+ model

ARTICLE IN PRESS

Available online at www.sciencedirect.com

SCIENCE DIRECT®

Sedimentary Geology xx (2006) xxx–xxx

Sedimentary Geology

www.elsevier.com/locate/sedgeo

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

Markus Jank [a,*], Christian A. Meyer [b,1], Andreas Wetzel [a,2]

[a] *Geologisch-Paläontologisches Institut Universität Basel, Bernoullistrasse 32, CH-4056 Basel, Switzerland*
[b] *Naturhistorisches Museum Basel, Augustinergasse 2, CH-4001 Basel, Switzerland*

Received 9 November 2004; received in revised form 15 July 2005; accepted 3 August 2005

Abstract

Geological sections of the shallow-water, carbonate-dominated sedimentary system of the Late Jurassic Reuchenette Formation in northwestern Switzerland have been studied between the southern Jura Mountains and the Tabular Jura. The largest sections show a characteristic cyclic stacking pattern. Up to now, the age of these sediments (including the type-section) linking the Boreal and Tethyan realms, was biostratigraphically poorly constrained.

In the Tabular Jura five 3rd order sequences can be assigned to the Planula- to Eudoxus-Zone (Late Oxfordian to Late Kimmeridgian) using index-fossils (ammonites and ostracodes; [Jank M., 2004, New insights into the development of the Late Jurassic Reuchenette Formation of NW Switzerland (Late Oxfordian to Late Kimmeridgian, Jura Mountains). Dissertationen aus dem Geologisch-Paläontologischen Institut der Universität Basel, 32, 121 pp.]). This time control and several new outcrops, in combination with mineralostratigraphical and lithological marker beds, allow the correlation and dating of the thickest sections of the Reuchenette Formation and thus serve to improve the previously estimated ages of their sequence boundaries.

The variability of stacking pattern and facies between sections also reveals distinctive changes in facies evolution, related to Late Palaeozoic basement structures and synsedimentary subsidence. These structures acted as important controlling factors for the sediment distribution of the Reuchenette Formation besides the sea level fluctuations. The interplay of sea level changes and synsedimentary subsidence is outlined by lateral thickness variations and shifting depositional environments.

A close examination of these changes also sheds much light on the nature of platform topography in the transition area between the Paris Basin in the north and the Tethys in the south, or more generally between the Boreal and Tethyan realms. During the Planula- to Divisum-time-intervals the study area was a flat platform with a more or less uniform facies distribution, which connected the above-mentioned realms. During the Divisum-to Acanthicum-time-intervals this platform changed into a pronounced basin-and-swell morpoholgy, with specific depositional environments and “separated” the Paris Basin from the Tethys.
© 2005 Elsevier B.V. All rights reserved.

Keywords: Kimmeridgian carbonate platform; Paleogeography; Boreal; Tethyan; Jura Mountains; NW Switzerland

* Corresponding author. Tel.: +41 61 2673607; fax: +41 61 2673613.
E-mail addresses: janmar@gmx.ch (M. Jank), christian.meyer@bs.ch (C.A. Meyer), andreas.wetzel@unibas.ch (A. Wetzel).
[1] Tel.: +41 61 2665599.
[2] Tel.: +41 61 2673585; fax: +41 61 2673613.

0037-0738/$ - see front matter © 2005 Elsevier B.V. All rights reserved.
doi:10.1016/j.sedgeo.2005.08.008

1. Introduction

The sequence boundaries of the Kimmeridgian sediments in northern and northwestern Switzerland were poorly defined because of the lack of index-fossils or condensation (e.g., Gygi et al., 1998). Especially the rarity of index-fossils within the thick shallow-water platform sediments of the Reuchenette Formation in northwestern Switzerland — including the type-section in the quarry La Reuchenette near Péry BE (No. 23 in Fig. 1) — has led to numerous differing suggestions of how to correlate the strata and to estimate their age (e.g., Thurmann, 1832; Greppin, 1870; Thalmann, 1966; Chevallier, 1989; Meyer, 1989; Gygi, 2000a). Even recent studies based on sequence-, cyclo- and mineralo-stratigraphy rely on only a few (if any) high-resolution biostratigraphical markers (Gygi and Persoz, 1986; Gygi, 1995; Mouchet, 1995, 1998; Gygi et al., 1998; Meyer, 2000a,b; Colombié, 2002). Unfortunately, most of these markers occur in quite distant or very small exposures, restricting their biostratigraphical use. Consequently, up to now the biostratigraphical data for the platform sediments of the Reuchenette Formation were too few to establish a solid high-resolution framework.

Recently, the construction work of the Transjurane motorway in the Ajoie-Region produced new outcrops with a considerable number of index-fossils and allowed establishing a biostratigraphically-dated reference-section for most of the Reuchenette Formation (Jank, 2004). New outcrops (Contournement de Glovelier and Moulin de Séprais; No. 19 and 20 in Fig. 1) in combination with already available litho-, mineralo- and sequence-stratigraphical data now allow to close the gap between the reference-section and the more distant large sections (including the type-section).

It is the purpose of this paper (1) to correlate the biostratigraphically dated spliced sections of the Ajoie-Region with the type-section of the Reuchenette Formation and other large outcrops in order, (2) to improve the dating and correlation of already established sequence boundaries (Gygi et al., 1998; Gygi, 2000a; Colombié, 2002), and (3) to analyse the platform topography, sea level fluctuations and synsedimentary subsidence and evaluate their palaeogeographical implications for selected, now well constrained, time intervals.

2. Geological background

The study area is located between the Ajoie-Region (Tabular Jura) and the southern Jura Mountains (Folded Jura) in northwestern Switzerland (Fig. 1). The sediments of the Reuchenette Formation were partly eroded

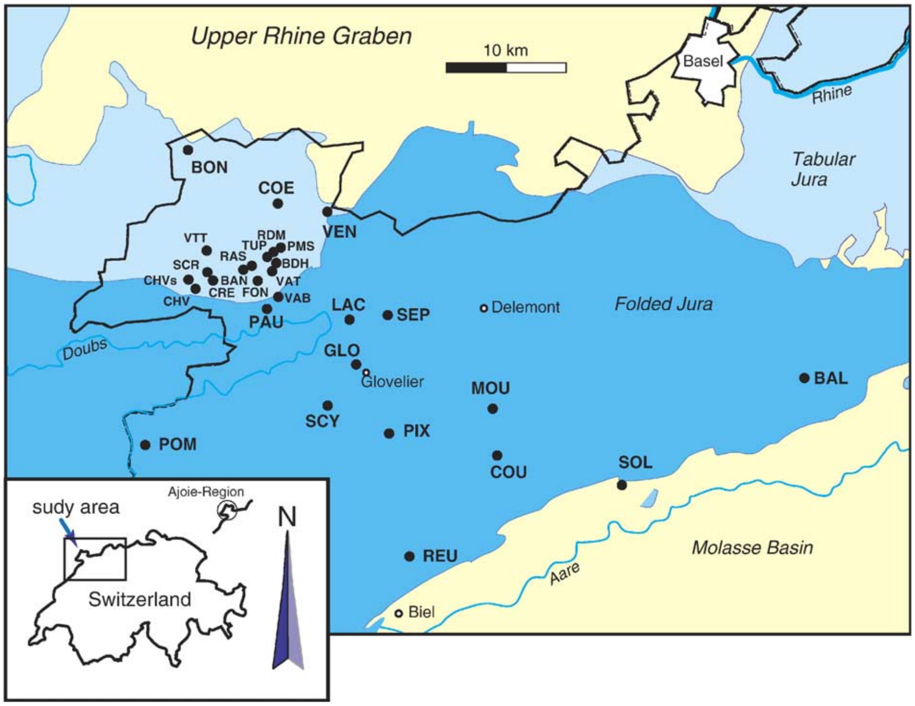


Fig. 1. Major geological units and Swiss coordinates of sections and outcrops.

ARTICLE IN PRESS

	No	Code	Localities	Swiss coordinates		Lithological intervals	References
Ajoie-Region	1	BAN	Tunnel Le Banné (Westportal), base	571,833	250,504	top Thalassinoides Limestones, base "Nautilidenschichten"	Jank (2004)
	2	CHV	La Combe (Carrière Combe de Varu)	567,753	248,930	Nerinean Limestones... Oyster Limestones	Jank (2004)
	3	CHVs	Chevenez (La Scierie)	567,175	249,675	Lower Grey and White Limestones, base Banné Marls	Jank (2004)
	4	COE	Coeuve (Carrière)	574,725	256,075	top Thalassinoides Limestones, "Nautilidenschichten"	Jank (2004)
	5	CRE	Creugenat	569,173	249,748	top Thalassinoides Limestones, base "Nautilidenschichten"	Jank (2004)
	6	FON	Fontenais (Carrière communale)	573,050	249,575	top Thalassinoides Limestones, base "Nautilidenschichten"	Jank (2004)
	7	PAU	Chemin Paulin	573,790	247,100	Thalassinoides Limestones... Banné Marls	Gygi (2000a), Jank (2004)
	8	PMS	Pré Monsieur (Carrière)	574,887	252,262	Coral Limestones	Jank (2004)
	9	RAS	La Rasse (Carrière)	572,560	250,840	Thalassinoides Limestones... Lower Grey and White	Gygi (2000a), Jank (2004)
	10	RDM	Roches de Mars	574,372	252,021	Nerinean Limestones, ("northern" Virgula Marls)	Jank (2004)
	11	SCR	Sur Combe Ronde	568,869	250,082	top Nerinean Limestones, "northern" Virgula Marls	Marty et al. (2003), Jank (2004)
	12	TUP	Cras d'Hermont	573,958	251,694	"Nautilidenschichten"... base Nerinean Limestones	Jank (2004)
	13	VAB	L'Alombre aux Vaches (Carrière Vabenau)	574,800	248,200	top Thalassinoides Limestones... Banné Marls	Mouchet (1995, 1998), Gygi (1995), Jank (2004)
	14	VAT	Vatelin (Carrière)	574,300	250,500	top Thalassinoides Limestones... Lower Grey and	Jank (2004)
	15	VEN	Vendlincourt (Carrière)	578,950	255,475	top "Nautilidenschichten"... Banné Marls	Jank (2004)
	16	VTT	Vâ tche Tchâ (Combe de Vâ tche Tchâ)	568,720	252,155	Banné Marls	Marty and Diedrich (2002)
	17	BDH	Bas d'Hermont (Carrière)	574,600	251,000	top Thalassinoides Limestones, base "Nautilidenschichten"	Jank (2004)
	18	BON	Boncourt	567,100	260,686	Nerinean Limestones	-
	19	SEP	Moulin de Séprais (Carrière)	584,157	246,690	top "Nautilidenschichten"... base Nerinean Limestones	Jank (2004)
	20	GLO	Contournement de Glovelier	581,521	242,515	Thalassinoides Limestones... Coral Limestones	Tschudin (2001)
	21	MOU	Gorges de Moutier	593,000	238,600	*not defined*	-
	22	PIX	Gorges de Pichoux	584,138	236,519	*not defined, merely the "southern" Virgula Marls are*	Gygi (2000a), Colombié (2002)
	23	REU	La Reuchenette (Carrière) - type-locality	585,890	226,240	*not defined, merely the "southern" Virgula Marls are*	Thalmann (1966), Mouchet (1995, 1998), Gygi (2000a),
	24	COU	Gorge de Court	593,377	234,704	*not defined*	Colombié (2002)
	25	SOL	Region around Solothurn			*not defined, merely the Solothurn Turtle Limestones*	Meyer (1990, 1993, 1994, 2000a), Meyer & Jordan (2000), Gygi
	26	BAL	Region around Balsthal			*not defined*	Gygi (2000a)
	27	LAC	La Coperie	580,849	246,243	*not defined, merely the Banné Marls are separated*	Gygi (2000a)
	28	POM	Les Pommerats	563,600	235,740	*not defined, merely the Banné Marls are separated*	-
	29	SCY	Saulcy	579,000	239,000	*not defined, merely the Banné Marls are separated*	-

Fig. 1 (*continued*).

during the Late Mesozoic and Early Tertiary and are covered by Tertiary deposits; it is unknown how much sediment has been eroded. The Twannbach Formation, which follows the Reuchenette Formation in the southern Jura Mountains, is not visible in the Ajoie-Region (Fig. 2).

ARTICLE IN PRESS

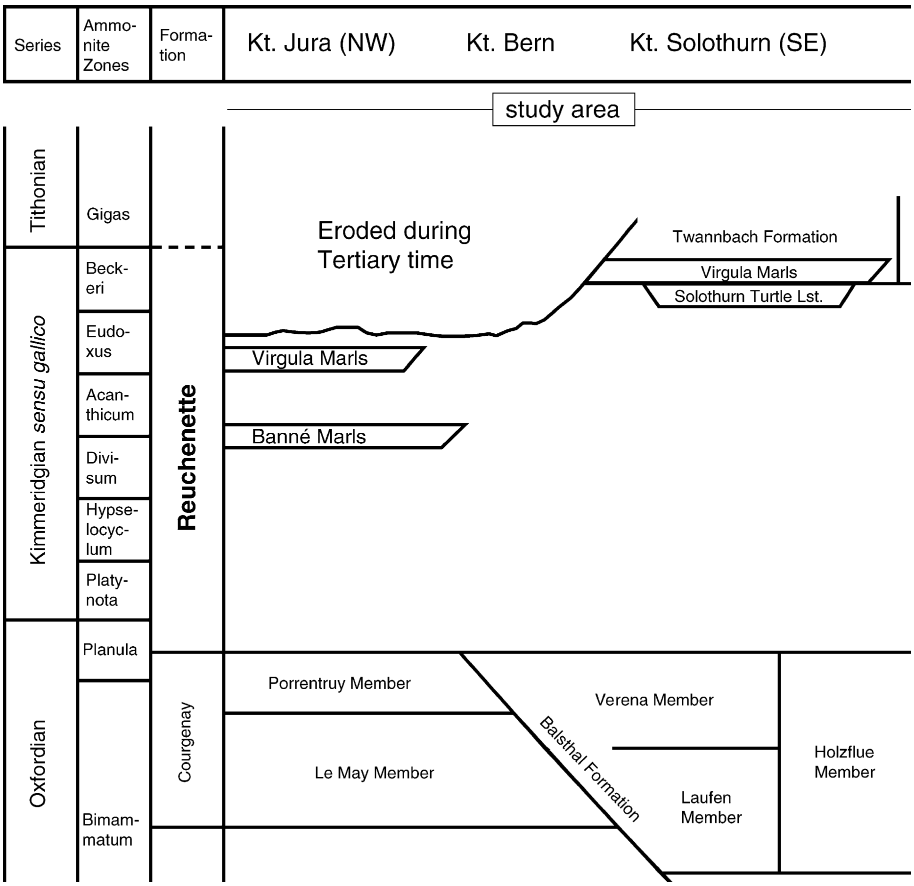


Fig. 2. Litho- and biostratigraphical scheme for the Reuchenette Formation, based on data from Meyer (1990, 1993), Gygi (2000a) and Jank (2004).The associated thickness-relation in the Ajoie- (Kt. Jura) and Solothurn-Region are not to scale (difference about 100 m; compare Introduction).

During the Late Jurassic, the study area was covered by a shallow epicontinental sea between the Tethys in the south and the Paris Basin in the north and northwest (Fig. 3). The climate was subtropical at this time (e.g., Frakes et al., 1992) and the sediments accumulated under sub- to supratidal, open to restricted conditions on a shallow carbonate platform (Mouchet, 1995, 1998; Colombié, 2002; Jank, 2004).

3. Methods

Twenty-nine outcrops of the Reuchenette Formation were investigated for their lithological, sedimentological, palaeontological, mineralostratigraphical, sequence-stratigraphical and facies record. Special attention was paid to signs of emersion, sequence boundaries, biostratigraphical markers and significant lithological changes. Nine sections (No. 2, 9, 12, 13, 15, 19, 20, 22 and 23 in Fig. 1) illustrate the correlation of the type-locality La Reuchenette (=R) in the southern Jura Mountains with the biostratigraphically dated composite-section (=A) of the Ajoie-Region along a NW–SE transect A–R.

The given biostratigraphical frame and descriptions of the ammonites found in the Ajoie-Region are given in Jank (2004) and Schweigert et al. (in preparation) and illustrated in Fig. 4. Gygi and Persoz (1986) and Gygi (1995, 2000a, 2003) gave further information about index-fossils found in the Reuchenette Formation.

The sediments in the Ajoie-Region (Jank, 2004), at Contournement de Glovelier and Moulin de Séprais are assigned to ten lithological intervals. The other sections (No. 21 to 29 in Fig. 1) are not further subdivided; La Reuchenette and Gorges de Pichoux are compiled after Thalmann (1966), Gygi (1982, 2000a,b), Gygi and Persoz (1986), Mouchet (1995, 1998), Colombié (2002) and own field observations (Fig. 5).

The investigated sections were sequence-stratigraphically subdivided by Gygi et al. (1998), Gygi

ARTICLE IN PRESS

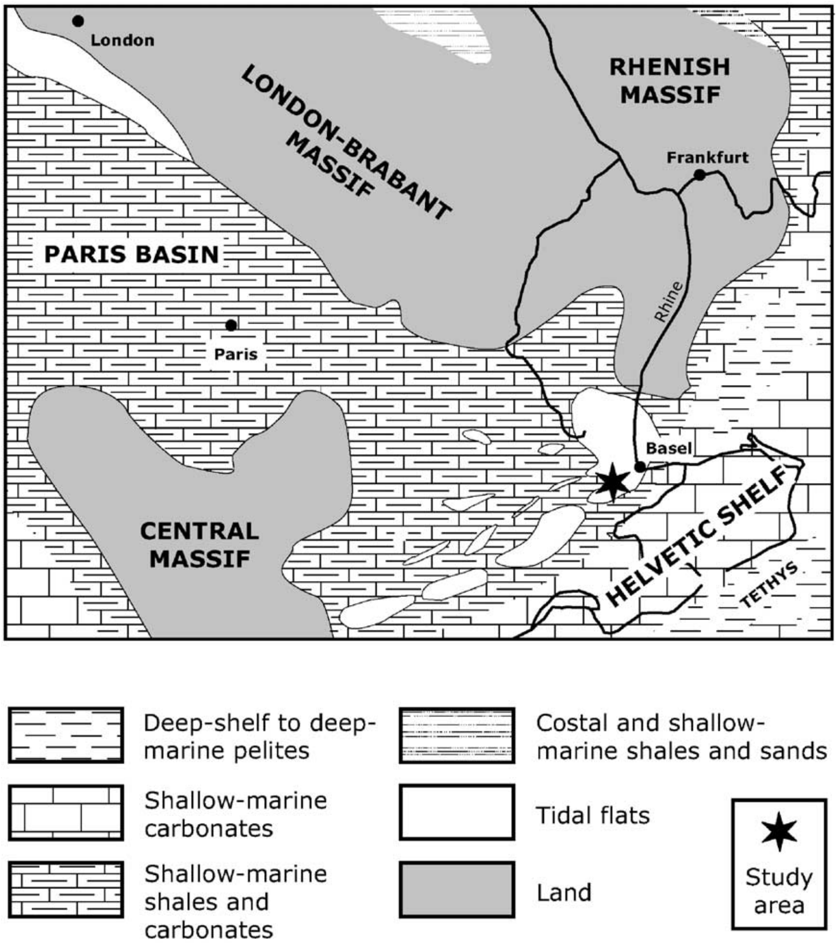


Fig. 3. Kimmeridgian paleogeographical map (Divisum- and Acanthicum-Zone). Compiled after Ziegler (1990), Meyer and Lockley (1996), Marty et al. (2003), Diedrich (2004) and this study.

(2000a), Colombié (2002) and Jank (2004). The characteristics and the compilation of the sequence-stratigraphical interpretations of Gygi et al. (1998), Gygi (2000a), Colombié (2002) and Jank (2004) are given in Figs. 5 and 6. However, a detailed documentation and discussion of this interpretation would be beyond the scope of this paper. The cycles display 3rd order sea level cycles (Jank, 2004) sensu Van Wagoner et al. (1988) and Vail et al. (1991). With respect to terminology, numbering of cycles and systems tracts is related to the underlying sequence boundary, for instance, TST3 = transgressive systems tract following sequence boundary SB3. They are named after Jank (2004; see Discussion).

Additionally, for selected time intervals, the distribution of thickness and facies was used to reconstruct platform topography and to decipher the spatial relation to Late Palaeozoic structures in the basement. Thickness maxima of distal facies probably represent depressions; subtle variations in facies and thickness are suggestive of a syndepositionally formed relief (e.g., Wetzel and Allia, 2000; Wetzel et al., 2003). Calculation of decompaction is based on Moore (1989), Goldhammer (1997) and Matyszkiewicz (1999). The palinspastic restoration is based on the studies of Laubscher (1965) and Philippe et al. (1996). Tectonic shortening is greatest along the southern foot of the Jura Mountains and decreases gradually towards the unfolded Tabular Jura in the north and east of the study area (e.g., Laubscher, 1965).

4. Results

Lithology, facies and mineralostratigraphy provided markers to correlate the largest outcrops of the Reuchenette Formation and they allowed reconstructing the evolution of the platform.

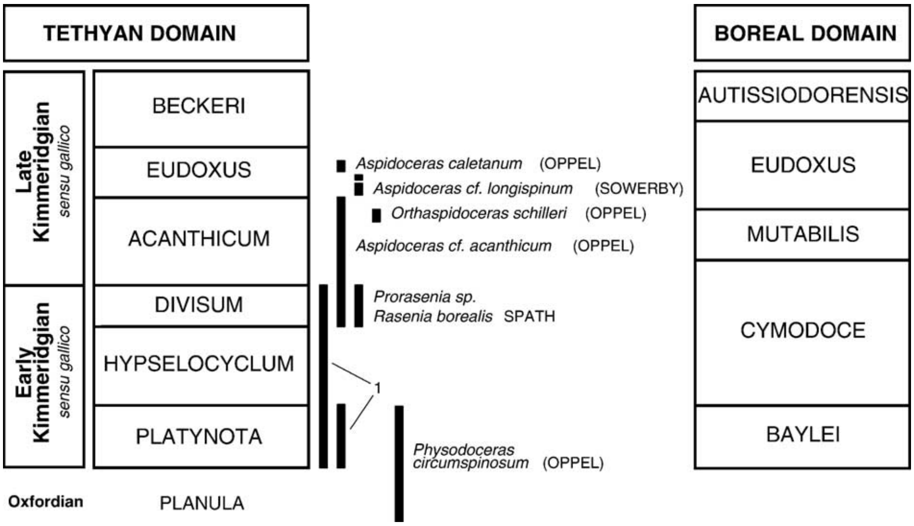


Fig. 4. Biostratigraphical frame based on ammonites. Zonation of the Kimmeridgian sensu gallico after Hantzpergue et al. (1997). Tethyan Domain is used sensu Domaine Téthysien, Province subméditerraneénne; Boreal Domain is used sensu Domaine Boréal, Province subboréale. All ammonites were collected in situ, except *Aspidoceras cf. acanthicum* (OPPEL) (Gygi, 1995). Biostratigraphical reach and localities: 1: *Lithacosphinctes cf. janus* (CHOFFAT); Platynota-Zone (according to Schweigert, pers. comm.) or *Perisphinctidae indet.*; ≈ Early Kimmeridgian (according to Gygi, pers. comm.); L'Alombre aux Vaches. *Physodoceras circumspinosum* (OPPEL); Late Oxfordian to Early Kimmeridgian (Planula- and Platynota-Zone) (according to Hantzpergue, pers. comm.); excavation pit near Fontenais. *Rasenia borealis* SPATH; Divisum-Zone; Coeuve. *Prorasenia sp.*; Divisum-Zone; Vâ tche Tchâ. *Aspidoceras cf. acanthicum* (OPPEL); Divisum- to Acanthicum-Zone; L'Alombre aux Vaches. *Orthaspidoceras schilleri* (OPPEL); Acanthicum-Zone, Lallierianum-Sub-Zone, Schilleri-Horizon; La Combe, Roches de Mars and Sur Combe Ronde. *Aspidoceras cf. longispinum* (SOWERBY); lowermost Eudoxus-Zone; La Combe. *Aspidoceras caletanum* (OPPEL); Eudoxus-Zone, Caletanum-Sub-Zone, Caletanum-Horizon; La Combe and Sur Combe Ronde.

4.1. NW–SE transect A–R — correlations between the type-locality (R) and the Ajoie-Region (A)

The stratigraphical order of the sections was achieved by a combination of lithological and sedimentological correlations. These correlations are based on the following marker beds (Figs. 5 and 7).

4.1.1. Lower boundary of the Reuchenette Formation

In the Ajoie-Region the shallow-water limestones of the Reuchenette Formation rest on the Courgenay Formation, in the southern and central Jura Mountains on the Balsthal Formation (Fig. 2). The top of the Balsthal Formation (i.e. Verena Member sensu Desor and Gressly, 1859; in Gygi, 2000b) grades laterally into the Courgenay Formation (i.e. Porrentruy sensu Gygi 1995) (Gygi, 2000a).

Thalmann (1966) defined the Reuchenette Formation in the quarry of La Reuchenette near Péry BE as a monotonous succession of bedded limestones with few and thin marl intercalations. The base of the Reuchenette Formation is marked by an uneven erosion surface (Thalmann, 1966) overlain by a massive 18 m thick limestone unit (Gygi and Persoz, 1986). Locally a horizon with blackened lithoclasts is developed in the basal lower part. The lower 8 m of this massive unit are composed of oo- to oncolitic carbonates. The upper 10 m are primarily mudstones with local patches of oolitic wackestone. Above this massive limestone unit, well-bedded mudstones and peloidal wacke- to grainstones with two bands of fenestrate stromatolites occur (Gygi, 1982, 2000a; Colombié, 2002). The boundary between the massive unit and well-bedded limestones is conspicuous and it can be easily observed, whereas the horizon with blackened lithoclasts is restricted to a small part of La Reuchenette (Gygi and Persoz, 1986). This sharp lithological contrast is developed between the underlying members and the Reuchenette Formation in (almost) all sections in the Ajoie-Region and southern and central Jura Mountains (Gygi, 2000a,b; Fig. 7). For this reason, Gygi and Persoz (1986) and Gygi (2000a,b) defined the boundary between the Reuchenette Formation and the underlying Porrentruy and Verena Member at the base of the well-bedded limestones.

This boundary is visible in the Ajoie-Region and at Contournement de Glovelier (Fig. 8) where the Porrentruy Member is composed of smoothly fracturing, massive-layered, white, calcarenitic to micritic, chalky limestones with Nerinean gastropods, small oncoids

ARTICLE IN PRESS

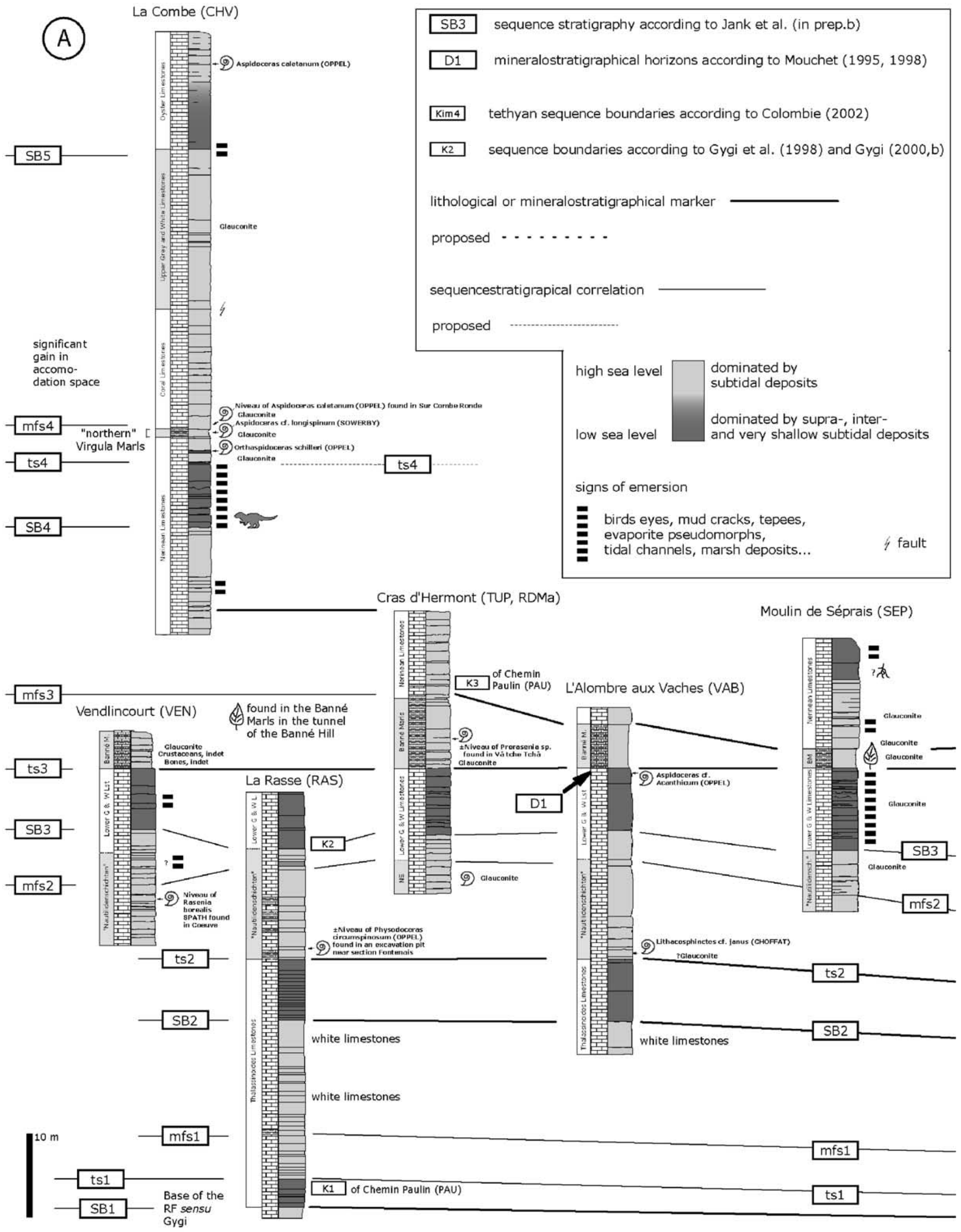


Fig. 5. NW–SE transect A–R. For additional legend see Fig. 8. La Reuchenette (REU) compiled after Thalmann (1966), Gygi (1982, 2000a,b), Gygi and Persoz (1986), Mouchet (1995, 1998) and Colombié (2002). Gorges de Pichoux (PIX) compiled after Gygi (2000a,b) and Colombié (2002). Contournement de Glovelier (GLO) based on Tschudin (2001) and this study. L'Alombre aux Vaches (VAB) 1–8 based on Gygi (1995) and Mouchet (1995, 1998). La Rasse (RAS) based on Gygi (2000a).

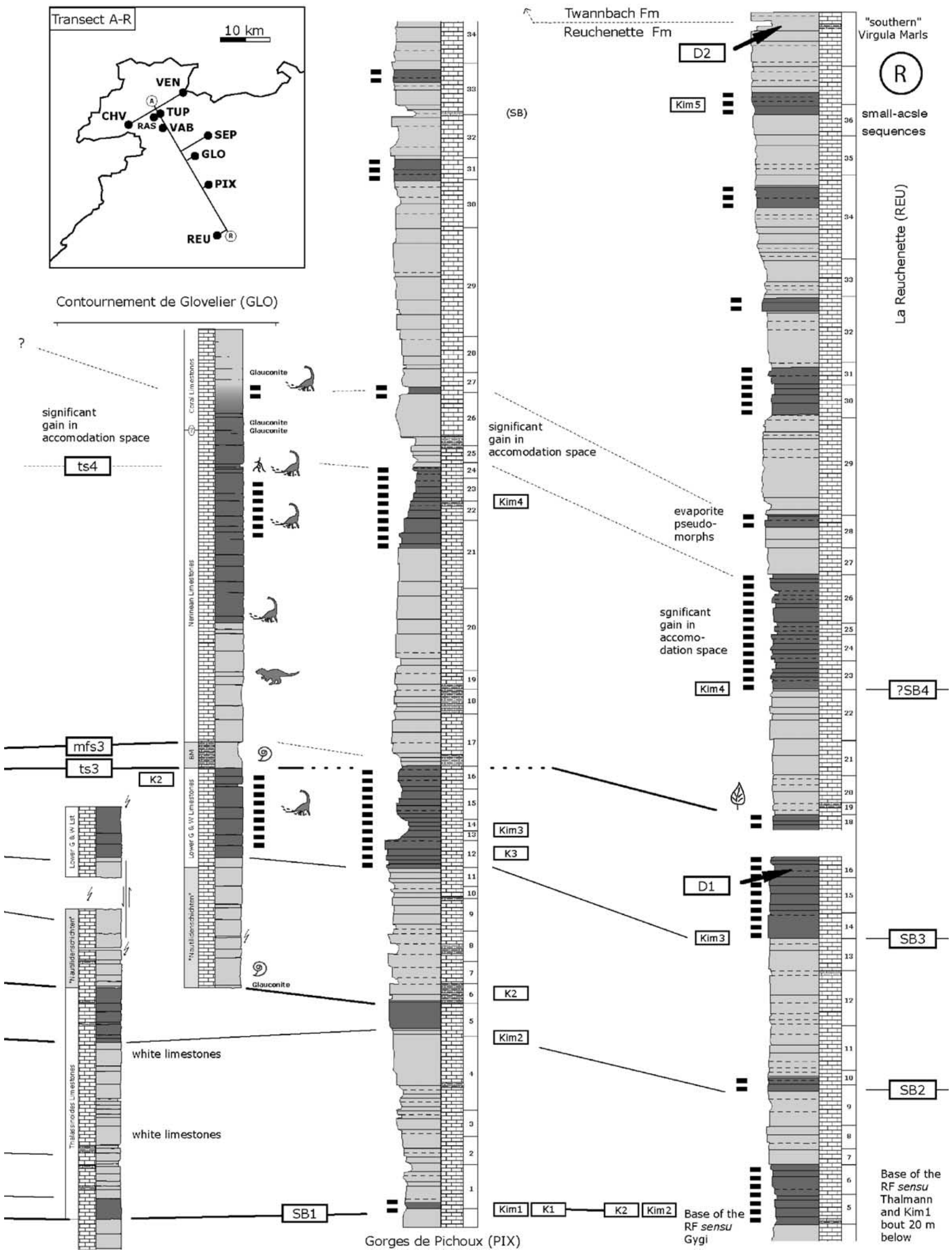


Fig. 5 (*continued*).

Systems tracts LST	TST	HST	Facies	Bathymetry	Depositional environment	Facies association	Developm. of facies
√	√		Cast and filled *Thalassinoides* -tubes	shallow subtidal (storm wave-base) to intertidal	lagoon	*Thalassinoides* and storm sediment association	–
√	√		Intraclastic pack- to grainstones (-layer)	shallow subtidal (storm wave-base) to intertidal	lagoon	*Thalassinoides* and storm sediment association	–
	√	√	Lumachelle (shell bed)	shallow subtidal (storm wave-base) to intertidal	lagoon	*Thalassinoides* and storm sediment association	–
	√	√	Bioclastic mud- and wackestone (± *in situ* macrofauna)	shallow subtidal	lagoon or platform (with open circulation; quiet water at or just below fair-weather wave-base)	open lagoon and bight association	distal
		√	Chalky bioclastic mudstones with coral meadows	shallow subtidal	lagoon or bight (with open circulation; quiet water below fair-weather wave-base)	open lagoon and bight association	
	√	√	Marly bioclastic wacke- to packstones and float- to rudstones with *in situ* macrofauna	shallow subtidal	protected lagoon or bight (normal marine; quiet water below fair-weather wave-base)	open lagoon and bight association	
	√	√	Bioclastic wacke- and packstones with *in situ* macrofauna (± argillaceous, slightly nodular)	shallow subtidal	open lagoon, next to shell shoals	open lagoon and bight association	
		√	Oncoidal (chalky) wacke- to packstones and float- to rudstones	(very) shallow subtidal	restricted and relatively quiet lagoon	restricted platform association	
√		√	Peloidal mud- to grainstones	intertidal and shallow subtidal	restricted, shallow lagoon and tidal flat	restricted platform association	<== basinward migration of facies (regression); landward migration of facies (transgression) ==>
√			Non-laminated homogeneous micrite	intertidal and very shallow subtidal	tidal pond and protected, quiet, very shallow bight or lagoon	restricted platform association	
√			Lensoidal pack-/rudstone	intertidal	storm surge channel or rip channel in a tidal flat environment	restricted platform association	
√		√	Laminated mudstones	supratidal and intertidal	restricted plarform areas	supratidal and intertidal platform area association	
√			Crumbly and platy mudstones and wackestones	supratidal and intertidal	mud flat or marsh	supratidal and intertidal platform area association	proximal

	Systems tracts, major bounding surfaces and their sedimentological and palaeontological features
SB, LST	Sequence boundaries (SB) form in response to rapid relative sea level falls (abrupt basinward shift of facies). They are marked by changes in lithology or variation in the facies curve (onset of landward facies). Lowstand systems tracts (LST) overlie SBs and form during maximum regression. **Features:** Mud cracks, birds eyes, keystone vugs, circum granular cracks, erosion surfaces, multicoloured breccia, calcretes, raggioni, meniscus and stalactitic cements, tepees, evaporite pseudomorphs, small-scale ripples, dinosaur foot prints, tidal channels, charophytes. Coarse components are commonly ferruginous, worn and rounded and often show signs of corrosion and abrasion. Minor iron-stained bed surfaces. Quasi absence of fauna. Grain-size displays a coarsening-upward trend. Facies display a shallowing-upward trend.
ts, TST	A transgressive surface (ts) is the first pronounced sign of marine flooding (onset of landward migration of facies), marks the base of the transgressive systems tract (TST), the onset of (rapid) sea level rise and change to more open marine conditions (deepening-upward trend). **Features:** Coaly plants, black pebbles, (large) intraclasts, cephalopods. Low diversity and high abundance of fauna. Grain-size displays a fining-upward trend. Rapid sea level rise may led to reduced sedimentation and condensation, indicated by hardgrounds, accumulation of shells (winnowing), highly bioturbated and nodular sediments and glauconite accumulation (e.g. Loutit et al., 1988; Sarg, 1988; Brett, 1995); lumachelle and worn and rounded material is deposited as storm sheets.
mfs, HST	The maximum flooding surface (mfs) forms in response to the most rapid sea level rise and separates the TST form the highstand systems tract (HST). After an episode of deposition displaying relative deep water increasingly shallower water is recorded (shallowing-upward trend, basinward migration of facies). A sharply defined surface related to maximum flooding may not be identifiable, instead a maximum flooding zone (mfz) is recognised. **Features:** Cephalopods. High abundance and diversity of fauna. Grain-size displays a coarsening-upward trend. Depending on the distance to the shoreline the sediments are composed of bioclastic, oncoidal, coral, and peloidal and laminated limestones.The maximum flooding often leads to condensation similar to those described above; condensation may be indicated by sediments rich in tests of fauna, which are no longer masked by sediment accumulation.

Fig. 6. Facies and facies characteristics of the systems tracts of the Reuchenette Formation (compiled after Gygi et al., 1998; Colombié, 2002; Jank, 2004). LST: lowstand systems tract, TST: transgressive systems tract, HST: highstand systems tract, SB: sequence boundary, ts: transgressive surface; mfs: maximum flooding surface.

ARTICLE IN PRESS

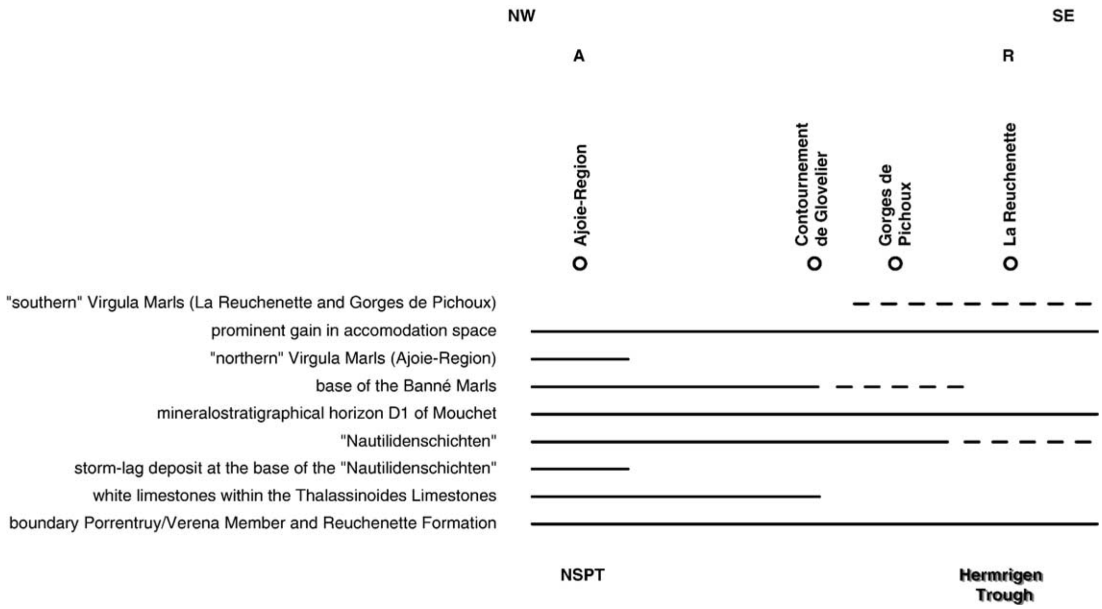


Fig. 7. Reach of marker beds along transect A–R. Palinspastic restoration after Laubscher (1965) and Philippe et al. (1996). Position of the basement structures after various sources (see Allenbach, 2001; Wetzel and Allia, 2003; Ustaszewski et al., 2005 and references therein). NSPT: North-Swiss Permo-Carboniferous Trough (=western prolongation of the Constance–Frick Trough).

and coated intraclasts (Gygi, 2000a; Jank, 2004). The latter two occasionally display brownish rims. At Contournement de Glovelier, the Porrentruy Member follows the Verena Member (developed as lensoidal cross-bedded oolites; not figured in this study) above a minor tectonic contact and illustrates the lateral facies change mentioned earlier on. At La Reuchenette (between cycles 4 and 5 of Colombié, 2002) and Gorges de Pichoux the lithological change at the lower boundary of the Reuchenette Formation sensu Gygi and Persoz (1986) and Gygi (2000a,b) is developed as described above (Fig. 5). This lithological boundary coincides with sequence boundary SB1.

4.1.2. White limestones within the Thalassinoides Limestones

Between the Ajoie-Region and Contournement de Glovelier the Reuchenette Formation starts with the Thalassinoides Limestones (sensu Jank, 2004); monotonous, thick- to massive-layered, well-bedded, bioturbated, grey, micritic limestones containing some bioclasts and reddish-brown or greyish, coarse-grained pseudo-oolites (mainly rounded intraclasts and peloids) within pockets, patches and strings in a micritic matrix. Thin- to thick-bedded layers commonly show abundant *Thalassinoides* and iron impregnated bed surfaces and fracture conchoidally The burrows are often filled with coarse-grained, rounded intraclasts and peloids (pseudo-oolites). About 7 to 9 m below the boundary to the "Nautilidenschichten" (right beneath SB2; Jank, 2004) a set of two several metres thick, white, massive limestones, which are intercalated in the grey Thalassinoides Limestones (Fig. 9), can be followed between the Ajoie-Region and Contournement de Glovelier (Figs. 5 and 7).

4.1.3. "Nautilidenschichten"

The "Nautilidenschichten" (sensu Jank, 2004) are thick- to massive-layered, strongly bioturbated, marly limestones and limestones with a weakly internal nodular bedding. The lower part tends to exhibit "marl-limestone alternations" when weathered; calcarenitic, probably storm-influenced marly limestones alternate with bioturbated marly micritic background sediment. Some bored and biogenically encrusted local hardgrounds are intercalated. The "Nautilidenschichten" occur as such between the Ajoie-Region and Gorges de Pichoux (Fig. 7). The lower boundary of this marker interval is illustrated as transgressive surface ts2. A conspicuous reddish brown, proximal intraclastic wacke- to packstone storm-lag layer (Fig. 10), at the base of the "Nautilidenschichten", is well traceable in the Ajoie-Region (Jank, 2004).

4.1.4. Banné Marls and mineralostratigraphical horizon D1

The sections in the Ajoie-Region, at Moulin de Séprais, Contournement de Glovelier and Gorges de

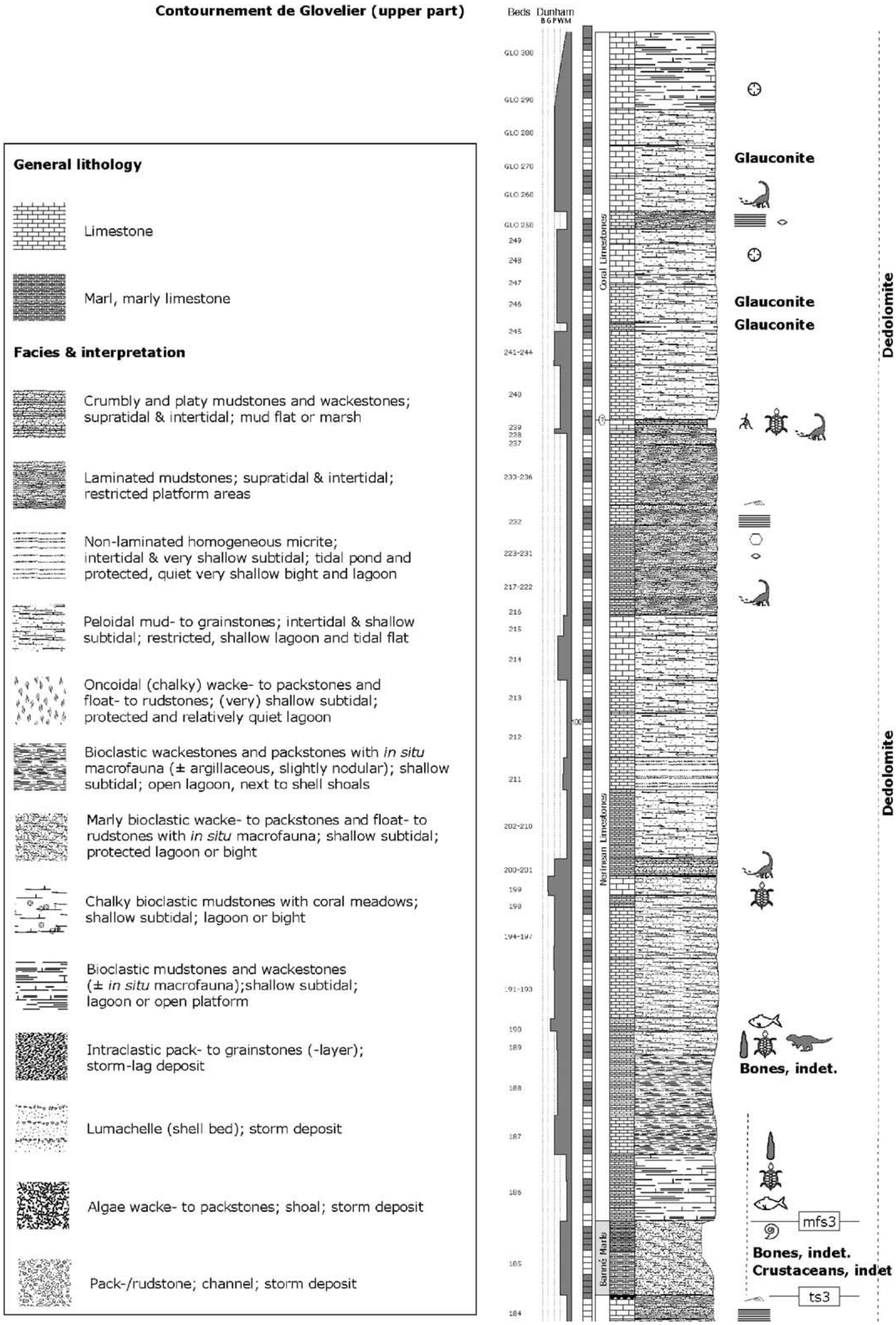


Fig. 8. Section Contournement de Glovelier. The marine benthos is not illustrated (details in Tschudin, 2001).

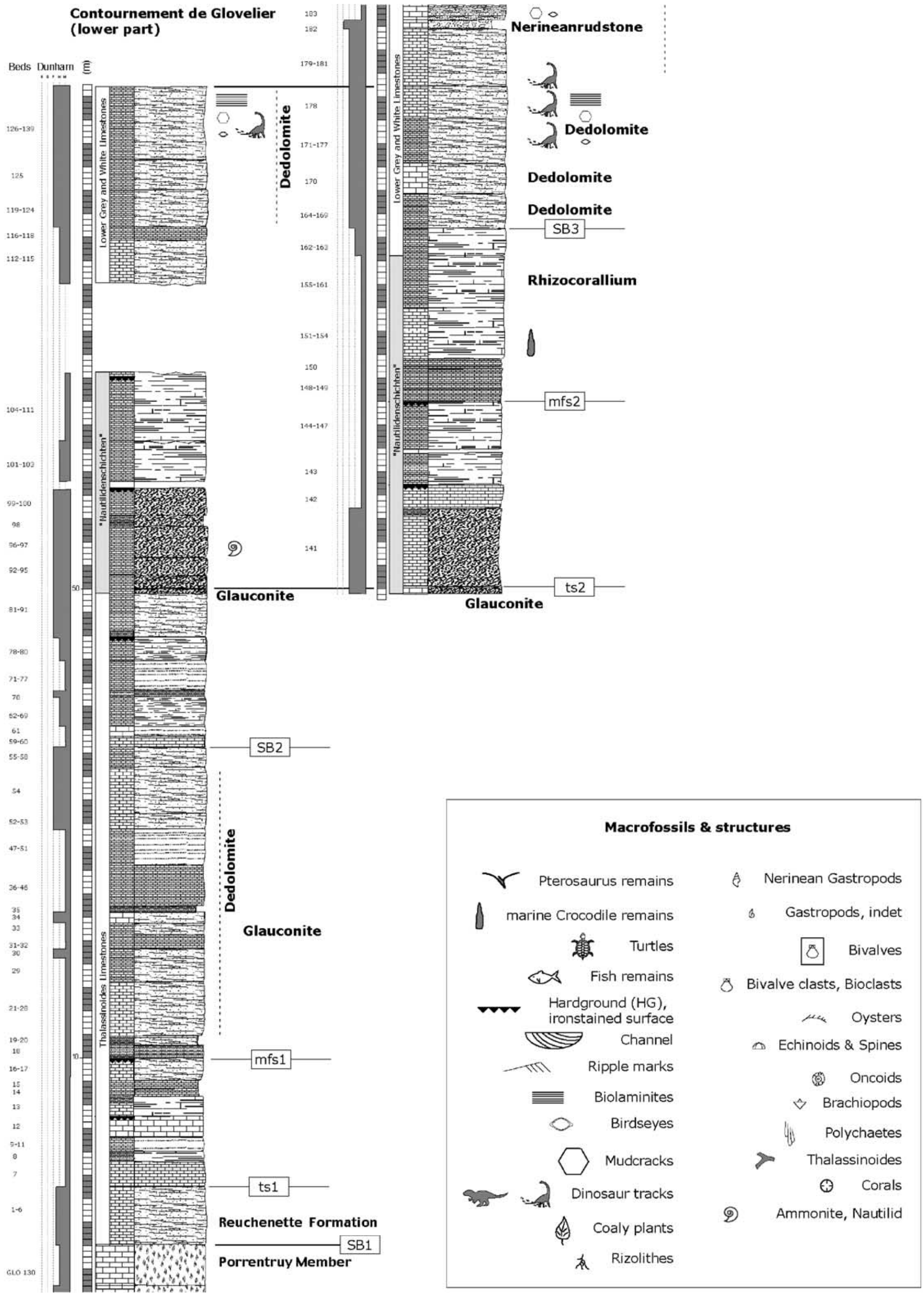


Fig. 8 (*continued*).

ARTICLE IN PRESS

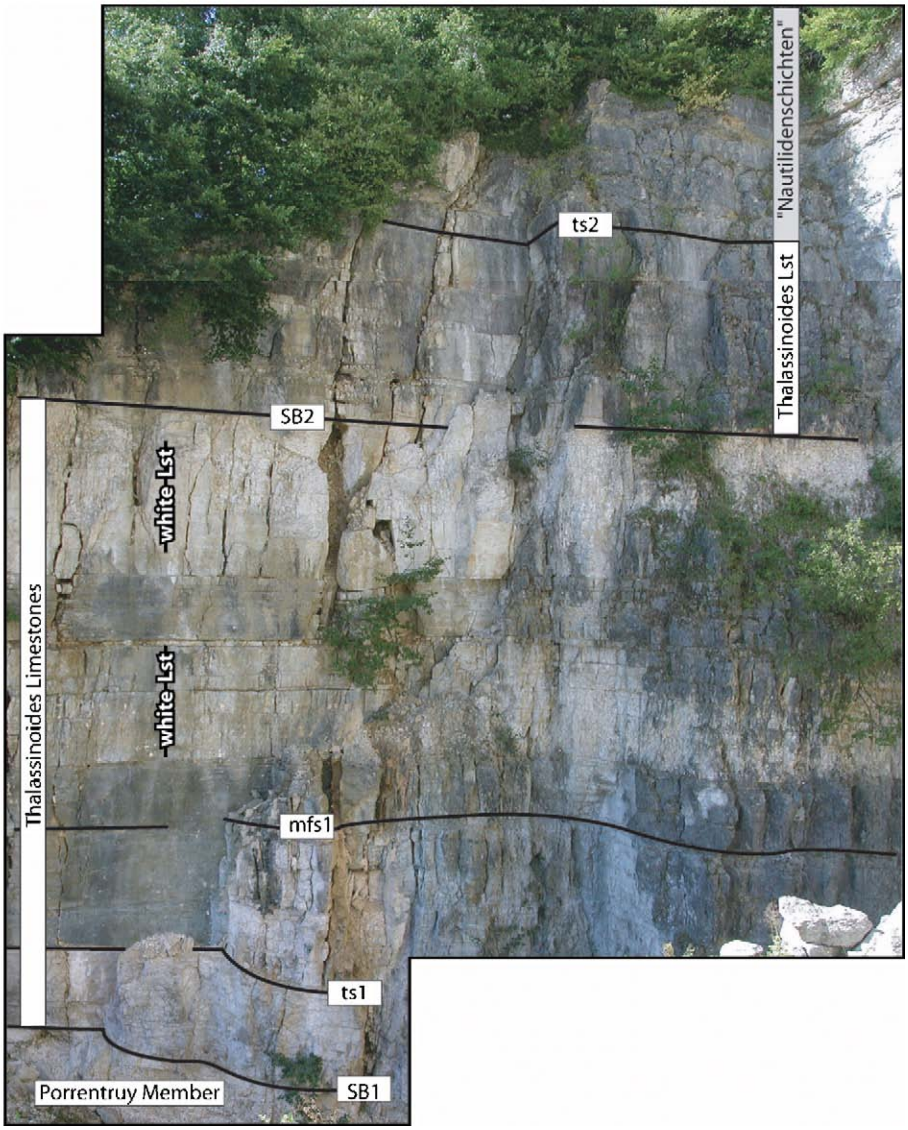


Fig. 9. Lower part of the quarry La Rasse with conspicuous grey-white color pattern.

Moutier can be exactly correlated using the lower boundary of the Banné Marls (Fig. 7; ts3 in Fig. 5). The Banné Marls (=Banné Member sensu Marçou, 1848; in Gygi, 2000a,b) comprise grey, thin- to thick-layered, slightly nodular marlstones, calcarenitic marls and marly limestones with a rich fauna of bivalves associated with some brachiopods, nautilids, echinoids, vertebrate remains, *Thalassinoides* and very rare ammonites. Shelly and calcarenitic horizons, reworked and winnowed by storms, are intercalated and often separate the beds. At Contournement de Glovelier and Moulin de Séprais the thickness of the Banné Marls is reduced compared to their thickness in the Ajoie-Region. In the central and southern Jura Mountains the Banné Marls are represented in a different facies as in the Ajoie-Region. For example, in the Gorges de Moutier (Fig. 11) only a thin fossiliferous (calcareous) layer, correlative to the base of the Banné Marls in Contournement de Glovelier, has been identified at the top of the section. In the Gorges de Pichoux, Gorges de Court and La Reuchenette the level corresponding to the Banné Marls is made up of slightly marly, fossil-rich limestones. Mouchet's (1995, 1998) mineralostratigraphical horizon D1, defined by a clear peak in the kaolinite content, occurs within the sediments of lowstand systems tract LST3 just below the Banné Marls; it has been recognised in L'Alombre aux Vaches (Ajoie-Region) and La Reuchenette (Fig. 7). The sediments

ARTICLE IN PRESS

Fig. 10. Storm-lag deposit at the base of the "Nautilidenschichten". Bottom side of intraclastic pack to grainstone layer with cast *Thalassinoides* (positive hypichnia) deposited as tempestite, indicating erosion followed by lag deposition. The occurrence of this storm sheet is restricted to the Ajoie-Region and might already indicate a slightly developed depression. (scale: coin ≈ 3 cm; bed COE-260, Coeuve).

around D1 are well correlatable in terms of lithology as well as sequence-stratigraphical development (see below).

D1 is on top or within very shallow subtidal to supratidal sediments with comprehensive emersion features and it is followed by the Banné Marls or slightly marly limestones with a rich, fully marine macrofauna. In the Banné Marls exposed in the motorway tunnel of the Banné Hill (next to No. 1 in Fig. 1; D. Marty, pers. comm.), Moulin de Séprais (bed SEP-180, Fig. 11) and at La Reuchenette (in cycles 19 and 20 of Colombié, 2002) coaly plant remains also support this interpretation (see Fig. 5).

4.1.5. "*Northern*" *Virgula Marls*

In the Ajoie-Region the Nerinean Limestones (sensu Jank, 2004) follow the Banné Marls. The top of this limestone interval (lower part of TST4) is composed of greenish-weathering, glauconitic, calcarenitic limestones, which show characteristic, strongly bored and biogenically encrusted, regional hardgrounds with cephalopods on top. They are followed by the "northern" Virgula Marls (=Virgula Marls of Laubscher, 1963; upper part of TST 4), which contain a rich fauna of bivalves and cephalopods, but small oysters (*Nanogyra virgula*) dominate. Vertebrate remains are common (e.g., turtles, crocodile teeth, pycnodont teeth). These Virgula Marls are glauconitic, dark-grey and thin-layered. They are overlain by the Coral Limestones interval (sensu Jank, 2004; lower part of HST4). The latter starts with some metres of thin-layered, grey, micritic limestones at the base, overlain by the Coral Limestones "sensu stricto"; a massive unit composed of thin- to thick-layered, white, chalky, micritic limestones (with re-crystallized corals and conspicuous red-brown shelled rhynchonellid brachiopods).

At Contournement de Glovelier the top of the Nerinean Limestones is assigned to a conspicuous crumbly and platy, almost fossil-free, marly limestone (bed GLO-239; Fig. 5), which is not comparable at all with the strongly glauconitic "northern" Virgula Marls. The composition of the crumbly and platy limestone is comparable to crumbly and platy limestones just a few metres below the "northern" Virgula Marls in La Combe (Ajoie-Region; bed CHV-170; Fig. 5). At Contournement de Glovelier the Nerinean-bearing Limestones are overlain by slightly coral-bearing, coarse-grained, massive layered, white limestones, which are comparable to the Coral Limestones in the Ajoie-Region; the "northern" Virgula Marls are not identified. These Marls were probably never deposited at Contournement de Glovelier, Gorges de Pichoux or La Reuchenette because there is no sign of erosion at the top of the Nerinean Limestones or the base of the Coral Limestones nor in the Coral Limestones, which might indicate that the Virgula Marls were removed.

Indeed the "southern" Virgula Marls (=Virgula Marls of Thalmann, 1966) of the central and southern Jura Mountains (Gorges de Pichoux, La Reuchenette) probably correlate with each other (Colombié, 2002; Figs. 5 and 7) but they are younger than the "northern" Virgula Marls (Gygi et al., 1998; Jank, 2004).

The "northern" Virgula Marls are exactly correlatable between the closely spaced sections at La Combe, Roches des Mars and Sur Combe Ronde (Nos. 2, 10 and 11 in Fig. 1) and also with the Marnes à Virgula inferieur in the region of Montbéliard west of the Ajoie-Region (Contini and Hantzpergue, 1973; Chevallier, 1989). The vertical facies changes above and below these Virgula Marls are also correlative to each other (Jank, 2004).

4.2. *Platform topography*

Along the NW–SE transect the lateral variation in thickness and lithofacies, facies and associated depositional conditions provide information about platform morphology and extent of the depositional environments. This allows reconstructing the development of the platform for selected time intervals.

4.2.1. *Planula- to Divisum-Zone time interval*

The sediments between sequence boundary SB1 and lowstand systems tract LST3 document depositional environments shifting between shallow subtidal open

ARTICLE IN PRESS

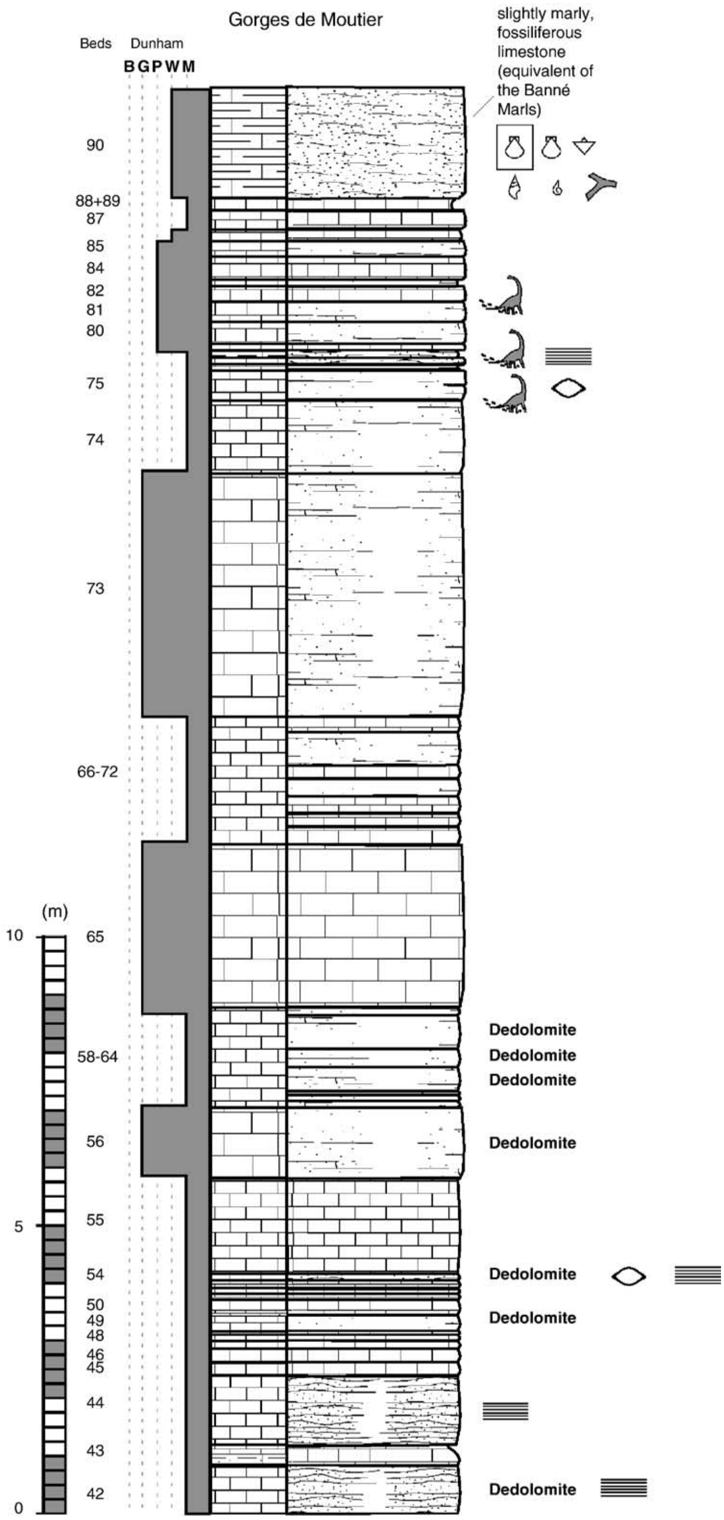


Fig. 11. Sections Gorges de Moutier and Moulin de Séprais. For legend see Fig. 8.

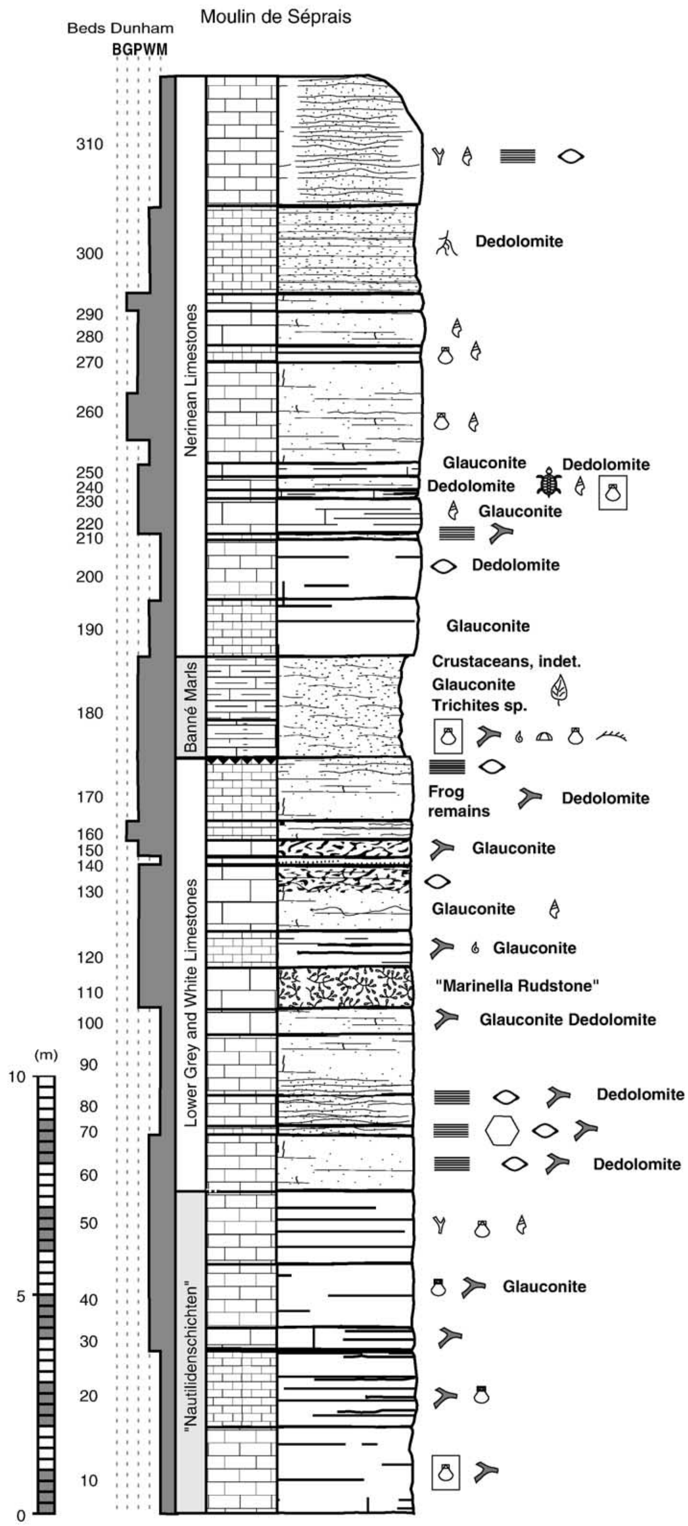


Fig. 11 (*continued*).

ARTICLE IN PRESS

marine platform conditions below the fair weather wave-base and high-energy conditions in tidal flat areas (Gygi et al., 1998; Gygi, 2000a; Colombié, 2002; Jank, 2004). Shelly lime muds (bioclastic limestones) and muddy lime sands (peloidal limestones) with intercalated storm deposits dominate. Laterally depositional environments do not vary significantly. Nevertheless, the different lateral extent of some marker beds (Fig. 7) and a slightly thinning towards the south (Fig. 5) are suggestive of a gently NW dipping open (unprotected) carbonate platform (Fig. 12), which was often affected by storms (Jank, 2004). Subtle variations in thickness, lithology and facies (e.g., the limited occurrence of the proximal storm-lag sheet at the base of the "Nautilidenschichten") point to a weak basin-and-swell morphology. For instance during LST2 (Platynota-Zone) a weak topographic rise in the northern Ajoie-Region might be indicated by the simultaneous occurrence of stromatolites at Coeuve (No. 4 in Fig. 1), a tidal channel at Le Banné (No. 1 in Fig. 1) and very shallow subtidal deposits in the central part of the Ajoie-Region. This deduction is supported by the fact that during lowstand systems tracts LST1 and 2 the Ajoie-Region and Contournement de Glovelier did not

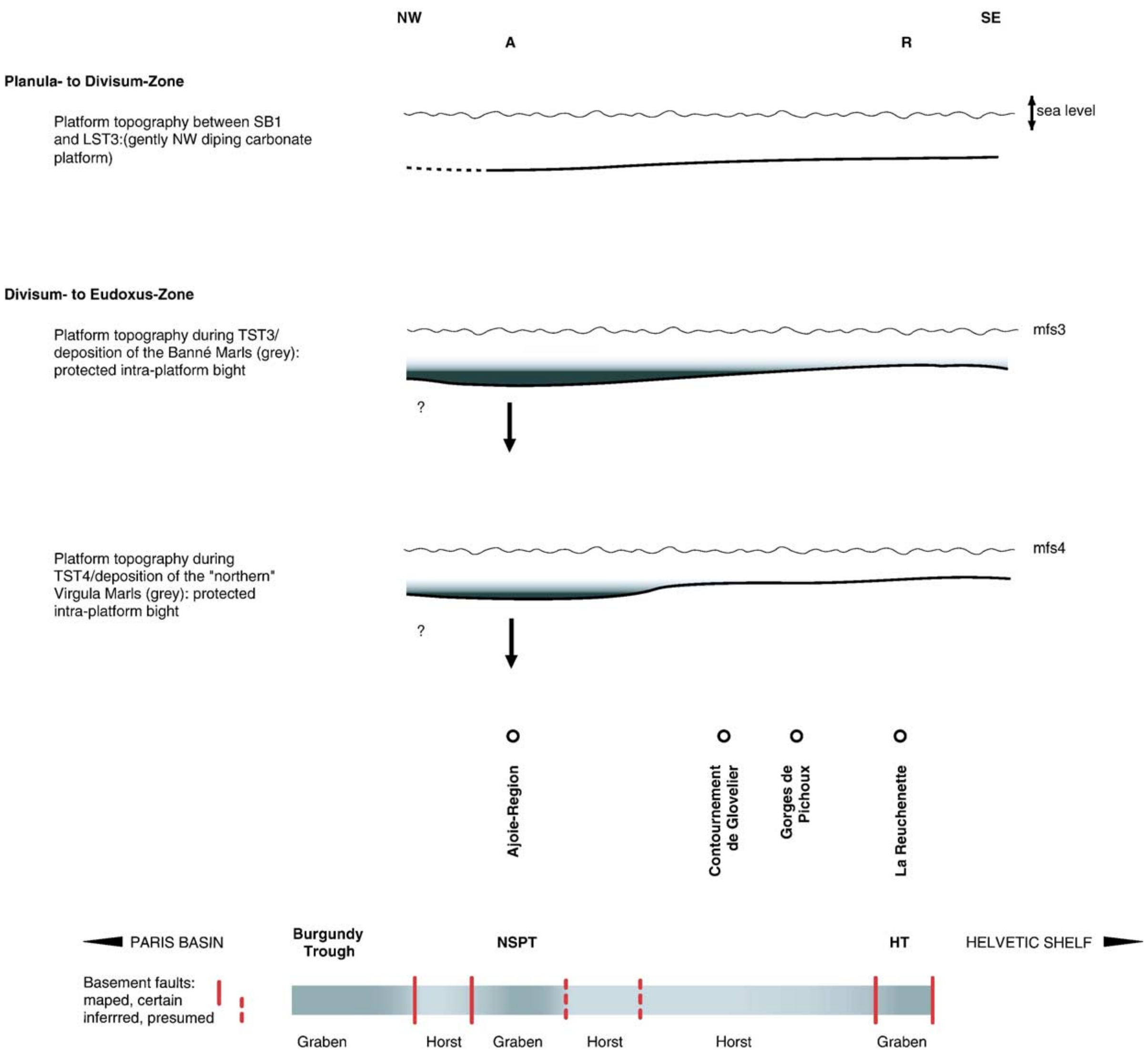
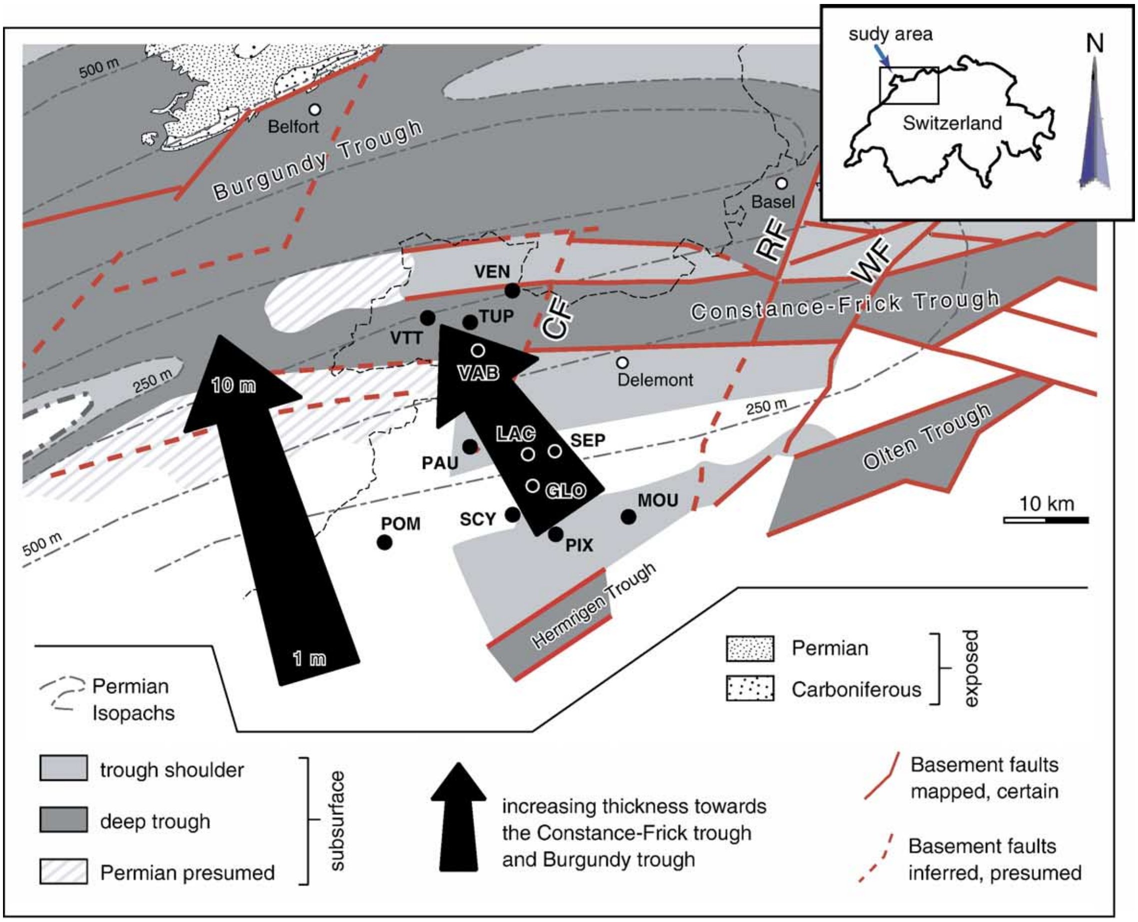


Fig. 12. Schematic platform topography for selected time intervals and/or facies between the Ajoie-Region (A) and the type-locality La Reuchenette (R). Arrow indicates positions of enhanced synsedimentary subsidence. Palinspastic restoration after Laubscher (1965) and Philippe et al. (1996). Position of the basement structures after various sources (see Allenbach, 2001; Wetzel and Allia, 2003; Ustaszewski et al., 2005 and references therein). NSPT: North-Swiss Permo-Carboniferous Trough (=western prolongation of the Constance–Frick Trough), HT: Hermrigen Trough.

emerge in contrast to Gorges de Pichoux and La Reuchenette (see Fig. 5).

4.2.2. Divisum- to Eudoxus-Zone time interval

A significant palaeoenvironmental change occurred following the ts3-sea-level-rise in the Divisum-Zone. On a part of the platform in the vicinity of the transect the Banné Marls accumulated during this transgression (TST3) under normal-marine conditions. The Banné Marls are thickest in the Ajoie-Region (Fig. 13) and west of it (where they are called Marnes à Ptérocères sensu Contini and Hantzpergue, 1973 or Marnes de



No.	Code	Sections	Coordinates	Thickness Banné	Literature
7	PAU	Chemin Paulin	573,790 247,100	6 m	Gygi (2000a)
12	TUP	Cras d'Hermont	573,958 251,694	8,5 m	Jank (2004)
13	VAB	L'Alombre aux Vaches (Carrière Vabenau)	574,800 248,200	5,2 m	Gygi (1995)
15	VEN	Vendlincourt (Carrière)	578,950 255,475	>3,5 m	Jank (2004)
16	VTT	Vâ tche Tchâ (Combe de Vâ tche Tchâ)	568,720 252,155	>6,6 m	Marty et al. (2003)
19	SEP	Moulin de Séprais (Carrière)	584,157 246,690	2,3 m	Jank (2004)
20	GLO	Contournement de Glovelier	581,521 242,515	3 m	Tschudin (2001), Jank
21	MOU	Gorges de Moutier; slightly marly, fossil rich limestone	593,000 238,600	(>2 m)	
22	PIX	Gorges de Pichoux; slightly marly, fossil rich limestone	584,138 236,519	(≈ 1,5 m)	
27	LAC	La Coperie	580,849 246,243	3,5 m	Gygi (2000a)
28	POM	Les Pommerats	563,600 235,740	6,5 m	
29	SCY	Saulcy	579,000 239,000	1 m	
		"West of the Ajoie-Region"		1-10m	Chevalier (1989)

Fig. 13. Thicknesses of the Banné Marls and their lateral equivalents plottet above Palaeozoic basement structures. The thickness distribution for "West of the Ajoie-Region" (left arrow) is from literature and based on a thickness-distribution map. Exact coordinates do not exist. Palinspastic restoration after Laubscher (1965) and Philippe et al. (1996). Map of the basement structures after various sources (see Allenbach, 2001; Wetzel and Allia, 2003; Ustaszewski et al., 2005 and references therein). CF: Caquerelle fault, RF: Rheinish fault, WF: Werra fault.

Rang sensu Chevallier, 1989). The significant decrease in thickness and the transition into calcareous fossiliferous sediments towards the southeast seems to reflect the palaeotopography. Amalgamation of marl layers to the southeast would explain the reduced thickness to the south and southeast but not the decrease in marl content. It is more likely that the Banné Marl deposition occurred preferentially in deep, calmer waters in the northwest and that they pinch out at the basin margin in the southeast where deposition of clastic fines was obstructed by increased water energy (Ruf et al., 2005). Therefore a protected, normal-marine depositional environment is postulated for the Banné Marls (Jank, 2004; Chevallier, 1989), probably in an intra-platform bight. The thinning of the Banné Marls to the southeast (partly) points to the spatial delimitation of this bight and suggests a (submarine) swell in the south (Fig. 12).

When a sea level fall affects a structured morphology, different areas emerge at different times (e.g., Strasser et al., 1999) and hence, in the case of a small-scale basin-and-swell topography different facies occur at the same level simultaneously. During the Acanthicum-Zone such a morphology is indicated by restricted, very shallow sub- to supratidal deposits associated with significant hydrodynamical, sedimentological and faunal modifications (as for example tidal channels, coaly plants, crocodile teeth, turtles, pterosaur remains, stromatolites, dinosaur foot prints, birds eyes, mud cracks and rhizoliths, etc; Fig. 14) occurring at different levels in the sediments of HST3 and LST4 in different sections (compare Figs. 5, 8 and 11). Nevertheless the sediments (Nerinean Limestones and lateral equivalents) that accumulated after the Banné Marls almost completely filled the accommodation space (levelling of the topography) and this facies migrated basinward (at least direction northwest with respect to the Banné Marls).

In the Late Acanthicum-Zone, around the onset of TST4, the platform recovered and subtidal, very massive layered deposits dominate across the platform during the Late Eudoxus-Zone (HST4), suggesting a prominent gain in accommodation space (Colombié, 2002; Jank, 2004). Consequently, with respect to the situation in the southeast, the occurrence of "northern"

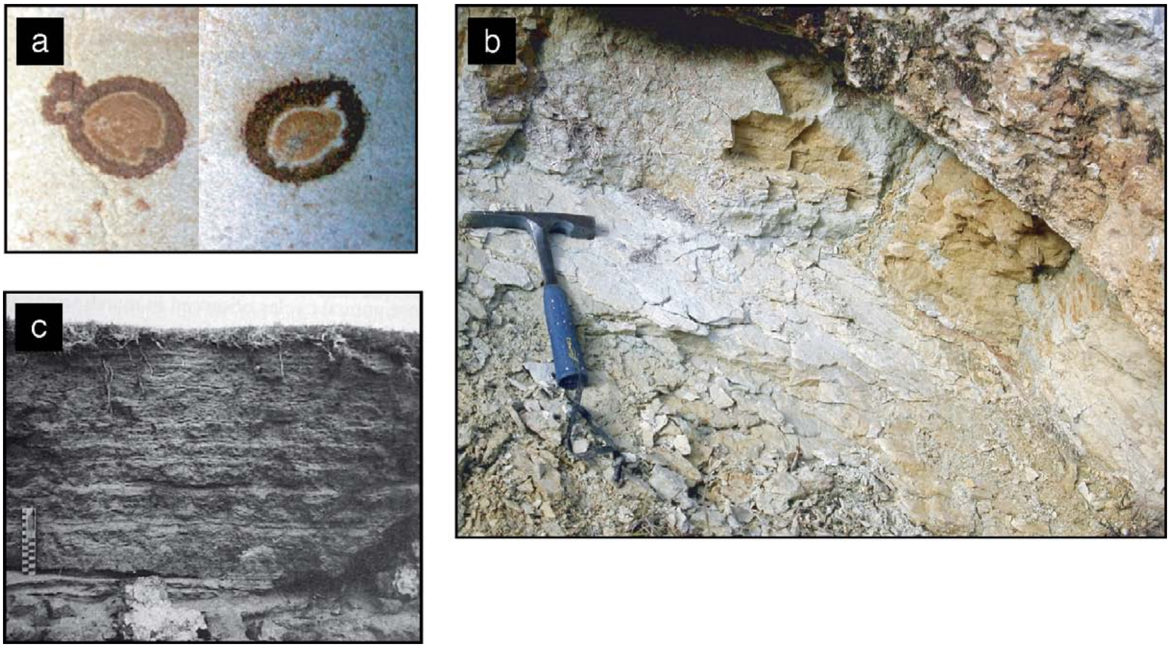


Fig. 14. Rhizolith–Rhizomorphs* (a) (diameter ≈ 2.5 mm) found in a crumbly and platy limestone (b) at Contournement de Glovelier (bed GLO-239). This (almost) fossil-free crumbly and platy limestone (b) appears quite abruptly above emerged stromatolites with mud cracks (not visible). It is comparable with modern marsh deposits, for example from the Mont-Saint-Michel estuary, France (c) (Tessier, 1998). The rhizomorphs, the crumbly and platy structure and the lack of fossils allow one to interpret this marsh deposit as palaeosol as well. Note: *Rhizomorphs are interpreted as fossilized roots of plants. They probably come from Gymnosperms (Conifers, Seedferns, Cycads, etc.). Equisetaleans and fern rhizomorphs can be almost certainly ruled out because they have a completely different structure. Cycads, Ginkgos, etc. usually grew in delta plains, but not really very near the coast. Some seedferns were mangrove plants, but only a few; and some conifers were probably coastal plants (like some *Araucariaceae* and *Cheirolepidiaceae*), but others were upland vegetation; and some *Taxodiaceae* were quite often marsh plants (pers. comm. J.H.A.van Konijnenburg-van Cittert).

ARTICLE IN PRESS

Fig. 15. *Nanogyra virgula* (DEFRANCE) in the Virgula Marls of Sur Combe Ronde — *N. virgula* lived on soft sediment in calm offshore basins (for example as verified in the Boreal realm of western France; Fürsich and Oschmann, 1986a,b). (scale: coin ≈ 2.5 cm).

Virgula Marls restricted to the Ajoie-Region and the region west to it (Contini and Hantzpergue, 1973; Chevallier, 1989), point to a second significant palaeoenvironmental change, i.e., the formation of a second (but probably smaller) intra-platform bight in the northwest as displayed in Fig. 12. The postulated protected, normal marine depositional environment for the "northern" Virgula Marls (e.g., Jank, 2004; Fig. 15) supports the development of such a bight.

5. Discussion

5.1. Sequence-stratigraphy and age-assignments

Obviously the marker-correlations along the NW–SE transect are confirmed by the vertical changes of facies and inferred sequence-stratigraphy. However the sequence boundaries of the investigations of Gygi et al. (1998), Gygi (2000a), Colombié (2002) and Jank (2004) occasionally markedly differ in age (Fig. 16).

Jank (2004) assign the sequence boundaries SB1 and 2 to the Planula- and Platynota-Zone; SB3 to SB5 to the Boreal sequence boundaries Kim3 to Kim5 of Hardenbol et al. (1998). Gygi et al. (1998) and Gygi (2000a) assigned K1 around the boundary between the Platynota- and Hypselocyclum-Zone (Fig. 16). K2 is placed in the Divisum-Zone (K3 "at, or near, the base of the Eudoxus-Zone"; Gygi et al., 1998; Gygi, 2000a). Colombié (2002) assigns the sequence boundaries in Gorges de Pichoux, Gorges de Court and La Reuchenette to the Tethyan sequence boundaries Kim1 to Kim5 of Hardenbol et al. (1998) (Fig. 6). Based on the new biostratigraphical data of Jank (2004) and Schweigert et al. (in preparation), Colombié et al. (2004) proposed replacing the tethyan Kim4 at La Reuchenette, Gorges de Pichoux and Gorges de Court by the Boreal Kim4 of Hardenbol et al. (1998) and introduced a Boreal age-assignment. The marker correlations and the age-assignments of Jank (2004), which are proved by biostratigraphical markers, substantiate the latest proposed age assignments of Colombié et al. (2004).

Consequently, based on this study, it seams reasonable to assign the corresponding sequence boundaries (K1 to 3 and Kim1 to 4) of Gygi et al. (1998), Gygi (2000a) and Colombié (2002) to the same age as Jank (2004). That means SB1, K1, Kim1 in Gorges de Pichoux and Kim2 in La Reuchenette are assigned to the Planula-Zone (Late Oxfordian); SB2, K2 and Kim2 in Gorges de Pichoux and the sequence boundary between cycle 9 and 10 in La Reuchenette to the Platynota-Zone (Early Kimmeridgian); SB3, K2 in the Ajoie-Region, K3 and Kim3 in Gorges de Pichoux and Kim3 in La Reuchenette to Boreal Kim3 (Divisum-Zone) of Hardenbol et al. (1998) and SB4 and Kim4 to Boreal Kim4 (Acanthicum-Zone) of Hardenbol et al. (1998). Gygi's K3 (2000a) in Chemin Paulin probably correlates with SB4.

The presumed sequence-stratigraphical correlations (Fig. 5), upsection the Divisum-Zone (D1/ts3), are based on the fact that a prominent gain in accommodation space (HST4 in the Ajoie-Region and sediments above "Tethyan" Kim4 in the southern Jura Mountains) is documented about 50 m above D1 in the Ajoie-Region, at Contournement de Glovelier, Gorges de Pichoux, Gorges de Court (No. 24 in Fig. 1) and La Reuchenette (Colombié, 2002; Jank, 2004).

5.2. Influence of Late Palaeozoic basement structures and sea level changes on sedimentation and palaeogeography

The lithological and mineralostratigraphical correlations between the sections are in agreement with the sequence-stratigraphy and the biostratigraphical data. Nevertheless surplus accommodation space must have been provided syndepositionally, because the thickness of the Reuchenette Formation clearly exceeds the depositional water depth (Jank, 2004). Therefore the question arises, how the lateral thickness changes, the isolated occurrences of some lithologies and the (occasionally conspicuous) lateral facies changes might have been controlled (besides by sea level fluctuations)? To answer this question, comparisons with Late Palaeozoic basement structures are useful to illustrate the reasons for such lateral changes, if changes in accommodation space and the palaeogeographical situation are considered.

In recent years a series of Late Palaeozoic (Permo-Carboniferous) E-W-striking troughs and highs has been identified in the basement underlying the Jura Mountains and Molasse Basin (Matter, 1987; Diebold, 1988; Diebold and Noack, 1997; Ustaszewski et al., 2005). Other studies have shown the effects of these troughs and highs on Mesozoic sedimentation (Wetzel et al., 1993; Burkhalter, 1996; Pittet, 1996). Additionally, facies and thickness variations of Mesozoic sediments in the Jura Mountains in Switzerland have shown that depo-centres were related to synsedimentary reactivation of basement structures (Gonzalez, 1996; Wetzel and Allia, 2000, 2003; Allenbach, 2002; Wetzel et al., 2003). This study suggests that these Late Palaeozoic structures also acted as an important factor affecting the sediments of the Reuchenette Formation.

For example the influence of the North-Swiss Permo-Carboniferous Trough NSPT (=Constance–Frick Trough and its western prolongation) and the Burgundy Trough is indicated by the reduced thickness of the Banné Marls above the palaeohigh south of the NSPT and the increased thickness across the NSPT and the transition area into the Burgundy Basin (Fig. 13). The slightly increasing thickness of the sediments accumulated during the Planula- to Divisum-Zone in the same direction points to the same depo-centre (NSPT and Burgundy Trough).

The absence of the Banné Marls, and virgula-bearing marls and the reduced thickness of the Reuchenette Formation in the region around Solothurn and Balsthal compared to the sediments between the Ajoie-Region

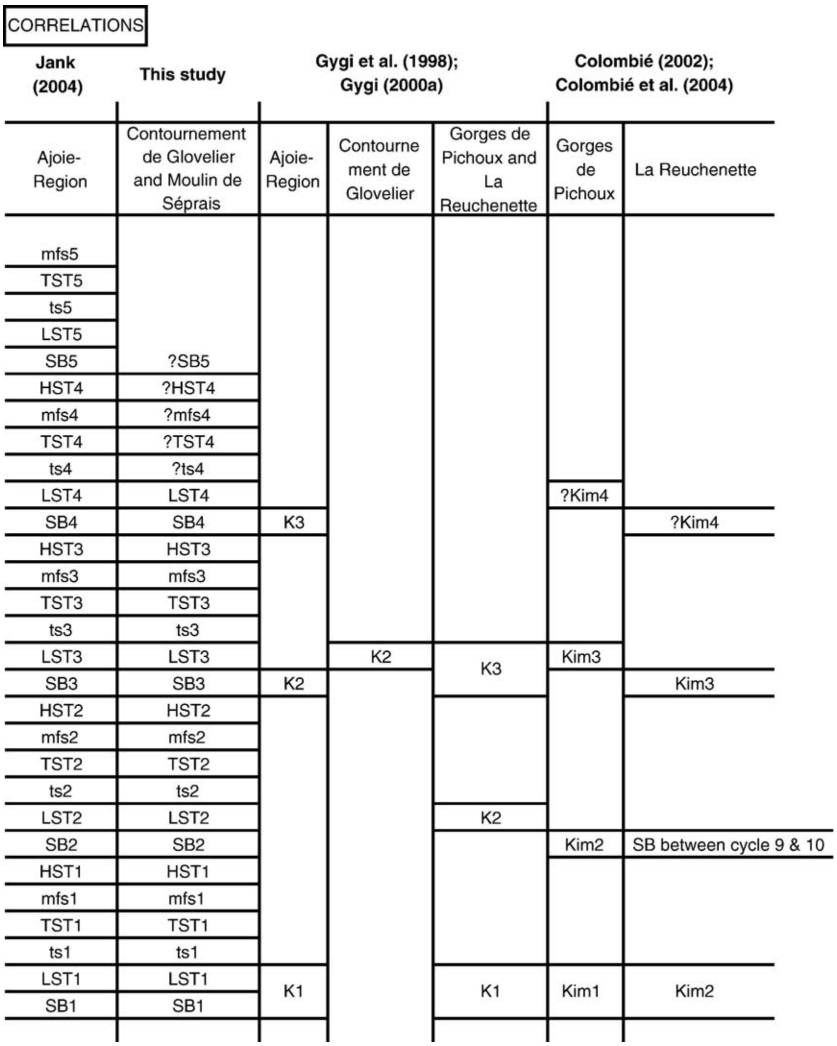


Fig. 16. Comparison of sequence boundaries in terms of correlations and ages. Stippled line is the base of the Reuchenette Formation.

ARTICLE IN PRESS

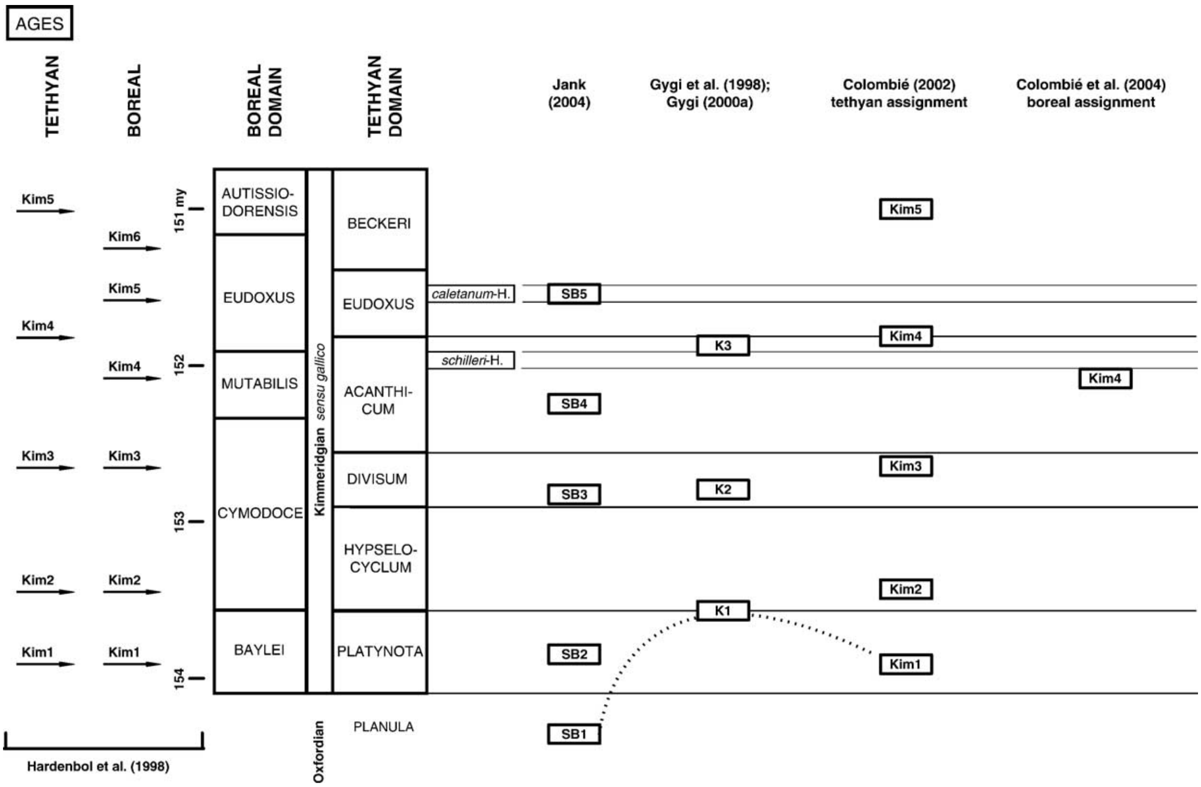


Fig. 16 (*continued*).

and La Reuchenette (variation up to 100 m; Meyer, 1993; Figs. 13, 17) are probably evidence for an uplifted area bounded to the west by the NNE–SSW-striking Rhenish Lineament and its neighbouring faults.

The different not time-equivalent Virgula Marls at La Reuchenette and in the Ajoie-Region (i.e., “southern” and “northern” Virgula Marls) also occur across Palaeozoic troughs (Hermrigen Trough and NSPT; Fig. 17).

During the Planula- to Divisum-Zone the influence of the northern trough shoulder of the NSPT and the palaeohigh between the NSPT and Hermrigen Trough were not prominent. The swells above these highs were presumably topographically insignificant because the lateral discontinuity of some marker beds and minor variations in facies only point to a weak basin-and-swell morphology, during low sea level as well (Fig. 12).

Several probably submarine swells in the northwest, above the E–W– to ENE–WSW-striking Late Palaeozoic highs between the Burgundy Trough and the NSPT and their southwestern prolongation (compare Fig. 17), would support the development of a depositional environment necessary to accumulate the Banné Marls during TST3. A swell above the palaeohigh between the NSPT and Hermrigen Trough is interpreted as the southern delimitation of the Banné Marls.

Therefore the study area is considered, depending on the sea level stage, as the flooded or emergent NE–SW striking barrier or overlap area between the Boreal and Tethyan realms (e.g., Hantzpergue, 1985, 1993; Mouchet, 1995, 1998) composed of a detached carbonate platform with more or less strongly developed intraplatform basins and swells. The subtle lateral variations in lithology and facies during the Planula- to Divisum-Zone and the conspicuous lateral variations in facies and thickness during the Divisum- to Eudoxus-Zone point to synsedimentary subsidence across the NSPT and probably Burgundy Trough (Fig. 18). During low sea level stand (especially during LST3 and 4) the emerged swells might have been a part of the proposed connection between the London-Brabant Massif and the Central Massif, which have been crossed by dinosaurs (Meyer and Lockley, 1996; Diedrich, 2004; Fig. 2).

6. Conclusions

Lithology, marker beds, facies, bio- and sequence-stratigraphy allow defining intervals useful for litholog-

ARTICLE IN PRESS

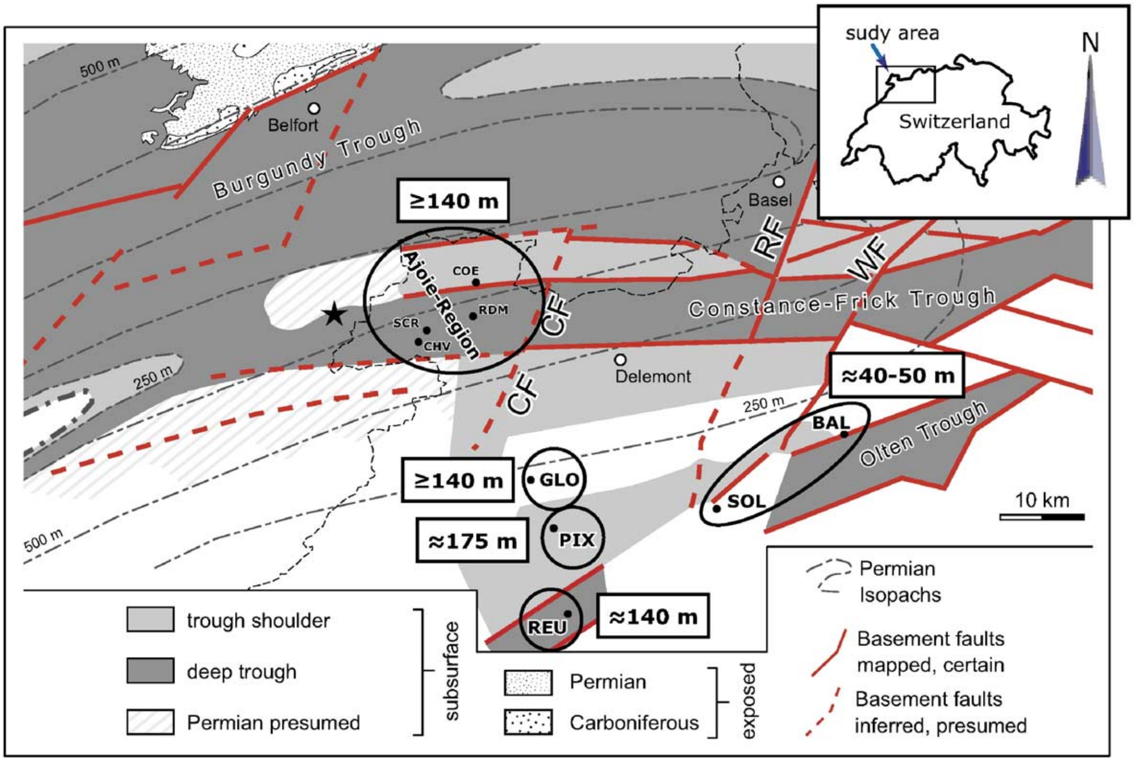


Fig. 17. Thicknesses of the Reuchenette Formation plottet above Palaeozoic basement structures. Thickness increases west of the Rhenish Fault (RF) and Caquerelle Fault (CF). The different Virgula Marls occur in the Ajoie-Region (localities CHV, RDM, SCR) and west of it in the region of Montbéliard (star; Contini and Hantzpergue, 1973; Chevallier, 1989), and La Reuchenette (REU) above the Late Palaeozoic troughs. Palinspastic restoration of sections after Laubscher (1965) and Philippe et al. (1996). Map of the basement structures after various sources (see Allenbach, 2001; Wetzel and Allia, 2003; Ustaszewski et al., 2005 and references therein). WF: Werra Fault. For codes of localities see Fig. 1.

ical and sequence-stratigraphical correlations over large distances. This study provides biostratigraphically dated interpretation of the development of the platform topography, at the transition between the Boreal and Tethyan realms.

(1) At least three markers (the lithological change at the base of the Reuchenette Formation, Banné Marls and mineralostratigraphical horizon D1) provide a direct correlation of the type-section of the Reuchenette Formation in the southern Jura Mountains with the biostratigraphically well dated spliced section in the Ajoie-Region. This correlation also represents a new lithological frame for the Reuchenette Formation because this is for the first time the thickest sections of the Reuchenette Formation can be placed in a high-resolution biostratigraphical frame. Several minor marker beds support this correlation and provide useful additional data for more precise correlation between the shorter section.
There are no significant marker beds and biostratigraphical markers in the top part of the sections in the Gorges de Pichoux and La Reuchenette, which might confirm the sequence-stratigraphical correlations between the Ajoie-Region, Contournement de Glovelier and these sections. Nevertheless, a gain in accommodation space (indicated by thick bedded sediments), biostratigraphically assigned to the Late Eudoxus-Zone, can be used for an approximated correlation.
(2) The vertical facies development, and the position and the number of sequence boundaries support the marker bed correlations.
(3) The base of the Reuchenette Formation lies within the Planula-Zone (Late Oxfordian). The marker bed correlations allow refining and improving former age-assignments of the sequence boundaries. The five sequence boundaries (SB1 to 5) can be assigned to the Planula-, Platynota-, Divisum-, Acanthicum and uppermost Eudoxus-Zone, whereas sequence boundaries SB3 to 5 additionally can be attributed to the Boreal sequence

ARTICLE IN PRESS

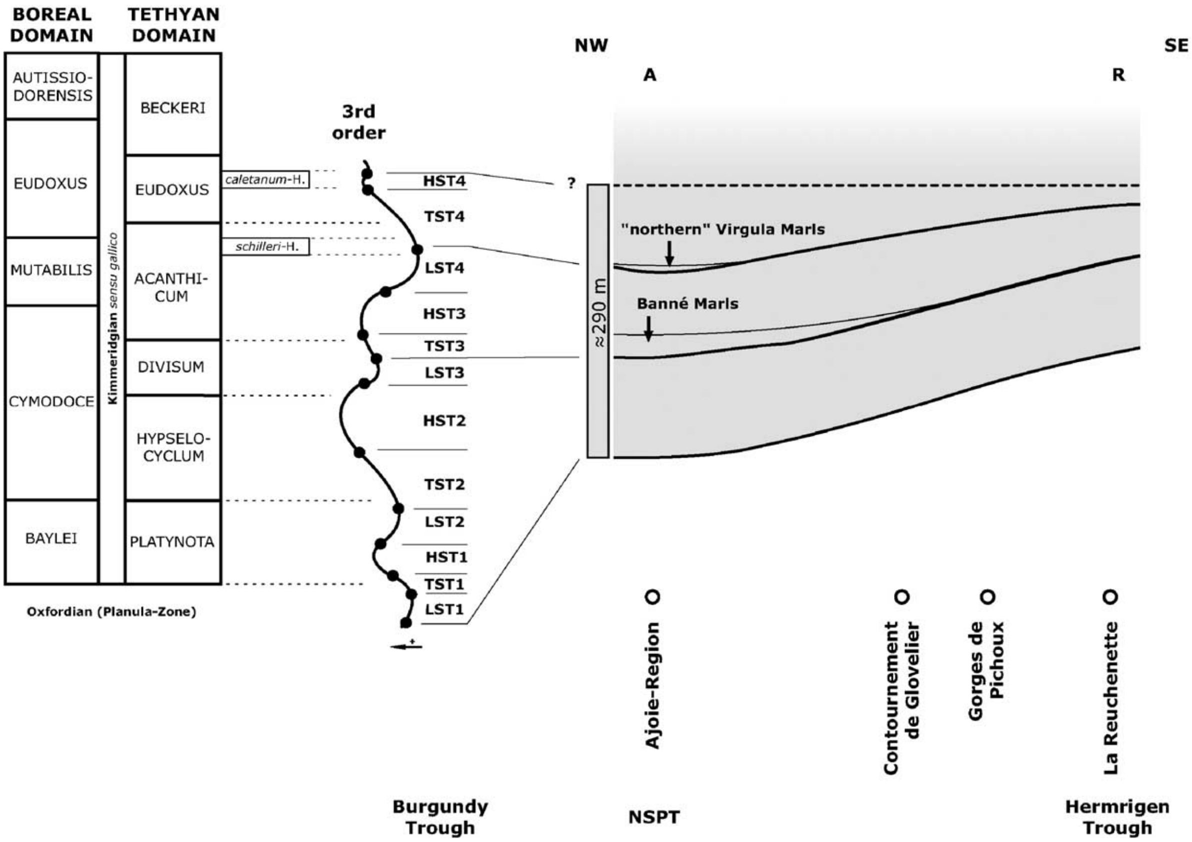


Fig. 18. Schematic decompacted NW–SE section across the study area between the Ajoie-Region (A) and the type-locality La Reuchenette (R) for selected time intervals. Across the North-Swiss Permo-Carboniferous Trough (NSPT) thickness significantly increases. Note that the section was drawn by interpolating between outcrops. Tentative sea level curve after Jank (2004). Approximated decompaction factors: marl ×3, limestone ×2 (based on Moore, 1989; Goldhammer, 1997; Matyszkiewicz, 1999). Palinspastic restoration after Laubscher (1965) and Philippe et al. (1996).

boundaries Kim3 to 5 of Hardenbol et al. (1998) as well.

(4) As the thickness of the investigated sediments clearly exceeds the depositional water depth, surplus accommodation space was provided by synsedimentary differential subsidence. The reactivation of structures that formed during the Late Palaeozoic in the basement, significantly affected the deposition of the sediments of the Reuchenette Formation. The interplay of sea level changes and synsedimentary subsidence above these structures is documented by the lateral facies pattern and the associated platform topography.
w?>The Rhenish Lineament and associated faults probably played a role during the Planula- to Eudoxus-Zone (?and even longer) in terms of differential synsedimentary subsidence. Evidence might be given by the conspicuous thickness variation of the Reuchenette Formation parallel to the strike of the Late Palaeozoic structures.

(5) During the Planula- to Divisum-Zone the platform topography along a NW–SE transect from the Ajoie-Region to the southern Jura Mountains is considered as having been rather flat because the depositional environments were not deeper Dthan shallow subtidal. The facies distribution was relatively uniform within the individual systems tracts, especially within the highstands. Nevertheless, the deposits on this low relief topography were highly susceptible to sea level changes and even low-amplitude sea level changes resulted in widespread and nearly synchronous exposure or flooding. Variations in lithology and facies suggest a weak basin-and-swell morphology. These variations are also suggestive for a syndepositionally formed relief. The influence of the local syndepositional differential subsidence on sedimentation is of minor importance.
During the Divisum- and Acanthicum-Zone a prominent basin-and-swell morphology with

intra-platform basins developed. This morphology is probably related to enhanced synsedimentary subsidence across Late Palaeozoic basement structures, and lower sea level and probably "separated" the Paris Basin from the Tethys.

Acknowledgements

A part of this work has been carried out in collaboration between the University of Basel and the Section de Paléontologie de la République et du Canton Jura. We are grateful to Günter Schweigert and Ulla Schudack for taxonomic assignment of ammonites and ostracodes. Reinhard Gygi and Pierre Hantzpergue are thanked for discussions about taxonomic assignments and interpretations of some ammonites. We thank also Bernhard Hostettler for providing very important ammonites and very helpful field trips. Thanks to the colleagues James MacKenzie and Achim Reisdorf for discussions and logistic support. Special thanks to Pascal Tschudin for discussions and providing material.

References

Allenbach, R.P., 2001. Synsedimentary tectonics in an epicontinental sea; a new interpretation of the Oxfordian basins of northern Switzerland. Eclogae Geologicae Helvetiae 94 (3), 265–287.

Allenbach, R.P., 2002. The ups and downs of "tectonic quiescence"; recognizing differential subsidence in the epicontinental sea of the Oxfordian in the Swiss Jura Mountains. Sedimentary Geology 150 (3–4), 323–342.

Burkhalter, R.M., 1996. Die Passwang-Alloformation (oberes Aalenien bis unteres Bajocien) im zentralen und nördlichen Schweizer Jura. Eclogae Geologicae Helvetiae 89 (3), 875–934.

Chevallier T., 1989. Les formations carbonatées de la séquence ptérocerienne (Kimmeridgien pars) dans le Jura francais et les regions voisines, PhD Thesis Lyon. 194 pp.

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

Colombié, C., Hug, W.A., Mora, R., Rameil, N., Strasser, A., 2004. High- resolution correlations in peritidal environments of the Jura Mountains' Upper Kimmeridgian using a multidisciplinary approach. Abstract SwissSed Meeting, vol. 12, pp. 16–17.

Contini, D., Hantzpergue, P., 1973. Le Kimmeridgien de la région de Montbeliard. Annales Scientifiques de l'Universite de Besançon. Geologie 18, 143–179.

Desor, E., Gressly, A., 1859. Etudes géologiques sur le Jura neuchâtelois. Mém. Soc. Sci. nat. Neuchâtel, vol. 4, pp. 1–159.

Diebold, P., 1988. Der Nordschweizer Permokarbon–Trog und die Steinkohlenfrage der Nordschweiz. Vierteljahresschrift der Naturforschenden Gesellschaft in Zürich 133 (3), 143–174.

Diebold, P., Noack, T., 1997. Jura Mountains; Late Palaeozoic troughs and Tertiary structures in the eastern folded Jura. In: Pfiffner, O.A., Lehner, P., Heitzman, P., Müller, S., Steck, A. (Eds.), Results of NRP 20; Deep Structure of the Swiss Alps. Birkhäuser Verlag, Basel, Switzerland, pp. 59–63.

Diedrich, C., 2004. Dinosaurier im Wiehengebrige. Fossilien 3, 180–185.

Frakes, L.A., Francis, J.E., Syktus, J.I., 1992. Climate Modes of the Phanerozoic; The History of the Earth's Climate Over the Past 600 Million Years. Cambridge Univ Press, Cambridge, United Kingdom. 274 pp.

Fürsich, F.T., Oschmann, W., 1986a. Storm shell beds of Nanogyra virgula in the Upper Jurassic of France. Neues Jahrbuch für Geologie und Paläontologie Abhandlungen 172 (2), 141–161.

Fürsich, F.T., Oschmann, W., 1986b. Autecology of the Upper Jurassic oyster *Nanogyra virgula* (DEFRANCE). Paläontologische Zeitschrift 60 (1–2), 65–74.

Goldhammer, R.K., 1997. Compaction and decompaction algorithms for sedimentary carbonates. Journal of Sedimentary Research 67 (1), 26–35.

Gonzalez, R., 1996. Response of shallow-marine carbonate facies to third-order and high-frequency sea-level fluctuations; Hauptrogenstein Formation, northern Switzerland. Sedimentary Geology 102, 111–130.

Greppin, J.B., 1870. Description géologique du Jura bernois et de quelques districts adjacent. Matériaux Pour la Carte Géologique. Suisse 8, 1–357.

Gygi, R.A., 1982. Sedimentation und Facies des Späten Jura im zentralen Juragebirge (Exkursion A am 15. und 16. April 1982). Jahresberichte und Mitteilungen des Oberrheinischen Geologischen Vereines 64, 17–28.

Gygi, R.A., 1995. Datierung von Seichtwassersedimenten des Späten Jura in der Nordwestschweiz mit Ammoniten. Eclogae Geologicae Helvetiae 88 (1), 1–58.

Gygi, R.A., 2000a. Integrated stratigraphy of the Oxfordian and Kimmeridgian (Late Jurassic) in northern Switzerland and adjacent southern Germany. Denkschriften der Schweizerischen Akademie der Naturwissenschaften 104, 151 pp.

Gygi, R.A., 2000b. Annotated index of lithostratigraphic units currently used in the Upper Jurassic of northern Switzerland. Eclogae Geologicae Helvetiae 93 (1), 125–146.

Gygi, R.A., 2003. Perisphinctacean ammonites of the Late Jurassic in northern Switzerland — a versatile tool to investigate the sedimentary geology of an epicontinental sea. Schweizerische Paläontologische Abhandlungen 123 232, pp.

Gygi, R.A., Persoz, F., 1986. Mineralostratigraphy, litho- and biostratigraphy combined in correlation of the Oxfordian (Late Jurassic) formations of the Swiss Jura Range. Eclogae Geologicae Helvetiae 79 (2), 385–454.

Gygi, R.A., Coe, A.L., Vail, P.R., 1998. Sequence stratigraphy of the Oxfordian and Kimmeridgian stages (Late Jurassic) in northern Switzerland. In: de Graciansky, P.C., Hardenbol, J., Jacquin, T., Vail, P.R. (Eds.), Mesozoic and Cenozoic Sequence Stratigraphy of European Basins. Special Publication, vol. 60. SEPM, Tulsa, OK, United States, pp. 527–544.

Hantzpergue, P., 1985. Les discontinuites sedimentaires majeures dans le Kimmeridgien français; chronologie, extension et correlations dans les bassins ouest-europeens. Geobios 18 (2), 179–194.

Hantzpergue, P., 1993. Biogeographie des ammonites et variations du niveau marin; analyse quantitative des peuplements du Kimmeridgien ouest-europeen. Comptes Rendus de l'Academie des Sciences, Serie 2, Mecanique, Physique, Chimie, Sciences de l'Univers, Sciences de la Terre 317 (4), 493–498.

Hantzpergue, P., Atrops, F., Enay, R. and Groupe Francais d'Etude du Jurassique, 1997. Biozonations; Kimmeridgien. In: E. Cariou and P. Hantzpergue (Editors), Biostratigraphie du Jurassique ouest-européen et mediterranéen; zonations paralleles et distribution des invertebres et microfossiles. Memoire 17. Bulletin des Centres de Recherches Exploration-Production Elf-Aquitaine, pp. 87–96 and 148–151.

Hardenbol, J., Thierry, J., Farley, M.B., de Graciansky, P.C., Vail, P.R., 1998. Mesozoic and Cenozoic sequence chronostratigraphic framework of European basins. In: de Graciansky, P.C., Hardenbol, J., Jacquin, T., Vail, P.R. (Eds.), Mesozoic and Cenozoic Sequence Stratigraphy of European Basins. Special Publication, vol. 60. SEPM, Tulsa, OK, United States, pp. 3–13.

Jank M., 2004, New insights into the development of the Late Jurassic Reuchenette Formation of NW Switzerland (Late Oxfordian to Late Kimmeridgian, Jura Mountains). Dissertationen aus dem Geologisch-Paläontologischen Institut der Universität Basel 32. 121 pp.

Laubscher, H.P., 1963. Geologischer Atlas der Schweiz. Erläuterungen zum Blatt1085 St-Ursanne. Schweizerische Geologische Kommission, Bern.

Laubscher, H.P., 1965. Ein kinematisches Modell der Jurafaltung. Eclogae Geologicae Helvetiae 58, 231–318.

Marçou, J. 1848. Recherches géologiques sur le Jura salinois. Première partie. Mém. Soc. géol. France (2), 3(1): 1-151.

Marty, D., et al., 2003. Preliminary report on the Courtedoux dinosaur tracksite from the Kimmeridgan of Switzerland. Ichnos 10, 209–219.

Matter, A., 1987. Faciesanalyse und Ablagerungsmilieus des Permokarbons im Nordschweizer Trog. Eclogae Geologicae Helvetiae 80 (2), 345–367.

Matyszkiewicz, J., 1999. Sea-bottom relief versus differential compaction in ancient platform carbonates; a critical reassessment of an example from Upper Jurassic of the Cracow-Wielun upland. Annales Societatis Geologorum Poloniae 69 (1–2), 63–79.

Meyer, C.A., 1989. Der Lebens- und Ablagerungsraum der Solothurner Schildkrötenkalke. Mitteilungen der Naturforschenden Geselllschaft des Kantons Solothurn 34, 185–190.

Meyer, C.A., 1990. Sauropod tracks from the Upper Jurassic Reuchenette Formation (Kimmeridgian, Lommiswil, Kt. Solothurn) of northern Switzerland. Eclogae Geologicae Helvetiae 83 (2), 389–397.

Meyer, C.A., 1993. A sauropod dinosaur megatracksite from the Late Jurassic of northern Switzerland. Ichnos 3, 29–38.

Meyer, C.A., 2000a. Ein Jura-Querschnitt von Solothurn bis Basel. Jahresberichte und Mitteilungen des Oberrheinischen Geologischen Vereines, neue Folge 82, 41–54.

Meyer, M., 2000b. Le Complexe récifal kimméridgien — tithonien du Jura méridional interne (France), évolution multifactorelle, stratigraphie et tectonique. Terre & Environnement 24. 179 pp.

Meyer, C.A., Lockley, M.G., 1996. The Late Jurassic continental record of Northern Switzerland — evidence and implications. The Continental Jurassic. Museum of Northern Arizona, Flagstaff, pp. 421–426.

Moore, C.H., 1989. Carbonate diagenesis and porosity. Developments in Sedimentology vol. 46. Elsevier, Amsterdam. 338 pp..

Mouchet P.O.J., 1995. Le Kimméridgien du Jura central. Microfaciès, minéralogie et interprétation séquentielle, PhD Thesis Neuchâtel. 204 pp.

Mouchet, P.O.J., 1998. Stratigraphy and mineralostratigraphy of the Kimmeridgian in the central Jura Mountains of Switzerland and eastern France. Eclogae Geologicae Helvetiae 91 (1), 53–68.

Philippe, Y., Colletta, B., Deville, E., Mascle, A., 1996. The Jura fold-and-thrust belt; a kinematic model based on map-balancing, Peri-Tethys memoir 2; structure and prospects of Alpine basins and forelands. In: Ziegler, P.A., Horvath, F. (Eds.), Memoires du Museum National d'Histoire Naturelle. Ed. du Museum National d'Histoire Naturelle, Paris, France, pp. 235–261.

Pittet B., 1996. Contrôles climatiques, eustatiques et tectoniques sur des systèmes mixtes carbonates-siliciclastiques de plate-forme: exemples del'Oxfordien (Jura Suisse, Normandie, Espagne). PhD Thesis Fribourg. 258 pp.

Ruf, M., Link, E., Pross, J., Aigner, T., 2005. Integrated sequence, stable isotope and palynofacies analysis in deeper epicontinental shelf carbonates from the Upper Jurassic of SW Germany. Sedimentary Geology 175 (14), 391–414.

Schweigert, G., Hostettler, B., Jank, M., and Marty, D., in preparation. Ammonites and high resolution biostratigraphic markers in the shallow marine Upper Jurassic Reuchenette Formation and underlying beds of the Ajoie (Canton Jura, Switzerland). Eclogae Geologicae Helvetiae.

Strasser, A., Pittet, B., Hillgärtner, H., Pasquier, J.B., 1999. Depositional sequences in shallow carbonate-dominated sedimentary systems; concepts for a high-resolution analysis. Sedimentary Geology 128 (3–4), 201–221.

Tessier, B., 1998. Tidal cycles; annual versus semi-lunar records. In: Alexander, C.R., Davis, R.A., Henry, V.J. (Eds.), Tidalites; Processes and Products. Special Publication, vol. 61. SEPM, Tulsa, OK, United States, pp. 69–74.

Thalmann, H., 1966. Gliederung und Fazies des obersten Malm (Reuchenette- und Twannbachformation) im südlichen Berner und Solothurner Jura. Eclogae Geologicae Helvetiae 59 (2), 931–934.

Thurmann, 1832. Essai sur les soulèvements jurassiques du Porrentruy. Mémoires de la Société d'Histoire Naturelle de Strassbourg 1, 1–84.

Tschudin, P., 2001. Teil II: Geländearbeiten im Schweizer Jura: Profilaufnahme Glovelier (JU), Kartierung Hautes Roches (BE). Diploma Thesis Bern, pp. 59–109.

Ustaszewski, K., Schumacher, M.E., Schmid, S.M., 2005. Simultaneous faulting and extensional flexuring during Palaeogene rifting a case study from the southern Upper Rhine Graben. International Journal of Earth Sciences (Geologische Rundschau) 94 (4), 680–696.

Vail, P.R., Audemard, F., Bowman, S.A., Eisner, P.N., Perez, C.G., 1991. The stratigraphic signatures of tectonics, eustacy and sedimentology; an overview. In: Einsele, G., Ricken, W., Seilacher, A. (Eds.), Cycles and Events in Stratigraphy. Springer Verlag, Berlin, Germany, pp. 617–659.

Van Wagoner, J.C., et al., 1988. An overview of the fundamentals of sequence stratigraphy and key definitions. In: Wilgus, C.K., et al., (Eds.), Sea-Level Changes; An Integrated Approach. Special Publication, vol. 42. SEPM, Tulsa, OK, United States, pp. 39–45.

Wetzel, A., Allia, V., 2000. The significance of hiatus beds in shallow-water mudstones; an example from the Middle Jurassic of Switzerland. Journal of Sedimentary Research 70 (1), 170–180.

Wetzel, A., Allia, V., 2003. Der Opalinuston in der Nordschweiz: Lithologie und Ablagerungsgeschichte. Eclogae Geologicae Helvetiae 96 (3), 451–469.

Wetzel, A., Allia, V., Gonzalez, R., Jordan, P., 1993. Sedimentation und Tektonik im Ostjura. Eclogae Geologicae Helvetiae 86 (1), 313–332.

Wetzel, A., Allenbach, R., Allia, V., 2003. Reactivated basement structures affecting the sedimentary facies in a tectonically "quiescent" epicontinental basin; an example from NW Switzerland. Sedimentary Geology 157 (1–2), 153–172.

ARTICLE IN PRESS

Ziegler, P.A., 1990. Geological Atlas of Western and Central Europe. Shell International Petroleum Maatschappij B. V, The Netherlands. 239 pp.

Further reading

Brett, C.E., 1995. Sequence stratigraphy, biostratigraphy, and taphonomy in shallow marine environments. Palaios 10 (6), 597–616.

Loutit, T.S., Hardenbol, J., Vail, P.R., Baum, G.R., 1988. Condensed sections; the key to age determination and correlation of continental margin sequences. In: Wilgus, C.K., et al., (Eds.), Sea-Level Changes; An Integrated Approach. Special Publication, vol. 42. SEPM, Tulsa, OK, United States, pp. 183–213.

Marty, D., Diedrich, C., 2002. Fouilles paléontologiques dans les unités du Secondaire (Mésozoïque): Combe de Vâ tche Châ, Déblais du Tunnel du Banné. In: Rapport de l'Office du Patrimoine Historique, Section de Paléontologie (Ed.), Rapport d'activités 2001, Paléontologie et Transjurane, pp. 1–13.

Meyer, C.A., 1994. Depositional environment and paleoecology of the Solothurn Turtle Limestone. Géobios Mémoire Spécial 16 (1991), 227–236.

Meyer, C.A., Jordan, P., 2000. Stratigraphie, Paläontologie und Tektonik der Verena-Kette nördlich von Solothurn. Jahresberichte und Mitteilungen des Oberrheinischen Geologischen Vereines, neue Folge 82, 17–28.

Sarg, J.F., 1988. Carbonate sequence stratigraphy. In: Wilgus, C.K., et al., (Eds.), Sea-Level Changes; an Integrated Approach. Special Publication, vol. 42. SEPM, Tulsa, OK, United States, pp. 155–181.