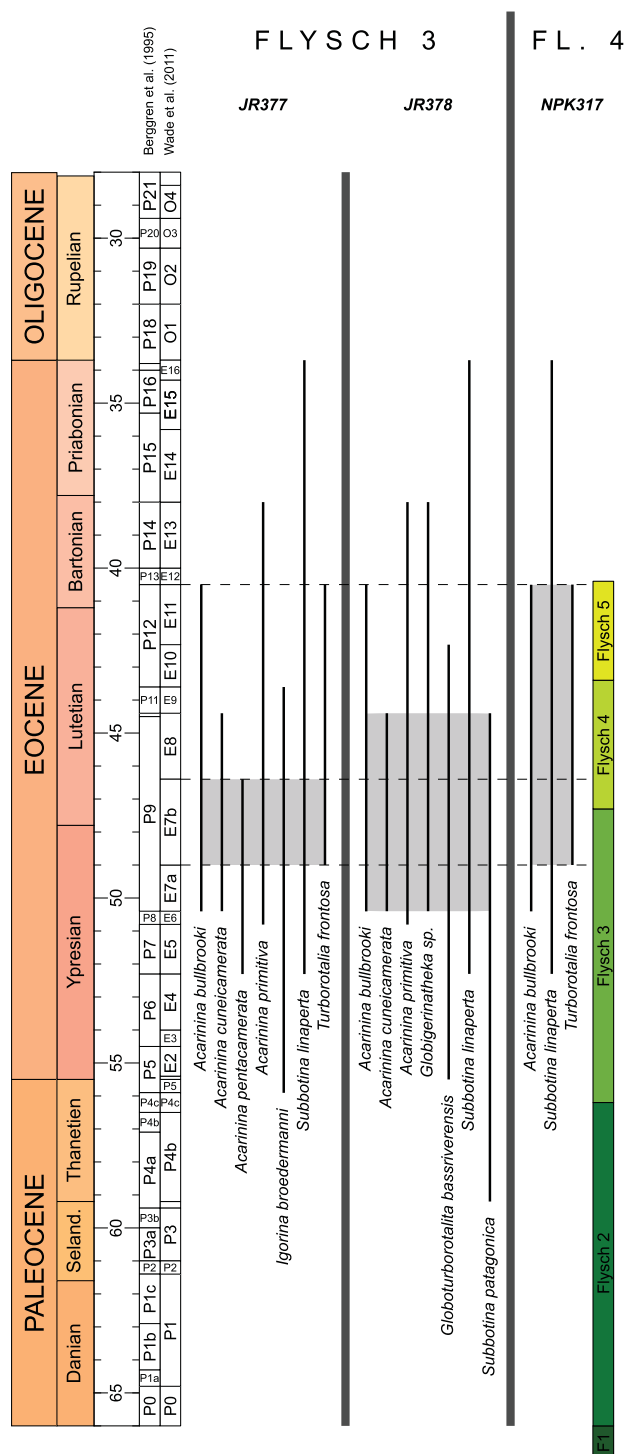


Fig. 4 Age ranges of the Gurnigel Flysch based on nannofossil biostratigraphy (Weidmann et al. 1976; Morel 1980), and age ranges of the studied and revised samples based on planktonic foraminifera biostratigraphy. Dark grey shades correspond to the age range of samples

clean spatula to avoid field contamination. Samples were then disaggregated with gasoline, washed, and wet-sieved through 90–1000 μm sieves for qualitative planktonic

foraminiferal analyses. For the Voirons Flysch, we simply used the leftover residues of samples collected by previous researchers (Frébourg 2006; Ospina-Ostios 2017). After manual picking, selected specimens were photographed with a Nikon digital camera mounted on a Nikon SMZ18 stereomicroscope fitted with a 0.5 \times SHR Plan Apo objective. Images were taken of each specimen using the NIS Elements Imaging Software v4.60. Finally, the foraminifera illustrated in the plates published by Ospina-Ostios et al. (2013) and Ospina-Ostios (2017) were re-examined and, in some cases, re-determined. Species determinations and age ranges are based on Pearson et al. (2006) and Wade et al. (2011). The P Zones of Berggren et al. (1995) are also used in the text to facilitate comparison with previous works. The comparison with E and P Zones are reported in Figs. 4, 5 and 6. Nannofossil biostratigraphy is based on Martini (1971) (Fig. 6).

4 Results

4.1 Gurnigel Flysch

The exposure in the Veveyse de Fégire gorges (Figs. 2, 7a; GPS coordinates in Table 1) consists of well-exposed, shale-dominated, distal turbidites (F8–F9; Mutti et al. 2003) characterized by the Tb–Te intervals of the Bouma sequence. The thickness of sandstone beds seldom exceeds 10 cm, whereas that of intercalated shales varies between 50 cm and 1 m. Strata occur in normal position, and dip sharply (60°) towards the East. These turbidites were originally correlated with the Early to Middle Eocene (nannofossil zones NP 12 to NP 15; Weidmann et al. 1976). Samples JR 377 and JR 378 (Fig. 3a) were collected from pelagic marls identified by their greenish colour that contrasts with the dark-grey tint of the Te intervals (Fig. 7b). The assemblage of poorly preserved planktonic foraminifera retrieved from these samples contains acariniids (Online Resource 1), and suggests also an Early to Middle Eocene age (planktonic foraminiferal zones E7b or P9) for this exposure.

The Veveyse de Châtel outcrop (Figs. 2, 7c; GPS coordinates in Table 1) likewise shows distal turbidites (F8–F9; Mutti et al. 2003) with dm-scale, bioturbated, shaly intervals and thin (5–20 cm) laminated sandstone beds (Tb–Td). This succession is in normal position and displays a low dip (30°) towards the SE (Fig. 7c). A few pebbly sandstone beds (F2; Mutti et al., 2003) occur near the top of the exposure. These deposits were previously attributed to the Middle Eocene (nannofossil zones NP 15 to NP 16; Weidmann et al. 1976; Morel 1980). Sample NPK 317 was collected from grey marls located just below a 5 cm-thick sandstone bed (Fig. 7d). The assemblage of

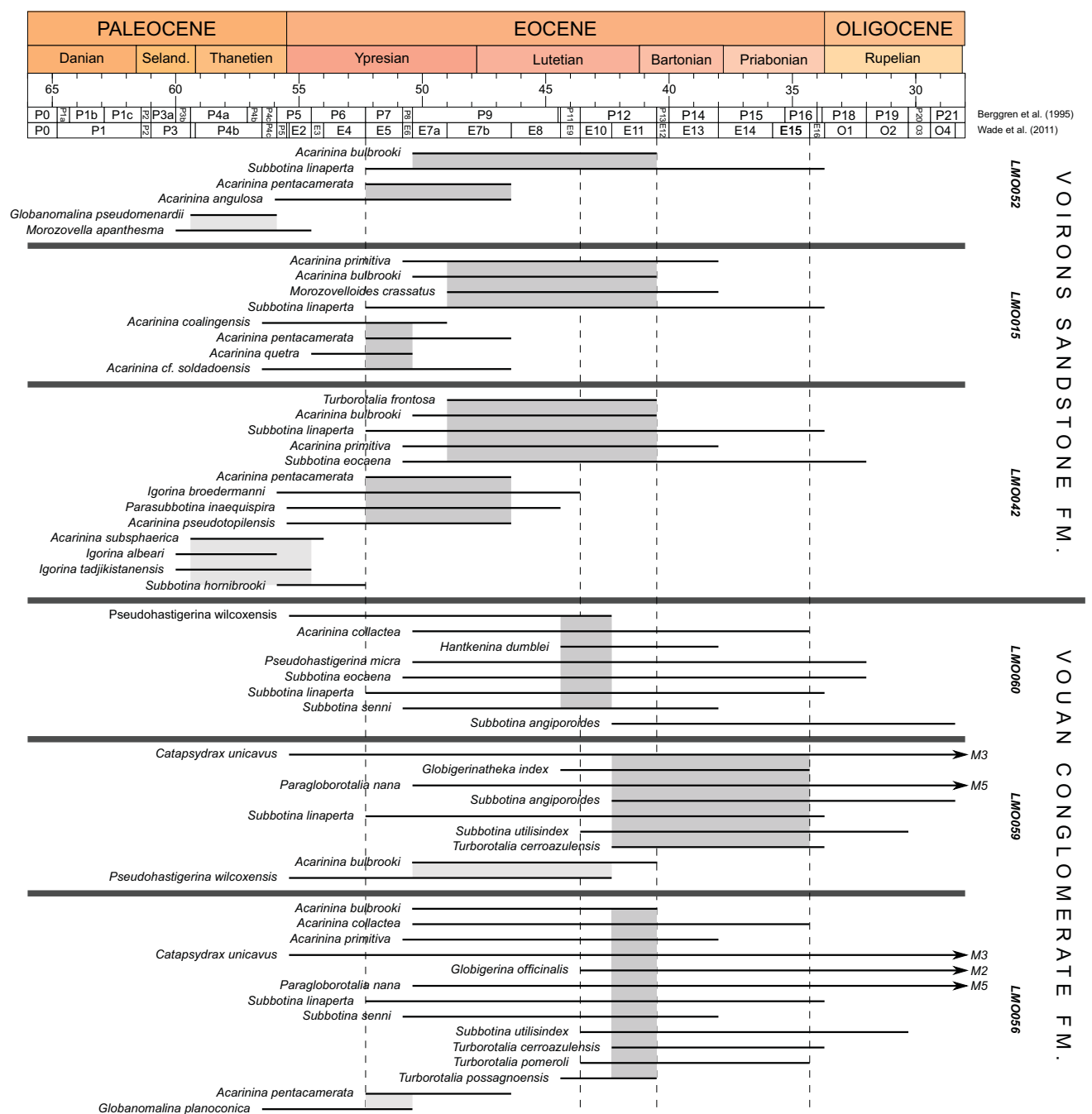


Fig. 5 Age ranges of the studied and revised samples of the Voirons Flysch based on planktonic foraminifera biostratigraphy. Dark grey shades correspond to the age range of samples and light grey shades for reworking

poorly preserved planktonic foraminifera found in this sample (Online Resource 1 and 2) gave an age ranging from the late Early Eocene to the late Middle Eocene (planktonic foraminiferal zones E7b to E11, or P9 to P12).

4.2 Voirons Flysch

The residues of five samples regularly distributed within the sandstone-dominated Voirons Sandstone Fm. were re-

picked and re-examined. Their geographic and stratigraphic positions are given in Figs. 2, 3b and Table 1. Previous studies based on nannofossils (Jan du Chêne et al. 1975; Van Stuijvenberg 1980) and planktonic foraminifera (Ospina-Ostios et al. 2013; Ospina-Ostios 2017) placed this formation in the Paleocene to Middle Eocene (nannofossil zones NP2 to NP16) and in the Middle Eocene to Early Oligocene (planktonic foraminiferal zones P13 to P19), respectively. The planktonic foraminiferal assemblages,

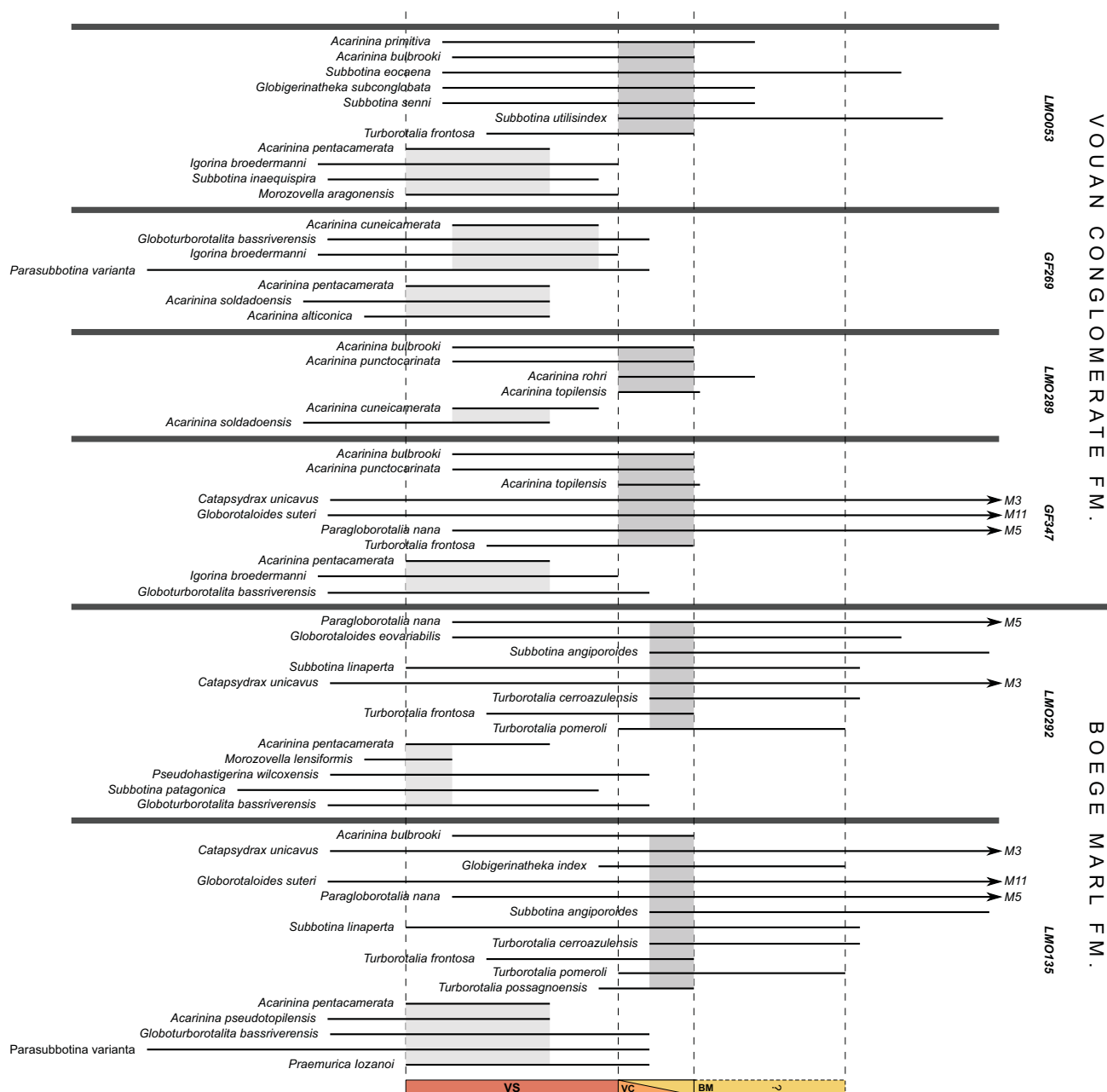
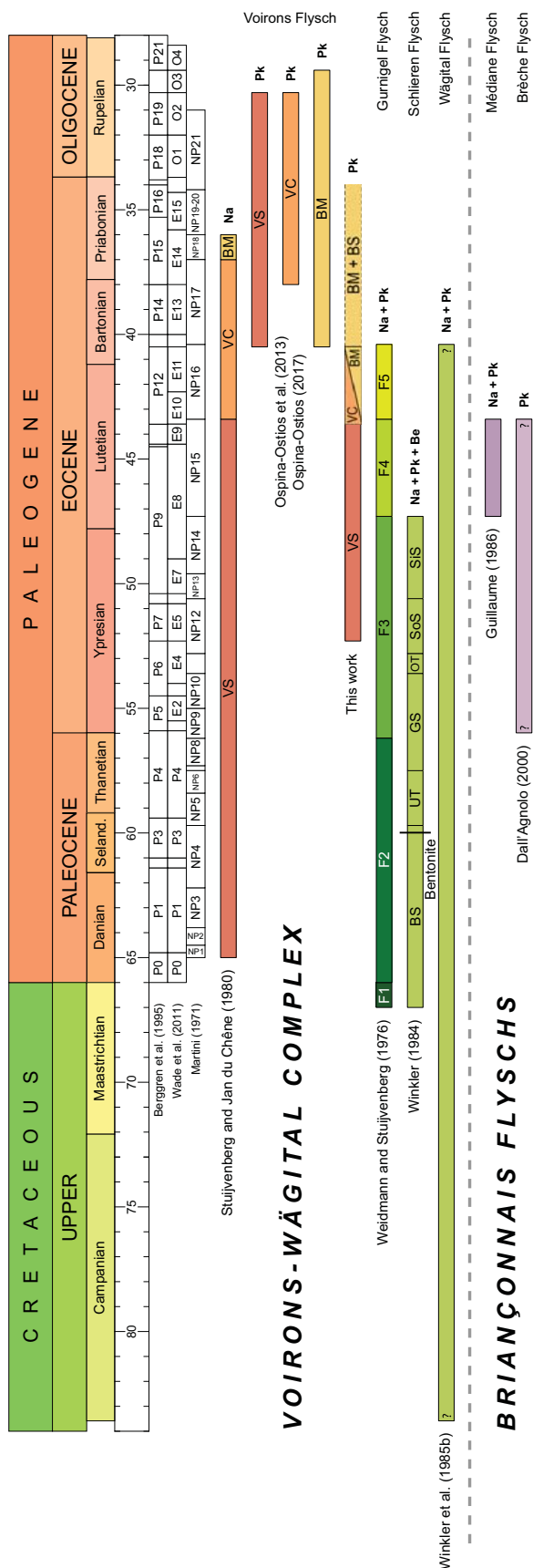


Fig. 5 continued

some of them well-preserved (e.g. sample LMO042), are presented in Online Resource 1. Collectively, these revised data constrain the age of the Voiron Sandstone Fm. between the Early and the Middle Eocene (planktonic foraminiferal zones E5–E9, or P7–P11). Reworked specimens of Cretaceous and Paleocene age have also been observed in these assemblages.

Likewise, the residues of four samples gathered from rare shaly intervals or mud pebbles (e.g. sample GF 269) scattered in the coarse-grained Voiron Conglomerate Fm. were reconsidered. The geographic and stratigraphic

position of the outcrops from which they were collected are given in Figs. 2, 3b and Table 1, respectively. Previous studies based on nannofossils (Jan du Chêne et al. 1975; Van Stuijvenberg 1980) and planktonic foraminifera (Frébourg 2006; Ospina-Ostios et al. 2013; Ospina-Ostios 2017) placed this formation in the Middle Eocene (nannofossil zones NP 15 to NP16) and in the late Middle Eocene to Early Oligocene (planktonic foraminiferal zones P15–P19), respectively. The planktonic foraminiferal assemblages are shown in Online Resource 1, and selected specimens are illustrated in Online Resource 2 and 3. The



◀Fig. 6 Comparison of the successive age ranges of the Voiron flysch with the other flyschs of the Voiron-Wägital complex and the Briançonnais flyschs. Bentonite age from Koch et al. (2015). *Be* large benthic foraminifera, *Na* calcareous nannofossils, *Pk* planktonic foraminifera

assemblages from all four samples contain numerous reworked forms, and yield up to three ages in the Eocene. Sample LMO056 gave the most recent and precise age in the Middle Eocene (planktonic foraminiferal zone E11 or P12), which overlaps the Lutetian-Bartonian boundary.

Only two samples from the lower part of the shale-dominated Boège Marl Fm. were re-evaluated. Section from upper layers are barren of planktonic specimens (Dransé outcrop; Jan du Chêne et al. 1975). Their geographic and stratigraphic positions are in Figs. 2, 3b and Table 1. The planktonic foraminiferal assemblages are listed in Online Resource 1, and selected specimens are illustrated in Online Resource 2 and 3. Previous studies based on nannofossils (Van Stuijvenberg and Jan du Chêne 1980) and planktonic foraminifera (Coppo 1999; Ospina-Ostios et al. 2013; Ospina-Ostios 2017) placed this formation in the Late Eocene (nannofossil zones NP18) and in the late Middle Eocene to Early Oligocene (planktonic foraminiferal zones P13 to P20), respectively. Like the material retrieved from the Vouan Conglomerate Fm., the planktonic foraminiferal assemblages identified in these two samples contain numerous reworked Early to Middle Eocene and even Cretaceous forms (e.g. hedbergellids in LMO292). The youngest age obtained for both samples is Middle Eocene (planktonic foraminiferal zones E11 or P12). It is identical to that obtained from the underlying Vouan Conglomerate Fm. Due to the paucity of shaly layers, no samples were collected from the sandstone-dominated, highly tectonised Bruant Sandstone Fm.

Thus, according to our new and revised data, the age of the Voiron flysch ranges from the Early Eocene to the late Middle Eocene, i.e. from the Late Ypresian to the Early Bartonian (planktonic foraminiferal zones P7-P12). No specimen of planktonic foraminifera with a range restricted to the Late Eocene or Early Oligocene age was detected in the studied residues.

5 Discussion

5.1 Comparison with previous biostratigraphic results

The foraminiferal ages acquired from the two samples collected from the Gurnigel Flysch agree with the previous biostratigraphic data based on nannofossils (Weidmann et al. 1976; Morel 1980). By contrast, our new data do not



Fig. 7 Studied exposures in the Gurnigel Flysch. **a** Partial view of the Veveyse de Feygire exposure. Arrow indicates where samples JR 377 and 378 were collected. Person for scale is 1.58 m tall. **b** Same location. Close-up on sampling spot. Note color difference between pelagic marls (greenish) and Te interval (grey). Bottle for scale is

3 cm long. **c** Partial view of the Veveyse de Châtel exposure. Arrow indicates where sample PK 317 was collected. Dog (for scale) is approximately 1 m long from head to tail base. **d** Closer view of sampling spot (arrow)

fully agree with any biostratigraphic result previously found in the Voirons Flysch. The older ages obtained from nannofossil analyses (Jan du Chêne et al. 1975; Van Stuijvenberg and Jan du Chêne 1980) for the onset of flysch sedimentation (Danian or Thanetian *versus* Ypresian) can be explained by considering that the Paleocene forms observed by these authors have been reworked (see Sect. 5.2). Similarly, the slight offset between the nannofossil age (Early Priabonian; Van Stuijvenberg and Jan du Chêne 1980) and our data (Early Bartonian) for the end of flysch deposition could likely be related to the small number of revisited samples from the Boège Marl Fm. However, the important discrepancies between our study and those of Ospina-Ostios et al. (2013) and Ospina-Ostios (2017), all of which relying on planktonic foraminifera biostratigraphy, cannot be easily dismissed, and are further discussed below.

5.2 Discrepancies in planktonic foraminifera biostratigraphy

The expansion of the Ocean Drilling Program (ODP) in the 80's and more recently of the Integrated Ocean Drilling and International Discovery Programs (IODP) have added a huge amount of information about planktonic foraminiferal ranges and taxonomy with the recovery of continuous sedimentary sequences and very well-preserved planktonic foraminiferal species. The pioneering comprehensive work of Toumarkine and Luterbacher (1985) on Palaeogene planktonic foraminifera has been revised and completed in the Atlases of Paleocene and Eocene Planktonic Foraminifera compiled by the Palaeogene Planktonic Foraminifera Working Groups (PPFGW) active since 1987 (Olsson et al. 1999; Pearson et al. 2006). These comprehensive monographies not only present a new biologically guided classification of planktonic foraminifera based on the characteristics of the wall textures, but also refined

Table 1 Geographical location and age ranges of the studied samples

Sample	Geological unit	Site	Location Fig. 2	Geographic coordinates (WGS84)	Age ranges (Wade et al. 2011)	Remarks
Voirons Flysch						
LMO052	Voirons Sandstone Fm.	Bons quarry	A	E6.391322– N46.255011	E5–E7b, E7a–E11, P4	
LMO015	Voirons Sandstone Fm.	Monastery road	B	E6.358315–N46.22799	E5–E6, E7b–E11	Late Cretaceous forms
LMO042	Voirons Sandstone Fm.	Morand bridge	C	E6.371186– N46.164862	P4–P5, E5–E7, E7b– E11	Late Cretaceous forms
LMO060	Vouan Conglomerate Fm.	Saxel upper quarry	D	E6.396003– N46.252292	E9–E10	
LMO059	Vouan Conglomerate Fm.	Saxel upper quarry	D	E6.396003– N46.252292	E7–E10, E11–E15	
LMO056	Vouan Conglomerate Fm.	Saxel upper quarry	D	E6.396003– N46.252292	E5, E11	
LMO053	Vouan Conglomerate Fm.	Saxel upper quarry	D	E6.396003– N46.252292	E5–E7, E10–E11	
GF269	Vouan Conglomerate Fm.	Molière grind quarry	E	E6.370147– N46.187306	E5–E7, E7–E8	Entirely reworked
LMO289	Vouan Conglomerate Fm.	Vachat grind quarry	F	E6.376809– N46.175282	E5–E7, E10–E11	
GF347	Vouan Conglomerate Fm.	Vachat grind quarry	F	E6.376809– N46.175282	E7b, E10–E11	
LMO292	Boège Marl Fm.	Chauffemérande stream	G	E6.389323– N46.169689	E5–E6, E11	(Late) Cretaceous forms
LMO135	Boège Marl Fm.	Supersaxel road	H	E6.403001– N46.243125	E5–E7, E11	
Gurnigel Flysch						
JR377	Flysch 3	Veveyse de Fégire	I	E6.932667– N46.503267	E7b	
JR378	Flysch 3	Veveyse de Fégire	I	E6.932667– N46.503267	E7a–E8	
NPK317	Flysch 4	Veveyse de Châtel	J	E6.944167– N46.526667	E7b–E11	

ranges for each species at a global scale. The advantage of these atlases is that holotypes and, in some cases, also paratypes of each species are imaged, mostly with the environmental SEM, and we have now the documentation of type specimens that, in most cases, were only illustrated by drawings.

Ospina-Ostios et al. (2013) and Ospina-Ostios (2017) mostly used the taxonomy and species ranges reported in Toumarkine and Luterbacher (1985) and the time scale of Luterbacher et al. (2004). The more recent biostratigraphy and taxonomic works of Pearson et al. (2006) and Wade et al. (2011) have been only used to update generic names. Additionally, they have not used the classification of planktonic foraminifera based on wall texture. Although the planktonic foraminifera from the Gurnigel Flysch are very poorly preserved, it is still possible to identify the details of the wall texture for most specimens. One example is the specimen illustrated on Online Resource 3 (6b) of Ospina-Ostios et al. (2013) identified as *Tenuitellinata angustiumbilitata*. This form shows a coarsely cancellate wall texture typical of macroperforate genera

(e.g. *Paragloborotalia* or *Subbotina*) instead of the microperforate wall texture typical of the genus *Tenuitellinata*. The main discrepancies between the studies of Ospina-Ostios et al. (2013) and Ospina-Ostios (2017) and the present work are generally due to the different approaches in classification of species and the use of different zonal schemes.

Thus, based on our revision of previous data, the onset of sedimentation of the Voirons Flysch spans the interval zones P7–P9 (as in Berggren et al. 1995) corresponding to Zones E5–E7 of Wade et al. (2011), whereas the end of deposition can be mostly restricted to zone P12 (as in Berggren et al. 1995) corresponding to zones E10–E11 (Wade et al. 2011). However, we cannot rule out that sedimentation continued as late as the Priabonian (Figs. 5, 6) because we only revised two samples from the lower part of the Boège Marl Fm. and none from the overlying Bruant Sandstone Fm. Such an attribution would agree with previously obtained results based on nannofossil biostratigraphy that suggested an early Priabonian maximum age (nannofossil zone NP 18) for the Boège Marl Fm.

(Jan du Chêne et al. 1975; Van Stuijvenberg and Jan du Chêne 1980).

5.3 Reworking in the Voirons Flysch

The comparison of biostratigraphic ranges allows to reconstruct some sedimentary processes throughout the Voirons Flysch. Samples of the Voirons Sandstone Fm. include reworked specimens of Late Paleocene age (Fig. 5). Such an age is not reported in the Voirons Flysch, and may be derived either from (1) extrabasinal marly successions or (2) an older upstream equivalent of the Voirons Sandstone Fm. The latter hypothesis suggests that, in contrast to the other flyschs from the Voirons-Wägital complex (Fig. 6), Paleocene sediments might have been tectonically removed during an early phase of thrusting. Similarly, the presence of Upper Cretaceous specimens (Campanian to Maastrichtian) may involve a contribution from basinal marls of Mesozoic age.

The Vouan Conglomerate Fm. consistently comprises specimens reworked from the Voirons Sandstone Fm. However, these elements are missing in the sample LMO060 collected from the lower part of this unit, indicating that reworking processes started after a short delay. This break can also be observed in the field where the basal part of the Vouan Conglomerate Fm. corresponds to a sandstone-marl alternation (Saxel upper quarry; Ragusa 2015). In addition, the restricted range of sample GF269 (Fig. 5) suggests that the mud pebbles occurring within some beds of the Vouan Conglomerate Fm. may directly derive from the Voirons Sandstone Fm.

The biostratigraphic range of the Boège Marl Fm. does not differ from that of the Vouan Conglomerate Fm (Fig. 5), and also comprises reworked specimens from the Voirons Sandstone Fm. We suppose that the youngest age obtained from the Boège Marl Fm. reflects reworking from the Vouan Conglomerate Fm. This marly succession corresponds to a starvation period, enabling the destabilisation of the turbiditic system. Hence, the obtained Lutetian–early Bartonian age may emphasize the remobilisation of upstream components of the Vouan Conglomerate Fm. basinward, corroborating the occurrence of one single conglomeratic bed at the base of the Boège Marl Fm (Ragusa 2015; Ospina-Ostios 2017). The presence of late Ypresian to Lutetian foraminifera also confirms a contribution from the Voirons Sandstone Fm. Finally, the occurrence of Upper Cretaceous specimens, that are missing in the Vouan Conglomerate Fm., also suggests that this unit originates from the same source as the Voirons Sandstone Fm., as previously confirmed by the similar detrital composition (Ragusa et al. 2017). Consequently, sampling in the upper part of the unit, where detrital sedimentation rate increases, may better constrain the

depositional age of the Boège Marl Fm. which probably ends during Priabonian (planktonic foraminiferal zones E15–P16) from calcareous nannofossil biostratigraphy.

5.4 Comparison with the other flyschs of the Voirons-Wägital complex and palaeogeographic implications

As the age of the Voirons Flysch is now constrained between the Ypresian and the Priabonian, the whole Voirons-Wägital complex ranges from the Campanian to the Late Eocene (Fig. 6), which corresponds to a ca. 49.7 Ma-long interval. The accumulation time of the Voirons Flysch (ca. 18 Ma) is shorter than that of the Gurnigel (ca. 26.6 Ma; Weidmann et al. 1976; Morel 1980) and Schlieren Flyschs (ca. 19.7 Ma; Winkler 1983, 1984), whereas sedimentation of the Wägital Flysch lasted for about 45.6 Ma (Winkler et al. 1985), spanning the time interval of the complex. The age ranges of the different flyschs become younger towards the West, suggesting a scissor-like closure of the basin (Winkler 1984). Sedimentation started during the Late Cretaceous in the eastern units, but only initiated during the Early Eocene in the Voirons Flysch. Similarly, sedimentation ended in the Early Eocene in the Wägital Flysch, and probably stopped in the Late Eocene in the Voirons Flysch.

Although our revised age of the Voirons Flysch is similar to that previously obtained from nannofossil biostratigraphy (Fig. 6; Jan du Chêne et al. 1975; Van Stuijvenberg and Jan du Chêne 1980), it does not necessarily re-establish a South Penninic origin for this unit, and for that matter for the whole Voirons-Wägital complex. These flyschs needed accommodation space before, during and after the deposition of the Briançonnais flyschs, especially of the Médiante Flysch (Fig. 6; Guillaume 1986), which substantiates a palaeogeographic location in the Valais domain. Thus, our revised biostratigraphic data on the Voirons Flysch requires an update of the palaeogeographic model proposed by Ragusa et al. (2017), which will be detailed in a publication currently in preparation.

6 Conclusion

The ages derived from the examination of planktonic foraminiferal assemblages from the Gurnigel Flysch and from our revision of material gathered by previous researchers from the Voirons Flysch reveal only minor discrepancies with earlier studies based on nannofossil biostratigraphy (Jan du Chêne et al. 1975; Weidmann et al. 1976; Morel 1980; Van Stuijvenberg and Jan du Chêne 1980; Van Stuijvenberg 1980). By contrast, there are major divergences between the results of our work and those of

previous studies on the Voirons Flysch similarly based on planktonic foraminifera (Ujetz 1996; Coppo 1999; Frébourg 2006; Ospina-Ostios et al. 2013; Ospina-Ostios 2017). These discrepancies are generally related to the different approaches in species classification and the use of different zonal schemes. Based on our revised data, the age of the Voirons Flysch extends from the Early Eocene (planktonic foraminiferal zone E5 or P7) to the Middle Eocene (planktonic foraminiferal zone E11 or P12). Contrary to claims made in the aforementioned studies, specimens restricted to Late Eocene or Early Oligocene age have not been observed in the samples and in the illustrations we re-examined. However, we cannot exclude a younger age (possibly early Late Eocene) for the upper reaches of this flysch from which we did not have samples to re-examine. Further sampling in the upper part of the Boège Marl Fm. and Bruant Sandstone Fm. will be investigated to better constrain the age from the top of the flysch deposition. Thus, additional research and sampling are needed to resolve this question. Finally, the palaeogeographic origin of the Voirons-Wägital complex as well as the sedimentation history of these flyschs need now to be re-evaluated in light of this revised biostratigraphic data.

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