Late jurassic dinosaur tracksites of the Transjurane highway (Canton Jura, NW Switzerland): Overview and measures for their protection and valorisation

Article *in* Bulletin fuer Angewandte Geologie · July 2007

CITATIONS
36

READS
484

8 authors, including:

Daniel Marty
Office de la culture
156 PUBLICATIONS **1,873** CITATIONS
SEE PROFILE

Jacques Ayer
Museolis
13 PUBLICATIONS **127** CITATIONS
SEE PROFILE

Damien Becker
JURASSIC Museum
118 PUBLICATIONS **1,130** CITATIONS
SEE PROFILE

Luc Braillard
Université de Fribourg
27 PUBLICATIONS **254** CITATIONS
SEE PROFILE

Bull. angew. Geol. Vol. 12/1 Juli 2007 S. 75-89

Late Jurassic dinosaur tracksites of the Transjurane highway (Canton Jura, NW Switzerland): overview and measures for their protection and valorisation

Daniel Marty[1,2], Jacques Ayer[1], Damien Becker[1], Jean-Pierre Berger[2], Jean-Paul Billon-Bruyat[1], Luc Braillard[1,2], Wolfgang A. Hug[1], Christian A. Meyer[3]

Keywords: Dinosaur footprint, Late Jurassic, palaeontological heritage, site protection and valorisation, Jura Mountains, NW Switzerland

Abstract
Since 2002 six dinosaur tracksites have been discovered by the «Palaeontology A16» on the future course of the Transjurane highway in the Ajoie district of the Canton Jura. These tracksites are systematically excavated prior to the construction of the highway. So far, over 4'000 dinosaur footprints including 280 trackways have been excavated and documented within three different time intervals of the Kimmeridgian. This indicates the presence of dinosaur populations, which lived on the northern margin of the Jura carbonate platform. The dinosaur assemblages revealed by footprints are composed of different size classes of both sauropod (quadrupeds, herbivores) and theropod (bipeds, carnivores) dinosaurs. The tracksites are of major importance for Switzerland's palaeontological heritage. In 2006, the Chevenez - Combe Ronde tracksite has been spanned by an additional bridge specifically built for this purpose. This is the first large palaeontological site in Switzerland, which is protected and made accessible by the construction of a highway. In May 2006 the Canton Jura decided to pursue the political discussion of a valorisation of the tracksites. A valorisation with a combined promotion of tourism, science and education might facilitate palaeontological excavations and research in the Canton Jura, once the construction of the highway will be accomplished.

Zusammenfassung
Sechs Fundstellen mit Dinosaurierspuren wurden von der «Paläontologie A16» auf der zukünftigen Trassee der Transjurane Autobahn A16 in der Ajoie (Kanton Jura) seit dem Jahre 2002 entdeckt. Alle diese Fundstellen werden vor Baubeginn systematisch ausgegraben. Bisher wurden insgesamt über 4'000 Trittsiegel oder 280 Fährten von Dinosauriern in drei verschiedenen Zeitabschnitten des Kimmeridge ausgegraben und dokumentiert. Dies belegt, dass Dinosaurier am nördlichen Rand der Jura-Karbonatplattform lebten. Die Dinosaurier Spurenassoziationen bestehen aus unterschiedlichen Grössenklassen von fleischfressenden Theropoden und pflanzenfressenden Sauropoden. Die Fundstellen sind von grösster Bedeutung für das paläontologische Kulturgut der Schweiz. Im Jahre 2006 wurde die Fundstelle Chevenez - Combe Ronde durch eine extra dafür verlängerte Autobahnbrücke überquert und somit geschützt. Dies ist die erste paläontologische Fundstelle in der Schweiz, die im grossen Rahmen durch die Autobahn geschützt und zugänglich gemacht wird. Im Mai 2006 entschied der Kanton Jura, die Diskussion um eine Aufwertung der Fundstellen weiter zu verfolgen. Dabei könnte eine kombinierte Förderung in den Bereichen des Tourismus, der Wissenschaft und der Ausbildung auch nach Beendigung der Autobahn-Bauarbeiten ein Fortdauern paläontologischer Ausgrabungen und Forschung im Kanton Jura ermöglichen.

[1] République et Canton du Jura, Office de la culture, Section d'archéologie et paléontologie (Paléontologie A16), Hôtel des Halles, P.O. Box 64, 2900 Porrentruy 2, Switzerland, daniel.marty@palaeojura.ch, www.palaeojura.ch
[2] University of Fribourg, Department of Geosciences-Geology, Pérolles, Chemin du Musée 6, 1700 Fribourg, Switzerland
[3] Natural History Museum Basel, Augustinergasse 2, 4001 Basel, Switzerland

Résumé
Six sites à traces de dinosaures ont été découverts depuis 2002 en Ajoie (Canton du Jura) par la «Paléontologie A16», le long du futur tracé autoroutier de la Transjurane. Ces sites à traces sont fouillés de manière systématique avant la construction de l'autoroute. Plus de 4'000 empreintes ou 280 pistes de dinosaures ont été mises au jour et documentées sur des niveaux représentant trois intervalles de temps du Kimméridgien. Les premiers résultats mettent en évidence la présence de populations de dinosaures, qui vivaient sur la marge nord de la plate-forme carbonatée du Jura. Les communautés de dinosaures révélées par les traces sont composées de différentes classes de taille, à la fois chez les dinosaures théropodes (bipèdes, carnivores) et sauropodes (quadrupèdes, herbivores). Ces sites à traces sont d'une importance majeure pour le patrimoine paléontologique suisse. En 2006, le site de Chevenez - Combe Ronde a été protégé sous un pont, grâce à une extension exceptionnelle de ce dernier. Il s'agit du premier site paléontologique d'envergure à être protégé (non détruit) et maintenu accessible (non recouvert) par la construction d'une route nationale. En mai 2006, le Canton du Jura a décidé de poursuivre la discussion du projet de valorisation des sites à traces. Cette dernière devrait à la fois promouvoir les domaines du tourisme, de la science et de l'éducation afin de contribuer au maintien et au développement de fouilles et de recherches paléontologiques dans le Canton du Jura, après la fin de la construction de l'autoroute.

1. Introduction

Since the late 18th century, many well-known scientists (e.g. De Loriol, Greppin, Gressly, Koby, Rollier, Thurmann) published important palaeontological monographs based on specimens from the Jura Mountains. During the last few decades, many authors focused on the regional geology, sedimentology, and stratigraphy (e.g. Laubscher 1948; Ziegler 1956; Diebold 1960; Schneider 1960; Tschopp 1960; Ziegler 1962; Pümpin 1965; Thalmann 1966; Bolliger & Burri 1967; Liniger 1970; Bläsi 1980; Gygi 2000a, b). Moreover, since the first dinosaur footprints were discovered in the Lommiswil quarry near Solothurn (Meyer 1990), many more track-sites have been found in the Late Jurassic of the Swiss Jura Mountains (review in Meyer & Thüring 2003), and more recently in the adjacent French part of the Jura Mountains (Le Loeuff et al. 2006; Mazin & Hantzpergue 2006).

In Switzerland, archaeological survey projects are common since the sixties of the last century. Nevertheless, only recently the importance of safeguarding the palaeontological heritage has been recognized in the Canton Jura. As a result of the construction of the Transjurane highway A16, a new project, further named «Palaeontology A16», was established in February 2000. Initially named «Section de paléontologie», this project is now integrated in the «Section d'archéologie et paléontologie (SAP)» of the «Office de la culture (OCC)» of the Canton Jura. The «Palaeontology A16» is financed by the Swiss Federal Roads Authority (FEDRO, 95%) and the Canton Jura (5%). Its purpose is to excavate and document the palaeontological heritage along the future highway course in the Canton Jura, and to make it accessible for scientific research (Hug et al. 2004).

2. Methodology

Palaeontological and sedimentological prospection (Fig. 1) combined with geological mapping determines the approximate position of the most promising beds on the highway course. Afterwards, prospective excavations are performed using a shovel excavator (Fig. 2). If significant findings are made, an excavation can be planned. All excavations are carried out well before the construction of the highway, and they may last up to several years.

However, important discoveries are sometimes also made during the construction of the highway. In this case, a suitable solution for an emergency excavation has to be worked out with the highway engineers in charge. This happened for example at the Oligocene «La Beuchille» site near Delémont, where numerous vertebrate remains and

large fossil tree trunks have been discovered and excavated in 2001 (Becker et al. 2004). The extraction of macrofossils happens in the field applying classical palaeontological excavation and documentation techniques. Microfossils are isolated in the laboratory by screen-washing. During the excavation of dinosaur footprints (Fig. 3), modern documentation techniques such as laser scanning (Leica Geosystems 2003) and photogrammetry are applied. This completes the classical manual techniques and casts, and enables a virtual reconstruction of the tracksites. This is particularly important, if a track-bearing surface is later displaced, covered up, or destroyed.

3. Geographical and geomorphological setting

All tracksites are located in the Ajoie district on the future course of the Transjurane highway, on a plateau between Courtedoux and Chevenez (Fig. 4). The Ajoie district borders in the south to the Delémont and Franches-Montagnes district, and most parts are relatively flat with a mean elevation of about 500 metres a.s.l. The dominant morphological features are the dry valleys, which have been generated by karstic dissolution (main process) and fluviatile erosion (accessory process) along faults (Braillard 2006a, b). This karstification also caused an important subterranean fluviatile network, and only three small superficial streams still pervade the Ajoie.

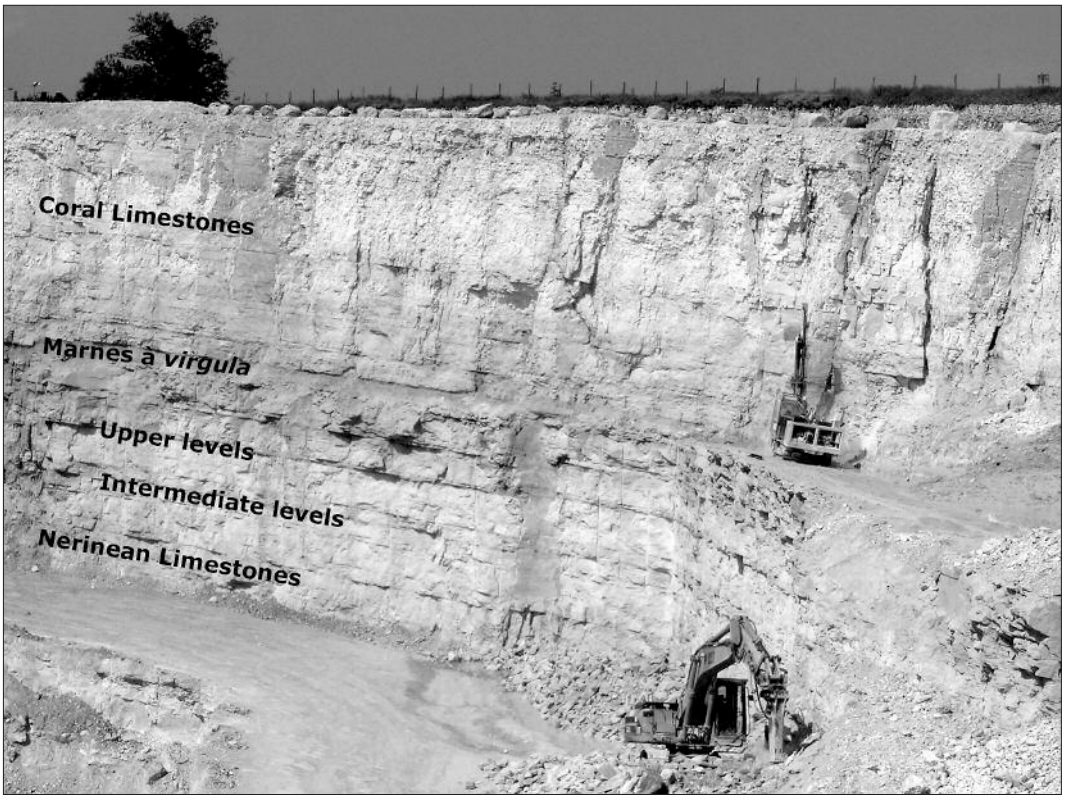

Fig. 1: The study of reference quarries is important to locate fossiliferous beds on the highway course. The La Combe quarry near Chevenez is a reference section (Jank et al. 2006a, b) for the upper Reuchenette Formation.

Fig. 2: Archaeological and palaeontological prospecting along the future course of the highway (here in Bure) allows to identify the most important beds and determines the approximate position of a future excavation area.

Fig. 3: Excavation of the main track level at the Chevenez - Combe Ronde tracksite. This site is protected by the extension of the highway bridge, which is visible in the upper left corner of the picture.

4. Geological and stratigraphical setting

The Ajoie is located at the eastern end of the Rhine-Bresse transfer zone between the Folded Jura Mountains to the south and east and the Upper Rhine Graben and Vosges Mountains to the north (Fig. 5). It belongs almost entirely to the Tabular Jura, which consists of slabs of subhorizontally layered Mesozoic strata, separated by narrow dislocation belts (Trümpy 1980). Near the front of the Folded Jura (Mont Terri anticline), detached folds of the Folded Jura are overthrusted onto the Tabular Jura (Tschopp 1960). From the Eocene to the Pleistocene, five tectonic phases created a complex set of fractures in the bedrock, as well as small, low amplitude anticlines (Giamboni et al. 2004; Ustaszewski et al. 2005; Braillard 2006b).

In the Ajoie district the highway cuts almost entirely through Late Jurassic strata. The lithostratigraphy of the Late Jurassic is based on Gygi (2000a, b). Excavations are mainly undertaken in the St. Ursanne and Vellerat Formations (Middle to Late Oxfordian), and in the Reuchenette Formation (Kimmeridgian). Further, Quarternary fillings of dolines are excavated for Pleistocene mammals such as mammoths.

In the Oxfordian, mainly invertebrates (including abundant crinoids) have been excavated so far. The Kimmeridgian from the Banné Marls (Banné Member *sensu* Gygi 2000a, b) up to the «Marnes à *virgula*» (Vir-

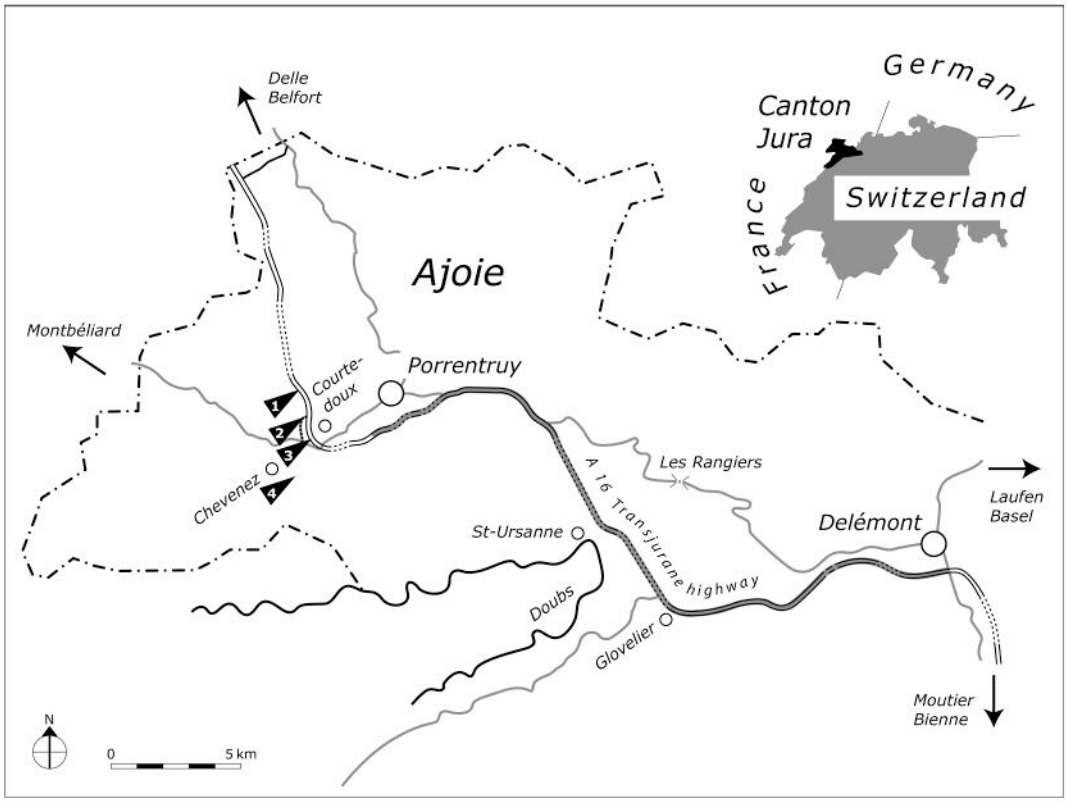

Fig. 4: Location of the tracksites along the future Transjurane highway. From north to south 1: Courtedoux - Béchat Bovais and Courtedoux - Bois de Sylleux, 2: Courtedoux - Tchâfouè and Chevenez - Combe Ronde, 3: Courtedoux - Sur Combe Ronde and Chevenez - Crât, 4: La Combe quarry (Chevenez).

gula Member s.l. of Gygi 2000a, b; northern Virgula Marls in Jank et al. 2006a; Virgula Marls in Jank et al. 2006b; lower Virgula Member in Colombié & Rameil 2007) is particularly fossiliferous, yielding dinosaur footprints and remains of vertebrates and invertebrates (e.g., Marty & Hug 2003a; Billon-Bruyat & Marty 2004; Billon-Bruyat 2005a, b) (Fig. 6).

Until recently, the Late Jurassic stratigraphy of the Ajoie has been understood only insufficiently. This was due to a lack of biostratigraphical markers (mainly ammonites) related to bad outcrop conditions (Gygi 2000a). The construction of the highway and associated quarrying at several localities is thus a unique possibility to study not only the palaeontology, but also the stratigraphy of the Late Jurassic of northwestern Switzerland. Since the excavations of the «Palaeontology A16» started, many ammonites have been discovered. These ammonites allowed to establish a well-defined biostratigraphical frame for the upper Reuchenette Formation of northwestern Switzerland (Jank et al. 2005; Jank et al. 2006a, b). This also showed that no Tithonian («Portlandian») sediments crop out in the Ajoie, contrary to what was mentioned previously on the geological map of St. Ursanne (Diebold 1960). Further, a sedimentological, sequential, and cyclostratigraphic framework for the Late Jurassic carbonate platform of the Swiss Jura Mountains has been established by Gygi et al. (1998) and Hug (2003) for the Oxfordian, Colombié (2002), Colombié & Strasser (2005) and Jank et al. (2005, 2006a, b) for the Kimmeridgian, and by Rameil (2005) for the Late Kimmeridgian and Tithonian. Finally, this enabled to put forward a tethyan-to-boreal correlation in the Kimmeridgian (Jank et al. 2005, 2006a, Colombié & Rameil 2007).

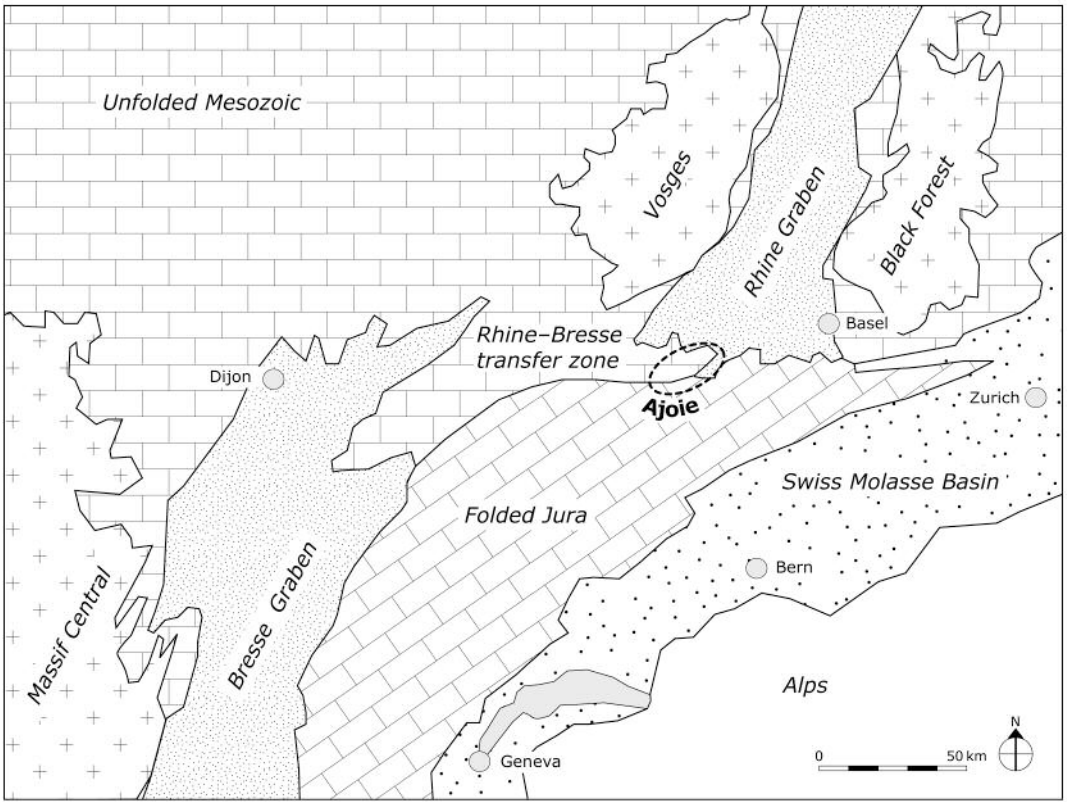

Fig. 5: Geological setting showing the position of the Ajoie. Modified from Braillard (2006b).

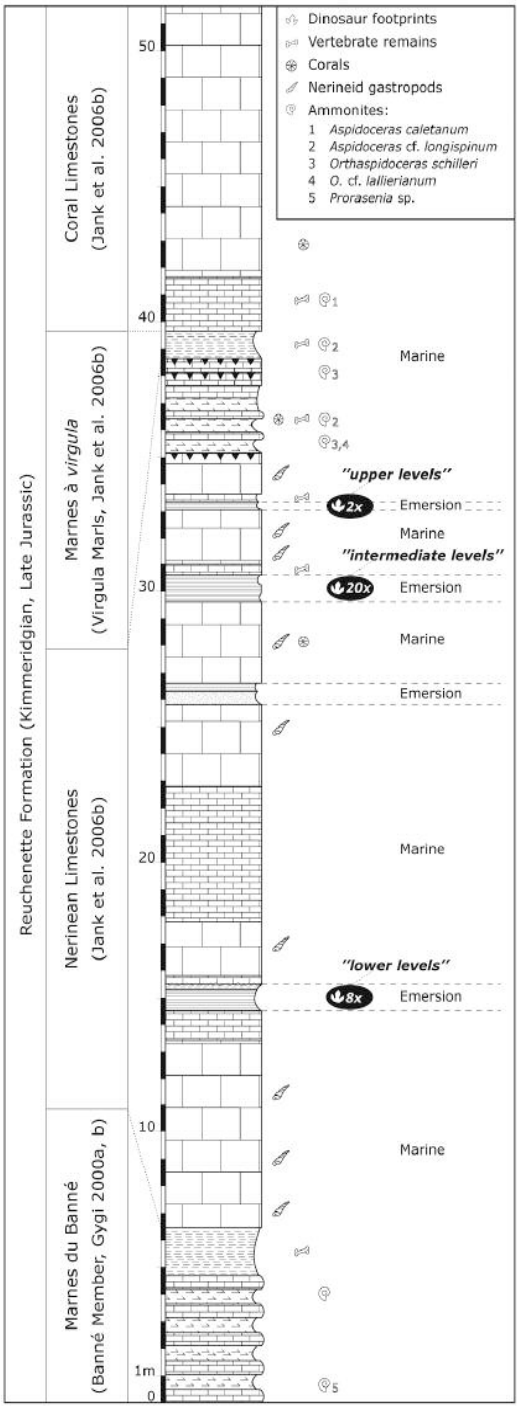

Fig. 6: Stratigraphical setting of the Kimmeridgian between the «Marnes du Banné» and the «Marnes à *virgula*». Three time intervals each with several levels bearing dinosaur footprints have been identified so far. Ammonites precisely pinpoint the section within the Kimmeridgian.

5. Palaeogeography and palaeoenvironment

During the Late Jurassic, the domain of today's northwestern Swiss Jura Mountains was located at the northern margin of the oceanic Ligurian Tethys and it was the central part of the large, structurally complex Jura carbonate platform. This platform was located at the threshold between the Paris Basin to the northwest and the Tethys Ocean to the south, and thus, subjected to influences from both the Tethyan and Boreal realms (Ziegler 1988; Smith et al. 1994; Dercourt et al. 2000). The climate was subtropical and the palaeolatitude was around 28° N (Frakes et al. 1992; Thierry 2000a, b).

The Jura platform was subdivided into land surfaces, tidal flats, internal lagoons, lagoons, and barriers (e.g., Hillgärtner 1999; Hug 2003; Colombié & Strasser 2005). Consequently, the Late Jurassic of the Ajoie is essentially made up of shallow marine carbonates and marls, in function of terrestrial input related to eustatic sea-level changes and climatic conditions.

A first sedimentological analysis of the tracksites suggests the presence of several micro-environments ranging from shallow lagoon to beach and to supratidal flats and marshes (Marty & Strasser 2005). Similar zonations in laminated sediments have been described from the Shark Bay (Australia), the Persian Gulf, and the Bahamas (e.g., Logan et al. 1970; Purser 1973; and Hardie 1977, respectively). In such environments, the preservation of dinosaur footprints basically depends on the water content of the sediment (Allen 1997, Manning 2004), and on the presence of microbial mats that bind and stabilize the sediment and induce early-diagenetic carbonate cementation (e.g., Dupraz et al. 2004). This results in a wide range of footprint morphologies (Marty 2005).

Small-scale sea-level drops created vast emergent areas in a carbonate lagoon and tidal flat environment, as proven by the

numerous track-bearing horizons (Billon-Bruyat et al. 2004). Dinosaurs probably accessed the platform from the coastal zone of the «Süddeutsche Schwelle» in the north-east, which was located at the south-eastern border of the London-Brabant Massif, or from the coastal zone of the Massif Central (Meyer & Lockley 1996; Meyer et al. 2006).

6. The dinosaur track excavations

So far, six dinosaur tracksites have been discovered on the future course of the highway, on a plateau between Courtedoux and Chevenez. They are located at three time intervals (named lower, intermediate, and upper levels) each with several levels bearing dinosaur footprints (Fig. 6). Furthermore, tracks have also been found within the same levels in the La Combe quarry near Chevenez. Over 4'000 dinosaur footprints including 280 trackways have been excavated and documented so far (Table 1). On the tracksites of the Transjurane highway, considerably large surfaces remain to be excavated over the next few years. To date, four sites have partially been excavated, and the first results are briefly summarized here:

Courtedoux - Béchat Bovais tracksite
This tracksite is located within the lower levels, and it is with a total surface of around 4'000 m^2 the largest tracksite on the highway course. So far, only a surface of about 15×25 m has been excavated. This revealed six trackways of small to large sauropods, three of which are crossing each other at the same place. It is interesting to note that in the immediate proximity of this site, a roman road and several dolines with remains of mammoths and silex of Neanderthals have been excavated. Thus, this site is a true «time crossroad».

Courtedoux - Tchâfouè tracksite
Here, excavations in the intermediate levels lasted from summer 2004 until spring 2007. During this period, over 2'100 footprints and 68 trackways of sauropods and 96 trackways of tridactyl dinosaurs (chiefly ascribed to theropods) (Fig. 8) have been uncovered and documented on 15 superimposed palaeosurfaces. These include level 1060 with several partially parallel trackways of tiny sauropods associated with a trackway of a large sauropod and several trackways of small to medium-sized theropods (Marty et al. 2006a). Level 1030 exhibited trackways of small and medium-sized sauropods associated with medium-sized and large theropods. On the main track level (level 1000) finally, over 800 footprints or 25 trackways of small to medium-sized sauropods, and 19 trackways of small to large tridactyl (mainly theropods) dinosaurs have been found. The main track level of this site is actually covered due to the construction of the highway. A small part of the main track level will be destroyed during the construction. The remaining surface will be covered, once the construction of the highway is accomplished. On the same site, a rich coastal marine vertebrate fauna with remains of turtles, crocodilians, and fish has been excavated in the overlying «Marnes à *virgula*» (Billon-Bruyat 2005b).

Chevenez - Combe Ronde tracksite
This tracksite was discovered in August 2003. Footprints occur within the calcareous laminites of the lower levels. Totally, over 1'100 dinosaur tracks including 73 trackways have been documented and measured. The track-bearing laminites have systematically been uncovered level-by-level, displaying sauropod footprints on eight superimposed surfaces, and facilitating to distinguish between true tracks, undertracks, and overtracks (Marty 2005; Marty et al. 2006b). The main track level (level 500), which is located at the base of the laminites, bears a particularly rich ichnocoenosis. On a surface of about 800 m^2, tridactyl dinosaurs are represented by 48 trackways heading in different directions. Different size classes of prints

	No. of track level	Courtedoux Béchat Bovais			Courtedoux Bois de Sylleux			Courtedoux Tchâfouè			Chevenez Combe Ronde			Courtedoux Sur Combe Ronde			Courtedoux Crât			Chevenez La Combe quarry			**Tracks & trackways per level**		
		Trackways		Total	Trackways		Total	Trackways		Total	Trackways		Total	Trackways		Total	Trackways		Total	Trackways		Total	**Trackways**		**Total**
		Sauropod	Tridactyl	tracks	Sauropod	Tridactyl	tracks	Sauropod	Tridactyl	tracks	Sauropod	Tridactyl	tracks	Sauropod	Tridactyl	tracks	Sauropod	Tridactyl	tracks	Sauropod	Tridactyl	tracks	**Sauropoda**	**Tridactyl**	**tracks**
upper levels	1600															5				no tracks reported as yet			0	0	5
	1500					2	16		1	4													0	3	20
intermediate levels	1075					2	13																0	2	13
	1070							2	5	120													2	5	120
	1069								7	27													0	7	27
	1065					1	9		25	198													0	26	207
	1060							9	15	302													9	15	302
	1055							7	9	185													7	9	185
	1052								2	12													0	2	12
	1050						12																0	0	12
	1040						7																0	0	7
	1035				1		7																1	0	7
	1031				2		30																2	0	30
	1030				1		7	5	7	170				1		10							7	7	187
	1029									2													0	0	2
	1025							1	2	25													1	2	25
	1020							6	3	109													6	3	109
	1015							10	1	117													10	1	117
	1014							1		14													1	0	14
	1010							1		13													1	0	13
	1003							1		13													1	0	13
	1000							25	19	806				17	2	678						10	42	21	1494
lower levels	540										1		20										1	0	20
	530										2		27										2	0	27
	520										3		98										3	0	98
	515	4		123							2		44										6	0	167
	510	1		7							3		53										4	0	60
	505												25										0	0	25
	502	1		13																			1	0	13
	500										14	48	840						50	8		58	22	48	948
Total		6		143	4	5	101	68	96	2117	25	48	1107	18	2	693			50	8		68	**129**	**151**	**4279**

Tab. 1: Distribution and abundance of documented dinosaur tracks and trackways on the tracksites of the Transjurane highway and the adjacent La Combe quarry (Chevenez). Apart from a few trackways of a possible Ornithischian origin, most tridactyl trackways may be attributed to theropods. The shaded levels do not crop out at a given tracksite.

ranging from 8 to 30 cm in length have been observed. The smallest footprints make up an over 60 m long trackway composed of almost 80 footprints. Additionally, very small to medium-sized sauropod dinosaurs are represented by 14 trackways (Fig. 8), nine of which are approximately parallel and heading in the same direction. Two other parallel trackways are those of very small «baby» sauropods with a pes length of not even 20 cm. In 2006, the Combe Ronde - site has been crossed and protected by the extension of a highway bridge.

Courtedoux - Sur Combe Ronde tracksite

Dinosaur footprints are located within a meter-thick interval of inter- to supratidal calcareous laminites (sub-lithographic limestones) of the intermediate levels. These laminites will be excavated over a surface of approximately 1'500 m^2. So far, the main track level (level 1000), which is located at the base of the laminites, has been uncovered over an area of about 650 m^2, revealing two trackways of medium-sized theropods and seventeen trackways of small- to medium-sized sauropods (Fig. 9) (Marty et al. 2003). Further, a trackway of a very small «baby» sauropod has been excavated on an overlying level (Marty & Cavin 2003). All sauropod trackways belong to the ichnotaxon *Parabrontopodus*, the narrow-gauge sauropod trackway type (Lockley et al. 1994), commonly attributed to diplodocid sauropods (e.g., Day et al. 2002). The main track level is now covered with sand for protection and thus not accessible. This tracksite will be protected under a bridge.

7. Site protection and valorisation

In most parts of the world, fossil footprint sites are considered as an important part of the natural heritage and have become integral parts of the cultural heritage in the regions where they are located (Lockley & Meyer 1997). As they are normally very large sites, they can only be preserved *in situ*. Most of the protected tracksites are made

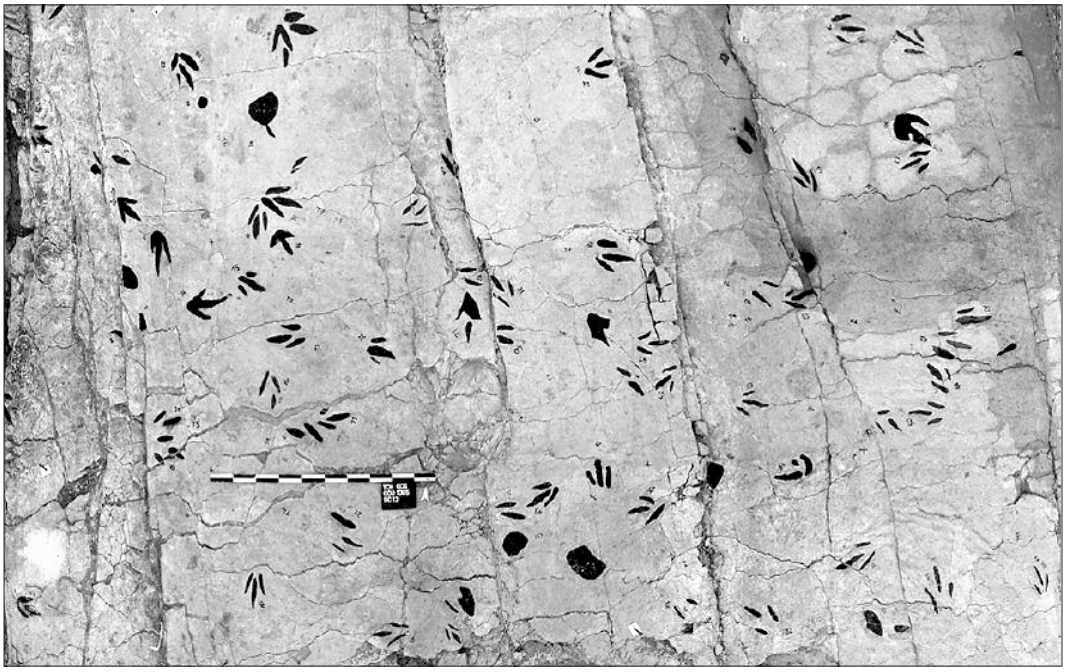

Fig. 7: Track level 1065 of the Courtedoux - Tchâfouè tracksite. Tridactyl footprints of medium-sized theropods. Scale bar is 1 m.

Fig. 8: Chevenez - Combe Ronde tracksite, main track level (level 500): trackway with oval pes and semi-circular manus of a juvenile sauropod dinosaur. Pes length is 35 cm.

Fig. 9: Main track level (level 1000) of the Courtedoux - Sur Combe Ronde tracksite, situated at the base of the laminites. The total area is about 650 m^2. About 400 of the 650 observed footprints are resolved into seventeen sauropod and two theropod trackways (Marty et al. 2003).

accessible to the public and used as tourist attractions in geoparks or dinosaur-parks.
The dinosaur tracksites along the Transjurane highway are of major importance for Switzerland's palaeontological heritage. They are part of the larger, well-known geological landscape of the Jura Mountains, and they are easily accessible and offer excellent opportunities for public viewing. During visiting days totalizing approximately 4 months over 45'000 people flocked to the sites to learn more about dinosaurs and palaeontological excavations and research. Thus, the tracksites have proven their excellent scientific, educational and touristic potential. They offer the possibility of combining scientific study with a didactic and cultural purpose (Marty et al. 2004).
Actually, the idea of a centre with a multiple tourism-, research-, and educational-based approach is discussed by the politicians. Such a project, integrated into a regional tourism concept, may create and safeguard jobs and provide sustainable economic development in the Ajoie district (Marty & Hug 2003b, 2004). So far, a commission evaluated the general orientation of such a project, and a first assessment was accomplished by Urbaplan (a project planning office from Lausanne). In May 2006 the Canton Jura decided to pursue the project, to finance the preparation of a detailed project definition, and to examine the possibility of the acquisition of further track-bearing land outside of the highway course, which could be used for ongoing excavations and for the construction of an interpretative centre.

8. Concluding remarks

- So far, dinosaur footprints occur on 30 distinct levels at three time intervals in the Kimmeridgian of the Ajoie. These repetitive occurrences are important for the interpretation of the terrestrial ecosystem, the platform evolution and the cyclostratigraphic framework.

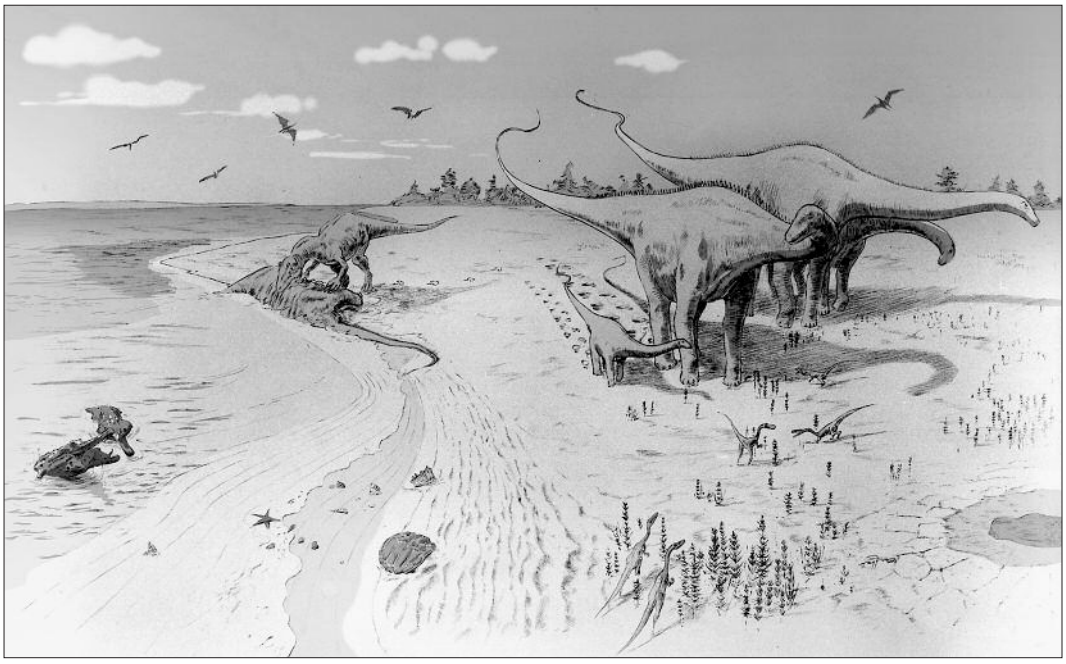

Fig. 10: Reconstruction of the Kimmeridgian coastal reptile fauna based on the Late Kimmeridgian (ichno-)fossil record of the Ajoie.

- To date, over 4'000 footprints including 280 trackways of dinosaurs have been excavated and documented. These exhibit a wide range of footprint size and trackway patterns and configurations. They suggest that dinosaurs including small to large carnivores and herbivores regularly roamed through this coastal marine environment. This implies the presence of vegetated areas in the interior platform as a food source (Fig. 10).
- Following the discovery of the tracksites, both, the political reactions as well as the highway construction measures for the protection of the tracksites (namely of the Chevenez - Combe Ronde tracksite) are an important signal for the protection of palaeontological heritage in Switzerland.
- Finally, a valorisation of the palaeontological heritage, combined with a multiple tourism-, research-, and educational-based approach, might facilitate palaeontological excavations and research in the Canton Jura, once the construction of the highway will be accomplished.

Acknowledgements

The «Palaeontology A16» is funded by the Swiss Federal Roads Authority and the Canton Jura. A part of the ichnological research forms part of a PhD thesis (D. M.), which is financially supported by the Swiss National Science Foundation (grant 20-109214.05). Earlier versions of the manuscript benefited from reviews by A. Strasser and K. Ustaszewski. All these contributions are gratefully acknowledged. Finally, we thank the Swiss Association of Petroleum Geologists and Engineers for inviting us to contribute to their annual meeting 2006 and to the present volume of the Bulletin for Applied Geology.

References

Allen, J. R. L. 1997: Subfossil mammalian tracks (Flandrian) in the Severn Estuary, S.W. Britain: mechanics of formation, preservation and distribution. Philosophical Transactions of the Royal Society of London ser. B352, 481-518.

Becker, D., Lapaire, F., Picot, L., Engesser, B. & Berger, J.-P. 2004: Biostratigraphie et paléoécologie du gisement à vertébrés de La Beuchille (Oligocène, Jura, Suisse). Revue de Paléobiologie volume spécial 9, 179-191.

Billon-Bruyat, J.-P. 2005a: First record of a non-pterodactyloid pterosaur (Reptilia: Archosauria) from Switzerland. Eclogae geol. Helv. 98, 313-317.

Billon-Bruyat, J.-P. 2005b: A turtle «cemetery» from the Late Jurassic of Switzerland. Abstract volume, Swiss Geoscience Meeting 2005, Zürich, p. 238.

Billon-Bruyat, J.-P. & Marty, D. 2004: A new coastal reptilian fauna from the Kimmeridgian of northwestern Switzerland. 52nd Symposium of Vertebrate Palaeontology and Comparative Anatomy (Leicester, England), abstract volume, p. 8.

Billon-Bruyat J.-P., Marty D. & Hug, W. A. 2004: New dinosaur tracks from the Kimmeridgian of northwestern Switzerland: evidence for emersions. Réunion des Sciences de la Terre (Strasbourg, France), abstract volume, p. 34.

Bläsi, H. R. 1980: Die Ablagerungsverhältnisse im Portlandien des Schweizerischen und Französischen Jura. Unpublished PhD thesis, University of Bern, 151 pp.

Bolliger, W. & Burri, P. 1967: Versuch einer Zeitkorrelation zwischen Plattformkarbonaten und tiefmarinen Sedimenten mit Hilfe von Quarz-Feldspat-Schüttungen (mittlerer Malm des Schweizer Jura. Eclogae geol. Helv. 60, 491-507.

Braillard L. 2006a: Rôles de la tectonique et de la stratigraphie dans la formation des vallées sèches de l'Ajoie. Actes 2005 de la Société jurassienne d'Émulation, 33-65.

Braillard L. 2006b: Morphogenèse des vallées sèches du Jura tabulaire d'Ajoie (Suisse): rôle de la fracturation et étude des remplissages quaternaires. GeoFocus 14, 224 pp.

Colombié, C. 2002: Sédimentologie, stratigraphie séquentielle et cyclostratigraphie du Kimméridgien du Jura suisse et du Bassin vocontien (France): relations plate-forme - bassin et facteurs déterminants. GeoFocus 4, 198 pp.

Colombié, C. & Rameil, N. 2007: Tethyan-to-boreal correlation in the Kimmeridgian using high-resolution sequence stratigraphy (Vocontian Basin, Swiss Jura, Boulonnais, Dorset). International Journal of Earth Sciences 96, 567-591.

Colombié, C. & Strasser, A. 2005: Facies, cycles, and controls on the evolution of a keep-up carbonate platform (Kimmeridgian, Swiss Jura). Sedimentology 52, 1207-1227.

Day, J. J., Upchurch, P., Norman, D. B., Gale, A.S. & Powell, H. P. 2002: Sauropod trackways, evolution and behavior. Science 296, p. 1659.

Dercourt, J., Gaetani, M., Vrielynck, B., Barrire, E., Biju-Duval, B., Brunet, M. F., Cadet, J. P., Crasquin, S. & Sandulescu, M. 2000: Atlas Peri-Tethys - Palaeogeographical maps. Commission of the Geological Map of the World, Paris.

Diebold, P. 1960: Geologie des Gebietes von Siegfriedblatt Ocourt (Berner Jura). Beiträge zur Geologischen Karte der Schweiz [N.F.] 111/141, 60 pp.

Dupraz, C., Visscher, P. T., Baumgartner, L. K. & Reid, R. P. 2004: Microbe-mineral interactions: early carbonate precipitation in a hypersaline lake (Eleuthera Island, Bahamas). Sedimentology 51, 745-765.

Frakes, L. A., Francis, J. E. & Sykes, R. M. 1992: Climate modes of the Phanerozoic. Cambridge University Press, Cambridge, 274 pp.

Giamboni, M., Ustaszewski, K., Schmid, S. M., Schumacher, M. E. & Wetzel, A. 2004: Plio-Pleistocene transpressional reactivation of Paleozoic and Paleogene structures in the Rhine-Bresse transform zone (northern Switzerland and eastern France). International Journal of Earth Sciences (Geologische Rundschau) 93, 207-223.

Gygi, R. A. 2000a: Integrated stratigraphy of the Oxfordian and Kimmeridgian (Late Jurassic) in northern Switzerland and adjacent southern Germany. Memoire of the Swiss Academy of Sciences 104, 152 pp.

Gygi, R. A. 2000b: Annotated index of lithostratigraphic units currently used in the Upper Jurassic of Northern Switzerland. Eclogae geol. Helv. 93, 125-146.

Gygi, R. A., Coe, A. L. & Vail, P. R. 1998: Sequence stratigraphy of the Oxfordian and Kimmeridgian (Late Jurassic) in northern Switzerland. In: Hardenbol, J., De Graciansky, P. C., Thierry, J., Farley, M. & Vail, P. R. (eds.), Mesozoic-Cenozoic sequence stratigraphy of European basins. SEPM (Society for Sedimentary Geology) special publication 60, 527-544.

Hardie, L. A. (ed.) 1977: Sedimentation on the modern carbonate tidal flats of Northwest Andros Island, Bahamas. The Johns Hopkins University Studies in Geology 22, 202 pp.

Hillgärtner, H. 1999: The evolution of the French Jura platform during the Late Berriasian to Early Valanginian: controlling factors and timing. GeoFocus 1, 203 pp.

Hug, W. A. 2003: Sequenzielle Faziesentwicklung der Karbonatplattform des Schweizer Jura im Späten Oxford und frühesten Kimmeridge. GeoFocus 7, 154 pp.

Hug, W. A., Becker, D., Marty, D. & Oriet, A. 2004: La Section de paléontologie de la République et Canton du Jura: une brève présentation. Actes 2003 de la Société Jurassienne d'Émulation, 9-26.

Jank, M., Meyer, C. A. & Wetzel, A. 2006a: Late Oxfordian to Late Kimmeridgian carbonate deposits of NW Switzerland (Swiss Jura): Stratigraphical and palaeogeographical implications in the transition area between the Paris Basin and the Tethys. Sedimentary Geology 138, 237-263.

Jank, M., Wetzel, A. & Meyer, C. A. 2006b: A calibrated composite section for the Late Jurassic Reuchenette Formation in northwestern Switzerland (?Oxfordian, Kimmeridgian sensu gallico, Ajoie-Region). Eclogae geol. Helv. 99, 175-191.

Jank, M., Wetzel, A. & Meyer, C. A. 2005: Late Jurassic sea-level fluctuations in NW Switzerland (Late Oxfordian to Late Kimmeridgian): closing the gap between the Boreal and Tethyan realm in Western Europe. Facies 52, 487-519.

Laubscher, H. 1948: Geologie des Gebiets von Siegfriedblatt St-Ursanne (Berner Jura). Beiträge zur Geologischen Karte der Schweiz [N.F.] 92, 49 pp.

Leica Geosystems 2003: Sensationelle Dinosaurier-Fussspuren mit 3D-Lasermass. Vermessung Photogrammetrie Kulturtechnik 1/2003, 36-38.

Le Loeuff, J., Gourrat, C., Landry, P., Hautier, L., Liard, R., Souillat, C., Buffetaut, E & Enay, R. 2006: A Late Jurassic sauropod tracksite from Southern Jura (France). Comptes Rendus Palevol. 5, 705-709.

Liniger, H., 1970: Blatt 1065 Bonfol (Atlasblatt 55) - Geologischer Atlas der Schweiz 1:25'000. Schweizerische geologische Kommission, Erläuterungen, 39 pp.

Lockley, M. G. & Meyer, C. A. 1997: Sacred Ground: Walking in the Footsteps of our ancestors. In: Huh, M., Yang, S. S. Y., Lockley, M. G. & Lee, Y. N. (eds.), Proceedings of the International Dinosaur Symposium for the Uhangri Dinosaur Centre and Theme Park. Chonnam National University, 211-220.

Lockley, M. G., Farlow, J. O., Meyer, C. A. 1994: *Brontopodus* and *Parabrontopodus* ichnogen. nov. and the significance of wide- and narrow-gauge sauropod trackways. Gaia 10, 135-146.

Logan, B. W., Davies, G. R., Read, J. F. & Cebulski, D. E. (eds.) 1970: Carbonate sedimentation and environments, Shark Bay, Western Australia. AAPG (American Association of Petroleum Geologists) memoir 13, 223 pp.

Manning, P. L. 2004: A new approach to the analysis and interpretation of tracks: examples from the Dinosauria. In: McIlroy, D. (ed.), The Application of Ichnology to Palaeoenvironmental and Stratigraphical Analysis, Geological Society of London, Special Publication 228, 93-128.

Marty, D. 2005: Sedimentology and Taphonomy of Dinosaur Track-bearing Plattenkalke (Kimmeridgian, Canton Jura, Switzerland). 4th International Symposium on Lithographic Limestone and Plattenkalk, 12th-18th September 2005, Eichstätt, Zitteliana B26, p. 20.

Marty, D. & Cavin, L. 2003: A «baby»-sauropod trackway from the Late Jurassic Courtedoux dinosaur tracksite excavations, Canton Jura, Northern Switzerland. Abstract, 1st Meeting of the European Association of Vertebrate Palaeontologists, Basel, 15.-19. July, Basel, p. 29.

Marty, D. & Hug, W. A. 2003a: Le Kimméridgien en Ajoie (Mésozoïque): Premiers résultats de fouilles et de recherches paléontologiques sur le tracé de la Transjurane (A16). Actes 2003 de la Société jurassienne d'Émulation, 27-44.

Marty, D. & Hug, W. A. 2003b: Das Dinosaurier-Spurenvorkommen von Courtedoux, Kanton Jura: Dauerhafter Geotopschutz und nachhaltige Nutzung. In: Jordan, P., Heinz, R., Heitzmann, P., Hipp, R. & Imper, D. (eds.), Geotope - wie schützen / Geotope - wie nutzen. Schriftenreihe der Deutschen Geologischen Gesellschaft 32, 115-121.

Marty, D. & Hug, W. A. 2004: Dinosaurier-Spurenvorkommen auf der Transjurane, Kanton Jura: paläontologische Grabungen, Schutz und nachhaltige Nutzung. Geoforum Aktuell 19, 2-9.

Marty, D. & Strasser, A. 2005: Sedimentology and palaeoenvironment of dinosaur-track bearing laminites (Late Kimmeridgian, Canton Jura): first results. Abstract volume, SwissSed, 29.01.05, Fribourg, 36-37.

Marty, D., Cavin, L., Hug, W. A., Jordan, P., Lockley, M. G. & Meyer, C. A. 2004: The protection, conservation and sustainable use of the Courtedoux dinosaur tracksite, Canton Jura, Switzerland. Revue de Paléobiologie, volume spéciale 9, 39-49.

Marty, D., Cavin, L., Hug, W. A., Meyer, C. A., Lockley, M. G. & Iberg, A. 2003: Preliminary report on the Courtedoux dinosaur tracksite from the Kimmeridgian of Switzerland. Ichnos 10, 209-219.

Marty, D., Paratte, G., Meyer, C. A., Billon-Bruyat, J.-P. & Ayer, J. 2006a: New multiple ichnocoenoses of Switzerland: evidence for enduring dinosaur communities on the northern Tethys platform. Journal of Vertebrate Paleontology 26 (suppl. to no. 3), p. 96A.

Marty, D., Meyer, C. A. & Billon-Bruyat, J.-P. 2006b: Sauropod trackway patterns expression of special behaviour related to substrate consistency? An example from the Late Jurassic of northwestern Switzerland. Hantkeniana 5, 38-41.

Mazin, J. M. & Hantzpergue, P. 2006: The first sauropod megatracksite from France: the Loulle quarry (Late Oxfordian, Jura, France). 54th Symposium of Vertebrate Palaeontology and Comparative Anatomy, 12.-16.09.2006, Paris, Abstract, p. 21.

Meyer, C. A. 1990: Sauropod tracks from the Upper Jurassic Reuchenette Formation (Kimmeridgian, Lommiswil, Kt. Solothurn) of Northern Switzerland. Eclogae geol. Helv. 82, 389-397.

Meyer, C. A. & Lockley, M. G., 1996, The Late Jurassic continental fossil record of Northern Switzerland - evidence and implications, In: Morales, M. (ed.), The continental Jurassic, Museum of Northern Arizona, Flagstaff, 421-426.

Meyer, C. A. & Thüring, B. 2003: Dinosaurs of Switzerland. Comptes Rendus Palevol. 2, 103-117.

Meyer, C. A., Thüring, B. & Wetzel, A. 2006: The hitch-hikers guide to the Late Jurassic - Basement structures provide clues to dinosaur migration routes. Hantkeniana 5, p. 96.

Pümpin, V. F. 1965: Riffsedimentologische Untersuchungen im Rauracien von St. Ursanne und Umgebung (Zentraler Schweizer Jura), Eclogae geol. Helv. 58, 799-876.

Purser, B. H. 1973: The Persian Gulf: Holocene carbonate sedimentation and diagenesis in a shallow epicontinental sea. Springer-Verlag, Berlin, 471 pp.

Rameil, N. 2005: Carbonate sedimentology, sequence stratigraphy, and cyclostratigraphy of the Tithonian in the Swiss and French Jura Mountains. GeoFocus 13, 245 pp.

Schneider, A. 1960: Geologie des Gebietes von Siegfriedblatt Porrentruy (Berner Jura). Beiträge zur Geologischen Karte der Schweiz [N.F.] 109, 72 pp.

Smith, G. A., Smith, D. G. & Funnell, B. M. 1994: Atlas of Mesozoic and Cenozoic coastlines. Cambridge University Press, 120 pp.

Thalmann, H.-K. 1966: Zur Stratigraphie des oberen Malm im südlichen Berner und Solothurner Jura. Unpublished PhD thesis, University of Bern, 125 pp.

Thierry, J. 2000a: Early Kimmeridgian, In: Dercourt, J., Gaetani, M., Vrielvynck, B., Barrier, E., Biju-Duval, B., Brunet, M.F., Cadet, J.P., Crasquin, S. & Sandulescu, M. (eds.), Atlas Peri-Tethys, Palaeogeographical maps - Explanatory Notes, 85-97.

Thierry, J. 2000b: Early Tithonian, In: Dercourt, J., Gaetani, M., Vrielvynck, B., Barrier, E., Biju-Duval, B., Brunet, M.F., Cadet, J.P., Crasquin, S. & Sandulescu, M. (eds.), Atlas Peri-Tethys, Palaeogeographical maps - Explanatory Notes, 99-110.

Trümpy, R. 1980: Geology of Switzerland - a guide book, Part A: An outline of the Geology of Switzerland. Wepf & Co. Publishers, 104 pp.

Tschopp, R. 1960: Geologie des Gebietes von Siegfriedblatt Miécourt (Berner Jura). Beiträge zur Geologischen Karte der Schweiz [N.F.] 110, 62 pp.

Ustaszewski, K., Schumacher, M. E. & Schmid, S. M. 2005: Simultaneous normal faulting and extensional flexuring during rifting - an example from the southernmost Upper Rhine Graben. International Journal of Earth Sciences (Geologische Rundschau) 94, 680-696.

Ziegler, M. A. 1962: Beiträge zur Kenntnis des unteren Malm im zentralen Schweizer Jura. Unpublished PhD thesis, University of Zürich, 55 pp.

Ziegler, P. A. 1956: Zur Stratigraphie des Séquanien im zentralen Schweizer Jura. Mit einem Beitrag von E. Gasche. Beiträge zur Geologischen Karte der Schweiz [N.F.] 102, 37-101.

Ziegler, P. A. 1988: Evolution of the Arctic - North Atlantic and the Western Tethys. AAPG (American Association of Petroleum Geologists) memoir 43, 198 pp.