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New paleontological and biostratigraphical data (calcareous nannofossils, ostracods, brachiopods), correlations and lithostratigraphic units in the Urgonian facies (latest Hauterivian-Barremian) of the Swiss and French Jura Mountains: the Falaises Member and the Saars Formation (former "Gorges de l'Orbe Formation")

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Abstract

From latest Hauterivian to latest Barremian, the Urgonian facies of the Swiss and French Jura Mountains are subdivided into three formations and five members: new Saars Formation (= former "Gorges de l'Orbe Formation" *sensu* Strasser et al., 2016; Pictet, 2021) with a new Falaises Member below the Montcherand and Bôle members of Pictet (2021), Rocher des Hirondelles Formation with Fort de l'Ecluse and Rivière members (Pictet, 2021, revised), and Vallorbe Formation (revised from Strasser et al., 2016 and the "Vallorbe Member" of Pictet, 2021). The latest Hauterivian-early Late Barremien Saars Formation includes three members 1) to 3): 1) Latest Hauterivian-Early Barremian Falaises Member with new Early Barremian nannoflora from the Corcelles Marls (much younger than the late Early Hauterivian nannoflora from the Uttins Marls of the type locality at Mont de Chamblon), primitive orbitolinids *Praedictyorbitolina claveli* Schroeder, 1994; and fossils/microfossils usually considered as Hauterivian markers: echinids *Pseudholaster intermedius* (Münster *in* Goldfuss, 1826), brachiopods *Glosseudesia semistriata* (Defrance, 1828), *Lamellaerynchia hauteriviensis* Burri, 1953 and *Plicarostrum aubersonense* Burri, 1956, and ostracods of the Assemblage 1 [*Protocythere triplicata* (Roemer, 1841), *Rehacythereis bernardi* (Grosdidier, 1964), *Schuleridea clunicularis* (Triebel, 1938), *Schuleridea* gr. *thoerenensis* (Triebel, 1938)]. 2) Early Barremian Montcherand Member with brachiopods *Glosseudesia inexpectata* Mojon, n. sp. and *Glosseudesia ebrodunensis* (de Loriol, 1864), and ostracods of the Assemblage 2 [*Strigosocythere strigosa* (Grosdidier, 1964), *P. triplicata*, and juvenile immature species markers of the next ostracod Assemblage 3]. 3) Early to early Late Barremian Bôle Member with adult ostracod markers of the Assemblage 3 [*Rehacythereis geometrica* (Damotte and Grosdidier, 1963), *Bairdoppilata barremiana* Mojon, n. sp., *Bairdoppilata luminosa* Kuznetsova, 1961;

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Neocythere (Centrocythere) gottisi Damotte and Grosdidier, 1963; *Schuleridea derooi* Damotte and Grosdidier, 1963; *Schuleridea alata* Kaye, 1965; *Dolocytheridea intermedia* Oertli, 1958]. 4) The Early to Late Barremian Fort de l'Ecluse Member/Rocher des Hirondelles Formation and Late Barremian Rivière Member/Vallorbe Formation are characterized by markers such as echinids *Heteraster couloni* (L. Agassiz, 1839), orbitolinids [*Praedictyorbitolina carthusiana* Schoeder et al., 1990; *Eopalorbitolina charollaisi* Schroeder and Conrad, 1967; *Valserina broennimanni* Schroeder and Conrad, 1967; *Paleodictyoconus actinostoma* Arnaud-Vanneau and Schroeder, 1976; *Paracoskinolina maynci* (Chevalier, 1961)], and typical ostracods of the Assemblage 4 [*Strigosocythere chalilovi* (Kuznetsova, 1961), *Rehacythereis buechlerae* (Oertli, 1958) only in the southern Jura and replaced by *R. geometrica* in the central Jura, *Platycythereis rostrata* Sauvagnat, 1999] extended in the latest Barremian-Early Aptian Fulie Member of the basal Perte-du-Rhône Formation defined by Pictet et al. (2016).

Keywords: Stratigraphy, Nannofossils, Ostracods, Brachiopods, Urgonian facies, Barremian, Jura Mountains, W-Switzerland, E-France

1 Introduction

The aim of this study is new micropaleontological data precising the age of the Urgonien Jaune (UJ) facies in the Neuchâtel area and the correlations for the Urgonian facies of the whole Jura Mountains. A Barremian age is reported for the Urgonian facies of the Jura Mountains since the beginning of the 19th century (Baumberger, 1901; Schardt and Dubois, 1902), but was confirmed with certainty only much later (Adatte et al., 2005; Godet et al., 2010, 2011). More recently, very significant updates were presented for a latest Barremian age at the top of Urgonien Blanc (UB) facies in the southern Jura (ammonite *Martelites* sp. juv. from the Tethyan Sarasini ammonite Zone, Pictet et al., 2019), and for the Early to early Late Barremian age of the UJ facies in the central Jura (nannofloras from the Tethyan Hugii to lower Sartousiana ammonite Zones, De Kaenel et al., 2020). This study documents new calcareous nannofossil data attesting mainly an Early Barremian age for the UJ facies of the central Jura (Western Switzerland). New ostracod data from the UB facies in the southern Jura allow revised datings and correlations with the Urgonian facies (UJ and UB) of the central Jura.

2 Geological settings

The Urgonian facies are Early Cretaceous shallow marine sediments of large Jurassic-Cretaceous carbonate platforms covering the Jura Mountains area (Fig. 1A, B), with intercalated brackish and freshwater deposits in the Oxfordian-Kimmeridgian and Berriasian-Valanginian (Mojon, 2002) as well as in the latest Barremian (Pictet et al., 2019). Although Urgonian deposits *in situ* are unknown in the eastern part of the Swiss Jura Mountains already from the Biel/Bienne area (canton Bern), it can be attested that these deposits were present before an Eocene period of intense erosion and soil alteration. Early Cretaceous ostracods and orbitolinids are reported in the Late Priabonian "Terre Jaune" of the Delémont Basin (Mojon et al., 2018, p. 9; cf. Rossemaison Formation, Pirkenseer et al., 2018) and it can be specified here that these microfossils are reworked from Barremian marls of the Saars Formation. In 2019, one of us (POM) found in a vineyard above Alfermée (coord. 2582.135/1218.995, 2 km west of Biel/Bienne) a reworked and deeply rubefied pebble of Urgonien Blanc facies (upper part of the Vallorbe Fm with Late Barremian orbitolinid *Paracoskinolina* cf. *maynci*, Fig. 2) from the famous Eocene paleokarst infilling (Siderolithic Group deposits, Mojon et al., 2018) having provided other similar remarkable rubefied pebbles and blocks with large Maastrichtian benthic foraminifera (Renz, 1936). The studied sections in the central Swiss Jura (W-Switzerland) are located along the first chain bordering the Swiss Molasse Basin or within inner synclines. Their position is indicated by Swiss Federal Coordinates LV95 (Fig. 1C) and they can be plotted precisely with the Geological Atlas of Switzerland 1:25'000 (managed and edited by the Federal Office of Topography swisstopo at Wabern/Bern, URL: https://www.swisstopo.admin.ch/en/knowledge-facts/geology/geological-data/geological-maps.html) using seven maps/explanatory notes, titled and numbered as following: Neuchâtel (67/1164), Travers (162/1163), Grandson (114/1183), Ste-Croix (95/1182), Yverdon-les-Bains (94/1203), Orbe (42/1202), Cossonay (5/1222). In the central and southern French Jura (E-France), the studied sections in the valleys of Morteau (Fallot and Perrodon, 1968) and Valserine (Conrad, 1969; Arnaud et al., 1998; Charollais et al., 2013; Pictet et al., 2019) are also indicated by Swiss Federal Coordinates LV95 extended outside Switzerland or DMS coordinates (Fig. 1C). The historical importance of the Neuchâtel area for the Early Cretaceous stratigraphy as well as the lithology and some paleontological elements of the Valanginian-Hauterivian stages and the Urgonian facies in the Swiss/French Jura Mountains

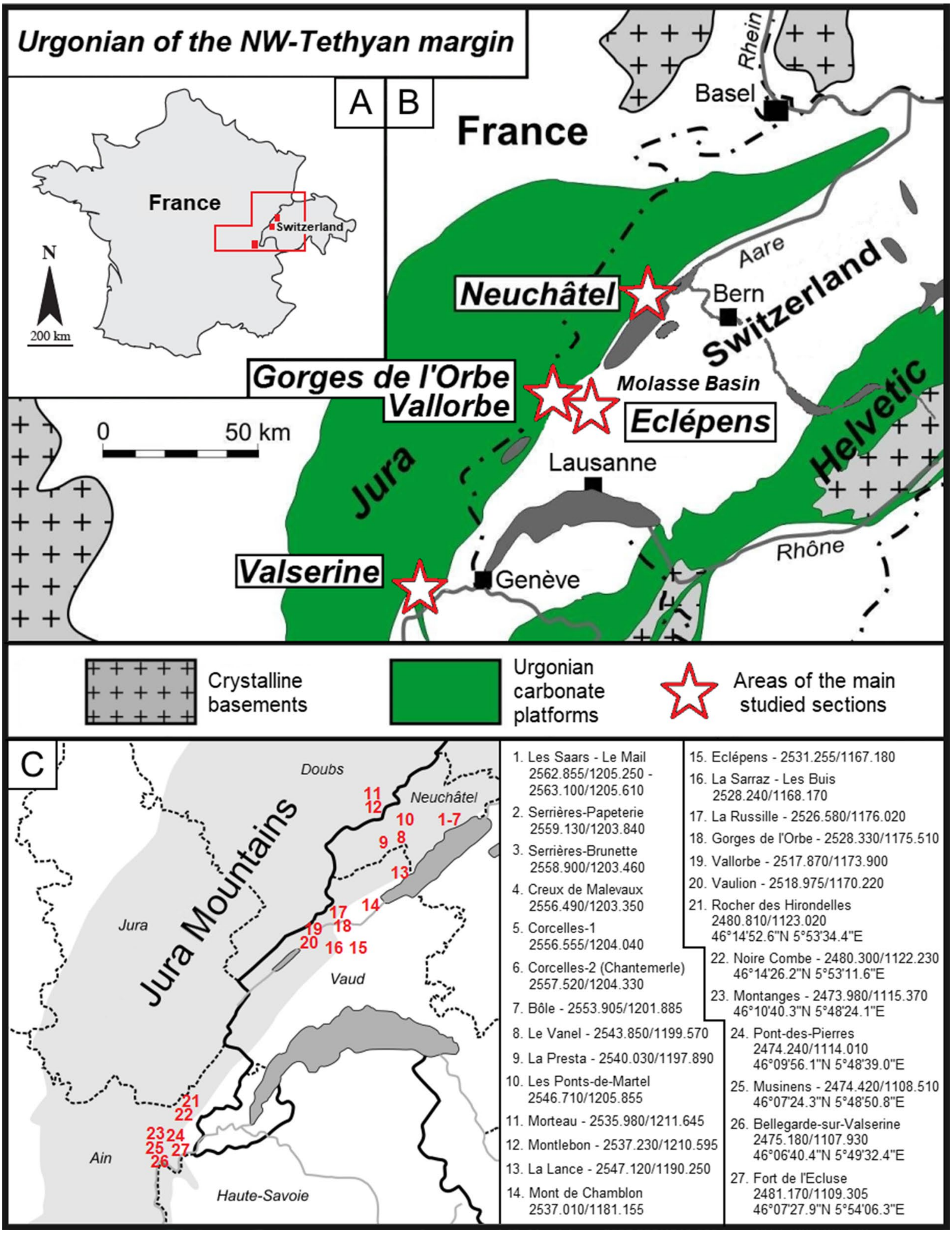

Fig. 1 General map (**A**) with the red frameworks of map B and the 3 groups of studied sections, detailed map (**B**) with location of the studied sections indicated (**C**) by numbers in red and coordinates after the map of Switzerland (Swiss Federal Coordinates LV95) and IGN map of France (DMS coordinates); see also Fig. 10 for the detailed Neuchâtel area (sections 1–7)

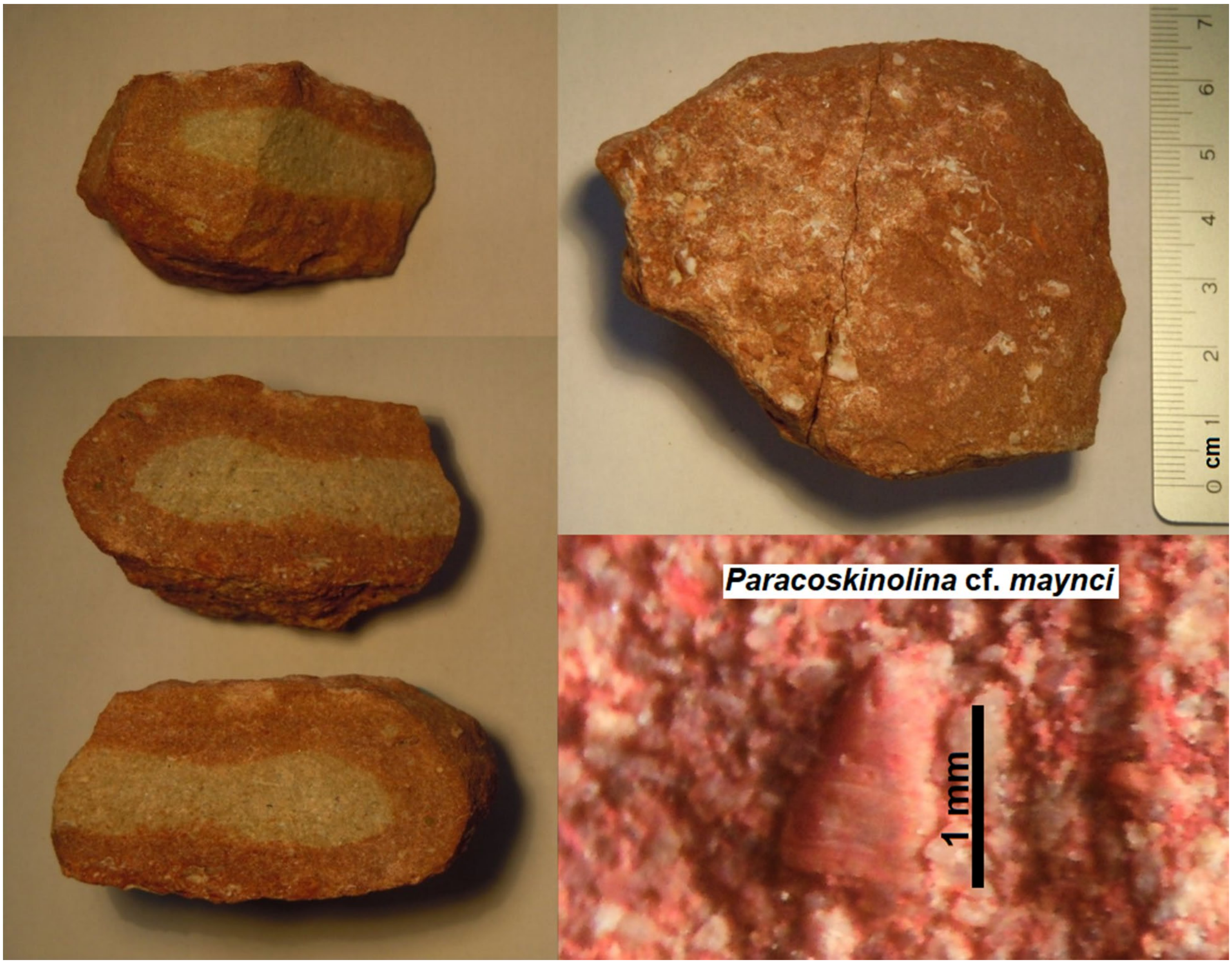

Fig. 2 Reworked pebble of Urgonien Blanc facies (whitish bioclastic packstone with detrital quartz and glauconite of the upper Vallorbe Formation) from the Eocene paleokarst infilling of Alfermée (Canton Bern) described by Renz (1936). External part of the sample characterized by thick red halo of deep impregnation with iron hydroxides after very long stay in ferruginous "terra rossa" of paleosols and karst cavities, and weathered surface of alteration with loose micritized Late Barremian orbitolinid *Paracoskinolina* cf. *maynci* (Chevalier, 1961) of approximately 1.3 × 0.8 mm, spines of sea urchins and fragments of small oysters. Collection and photos P.-O. Mojon with field binocular stereomicroscope Leitz and Nikon Coolpix S8000

are reported and discussed by Remane (1989), Remane et al. (1989a) and Strasser et al. (2018), whereas detailed significant data on the sedimentology and micropaleontology were collected and exposed by Blanc-Alétru (1995) and Godet (2006). The Urgonian facies of the Jura Mountains are fossil-rich, but the macrofossils and most microfossils often do not allow accurate datations, although calcareous nannofossils have provided the best results for this purpose (De Kaenel et al., 2020). Among the benthic foraminifers, phylogenetic lineages of orbitolinids were particularly and mainly studied for biostratigraphy (Schroeder, 1993; Schroeder et al., 1999, 2002). The ostracods were poorly known and illustrated (Oertli *in* Conrad, 1969; Clavel et al., 1994; Sauvagnat et al., 2001; Mojon et al., 2013; Pasquier et al., 2013), but are very useful for detailed correlations between the central and southern Jura as presented in this study.

3 Materials and methods

This study was performed from 2008 to 2021 in permanent outcrops and temporary sections within construction sites of the Neuchâtel area (listed in Sect. 4, NB: all the coordinates of sections indicated in the text are reported from the map of Switzerland 1:25′000). Most sections from the central and southern Jura Mountains (Fig. 1C, n° 8, 10, 12–27) are still well visible, but marly sections were only accessible and sampled in 2014 at La Presta (n° 9, cf. log *in* Pictet et al., 2016, 2019) and Morteau (n° 11) sampled in thick marly limestones within a construction site.

Macrofossils (echinids, brachiopods, oysters, stromatoporoids, corals) and microfossils (ostracods, benthic foraminifers, sclerites of stromatoporoids, spines of sea urchins) were collected in the Jura Mountains from marly layers of the Urgonian facies (Corcelles Marls, and many others marly intercalations), and also from soft marls of the Hauterivian (Hauterive Marls, Uttins Marls) and latest Barremian-earliest Aptian (Poet Beds, Vauglène Beds). The micropaleontological material was obtained in the laboratory from 68 productive samples of the studied sections [counted from the collection of P.-O. Mojon, sterile samples not reported: Vauseyon/Neuchâtel City-West (1), Les Saars-Le Mail (4), Serrières-Papeterie (1), Serrières-Brunette (3), Creux de Malevaux (2), Corcelles-1 and 2/Chantemerle (4), Bôle (4), Boudry (2), Le Vanel (4), La Presta (2), Ponts-de-Martel (1), Morteau (2), Montlebon (2), La Lance (2), Les Uttins/Mont de Chamblon (1), Eclépens quarry and railway trench (4), La Sarraz-Les Buis quarry (3), La Russille (4), Gorges de l'Orbe/Montcherand (7), Vallorbe (3), Vaulion (2), Rocher des Hirondelles (1), Noire Combe (1), Montanges (2), Pont-des-Pierres (1), Musinens (1), Bellegarde-sur-Valserine (3), Fort de l'Ecluse (1); cf. Figs. 1C, 15].

These samples each of about 1–5 kg dry weight were wet-sieved with mesh width ranging from 250 µm to 2 mm and picked using a binocular loupe. 12 samples with nannofossils from the sections of Corcelles-2 (Corcelles Marls) and Mont de Chamblon (Uttins Marls) were prepared on glass slides (Figs. 12, 13) according to the improved method described by De Kaenel and Villa (1996), but only the two most interesting were studied using a Leica DM2500P light microscope. Photographs and micrographs of the paleontological material were obtained using natural light, optical microscopy with artificial light (cross-polarized/XP light and phase-contrast light for nannofossils using an Olympus DP71 digital camera) or scanning electron microscopy (SEM). Light micrographs (LM) are included in Fig. 13. The reference material for the nannofossils is archived in the collection of E. De Kaenel, reference samples of sediments as well as the macrofossils and microfossils illustrated from the collection P.-O. Mojon (Figs. 15, 16) will be archived in the collection of the Musée géologique de Lausanne (abbr. MGL, UNIL-Dorigny, Lausanne).

4 Results

The Urgonien Jaune (UJ) facies are represented by bioclastic/oolitic limestones and some marly intervals with sediments mainly yellowish to brownish, but some limestone beds can be whitish or greenish by glauconite enrichment, and small scale cross-bedding (cross-stratification formed by current ripples) is very frequent. Sections in the Neuchâtel area are very important for this study and several of them are known since the middle 19th century, at Le Mail where Desor (1858, cf. Schaer, 2006, p. 23) found in 1855 spines of sea urchin *Goniopygus* (*G. peltatus* L. Agassiz, 1838) in yellowish marls between the "Middle Neocomian" (= Early Hauterivian "Pierre jaune de Neuchâtel") and the "Urgonian" (= Late Barremian Urgonien Blanc facies), and at Bôle with "calcaires intermédiaires de Bôle" or "couches de Bôle" (de Tribolet, 1856, 1857) and echinids reported in *Paléontologie française* (Cotteau 1862–1867, p. 107–108). At Serrières, the Serrières-Brunette section described by Remane et al., (1989b, p. 44–45, fig. 13) and the Serrières-Papeterie section (Papeterie Way) are still visible behind a wire fence. The interesting section of Corcelles-1 was studied and sampled between 2008 and 2011 within a temporary excavated construction site for grouped houses, and the small outcrop of Corcelles-2 within the Chantemerle forest was observed and analyzed in December 2020 along a pathway excavation. Three other sections are also considered and listed below, but not reported minutely in this study because completely covered by vegetation (Rochefort, Cornaux) or not providing fundamentally new data (Boudry).

4.1 Lithostratigraphy and lithostratigraphic nomenclature with report of sequential and paleontological data

The correlations and subdivisions of the Urgonian facies in the Jura Mountains imply new names for the lithostratigraphic nomenclature and terminology (Figs. 3, 10, 11), with logs and descriptions of significant features according to guidelines for stratigraphic nomenclature (Remane et al., 2005).

NB: In this study, the term of facies "Pierre Jaune de Neuchâtel" (PJN) is often mentioned with the Neuchâtel Member named and defined by Strasser et al. (2018) such as the corresponding lithostratigraphic unit, which is paradoxically incomplete in the Neuchâtel area where the Uttins Marls are not recognized clearly between lower and upper PJN limestones. So, the Uttins Marls constitute an exception developed locally (Grand-Essert, Mont de Chamblon), but the reference in Neuchâtel is maintained for practical and historical reasons.

The problematic data of Pictet (2021) are another matter, therefore they are not considered nor reported in this study. Ostracods already required an erratum (Pictet, 2022), but the reference sections show also important differences of thickness compared to the values of previous authors as well as more numerous 3rd order discontinuities than in the Barremian

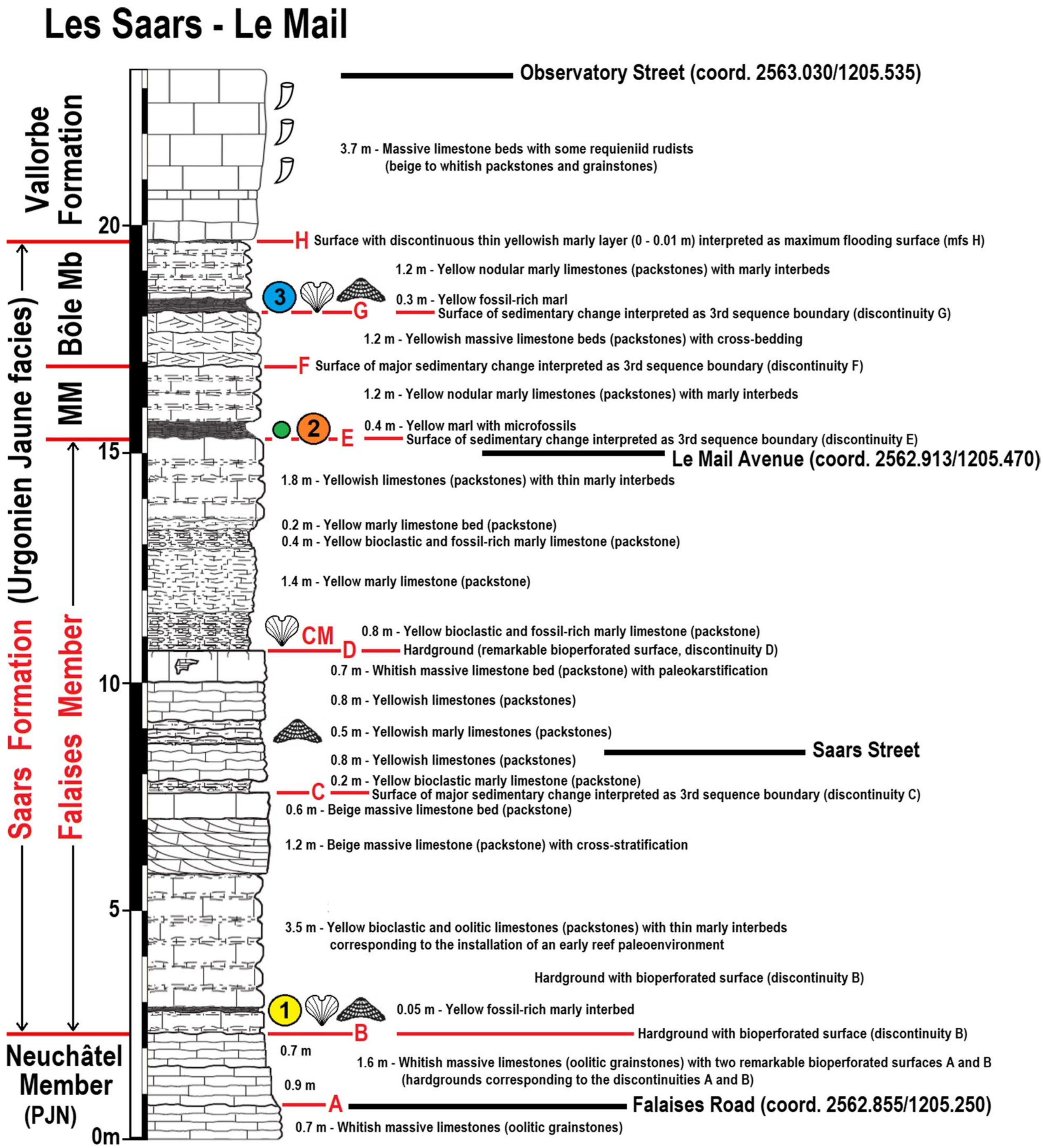

Fig. 3 Type section of the Saars Formation (Urgonien Jaune facies) in the central Jura Mountains (Les Saars-Le Mail section, Neuchâtel City), see Figs. 4, 5, 6, 7, 10, 11. Abbreviations: PJN: Pierre Jaune de Neuchâtel (facies); MM: Montcherand Member; Bôle Mb: Bôle Member

stratotype, without any explanation provided. So, Pictet (2021) indicates 91 m for his "RDH Formation" of the Rocher des Hirondelles-La Rivière section (*versus* 140 m in Conrad, 1969), 54 m for the "GdO Formation" of the Gorges de l'Orbe section (*versus* 75 m in Conrad and Masse, 1989), and 103 m for his "GdO Formation" and "Vallorbe Member" of the Vallorbe section (*versus* 95 m in Conrad and Masse, 1989). Furthermore, twelve 3rd discontinuities are reported by Pictet (2021, fig. 25) for the PJN/Urgonien facies of the Jura Mountains and only ten by Arnaud (2005, cf. Fig. 11) in the Barremian stratotype of Angles very well calibrated by ammonite zones.

A last remark concerns the report of the paleontological data in order to simplify the text, the names of the genera for the taxa of ostracods or other fossils are often abbreviated and the names of the authors indicated mainly in key sub-chapters (Calcareous nannofossils, Ostracods, Brachiopods) and paragraphs of the lithostratigraphy and lithostratigraphic nomenclature.

4.1.1 Saars Formation (new)

Prior to the new results of this study, it was commonly accepted that the Urgonien Jaune facies (cf. Remane et al., 1989a) of the Jura Mountains matched the Gorges de l'Orbe Formation (Strasser et al., 2016) with the Montcherand and Bôle members (Pictet, 2021). The Gorges de l'Orbe reference section in the central Jura Mountains was first described by Conrad and Masse (1989, fig. 1, p. 308, 310–311) and studied again by Blanc-Alétru (1995, figs. 67, 68, p. 157–161) and Pictet (2021). Remarkable outcrops with thick fossiliferous deposits of yellowish limestones and marls are developed along 1.3 km in the cliffs of the Gorges de l'Orbe pathway from the footbridge of the Montcherand hydroelectric plant and in the Orbe River streambed. But, in the central Jura Mountains, significant sections of the Neuchâtel area (Les Saars-Le Mail, Corcelles-1–2, Fig. 1) highlight the new Falaises Member and imply a redefinition of the incomplete Gorges de l'Orbe Fm into the new Saars Formation (Figs. 10, 11). The Saars Fm is named from the "rue des Saars" or Saars Street (Neuchâtel City), an etymology according to related words of old french from the Middle-Age such as "essarter" and "essartage" (clear up the vegetation).

4.1.2 Falaises Member (new)

Derivation of name: From the "route des Falaises" or Falaises Road (Neuchâtel City) bordering the cliffs of the ancient shore of Lake Neuchâtel.

Type locality: Les Saars-Le Mail section (Figs. 3, 10), base at 2.3 m along the Falaises Road (coord. 2562.855/1205.250, Figs. 4a–d, 5f), top at 15.3 m above the Saars Street (coord. 2562.805/1205.265, Figs. 5d–e, 6e). This type section is quite similar and can be compared with the log of the currently covered Pourtalès Hospital section located 500 m west (Godet, 2006, fig. B.18; Godet et al., 2010, fig. 12).

Thickness: 12.9 m in the reference section of Les Saars-Le Mail, but absent in the Gorges de l'Orbe section where the Falaises Mb is reworked in a condensed layer of the basal Montcherand Mb. The maximum thickness is certainly more important in the Corcelles-1 section and much greater (about 50 m) in the French southern Jura Mountains ("Hauterivien supérieur-Barrémien inférieur" interval assimilated to Urgonien Jaune facies by Viéban, 1983, figs. 52–55; or to "Pierre Jaune de Neuchâtel" facies by Blanc-Alétru, 1995, fig. 75), but the extension and thickness of the Falaises Mb and Saars Fm are not known precisely in this area.

Definition and boundaries: The Falaises Mb typically belongs to the Urgonien Jaune facies with well-developed bioclastic and oolitic limestones (packstones) with cross-bedding and some marly layers more or less developed (e.g., Corcelles Marls of the Neuchâtel area). It starts above Late Hauterivian discontinuities A and B with fossil-rich deposits of early reef paleoenvironment, includes 3rd order discontinuities C and D (hardgrounds with bioperforated surfaces) coresponding respectively to latest Hauterivian SbH7 and earliest Barremian SbB1, and ends with the next 3rd discontinuity E or Early Barremian SbB1' at the base of the Montcherand Mb (Figs. 3, 10, 11).

Geographic distribution and lateral equivalents: The Falaises Mb is irregularly developed in the Swiss and French Jura Mountains. In the central Jura (Neuchâtel area), the Falaises Mb deposits precede the installation of reefs with stromatoporoids (Le Mail, Serrières-Brunette), corals and rudists *Pachytraga* (Ponts-de-Martel) bordering a deeper sea strait between Tethyan Ocean and Paris Basin at the location of the Morteau Valley (Doubs department, France). This connection through the Jura-Burgundy threshold is particularly obvious during the Aptian-Albian (Pictet et al., 2019). At 50 km southwest, the sedimentation within the paleotectonized area of the Vaud Jura was disrupted by the Pontarlier fault presumably active in the Early Cretaceous (Mormont-La Sarraz fault system, cf. De Kaenel et al., 2020) and the Falaises Mb is incomplete (Eclépens, La Sarraz-Les Buis) or only residual after sedimentary reworking and condensation (Gorges de l'Orbe, Vallorbe). In the French southern Jura, the Falaises Mb seems to be very developed, but its thickness is not known exactly because of discontinuous or incomplete sections (e.g., La Chambotte, Sillens and Rocher des Hirondelles; Viéban, 1983; Blanc-Alétru, 1995; Arnaud et al., 1998).

Biostratigraphic data and age: Reliable biostratigraphic data and age are based on Early Barremian nannofloras from Eclépens (De Kaenel et al., 2020) and Corcelles Marls at Corcelles-2 (this study), complemented by the Hauterivian-Early Barremian ostracod Assemblage 1 including the Early Hauterivian ostracod microfauna from the Swiss Jura Mountains described by Oertli (1989). The Falaises Mb has also provided fossils of mainly Hauterivian affinities (micro- or macrofossils of shallow carbonate platform and mostly considered

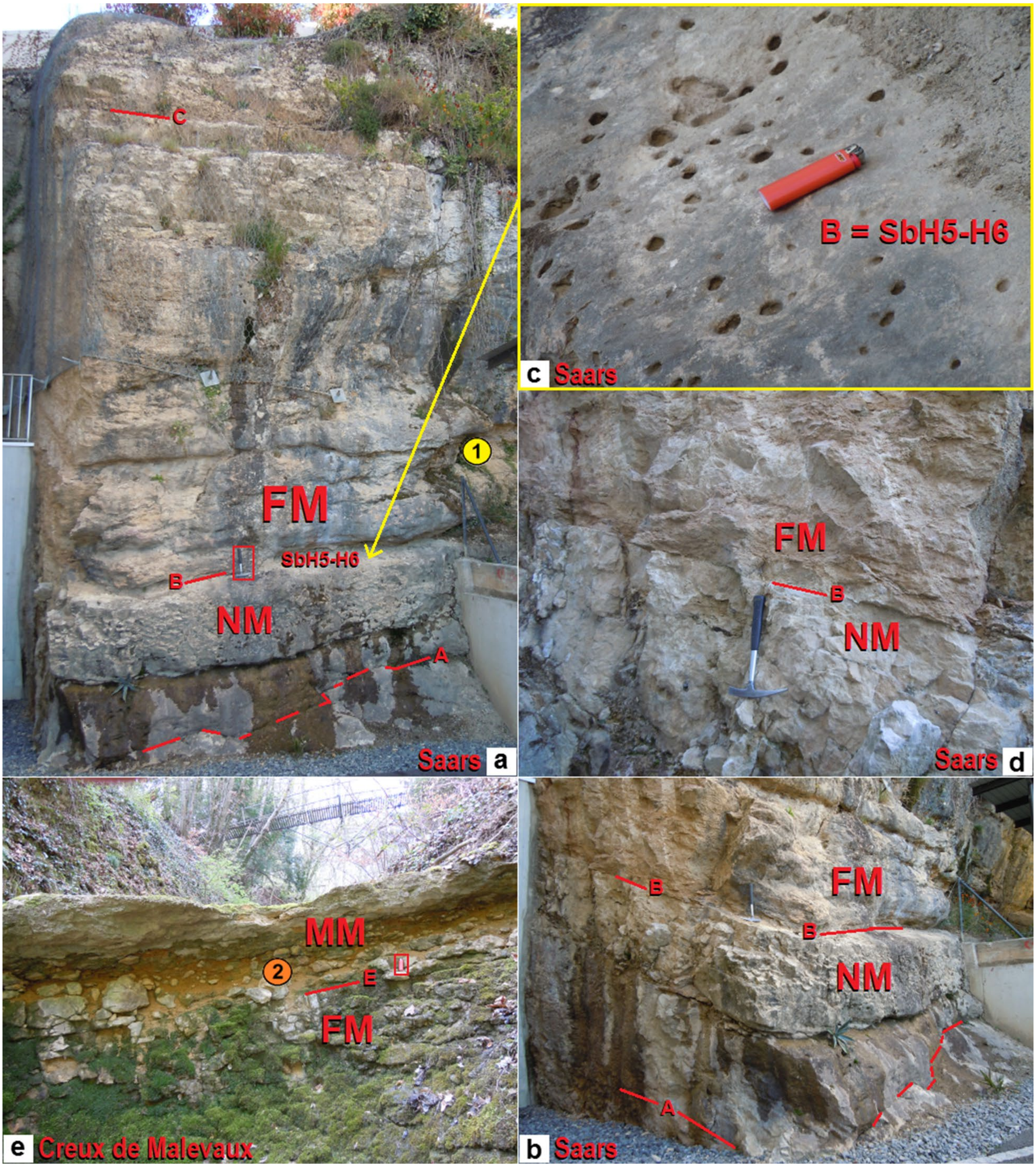

Fig. 4 Saars Formation of the Neuchâtel area (central Jura Mountains). **a**–**d** Les Saars-Le Mail section with well visible lower Falaises Member boundary (**a**, **b**, **d**) and deeply bioperforated Late Hauterivian discontinuity surface B (**c**). **e** Creux de Malevaux section with Early Barremian conglomeratic and marly deposit. Captions: NM: Neuchâtel Member; FM: Falaises Member; MM: Montcherand Member. For the reported discontinuities (A, B, C, E) and ostracod assemblages (colored circles 1, 2), see Figs. 10 and 11. The hammer (**a**: red frame; **b**, **d**) and the orange lighter (**c**; **e**: red frame) are respectively 31.5 cm and 8 cm long

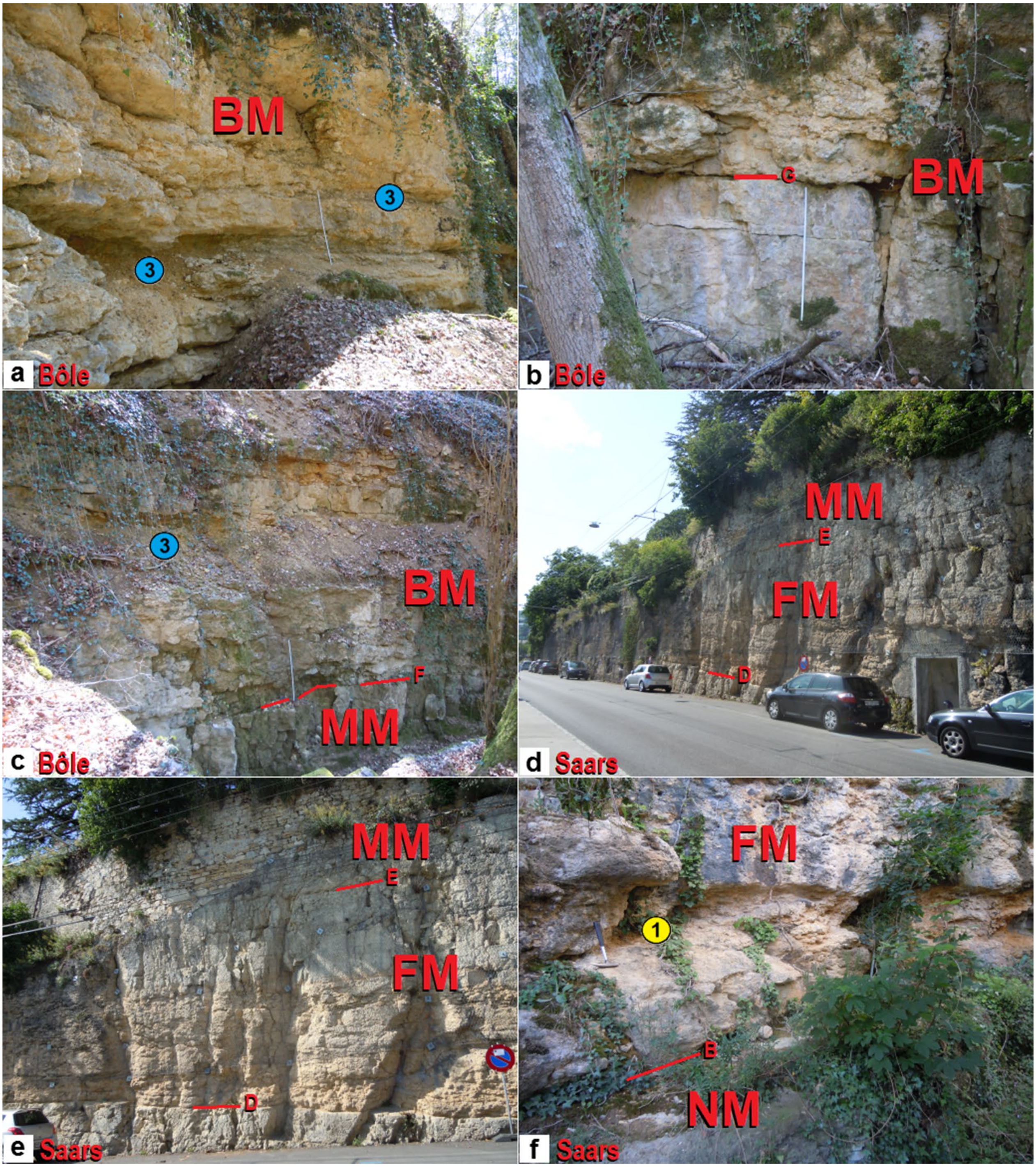

Fig. 5 Saars Formation of the Neuchâtel area (central Jura Mountains). **a**–**c** Bôle section. **d**–**f** Les Saars-Le Mail section (**f**: ancient shore of Lake Neuchâtel). Captions: NM: Neuchâtel Member; FM: Falaises Member; MM: Montcherand Member; BM: Bôle Member. For the reported discontinuities (B, D, E, F, G) and ostracod assemblages (colored circles 1, 2, 3), see Figs. 10 and 11. Detailed scales are indicated by white foldable ruler of 1 m (**a**–**c**) and hammer (**f**) of 31.5 cm long

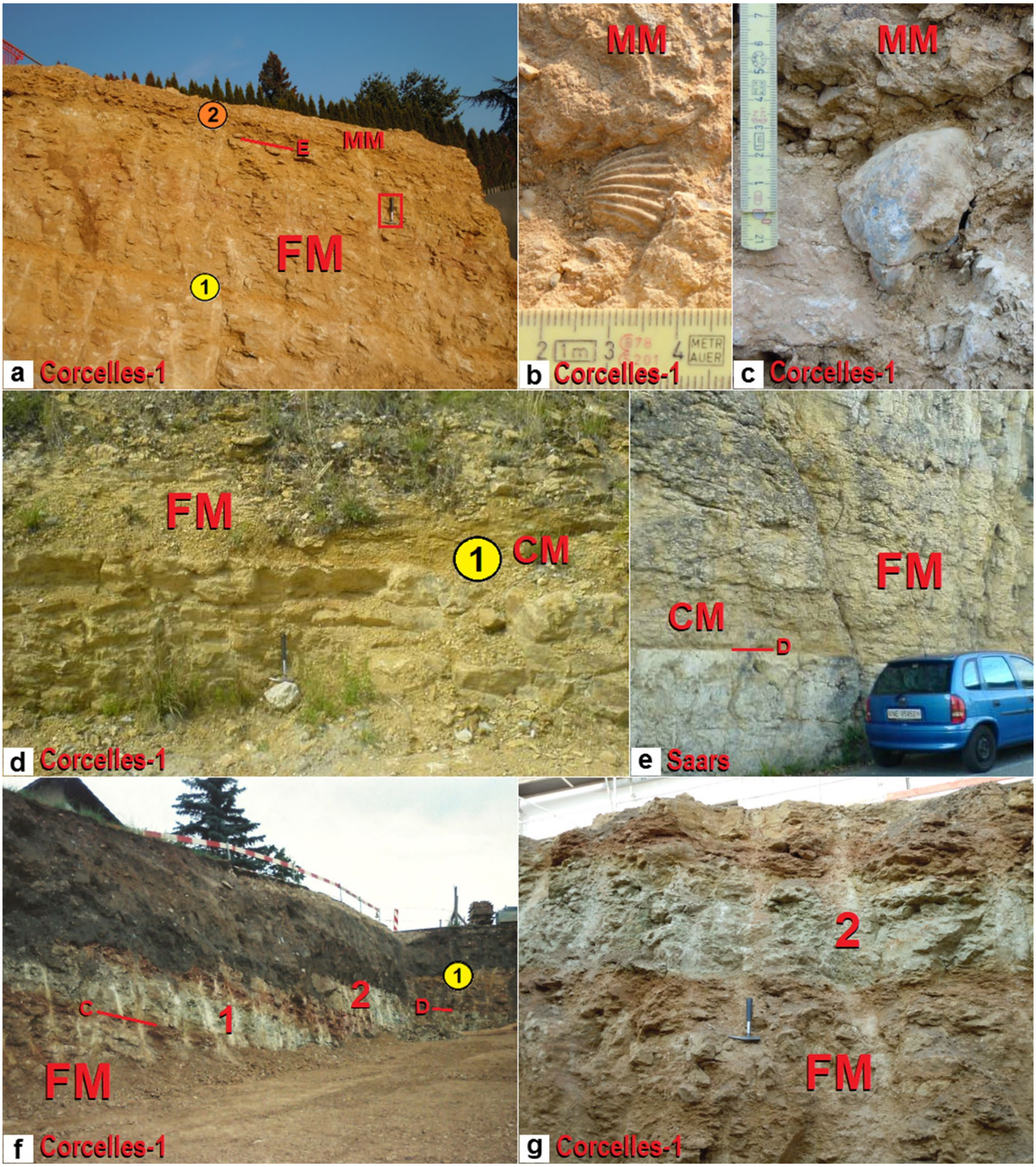

Fig. 6 Saars Formation of the Neuchâtel area (central Jura Mountains). **a**–**d**, **f**, **g** Corcelles-1 section: **a**–**c** Upper part with (**b**) holotype of *Glosseudesia inexpectata* Mojon, n. sp. and (**c**) ostreid bivalve *Exogyra (Aetostreon) latissima* (Lamarck, 1801) *in situ*; **d**, **f**, **g** Lower part with glauconite-rich beds 1 and 2. **e** Les Saars-Le Mail section. Captions: FM: Falaises Member; CM: Corcelles Marls (lithostratigraphic bed); MM: Montcherand Member. For the reported discontinuities (C, D, E) and ostracod assemblages (colored circles 1, 2), see Figs. 10 and 11. The hammer (**a**: red frame; **d**, **g**) is 31.5 cm long

typical of the Early Hauterivian, Figs. 15.19–22, 16.1–4) such as echinids [*Pseudholaster intermedius* (Münster *in* Goldfuss, 1826); cf. Kroh, 2010; Saucède et al., 2012], brachiopods [*Glosseudesia semistriata* (Defrance, 1828), *Plicarostrum aubersonense* Burri, 1956; *Lamellaerynchia hauteriviensis* Burri, 1953; *Sulcirynchia renauxiana* (d'Orbigny, 1847)], ostreid bivalves *Rastellum (Arctostrea) rectangulare* (Roemer, 1839) and benthic foraminifers. In the Neuchâtel area, six sections listed below have provided paleontological data from the Falaises Mb:

1. Le Mail-Les Saars section with a basal part characterized by a fossil-rich marly layer (Figs. 3, 4a, 5f) with very fine and coarse grains of detrital quartz, ostracods of the Assemblage 1 [*Protocythere triplicata* (Roemer, 1841), *Rehacythereis bernardi* (Grosdidier, 1964), *Hechticythere pumila* (Grosdidier, 1964), *Schuleridea clunicularis* (Triebel, 1938), *Cytherella* gr. *parallela* (Reuss, 1846), *Neonesidea* sp., *Bairdoppilata* aff. *barremiana**, *Neocythere (Centrocythere)* aff. *gottisi**, *Cytherelloidea* sp. 1* (Scarenzi-Carboni, 1984), *see 4.3.1], benthic foraminifers (abundant orbitolinids *Praedictyorbitolina claveli* Schroeder, 1994; large lituolids, *Reophax* and *Acruliammina* spp., *Nautiloculina cretacea* Peybernès, 1976; *Choffatella decipiens* Schlumberger, 1905; Involutinidae with *Trocholina* and *Neotrocholina* spp., nodosariids with *Lenticulina* and *Citharina* spp., some miliolids; cf. Bartenstein, 1989; Arnaud-Vanneau and Masse, 1989), stromatoporoids, various spines of sea urchin, ossicles of brittle stars (Ophiuroidea), starfishes (Asteroidea) and crinoids, sclerites of Alcyonarian corals (Octocorallia), gastropods, bryozoans, small juvenile terebratulids *Loriolithyris* sp. and rynchonellids *L. hauteriviensis*. Along the Saars Street (Figs. 3, 5d–e, 6e), orbitolinids *P. claveli* are also present higher in the section with sclerites of Octocorallia, spines of sea urchins *Goniopygus*, large *N. cretacea*, *C. decipiens*, *Neotrocholina* sp. and some ostracods (*P. triplicata*, *Bairdoppilata* sp., *Schuleridea* sp.), and a paleokarst infilling (quartz-rich yellowish grainstone) in the massive whitish limestone just below the discontinuity D has provided micritized orbitolinids indet. and one specimen of large ostracod *Strigosocythere chalilovi* (Kuznetsova, 1961) indicating at least a much younger Late Barremian-Early Aptian age for this peculiar sediment. Above the discontinuity D, rynchonellids *P. aubersonense*, *L. hauteriviensis* and *S. renauxiana* were collected with A. Pictet in 2014 within the thick bed of marly limestone equivalent to the Corcelles Marls of the sections Corcelles-1 and Corcelles-2.

2. Serrières-Papeterie section (Papeterie Way): rare *P. triplicata* from conglomeratic marls of the basal Falaises Mb.

3. Corcelles-1 section (Fig. 6a–d, f, g): Corcelles Marls with *P. intermedius*, *P. aubersonense*, *L. hauteriviensis*, *P. triplicata*, and brittle stars just above the discontinuity D (one small fragmented specimen nearly complete in a marl sample collected within the construction site in 2010).

4. Corcelles-2 section (isolated outcrop, Fig. 7b): Corcelles Marls with *G. semistriata*, *R. (A.) rectangulare*, *P. triplicata*, *R. bernardi*, *S.* gr. *thoerenensis*, *Cytherelloidea* sp., nannofossils.

The lithostratigraphic bed of Corcelles Marls is well developed at Corcelles-1 (Fig. 6d) above glauconite-rich green limestones (Fig. 6f, g), Saars Street (Fig. 6e) and Corcelles-2 (Fig. 7b). Just above the glauconite-rich beds of Corcelles-1, thin marl layers and limestone interbeds are also characterized by abundant rynchonellids (*L. hauteriviensis*, *P. aubersonense*) and brittle stars (Ophiuroidea) aforementioned, and therefore have also certainly provided the remarkable starfishes (Asteroidea) from yellow limestones of the "Middle Neocomian" or "Lower Urgonian" in the Neuchâtel area (Coulon, 1872; de Loriol, 1874) at Neuchâtel City and at Vaumarcus (Gorges du ruisseau de la Vaux) near La Lance section (Fig. 1C, n° 13).

Not far away from Corcelles-1, the Falaises Member was also visible during the years 1970–1990 in small sections (not reported on Fig. 1C) at 4.5 km WSW along the entrance roadside at Rochefort (coord. 2552.255/1203.225) and 13.5 km NE in a quarry at Cornaux (coord. 2567.990/1210.150).

5. Rochefort section: Corcelles Marls with *G. semistriata*, *P. aubersonense*, *L. hauteriviensis* (collected by P.-O Mojon in 1975 and with A. Pictet in 2019).

6. Cornaux section: Marly layers with *P. intermedius* (abundant specimens more or less crushed) and brittle stars (two small specimens on a limestone bed surface harvested in 1981 by Ch.-Ph. Huguenin, a fossil collector from Neuchâtel), which correspond to the Corcelles Marls and the informal inexplicit term of "Marnes de Cornaux" (Pictet, 2021, fig. 2).

In the southern Jura Mountains (Savoie and Ain departments), the sections of La Chambotte (Savoie) and Sillens (southern Ain) about 40 km south of Bellegarde-sur-Valserine (outside of Fig. 1C) has provided quite similar fossils and microfossils in thick deposits (40–50 m) of the Late Hauterivian-Early Barremian transition (Viéban, 1983, figs. 73, 87), but the base and total thickness of these strata equivalent to the Falaises Mb of the central Jura are not defined precisely.

4.1.3 Montcherand Member (Pictet, 2021)

Derivation of name: From the village of Montcherand beside the natural site of the Gorges de l'Orbe (Canton Vaud, VD).

Type locality: Gorges de l'Orbe section described by Conrad and Masse (1989, fig. 1), base at 8 m (base of "Marnes d'Uttins"/layer 2) downstream from a footbridge crossing the Orbe River ("passerelle sur l'Orbe", coord. 2527.840/1175.680), top at 63 m (top of "Calcaires gris/jaunes variés, oolithiques et bioclastiques"/layer 7 *pro parte*).

Thickness: maximum 55 m thickness in the Gorges de l'Orbe reference section reported on Fig. 10, and minimum of only 1.6 m in the Neuchâtel area (Les Saars-Le Mail section, Figs. 3, 10).

Definition and boundaries: In the GdO section, the marly glauconite-rich base (mostly reworked glauconite grains) of the Montcherand Mb is located above the Early Hauterivian "Pierre Jaune de Neuchâtel" (PJN) facies of the upper Neuchâtel Member and merged discontinuities A-E in the hard-to-reach streambed of the Orbe River (coord. 2528.420/1175.505) and was previously considered by Conrad and Masse (1989) as Early Hauterivian Uttins Marls based on very incomplete micropaleontological data with Hauterivian ostracod species *S. clunicularis* (det. H.-J. Oertli), probably reworked according to the data from the Falaises Mb. However, the marls of the mainly oolitic Montcherand Mb well visible in the Orbe River streambed (Fig. 8f) are characterized by Barremian ostracods of the Assemblage 2 [*Strigosocythere strigosa* (Grosdidier, 1964), *P. triplicata*, and mostly juvenile specimens of *R. geometrica*, *B. barremiana*, *B. luminosa*, *N. (C.) gottisi*, *S. derooi*, *Asciocythere* sp]. Above the coastal oolitic facies (tidal bars) of the Early Hauterivian PJN facies (upper Neuchâtel Mb), the marly condensed glauconite-rich base of the Montcherand Mb contains also bryozoans and spines of regular sea-urchins, but is devoid of orbitolinids and typical Barremian benthic foraminifers, as well as stromatoporoids or sclerites of Octocorallia. These representative fossils of the Urgonian facies occur progressively later in the Saars Fm with the installation of estuarine (Montcherand Mb) then recifal conditions (Bôle Mb). Cross-bedding is frequent and indicates deposits in shallow paleoenvironments dominated by tidal currents with transportation of floating nautilid shells [*Cymatoceras pseudoelegans* (d'Orbigny, 1840)]. The top of the Montcherand Mb is represented by the discontinuity F below the lower bioclastic and fossiliferous marls of the Bôle Mb on the right side of the Orbe river streambed (coord. 2528.790/1175.510, Fig. 8e), with ostracods of the Assemblage 3 and the late Early Barremian ammonite *Pseudometahoplites* sp. juv. reported by De Kaenel et al. (2020). Above and notably along the pathway 45 m higher (Fig. 8d, coord. 2528.580/1175.400), the fossil-rich Bôle Member with stromatoporoids and orbitolinids *Praedictyorbitolina* spp. points out recifal conditions and transition marls with the thick marine limestones of the lagoonal Urgonien Blanc facies (Vallorbe Formation).

The Montcherand Mb includes the "Marne(s) de la Russille" or "Russille Marl(s)" defined by Jaccard (1869) in the lower part of La Russille section (located 500 m south from La Russille hamlet) with the brachiopod *Glosseudesia ebrodunensis* (de Loriol, 1864). In his original definition, Jaccard mentioned in the first place and in singular the "Marne de la Russille" (as a lithostratigraphic bed *sensu stricto*), then he used ambiguously the plural form to designate several marly layers omitting to precise if it was for all the marly intercalations of La Russille section. Our samplings of fossils in the Jura Mountains confirmed that *G. ebrodunensis* (Fig.16.10–13) is restricted to the Montcherand Mb at La Russille and Eclépens (cf. De Kaenel et al., 2020) and is presumably extinct above in the upper marls and limestones of the Bôle Mb at La Russille (Fig. 8c) and everywhere else in the Jura Mountains. Moreover, according to the *Glosseudesia* phyletic lineage (cf. 4.4. Brachiopods), an ancestral species *G. inexpectata* Mojon, n. sp. from Corcelles-1 (Fig. 16.5–9) predates *G. ebrodunensis* and can be reported to prior strata of the lowermost Montcherand Mb. So, the term of "Marnes de la Russille" ("Russille Marls") is therefore a great source of confusion broadly diffused in the literature, because extended *sensu lato* to the Urgonien Jaune marls of the Jura Mountains (Remane, 1989; Remane et al., 1989a; Blanc-Alétru, 1995; Godet et al., 2010). De Kaenel et al. (2020) introduced the terminology "Marnes de la Russille complex" (or "Russille Marls complex") in an attempt to correct this old problem of definition. The new paleontological data as well as the sedimentology imply to subdivide the "Russille Marls complex" into distinct and separate units: the Montcherand Member with *G. inexpectata*, *G. ebrodunensis* and Assemblage 2 of ostracods, and the Bôle Mb with ostracod Assemblages 3 and basal 4. More precisely, a set of four main successive marly layers I-IV of informal "Russille Marls" can be defined within the "Russille Marls complex" (Fig. 10), with secondary much thinner marl levels also present locally in connection with "Russille Marls" I and III within the Montcherand Mb (I', I", I'") and Bôle Mb (III'). The "Russille Marls" are absolutely not restricted to the basal Bôle Mb as indicated by the "Russille Bed" of Pictet (2021, p. 12–15, figs. 5, 8–9), but extend from the basal Montcherand Mb (layer I with *G. ebrodunensis* of the

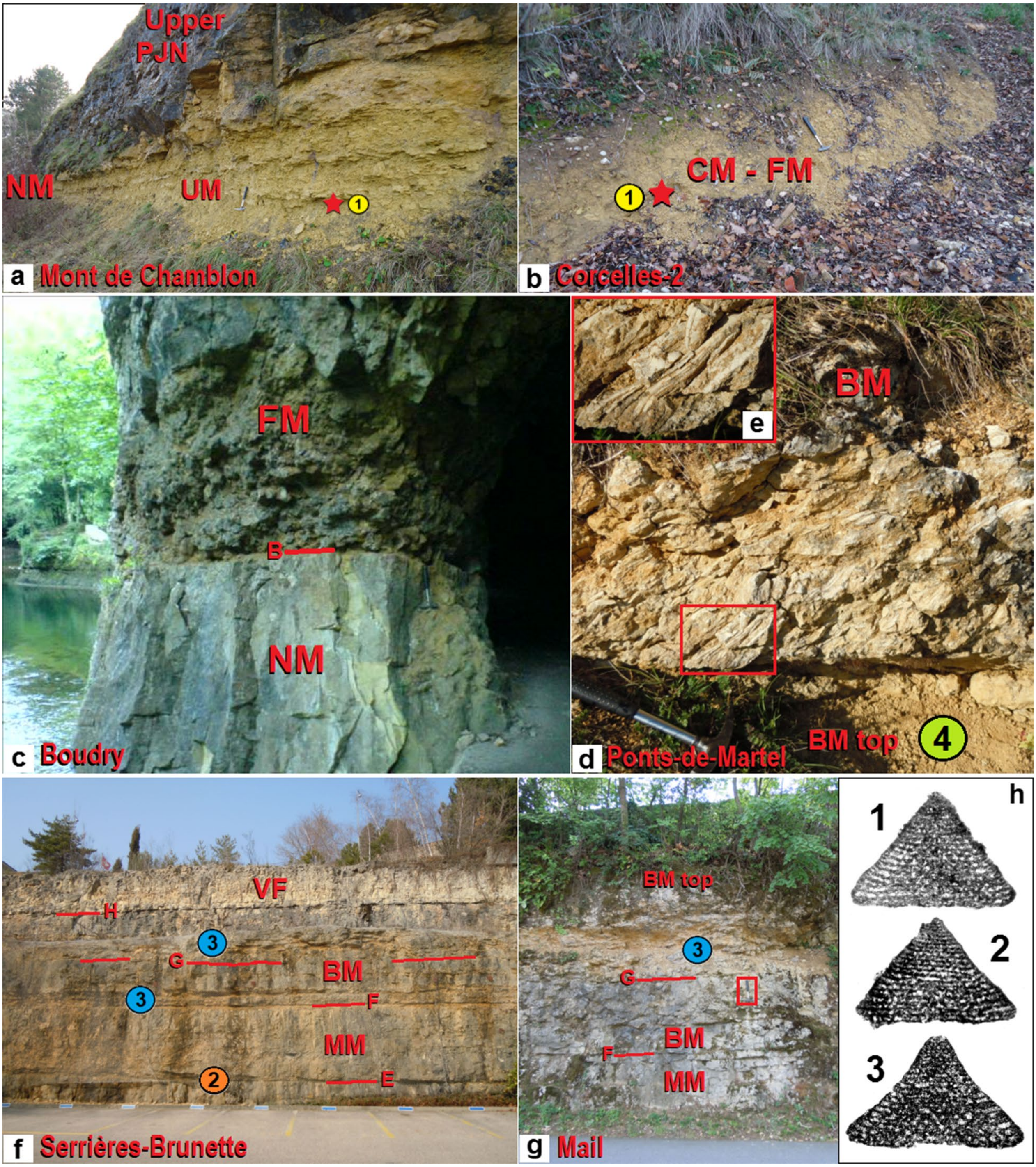

Fig. 7 Sections in the central Jura Mountains (**a**: Grand-Essert Formation of the Vaud Jura; **b–g**: Saars Formation of the Neuchâtel Jura). **a** Mont de Chamblon section with late Early Hauterivian Uttins Marls. **b** Corcelles-2 section with Early Barremian Corcelles Marls. **c** Lower Boudry section, latest Hauterivian topmost massive PJN facies (NM) and basal Urgonien Jaune facies (FM) with marly conglomerate (cf. Godet et al., 2010, fig. 10). **d**, **e** Ponts-de-Martel section, reversed strata of overturned fold with *Pachytraga* reef (**e**: rudists *Pachytraga tubiconcha* Astre, 1961) and marls with ostracods (below). **f** Serrières-Brunette section with large stromatoporoid reef (cf. Remane et al., 1989b). **g**, **h** Upper Les Saars-Le Mail section, historical fossil-rich site of Le Mail (Desor, 1858; Schaer, 2006) with orbitolinids (**h**: axial sections 1–3 of *Praedictyorbitolina claveli* Schroeder, 1994) and various macrofossils [*Goniopygus peltatus* L. Agassiz, 1838; *Belbekella lata* (d'Orbigny, 1847), stromatoporoids, corals]. Captions: NM: Neuchâtel Member; PJN: Pierre Jaune de Neuchâtel (facies); UM: Uttins Marls (lithostratigraphic bed); FM: Falaises Member; CM: Corcelles Marls (lithostratigraphic bed); MM: Montcherand Member; BM: Bôle Member; VF: Vallorbe Formation; red stars: samples with nannofloras. For the reported discontinuities (B, E, F, G, H) and ostracod assemblages (colored circles 1, 2, 3, 4), see Figs. 10 and 11. The hammer (**a**–**d**; **g**: red frame) is 31.5 cm long

"Russille Marl" *sensu stricto* according to Jaccard, 1869) to the entire Bôle Mb (layers II, III and IV).

Geographic distribution and lateral equivalents: The Montcherand Mb is developed in the Swiss and French Jura Mountains. Strong lateral facies changes can be observed in the French southern Jura (Rocher des Hirondelles and Pont-des-Pierres sections) and locally in the Swiss central Jura (Vaulion section) with nodular marly-limestone facies of outer platform containing glauconite and muddy facies fossils like irregular sea urchins *Toxaster retusus* (Lamarck, 1816) of Hauterivian affinity and bivalves *Panopea* sp. These atypical Urgonien Jaune facies of the Saars Fm (including the Falaises Mb in addition to the Montcherand Mb) correspond to the "Zone de transition inférieure" defined by Conrad (1969, p. 6–7) between the limestones of the Hauterivian Neuchâtel Mb (Grand-Essert Fm; Strasser et al., 2018) and the Urgonien Blanc facies of the Fort de l'Ecluse Mb (Rocher des Hirondelles Fm; Pictet, 2021).

Above the 3rd order discontinuity E recognized by Viéban (1983, p. 221) and interpreted in this study as Early Barremian sequence boundary B1' (SbB1', Figs. 10, 11), the basal Rocher des Hirondelles section along the Valserine River (path on the left river bank) or before the tunnel entry of the D991 Road shows deeply bioturbated/brecciated marly limestones and dark marls with nodular/pseudoconglomeratic aspect of about 6 m thickness (Fig. 9e, f) having provided rare ostracods of the Early Barremian Assemblage 2 [juveniles of *R. geometrica*, *P. triplicata*, *Dolocytheridea*, *Neocythere (Centrocythere)*, *Paracypris* and *Asciocythere* spp.]. At the Pont-des-Pierres (below the bridge over the canyon of the Valserine River), the top of this series presents a ferruginous paleosol with molds of rootlets and siliciclastic dark marls (Fig. 9d) with microfossils such as mostly juvenile ostracods of the Assemblage 2 [*S. strigosa*, *P. triplicata*, *N. (C.) gottisi*, *R. geometrica*, *B. barremiana*, *S. derooi*, *T. consuetus*, *Asciocythere* sp.], benthic foraminifers (orbitolinids *Eopalorbitolina*? and *Paracoskinolina* spp., large *Reophax* and lituolids spp., *Spirillina* sp., nodosariids), small gastropods, spines of regular sea-urchins and sclerites of Octocorallia. These sediments with marly and pseudoconglomeratic facies interpreted as mangrove deposits are equivalent to the Montcherand Mb. In the central Jura, the lower Urgonien Jaune facies of the Vaulion section contain similar marly deposits (including Falaises Mb) not dated precisely (Conrad and Masse, 1989, fig. 2, p. 312–313: layers 8–9, 20 m thick).

Biostratigraphic data and age: Reliable biostratigraphic data are based on Early Barremian nannoflora (De Kaenel et al., 2020), ostracod Assemblage 2 and brachiopod species *Glosseudesia inexpectata* and *ebrodunensis* (this study), these data and their correlations are presented in Figs. 10 and 11. In main sections of the Neuchâtel area such as Corcelles-1–2 (Figs. 6a–c, 7b), Les Saars-Le Mail and Serrières-Brunette (Fig. 7f), the basal Montcherand Mb can be characterized by mostly reworked glauconite (notably at Corcelles-1), *Glosseudesia inexpectata* Mojon, n. sp., ostreid bivalves *Exogyra (Aetostreon) latissima* (Lamarck, 1801) [=*Exogyra sinuata* (Sowerby, 1822)] and poor ostracod Assemblage 2 (*P. triplicata*, dwarf *R.* cf. *geometrica*, *B. barremiana*), sclerites of Alcyonarian corals, spines of sea urchin *Goniopygus* and benthic foraminifera *N. friburgensis*. At Creux de Malevaux (Cormondrèche), a small section 5 m thick in a streambed (coord. 2556.490/1203.350 to 2556.370/1203.440, Fig. 4e) has also provided ostracods of the Assemblage 2 (dwarf *R. geometrica* and *B. barremiana*, *P. triplicata*, *S. strigosa*, *N. (C.)* cf. *gottisi*, *N. (C.) djaffarovi*, *S. derooi*, *D. longa*, *D. intermedia*, *H. hechti*), benthic foraminifers (large lituolids, *Reophax* and *Acruliammina* spp., *N. cretacea*, rare *C. decipiens* and *Neotrocholina* sp., *Lenticulina* sp.), stromatoporoids, ossicles of brittle stars (Ophiuroidea) and starfishes (Asteroidea), crinoids, sclerites of Octocorallia, spines of *Goniopygus* and other echinids, bryozoans. Compared to the ostracod Assemblage 1, the Assemblage 2 indicates a significant change in the ostracod microfauna and a biological event everywhere in the Jura Mountains by emergence of mostly immature marker species with never abundant small juveniles (but frequent and typical large adult specimens characterize the next Assemblage 3), and some quite common species such as *S. strigosa* and *P. triplicata* notably in the lower Gorges de l'Orbe section (Fig. 8f) and below the Rocher des Hirondelles Fm in the southern Jura (Pont-des-Pierres section, Fig. 9d).

4.1.4 Bôle Member (Pictet, 2021)

Derivation of name: From the village of Bôle (Canton Neuchâtel, NE), name referred by Pictet (2021) to the"Couches de Bôle" or "Calcaires intermédiaires de Bôle" (de Tribolet, 1856, 1857).

Type locality: Bôle section within the Merdasson ravine (Fig. 10), base at 1.4 m in the Merdasson streambed (coord. 2554.045/1201.705), top at 14.1 m (coord. 2553.920/1201.885).

Thickness: 14.1 m in the Bôle reference section, maximum 38.5 m in the Eclépens section (Fig. 10), and minimum of only 0.5 m in La Sarraz-Les Buis section (cf. De Kaenel et al., 2020, fig. 3).

Definition and boundaries: The Bôle Mb starts above the 3rd order discontinuity F with a yellowish series of limestones (packstones) interbedded by marly layers and ends with the maximum flooding surface H, before the deposition of the Vallorbe Fm. The Bôle section in the Merdasson ravine is well known since the 19th century

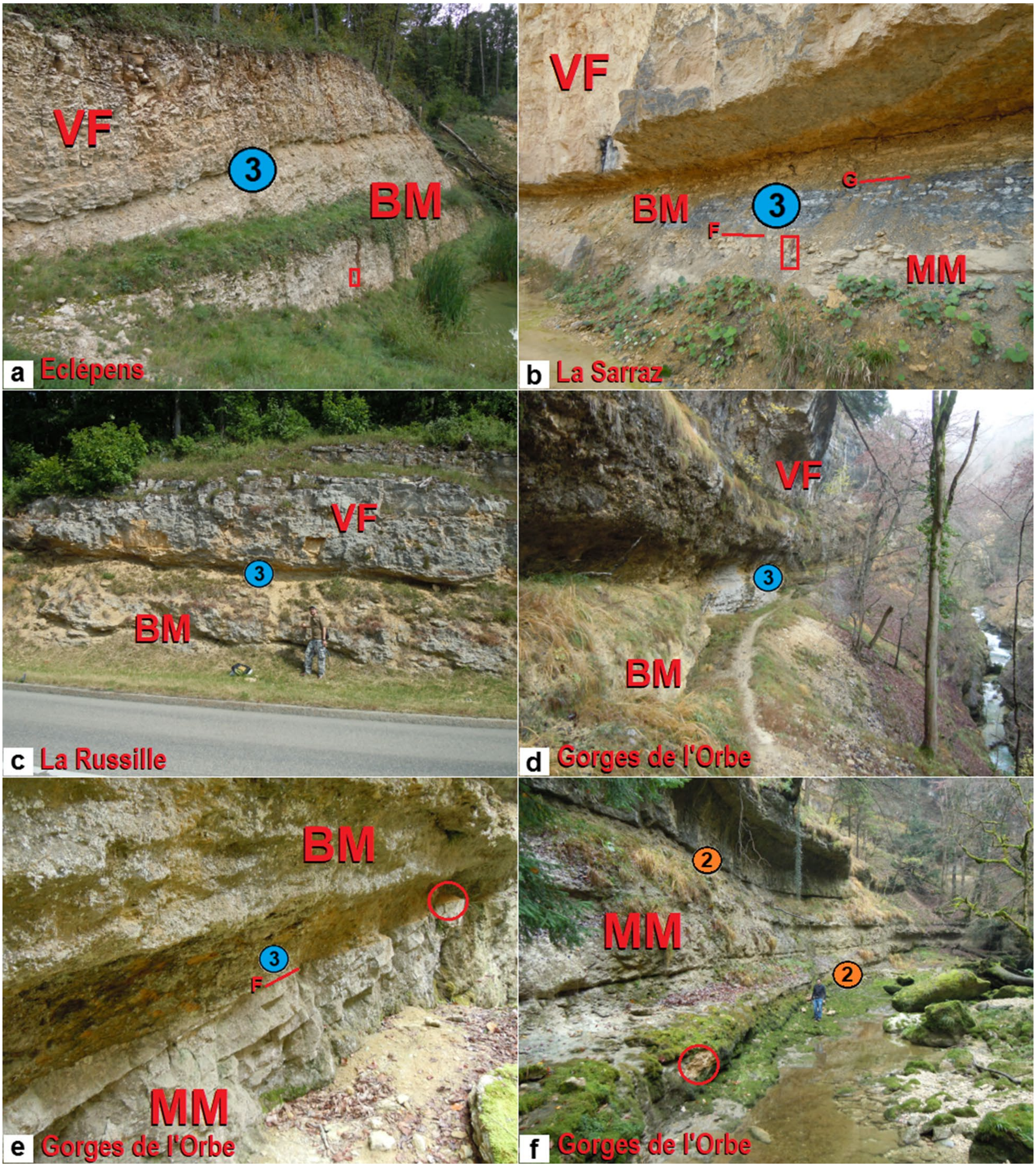

Fig. 8 Saars Formation of the Vaud Jura (central Jura Mountains). **a** Eclépens railway trench section. **b** Upper La Sarraz-Les Buis quarry section (cf. De Kaenel et al., 2020). **c** Upper La Russille section. **d**–**f** Gorges de l'Orbe section, upper part (**d**), middle part (**e**) with ammonite *Pseudometahoplites* sp. (in red circle Ø 31.5 cm; cf. De Kaenel et al., 2020) and lower part (**f**) with nautilid *Cymatoceras pseudoelegans* (d'Orbigny, 1840) located in red circle. Captions: BM: Bôle Member; MM: Montcherand Member; VF: Vallorbe Formation. For the reported discontinuities (F, G) and ostracod assemblages (colored circles 2, 3), see Figs. 10 and 11. The hammer (**a**, **b**: red frame) is 31.5 cm long

for its very fossiliferous yellow marls and limestones, but neither log nor description were ever provided for the "Couches de Bôle" or "Calcaires intermédiaires de Bôle" simply mentioned by de Tribolet (1856, 1857). The aspect of the Bôle Mb can change a lot in some sections, the series of the Eclépens railway trench (Fig. 8a, coord. 2532.060/1168.570, at 1.25 km NE from the Eclépens section) and La Sarraz-Les Buis section (Fig. 8b, at 2 km WNW from the Eclépens section, cf. De Kaenel et al., 2020) are very different according to respectively lagoon or estuarine deposition paleoenvironments.

Geographic distribution and lateral equivalents: The Bôle Mb is developed in the Swiss and French central Jura Mountains. In the French southern Jura, whitish massive limestones of the Fort de l'Ecluse Mb (lower Urgonien Blanc facies) replace the Bôle Mb.

Biostratigraphic data and age: Reliable biostratigraphic data are based on early Late Barremian nannoflora (De Kaenel et al., 2020) and ostracod Assemblage 3 (data and correlations in Figs. 10, 11). The Early to Late Barremian Assemblage 3 is characterized by typical and abundant Barremian ostracod markers with mostly subadult or adult specimens [*Rehacythereis geometrica* (Damotte and Grosdidier, 1963); *Bairdoppilata barremiana* Mojon, n. sp.; *Bairdoppilata luminosa* Kuznetsova, 1961; *Neocythere (Centrocythere) gottisi* Damotte and Grosdidier, 1963; *Schuleridea derooi* Damotte and Grosdidier, 1963; *Dolocytheridea intermedia* Oertli, 1958] collected in the Bôle Mb at Bôle (Fig. 5a, c), Serrières-Brunette (Fig. 7f), Le Mail (Fig. 7g), Boudry (section not reported in this study, coord. 2553.550/1201.135, cf. logs *in* Blanc-Alétru, 1995 and Adatte et al., 2005), Le Vanel, La Sarraz-Les Buis (Fig. 8b), La Russille (Fig. 8c), Gorges de l'Orbe (Fig. 8d), Vallorbe, Vaulion, and in the Eclépens railway trench (Fig. 8a). The Eclépens section has only provided very poor ostracod microfaunas (De Kaenel et al., 2020) of Assemblages 3 and basal 4. Locally at the top of the Bôle Mb (Pont-de-Martel, Eclépens, Vaulion), the next Late Barremian-Early Aptian ostracod Assemblage 4 is characterized by the occurrence of *Strigosocythere chalilovi* (Kuznetsova, 1961). In the French southern Jura, this nice species *S. chalilovi* is associated with *Rehacythereis buechlerae* (Oertli, 1958) in Late Barremian marls (Rivière Mb at Noire Combe, emersive layers on top of the Vallorbe Fm at Montanges and Bellegarde-sur-Valserine, Fig. 9a), and in paleokarst infilling by latest Barremian marls of Poet Beds (Fulie Mb, Perte-du-Rhône Fm) at Musinens (Fig. 9b). However, in the Fulie Mb of the Swiss central Jura Mountains, *S. chalilovi* is commonly associated with typical *R. geometrica* in the marls of the latest Barremian Poet Beds and earliest Aptian Vauglène Beds at La Presta (Sauvagnat, 1999; Pictet et al., 2019).

The Bôle Mb is particularly fossil-rich (notably at Le Mail, Serrières-Brunette, Boudry, Le Vanel, Pont-de-Martel, Montlebon, Gorges de l'Orbe) with stromatoporoids, isolated colonial corals (Hexacorallia), bryozoans, abundant sclerites of Alcyonarian corals (Octocorallia), regular echinids [mainly frequent spines of *Goniopygus*; *Goniopygus peltatus* L. Agassiz, 1838; *Pseudocidaris clunifera* (L. Agassiz 1840); *Cidaris lardyi* Desor, 1855; *Hyposalenia stellulata* (L. Agassiz, 1838); *Pseudodiademma jaccardi* Cotteau, 1863], rynchonellids [*Sulcirynchia gillieroni* (Pictet, 1872), *Sulcirynchia picteti* (Burri, 1956) and *Belbekella lata* (d'Orbigny, 1847); cf. Burri, 1956; Gaspard, 1989; Smirnova, 2012], rare nautilids [*Cymatoceras pseudoelegans* (d'Orbigny, 1840), *Eucymatoceras plicatum* (Fitton, 1836)] and one single very rare ammonite *Pseudometahoplites* sp. juv. (cf. De Kaenel et al., 2020), benthic foraminifera such as orbitolinids *Praedictyorbitolina claveli* Schroeder, 1994 and others (*Choffatella decipiens* Schlumberger, 1905; *Neotrocholina friburgensis* Guillaume and Reichel, 1957; *Cuneolina hensoni* Dalbiez, 1958; *Nautiloculina cretacea* Peybernès, 1976; *Nautiloculina broennimanni* Arnaud-Vanneau and Peybernès, 1978; big *Reophax* sp., various large lituolids, nodosariids, miliolids; cf. Bartenstein, 1989; Arnaud-Vanneau and Masse, 1989). The Bôle Mb has provided other typical irregular echinids such as *Astrolampas productus* (L. Agassiz, 1836) and *Heteraster couloni* (L. Agassiz, 1839) in the sections of Ponts-de-Martel, Montlebon and Gorges de l'Orbe. The Bôle Mb top is also characterized in internal platform sections of the Swiss and French central Jura Mountains by rudist reefs with *Pachytraga tubiconcha* Astre, 1961 (Masse et al., 1989). The Ponts-de-Martel section with early Late Barremian marls (basal Assemblage 4 of marine ostracods) above a reef with *P. tubiconcha* and rare requieniid rudists *Requienia ammonia* (Goldfuss, 1838) is located in a tilted and overturned series of Urgonien Jaune facies (Fig. 7e, d; Pasquier et al., 2013; Eichenberger et al., 2020).

4.1.5 Rocher des Hirondelles Formation (Pictet, 2021, revised)

This formation is well developed in the French southern Jura Mountains (Valserine Valley, defile of Fort de l'Ecluse) with cliffs of massive limestones and marly outcrops (Geological map of France 1:50′000 n° 653, Saint-Julien-en-Genevois, Donzeau et al., 1997), and includes the Fort de l'Ecluse and Rivière members (Pictet, 2021). Discontinuous outcrops at Fort de l'Ecluse (Charollais et al., 2013) are more difficult to follow in the topography, but allow to recognize clearly these two members. The original Rocher des Hirondelles Fm (Pictet, 2021) is revised in this study by excluding its third "Vallorbe

Member" of Pictet (2021), which is clearly a distinctive formation (cf. remarks about the Vallorbe Fm below).

4.1.6 Fort de l'Ecluse Member (Pictet, 2021)

Derivation of name: From the defile of Fort de l'Ecluse.

Associate locality: Rocher des Hirondelles section with massive limestones (Figs. 9c) described as "Calcaires inférieurs urgoniens" by Conrad (1969), base at the entry of the D991 Road tunnel through the Rocher des Hirondelles and top just after the tunnel exit (coord. 2480.800/1123.050 to 2480.940/1122.800), the section is also accessible above the path along the left side of the Valserine River, the total thickness is 99 m (Conrad, 1969; Viéban, 1983; Arnaud et al., 1998). The massive limestones are easily accessible and observable all around the sheer cliff of Rocher des Hirondelles and the Noire Combe escarpments.

Thickness: 101 m in the Rocher des Hirondelles-La Rivière reference section (Fig. 10), 99 m at Rocher des Hirondelles and only 2 m visible at the base of La Rivière section (Conrad, 1969), approximately 60 m in the Fort de l'Ecluse and Vuache sections (Charollais et al., 2013; Pictet, 2021).

Definition and boundaries: The Fort de l'Ecluse Mb starts below the 3rd order discontinuity F on oolithic limestones of the uppermost Montcherand Mb and ends below the marly Rivière Mb with the surface H interpreted as the maximum flooding surface B3 (mfs B3). The boundaries F, G, H indicated by Viéban (1983) and Arnaud et al. (1998, p. 54) are interpreted differently in this study (F as 3rd order Early Barremian SbB2, G and H as Late Barremian SbB3 and mfsB3 respectively, Fig. 10). The lower Fort de l'Ecluse Mb incorporates massive whitish Urgonien Blanc (UB) facies including basal oolitic limestones with stromatoporoids in their upper part, these beds on either side of the discontinuity F can be correlated in the Gorges de l'Orbe reference section with the upper Montcherand Mb (first strata of oolitic UB facies) and the Bôle Mb (stromatoporoids). On either side of the Rivière Mb, massive limestones with rudists correspond to those of the Vallorbe Fm (cf. Vallorbe type section; Conrad and Masse, 1989; Pictet, 2021).

Geographic distribution and lateral equivalents: The Fort de l'Ecluse Mb is developed only in the French southern Jura, it is replaced in the central Jura Mountains by the Bôle Mb (Saars Fm, cf. correlations in Fig. 10).

Biostratigraphic data and age: The Fort de l'Ecluse Mb has provided typical late Early to Late Barremian benthic foraminifers in thin sections (Conrad, 1969; Viéban, 1983; Arnaud et al., 1998), notably the orbitolinids *Eopalorbitolina charollaisi* Schroeder and Conrad, 1967; *Valserina broennimanni* Schroeder and Conrad, 1967; *Paleodictyoconus actinostoma* Arnaud-Vanneau and Schroeder, 1976; *Paracoskinolina maynci* (Chevalier, 1961), associated with other species such as *Melathrokerion valserinensis* Brönnimann and Conrad, 1966.

4.1.7 Rivière Member (Pictet, 2021)

Derivation of name: From the hamlet of La Rivière beside the type section.

Type locality: La Rivière section (Conrad, 1969) in a small cliff (coord. 2480.600/1122.180 to 2480.590/1122.250) accessible with a forest pathway on the right side of the Valserine River.

Thickness: 8.5 m in the type section of La Rivière (Fig. 10), where the Rivière Mb must be restricted to the marly layers 20–23 of the "Calcaires marneux de La Rivière" described by Conrad (1969), because the layers 24–32 (19.2 m thick with an observation gap of the layer 29 estimated at 2 m, Conrad, 1969, Pl. 7) can be assigned to mostly massive limestones of the upper Vallorbe Fm with rudists and sea urchins *H. couloni* in the slightly marly layer 30. In the central Jura Mountains, similar beds along the road at 1 km south of Croy (Vaud Jura) are mentioned and placed by Pictet (2021, p. 26) in the upper Bôle Mb, but more likely belong to the Vallorbe Formation above SbB4 according to the ostracod datings (cf. Fig. 10) and the fact that globose morphotypes of *H. couloni* are absolutely not typical and abundant markers for the Bôle Mb. In the Fort de l'Ecluse section, the lithostratigraphic bed of the "Calcaires marneux de La Rivière *sensu stricto*" is also 8 m thick (Conrad, 1969; Charollais et al., 2013; 11 m by Pictet, 2021).

Definition and boundaries: The Rivière Mb is developed on the maximum flooding surface H (considered as early Late Barremian mfsB3) with a micritic and marly series including fossil-rich dark gray marls above a bioperforated 3rd discontinuity interpreted as the Late Barremian sequence boundary B4 (SbB4).

Geographic distribution and lateral equivalents: The marly facies of the Rivière Mb are developed only in the French southern Jura, they are replaced in the central Jura Mountains by limestones of the upper Vallorbe Fm (cf. correlations in Fig. 10).

Biostratigraphic data and age: The marly limestones and marls of the Rivière Mb are characterized by abundant loose specimens of typical Barremian fossils and microfossils such as echinids *Heteraster couloni* (L. Agassiz, 1839) and small *Pygaulus desmoulinsi* L. Agassiz, 1847; orbitolinids [*E. charollaisi*, *V. broennimanni*, *P. actinostoma*, *P. maynci*) and other benthic foraminifers (large *Reophax* spp., *C. decipiens*, *N. friburgensis*, *M. valserinensis*, nodosariids), and ostracods of the Late Barremian Assemblage 4 (gray marls of Noire Combe with *S. chalilovi*, *R. buechlerae*, rare *B. barremiana*, *N. (C.) gottisi*, *S.*

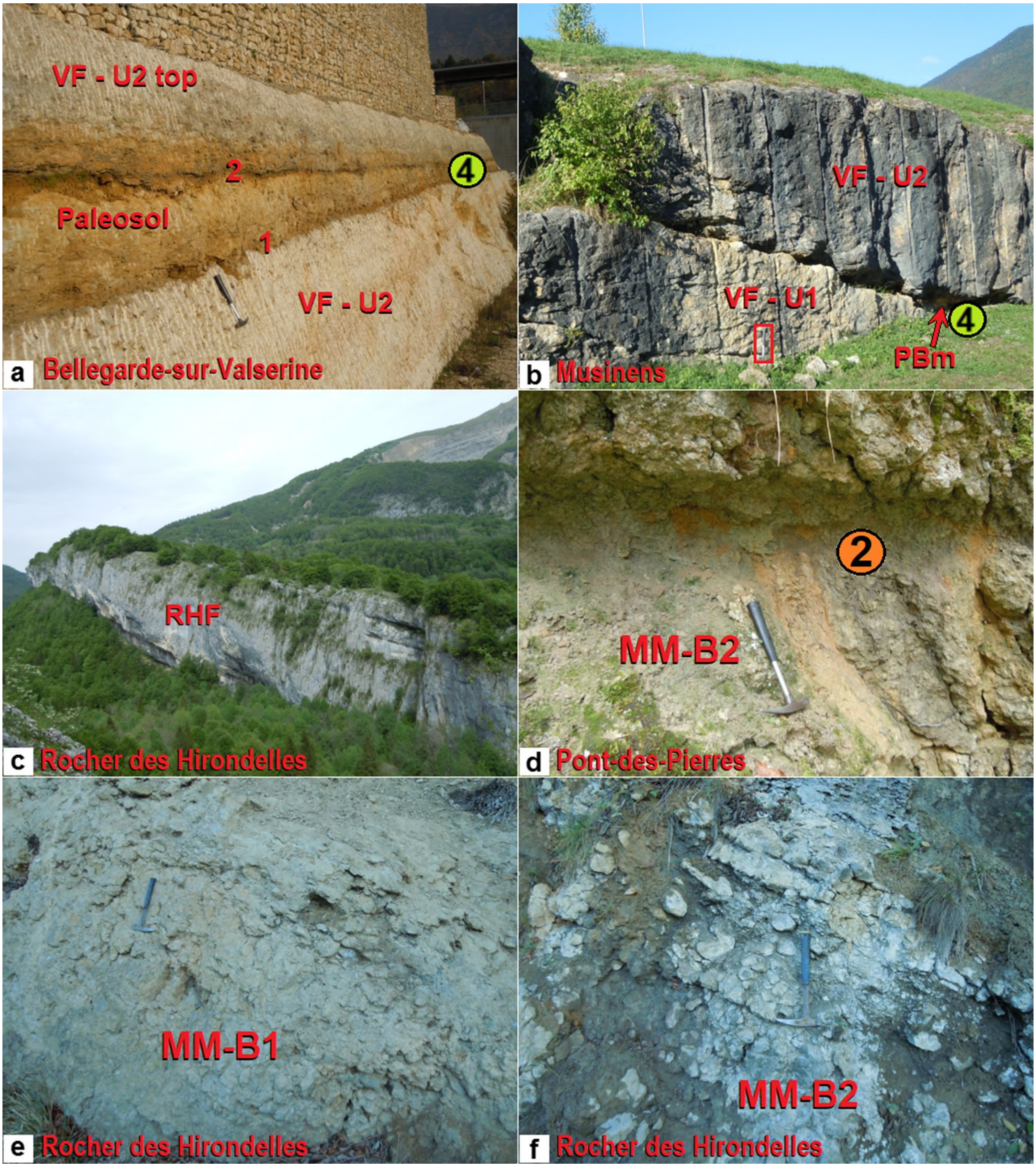

Fig. 9 Sections in the Valserine Valley (southern Jura Mountains). **a** Bellegarde-sur-Valserine railway station section, upper Vallorbe Formation with yellow–brown paleosol marked by molds of rootlets and two layers of brackish/lacustrine marls (1, 2) characterized by Late Barremian microfossils (charophytes, ostracods). **b** Musinens section, upper Vallorbe Formation with oblique irregular paleokarst surface (between U1 and U2) and Late Barremian marly infilling (marls of Poet Beds) with orbitolinids and marine ostracods. **c** Rocher des Hirondelles section with steep cliff of thick massive Rocher des Hirondelles Formation (RHF). **d** Pont-des-Pierres section, dark shallow and bioturbated marly limestones (B2) with limonite, detrital quartz and Early Barremian ostracods. **e**, **f** Basal Rocher des Hirondelles section with nodular and pseudoconglomeratic marly limestones (B1, B2) at the northern tunnel entry (D991 Road). Captions: VF: Vallorbe Formation; U1–U2: units of the upper Vallorbe Formation (cf. Pictet et al., 2016, 2019); PBm: marls of Poet Beds; MM: Montcherand Member; B1–B2: Early Barremian deeply bioturbated and brecciated deposits (B1: lower layer; B2: upper layer). For the reported ostracod assemblages (colored circles 2, 4), see Figs. 10 and 11. The hammers are 31.5 cm (**a**, **b**: red frame; **d**) and 37.5 cm long (**e**, **f**)

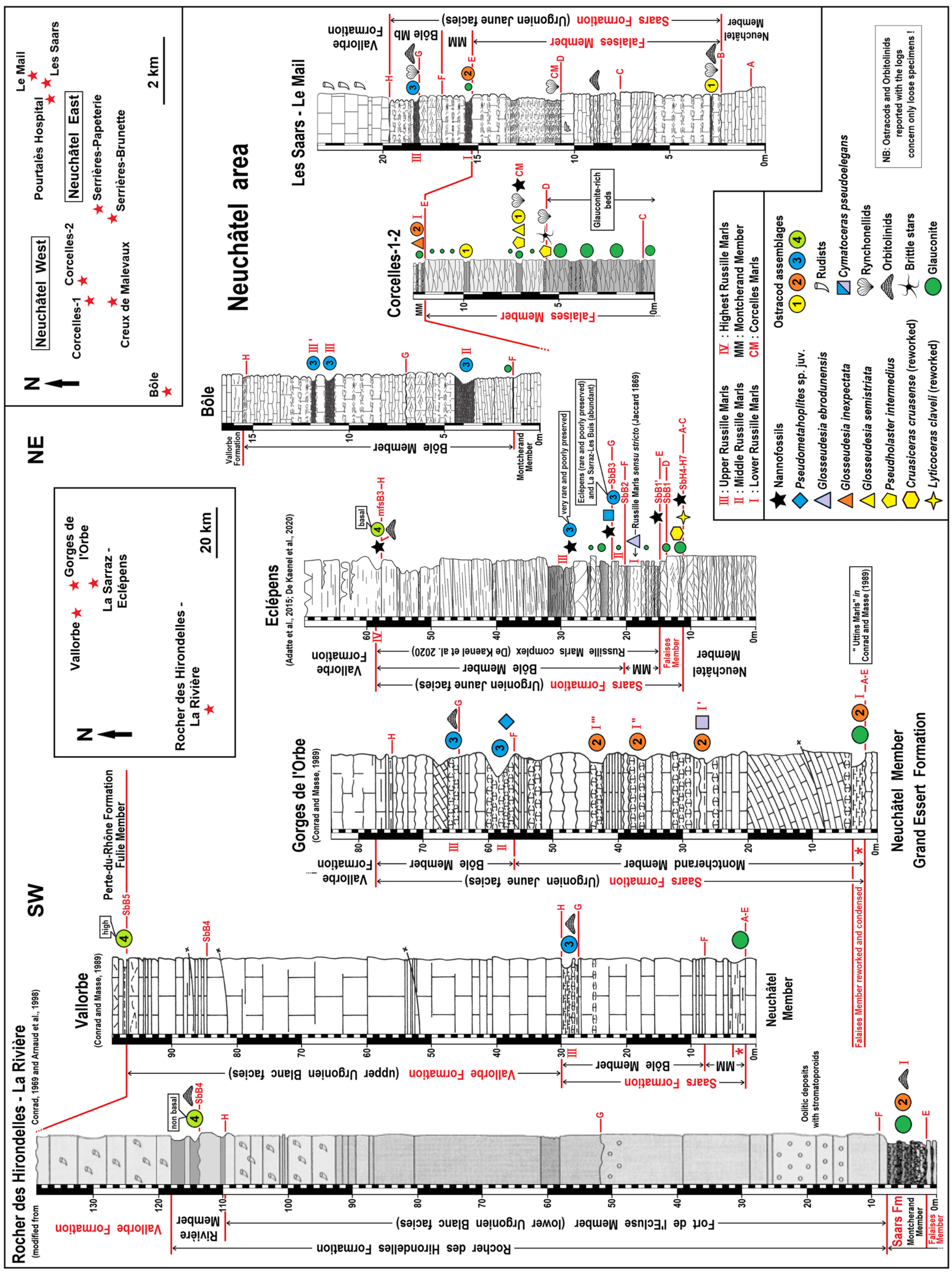

Fig. 10 Correlations of the Urgonian facies in the Swiss and French Jura Mountains according to schematic section logs (sections reported in Fig. 1C) and 3rd order sedimentary discontinuities SbH4 (A) to mfsB3 (H), SbB4 and SbB5 (cf. Figure 11). The revised and new lithostratigraphic units according to data of biostratigraphy and sequence stratigraphy are indicated in red

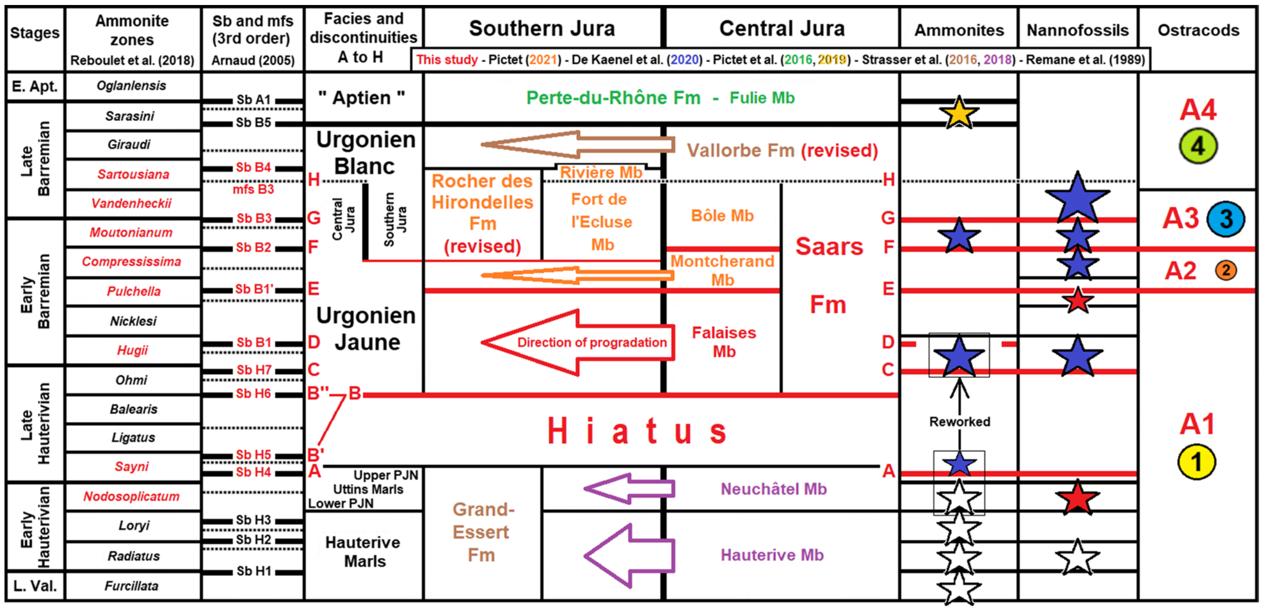

Fig. 11 Synthetic data of the Urgonian facies in the Swiss and French Jura Mountains: lithostratigraphic units, stratigraphical discontinuities and ages with currently available results about the collected ammonites, nannofossils and ostracods. The coloured large arrows indicate the general direction of progradation for the related lithostratigraphic units

alata, *C.* gr. *parallela*, *D. intermedia* and *Cresacytheridea* sp.).

4.1.8 Vallorbe Formation (revised from Strasser et al., 2016 and Pictet, 2021)

The Vallorbe Fm (Fig. 10) was introduced and defined by Strasser et al. (2016) for the Urgonien Blanc facies of the Swiss Jura Mountains (cf. Remane et al., 1989a), according to previous descriptions and data (Nolthenius, 1921; Conrad and Masse, 1989, fig. 4, p. 315–316; Blanc-Alétru, 1995). Pictet (2021) revised it as "Vallorbe Member" of his Rocher des Hirondelles Fm and by placing the "Russille Marls" *sensu* Strasser et al. (2016) at the top of the Bôle Mb. But, the Vallorbe Fm is a separate formation according to the ostracod chronology and the general NE-SW progradation of the Urgonian platform towards the Vocontian basin in the southwest, a concept unanimously recognized in the literature by all the previous authors. The lower boundary of the "Vallorbe Mb" reported by Pictet (2021) is indeed older in the Vallorbe section above "Russille Marls" III dated by ostracod A3, and clearly younger 60 km southwest in the reference section of Rocher des Hirondelles-La Rivière above the Rivière Mb dated by non basal ostracod A4. In the Vallorbe type section, Pictet (2021, fig. 20) does not explain either why only the "Vallorbe Mb" would represent the whole "Rocher des Hirondelles Fm", whereas a large part of the Vallorbe Fm is obviously equivalent to the Rivière Mb. Other inaccuracies and inconsistencies can be also noticed from this author, as in his fig. 24 (top) with a direction of progradation SW-NE towards the northeast and a "Vallorbe Mb" strangely splitted in two separate sedimentary bodies (therefore distinct lithostratigraphic units which must be named differently), and in his fig. 25 where the Bôle and Rivière members can in no way be considered as equivalent but are superimposed according to the ostracod chronology.

The type section of the Vallorbe Fm (Canton Vaud) is accessible in a steep cliff in front of the Vallorbe railways station (coord. 2517.900/1173.910 to 2517.960/1173.935), between the Saars Fm and the latest Barremian Poet Beds ("Aptien"/Bédoulien *in* Conrad and Masse, 1989) with a thin layer of yellow marl containing marine ostracods *Platycythereis rostrata* Sauvagnat, 1999. The Vallorbe Fm is well developed in the central and southern Jura Mountains, and locally characterized by requieniid and agriopleurid rudists [*Requienia ammonia* (Goldfuss, 1838), *Requienia renevieri* Paquier, 1903; *Agriopleura* spp.], which are also present in the upper part of the Fort de l'Ecluse Mb (Rocher des Hirondelles Fm).

In the Vallorbe section (Fig. 10), five sequence boundaries can be reported in the Urgonian series. The 3rd order discontinuities A-E (SbB1'), F (SbB2), G (SbB3) are indicated by bioperforated and oysters encrusted hardgrounds, SbB4 corresponds to facies/microfaciès change from thick massive grainstones to thinner beds and micritic limestones with rudist debris, and SbB5 is a well visible karstified and rubefied hardground already reported by Conrad and Masse (1989). Furthermore, the surface H indicates clearly the maximum flooding surface B3 (mfsB3) below the middle Late Barremian prograding Urgonien Blanc facies corresponding to the highstand system track of the sequence Ba3 (Godet et al., 2010; De Kaenel et al., 2020).

Emersions with brackish and lacustrine conditions are present at Bellegarde-sur-Valserine and Montanges in the top of the Vallorbe Fm with paleokarst surfaces (Musinens, Fig. 9b) and marly layers (Fig. 9a) containing black pebbles and various microfossils (Pictet et al., 2019) such as charophytes and fresh- or brackishwater ostracods (cf. Sect. 4.3.2), serpulids, small gastropods, spines of regular sea-urchins, transported Dasycladalean algae [*Salpingoporella genevensis* Conrad, 1969 ex Conrad, Praturlon and Radoičić, 1973; *Clypeina paucicalcarea* (Conrad, 1970) Granier, 2013] and benthic foraminifers (orbitolinids *P. actinostoma*, *P. maynci*, *Praedictyorbitolina*, *Cribellopsis* and *Orbitolinopsis* spp., *C. decipiens*, *C. hensoni*, *N. cretacea*, *N. broennimanni*, large *Reophax* and lituolids spp., miliolids) as well as some marine ostracods of the Assemblage 4 (*S. chalilovi*, *R. buechlerae*, *Rehacythereis* spp. 2 and 3, *B. barremiana*, *P. rostrata*, *D. intermedia*, *Schuleridea* and *Asciocythere* spp.); the rare specimens of primitive *R. buechlerae* were formerly assimilated *sensu lato* to *Rehacythereis* gr. *geometrica* (*in* Pictet et al., 2019).

4.1.9 Perte-du-Rhône Formation (Pictet et al., 2016)

The Rocher des Hirondelles Fm (Pictet, 2021, revised) is overlaid by the Perte-du-Rhône Fm (Pictet et al., 2016, 2019) including latest Barremian-Late Aptian Fulie Member (Poet Beds and Vauglène Beds) below a thick Late Aptian-Early Albian Mussel Member. In the north of Bellegarde-sur-Valserine, the Musinens section (along a football pitch) shows a paleokarst infilling of green marls from the Poet Beds (Fig. 9b) characterized by diverse typical benthic foraminifers (orbitolinids *P. actinostoma* and *P. maynci*, *C. decipiens*, *N. friburgensis*, *C. hensoni*, *N. cretacea*, *N. broennimanni*; *Nezzazatinella macovei* Neagu, 1979; large *Reophax* and various lituolids spp., nodosariids, miliolids) and ostracods of the shallow marine Assemblage 4 (*S. chalilovi*, *R. buechlerae*, *B.* sp. 302, *B. barremiana*, *B. luminosa*, *D. intermedia*, *Hechticythere* sp. 1). The species *B.* sp. 302 derived from *B. barremiana* indicates a deposit younger than the top of the Vallorbe Fm, sclerites of Alcyonarian corals are also present but rare.

At La Presta (Pictet et al., 2016, fig. 5; Pictet et al., 2019, fig. 12), the Vallorbe Fm top correspond to a thick ferruginous crust of emersion surface covered by whitish marls (Poet Beds) of confined marine paleoenvironment with serpulids, small gastropods and bivalves, benthic foraminifers (orbitolinids *P. actinostoma*, *P. maynci*, *Cribellopsis* and *Orbitolinopsis* spp., *C. decipiens*, *C. hensoni*, large *Reophax* and lituolids spp., *Haplophragmoides* and small *Nautiloculina* spp., miliolids), and abundant well preserved ostracods of the Assemblage 4 with *S. chalilovi*, *R. geometrica*, *B. barremiana*, *B. luminosa*, *N. (C.) gottisi*, *S. alata*. Directly above, the earliest Aptian Vauglène Beds correspond to superposed blue marls characterized by profusion of orbitolinids *Palorbitolina lenticularis* (Blumenbach, 1805) and a slightly different (of more open sea) ostracod microfauna (Sauvagnat, 1999) of the Assemblage 4, with *S. chalilovi*, *R. geometrica*, *P. derooi*, *S. alata*, *S. derooi*, *N. (C.) gottisi*, and still present species of Hauterivian affinities such as *P. triplicata* and *H. hechti*.

12 km to the south, the section of La Lance (Charollais et al., 1994; Blanc-Alétru, 1995) shows in the Vallorbe Fm a paleokarst infilling of earliest Aptian green marls (Vauglène Beds) with very abundant *P. lenticularis* (and some large lituolids), spines of regular sea-urchins, fish teeth (selachians, pycnodonts), and reworked Late Barremian microfossils (in its basal part) from the Vallorbe Fm top such as marine ostracods (rare *R. geometrica*), benthic foraminifers (orbitolinids *P. actinostoma*, *C. decipiens*, *N. friburgensis*, miliolids), serpulids, small gastropods, charophytes (*Atopochara trivolvis triquetra* Grambast, 1968; *Clavatoraxis* thallus, rare poorly preserved *Globator trochiliscoides* Grambast, 1966 and *Hemiclavator* sp.) and small crocodile teeth.

The Fulie Mb and the Mussel Mb are mostly developped in the Valserine Valley (Pictet et al., 2016, 2019). In the Neuchâtel Jura Mountains, the upper part of the Fulie Mb with Early to Late Aptian blue-green marls completely devoid of microfossils is covered by the Mussel Mb with greensands/sandstones (Late Aptian—Early Albian) and thick gray-beige soft marls (Early Albian) at La Presta (Pasquier et al., 2013; Pictet et al., 2016, 2019). Nearby in Le Vanel section (Thiébaud, 1937), the latest Barremian-Aptian marls and sandstones are absent, Early Albian greensands with phosphate pebbles and soft gray-beige marls overlay directly the Vallorbe Fm by non-deposition or erosion following an Aptian-Albian synsedimentary paleotectonics (Pictet et al., 2019).

4.2 Calcareous nannofossils

Five samples were analysed in the Uttins Marls and seven in the Corcelles Marls. The nannofossil data of these analyses are grouped within two main samples Uttins (Figs. 7a, 12A, 13, 14) and Corcelles C-2 (Figs. 7b, 12B,

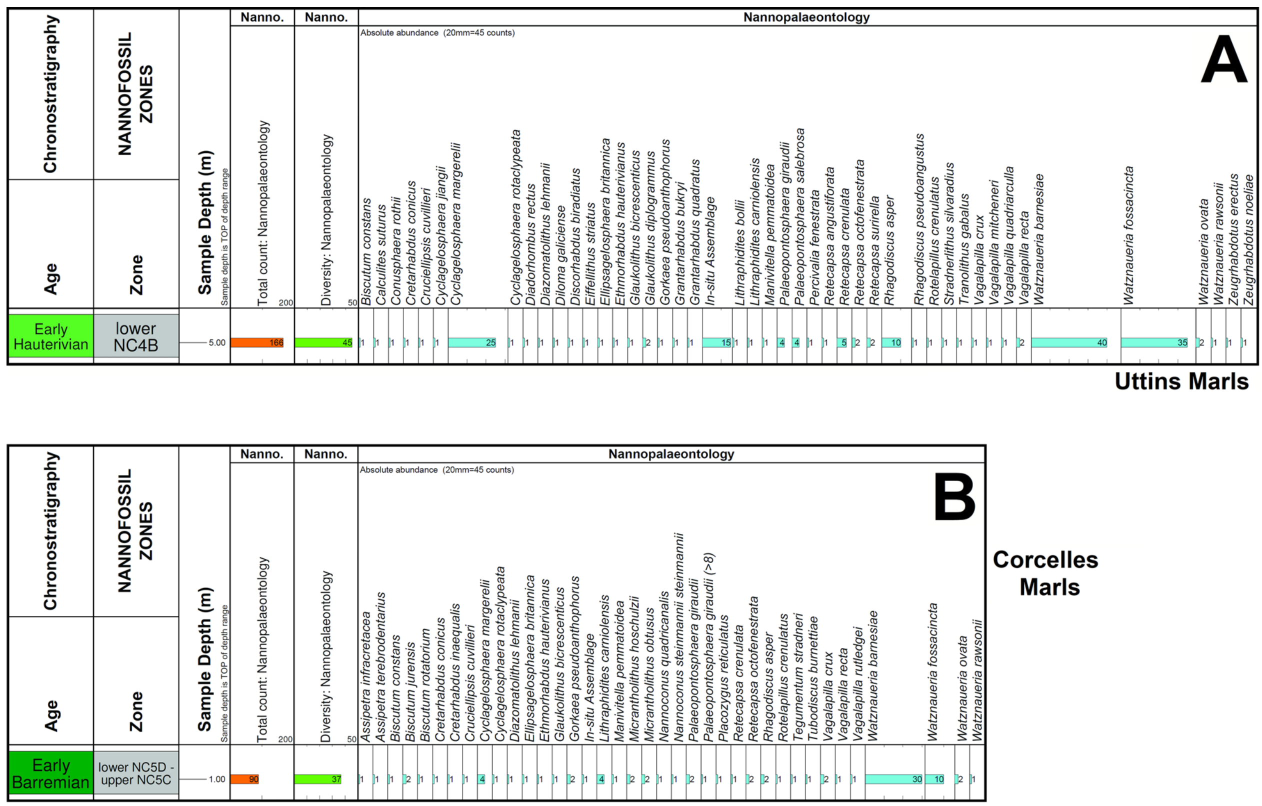

Fig. 12 Nannofloras from the late Early Hauterivian Uttins Marls (**A**: sample from the Mont de Chamblon section, VD) and Early Barremian Corcelles Marls (**B**: sample from the Corcelles-2 section, NE). In order to avoid very high numbers for nannofossil counts, a 0–100 based counting system is used. The numbers for individual species represent semi-quantitative count estimation of specimens/100 fields of view (FOV). Numbers from 1 to 20 represent the estimation of species per 100 FOV. Numbers above 20 are coded: 25 (one specimen/4FOV), 30 (one specimen/3FOV), 35 (one specimen/2FOV), 40 (one specimen/1FOV). The numbers for total abundance (*in situ*) estimation represent the number of specimens per 5 FOV. For the taxonomy (names by authors) and detailed biostratigraphy, see also Internet website https://www.mikrotax.org

13, 14). This study on calcareous nannofossils from Barremian marls started in 2005 for the publications of Godet et al. (2010) and De Kaenel et al. (2020). This third publication is another step for the knowledge of calcareous nannofossils in the Swiss Jura Mountains. New data have been also acquired by the study of the late Early Hauterivian Uttins Marls.

4.2.1 Calcareous nannofossil abundance and preservation

The nannoflora of sample 5m in the glauconite-rich Uttins Marls is common (3 specimens per field of view, cf. *In situ* Assemblage, Fig. 12A) and the preservation poor to moderate. The diversity is moderate with 28 genera and 45 species observed. In this assemblage, *Watznaueria* and *Cyclagelosphaera* species are abundant. Other species are rare to very rare. The nannoflora of sample 1m in the Corcelles Marls is also common (1 specimen per field of view, cf. *In situ* Assemblage, Fig. 12B) with a poor to very poor preservation. The diversity is moderate with 23 genera and 36 species observed. This assemblage is also dominated by abundant *Watznaueria* species. Only few *Cyclagelosphaera* species are observed.

4.2.2 Calcareous nannofossil systematic taxonomy

Important markers from the samples of the Uttins Marls and Corcelles Marls are reported (Fig. 12A, B) and also illustrated (Fig. 13), the species are listed by generic epithet. Among them, one new combination is introduced such as *Vagalapilla mitcheneri* De Kaenel and Mojon, n. comb.

Assipetra terebrodentarius (Applegate, Bralower, Covington and Wise *in* Covington and Wise, 1987) Rutledge and Bergen *in* Bergen, 1994

Figure 13.16–20

Discussion: Several specimens of *A. terebrodentarius* are observed in the Corcelles Marls. All of them have the typical petaloid structure and are between 5 and 6 microns. The LO (lowest occurrence) of *A.*

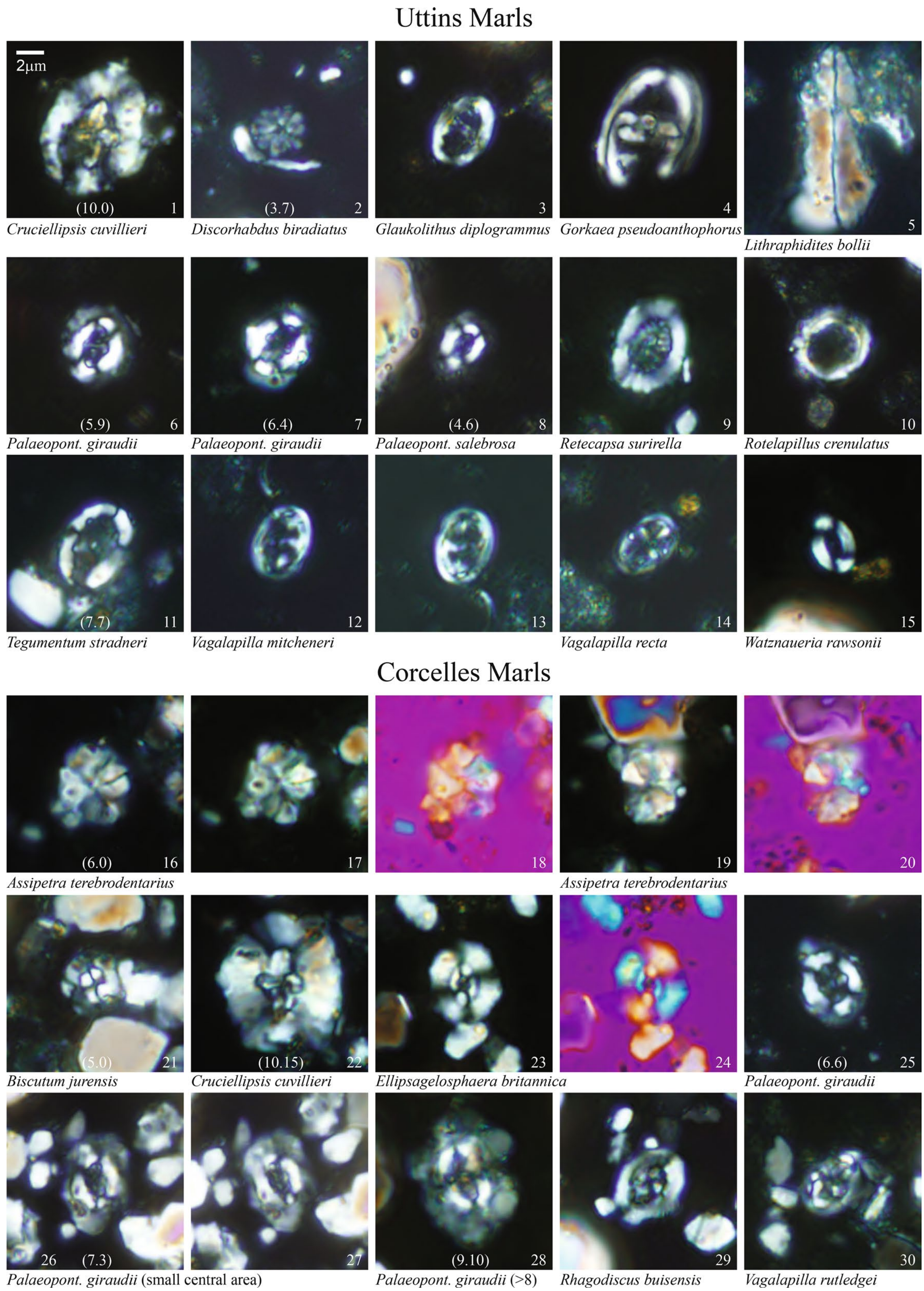

Fig. 13 Calcareous nannofossils from the late Early Hauterivian Uttins Marls (sample from the Mont de Chamblon section, VD) and Early Barremian Corcelles Marls (sample from the Corcelles-2 section, NE), collection E. De Kaenel

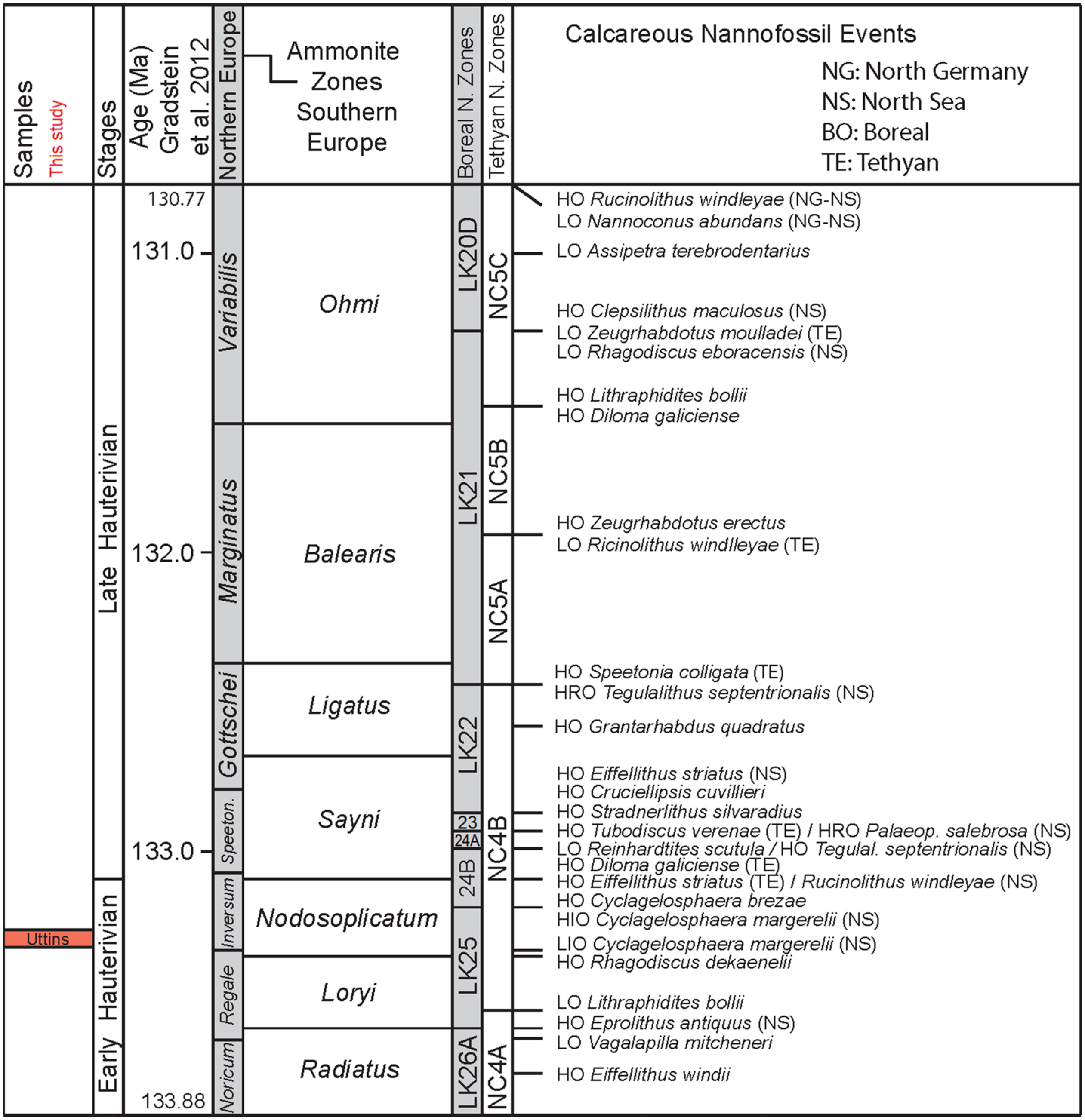

Fig. 14 Integrated Hauterivian and Barremian nannofossil biostratigraphy with Boreal–Tethyan ammonite and calcareous nannofossil zones calibrated to ages from Gradstein et al. (2012). Boreal LK Zones by Jeremiah (2001) and Tethyan NC Zones by Roth (1978, 1983) with subdivisions of Bralower (1987), modified by Applegate and Bergen (1988) for the Hauterivian. In the left column, the stratigraphic position is indicated within red frameworks for the samples from the Uttins Marls (Uttins/Mont de Chamblon section, VD) and Corcelles Marls (C-2/Corcelles-2 section, NE), and in blue frameworks for the samples from Eclépens (EC) and La Sarraz–Les Buis (LSBM) previously studied by De Kaenel et al. (2020). The following terms are used to indicate the individual species abundance: HO = highest occurrence, HRO = highest regular occurrence, HFO = highest few occurrence, HIO = highest increase occurrence, LIO = lowest increase occurrence, LFO = lowest few occurrence, LRO = lowest regular occurrence, LO = lowest occurrence

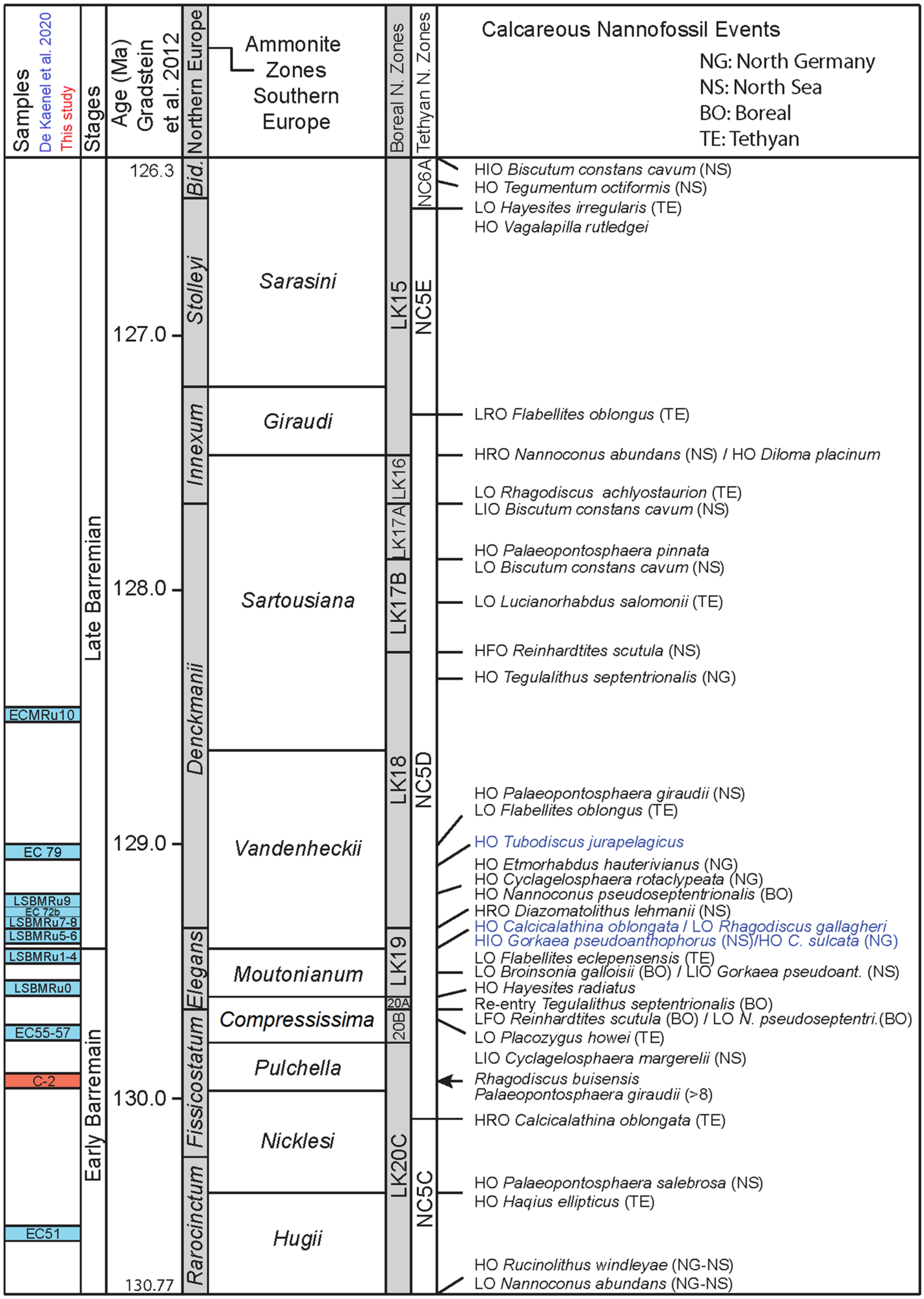

Fig. 14 continued

terebrodentarius is placed in the Late Hauterivian Angulicostata (= Ohmi) ammonite Zone by Bergen (1994) and in the Late Hauterivian Variabilis ammonite Zone by Rutledge (1994). The LO of *A. terebrodentarius* is similar between the Tethyan and North Sea areas. The presence of *A. terebrodentarius* indicates that the Corcelles Marls are younger than the Uttins Marls.

Biscutum jurensis De Kaenel *in* De Kaenel et al., 2020
Figure 13.21
Discussion: *B. jurensis* was described in late Early Barremian sediments from the "Marnes de la Russille complex" and recorded from the Early Barremian Hugii ammonite Zone to the Late Barremian Vandenheckii ammonite Zone. Very rare specimens of *B. jurensis* are observed in the Corcelles Marls. *B. jurensis* is absent from the Early Hauterivian Uttins Marls.

Calculites suturus Bown and Concheyro, 2004
Discussion: Very rare specimens of *C. suturus* are observed in the Uttins Marls. Bown and Concheyro (2004) recorded this species from the late Early Hauterivian to the base of the Late Hauterivian (basal Sayni ammonite Zone).

Cruciellipsis cuvillieri (Manivit, 1966) Thierstein, 1971
Figure 13.1, 13.22
Discussion: A single specimen of *C. cuvillieri* is observed in the Uttins Marls (Fig. 13.1). Even very rare occurrences of nannofossils can be used to date samples. In a nannofossil assemblage, the dominant species are usually not the markers and rare species are more important. The HRO (highest regular occurrence) of *C. cuvillieri* is used as zonal marker to define the NC4/NC5 zonal boundary in the Tethyan zonal diagram of Roth (1978, 1983), Bralower (1987) and Bralower et al. (1995). In Figure 14, the NC4/NC5 boundary is placed at the HO of *Speetonia colligata* following the emendation of the nannofossil zones of Applegate and Bergen (1988) and Bergen (1994). This boundary occurs in the early Late Hauterivian Sayni ammonite Zone. Sporadic occurrences of *C. cuvillieri* have been observed by several authors in NC5 (Applegate and Bergen, 1988; Bralower, 1991). These occurrences of very isolated specimens are always interpreted as reworked. The LO of *C. cuvillieri* is placed by De Kaenel and Bergen (1996) in the Late Tithonian. A single specimen is observed in the Corcelles Marls. The observed specimen is large (10.15 microns) with a broad, tapering central cross. Based on the presence of *A. terebrodentarius* (LO in upper NC5C) and on Barremian markers, the occurrence of *C. cuvillieri* in the Corcelles Marls is also interpreted as being reworked.

Cyclagelosphaera jiangii Covington and Wise, 1987
Discussion: Very rare specimens of *C. jiangii* are observed in the Uttins Marls. This *Cyclagelosphaera* species is differentiated from other small *Cyclagelosphaera* by its larger central opening. According to Bown (2005), this species ranges from the Berriasian to the early Late Hauterivian (nannofossil Subzone NC4B).

Cyclagelosphaera margerelii Noël, 1965
Discussion: The HOA (highest occurrence acme) is used as a zonal marker in Boreal nannofossil biostratigraphy by Jeremiah (2001) to define the top of the Zone LK25 (Boreal middle Inversum ammonite Zone). Common *C. margerelii* are observed in the Uttins Marls. Together with *E. striatus*, *S. silvaradius* and Tethyan marker *L. bollii*, this sample belongs to the upper LK25 Zone, which corresponds to the Tethyan upper Loryi and basal Nodosoplicatum ammonite Zones.

Diloma galiciense Bergen, 1994
Discussion: A single specimen of *D. galiciense* is recorded in the Uttins Marls. According to Rutledge (1994), this species ranges in Boreal area from the Early Hauterivian (Radiatus ammonite Zone) to the Late Hauterivian (Variabilis ammonite Zone).

Discorhabdus biradiatus (Worsley, 1971) Thierstein, 1973
Figure 13.2
Discussion: A single specimen of *D. biradiatus* (3.7 micron and 11 elements) is observed in the Uttins Marls. According to Thierstein (1973), the known range of *D. biradiatus* is Late Valanginian to Late Barremian, but in South France, this author indicated that the HO (highest occurrence) of *D. biradiatus* is just above the Early/Late Hauterivian boundary.

Ellipsagelosphaera britannica (Stradner, 1963) Perch-Nielsen, 1968
Figure 13.23–24
Discussion: *Ellipsagelosphaera* and *Watznaueria* species are separated based on their central area constructions. The holotype of the genus *Ellipsagelosphaera*, *E. britannica*, has a central transverse bar. All Ellipsagelosphaeraceae species with a transverse bar are placed in the genus *Ellipsagelosphaera* (Noël, 1965). And all Ellipsagelosphaeraceae species with a central area open or filled by cycles of elements or plates are placed in the genus *Watznaueria* (Reinhardt, 1964). Bown (1987) described the family Watznaueriaceae to replace the family Ellipsagelosphaeraceae described by Noël (1965), and considered *Ellipsagelosphaera* as a subjective junior synonym of *Watznaueria*. At the opposite, we consider that the two genera are distinct and separated by their central area constructions.

Eiffellithus striatus (Black, 1971) Applegate and Bergen, 1988

Discussion: This Hauterivian marker is observed in the Uttins Marls. The HO of *E. striatus* is placed by Bergen (1994) at the base of the Sayni ammonite Zone (lowermost Late Hauterivian).

Glaukolithus diplogrammus (Deflandre *in* Deflandre and Fert, 1954) Reinhardt, 1964

Figure 13.3

Discussion: Several specimens of *G. diplogrammus* are observed in the Uttins Marls. *G. diplogrammus* is reported from the Early Valanginian to the Late Campanian.

Gorkaea pseudoanthophorus (Bramlette and Martini, 1964) Varol and Girgis, 1994

Figure 13.4

Discussion: Several specimens of *G. pseudoanthophorus* are observed in the Uttins Marls and Corcelles Marls. No increases of this species are recorded in these two samples.

Grantarhabdus quadratus (Worsley, 1971) Bergen, 1994

Watznaueria quadrata Worsley, 1971; p. 1315, Pl. 2, figs. 20–22.

Non *Microstaurus quadratus* Black, 1971; p. 404–405, Pl. 32, Fig. 2.

Grantarhabdus quadratus (Worsley, 1971) Bergen, 1994; p. 61, Pl., 1, Fig. 10.

Helenea quadrata (Worsley, 1971) Rutledge and Bown *in* Bown et al., 1998; p. 108, Pl. 5.4, Fig. 5.

Discussion: Because of the species name *quadrata*, there are some confusions in the literature between *Grantarhabdus quadratus* and *Microstaurus quadratus*. The species *Watznaueria quadrata* described by Worsley (1971) belongs to the genus *Grantarhabdus* based on the diagonal cross structure. The species *Microstaurus quadratus* described by Black (1971) is a junior synonym of *Helenea staurolithina* described by Worsley (1971). Contrary to Rutledge and Bown (*in* Bown et al., 1998) and the Nannotax3 website, we include the Cretarhabdaceae species with diagonal central structure in the genus *Grantarhabdus*. Rare specimens of *G. quadratus* are recorded in the Uttins Marls. The extinction of *G. quadratus* is placed by Bergen (1994) in the Late Hauterivian Ligatus ammonite Zone.

Lithraphidites bollii (Thierstein, 1971) Thierstein, 1973

Figure 13.5

Discussion: Very rare specimens of *L. bollii* are recorded in the Uttins Marls. All of them are overgrowth, but the outer irregular outlines are similar to the holotype of this species described by Thierstein (1971). Thierstein (1971, 1973) used the LO of *L. bollii* to define the top of the *Calcicalathina oblongata* and the base of the *Lithraphidites bollii* Zones. This marker is used in most Tethyan zonations. In the zonal diagram of Roth (1978, 1983), the LO of *L. bollii* defined the NC4A/NC4B subzonal boundary. The LO of *L. bollii* lies within the lower part of the Early Hauterivian Loryi ammonite Zone.

Nannoconus quadricanalis Bown and Concheyro, 2004

Discussion: Bown and Concheyro (2004) recorded *N. quadricanalis* from the Late Valanginian to the Late Hauterivian in the Neuquén Basin (Argentina). Similar specimens were observed in the Eclépens quarry section by De Kaenel et al. (2020) from the Early Barremian to the early Late Barremian. *N. quadricanalis* is also present in the Corcelles Marls (Fig. 12B). This quadriangular *Nannoconus* species with wide canal probably evolved in *N. truittii* during the Late Barremian. The basal occurrence of *N. truittii* was observed by De Kaenel et al. (2020, fig. 13) in the early Late Barremian.

Palaeopontosphaera giraudii De Kaenel *in* De Kaenel et al., 2020

Figure 13.6–7, 13.25–28

Discussion: *P. giraudii* is frequent in both the Uttins Marls and Corcelles Marls. Medium-sized specimens (between 4.5 and 8.0 microns) are present in both sections of Uttins and Corcelles-2, but specimens with smaller central areas (Fig. 13.26–28) are observed in the Corcelles Marls. Some of these specimens are very large, between 8 and 10 microns (Fig. 13.28). All of these specimens have a small central area, almost filled by the axial cross and are recorded as *P. giraudii* (> 8 microns). This variation of typical forms of *P. giraudii* may thus provide an alternative marker for the Early Barremian. These forms were not observed by De Kaenel et al. (2020) in the late Early Barremian-early Late Barremian from the "Marnes de la Russille complex". Bown and Concheyro (2004) described two Biscutaceae species from the Hauterivian in the Neuquén Basin (Argentina). The first species, *Crucibiscutum trilensis* (between 5 and 5.5 microns) is broadly elliptical with a central area spanned by off-axial cross-bars. This species restricted to the Late Hauterivian (Bown and Concheyro, 2004) is not observed in both the Uttins Marls and Corcelles Marls. The second species, *Crucibiscutum neuquenensis* (between 6.1 and 6.2 microns) is also broadly elliptical with a broad rim, a narrow inner distal cycle, and a central area spanned by axial cross-bars and is similar to *P. giraudii*. *P. giraudii* is differentiated from C. *neuquenensis* by the thicker inner rim cycle and thicker axial cross structure. According to Bown and Concheyro (2004), C. *neuquenensis* is restricted to the Early Hauterivian Nodosoplicatum ammonite Zone. Jeremiah (2001) described from the basal Cretaceous (Ryazanian from Boreal area) *Crucibiscutum ryazanicum*, a form with an asymmetrical axial cross between 4 and 5 microns. Some of the specimens of *P. giraudii* observed in the Uttins Marls are similar, with off-axial (slightly rotated) cross-bars, but are larger (Fig. 13.6).

Palaeopontosphaera salebrosa (Black, 1971) Prins and Sissingh *in* Sissingh, 1977
Figure 13.8
Discussion: *P. salebrosa* is only recorded in the Uttins Marls. *P. salebrosa* is a small *Palaeopontosphaera* species (between 3 and 5.5 microns) with an axial cross filling the central area. In *P. giraudii*, the axial cross does not fill the central area. *P. salebrosa* disappeared in the Early Barremian at the top of the Hugii ammonite Zone. The *Palaeopontosphaera* species are frequent in the Uttins Marls and Corcelles Marls and the absence of *P. salebrosa* in the Corcelles Marls indicates a Barremian age conjointly with other markers.

Placozygus reticulatus (Black, 1971) De Kaenel *in* De Kaenel et al., 2020
Discussion: *P. reticulatus* is only observed in the Corcelles Marls. *P. reticulatus* was reported by Black (1971) from the Early Barremian to the Late Albian. De Kaenel et al. (2020) reported the LO of *P. reticulatus* in the Early Barremian (Hugii ammonite Zone) and the HO at the Early/Late Barremian boundary.

Retecapsa surirella (Deflandre and Fert, 1954) Grün *in* Grün and Allemann, 1975
Figure 13.9
Discussion: Several *Retecapsa* species are observed in both sections of Uttins (Mont de Chamblon) and Corcelles-2. Because of the poor preservation of the central area, the axial cross and accessory lateral bars are not visible in most specimens. Four species of the genus *Retecapsa* were identified in the Uttins Marls and Corcelles Marls including *R. surirella*, *R. angustiforata*, *R. crenulata* and *R. octofenestrata*. None of these four species are markers for the Hauterivian-Barremian interval.

Rhagodiscus buisensis De Kaenel *in* De Kaenel et al., 2020
Figure 13.29
Discussion: A single specimen of *R. buisensis* is recorded in the Corcelles Marls from Corcelles-2 section. The specimen illustrated (Fig. 13.29) has the typical weakly birefringent small circular spine base. De Kaenel et al. (2020) reported the LO of *R. buisensis* in the late Early Barremian Moutonianum ammonite Zone. The presence of *R. buisensis* in the Corcelles Marls indicates that the LO of this species is slightly older, below the re-entry of *Tegulalithus septentrionalis* (Compressissima ammonite Zone) and also below the LIO (lowest increase occurrence) of *Cyclagelosphaera margerelii* (basal Compressissima ammonite Zone). *R. buisensis* is the youngest marker reported from the Corcelles Marls and may indicate that they belong to the previous Early Barremian Pulchella ammonite Zone.

Rhagodiscus pseudoangustus Crux, 1987
Discussion: Several specimens of *R. pseudoangustus* are observed in the Uttins Marls. *R. pseudoangustus* ranges in Tethyan area from the Tithonian to the Late Aptian (De Kaenel and Bergen, 1996). In Boreal area, the HO of *R. pseudoangustus* is used by Crux (1989) as a zonal marker for the top of the *Nannoconus abundans* Zone, which corresponds to the top of the Boreal Rarocinctum ammonite Zone (= Tethyan early Nicklesi ammonite Zone). *R. pseudoangustus* is not observed in the Corcelles Marls, but very rare specimens were observed by De Kaenel et al. (2020) from the "Marnes de la Russille complex" in the Moutonianum and early Vandenheckii ammonite Zones at Eclépens and La Sarraz-Les Buis.

Rotelapillus crenulatus (Stover, 1966) Perch-Nielsen, 1984
Figure 13.10
Discussion: Very rare specimens of *R. crenulatus* are observed in the Uttins Marls. This species ranges from the Late Tithonian (De Kaenel and Bergen, 1996) to the Maastrichtian.

Stradnerlithus silvaradius (Filewicz, Wind and Wise *in* Wise and Wind, 1977) Rahman and Roth, 1991
Discussion: *S. silvaradius* is very rare in the Uttins Marls. Bergen (1994) reported the HO of this species at the level of the HO of *C. cuvillieri* in Tethyan sections from the southeastern France (Vocontian trough) and from the Deep Sea Drilling Site 534 (northwestern Atlantic Ocean), and placed them in the early Late Hauterivian Sayni ammonite Zone. In Boreal area, the HO of *S. silvaradius* is placed by Jeremiah (2001) in the late LK25 Zone (Boreal top Regale ammonite Zone), which corresponds to the latest Early Hauterivian (Tethyan basal Nodosoplicatum ammonite Zone) based on the Boreal–Tethys ammonite correlations of Mutterlose et al. (2014).

Tegumentum stradneri Thierstein in Roth and Thierstein, 1972
Figure 13.11

Discussion: *T. stradneri* is very rare in the Corcelles Marls. This species is not a marker for the Hauterivian-Barremian interval. *T. stradneri* ranges from the Valanginian to the Maastrichtian.

Vagalapilla mitcheneri (Applegate and Bergen, 1988) De Kaenel and Mojon, n. comb.

Figure 13.12–13

Basionym: *Vekshinella mitcheneri* Applegate and Bergen, 1988; p. 317, Pl. 23, figs. 7–9.

Staurolithites mitcheneri (Applegate and Bergen, 1988) Rutledge and Bown *in* Bown et al., 1998; p. 114, non Pl. 5.7, fig. 16.

Discussion: *V. mitcheneri* is differentiated from other bicyclic species of *Vagalapilla* by the structure of the central axial cross with strongly flaring terminations and median suture. The axial cross does not fill the central area. Rutledge and Bown (*in* Bown et al., 1998) recombined the species *mitcheneri* with the genus *Staurolithites*. As explained by De Kaenel et al. (2020), the type species and holotype of the genus *Staurolithites* (Caratini, 1963) is dubious and questionable. The type species *Staurolithites laffittei* is illustrated by a poor light microscope picture with some short visible spines protruding from the rim, and therefore may belong to the genus *Rotelapillus* described by Noël (1972). The genus *Vagalapilla* defined by Bukry (1969) is therefore used herein to recombine the species *mitcheneri*, but the Nannotax3 website of the International Nannoplankton Association (supervised by J.R. Young, P.R. Bown and J.A. Lees) regardless indicates that the genus *Staurolithites* is accredited for loxolith muroliths with an axial cross. We do not follow this concept of taxonomic classification, not valid in our opinion for the procedural reason of definition defect stated above. Few specimens of *V. mitcheneri* are recorded in the Uttins Marls. According to Applegate and Bergen (1988), *V. mitcheneri* ranges from the Early Valanginian to the Late Barremian.

Vagalapilla recta (Black, 1971) De Kaenel *in* De Kaenel et al., 2020

Figure 13.14

Discussion: Several species of *Vagalapilla* are observed in the Uttins Marls and Corcelles Marls. Because of the poor preservation, specimens of *Vagalapilla* could not be always identified at the species level. Only four *Vagalapilla* species are recognized in the Uttins Marls (*V. crux*, *V. mitcheneri*, *V. quadriarculla*, *V. recta*) and three in the Corcelles Marls (*V. crux*, *V. recta*, *V. rutledgei*). Except for *V. recta*, these species range throughout the Hauterivian-Barremian interval. *V. recta* is observed in the Uttins Marls and was never reported below the Barremian.

Vagalapilla rutledgei De Kaenel *in* De Kaenel et al., 2020

Figure 13.30

Discussion: *V. rutledgei* is only observed in the Corcelles Marls from Corcelles-2 section. The LO of this species is not yet well constrained and may not be present in the Early Hauterivian. De Kaenel et al. (2020) reported it from the Early to Late Barremian. Covington and Wise (1987) recorded this species (=*Eiffelithus*? sp. 2) from the Late Hauterivian to the Late Barremian.

Watznaueria rawsonii Crux, 1987

Figure 13.15

Discussion: Few *W. rawsonii* are recorded in both the Uttins Marls and Corcelles Marls. This species, described from the North Sea area, is not yet reported from the Tethyan area. Rutledge (1994) reported its range from the Early Valanginian to the Late Barremian in the Boreal area.

Zeugrhabdotus erectus (Deflandre, 1954) Manivit, 1971

Discussion: Several specimens of *Z. erectus* observed in the Uttins Marls are typical of the Early Hauterivian nannofossil assemblage. The HO of *Z. erectus* is placed by Bergen (1994) in the Late Hauterivian Balearis ammonite Zone. Only specimens with faint birefringence rim, white birefringence and thin transverse bar are included in the *Z. erectus* concept. This species is not observed in the Corcelles Marls.

4.2.3 Calcareous nannofossil biostratigraphy

Biostratigraphic zonation diagrams are separated between Boreal and Tethyan areas. The Hauterivian and Barremian nannofossil events observed in the Uttins Marls (Fig. 7a) and Corcelles Marls (Fig. 7b) include markers that are used in both areas. Not a single diagram can be applied to these sediments of the Swiss Jura Mountains. An integrated Hauterivian-Barremian nannofossil biostratigraphic diagram is presented in the local context of the Jura Mountains (Fig. 14) according to the Boreal LK nannofossil Zones by Jeremiah (2001) and Tethyan NC nannofossil Zones by Roth (1978, 1983) with Subzones of Bralower (1987) and Applegate and Bergen (1988). Additional stratigraphically useful nannofossil events are added to these diagrams. The Barremian integrated nannofossil diagram is based on the detailed work by De Kaenel et al. (2020) about the Urgonien Jaune facies (Saars Formation) of the Swiss Jura Mountains with Hauterivian-Barremian nannofossil assemblages including obvious species from Boreal and Tethyan areas. The appearance of Boreal species suggests that shallow connections to the Tethyan Ocean were open at this time. Shallow to very shallow connections in Barremian sediments are suggested by the presence of relatively abundant nannoflora and the absence of ammonites. Nannoflora are present from open sea up to few meters of water depth.

A typical Early Barremian nannoflora characterizes the Corcelles Marls, with notably *Assipetra terebrodentarius*, *Biscutum jurensis*, *Palaeopontosphaera giraudii* (>8), *Placozygus reticulatus*, *Vagalapilla rutledgei* (Fig. 12B). This nannoflora can be correlated more precisely with the Tethyan ammonite biozonation of the Early Barremian, since the typical markers of the Hugii Zone (*Palaeopontosphaera salebrosa*, *Haqius ellipticus*) and upper Compressissima Zone (*Placozygus howei*, re-entry of *Tegulalithus septentrionalis*) are lacking and imply presumably a non basal Early Barremian age corresponding to the Nicklesi, Pulchella and lower Compressissima Zones. *Cruciellipsis cuvillieri* is an unexpected species in this assemblage, presumably reworked from the late Early Hauterivian. In addition to these observations, the low number of *Cyclagelosphaera margerelii* recorded in the Corcelles Marls indicates an age older than the Compressissima Zone and probably the Pulchella Zone. Even with the poor preservation of the nannoflora from the Corcelles Marls, the Ellipsagelosphaeraceae species (*Cyclagelosphaera*, *Ellipsagelosphaera* and *Watznaueria*) are well identified and dominate the nannofossil assemblage. So the number of specimens of *C. margerelii* together with the presence of *B. jurensis* indicate that the Corcelles Marls indeed belong to the lower Pulchella Zone (lower NC5D nannofossil Subzone) with the first occurrence of *Rhagodiscus buisensis* (Fig. 14).

For comparison, the nannoflora of the glauconite-rich Uttins Marls (Jordi, 1955; Remane et al., 1989b, fig. 12) in the middle part of the Neuchâtel Member (upper Grand-Essert Formation) is analyzed for the first time from the type locality Mont de Chamblon near Yverdon-les-Bains (Fig. 1C), well dated in the central Jura Mountains by Tethyan ammonites (*Lyticoceras* spp.) of the late Early Hauterivian Nodosoplicatum Zone (Remane et al., 1989a; Godet et al., 2010). This nannoflora (Fig. 12A) is clearly different and notably characterized by taxa (*Calculites suturus*, *Cruciellipsis cuvillieri*, *Cyclygelosphaera jiangii*, *Diloma galiciense*, *Eiffellithus striatus*, *Grantarhabdus quadratus*, *Lithraphidites bollii*, *Palaeopontosphaera salebrosa*, *Rhagodiscus pseudoangustus*, *Stradnerlithus silvaradius*, *Vagalapilla mitcheneri*, *Zeugrhabdotus erectus*) of the late Early to early Late Hauterivian lower NC4B nannofossil Subzone (Bergen, 1994) including the non basal Loryi and Nodosoplicatum ammonite Zones of the Tethyan Realm (Reboulet et al., 2018). Based on the Boreal nannofossil diagram of Jeremiah (2001), the nannoflora of the Uttins Marls indicate the late Early Hauterivian LK25 Zone including the upper Regale and lower Inversum ammonite Zones of the Boreal Realm.

4.3 Ostracods

The samples collected in the Urgonian facies of the Jura Mountains allowed us to recognize marine ostracod microfaunas with affinities to those from the Hauterivien (Oertli, 1989), Barremian (Scarenzi-Carboni, 1984; Babinot and Colin, 2011) and Aptien (Oertli, 1958; Sauvagnat, 1999). In the Urgonien Jaune facies and especially in its lower part (Montcherand Mb), ostracods are mostly represented by juvenile or subadult specimens of reduced size with incomplete and inconspicuous morphological features. The immature aspect of these ostracods found in confined marine paleoenvironments with presumably unstable ecological parameters is interpreted as dwarfism by growth anomalies (heterochrony), with neoteny and progenesis of very old evolutionary origin and common in fossil and current ostracods (Kamiya, 1992; Honigstein et al., 1993; Bertholon and Carbonel, 1995; McNamara and McKinney, 2005; Newman, 2005; Bennett, 2008; Bennett et al., 2012).

24 genera with at least 44 species from four ostracod Assemblages A1 to A4 are recorded below in a non-exhaustive list, because some rare taxa should be still described and precised. The ostracods are reported by assemblages (A1 to A4), frequency, localities, lithological units, with some taxonomical remarks (if necessary and pertinent), and classified at first by genus lineage and importance (with a first number for the genus, and a second number for the species), then by alphabetical order. Among the species mentioned, several are very significant for the Barremian-Aptian biostratigraphy in Europe [*S. chalilovi*, *R. geometrica*, *R. buechlerae*, *N. (C.) gottisi* according to Oertli (1958), Ainsworth (1986, 1987), Sauvagnat (1999), Babinot et al. (2007), Babinot and Colin (2011)].

Surprisingly, the basal Bôle Mb at Gorges de l'Orbe has also provided rare reworked Berriasian-Valanginian ostracods such as Early Berriasian *Fabanella boloniensis* (Jones, 1882) from the Purbeckian facies, Berriasian-Valanginian large *Paracypris* sp. and Late Valanginian *Mandocythere (Costacythere) frankei* (Triebel, 1938) indicating northwestern emerged lands in erosion process on the Paris Basin side.

Fairly similar to the Early Barremian ostracod microfauna collected at Corcelles-2, the Early Hauterivian material from the Uttins Marls (Mont de Chamblon near Yverdon-les-Bains, VD) is poor and rather badly preserved with *P. triplicata*, *R. bernardi* and rare *Schuleridea extranea* Grosdidier, 1964 according to Oertli (1989) as well as our own observations [the specimen of *S. extranea* figured by Oertli, 1989 (Pl. III, fig. 2) is very poorly preserved, but our material allows to confirm fully this determination].

4.3.1 Marine ostracods

1.1) *Strigosocythere chalilovi* (Kuznetsova, 1961) - Fig. 15.1–2, A4 basal (rare): Ponts-de-Martel, Eclépens, Vaulion; A4: present at Noire Combe (Rivière Mb), Bellegarde-sur-Valserine and Montanges (emersive layers of the Vallorbe Fm top), abundant in the lower Fulie Mb at Musinens (reworked Poet Beds) and La Presta (Poet Beds and Vauglène Beds).

1.2) *Strigosocythere strigosa* (Grosdidier, 1964) - Fig. 15.17–18, A2–A3: never abundant but present everywhere.

1.3) *Strigosocythere villierensis* (Stchepinsky, 1955) - A3: Montlebon (present but not abundant).

2.4) *Rehacythereis bernardi* (Grosdidier, 1964) - Fig. 15.22, A1: Les Saars-Le Mail, Corcelles-2.

2.5) *Rehacythereis geometrica* (Damotte and Grosdidier, 1963) - Fig. 15.5–7, A2 to A4: common in the Barremian-Early Aptian of the central Jura, juvenile specimens are common in the Urgonien Jaune facies of the Jura Mountains (A2–A3) whose the lower part is devoid of adult specimens (Montcherand Mb with A2 at Corcelles-1, Le Mail and Gorges de l'Orbe in the central Jura, and at Rocher des Hirondelles and Pont-des-Pierres in the southern Jura).

2.6) *Rehacythereis buechlerae* (Oertli, 1958) - Fig. 15.3–4, A4 of the southern Jura: Noire Combe (present in the Rivière Mb), Bellegarde-sur-Valserine and Montanges (rare in the emersive layers of the Vallorbe Fm top), Musinens (abundant in reworked marls of Poet Beds). Presumably derived from the angular and reticulate *R. geometrica*, this Late Barremian-Aptian taxon is a smooth and tuberculate species with a very reduced median rib and small scattered tubercles (the most developed behind and below the large sub-central muscle tubercle). In the Late Barremian of the Jura Mountains, there is only a primitive form of *R. buechlerae* with a few tubercles (Fig. 15.3–4) also common in the Late Barremian of Serre de Tourre (Urgonien Blanc facies of Ardèche in SE-France, Cotillon et al., 1979; Pascal et al., 1989; = "*R.* aff. *geometrica*" *sensu* Scarenzi-Carboni, 1984, p. 39, Pl. 4, figs. 14–16; *in* Oertli et al., 1985, p. 192–193, Pl. 46, figs. 21, 22), which was formerly recognized at La Rivière (Valserine) in the southern Jura (= "*Cythereis* aff. *buechlerae*", Oertli *in* Conrad, 1969, p. 64) and in the Subalpine Urgonian facies of Chartreuse (SE-France) under the name "*Cythereis (R.)* aff. *glabrella*" (Triebel, 1940) *sensu* Sauvagnat, 1999 (cf. Sauvagnat et al., 2001, Pl. 2.9–11, p. 95), this primal variant does not coexist with *R. geometrica* in the Barremian deposits of SE-France and indicates clearly a southern marine influence from the Subalpine area towards the Jura carbonate platform.

2.7-8) *Rehacythereis* spp. 2, 3 (and 5) - A4: emersive layers of the Vallorbe Fm top at Bellegarde-sur-Valserine, these rare large species could be described later with more material available. According to Babinot and Colin (2011, p. 750, Pl. 6, *R.* sp. 2: figs. 5–9; *R.* sp. 5: fig 10, *R.* sp. 3: figs. 14, 15), they are known in the Barremian of SE-France (sp. 3 and sp. 5 from Serre de Bleyton) and the Aptian of northern Spain (sp. 2 = "*Cythereis* aff. *semiaperta*" Damotte and Grosdidier, 1963 *in* Brenner, 1976). Two are strongly costulate with a major transverse median rib subdivided (sp. 2) or continuous (sp. 5), and are close enough to be probably the same species. The latter (sp. 3) is clearly different with a very large smooth and elongate muscle tubercle.

3.9) *Protocythere triplicata* (Roemer, 1841) - Fig. 15.19–21, A1 (very abundant), A2 (frequent) and A3-A4 (occasional and rare), present everywhere. NB: The species is known since the Late Valanginian in the Jura Mountains (Mojon *in* Blanc, 1996; Mojon, 2002).

3.10) *Protocythere derooi* Oertli, 1958 - A4: La Presta (abundant in the Vauglène Beds).

4.11) *Bairdoppilata barremiana* Mojon, n. sp. - Fig. 15.9–12, A2 to A4 (incl. Poet Beds): common everywhere. The basal Falaises Mb (A1) has provided some small-sized specimens of *B.* aff. *barremiana*, maybe juveniles as in A2, but there is no available comparison with other sites of the Falaises Mb to be sure of this specific identity.

4.12) *Bairdoppilata luminosa* Kuznetsova, 1961 - Fig. 15.13–14, A2 to A4 (incl. Poet Beds): common everywhere.

4.13) *Bairdoppilata* sp. 302 (Oertli, 1958) - Fig. 15.8, A4: Musinens only (present in reworked marls of Poet Beds). This large species with elevated carapace and distinct triangular outline is presumably derived from *B. barremiana*, it is common with *S. chalilovi* and *R. buechlerae* in the Late Barremian Urgonien Blanc facies of Serre de Tourre (Ardèche, SE-France) as already reported as *B.* aff. sp. 302 by Scarenzi-Carboni (1984, p. 24, Pl. 2, figs. 5, 6; *in* Oertli et al., 1985 as *B.* cf. sp. 302, p. 192–193, Pl. 46, fig. 2).

5.14) *Neonesidea* sp. - A1 to A4: occasional and rare.

6.15) *Neocythere (Centrocythere) gottisi* Damotte and Grosdidier, 1963 - Fig. 15.15–16, A2 to A4: common everywhere. The basal Falaises Mb (A1) has provided at Neuchâtel some small-sized stubby and globular specimens of *N. (C.)* aff. *gottisi* with ornamentation close to the type species.

6.16) *Neocythere (Centrocythere) bordeti* Damotte and Grosdidier, 1963 - A2 to A4 (presumably): smaller species of *Neocythere* with small knobs on the concentric ornamentation ribs, observed for sure in A3 (Bôle Mb of Gorges de l'Orbe) and probably also present much more widely, but very difficult to identify with certainty because the poor preservation of most small specimens collected.

6.17) *Neocythere (Centrocythere) djaffarovi* (Kuznetsova, 1961) - A2: rare species from the Barremian of Azerbaijan, only some specimens found at the Creux de Malevaux, with a typical coarsely pustulate ornamentation of small knobs on the outer surface of the valves.

7.18) *Schuleridea clunicularis* (Triebel, 1938) - A1: Basal Falaises Mb of Les Saars-Le Mail (reworked in A2/basal Montcherand Mb of Gorges de l'Orbe), very typical large species with strong sexual dimorphism.

7.19) *Schuleridea* gr. *thoerenensis* (Triebel, 1938) - A1: rare (Corcelles-2).

7.20) *Schuleridea derooi* Damotte and Grosdidier, 1963 - A2 to A4: present everywhere, abundant in the Bôle Mb of La Sarraz-Les Buis.

7.21) *Schuleridea alata* Kaye, 1965 - A3–A4: present everywhere, abundant in the Rivière Mb (Noire Combe) and the Vauglène Beds (La Presta).

7.22) *Schuleridea* sp. 1 formerly known in SE-France (Scarenzi-Carboni, 1984, p. 31, Pl. 2, figs. 24, 25; Babinot and Colin, 2011, p. 746, Pl. 4, figs. 14–16) - A3: rare in the Bôle Mb (Le Mail, Boudry, Bôle, Gorges de l'Orbe). This small species coarsely punctuate with a prominent smooth ridge has a biostratigraphical interest, but a precise description considering its particular features (pronounced sexual dimorphism notably) would need more material with many specimens (difficult to collect and currently not available because of their rarity).

8.23) *Asciocythere* sp. - A2 to A4: very small smooth species without interest for biostratigraphy, but very common everywhere.

9.24) *Cytherelloidea* sp. 1 formerly known in the Barremian of SE-France (Scarenzi-Carboni, 1984, p. 21–22, Pl. 1, figs. 14–16; Oertli et al., 1985, p. 192–193, Pl. 46, fig. 1) - A1: Basal Falaises Mb at Neuchâtel, some small-sized and short specimens characterized by valves ornamented with two main longitudinal ribs and a posterior vertical rib underlined by two protuberances at the dorsal and ventral ends.

9.25) *Cytherelloidea ghabounensis* Bischoff, 1964 - A2–A4: present everywhere, common but never abundant.

10.26) *Paracypris levis* Kuznetsova, 1961 - A2-A4: small species present everywhere, but never abundant.

10.27) *Paracypris acuta* (Cornuel, 1848) - A4: larger species of *Paracypris* frequent in the emersive layers of the Vallorbe Fm top at Bellegarde-sur-Valserine and also present in the Poet Beds of La Presta, some elongated specimens of big size could maybe belong to another species.

11.28) *Hechticythere hechti* (Triebel, 1838) - A1–A4: occasional and rare species of Hauterivian affinity.

11.29) *Hechticythere pumila* (Grosdidier, 1964) - A1–A4: occasional and rare species of Hauterivian affinity.

11.30) *Hechticythere* sp. 1 formerly known in SE-France (Babinot and Colin, 2011, p. 741, Pl. 2, figs. 1, 2) - A4: very rare (reworked marls of Poet Beds at Musinens), previously named "*Protocythere* aff. *croutesensis* Damotte and Grosdidier, 1963" (Scarenzi-Carboni, 1984, p. 47, Pl. 5, figs. 12–14; Babinot et al. *in* Oertli et al., 1985, p. 194–195, Pl. 47, figs. 6, 7). This particular large-sized species with elongated carapace broadly rounded anteriorly (without hinge ear) and ornamented by two (left valve) or three (right valve) large sub-parallel ribs belongs undoubtedly to the genus *Hechticythere* and has a biostratigraphical interest, but its detailed description would need many specimens currently not available because their rarity.

12.31) *Amphicythere* sp. - A3–A4: rare (Bôle Mb of Le Vanel, Poet Beds of La Presta).

13.32) *Candoniella*? sp. - A4: rare in the Poet Beds of La Presta. A medium-sized species of shallow marine environment presumably confined and brackish. The carapace is moderately inflated, smooth and symmetrical with a strongly arched dorsal margin (maximum height in its middle part), both ends narrowed and rounded, and ventral margin slightly incurved (cf. Late Albian-Early Cenomanian *Candoniella*? sp. 2 and sp. 3 *in* Bergue et al., 2016, p. 198, fig. 3G–J).

14.33) *Cresacytheridea* sp. - A4: rare (Rivière Mb of Noire Combe).

15.34) *Cytherella* gr. *ovata* (Roemer, 1841) - A3: rare (La Sarraz-Les Buis).

15.35) *Cytherella* gr. *parallela* (Reuss, 1846) - A1 to A4: species present everywhere, sometimes abundant (Rivière Mb of Noire Combe).

16.36) *Dolocythere longa* Gründel, 1966 - A3: rare (Creux de Malevaux, Le Vanel, Gorges de l'Orbe).

17.37) *Dolocytheridea intermedia* Oertli, 1958 - A3–A4: present in many localities [Bôle Mb of Bôle/Merdasson, Creux de Malevaux, Le Vanel, Eclépens, La Sarraz-Les Buis, Montcherand, La Russille, Vallorbe; Rivière Mb of Noire Combe (also reported by Oertli *in* Conrad, 1969); emersive layers of the Vallorbe Fm top at Bellegarde-sur-Valserine railway station; reworked marls of Poet Beds at Musinens]. According to our own observations, this Late Barremian-Aptian species is also frequent in the Late Barremian of Serre de Tourre (Urgonien Blanc facies of Ardèche, SE-France). Very rare and badly preserved specimens of *Dolocytheridea* sp. indet. are present in the Assemblage A2 of the basal Rocher des Hirondelles section.

18.38) *Parexophthalmocythere* sp. - A3: very rare (Le Mail, Gorges de l'Orbe).

19.39) *Platycythereis rostrata* Sauvagnat, 1999 - A4: common species in the emersive layers of Vallorbe Fm top at Bellegarde-sur-Valserine and Vallorbe.

20.40) *Trochinius consuetus* Kuznetsova, 1961 - A2–A3: rare, only at Pont-des-Pierres (this study), La Sarraz-Les Buis and Eclépens (De Kaenel et al., 2020).

21.41) *Xestoleberis* sp. - A4: La Presta (present in the Poet Beds).

4.3.2 Non-marine ostracods

Non-marine ostracods are common species in the emersive layers of the Vallorbe Fm top (with marine ostracods of A4) at Bellegarde-sur-Valserine and Montanges (Mojon *in* Pictet et al., 2019):

22.42) *Cypridea isasae* Kneuper-Haack, 1966.

23.43) *Macrodentina (Dictyocythere) gibbera* Brenner, 1976.

24.44) *Mantelliana* sp.

Among the listed taxa of ostracods and according to the references mentioned, most species (33) are known in the Barremian (Scarenzi-Carboni, 1984; Ainsworth, 1986, 1987; Schudack and Schudack, 2009 for the non-marine species; Babinot and Colin, 2011; Mojon *in* Pictet et al., 2019), four in the Aptian (*R. buechlerae*, *P. rostrata*, *B.* sp. 302, *D. intermedia*; Oertli, 1958; Sauvagnat, 1999; Babinot et al. 2007) and only seven are inherited from the Hauterivian (*P. triplicata*, *R. bernardi*, *S. clunicularis*, *S.* gr. *thoerenensis*, *H. hechti*, *H. pumila*, *D. longa*; Oertli, 1989).

4.3.3 New *Bairdoppilata* species systematics and taxonomy

Genus *Bairdoppilata* Coryell, Sample and Jennings, 1935.

Type species: *Bairdoppilata martyni* Coryell, Sample and Jennings, 1935; p. 2–4, figs. 1, 2.

Discussion: The taxonomy of the post-Paleozoic genus *Bairdoppilata* was argued by Coryell et al. (1935) and Maddocks (1969) according to a carapace morphology different from the genus *Bairdia* restricted to the Paleozoic. Although criteria of internal features could not be clearly observed because badly preserved, the Barremian material from the Jura Mountains is reported to *Bairdoppilata* (thin rounded subhexagonal valves, smooth or finely punctuate) in agreement with these authors and the different features of the Recent genera *Neonesidea* (elongate subtriangular valves, robust and coarsely punctuate) and *Paranesidea* (rotund thin valves, smooth or finely punctuate) created by Maddocks (1969).

***Bairdoppilata barremiana* Mojon, n. sp.**

Figure 15.9–12

Bairdia sp. 1 Scarenzi-Carboni, 1984; p. 24, Pl. 1, fig. 22.
Bairdia sp. 2 Scarenzi-Carboni, 1984; p. 24–25, Pl. 1, fig. 23.
Bairdia n. sp. Clavel et al., 1994; p. 30, 40, Pl. II, figs. 4–6.
Bairdoppilata sp. 1 Babinot and Colin, 2011; p. 753, Pl. 8, figs. 6, 7.

(See figure on next page.)

Fig. 15 Key-marker Hauterivian-Barremian ostracods from the Swiss and French Jura Mountains, collection P.-O. Mojon. 1–2: *Strigosocythere chalilovi* (Kuznetsova, 1961), RV, reworked marls of Poet Beds/A4 (latest Barremian paleokarst infilling), Musinens (Bellegarde-sur-Valserine, France). 3–4: *Rehacythereis buechlerae* (Oertli, 1958), RV, reworked marls of Poet Beds/A4 (latest Barremian paleokarst infilling), Musinens (Bellegarde-sur-Valserine, France). 5–7: *Rehacythereis geometrica* (Damotte and Grosdidier, 1963), adult specimens, Bôle Member/A3 (Early to Late Barremian transition), 5 (RV) – 6 (LV): same specimen, Le Vanel (Travers, NE); 7 (LV): Le Mail (Neuchâtel City). 8: *Bairdoppilata* sp. 302 (Oertli, 1958), RV, reworked marls of Poet Beds/A4 (latest Barremian paleokarst infilling), Musinens (Bellegarde-sur-Valserine, France). 9–12: *Bairdoppilata barremiana* Mojon, n. sp.; 9-11-12 (RV), 10 (LV), Bôle Member/A3 (Early to Late Barremian transition), Le Vanel (Travers, NE). 13–14: *Bairdoppilata luminosa* Kuznetsova, 1961; Bôle Member/A3 (Early to Late Barremian transition), 13 (RV): Le Vanel (Travers, NE); 14 (LV): Gorges-de l'Orbe/Montcherand (VD). 15–16: *Neocythere (Centrocythere) gottisi* Damotte and Grosdidier, 1963; 15 (LV), 16 (ventral view), Bôle Member/A3 (Early to Late Barremian transition), Gorges-de l'Orbe/Montcherand (VD). 17–18: *Strigosocythere strigosa* (Grosdidier, 1964), RV of rather poorly preserved specimens, basal Montcherand Member/A2 (Early Barremian), Gorges-de l'Orbe/Montcherand (VD). 19–21: *Protocythere triplicata* (Roemer, 1841), 19–20 (RV), Falaises Member/Corcelles Marls/A1 (Early Barremian), Corcelles-1 (NE); 21 (RV): Hauterive Member (Early Hauterivian), Vauseyon (Neuchâtel City). 22: *Rehacythereis bernardi* (Grosdidier, 1964), RV, Hauterive Member (Early Hauterivian), Vauseyon (Neuchâtel City). LV = left valve, RV = right valve, A1 to A4 = ostracod Assemblages 1 to 4

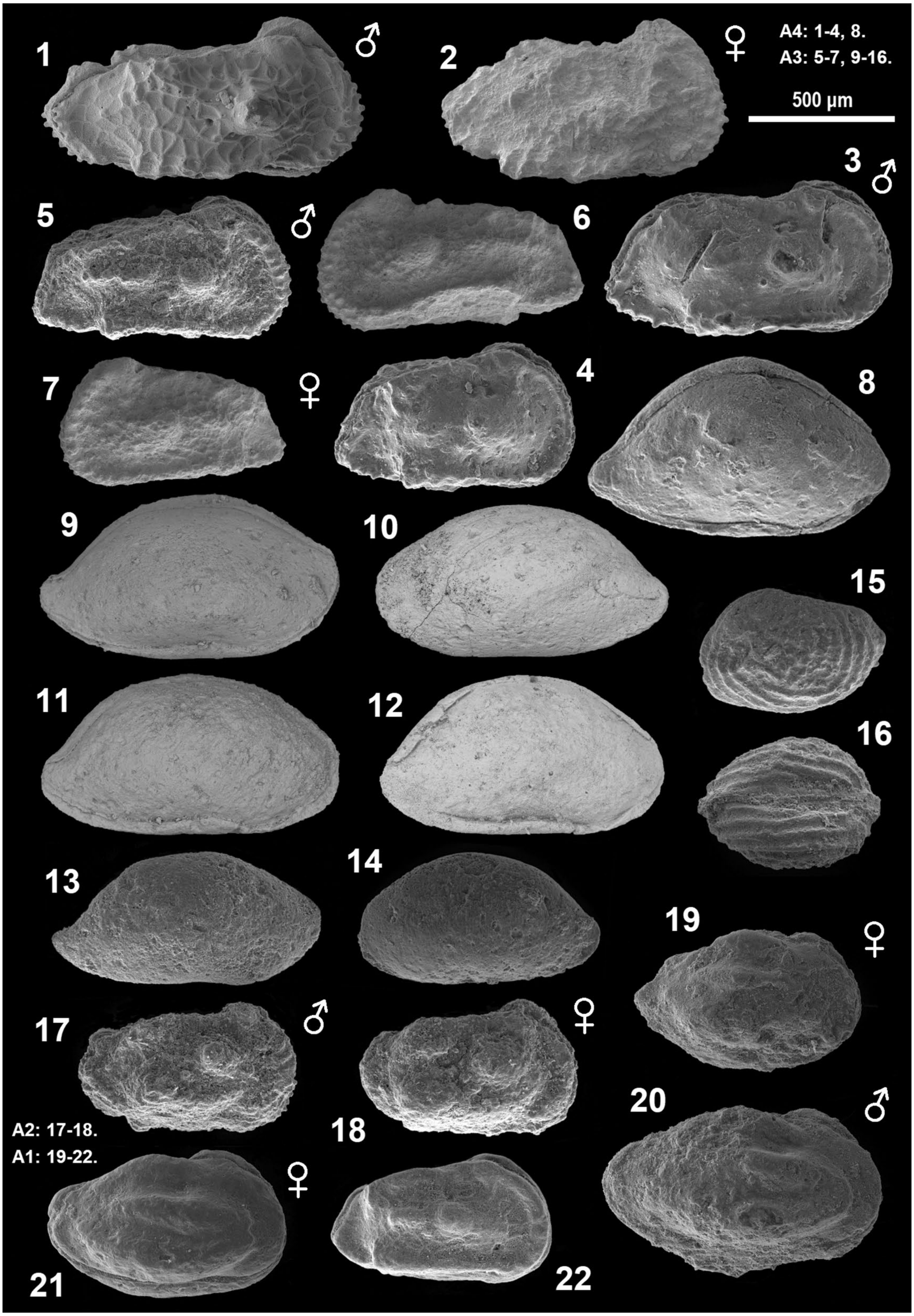

Fig. 15 (See legend on previous page.)

Derivation of name: Named after the Barremian Stage.

Material: Several hundred carapaces and valves collected in the Urgonien Jaune facies of the Jura Mountains.

Holotype: 1 carapace (Fig. 15.9), collection P.-O. Mojon (still under study, this collection will be deposited later in the MGL, UNIL-Dorigny, Lausanne).

Paratypes: 3 carapaces (Fig. 15.10–12), collection P.-O. Mojon (idem).

Dimensions: Holotype = Length 1 mm, Height 0.56 mm; Paratypes = Length 0.96–1 mm, Height 0.52–0.54 mm.

Type locality: Le Vanel near Travers (NE), western Swiss Jura Mountains.

Type level: Bôle Member, Early to Late Barremian transition.

Description: Large carapace with rounded subhexagonal outline and slightly convex thin valves with smooth and finely punctuate surface texture. In lateral view, the posterior end of the valves forms a protruding and short acute extension slightly curved up to their mid-height. The anterior border of the valves is rounded, sometimes also weakly curved up and widened to two-thirds of their height (Fig. 15.9). The left valve is the larger with a narrow dorsal and ventral overlap on the right valve, but anterior margin and posterior tip are not overlapped. The dorsal margin of the valves is rounded, the ventral margin is straight for the left valve and faintly arched inward in the middle part of the right valve.

Discussion: *Bairdoppilata barremiana* is close to *Bairdoppilata pseudoseptentrionalis* (Mertens, 1956) from the Albian-Cenomanian (Sauvagnat, 1999; Sauvagnat and Colin, 2013) and the Barremian species *Bairdoppilata* sp. 302 (Oertli, 1958) or cf. sp. 302 (Scarenzi-Carboni, 1984; Babinot et al. *in* Oertli et al., 1985), however markedly larger and higher with a distinctly triangular shape. The morphology of *Bairdoppilata luminosa* Kuznetsova, 1961 is also very similar, but the size is clearly smaller and the shape much more elongated. Other seemingly similar genera of Bairdiidae ostracods like *Neonesidea* or *Paranesidea* are presumably present in the Urgonien Jaune facies of the Jura Mountains. Specimens of *Neonesidea* sp. are attested (*Bairdia* sp. *in* Clavel et al., 1994, Pl. II, fig. 7), but not of *Paranesidea* however recognized in the Vocontian Basin (Babinot and Colin, 2011, Pl. 8, fig. 2).

Range and distribution: Barremian of SE-France (Vocontian Basin; Scarenzi-Carboni, 1984; Babinot and Colin, 2011) and W-Switzerland (Jura Mountains; Clavel et al., 1994; this study).

4.4 Brachiopods

This section is focused on the large *Glosseudesia* very useful for the biostratigraphy, and not on other interesting brachiopods such as rynchonellids (*Plicarostrum*, *Lamellaerynchia*, *Sulcirynchia*, *Belbekella*). The species *Sulcirynchia gillieroni* and *Sulcirynchia picteti* are quite common in the Bôle Member of Le Vanel section, large adult specimens of *Belbekella lata* are more unusual (one specimen from Le Mail section, found in 2009 and given on her request to Dr. D. Gaspard for the collections of the Muséum d'Histoire naturelle de Paris).

4.4.1 New Glosseudesia species systematics and taxonomy

Genus *Glosseudesia* Lobacheva, 1974.

Type species: *Terebratula semistriata* Defrance, 1828; p. 156.

Discussion: The taxonomy of the genus *Glosseudesia* was debated previously by Lobacheva (1974) and Middlemiss (1981, 1983).

***Glosseudesia inexpectata* Mojon, n. sp.**
Figure 16.5–9

Derivation of name: Named after the fortuitous discovery of this species in a construction site at Corcelles-1 (NE).

Material: 3 specimens collected in 2011 within excavations of the construction site Corcelles-1.

Holotype: 1 adult specimen well preserved (MGL 101598), Fig. 16.5–7.

Paratypes: 2 juvenile specimens with only the brachial valve well preserved (MGL 101598' and 101598"), Fig. 16.8–9.

Dimensions: Holotype (adult) = Length 3.15 cm, Width 2.8 cm, Thickness 2.2 cm.

Type locality: Corcelles-1 section nearby Neuchâtel City, western Swiss Jura Mountains.

Type level: Basal Montcherand Member, Early Barremian.

Description: A large species of *Glosseudesia* with an elongate and highly biconvex shell, strongly costulate with simple (undivided) longitudinal ribs. Adult shell ornamented with 12 ribs (holotype, Fig. 16.5–7), juveniles with 14 to 16 ribs (paratypes, Fig. 16.8–9). In dorsal view, umbo of the brachial valve with a very small smooth area (Fig. 16.6, 16.8-9).

Discussion: *Glosseudesia inexpectata* Mojon, n. sp. is part of an evolutionary lineage from the Late Valanginian to the Early Barremian in the Jura Mountains (Pictet and de Loriol, 1872; Middlemiss, 1989) and Transcaspia (Lobacheva, 1990). Late Valanginian to late Early Hauterivian *Glosseudesia cruciana* (Pictet, 1872) and Early to late Early Hauterivian *Glosseudesia marcousana* (d'Orbigny, 1847) have weaker ribs, bifurcated at their origin near the umbo of the brachial valve. Late Early Hauterivian to Early Barremian *Glosseudesia semistriata* (Defrance, 1828) is characterized by much more numerous fine undivided ribs and a large smooth umbo on the brachial valve (Fig. 16.3–4). Early Barremian *Glosseudesia ebrodunensis* (de Loriol, 1864) owns a few big undivided ribs and a very large smooth umbo on the brachial valve (Fig. 16.11, 16.13).

5 Discussion about datings and correlations

In addition to a previous study (De Kaenel et al., 2020), this work on the Urgonian Jaune (UJ) and Urgonien Blanc (UB) facies of the Jura Mountains introduces new lithostratigraphic units, as well as new datings by nannofossils and correlations according to ostracod Assemblages 1–4 and sedimentary discontinuities recognized in the reference sections presented (Figs. 10, 11). The nannofossils allow to date undoubtedly from the Early Barremian (Pulchella ammonite Zone) a non-basal lower part of the Urgonien Jaune (UJ) facies of the Neuchâtel area (new Falaises Mb) with a new lithostratigraphic bed named Corcelles Marls, and to differentiate it clearly from the late Early Hauterivian Uttins Marls of the Neuchâtel Mb in the central Jura (Fig. 11). Ostracod A1 to A4 can be used for precise correlations within the Barremian deposits of the UJ and UB facies in the central and southern Jura, as well as sedimentary discontinuities in order to demarcate the PJN, UJ and UB facies (discontinuities A to H).

The sedimentary discontinuities can correspond to parasequence boundaries (between relatively conformable and genetically interrelated rock strata, particularly in the Montcherand Mb of the lower Gorges de l'Orbe section) or to major 3rd order sequence boundaries (SbH4 to SbB3) indicated by bored surfaces often rubefied and encrusted with large oysters, or with major facies changes within 3rd order sequences linked to relative sea level variations (Barremian glacio-eustatism is not attested) and prograding deposits (mfsB3). The 3rd order sedimentary discontinuities are hardened surfaces (hardgrounds) strikingly bioperforated by lithophagous bivalves (pholads) and indicating relatively long periods of non-deposit before significative sedimentation changes, they must not be confounded with bioturbated surfaces of parasequences made of soft sediments affected by vertical borings of annelids and crustaceans.

The Late Hauterivian discontinuities A and B are often eroded and lacking, they are only preserved in some sections of the Neuchâtel area (Les Saars-Le Mail, Boudry) and are characterized by large bioperforations (Fig. 4c), the surface of the discontinuity A is also very irregular (Fig. 4a, b). In the sections of Les Saars-Le Mail (Figs. 4a–d) and Boudry (Fig. 7c), these major 3rd order discontinuities A and B are included in the top of the Neuchâtel Mb (PJN facies) constituted by typical massive limestone beds and are not in the basal marly UJ facies as reported by Godet et al. (2010, figs. 10, 11). These discontinuities A and B surround two thin limestone beds (1.6 m, Fig. 3), which can be attributed to the early Late Hauterivian Sayni ammonite Zone according to the data about the Grand-Essert Fm (Strasser et al., 2018) and the model of the Eclépens quarry section (Adatte et al., 2015; De Kaenel et al., 2020, fig. 3) with integrated data of ammonite zones and sequence boundaries by Arnaud (2005) reported in Fig. 11. The count of the discontinuities implies that the two later Late Hauterivian discontinuities SbH5 and SbH6 gathering the Ligatus and Balearis ammonite Zones (Arnaud, 2005) are superposed and merged in the discontinuity B corresponding to an important sedimentary hiatus, which must be considered and included in the top of the Neuchâtel Mb. The upper boundary of the Grand Essert Formation (Strasser et al.,

(See figure on next page.)

Fig. 16 Echinid and brachiopods from the Saars Formation of the Swiss Jura Mountains. 1–2: *Pseudholaster intermedius* (Münster *in* Goldfuss, 1826), same specimen in aboral (1) and oral (2) views, Falaises Member/Corcelles Marls (Early Barremian), Corcelles-1 (NE), MGL 101599. 3–4: *Glosseudesia semistriata* (Defrance, 1828), Falaises Member/Corcelles Marls (Early Barremian), Corcelles-2 (NE), collection P.-O. Mojon. 5–9: *Glosseudesia inexpectata* Mojon, n. sp.; basal Montcherand Member (Early Barremian), Corcelles-1 (NE); holotype (5–7): MGL 101598; paratypes (8–9): MGL 101598' and 101598''. 10–13: *Glosseudesia ebrodunensis* (de Loriol, 1864), Montcherand Member (Early Barremian), Eclépens quarry (VD), cf. De Kaenel et al. (2020), collection P.-O. Mojon. Ventral views of pedicle valves (3, 5, 10, 12), lateral view (7) and dorsal views of brachial valves (4, 6, 8, 9, 11, 13) of same specimens (3–4, 5–6–7, 8, 9, 10–11, 12–13)

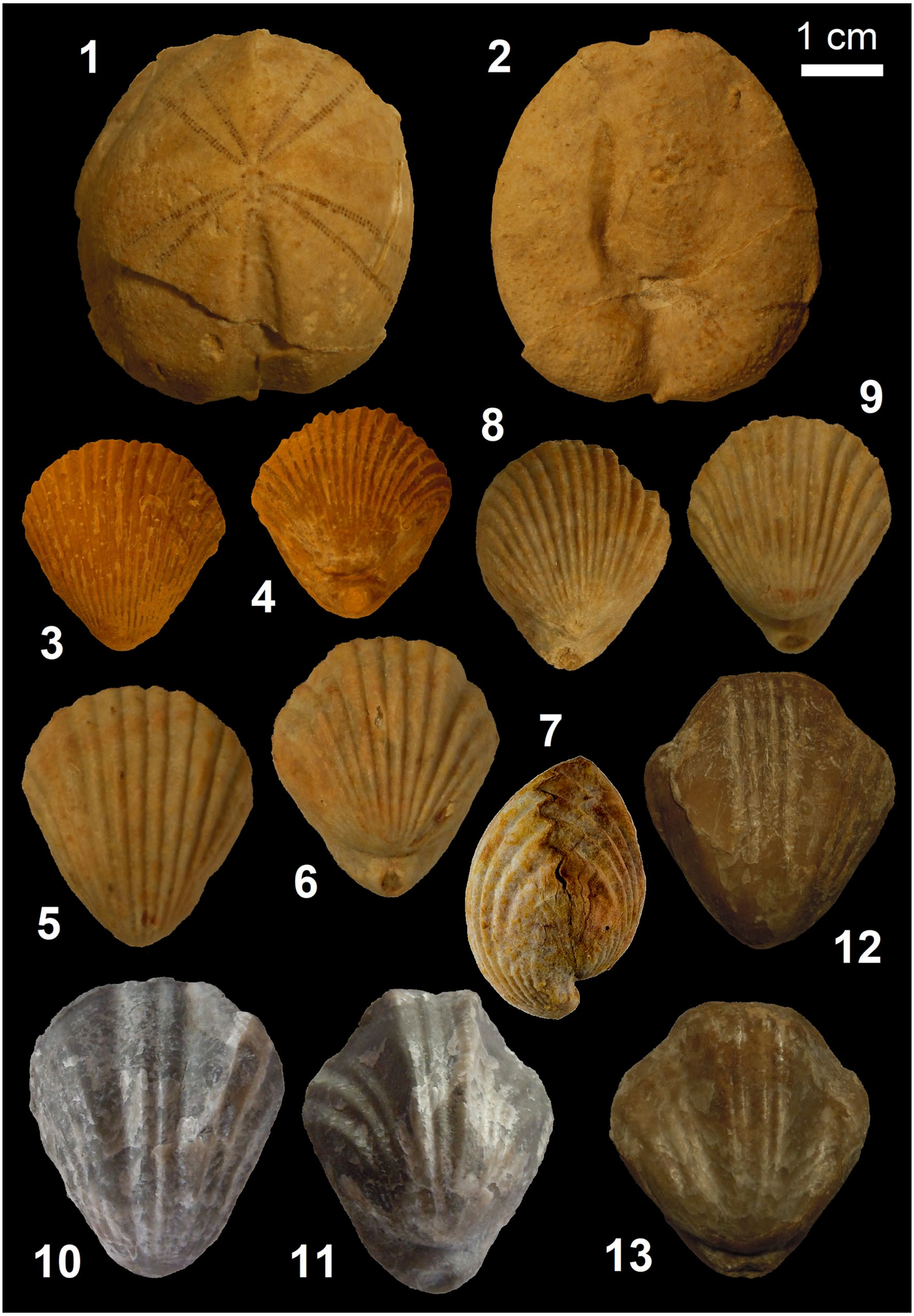

Fig. 16 (See legend on previous page.)

2016) and Neuchâtel Member (Strasser et al., 2018) can be therefore precised in order to integrate this long time gap between the 3rd discontinuities SbH5 and SbH6. In this way, only the basal UJ facies below the discontinuity C (SbH7) corresponds locally to the latest Hauterivian Ohmi ammonite Zone in the central Jura (Neuchâtel area as stated in this study, and La Sarraz-Les Buis quarry section according to De Kaenel et al., 2020).

Another point must be clarified absolutely about the non basal Late Hauterivian ammonite marker *Plesiospitidiscus ligatus* (d'Orbigny, 1841) mentioned by Strasser et al., (2018, p. 239) in the Salève section. This ammonite was a complete specimen badly preserved found by de Loriol (1861, p. 28) and also reported by Joukowski and Favre (1913), but neither figured by these authors nor revised later. There are neither illustration and trace of this ammonite in the collections of museums, nor plaster cast of this fossil apparently currently lost. Moreover, the origin of this ammonite would be the Uttins Marls of the Salève section and its determination was therefore incorrect (pers. comm. A. Pictet 2/9/2020), thus it is probably a late Early Hauterivian *Lyticoceras* of the Nodosoplicatum ammonite Zone according to the presence of well-developed flexuous ribs mentioned by de Loriol. Excepted two very rare early Late Hauterivian ammonites *Cruasiceras* cf. *cruasense* (Torcapel, 1884) at Eclépens (De Kaenel et al., 2020) and Grand-Essert (Strasser et al., 2018), no other typical and reliable markers of the Late Hauterivian were found in the Jura Mountains since the 19th century, and Late Hauterivian fossils seem therefore to be irrefutably almost completely absent. Consequently, there are no precise datings by fossils in the presumed non reworked Late Hauterivian deposits of the central Jura, especially since the ostracod Assemblage 1 of typical Hauterivian affinity extends in a large interval from the latest Valanginian to the Early Barremian.

The latest Hauterivian to Early Barremian discontinuities C (SbH7), D (SbB1) and E (SbB1') can be clearly observed on the field in the central Jura (De Kaenel et al., 2020; this study, Fig. 10), the discontinuity E corresponding to the base of the Montcherand Member. The discontinuities F (late Early Barremian SbB2 with ammonite *Pseudometahoplites* sp. juv. in the Gorges de l'Orbe section, Fig. 8e) and G (early Late Barremian SbB3 on top of the Mid-Barremian Event or MBE in the La Sarraz-Les Buis quarry section, Fig. 8b) are particularly well-marked in most sections (Fig. 10), and were also reported by De Kaenel et al. (2020) at Eclépens and La Sarraz-Les Buis. Another important surface boundary H is also well visible everywhere at the base of the UB facies of the central and southern Jura (De Kaenel et al., 2020; this study, Fig. 10), and corresponds to the mfsB3 or "maximum flooding surface" ending the transgressive interval of the early Late Barremian sequence Ba3 marked by a significant facies change between UJ and UB deposits in the central Jura (Les Saars-Le Mail, Bôle, Eclépens, Gorges de l'Orbe and Vallorbe sections) or between lower and upper UB sediments in the southern Jura (Rocher des Hirondelles section).

Several 3rd order sequence boundaries can sometimes be superimposed and merged (e.g., discontinuities A and B of the sequence boundaries SbH5 and SbH6 in the Saars-Le Mail section, and discontinuities A to E of the sequence boundaries SbH4 to SbB1' in the basal Gorges de l'Orbe and Vallorbe sections). Most of the reported sedimentary discontinuities do not provide themselves reliable dating because not associated with accurate biostratigraphical data, their positioning and correlations can be therefore essentially interpretative according to major changes in the lithology and facies if it is difficult or impossible to observe them directly on the field (e.g., sequence boundary SbB4 in the Vallorbe and Rocher des Hirondelles-La Rivière sections). The framework of the paleoenvironments and their correlations includes new elements for datings and sequences boundaries within the lower UJ facies (Falaises Mb and Montcherand Mb) with tidal dominated deposits of mainly oolitic/bioclastic sandbars as well as estuarine and mangrove marls, and within the upper UJ facies (Bôle Mb) and UB facies (Rocher des Hirondelles Fm, Vallorbe Fm) corresponding to more open sea conditions with lagoons and reefs. So, the synthesis diagram presented on Fig. 10 is very relevant and consistent with the stratigraphic model and integrated ammonite zones reported by De Kaenel et al., (2020, fig. 3).

6 Conclusions

The biostratigraphic and sequential datings and correlations of this study allow a fairly complete representation of the Urgonian facies in the Swiss and French Jura Mountains, with new Saars Formation (new Falaises Member with Corcelles Marls, Montcherand and Bôle members of Pictet, 2021 forming the "Russille Marls complex" *sensu* De Kaenel et al., 2020 with four main marly layers I–IV), Rocher des Hirondelles Formation (revised from Pictet, 2021) with Fort de l'Ecluse and Rivière members (Pictet, 2021) and Vallorbe Formation (revised from Strasser et al., 2016 and Pictet, 2021), which are of mostly Barremian age (Figs. 10, 11). The main results of this study are:

1) For the Urgonien Jaune facies, evidence of a new Falaises Member (latest Hauterivian-Early Barremian) and a new Saars Formation (latest Hauterivian-early Late Barremian) replacing the incomplete Gorges de l'Orbe Formation of Strasser et al. (2016).

2) Early Barremian nannoflora (lower Pulchella ammonite Zone) associated in the Falaises Mb with fossils

usually considered as Early Hauterivian, such as ostracods [Assemblage 1 with *Protocythere triplicata* (Roemer, 1841), *Rehacythereis bernardi* (Grosdidier, 1964), *Schuleridea clunicularis* (Triebel, 1938) and *Schuleridea* gr. *thoerenensis* (Triebel, 1938)], sea urchin *Pseudholaster intermedius* (Münster *in* Goldfuss, 1826) and brachiopods *Glosseudesia semistriata* (Defrance, 1828), *Plicarostrum aubersonense* Burri, 1956 and *Lamellaerynchia hauteriviensis* Burri, 1953, implying a stratigraphic range extended in the Early Barremian.

3) Hauterivian-Early Aptian ostracod zonation with four assemblages A1 to A4. The first typical Barremian ostracods [*Rehacythereis geometrica* (Damotte and Grosdidier, 1963), *Bairdoppilata barremiana* Mojon, n. sp., *Bairdoppilata luminosa* Kuznetsova, 1961; *Neocythere (Centrocythere) gottisi* Damotte and Grosdidier, 1963; *Schuleridea derooi* Damotte and Grosdidier, 1963] occur only in the Early Barremian (upper Pulchella and Compressissima ammonite Zones with A2 characterized by juveniles specimens), with an acme in A3 and A4 (late Early to latest Barremian-earliest Aptian).

4) Significant synsedimentary anomalies in the Urgonien Jaune facies of the central Swiss Jura with latest Hauterivian-Early Barremian Falaises Mb reworked in the basal Saars Fm (sections of Eclépens, Gorges de l'Orbe and Vallorbe) or overlying the uppermost Neuchâtel Mb (early Late Hauterivian Sayni ammonite Zone) with a hiatus of the Late Hauterivian Ligatus and Balearis ammonite Zones (Les Saars-Le Mail section). In the Gorges de l'Orbe section, the first Barremian ostracods A2 occur in a condensed marly layer at the base of the Montcherand Mb, with abundant glauconite and ostracods A1 [*Schuleridea clunicularis* (Triebel, 1938)] reworked from prior Late Hauterivian-basal Barremian Falaises Mb sediments. Another example of reworked glauconite and ammonite *Cruasiceras* cf. *cruasense* (Torcapel, 1884) from the early Late Hauterivian Sayni Zone is also reported in the Falaises Mb of the Eclépens section (De Kaenel et al., 2020). Other important synsedimentary anomalies are illustrated by Urgonien Blanc facies of the southern French Jura with the extra thickness of the Fort de l'Ecluse Mb (Rocher des Hirondelles) and Vallorbe Fm (Vallorbe type section), or in the Neuchâtel area by truncated Vallorbe Fm and incomplete Aptian deposits of the Vanel section (Thiébaud, 1937). Pictet et al. (2019) also reported major synsedimentary anomalies for the Aptian-Albian deposits of the Jura Mountains generated by depressions forming depocenters within sea straits connecting through a "Jura-Burgundy thresold" the Tethyan Ocean with the Paris Basin and the Boreal Ocean. All these synsedimentary anomalies can be presumably related to synsedimentary paleotectonics by "tilted blocks" influencing the Hauterivian-Barremian and Aptian-Albian sedimentation in the Jura area (Pictet et al., 2019; De Kaenel et al., 2020; Pictet, 2021), and generated by still active fractures of the Hercynian basement such as the Vuache, Morez and Pontarlier faults (cf. Mormont-La Sarraz fault system mentioned by De Kaenel et al., 2020).

Despite very significant advances, the following topics must be clarified absolutely with more detailed precisions:

This study is a general and still preliminary approach to the ostracods from the Urgonian facies of the Jura Mountains, the taxonomy of many species remains to be precised with exhaustive and more complete illustrations involving an additional harvest work, long and difficult given the relative scarcity and often poor preservation of these ostracods.

In the southern French Jura, the lower limit and thickness of the Falaises and Montcherand members as well as the extension of the Saars Fm are not known exactly because of observation gaps by areas covered with vegetation in the reference sections of La Chambotte, Sillens and Rocher des Hirondelles previously studied by Viéban (1983), and therefore remain to be specified using other sections (e.g., Pont-des-Pierres section).

According to the results of this study, the synthesis schemes for the Urgonian facies of the Jura Mountains by Pictet (2021, figs. 25, 26) are premature and marred by errors, new diagrams should be established including the requested details about the lithostratigraphy of the Saars Fm in the southern French Jura.

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Authors' contributions
POM produced the article except the part about the nannofossils performed by EdK. Both authors read and approved the final manuscript.

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Availability of data and materials
The reference fossil specimens of this study (ostracods and brachiopods, collection P.-O. Mojon) and reference samples of sediments for the nannofossils will be available at the paleontological collection of the Musée géologique de

Lausanne (abbr. MGL, UNIL-Dorigny, Lausanne, Switzerland), the glass slides with nannofossils are conserved and available in the collection of E. de Kaenel (De Kaenel Paleo Research, Mont-sur-Rolle, Switzerland).

Declarations

Ethics approval and consent to participate

"Not applicable".

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Competing interests

The authors declare that they have no competing interests.

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