New biostratigraphical data for the Burdigalian Montchaibeux Member at the locality Courrendlin-Solé (Canton of Jura, Switzerland)

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Abstract Geological surveys were carried out in the Miocene deposits at the place known as "En Solé" east of the village Courrendlin (Delémont Basin, Canton of Jura, Switzerland). This resulted in the discovery of new Miocene small mammal assemblages. The association of the rodents *Megacricetodon* aff. *collongensis* and *Melissiodon* sp. allows to biochronostratigraphically correlate for the first time the so-called "Rote Mergel des Mont Chaibeux" representing the lower part of the Montchaibeux Member of the Bois de Raube Formation to the regional *M. collongensis–Keramidomys* interval zone (MN 4; early Miocene).

Keywords Switzerland · Canton of Jura · Miocene · Biostratigraphy · Micromammals
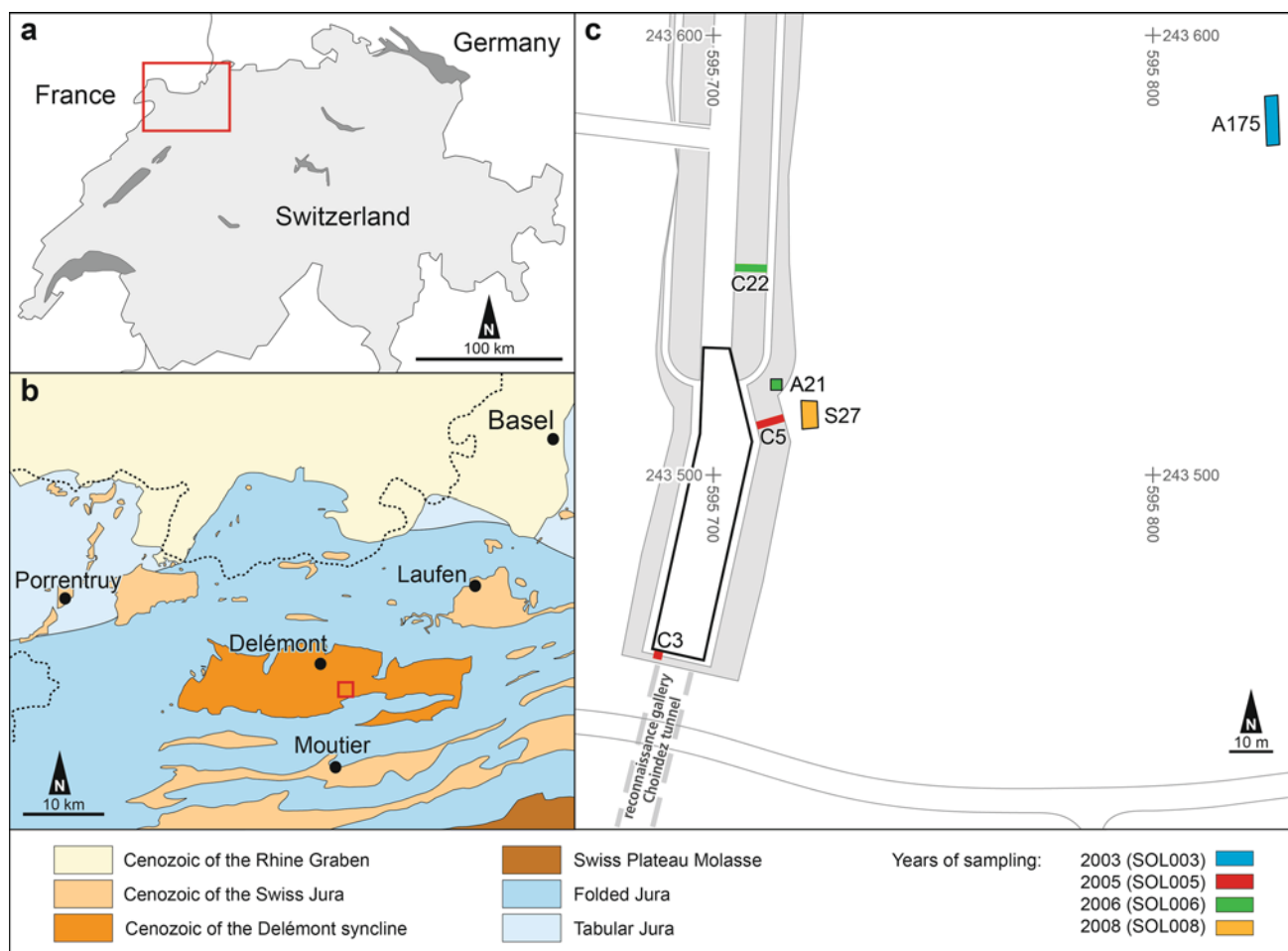
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Abbreviations

CRD-SOL	Courrendlin-Solé
M/m	Upper/lower molar
MJSN	JURASSICA Museum (old Musée jurassien des Sciences naturelles)
MN	Mammal Neogene
NAFB	North Alpine Foreland Basin
OMM	Obere Meeresmolasse (Upper Marine Molasse)
OSM	Obere Süsswassermolasse (Upper Freshwater Molasse)
P/p	Upper/lower premolar

1 Introduction

From 2003 to 2008 geological surveys and sampling were carried out in Miocene deposits during the construction of the motorway A16 (Transjurane) between kilometres 42.500 and 42.840 of section 8 at the place known as "En Solé" east of the village Courrendlin (Delémont Basin, Canton of Jura, Switzerland; Fig. 1). These recent investigations led to the documentation of a sedimentary series composed mainly of small mammal-bearing red marl, nearly reaching 10 m measured at the construction site of the motorway A16 just east of the Birse River (Fig. 2).

We report here the description and the identification of new Miocene small mammal assemblages discovered at the locality Courrendlin-Solé. The general stratigraphic context of the Bois de Raube Formation provided by Kälin (1997) is emended. Additionally, the biochronostratigraphical position of the so-called "Rote Mergel des Mont Chaibeux" sensu Liniger (1925) representing the lower part of the Montchaibeux Member of the Bois de Raube

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Fig. 1 The small mammal locality Courrendlin-Solé (red square). **a** The geographic position in Switzerland. **b** Simplified geologic map of the NW Switzerland, with the position of the locality in the Delémont Basin. **c** Position of sampling sites at Courrendlin-Solé near the entrance of the future Choindez tunnel

Formation, is established for the first time in the Delémont Basin.
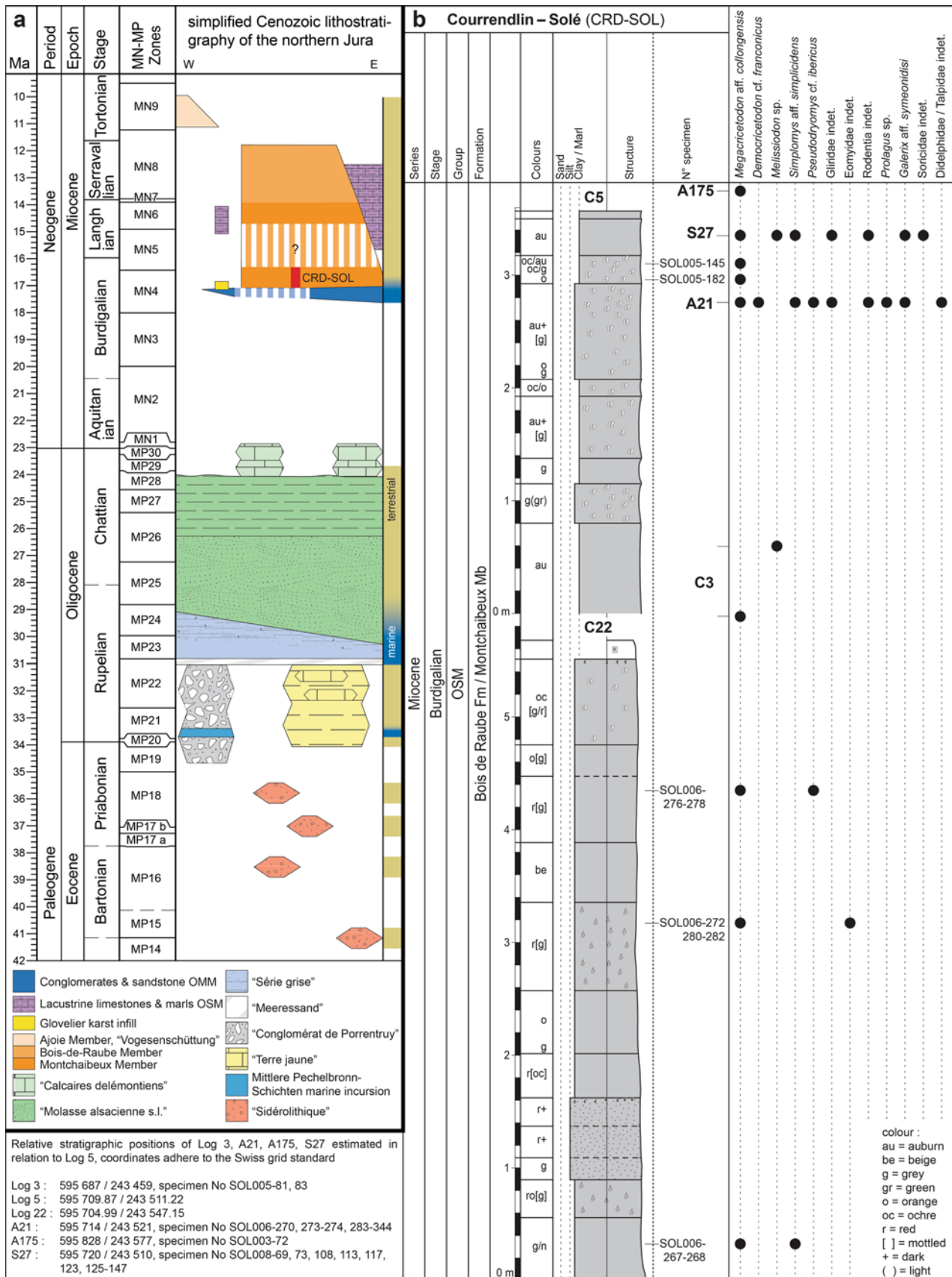
2 Geological setting

The Delémont Basin lies at the palaeogeographic junction between the Cenozoic tectonic and sedimentary provinces of the Upper Rhine Graben and the North Alpine Foreland Basin (Berger et al. 2005a; Sissingh 2006). The simplified synthetic post-Mesozoic stratigraphic column of the northern Jura (Ajoie and Delémont Basin; Fig. 2a) extends from the Late Eocene laterites (Sidérolithique) to the supposed Pliocene fluviatile clastics (Sundgauschotter, Argiles de Bonfol; not depicted here) (Berger et al. 2005b). The fluvio-lacustrine sediments of the Miocene Bois de Raube Formation were deposited after a long hiatus (e.g., Becker 2003) discordantly on different substrates (e.g., Chattian fluviatile sediments of the upper Molasse alsacienne or latest Chattian-earliest Aquitanian freshwater

Fig. 2 a Simplified lithostratigraphy of the northern Jura, with the ▶ stratigraphic position of Courrendlin-Solé (bold red line). Timescale after GTS 2012, MN5-8 biozones adapted according to Kälin and Kempf (2009) and Reichenbacher et al. (2013). **b** Synthetic log of the Courrendlin-Solé section, with range chart of small mammal taxa. Sample sites and logs refer to numbers in Fig. 1

limestone of the Calcaires delémontiens). Marine sands and gravels of the Upper Marine Molasse ("Obere Meeresmolasse", (abbreviated OMM) occur only to the south and the east of the research area (e.g., Liniger 1925; Becker 2003); they seem to be absent at Courrendlin-Solé.

Historically the "Rote Mergel des Mont Chaibeux" west of the Birse River have been discussed either as a lithostratigraphic unit directly related to the overlying "Dinotheriensande" with no distinct limit and abundant reworked material derived from older units (Calcaires delémontiens, OMM), or equivalent to red marls directly overlying the OMM sediments recorded in the eastern part of the Delémont Basin. "Dinotheriumsande"-equivalent deposits seem to be missing further to the east (Corban) and

a

Ma	Period	Epoch	Stage	MN-MP Zones
10	Neogene	Miocene	Tortonian	MN9
11				
12			Serravallian	MN8
13				MN7
14			Langhian	MN6
15				MN5
16			Burdigalian	MN4
17				
18				
19				MN3
20				
21			Aquitanian	MN2
22				
23				MN1
24	Paleogene	Oligocene	Chattian	MP30 / MP29 / MP28 / MP27
25				MP27
26				MP26
27				
28				MP25
29				MP24
30			Rupelian	MP23
31				MP22
32				
33				MP21
34				MP20
35			Priabonian	MP19
36		Eocene		MP18
37				MP17 b / MP17 a
38			Bartonian	MP16
39				
40				MP15
41				
42				MP14

simplified Cenozoic lithostratigraphy of the northern Jura

W   E

CRD-SOL

terrestrial / marine

Legend:
- Conglomerates & sandstone OMM
- Lacustrine limestones & marls OSM
- Glovelier karst infill
- Ajoie Member, "Vogesenschüttung"
- Bois-de-Raube Member
- Montchaibeux Member
- "Calcaires delémontiens"
- "Molasse alsacienne s.l."
- "Série grise"
- "Meeressand"
- "Conglomérat de Porrentruy"
- "Terre jaune"
- Mittlere Pechelbronn-Schichten marine incursion
- "Sidérolithique"

Relative stratigraphic positions of Log 3, A21, A175, S27 estimated in relation to Log 5, coordinates adhere to the Swiss grid standard

Log 3 : 595 687 / 243 459, specimen No SOL005-81, 83
Log 5 : 595 709.87 / 243 511.22
Log 22 : 595 704.99 / 243 547.15
A21 : 595 714 / 243 521, specimen No SOL006-270, 273-274, 283-344
A175 : 595 828 / 243 577, specimen No SOL003-72
S27 : 595 720 / 243 510, specimen No SOL008-69, 73, 108, 113, 117, 123, 125-147

b   Courrendlin – Solé (CRD-SOL)

Series | Stage | Group | Formation | Colours | Sand / Silt / Clay / Marl | Structure | N° specimen

Miocene | Burdigalian | OSM | Bois de Raube Fm / Montchaibeux Mb

Taxa columns:
Megacricetodon aff. *collongensis*, *Democricetodon* cf. *franconicus*, *Melissiodon* sp., *Simplomys* aff. *simplicidens*, *Pseudodryomys* cf. *ibericus*, Gliridae indet., Eomyidae indet., Rodentia indet., *Prolagus* sp., *Galerix* aff. *symeonidisi*, Soricidae indet., Didelphidae / Talpidae indet.

Samples/levels:
- C5 — A175
- S27
- au
- oc/au, oc/g, o — SOL005-145, SOL005-182
- A21
- au+ [g], o, g
- oc/o
- au+ [g]
- g
- g(gr)
- au — C3
- 0 m
- C22
- oc [g/r]
- o[g]
- r[g] — SOL006-276-278
- be
- r[g] — SOL006-272 280-282
- o
- g
- r[oc]
- r+
- r+
- g
- ro[g]
- g/n — SOL006-267-268

colour :
au = auburn
be = beige
g = grey
gr = green
o = orange
oc = ochre
r = red
[ ] = mottled
+ = dark
( ) = light

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southeast (Vermes), but red marls comparable to the "Rote Mergel des Mont Chaibeux" are present in both localities (Greppin 1855; Rollier 1898, 1910; Liniger 1925; Waibel 1925; Engesser et al. 1981) but are situated below the Vermes limestone (Upper Freshwater Molasse; "Obere Süsswassermolasse", abbreviated OSM). Effectively, Liniger (1925) described the red marly deposits situated below the church of Corban as "Rote Mergel von Corban", whereas in the Vermes area located at the southeastern end of the Delémont Basin similar red marls are sandwiched between the Molasse alsacienne, the Calcaires delémontiens and marine remnants ("poudingues polygeniques" of the Upper Marine Molasse) below and lacustrine marls and limestones above (Rollier 1910; Waibel 1925; Engesser et al. 1981).

Kälin (1997) revised the lithostratigraphy of the regional Miocene clastic sediments by the erection of the Bois-de-Raube Formation. Within the Delémont Basin, the formation was subdivided in a basal Montchaibeux Member (including the "Rote Mergel und Dinotheriensande des Mont Chaibeux" of Liniger 1925 as well as similar sediments recorded in the Delémont Basin), a middle conglomeratic Bois de Raube Member ("Vogesenschotter des Bois de Raube" of Liniger 1925) and a mixed upper Ajoie Member ("Hipparionsande von Charmoille" of Liniger 1925). The latter is exclusively recorded in Ajoie district and differs by a markedly different heavy mineral spectrum and pebble content.

Furthermore, Kälin (1997), due to the constrained biostratigraphic range of the Vermes assemblages (Kälin 1993) and the lack of a proper dating of the "Rote Mergel", stated a concordant superposition of the Montchaibeux Member on the Middle Miocene freshwater limestones of the Vermes locality, which is contrary to Engesser et al. (1981; see above).

Liniger (1925) interpreted the maximum contemporary thickness of the lower part of the Montchaibeux Member at its type locality to reach 10–20 m ("Rote Mergel"), which is overlain by 80 m of sandy deposits of the "Dinotheriensande". The typical red marls found at Courrendlin-Solé can accordingly be attributed to the lower part of the Montchaibeux Member. In detail, the sediments at Courrendlin-Solé range from ochre or red marls to similarly coloured siltstones, partly bearing abundant calcareous nodules. As a result, the small hill (47.34387°N, 7.38359°E) closer to the motorway A16 may be considered as a smaller erosional remnant similar to the hill of the Montchaibeux west of the Birse River.

3 Materials and methods

Samples were derived from 6 related sites (Fig. 1c) close to the entrance of reconnaissance gallery of the future Choindez Tunnel. C3 (47.34240°N, 7.38149°E), C5 (47.34303°N, 7.38189°E) and C22 (47.34330°N, 7.38192°E) represent inclined logs that have been corrected for vertical thickness (Fig. 2b). The relative stratigraphic position of the unlogged sample digs A21 (47.34318°N, 7.38198°E), A175 (47.34362°N, 7.38352°E) and S27 (47.34299°N, 7.38202°E) is indicated in Fig. 2b.

Several hundred kilograms of red marls were screen-washed down to 125 µm mesh size. Residues larger than 250 µm were systematically screened for small mammal teeth. The analysed material consists of 109 small mammal teeth and fragments. The measuring of *Megacricetodon* teeth adheres to the method described in Prieto et al. (2016). The referred small mammal teeth are stored in the collection PAL A16 of the JURASSICA Museum in Porrentruy (Canton of Jura, Switzerland).

The chrono- and biostratigraphic correlations follow Prieto and Rummel (2016), adapted from Kälin and Kempf (2009), Abdul Aziz et al. (2010) and Reichenbacher et al. (2013). In this work, and in contrast to Reichenbacher et al. (2013), we do not divided the MN 4 into two "subzones". The use of the MN-system has been shown to be problematic for the time range considered herein and allows only for an approximate long distance correlation (e.g., van der Meulen et al. 2011). We refer to Kälin and Kempf (2009) for the correlation of the Swiss local biozonation to the MN-system. Given the stratigraphic range considered herein, we implement some clarification regarding the correlation between the Swiss and German regional scales around the MN 4–MN 5 transition. This transition is traditionally linked in the NAFB to the Oberkulm-Sämlen/Tägernaustrasse assemblages in Switzerland and to the OSM A/OSM B in Germany (e.g., Reichenbacher et al. 2013). Prieto and Rummel (2016) conclude that the first occurrence of the eomyid rodent *Keramidomys* is the only taxon, which allows to clearly discriminate the Oberkulm-Sämlen assemblage on one hand and the OSM B on the other; the lack of the eomyid rodent *Ligerimys* cannot be used as a definitive argument for a primitive faunal imprint because of possible sampling bias. As a result, some German localities lacking Eomyidae are difficult to assign [assigned to OSM A or B in Prieto and Rummel (2016), but traditionally correlated to OSM B]. In contrast, such faunas are correlated to older deposits in the Swiss part of the basin, like for instance Eiboden (Kälin and Kempf 2009). In this locality *Megacricetodon* is rare, and the single M1 is relatively large for the primitive species *M.* aff. *collongensis* (Fig. 3a). This suggests that the Oberkulm-Sämlen/Tägernaustrasse transition also in Switzerland is difficult to characterize as seen in Germany. In addition, Fig. 3a shows that the first occurrence of *Keramidomys* is at present slightly heterochronous in both parts of the basin. Thus, and given the present state of knowledge, only a coarse correlation can be proposed (shaded area in Fig. 3d).
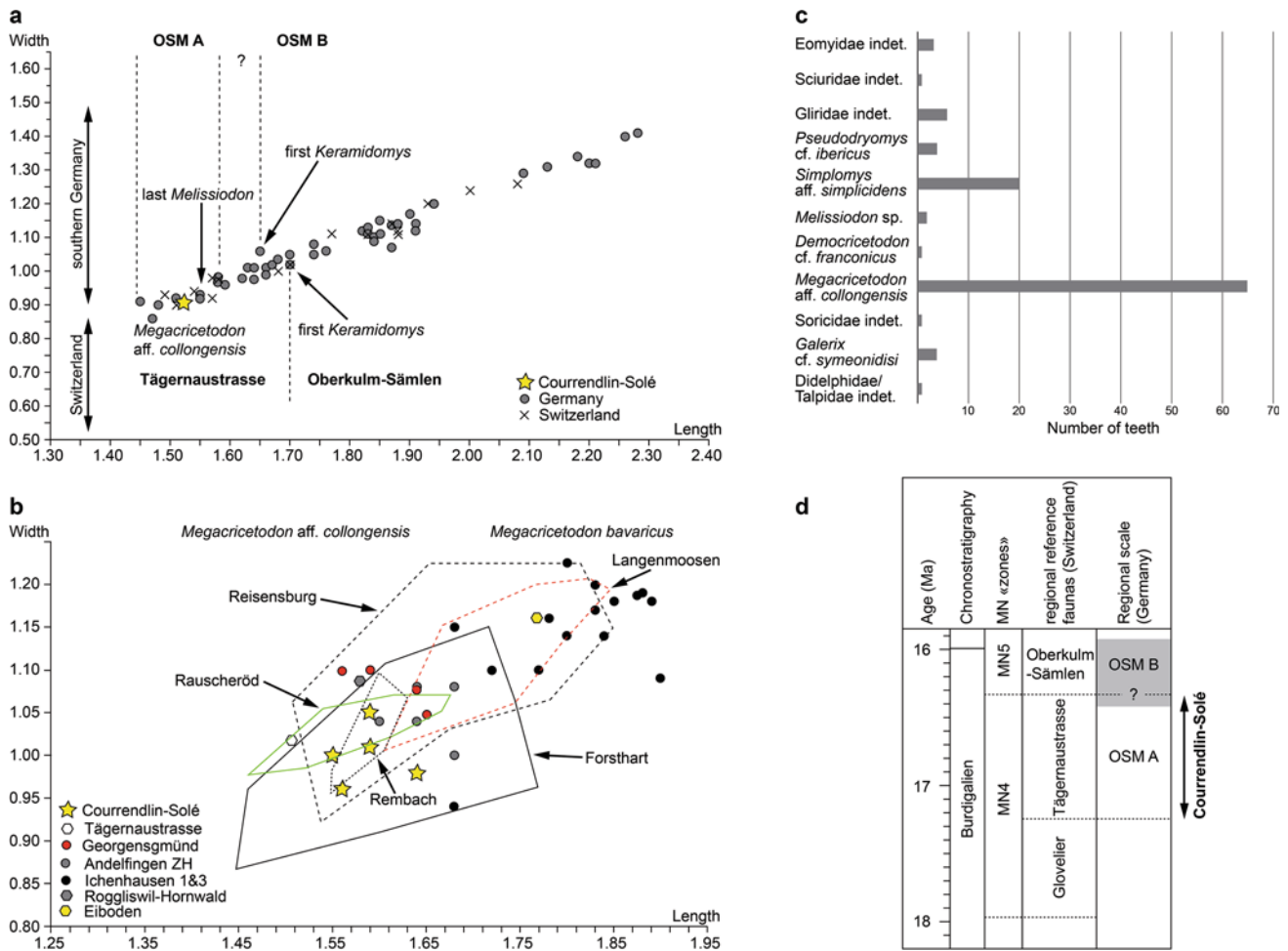
Fig. 3 **a** Length/width diagram of the first lower molar (mean values) of the cricetid rodents of the "*Megacricetodon bavaricus* group" from different localities in Southern Germany and Switzerland. Note the anagenetic trend in size increase through time, the smaller (older) species being assigned to *M*. aff. *collongensis*. The important stratigraphical divisions of the Molasse Basin, as well as occurrences of biostratigraphically important taxa are also included (see text for details; after Prieto and Rummel 2016). Be aware that the value of Courrendlin-Solé refers to one single specimen. **b** Size of the first upper molars from Courrendlin-Solé compared to the specimens of *M*. aff. *collongensis* from Germany (Forsthart, Rembach, Rauscheröd 1b + c, Georgensgmünd, Reisensburg; Ziegler and Fahlbusch 1986; Berger 2010; Seehuber 2015) and Switzerland (Andelfingen,

Roggliswil-Hornwald, Tägernaustrasse, Eiboden; Bolliger 1992; Jost et al. 2016; pers. data JP), and *M. bavaricus* from Langenmoosen (type locality; Fahlbusch 1964) and Ichenhausen 1 and 3 (pers. data JP). Note that the M1 from Courrendlin-Solé range in the size variation of *M*. aff. *collongensis*. **c** Abundance of the small mammal taxa from the composite fauna Courrendlin-Solé (in number of teeth). In order to make the diagrams (figs. **a** and **b**) easier to interpret, the scale used in the axes are different. The polygons are convex hulls. **d** Biostratigraphic correlation of Courrendlin-Solé to the two regional scales used in the North Alpine Foreland Basin. The shaded area refers to uncertainty range in the correlation between both scales (see text for details)

4 Small mammal assemblages

Most of the 109 determinable mammal teeth belong to the Rodentia. The cricetid rodents *Megacricetodon* aff. *collongensis* (Fig. 4a–c, e–h) represents around 60% of the recovered specimens (Fig. 4c) and occurs along the entire section (Fig. 2b). As discussed below, the genus is of high importance for the biostratigraphic correlation at the transition from the early to the middle Miocene. In the NAFB, the species assigned to the "*M. bavaricus* group" (sensu

Oliver and Peláez-Campomanes 2013) are traditionally included in the lineage *M*. aff. *collongenis*–*M. bavaricus*–*M. lappi* (e.g., Abdul Aziz et al. 2010 and references therein). Berger (2010) also includes *M. bourgeois*, but in our opinion the validity of this proposal, although plausible, has yet to be clearly demonstrated. Discrimination between these species remains vague being mainly based on their size differences. For this reason, Prieto and Rummel (2016) propose to use the general designation "*M. bavaricus* group" with indication of the mean size of
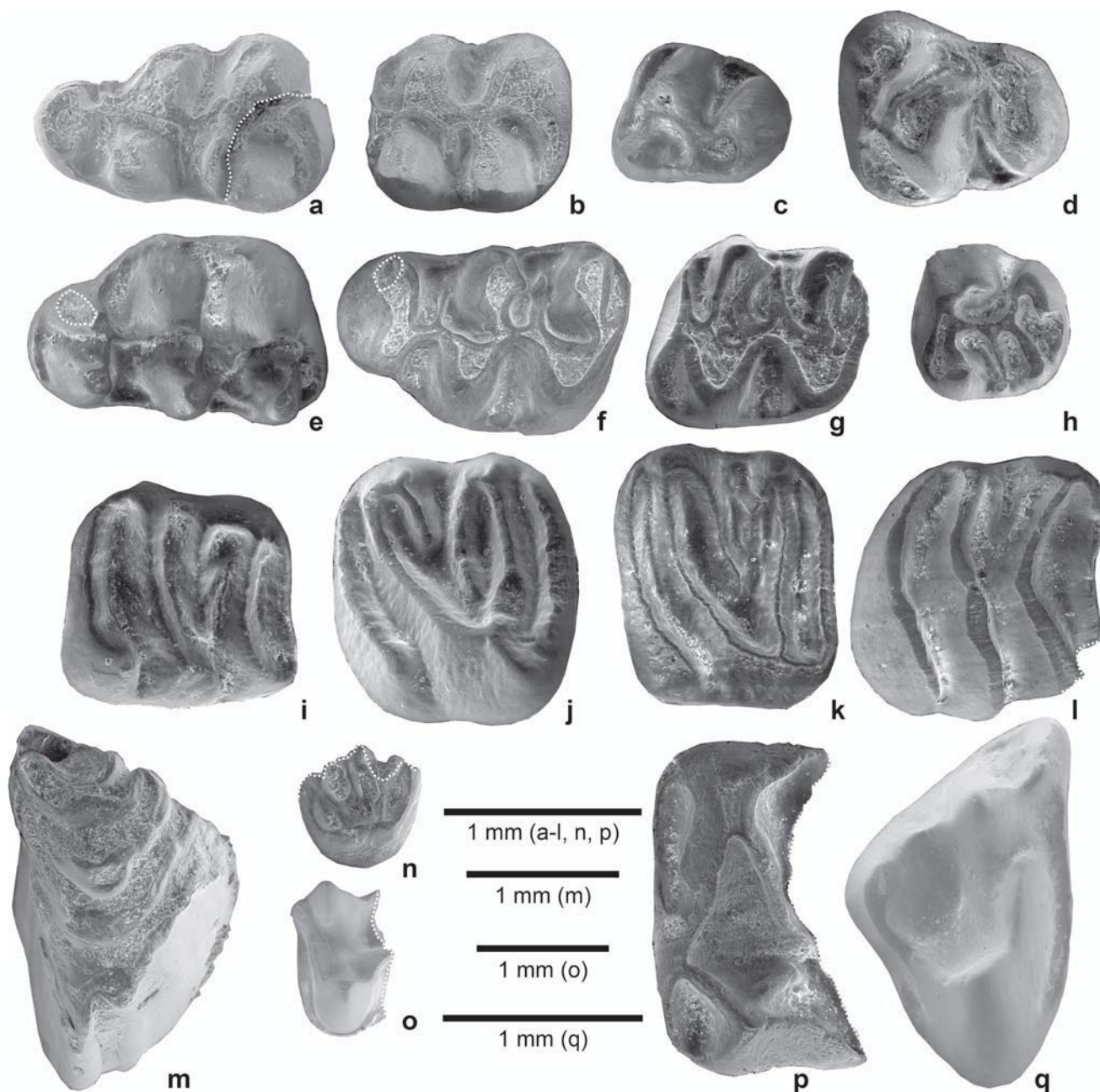
Fig. 4 Small mammal taxa from Courrendlin-Solé. *Megacricetodon* aff. *collongensis* (Mein [1958]). **a** Left m1 (SOL006-86). **b** Right m2 (SOL008-144). **c** Right m3 (SOL008-133). **e** Right M1 (SOL003-72). **f** Left M1 (SOL008-143). **g** Left M2 (SOL008-142). **h** Right M3 (SOL006-293). *Democricetodon* cf. *franconicus* (Fahlbusch [1966]). **d** Left m3 (SOL006-294). *Pseudodryomys* cf. *ibericus* de Bruijn ([1966]). **i** Right m1 (SOL006-278). **j** Left M1, 2 (SOL006-340). **k** Left M2 (SOL006-325). *Simplomys* aff. *simplicidens* (de Bruijn [1966]). **l** Right m2 (SOL006-329). *Prolagus* sp. **m** Right P3 (SOL006-344). The damaged areas in the teeth are marked using dotted lines. Eomyidae gen. et sp. indet. **n** Right M3 (SOL006-303). Soricidae gen. et sp. indet. **o** Right m1, 2 (SOL008-117; posterior part). *Melissiodon* sp. **p** Right M2 (or M3) (SOL005-275; anterior part). *Galerix* cf. *symeonidisi* Doukas ([1983]). **q** Right M3 (SOL008-135)

the m1. In this paper, we prefer to use the traditional species designations in order to simplify the text. The presence of a second Cricetidae is only documented by a right m3 of *Democricetodon* cf. *franconicus* (Fig. [4]d) in outcrop A21.

Dormice are also relatively abundant, in particular *Simplomys* aff. *simplicidens* (Figs. [4]l, [3]c) in outcrop S27. This genus is usually rare in the NAFB and its taxonomic status and palaeogeographic importance will be discussed in an upcoming contribution. *Pseudodryomys* cf. *ibericus*
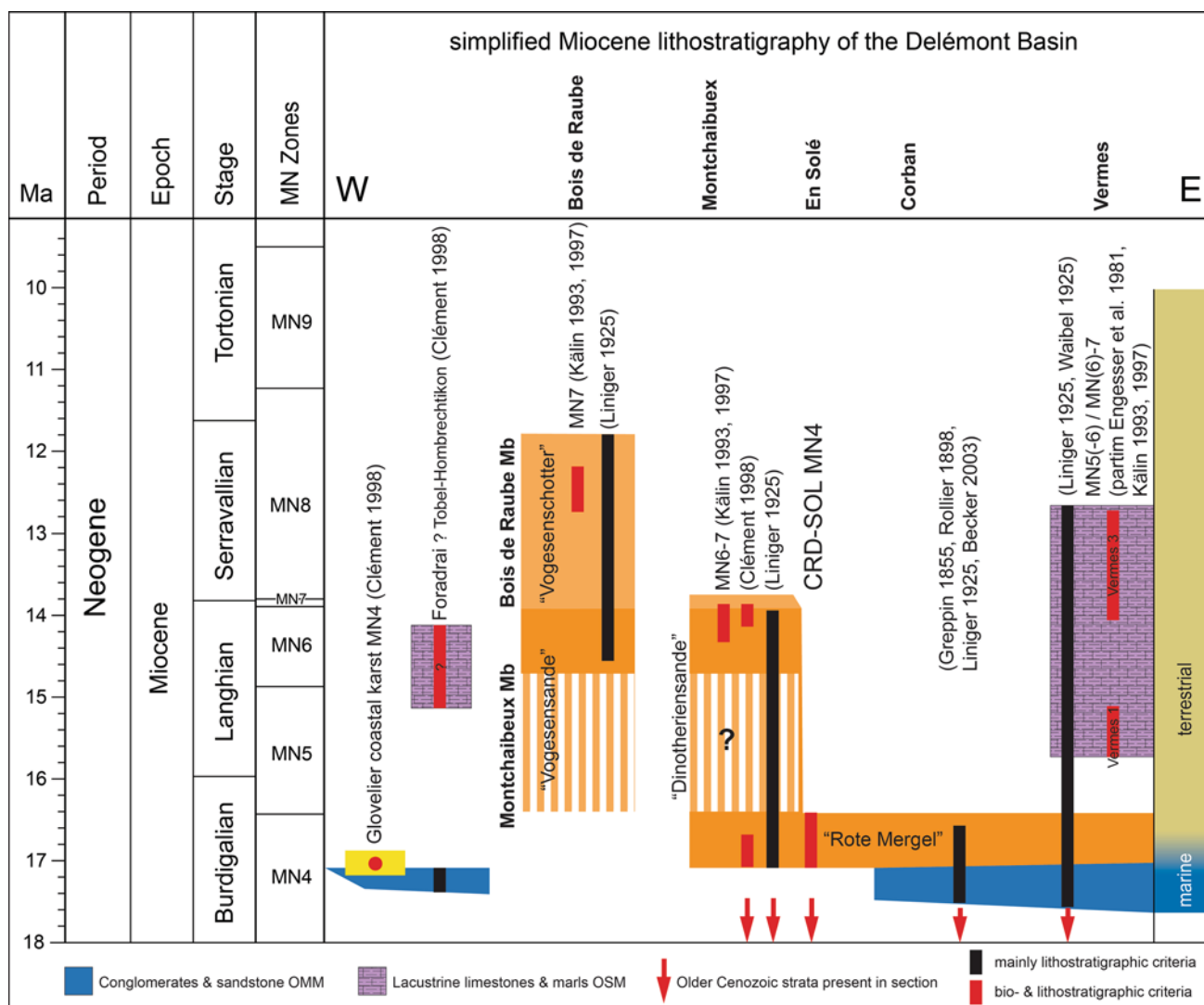
Fig. 5 Stratigraphic range of sediments on the Delémont Basin based on faunal assemblages and the interpreted lithostratigraphic record. Timescale after GTS 2012, MN5-8 biozones adapted according to Kälin and Kempf (2009) and Reichenbacher et al. (2013)

(Fig. 4i–k) is also present as well as scarce glirid material which could not been specifically determinated.

Melissiodon is an important taxon from CRD-SOL. Of the two available fragments, the better preserved specimen is a right M2 (Fig. 4p).

A single damaged M3 of an eomyid has been found (Fig. 4n). The tooth is very small and shares some characteristics with the genus *Keramidomys*, but also with members of *Pseudotheridomys/Ligerimys*.

Some rare pika (*Prolagus* sp.; Fig. 4m) and insectivore remains have been recovered. Accordingly, a talonid of a lower molar refers to an indeterminate shrew (Fig. 4o). Among the few teeth of the gymnure *Gallerix* (Fig. 4q), a fragment of a P3 shows the presence of two conules, indicating the possible assignment of the specimens to *G.* cf. *symeonidisi*. Finally, a tooth fragment is interpreted

as the lingual part of the upper molar of a didelphid (Marsupialia) or of a mole (Talpidae).

5 Biostratigraphy of Courrendlin-Solé

5.1 Biostratigraphic interpretation of the lower part of the Montchaibeux Member ("Rote Mergel") at Courrendlin-Solé

Figure 2b shows the vertical distribution of the small mammal teeth in the synthetic log of the red marls of the Montchaibeux Member at CRD-SOL. *Megacricetodon* is almost continuously present, but no size difference has been observed between the molars found in the different fossiliferous layers. Similarly, no faunal mixing (reworking

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of older layers) is evident. Regarding the small mammals, the assemblages recorded from CRD-SOL are thus considered to represent a single composite fauna.

The association of the rodents *Megacricetodon* aff. *collongensis* and *Melissiodon* suggests a correlation to the regional *Megacricetodon collongensis*–*Keramidomys* interval zone sensu Kälin and Kempf (2009; reference locality: Tägernaustrasse; mammal zone MN 4; see Fig. 3d). This regional zone correlates to the German OSM A (Fig. 3a) that shows the first occurrence of *Megacricetodon* in the NAFB fossil record, shortly postdating the occurrence of *Democricetodon* in the NAFB. The upper limits of the German and Swiss local zones are both defined by the first occurrence of *Keramidomys* (Fig. 3a), which replaces the other eomyid rodent *Ligerimys*. Unfortunately, the single eomyid molar from CRD-SOL cannot be assigned to any genus, but *Keramidomys* cannot be definitively excluded. At present, *Keramidomys* has not been recorded in association with *Melissiodon* and the presence of the genus in CDR-SOL is thus unlikely. On the other hand, unusual eomyid associations have been documented in Eitensheim and Langenau 1, but their biostratigraphic value is questioned (Prieto 2015; Prieto and Rummel 2016). In the NAFB, the species assigned to the "*Megacricetodon bavaricus* group" (including the species from CRD-SOL) are characterized by an anagenetic size increase through time (Fig. 3a; see details in Prieto and Rummel 2016, and references therein). The single m1 excavated in CRD-SOL is small and points to a relatively primitive *Megacricetodon* form (Fig. 3a). The sizes of the M1s (Fig. 3b) are included in the variation range of the primitive *Megacricetodon* species, such as the one from Forsthart in Germany (Ziegler and Fahlbusch 1986). The teeth are also a bit smaller than in Andelfingen (Switzerland; assigned to *M.* aff. *collongensis* by Bolliger 1992), but clearly smaller than those of *M. bavaricus*. Interestingly, the glirid *Simplomys* is recorded in Switzerland only in an older assemblage at Glovelier (Kälin and Kempf 2009), which just precludes the appearance of *Megacricetodon* in the NAFB.

5.2 Emended stratigraphic context of the Bois de Raube Formation

Large mammal finds have been reported from the Montchaibeux since the end of the nineteenth century (e.g., Greppin 1870; Liniger 1963; Becker 2003), which allowed a rough age estimation of the "Dinotheriensande" to the "Ober-Vindobon" (Tortonian). Kälin (1993, 1997) reported a small vertebrate fauna from the upper "Dinotheriensande" overlying the "Rote Mergel" at the Montchaibeux locality. This fauna only allowed an approximate biostratigraphic assignment based on the

presence of the genus *Cricetodon* (only tooth fragments) and *Megacricetodon minor* to the range of mammal zone MN 6–MN 7. Considering the size of the *M. minor* molars (see Kälin 1993), we can not entirely exclude that these indeed represent an early MN8 fauna. In addition *Cricetodon* sensu stricto (see details in Prieto et al. 2010) is still present during this period, being recorded for instance in Anwil, Kleineisenbach and Giggenhausen (Fahlbusch 1964; Engesser 1972; Prieto and Rummel 2016). In this regard, the large mammals *Prodeinotherium bavaricum* and *Brachypotherium brachypus* (Liniger 1963; Kälin 1997; Becker 2003) agree with these correlations (e.g., Böhme et al. 2012).

Based on much more abundant and diverse rodent teeth, Kälin (1997) restricts the assemblage Bois-de-Raube 3 from the overlying Bois-de-Raube Member (formerly "Vogesenschotter des Bois de Raube") to the mammal zone MN 7. This includes a *Megacricetodon gregarius*-like molar, a key taxon of mammal biozone MN 7 in the NAFB (e.g., Kälin and Kempf 2009; Prieto and Rummel 2016).

The lacustrine limestones and marls at Vermes correlate to mammal zone MN5 (Vermes 1 and 2 sensu Kälin 1993). The fossils originally attributed to mammal zone MN 8 by Engesser et al. (1981) in Vermes 2 (renamed Vermes 3 in Kälin 1993 and in the following) are indeed of uncertain origin and thus may not be used for biostratigraphic purposes (Kälin 1993). Anyway, the fossil material from Vermes 3 indicates the presence of younger deposits (MN8?) in the close vicinity. *Megacricetodon* aff. *bavaricus* teeth from Vermes 1 and 2 are distinctly larger than the *Megacricetodon* specimens from CRD-SOL, indicating an age of ~15.90 to ~15.20 My according to Prieto and Rummel (2016; based on Reichenbacher et al. 2013; ~15.70 to ~15.20 after Sant et al. 2017). As a result, the red marls situated below the lacustrine deposits at Vermes might be coeval to the Rote Mergel at Courrendlin-Solé. Engesser et al. (1981: 901; based on Rollier 1892) mentioned the possible correlation of the red marls at Vermes with the reddish Helicidae marls ("Helicidenmergel"), a widespread layer that was deposited at the OMM/OSM transition (e.g., Becker 2003; Berger et al. 2005b; Baier 2013), possibly contemporaneous to the formation of the so-called "Graupensandrinne" erosion gully during the retreat of the OMM (Doppler et al. 2005). Thus, and following this proposal, the biostratigraphic correlation of CDR-SOL may be of particular importance for the dating of this regression phase. Unfortunately, numerous uncertainties remain regarding long distance correlations as well as controversial apatite ages for the "Helicidenmergel" (Rahn and Stumm 2011). These considerations are however clearly beyond the scope of this paper.

The new data obtained at CRD-SOL thus emends the biostratigraphic position of the lower part of

the Montchaibeux Member and suggests the presence of a gap between the lower ("Rote Mergel") and the upper ("Dinotheriensande") part of the Montchaibeux Member sensu Kälin (1997), placing the former (MN 4) below and the latter (which is MN6 or younger) as approximately coeval to the Vermes freshwater limestones (Fig. 5). More precisely, Reichenbacher et al. (2013) proposed a time span from 16.3 to 17.2 Ma for the Tägernaustrasse biozone to which the CRD-SOL fauna can be attributed. In contrast, the first *Cricetodon* species—present in the upper part of the "Dinotheriensande" and the Bois de Raube Member—occurs at around 15 My in the NAFB (see details in Prieto and Rummel 2016), indicating more than 1 Ma difference between the deposition of the "Rote Mergel" and the upper part of the "Dinotheriensande" (Fig. 2a). Based on the estimated lithostratigraphic extension of the "Dinotheriensande" (Liniger 1925; Kälin 1993; Clément 1998), the sedimentary sequence at the Montchaibeux may well be continuous, and the biostratigraphic gap may just represent an artefact attributable to the lack of accessible intermediate localities.

6 Palaeogeographic perspectives and conclusions

The Burdigalian transgression shows clear geographic and stratigraphic differences in the Jura area. While the sea completely invaded the Swiss plateau in the early Burdigalian, it only reached the SE Jura synclines (e.g., Le Locle–La Chaux-de-Fonds; Becker 2003). During the late Burdigalian in contrast, a second transgression expanded northwards to the Delémont syncline (Liniger 1925), where both marine and terrestrial fossils were accumulated in the fissure fillings at Glovelier (Hug et al. 1997). This fauna is biostratigraphically correlated to the early part of the MN 4. There is no equivalent in the stratified deposits of the NAFB, but similar terrestrial faunas are known from the karsts of the Southern German Franconian Alb (e.g., Erkertshofen, Petersbuch 2; e.g., Fahlbusch 1966) without marine influence. The earliest MN 4 small mammal faunas from Bavaria belonging to the NAFB include small-sized *Megacricetodon* species, and are thus almost coeval to CRD-SOL. These faunas were derived from the "Brackwassermolasse" ("brackish molasse") (Kirchberg-Schichten, western Bavaria; Reichenbacher et al. 2004; Pippèrr and Reichenbacher 2017), from the transitional layers between the "Oncophora-Schichten" and OSM in Lower Bavaria (Ziegler and Fahlbusch 1986), or the base of the OSM in western Bavaria (Seehuber 2015). Numerous sites are recorded in the central and eastern Swiss part of the NAFB (upper OMM and (?) brackish deposits; Bolliger 1992; Reichenbacher et al. 2005; Kälin and Kempf 2009;

Jost et al. 2016). As a result, the CDR-SOL assemblage documents the earliest clearly terrestrial post-OMM deposits in the area and the westernmost small mammal fauna of the NAFB for this crucial time interval. In addition, it provides interesting new data regarding the paleo-bioprovinciality of the fauna.

The uniqueness of the fauna CDR-SOL lies primarily in the relatively high abundance of the dormouse *Simplomys*, which is usually rare in central Europe, but a common element in the western European early/middle Miocene localities, especially in Spain (García-Paredes et al. 2009). While present in Glovelier (Kälin and Kempf 2009) and some coeval southern Bavarian fissure fillings (Wu 1993), this genus has not been yet recorded in any of the rich faunas close in age to CDR-SOL (Tägernaustrasse, Mauensee, Forsthart, Rembach, Rauscheröd, Günzburg 2, Reisensburg). In contrast, *Simplomys* is recorded during small mammal biozone MN 4 in France, at Vieux-Collonges (Rhône; Maridet 2003; probably mixed fauna with MN 4 part), and in the Aquitanian Basin (García-Paredes et al. 2009 and references therein). Further research should clarify if during the initial deposition of the OSM the northwestern Swiss faunas show a higher influence of western European ecosystems than the eastern part of the NAFB.

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