

Revision of the planktonic foraminiferal biostratigraphy of the Voirons 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 Voirons Flysch reveal only minor discrepancies with previous studies based on nannofossil biostratigraphy. In contrast, major divergences between this work and previous studies on the Voirons 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 Voirons 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 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.

Keywords

biostratigraphy; flysch; Palaeogene; planktonic foraminifera; Valais domain; Voirons-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 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 ([Hekel, 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](#)).

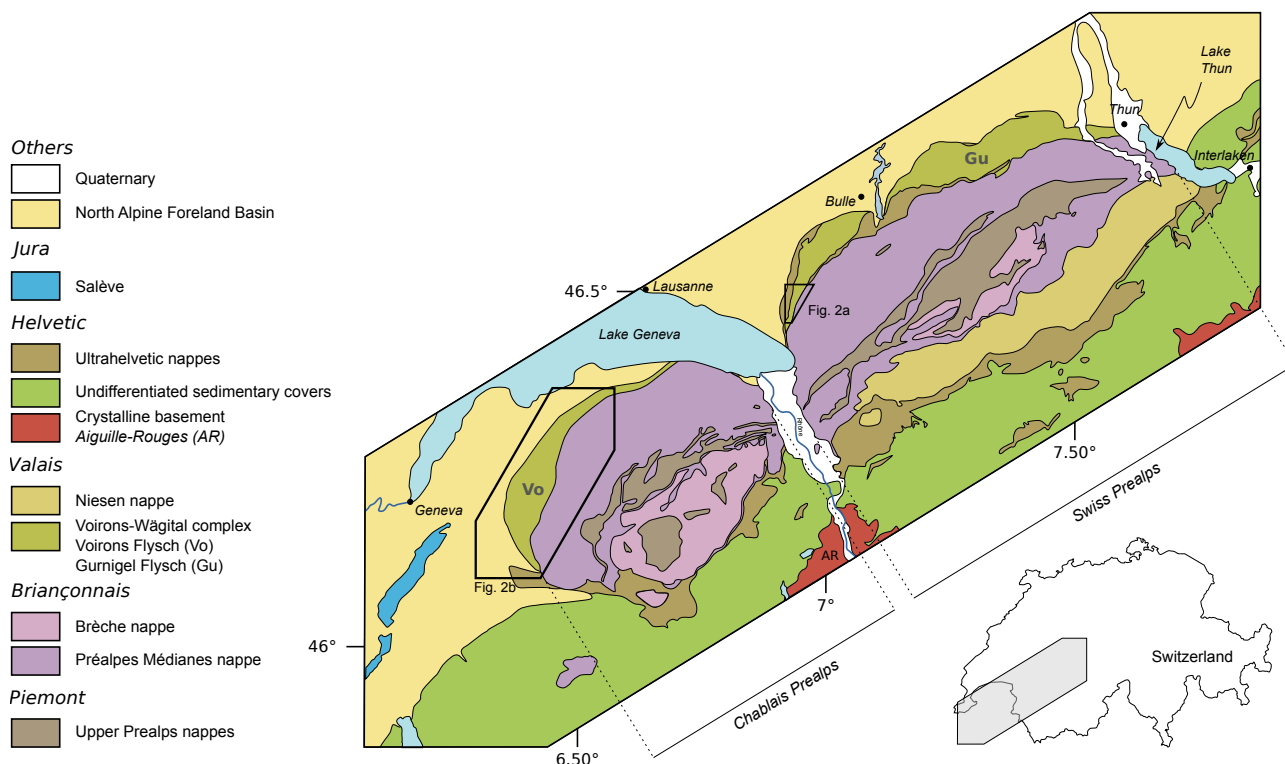


Figure 1: test.

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 (Médiannes 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 20th 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 Schmid et al. (2005) as well as the conclusions of Trümpy (2006) for the easternmost part of the Voirons-Wägital complex (e.g. the Iberg Klippes), the Voirons 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 Voirons-Wägital complex in the western part of Switzerland to possibly confirm and substantiate the research made in the Voirons 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 Voirons Flysch, which is now the main aim of this paper.

2 Geological Setting

The Voirons-Wägital complex, which includes the Voirons, 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 Ultrahelvetetic slices below and the Préalpes Médiannes nappe above (Figs. 1 and 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 (Figs. 2a and 2b, respectively). The former encompasses a succession of five units (Flyschs 1 to 5; Fig. 3a), discriminated by subtle differences in lithology, that have been dated from the Maastrichtian to the Middle Eocene by calcareous nannofossil biostratigraphy (Figs. 3a and 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 NP2 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 and 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 and 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., 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 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 0.5x 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).

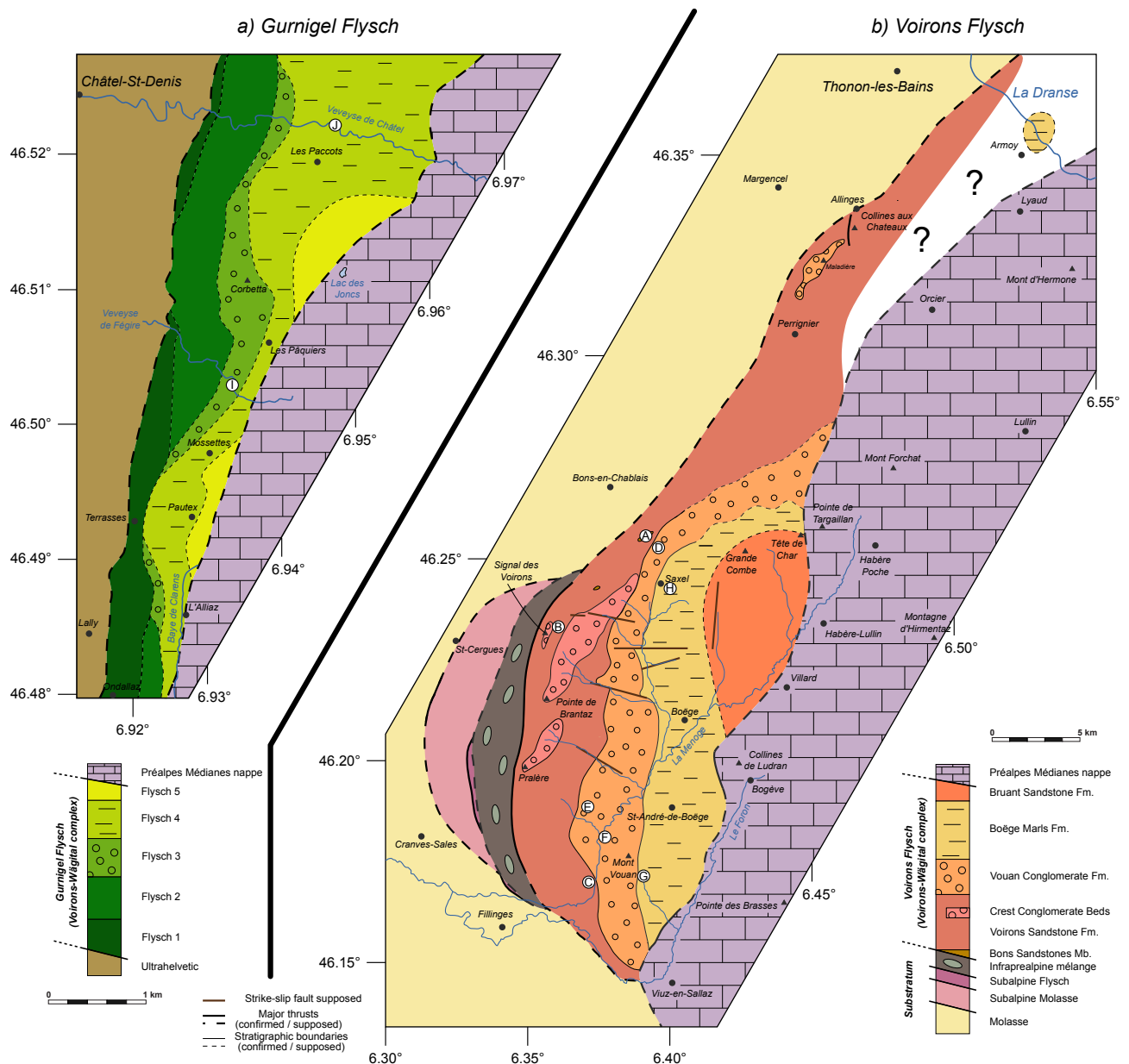


Figure 2: test.

4 Results

4.1 Gurnigel Flysch

The exposure in the Veveyse de Fégire gorges (Figs. 2 and 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 and 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 to 20 cm) laminated sandstone

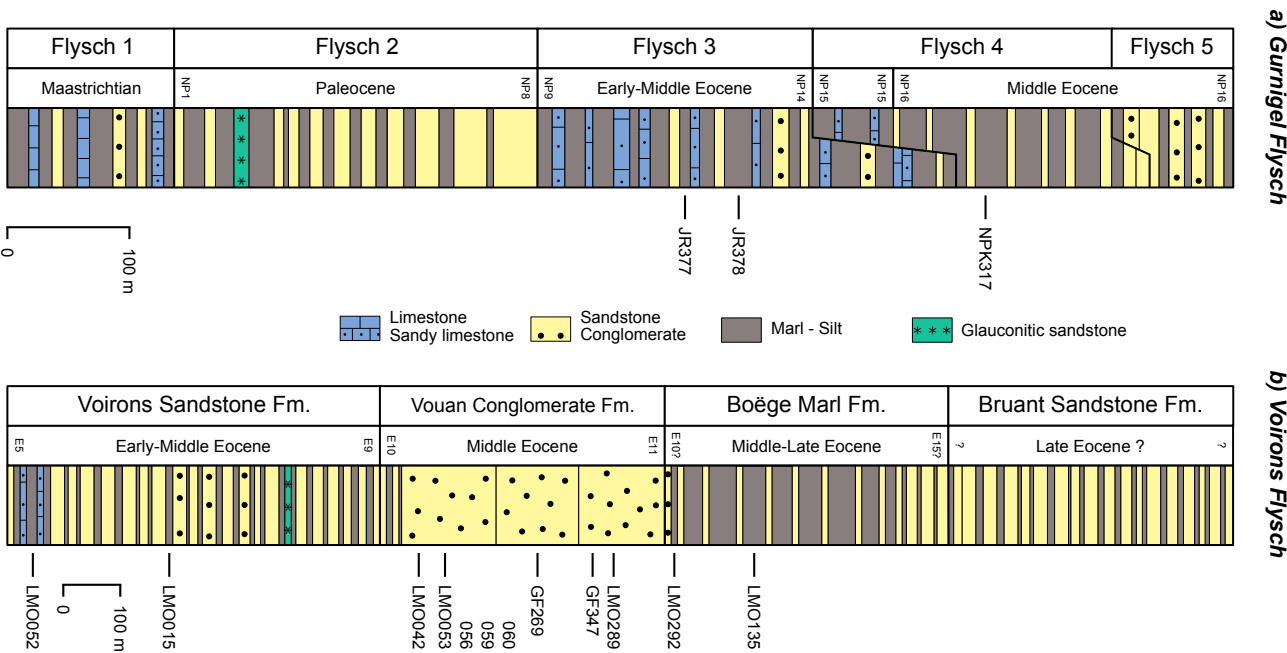


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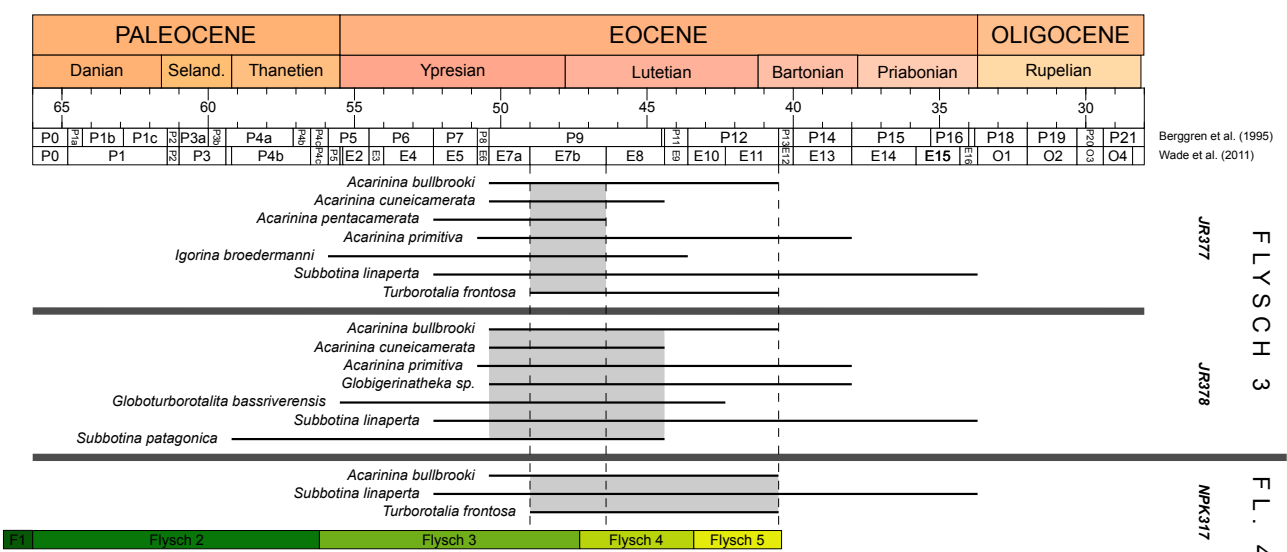


Figure 4: test.

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 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 Voiron Flysch

The residues of five samples regularly distributed within the sandstone-dominated Voiron Sandstone Fm. were re-picked and re-examined. Their geographic and stratigraphic positions are given in Figures 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, some of them well-preserved (e.g. sample LMO042), are presented in Table 2. Collectively, these revised data constrain the age of the Voiron Sandstone Fm. between the Early and the Middle Eocene (planktonic foraminiferal zones E5 to E9, or P7 to 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 Vouan Conglomerate Fm. were reconsidered. The geographic and stratigraphic position of the outcrops from which they were collected are given in Figures 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 to P19), respectively. The planktonic foraminiferal assemblages are shown in Online Resource 1, and selected specimens are illustrated in Online Resource 2 and 3. The 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 (Dranse outcrop; Jan du Chêne et al., 1975). Their geographic and stratigraphic positions are in Figures 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, 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 to 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 fully agree with any biostratigraphic result previously found in the Voiron 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 Section 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.

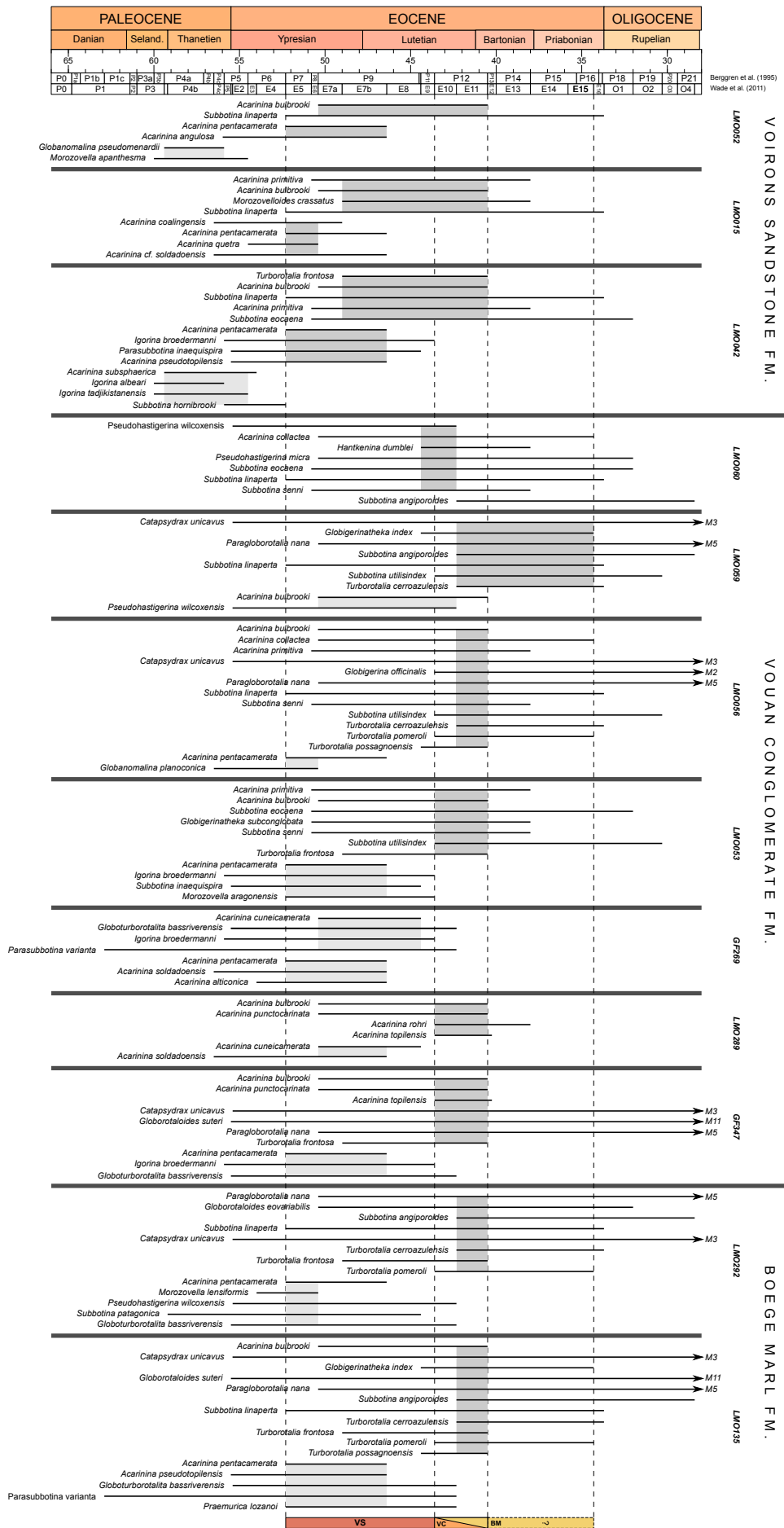


Figure 5: test.

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 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 Voiron 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 and 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](#))).

5.2.1 Reworking in the Voiron Flysch

The comparison of biostratigraphic ranges allows to reconstruct some sedimentary processes throughout the Voiron Flysch. Samples of the Voiron Sandstone Fm. include reworked specimens of Late Paleocene age (Fig. 5). Such an age is not reported in the Voiron Flysch, and may be derived either from (1) extrabasinal marly successions or (2) an older upstream equivalent of the Voiron Sandstone Fm. The latter hypothesis suggests that, in contrast to the other flyschs from the Voiron-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 Voiron 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 Voiron 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 Voiron 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 to P16) from calcareous nannofossil biostratigraphy.

5.3 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.

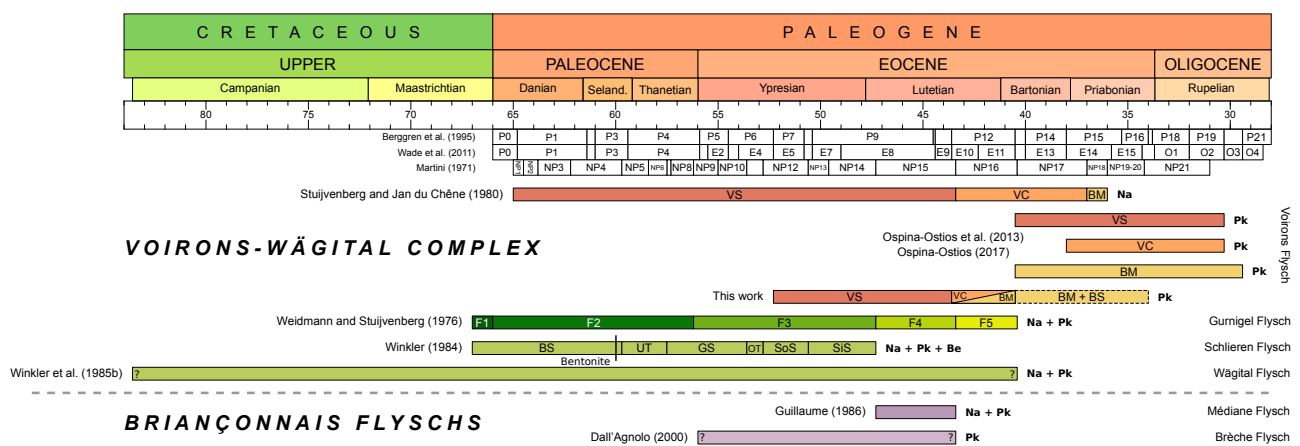


Figure 6: test.

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 Médiane Flysch (Fig. 6), 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, 1980 ; Van Stuijvenberg and Jan du Chêne, 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.,



Figure 7: test.

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 Voiron 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 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.

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Electronic supplementary materials

The online version of this article contains supplementary material:

- *Supplementary material 1*: Framework composition of the Voiron Flysch following the Gazzi-Dickinson method
- *Supplementary material 2*: SEM-EDS garnet geochemistry from the Voiron Flysch. Data include element and calculated oxide composition and enb-member abundance

- *Supplementary material 3*: SEM-EDS tourmaline geochemistry from the Voirons Flysch. Data include element and calculated oxide composition

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