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New vertebrate trackways from the autochthonous cover of the Aiguilles Rouges Massif and reevaluation of the dinosaur record in the Valais, SW Switzerland

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Abstract A new tracksite located in the Mesozoic autochthonous series covering the Aiguilles Rouges Massif, circa 7 km to the NNE of the tracksite of the Vieux Emosson, is briefly described. The trampled bed is most likely coeval with the outcrop in the Vieux Emosson area. Two poorly preserved quadrupedal trackways, almost parallel, measure 9.8 and 8 m in length, respectively. They are referred to the Chirotheriidae ABEL, 1835 form-family. A short and well-preserved quadrupedal trackway, composed of two manus-pes couples, is assigned to *Chirotherium* cf. *barthii* KAUP, 1835. A reinterpretation of the Vieux Emosson ichnotaxa reveals that most tracks, if not all, belong to indeterminate chirotheriid and that no clear evidence of dinosaur footprints is observed. The trampled bed of the cover of the Aiguilles Rouges Massif probably forms a megatracksite, which is Early or Middle Triassic in age.

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Introduction

In 2003, one of us (JB) discovered some faint footprints on a slab of sandstone preserved in situ at 2,200 m a.m.s.l. on the northern side of the Barberine pass, Valais (CH), in a place called "Cascade d'Emaney" (46°06′26″N/6°56′21″E). The site is situated circa 7 km to the NNE of the tracksite of the Vieux Emosson discovered in 1976 (Bronner and Demathieu 1977). Both sites form part of the Mesozoic autochthonous series covering the Aiguilles Rouges Massif (Fig. 1a). A preliminary study of the site in July and September 2011 revealed the occurrence of several trackways, together with isolated footprints. The state of preservation allows the identification of the ichnotaxa and leads to a reinterpretation of the Vieux Emosson footprints as well as a new age assignment for both sites.

Geological setting

The Mesozoic autochthonous series covering the Aiguilles Rouges Massif was studied by Amberger (1960) and, at a more regional scale, by Demathieu and Weidmann (1982). Amberger's sections 9 and 16 correspond to the Vieux Emosson site and the Cascade d'Emaney site, respectively (Fig. 1b, c). Although the Triassic series in the Cascade d'Emaney site is complicated by the occurrence of two thrusts, the base of the series at both sites is undeformed and very similar. Above the 'gneiss oeillé' of the basement lies ca 4.5 m (Vieux Emosson) and 5.5 m (Cascade d'Emaney) of sandstone beds, which show a thinning upward sequence. Next follow ca 5 m (Vieux Emosson) and 14 m (Cascade d'Emaney) of greenish and

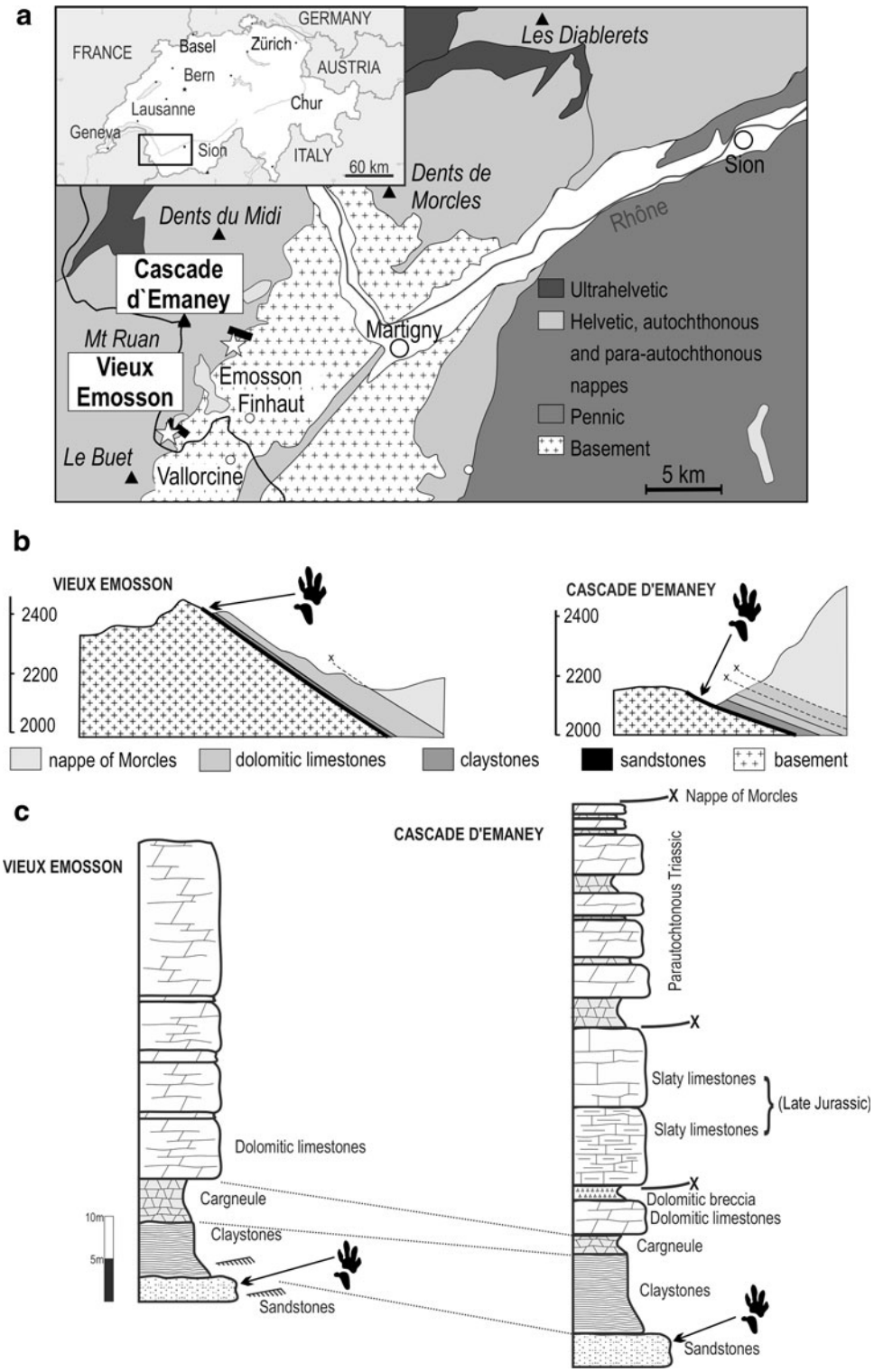

Fig. 1 **a** Simplified geological map of the area around the Cascade d'Emaney and Vieux Emosson sites (*stars*) with the locations of the geological sections (*black bars*). Schematic stratigraphical sections (**b**) and lithographical sections (**c**) at both sites. **b** and **c** Modified from Amberger (1960)

reddish clay, overlain by ca 50 m (Vieux Emosson) and 5 m (Cascade d'Emaney) of cargneule and dolomitic limestones. At both sites, the trampled beds are located at the top of the sandstone series, and we confidently conjecture that they are very close in age, and even possibly isochronous (see "Discussion" below). The uppermost sandstone beds and the lowermost clayey bed bear ripple marks and mud cracks, indicative of shallow waters alternating with emersive episodes.

The age of the footprint layer from the Vieux Emosson was debated. Amberger (1960) proposed an Early Triassic age for the sandstone on the basis of lithological comparisons with the Helvetic Triassic of Glarus, Switzerland, and the Germanic Buntsandstein. On the basis of the interpretation of footprints from the Vieux Emosson and in particular those regarded as produced by dinosaurs, Demathieu and Weidmann (1982) proposed a younger age for the trampled bed, i.e. Late Ladinian or Carnian (Middle/Late Triassic limit). Lockley and Meyer (2000) and Meyer and Thüring (2003) questioned the dinosaurian origin of the Vieux Emosson footprints, implicitly questioning the age of the site. In 2009, Avanzini and Cavin described a short trackway preserved on an isolated block near the Vieux Emosson site. They referred it to the ichnogenus *Isochirotherium*, close to *I. soergli* and *I. lomasi*, which would indicate a probable Early or Middle Triassic age.

Comparison of a resin cast of footprints made in 1979 in the Vieux Emosson site with the actual footprints indicate that erosion only weakly affected the prints after 30 years in the open air (Avanzini and Cavin 2009). This observation makes us confident in the reinterpretation of the Vieux Emosson footprints proposed here.

Materials and methods

The trampled surfaces have been mapped and measured using traditional methods (drawings on acetate layer, photographs). One of the best-preserved footprints (Fig. 2d) was cast in silicone rubber, allowing its analysis in the laboratory under artificial light. The cast is provisionally stored at the Museo delle Scienze (Trento, Italy).

Ichnological description of the Cascade d'Emaney tracksite

The sandstone layers contain numerous footprints, circa 100, that were identified during the preliminary analysis. All the footprints are preserved as concave epireliefs. They present uneven quality of preservation. In this note we focus on three trackways (Bar 1, Bar 2 and Bar 3) and some isolated prints only, because they are the most informative among the available set of footprints.

Bar1 and Bar2 (Fig. 3) are two poorly preserved quadrupedal trackways. Trackway Bar1 is composed of 28 manus-pes couples (three manus, very faint, and not drawn in Fig. 3) and is 9.8 m long; Bar2 is composed of 15

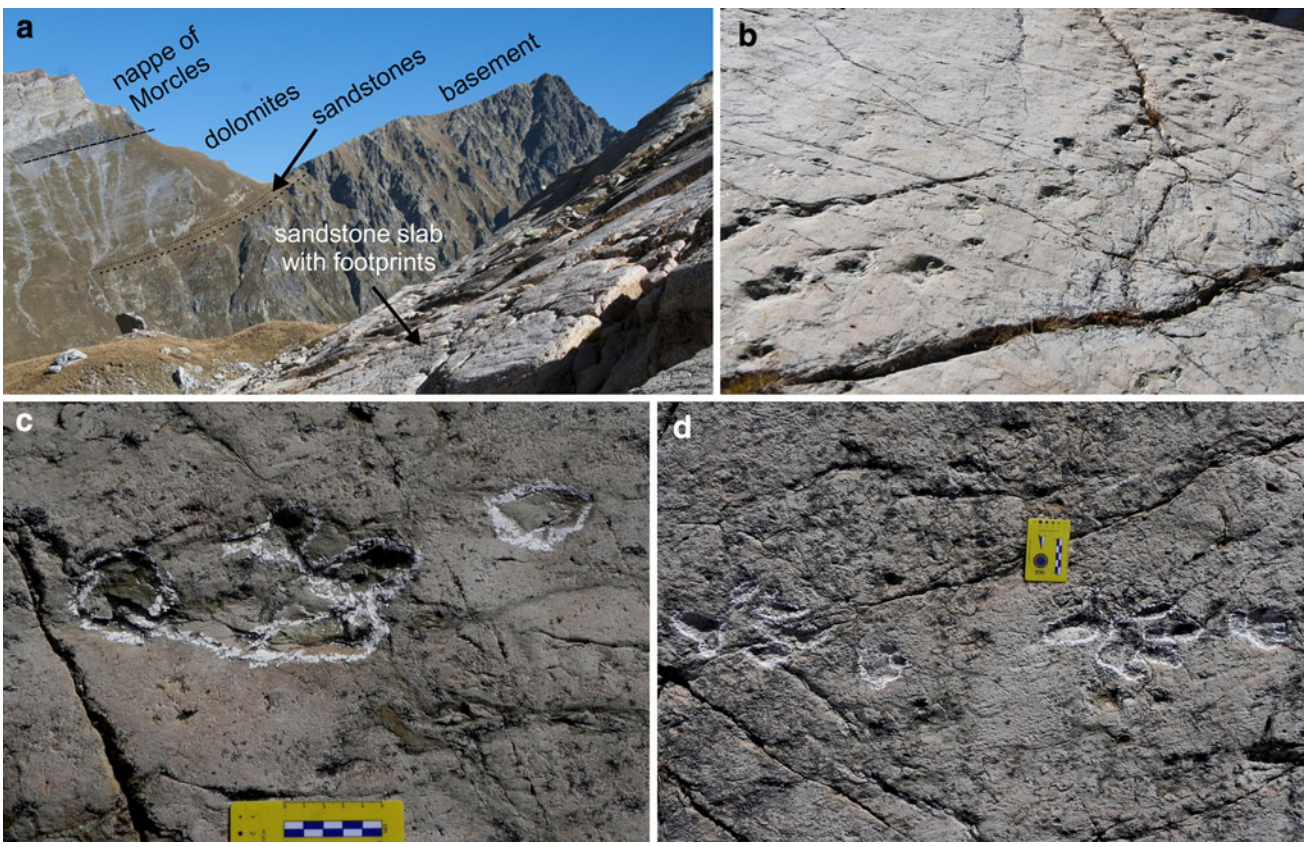

Fig. 2 **a** View of the slab with the footprints (*right side* of the photograph) and geological section of the area visible in the background (pass of Emaney). **b** Oblique view of the trackway Bar1. **c** Detail of a pes-manus pair from the trackway Bar2. **d** Detail of Bar3, two pes-manus pairs referred to *Chirotherium* cf. *barthii*

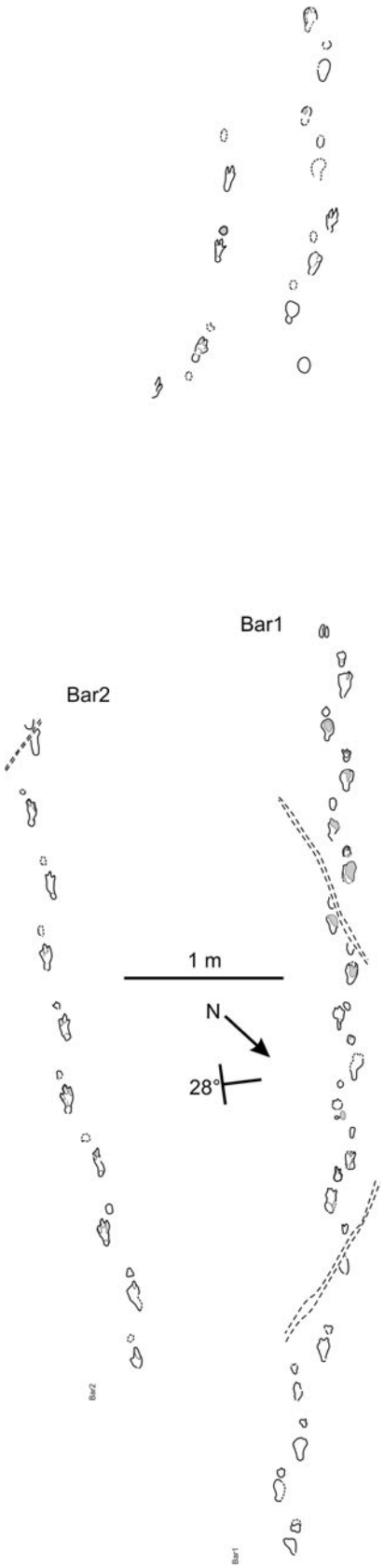

Fig. 3 Drawing of the trackways Bar1 and Bar2. *Grey* areas indicate infillings in the prints and *dashed lines* indicate cracks on the slab

manus-pes couples and is 8 m long. Both trackways are interrupted for 1.5–2 m by a crack. Bar1 and Bar2 have very similar parameters, with the main difference being the larger pes-length and stride of Bar1 (see Table 1). Trackways show a narrow gauge and pronounced heteropody; the manus-pes length ratio is 0.42:1 for Bar1 and 0.37:1 for Bar2. Pedal prints approach the midline and always have their long axis parallel to it. The pes is always longer than wide, generally showing the impression of three digits (II–IV) and the elongated metatarsal-phalangeal pad of digit V, which lies behind and slightly laterally. Digits imprints often coalesce in a single, 'cone-shaped' impression. Where visible, digit III is the longest (mesaxonic structure). Manual imprints are generally less well impressed, turned outward and placed antero-medially, a short distance from the pes prints. Manus are always wider than long, sub-elliptical in shape and smaller than the pes. Digit impressions are rarely preserved, but digit III appears to be the longest. Neither pes nor manus show clear pad or claw impressions. Given these characters, both Bar1 and Bar2 can be assigned to the Chirotheriidae ABEL, 1935 form-family.

Trackway Bar3 (Figs. 2d, 4; Table 1) is a short and well-preserved quadrupedal trackway composed of two manus-pes couples. It shows a narrow gauge and pronounced heteropody. Pedal prints approach the midline with their long axis parallel to it. The pes print is pentadactyl and digitigrade, longer than wide with digits III > IV ≥ II > I ≥ V (average digit lengths: I: 4.5, II: 6.5, III: 8.8, IV: 6.9, V: ca. 3 cm). Digit V points laterally or slightly backward and its metatarsal-phalangeal pad is pronounced. The total divergence between digits I–IV is 42°. Claw impressions are prominent on pes digits I–IV. Manual imprints are anterior-lateral to the pes digit III axis and do not seem to be rotated. The manus is longer than wide, sub-elliptical in shape and smaller than the pes. Manual imprints are possibly pentadactyl with digit III being the longest. The manus-pes length ratio is 0.39:1. Given the described parameters and the large size, Bar3 can be assigned to *Chirotherium* cf. *barthii* KAUP, 1835.

The Vieux Emosson tracksite

In the Vieux Emosson site, Demathieu and Weidmann (1982) recognized two chirotheriids, *Brachychirotherium* sp. BEURLEN, 1950 and *Isochirotherium* sp. HAUBOLD, 1970. Although poorly preserved, the large size and the digit formula of the pedal print of *Isochirotherium* sp. figured in their Fig. 6B (also figured and discussed in Avanzini and Cavin 2009, Fig. 7) might be referred with caution to *Chirotherium* cf. *barthii*, i.e. the same taxon as in the Cascade d'Emaney. A few isolated footprints and a poorly preserved trackway were referred by Demathieu and

Table 1 Mean parameters are given in cm, with their standard deviation (σ)

	PL	σ	PW	σ	ML	σ	MW	σ	OP	σ	S	σ	PA	σ
Bar 1	13.9	1.8	7.3	1.0	6.5	1.5	4.5	0.7	32.6	2.4	61.3	2.9	142.4°	3.8
Bar 2	16.6	1.6	6.8	1.1	5.3	0.5	4.2	0.8	44.4	2.4	88.4	3.5	160.0°	3.9
Bar 3	23.5	0.7	12.7	0.3	9.2	2.5	6.2	0.3	54.2	–	–	–	–	–

PL pes-length, *PW* pes width, *ML* manus length, *MW* manus width, *OP* oblique pace, *S* stride, *PA* pace angulation

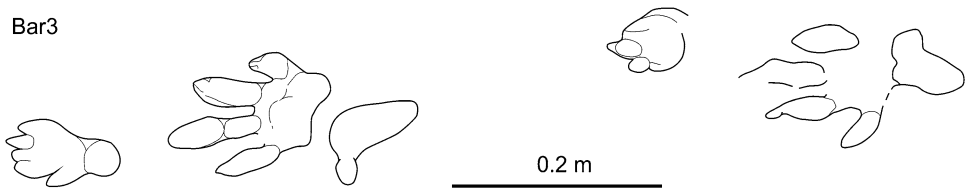

Fig. 4 Drawing of the trackway Bar3

Weidmann (1982, Fig. 6A) to *Brachychirotherium* sp. Because of the poor quality of preservation of these footprints in particular, we regard this determination with caution and prefer referring them to an undetermined chirotheriid.

The chirotheriid pedal footprints in the Vieux Emosson are preserved as 'two-holed' prints with the distal (anterior) hole corresponding to digits I–IV and the proximal (posterior) hole corresponding to the metatarsal-phalangeal pad of digit V (e.g., Demathieu and Weidmann 1982, Fig. 6AB–7AB). Apart from these few 'two-holed' prints of chirotheriids, Demathieu and Weidman regarded most of the other prints as completely preserved footprints.

New interpretation

The Vieux Emosson footprints are not easy to interpret because of their poor quality of preservation. In our view, most of the impressions correspond to incomplete footprints or belong to pairs of imprints corresponding to 'two-holed' pedal footprints. The distal impression corresponds to digit I–IV, in which single digit impressions collapsed into one broad imprint and the proximal impression corresponds to the metatarsal-phalangeal pad of digit V. Based on this new interpretation, these forms can be regarded as chirotheroids, for which badly preserved footprints are known to have a similar appearance (Lockley and Meyer 2000; Lockley and Hunt 1999).

A typical example of this new interpretation is provided by the footprint reproduced in Fig. 5a (this footprint, located in the lower part of the site, was not described by Demathieu and Weidmann (1982), probably because this zone was covered with snow all the year round). This specimen can be considered as a chirotheroid print consisting of a distal broad impression corresponding to digits I–IV and a proximal impression corresponding to the metatarsal-phalangeal pad of digit V. We highlight that if this proximal impression is interpreted as a single print, and is oriented upside-down (rotated by 180°), this can now be erroneously described as a 'tridactyl footprint' with 'digits' III > IV > II ('digit lengths': II: ~7 cm, III: ~13 cm, IV: ~9 cm, and II^IV angle of ~90°). Notably, these features perfectly match those used by Demathieu and Weidemann to diagnose *Paratrisauropus latus* (1982, see in particular Table 4), a supposed herbivorous dinosaur footprint (Demathieu and Weidmann 1982, p. 742). This new interpretation has an important impact on the identification of the ichnological assemblage, especially on the supposed occurrence of dinosaurs.

Among nine ichnotaxa identified at the Vieux Emosson site, Demathieu and Weidmann (1982) considered five trackmakers as possible dinosaurs. Two ichnogenera are attributed to 'tridactyl dinosauroids', one to a 'tetradactyl dinosauroid' and one to a 'pentadactyle dinosauroid'. These taxa deserve special attention here because they have rarely, if ever, been found in any other Triassic tracksites and because they were considered as the main argument for assigning the locality to the Middle-Late Triassic.

Paratriosauropus is one of the 'tridactyl dinosauroid' prints referred to indeterminate ornithischians. It is represented by three species, *P. mirus*, *P. bronneri* and *P. latus*, distinguished on the basis of qualitative characters, as well as on statistical comparisons of morphometric parameters. Demathieu and Weidmann (1982) noticed that *P. bronneri* and *P. latus* form a continuum on the basis of morphological characters, while *P. latus* and *P. mirus* are almost similar on the basis of morphometric features. Strangely enough, they considered these results as a case study for illustrating the importance in using both morphological and morphometric characters for characterizing ichnospecies. On the contrary, we consider these continua in morphometric and morphological features as a lack of support for

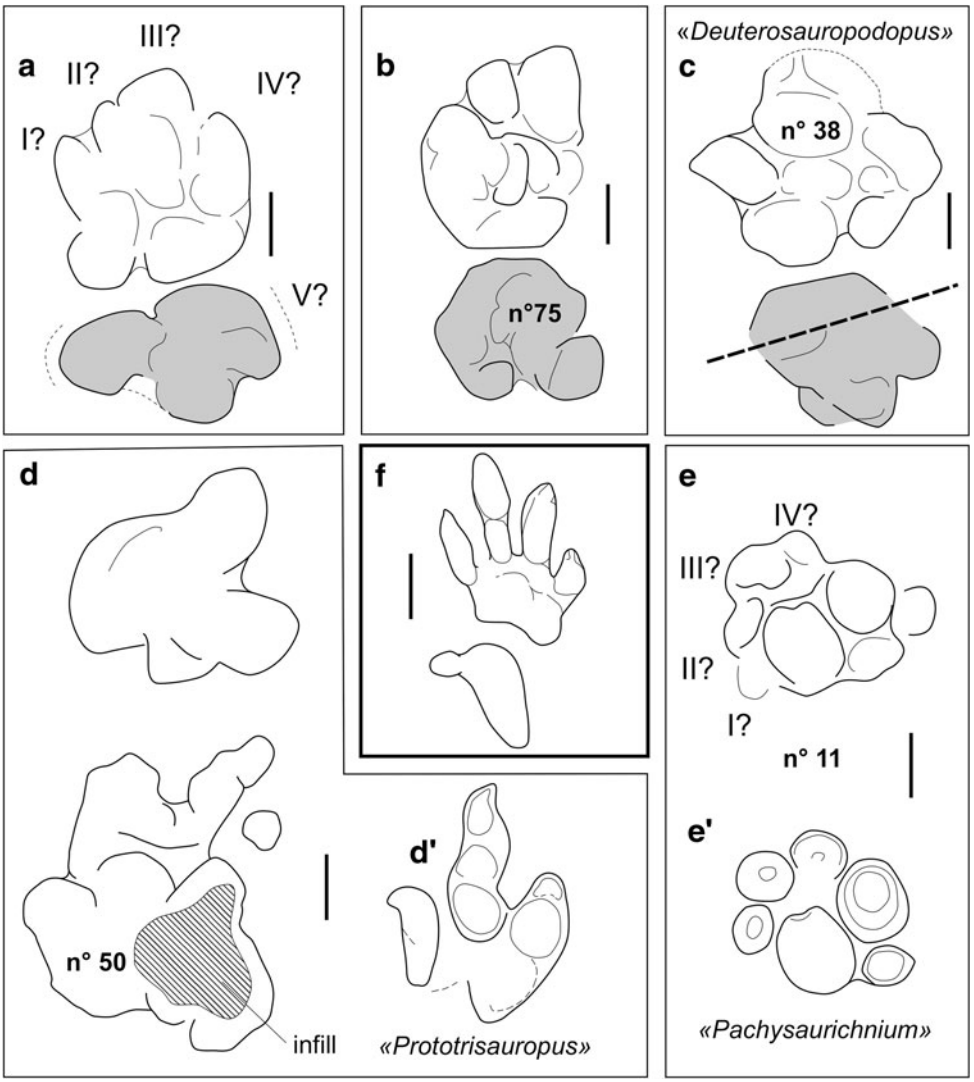

Fig. 5 **a**–**e** New tracings and interpretation of some of the footprints from the Vieux Emosson. **d**′ and **e**′ are redrawn from Demathieu and Weidmann (1982). *Grey imprints* correspond to the '*Paratrisauropus*' morphotype. **f** pes of *Chirotherium* cf. *barthii* from the Cascade d'Emanay site for comparison. *Numbers* on the footprints correspond to numbers recorded in Demathieu and Weidmann (1982). See main text for explanation. *Scale bars* 50 mm

discriminating the three species. In complement to the example described above and illustrated in Fig. 5a, other instances of *Paratrisauropus* footprints are associated with other imprints, which means that they probably represent the proximal part of chirotheriid pedal prints. We illustrate here a footprint referred to *P. latus* (recorded no. 75 in Demathieu and Weidmann) in association with an imprint regarded as the distal part of the pes of a chirotheriid (Fig. 5b) and a "*Paratrisauropus*" morphotype (not identified as such by Demathieu and Weidemann) associated with a "*Deuterosauropodopus*" footprint (no. 38, Fig. 5c). "*Deuterosauropodopus sedunensis*" is a tetradactyl ichnotaxon recorded at the Vieux Emosson site only. Because of the presence of four fingers and because of its association with the "*Paratrisauropus*" morphotype, we consider it here as the distal part of a chirotheriid footprint. This interpretation was already proposed for another "*Deuterosauropodopus*" print (no. 42) by Avanzini and Cavin (2009, Fig. 6). Isolated "*Paratrisauropus*" footprints are present in different places on the slab. We suggest that they are more parsimoniously interpreted as proximal parts of incompletely preserved chirotheriid pedal footprints.

Consequently, "*Paratrisauropus*" and "*Deuterosauropodopus*" are *nomina dubia*, both ichnotaxa likely representing the proximal and the distal parts of chirotheriid footprints, respectively. King and Benton (1996) described several similar cases of misidentifications of chirotheriid footprints previously referred to dinosaurs from the Early and Middle Triassic of Britain.

A single and poorly preserved footprint (no. 50) was referred by Demathieu and Weidmann to a bipedal tridactyl dinosaur, *Prototrisauropus* ELLENBERG, 1972. Our tracing and interpretation of this footprint strongly differ from Demathieu and Weidmann's interpretation (compare Fig. 5d, d′). In our view the authors misinterpreted what in fact is a badly preserved five-toed pes print assignable to the form-family Chirotheriidae and did not notice its relation with the manus imprint.

The last ichnospecies referred to a dinosaur is "*Pachysaurichnium emossonense*", which Demathieu and Weidmann characterized by the presence of five short digits, was interpreted as the track of unguligrade dinosaur possibly close to sauropods. Here again, our interpretation of the holotype (no. 11) differs from Demathieu and Weidmann's interpretation (Fig. 5e, e′). We based our tracing on a cast of the holotype and we noticed two supplementary faint impressions not recorded in the former study. This footprint is in all not easy to interpret, and we propose here to consider "*P. emossonense*" as a poorly preserved chirotheriid footprint. This ichnotaxon should be considered as a *nomen dubium* and cannot be regarded as evidence of footprints of dinosaurs in the Vieux Emosson site.

Discussion

The Cascade d'Emaney tracksite contains the most informative footprints of the area and constitutes an important discovery for understanding other tracksites in the neighbourhood. With the exception of the Vieux Emosson site, only assemblages of isolated footprints—often badly preserved—have been observed. Demathieu and Weidmann mentioned some footprints located 2.5 km to the south of the Vieux Emosson site in the Vallon de Tré-Les-Eaux, France, and others located 1.2 km to the north in a small valley descending from the Veudale mountain. We confirm the occurrence of footprints in the latter spot and record other poorly preserved footprints near the Lac Vert, ca 0.8 km to the South of the Vieux Emosson site. In a guidebook, Burri (2008) mentioned the occurrence of footprints near the Emaney pass, a site located ca 2 km to the north of the Cascade d'Emaney. Another site in coeval strata some kilometres farther west shows faint imprints that can be attributed to chirotheriids (Meyer and Thüring 2003). Although precise description of the stratigraphic sections of the different sites remains to be done, all the footprints occur in a single layer located at the top of the sandstone series, probably in the very same bed. The presence of these footprints in the likely same bed along a line of ca. 10 km is indicative of a megatracksite (Meyer and Thüring 2003). Because of the erosion of this bed subsequent to the uplift of the Aiguilles Rouges Massif, the surface with footprints outcrops in spots isolated from each other.

The good quality of preservation of at least some tracks and trackways in the Cascade d'Emaney provides a reference for the reinterpretation of the badly preserved specimens from the Vieux Emosson. Every single imprint was interpreted by Demathieu and Weidmann (1982) as a true, reliable imprint without considering possible track preservation variations, preservational bias or taphonomic artefact. This led the authors to conclude that several dinosaurian trackmakers trampled the surface. In our new interpretation, most, and probably all the footprints are referred to poorly preserved chirotheriids. No evidence for dinosauromorph footprint is present either at the Cascade d'Enamey or at the Vieux Emosson sites.

Chirotherian tracks are common throughout the Triassic (Haubold 1971a, b; Demathieu and Demathieu 2004; Klein and Haubold 2004; King et al. 2005; Haubold 2006). A *Chirotherium-Isochirotherium* association, however, is classically Early Triassic-early Middle Triassic in age (Lucas 2007; Hunt and Lucas 2006; Hunt and Lucas 2007).

Based on the new interpretation, the Vieux Emosson and Cascade d'Emanay sites represent the oldest known occurrence of Mesozoic vertebrates in Switzerland, similar in age or older than the Middle Triassic tracksite of Tödi in the Canton Glarus (Feldmann and Furrer 2009).

Conclusion

New finds and the reinterpretation of Demathieu and Weidmann (1982) specimens provide evidence of a chirotheriid-dominated ichnoassociation in the Vieux Emosson-Cascade d'Emaney megatracksite (Valais, southwestern Switzerland) and conclusively demonstrate that (i) no evidence for dinosaur footprints is available, (ii) the age of the megatracksite is most probably Early Triassic to early Middle Triassic based on the known world distribution of the *Chirotherium* ichnogenus.

Examination of a topographical map of the area published in 1965 (sheet 'Barberine' 1/25 000, 1324, with the state of the glaciers in 1960) shows that the tracksite was located at the very edge of a small permanent glacier, which has completely vanished now. The trackways were probably covered with snow during most part of the year and consequently much more difficult to detect.

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References

Amberger, G. F. (1960). L'autochtone de la partie nord-ouest du massif des Aiguilles-Rouges (Haute-Savoie et Valais). Unpublished PhD Thesis, University of Geneva, 103 pp.

Avanzini, M., & Cavin, L. (2009). A new *Isochirotherium* trackway from the Triassic of Vieux Emosson, SW Switzerland: Stratigraphic implications. *Swiss Journal of Geosciences, 102*, 353–361.

Bronner, G., & Demathieu, G. (1977). Premières traces de reptiles archosauriens dans le Trias autochtone des Aiguilles Rouges (Col des Corbeaux, Vieil Emosson, Valais, Suisse). Conséquences paléogéographiques et chronostratigraphiques. *Comptes Rendus Académie des Sciences (Paris), 285*(D), 649–652.

Burri, M. (2008). Balade géologique à Salanfe. Auberge de Salanfe (Ed.), 21 pp.

Demathieu, G., & Demathieu, P. (2004). Chirotheria and other ichnotaxa of the European Triassic. *Ichnos, 11*, 79–88.

Demathieu, G., & Weidmann, M. (1982). Les empreintes de pas de reptiles dans le Trias du Vieux Emosson (Finhaut, Valais, Suisse). *Eclogae Geologicae Helvetiae, 75*, 721–757.

Feldmann, M., & Furrer, H. (2009). Die Saurierspuren am Tödi und ihre geologische Umgebung. In: *Naturforschende Gesellschaft des Kantons Glarus, NGG*. Obersand 2008—Sommer der alpinen Artenvielfalt. Glarus, pp. 28–37.

Haubold, H. (1971a). Die Tetrapodenfahrten des Buntsandsteins in der Deutschen Demokratischen Republik und in Westdeutschland und ihre aquivalente in gesamten Trias. *Paläontologische Abhandlungen, Berlin, 4*, 397–548.

Haubold, H. (1971b). *Ichnia, Amphibiorum et Reptiliorum Fossilium. Handbuck der Paläoherpetologie, part. 18* (p. 124). Stuttgart: Fischer.

Haubold, H. (2006). Die Saurierfährten *Chirotherium barthii* KAUP, 1835—das Typusmaterial aus dem Buntsandstein bei Hildburghausen/Thüringen und das Chirotherium-Monument. *Veröffentlichungen Naturhistorisches Museum Schleusingen, 21*, 3–31.

Hunt, A. P., & Lucas, S. G. (2006). Triassic-Jurassic tetrapod ichnofacies. *New Mexico Museum of Natural History and Science Bulletin, 37*, 12–22.

Hunt, A. P., & Lucas, S. G. (2007). The Triassic tetrapod track record: Ichnofaunas, ichnofacies and biochronology. *New Mexico Museum of Natural History and Science Bulletin, 41*, 78–87.

King, M. J., & Benton, M. J. (1996). Dinosaurs in the Early and Mid Triassic?—The footprint evidence from Britain. *Palaeogeography, Palaeoclimatology, Palaeoecology, 122*, 213–225.

King, M. J., Sarjeant, W. A. S., Thompson, D. B., & Tresise, G. (2005). A revised systematic ichnotaxonomy and review of the vertebrate footprint ichnofamily Chirotheriidae from the British Triassic. *Ichnos, 12*, 241–299.

Klein, H., & Haubold, H. (2003). Differenzierung von ausgewählten Chirotherien der Trias mittels Landmarkanalyse. *Hallesches Jahrbuch für Geowissenschaften, B 25*, 21–36.

Lockley, M. G., & Hunt, A. P. (1999). *Dinosaur tracks and other fossil footprints of the Western United States*. New York: Columbia University Press.

Lockley, M. G., & Meyer, C. A. (2000). *Dinosaur tracks and other fossil footprints of Europe*. New York: Columbia University Press.

Lucas, S. G. (2007). Tetrapod footprint biostratigraphy and biochronology. *Ichnos, 14*, 5–38.

Meyer, C. A., & Thüring, B. (2003). Dinosaurs of Switzerland. *Comptes Rendus Palevol, 2*, 103–117.