New insights into the development of the
Late Jurassic Reuchenette Formation of NW Switzerland
(late Oxfordian to late Kimmeridgian, Jura Mountains)

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Professor Dr. A. Wetzel.

Basel, den 19. Oktober 2004

ORGANIZATION OF THE THESIS

This thesis focuses on the history of the Late Jurassic Reuchenette Formation of NW Switzerland revealed from lithological, sedimentological, facial and biostratigraphical investigations. It consists of three manuscripts submitted for publication, which describe the composition and development of this formation.

- Chapter I, for the Reuchenette Formation a new biostratigraphically dated composite reference-section is described; it has been composed of eighteen spliced sections by detailed lithological and sedimentological investigations and seven *in situ* collected species of ammonites;
- Chapter II, the vertical changes of (micro-) facies, bed thickness and grain size in these sections and their sequence-stratigraphical interpretation are presented;
- Chapter III, based on the results of Chapter I and II, a precise litho-, sequence- and biostratigraphical framework is used to correlate the reference-section with the type-section. This includes the resulting lateral distribution of lithology and depositional environments and their implications on platform topography.

The overall sedimentological, sequence-startigraphical and paleoenvironmental results of this thesis are summarized in the General Conclusions.

Within the chapters, a certain amount of repetition could not be avoided since they are organised as individual scientific papers, each one dealing with a different aspect of the geological evolution in the same sedimentary system. Nevertheless, I favoured this organization of the thesis in order to enhance the impact within the scientific community. Consequently, a certain amount of self-citation could also not be avoided since scientific journals do not accept „in review“ citations. Therefore the citation Jank (2004) refers to this thesis.

Detailed sections in support of the present knowledge on the Reuchenette Formation are reported in the Annex. Partly they were not included in the publications due to the normally limited space in scientific journals.

This thesis is also published online on the university homepage. Samples, thin sections, analytical and observational data and ostracode samples of this study are stored at B. Hostettler (Fondation Paléontologique Jurassienne; address: Au Village 16, CH-2855 Glovelier, Switzerland). The ammonites are stored at B. Hostettler and the Section de Paléontolgie (SPA) in Porrentruy (address: SPA, Office Cantonal de la Culture, Hôtel des Halles, Case postale 64, CH- 2900 Porrentruy, Switzerland).

CONTENTS

CHAPTER I

CHAPTER II

INTRODUCTION

In Late Jurassic times the carbonate platform in the Swiss Jura occupied the transition between the Paris Basin and the Tethys and therefore connected the Boreal and Tethyan realms. As the Tethys developed since the early to middle Jurassic, the Alemanic Island Chain subsided during the middle Jurassic and the epicontinental sea covering Western Europe and the Tethys became fully connected. Nevertheless, in the north Boreal faunas occur, in the south the Tethyan ones and hence, biostratigraphical correlation between both faunal provinces is still an important task. This holds true also for the Swiss Jura, including the Late Jurassic Reuchenette Formation (Fig. 1). However, up to now, the rarity of index-fossils in the Reuchenette Formation of northwestern Switzerland prevented a reliable correlation between both areas in Kimmeridgian times for the following reasons:

The sparseness of index-fossils within the shallow-water platform sediments of the Reuchenette Formation – including the type-section in the quarry La Reuchenette near Péry

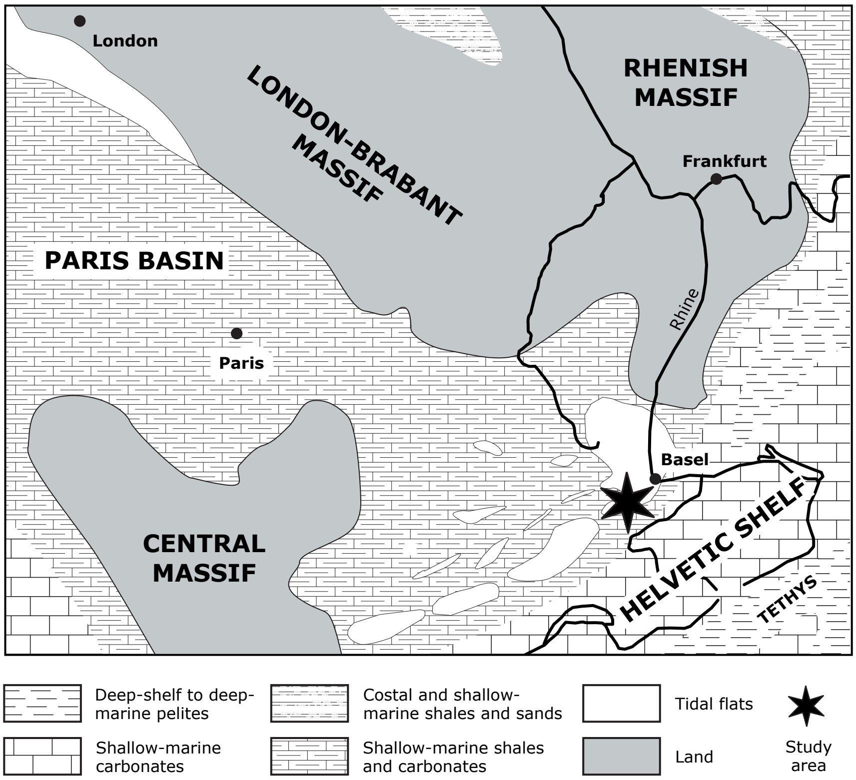
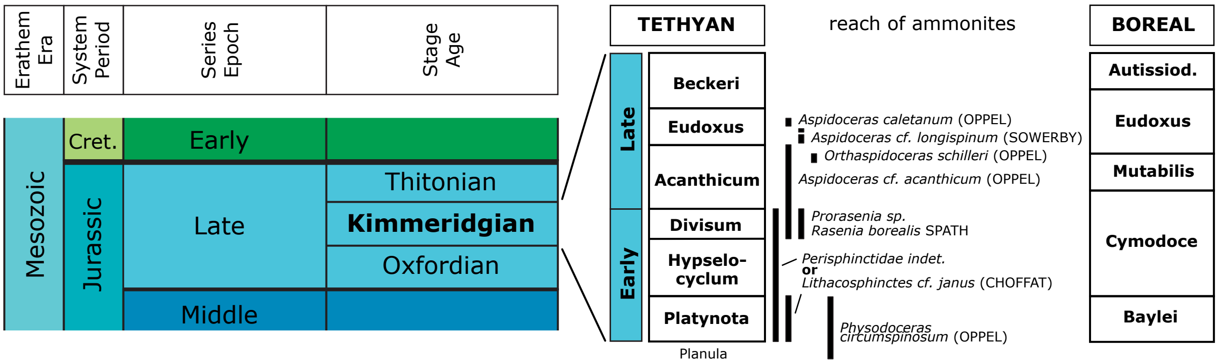
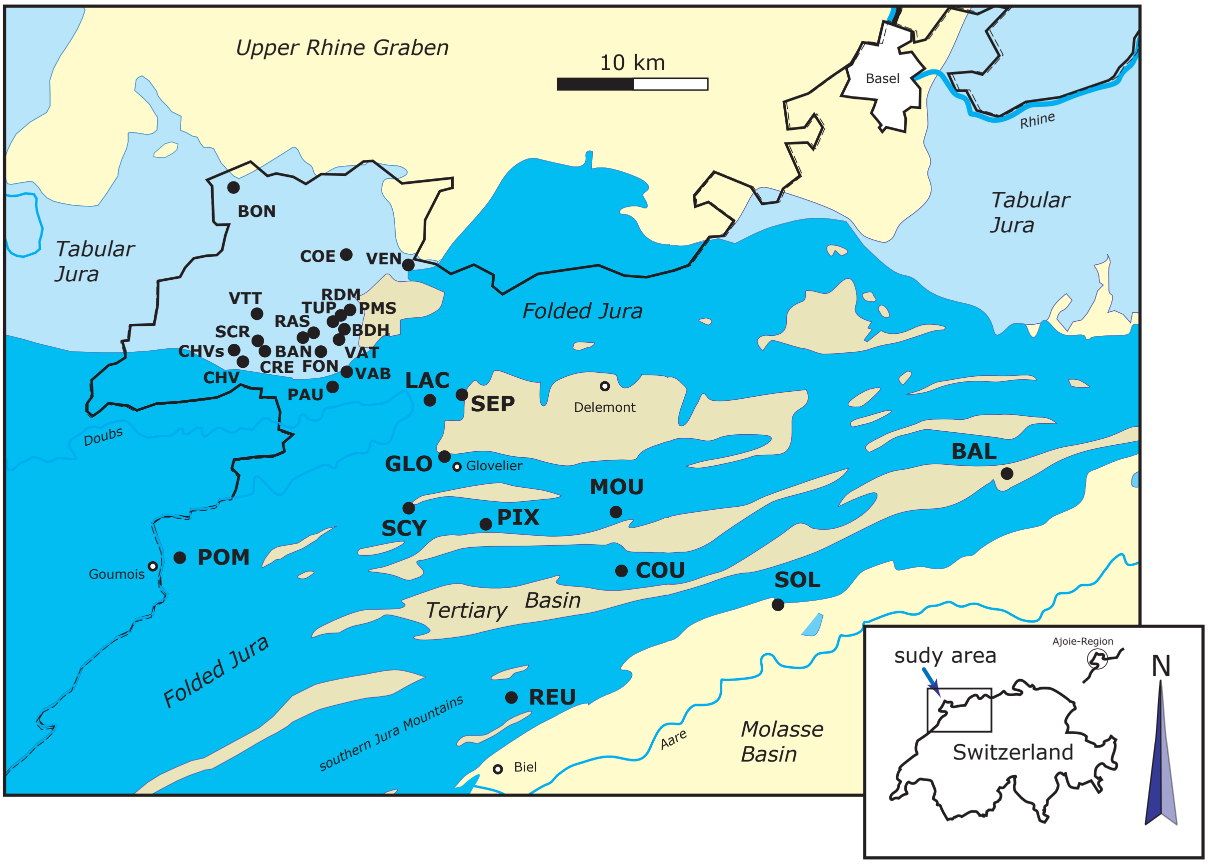


Fig. 1: Palaeogeographical situation in the vicinity of the study area in the Kimmeridgian stage (Divisum- and Acanthicum-Zone).
During the Late Jurassic the Tethys shelves of Western Europe were occupied by extensive carbonate-dominated platforms, which expanded to the north into the area of the Franconian platform, the southern and eastern parts of the Paris Basin and into the Aquitain Basin. Crustal extension led to rapid subsidence and extremely thick sediment packages of carbonates, shales, marls and evaporites in the Paris Basin; on the Helvetic Shelf an alternation of limestones and shales and shallow-water carbonates accumulated; typical for passive margins. During Kimmeridgian times the Paris Basin either stood in open or restricted communication with the Helvetic Shelf via the Swiss Jura carbonate platform (e.g. Chevalier, 1989; Ziegler, 1990 and references cited therein; Hantzpergue, 1993; Mouchet, 1995; this study). Seven species of ammonites and several new outcrops now allow closing the biostratigraphical and lithological gap between both realms. The palaeogeographical map is compiled after Ziegler, 1990; Meyer & Lockley, 1996; Marty et al., 2003; Diedrich, 2004 and this study; Tethyan and Boreal ammonite zones after Hantzpergue et al., 1997 and references cited therein.





	No	Code	Sections	Swiss Coordinates	
Ajoie-Region	1	BAN	Tunnel Le Banné	571.833	250.504
	2	CHV	La Combe	567.753	248.930
	3	CHVs	Chevenez	567.175	249.675
	4	COE	Coeuve	574.725	256.075
	5	CRE	Creugenat	569.173	249.748
	6	FON	Fontenais	573.050	249.575
	7	PAU	Chemin Paulin	573.790	247.100
	8	PMS	Pré Monsieur	574.887	252.262
	9	RAS	La Rasse	572.560	250.840
	10	RDM	Roches de Mars	574.372	252.021
	11	SCR	Sur Combe Ronde	568.869	250.082
	12	TUP	Cras d'Hermont	573.958	251.694
	13	VAB	L'Alombre aux Vaches	574.800	248.200
	14	VAT	Vatelin	574.300	250.500
	15	VEN	Vendlincourt	578.950	255.475
	16	VTT	Vâ tche Tchâ	568.720	252.155
	17	BDH	Bas d'Hermont	574.600	251.000
	18	BON	Boncourt	567.100	260.686

No	Code	Sections	Swiss Coordinates	
19	SEP	Moulin de Séprais	584.157	246.690
20	GLO	Contournement de Glovelier	581.521	242.515
21	MOU	Gorges de Moutier	593.000	238.600
22	PIX	Gorges de Pichoux	584.138	236.519
23	REU	La Reuchenette (type-section)	585.890	226.240
24	COU	Gorge de Court	593.377	234.704
25	SOL	Region around Solothurn		
26	BAL	Region around Balsthal		
27	LAC	La Coperie	580.849	246.243
28	POM	Les Pommerats	563.600	235.740
29	SCY	Saulcy	579.000	239.000

Fig. 2: The investigated outcrops are located in the Jura Mountains (Tabular Jura and Folded Jura) of NW Switzerland. Major geological and structural elements are the Molasse Basin to the south of the study area and the Upper Rhine Graben to the north. In terms of comparisons with Late Paleozoic basement structures, the localities in the Ajoie-Region, which lie at the transition into/in the Tabular Jura, do not have to be palinspastically restored in contrast to those, located in the Folded Jura. The seven species of ammonites, which allowed introducing a biostartigraphically-constrained frame for most of the Reuchenette Formation, exclusively were found in the Ajoie-Region.

BE (No. 23 in Fig. 2) – has led to numerous differing suggestions of how to correlate the strata and to estimate their age (e.g. Thurmann, 1832; Greppin, 1870; Häfeli, 1966; Thalmann, 1966; Chevallier, 1989; Meyer C.A., 1989; Gygi, 2000b). Additionally the fact that depocentres and thickness of Mesozoic sediments in the Swiss Jura Mountains have been affected by the synsedimentary reactivation of Late Palaeozoic basement structures complicating correlations (Wetzel et al., 1993, 2003; Allia, 1996; Burkhalter, 1996; Gonzalez, 1996; Pittet, 1996; Allenbach, 2002). This is also the case for the Late Jurassic Reuchenette Formation exhibiting thickness variations of up to 100 m (Meyer C.A., 1993). Even the recent studies based on sequence-, cyclo- and mineralo-stratigraphy rely on only a few (if any) high-resolution biostratigraphical markers (Gygi & Persoz, 1986; Gygi, 1995; Mouchet, 1995, 1998; Gygi et al., 1998; Meyer M., 2000; Colombie, 2002). Unfortunately most of these markers occur in quite distant or very small exposures restricting their biostratigraphical use due to the above-mentioned reasons. Consequently, up to now the biostratigraphical data for the platform sediments of the Reuchenette Formation were too few to develop a solid high-resolution framework.

Recently, the construction work of the Transjurane motorway in the Ajoie-Region JU (northernmost study area) provided new outcrops with a considerable number of index-fossils (Figs 1 and 2). The exposures are closely spaced and perfectly suited to study these sediments and allowed a biostratigraphically-dated reference-section for most of the Reuchenette Formation to be established. The combination of biostratigraphy, facies analyis, litho-, mineralo- and sequence-stratigraphy now allow closing the gap between the reference-section and the remote largest sections (including the type-section) and introducing a reliable link between the Paris Basin in the north and the Tethys in the south, or more generally between the Boreal and Tethyan realms.

It is the aim of this thesis to provide an improved lithological (Chapter I) and sequence-stratigraphical frame (Chapter II) for the Reuchenette Formation in northwestern Switzerland based on new, refined biostratigraphy and sedimentological, lithostratigraphical and microfacial data. Additional objectives of this research are the correlation of the biostratigraphically dated spliced outcrops of this reference-section with the two thickest sections – including the type-section – of the Reuchenette Formation in order to improve the dating and correlation of previously known sequence boundaries. Using this information this study also focuses on the relationship between sea level fluctuations and synsedimentary subsidence related to Permo-Carboniferous basement structures and their influence on platform topography and associated palaeogeography (Chapter III).

SUMMARY

In the Ajoie-Region, seven *in situ* collected species of ammonites helped to establish a new biostratigraphical and lithological frame for the platform sediments of the Reuchenette Formation, i.e. eighteen closely spaced sections have been spliced by means of lithological, sedimentological, microfacial data and index-fossils (ammonites). Three marker beds achieved the exact lithological correlations between the outcrops corroborated by the vertical facies changes.

Based on the biostratigraphical data five 3rd order sedimentary sequences could be asigned to the Late Oxfordian to Late Kimmeridgian time interval. The sequence boundaries lie within the Planula-, Platynota-, Divisum-, Acanthicum- and Eudoxus-Zone. The upper three 3rd order sequences correspond to the Boreal sequences Kim3 to Kim5 of Hardenbol et al. (1998). The deduced "large-scale" sea level trend matches those from other European regions (Spain, Russia).

At platform scale, this time control and further outcrops south of the Ajoie-Region, in combination with mineralostratigraphical and lithological marker beds, allowed the correlation

and dating of the thickest sections – including the type-section – of the Reuchenette Formation and thus serve to improve the previously estimated ages of their sequence boundaries (see above).

The variability of stacking pattern and facies between the sections also reveals distinct changes in facies evolution occurring across Late Palaeozoic basement structures and suggest synsedimentary differential subsidence. These structures acted as important controlling factors for the distribution of the sediments of the Reuchenette Formation besides the sea level fluctuations. The interplay of sea level changes and synsedimentary differential subsidence is outlined by lateral thickness variations and conspicuous laterally changing 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 and the Tethys. During the Planula- to Divisum-Zone time interval 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-Zone time interval this platform changed into a pronounced basin-and-swell morpoholgy with specific depositional environments and “separated” the Paris Basin from the Tethys. Dinosaurs might have used this boundary to traverse between the Central Massif and the London-Brabant Massif during sea level lowstands.

A calibrated composite section for the Late Jurassic Reuchenette Formation in northwestern Switzerland (?Oxfordian, Kimmeridgian *sensu gallico,* Ajoie-Region)

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(submitted to Eclogae Geologicae Helvetiae)

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ABSTRACT

A new stratigraphical frame for Kimmeridgian sediments of northwestern Switzerland has been established by correlating seventeen closely spaced sections by means of lithological, sedimentological, and microfacial data as well as by ammonites. This newly established stratigraphical frame is extraordinary, because these sediments are usually characterised by a prominent sparseness of index-fossils (i.e. ammonites).

The biostratigraphical frame is based on seven species of ammonites and corroborated by ostracodes. The investigated sedimentary record is divided into nine intervals and assigned to the Late Oxfordian to Late Kimmeridgian *sensu gallico* (middle Eudoxus-Zone). Exact lithological correlations between the outcrops are achieved by three marker beds.

The new startigraphical frame is a pre-requirement to refine correlations of sections, to reconstruct sea level fluctuations, and to quantify synsedimentary differential subsidence.

INTRODUCTION

The thickness of the Reuchenette Formation in the southern and central Jura Mountains in northwestern Switzerland varies from about 40 m in the region of Solothurn (Gygi & Persoz 1986; Meyer C. A. 1993) to about 160 m in the region of Biel (quarry La Reuchenette near Péry BE; Thalmann 1966). Recent investigations of Mesozoic sediments in the Jura Mountains show, or at least suggest, that depo-centres migrated with time and that thickness variations are spatially related to Permo-Carboniferous subcrop structures, which probably became reactivated (Gonzalez 1993; Wetzel et al. 1993, 2003; Allia 1996; Burkhalter 1996; Pittet 1996; Allenbach 2002).

The Reuchenette Formation was initiated by Thalmann (1966) to replace the Kimmeridgian *auctorum* without changing its boundaries and “fixing” the sediments biostratigraphically. Consequently, the rarity of index-fossils within the Reuchenette Formation – even the type-section in the quarry La Reuchenette near Péry BE (No. X in Fig. 1) does not yield any index-fossils – led to numerous, but different suggestions as how to subdivide the sediment column, to correlate the strata, and to assign their age (e.g. Thurmann 1832; Greppin 1870; Häfeli 1966, Thalmann 1966; Chevallier 1989; Meyer C.A. 1989; Gygi 2000b). As ammonites are rare in shallow-water platform carbonates that accumulated mainly in a restricted setting, correlation over small distances relies on lithology. Recently, sequence-, cyclo- and mineralo-stratigraphy were used in addition for correlation (Gygi & Persoz 1986; Gygi 1995; Mouchet 1995, 1998; Gygi et al. 1998; Meyer M. 2000; Colombié 2002). These studies, however, are based on only a few reliable high-resolution biostratigraphical markers, most of them unfortunately occurring in distant and/or small outcrops and/or different stratigraphical resolution. Therefore, a precise high-resolution chronostratigraphical correlation over larger distances is difficult to establish. The age assignment of Kimmeridgian platform sediments was attempted by benthic foraminifera (Tschudin 2001) and by the very rare ammonites (Gygi 1995, 2000b).

Therefore, a reliable biostratigraphical framework for Kimmeridgian sediments in NW Switzerland is still lacking with all consequences for their correlation.

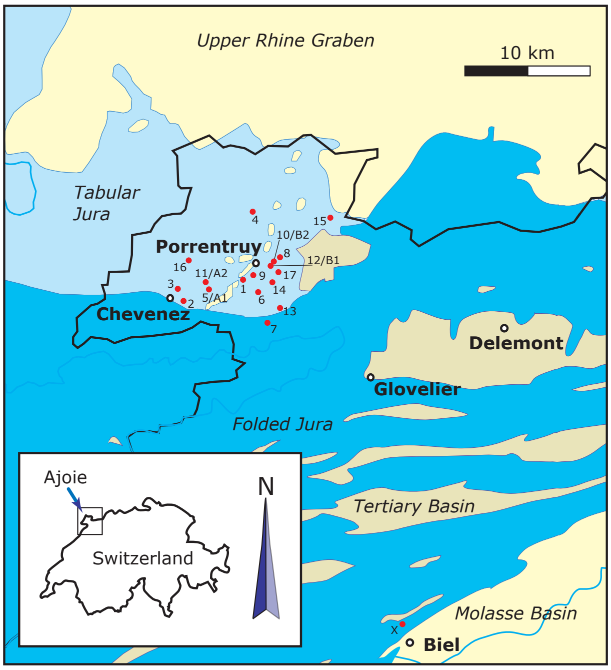


Fig. 1: Geological overview map (left) and swiss coordinates of locations and geological transects (below). Note the altitude difference (about 60 m) between the base of Creugenat (A1) and the base of the Virgula Marls (A2) in Sur Combe Ronde (keep into consideration that layers are ± horizontal; see swiss geol. map 1085 St-Ursanne).

	Code	**Sections**	**Swiss Coordinates**		**Altitude (m)**	**Interval(s)**
1	BAN	Tunnel Le Banné (Westportal), base	571.833	250.504	457	top Thalassinoides Limestones, base "Nautilidenschichten"
2	CHV	La Combe (Carrière Combe de Varu), base	567.753	248.930	491	Nerinean Limestones... Oyster Limestones
3	CHVs	Chevenez (La Scierie), base	567.175	249.675		Lower Grey and White Limestones, base Banné Marls
4	COE	Coeuve (Carrière), base	574.725	256.075		top Thalassinoides Limestones, "Nautilidenschichten"
5	CRE	Creugenat, base (= A1)	569.173	249.748	449	top Thalassinoides Limestones, base "Nautilidenschichten"
6	FON	Fontenais (Carrière communale), base	573.050	249.575		top Thalassinoides Limestones, base "Nautilidenschichten"
7	PAU	Chemin Paulin	573.790	247.100		Porrentruy Member… Banné Marls
8	PMS	Pré Monsieur (Carrière), base	574.887	252.262	437	Coral Limestones
9	RAS	La Rasse (Carrière)	572.560	250.840		Porrentruy Member… Lower Grey and White Limestones
10	RDM	Roches de Mars, base (= B2)	574.372	252.021	427	Nerinean Limestones, (Virgula Marls)
11	SCR	Sur Combe Ronde, base Virgula Marls (= A2)	568.869	250.082	511	top Nerinean Limestones, Virgula Marls
12	TUP	Cras d'Hermont (base little road)	573.958	251.694	443	"Nautilidenschichten", Lower Grey and White Limestones
12	TUP	Cras d'Hermont (end little road), base Banné Marls (= B1)	574.108	251.750	456	base Banné Marls
12	TUP	Cras d'Hermont (block between motorway and car shop)	574.058	251.797	447	top Banné Marls, base Nerinean Limestones
12	RDMa	Cras d'Hermont (car shop)	573.970	251.844	445	base Nerinean Limestones
13	VAB	L'Alombre aux Vaches (Carrière Vabenau)	574.800	248.200		top Thalassinoides Limestones... Banné Marls
14	VAT	Vatelin (Carrière)	574.300	250.500		top Thalassinoides Limestones... Lower Grey and White Limestones
15	VEN	Vendlincourt (Carrière), base	578.950	255.475		top "Nautilidenschichten"... Banné Marls
16	VTT	Vâ tche Tchâ (Combe de Vâ tche Tchâ)	568.720	252.155		Banné Marls
17	BDH	Bas d'Hermont (Carrière)	574.600	251.000		top Thalassinoides Limestones, base "Nautilidenschichten"
X	REU	La Reuchenette (Carrière)	585.890	226.240		Type-section

Since the beginning of the Transjurane motorway project, new large outcrops in the Ajoie-Region expose the shallow-water limestones of the Reuchenette Formaton very well. The exposures are closely spaced and perfectly suited to study these sediments, and they contain index-fossils. It is the purpose of this paper to provide a general lithological and a refined/precise biostratigraphical frame for the sediments of the Reuchenette Formation in the Ajoie-Region by means of lithological, sedimentological, and microfacial data and by ostracodes and *in situ* collected ammonites. The new biostratigraphical framework is essential for the Jura Mountains and adjacent areas as it allows the re-evaluation of existing and recent data.

GEOLOGICAL SETTING

The study area is located at the transition from the Folded Jura Mountains to the Tabular Jura of northwestern Switzerland (Ajoie-Region; Fig. 1). During the Late Jurassic, the area was covered by a shallow epicontinental sea between the Tethys in the south and the Paris basin in the north and northwest (e.g. Ziegler 1990). Under subtropical conditions (e.g. Frakes et al. 1992) mainly carbonates and some marls accumulated on the Kimmeridgian platform. The development in the Thitonian, Portlandian and Cretaceous is poorly known, because during the Tertiary, or probably even before, the study area was subjected to weathering and erosion that removed the uppermost Late Kimmeridgian deposits; it is not known how much has been eroded.

In the Ajoie-Region the shallow-water limestones of the Reuchenette Formation rest on the Courgenay Formation (Fig. 2). The top of the Courgenay Formation (Porrentruy Member *sensu* Gygi 1995) consists of massive, white, chalky limestones (Gygi 1995, 2000b). The top of the Reuchenette Formation is eroded and overlain by Tertiary sediments. In the southern and central Jura Mountains, the Reuchenette Formation is composed of well-bedded, grey and white limestones. They rest on the Balsthal Formation and are followed by the Twannbach Formation. The top of the Balsthal Formation (Verena Member *sensu* Desor & Gressly 1859; in Gygi 2000c) is composed of oo-oncolitic carbonates and grades laterally into the sediments of the Porrentruy Member (Fig. 2). The Twannbach Formation consists of cm-dm thick layers of dark-grey micritic limestones (Thalmann 1966).

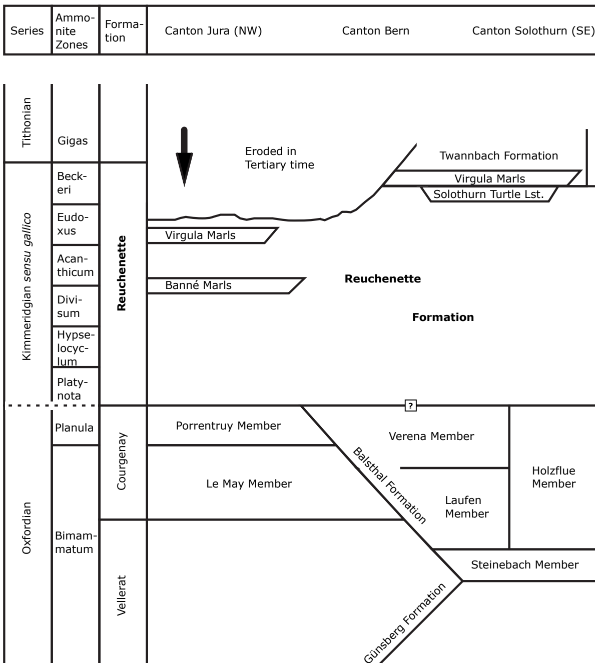


Fig. 2: Chrono-, litho- and biostratigraphical scheme for the Reuchenette Formation, based on data from Gygi (2000b), Meyer C.A. (1990, 1993) and this study. Arrow indicates position of the measured sections. The biostratigraphical position of the lithological boundary between the Reuchenette Formation and the Courgenay/Balsthal Formation is not proved, even the lithological boundary itself is a matter of debate. The associated thickness-relation in the Ajoie- and Solothurn-Region and are not to scale (difference about 100 m; compare introduction and results).

Thalmann (1966) defined the Reuchenette Formation in the limestone quarry of La Reuchenette near Péry BE as a monotonous succession of bedded limestones with few and thin marl intercalations. Lime mudstone (*sensu* Dunham 1962) is the dominant lithology there, but peloidal wacke- to grainstones and some oolitic horizons occupy some prominent intervals. Coral biostromes are uncommon (Gygi

& Persoz 1986). 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 & Persoz 1986). Locally a horizon with blackened lithoclasts is developed in the basal lower part (Gygi 1982, Colombié 2002). The lower 8 m of this massive unit are composed of oo-oncolitic carbonates (Verena facies). The upper 10 m are primarily mudstone 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, 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 the La Reuchenette quarry (Gygi & Persoz 1986). This sharp lithological contrast is developed between the underlying members (i.e. Porrentruy and Verena Member) and the Reuchenette Formation in all sections in the Ajoie-Region and southern and central Jura Mountains (Gygi 2000b,c). For this reason, Gygi defined the boundary between the Reuchenette Formation and the underlying Balsthal and Courgenay Formation at the base of the well-bedded limestones (Gygi 2000b,c). This boundary is visible in the quarry La Rasse south of Porrentruy (Section RG 340 of Gygi, Gygi 2000b, No. 9 in Fig. 1) and in Chemin Paulin near Courgenay (Section RG 350 of Gygi; Gygi 2000b, No. 7 in Fig. 1). The thickness of the Reuchenette Formation in terms of Gygi's boundaries is approximately 140 m at the type-section La Reuchenette.

METHODS AND MATERIAL

Seventeen outcrops were studied for their lithological, sedimentological, and facies record (Fig. 1). Twelve outcrops were measured and sampled in detail for polished slabs and thin sections.

The evaluation of the Standard Microfacies Types and the facies (Fig. 3) of approximately 500 thin sections are based on the classifications of Dunham (1962), Wilson (1975), and Flügel (1982). The interpretations of thin sections and depositional environments are illustrated by "Facies-Patterns" on the right column of the figures. The term "bedding" is used to describe the internal characteristics/composition of a bed, e.g. flaser bedding, nodular bedding, cross

Facies	**Bathymetry**	**Depositional environment**	**Facies association**
Intraclastic pack- to grainstones (-layer)	shallow subtidal to intertidal	lagoon	*Thalassinoides* and storm sediment association
Lumachelle (shell bed)	shallow subtidal to intertidal	lagoon	*Thalassinoides* and storm sediment association
Bioclastic mud- and wackestones (± *in situ* macrofauna);	shallow subtidal	open lagoon and open platform	Open lagoon and bight asociation
Chalky bioclastic mudstones with coral meadows	shallow subtidal	open lagoon or bight	Open lagoon and bight association
Marly bioclastic wacke- to packstones and float- to rudstones with insitu macrofauna	shallow subtidal	protected lagoon or bight	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	Rerstricted lagoon association
Peloidal mud- to grainstones	intertidal and shallow subtidal	restricted, shallow lagoon and tidal flat	Rerstricted lagoon association
Non-laminated homogeneous micrite	intertidal and very shallow subtidal	tidal pond and protected, quiet, very shallow bight or lagoon	Rerstricted lagoon association
Lensoidal pack-/rudstone	intertidal	storm surge channel or rip channel in a tidal flat environment	Rerstricted lagoon association
Laminated mudstones	supratidal and intertidal	restricted plarform areas	Supra- and intertidal platform area association
Crumbly and platy mudstones and wackestones	supratidal and intertidal	mud flat or marsh deposit	Supra- and intertidal platform area association

Fig. 3: Facies-types and depositional environment; Reuchenette Formation, Ajoie-Region.

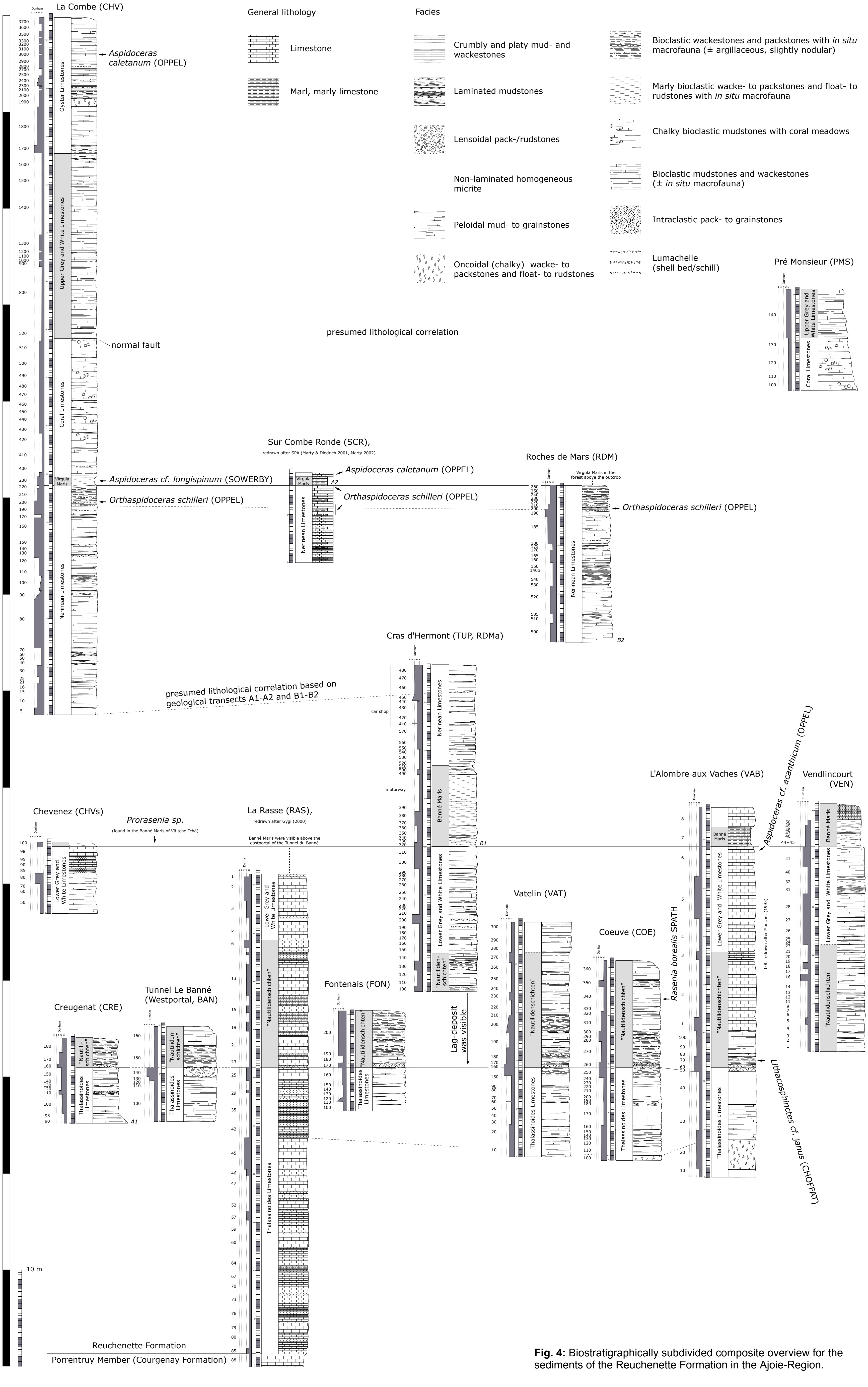


Fig. 4: Biostratigraphically subdivided composite overview for the sediments of the Reuchenette Formation in the Ajoie-Region.

bedding, laminated. The term “layering” is used to characterize the thickness of a bed, e.g. massive-layered (>1 m), thick-layered (0.3-1 m), thin-layered (1-3 dm), very thin-layered (<1 dm). Two geological transects (see Fig. 1; A1-A2, B1-B2) were evaluated to obtain an independent information about the regional trends in thickness.

Ammonites were collected by M. Jank, B. Hostettler (Fondation Paléontologique Jurassienne) and the Section de Paléontologie de la République et du Canton Jura (SPA). The taxonomic assignment was made by G. Schweigert (Staatliches Museum für Naturkunde, Stuttgart; Schweigert et al., in prep.). Ten marl samples were dissolved in H_2O_2 and ostracodes were collected from the outwash samples (fractions between 100 and 400 µm) in order to obtain an independent age-control. U. Schudack (Berlin, Germany) made the taxonomic determination and biostratigraphical interpretation.

The sections of La Rasse (No. 9 in Fig. 1) and Chemin Paulin (No. 7 in Fig. 1) were already measured and briefly described by Gygi (2000b). Due to the bad and dangerous outcrop conditions, some of the data added in these profiles consist of observations made on samples and field descriptions by Gygi, stored in the Natural History Museum Basel. The sections of La Rasse, Chemin Paulin and Bas d’Hermont (No. 17 in Fig. 1) were re-investigated to detect marker beds.

As the position of the boundary between the Courgenay Formation and the Reuchenette Formation is a matter of debate (Thalmann 1966; Gygi 2000b,c), this work follows Gygi (see above).

The composite section has been subdivided into nine intervals (see Fig. 4) that are named by characteristic features such as colour, fracturing, marl content or fossil content (Plate 1).

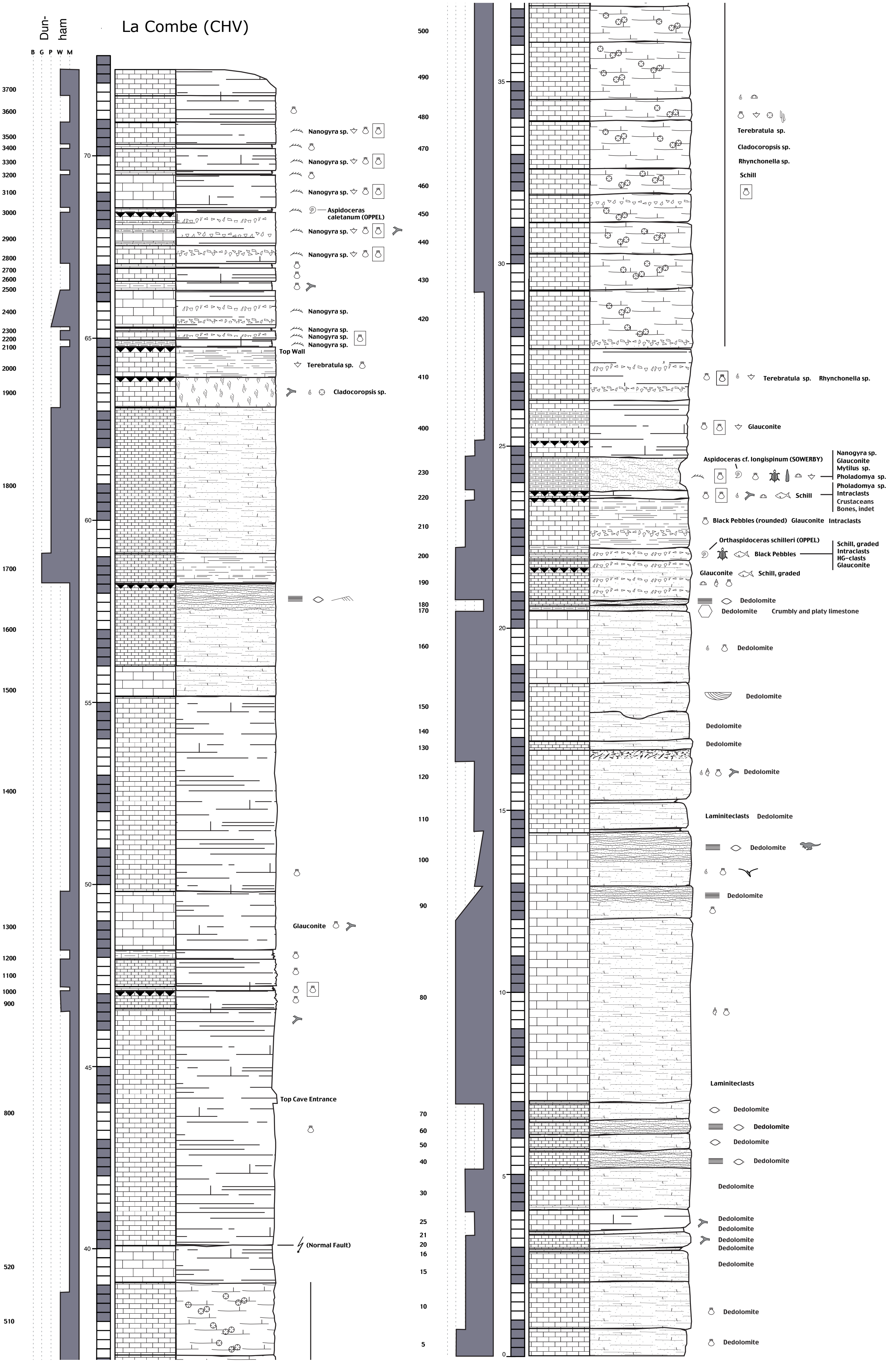
LITHOLOGY

Most of the lithologies are difficult to differentiate in the field outside road cuts and quarries; in addition, intense weathering often obliterates the typical features. Consequently, in the different outcrops the boundaries between the intervals are occasionally diffuse and changes are gradual. The upper four intervals are only visible in La Combe (Figs 4 and 5).

Porrentruy Member (top of the Courgenay Formation *sensu* Gygi 1995):
In the Ajoie-Region, the Porrentruy Member is composed of smoothly fracturing, massive, white, calcarenitic and micritic, chalky limestones with Nerinean gastropods, small oncoids and coated intraclasts (Fig. 6). The latter two occasionally display brownish rims.

Thalassinoides Limestone (≈30 m) (Plate 1, a):
The Reuchenette Formation starts with monotonous, thick- to massive-layered (m-thick), well-bedded, bioturbated, grey, micritic limestones with some bioclasts and reddish brown or greyish, coarse-grained, pseudo-oolitic (mainly rounded intraclasts and peloids) pockets, patches and strings within a micritic matrix. Generally, macrofossils are rare. Thin- to thick-bedded layers fracture conchoidally and commonly contain abundant *Thalassinoides*. These burrows are often filled with the coarse-grained pseudo-oolitic material mentioned above. Between 22 m and 30 m (composite section; Fig. 4) several conspicuous horizons with *Thalassinoides* are filled with coarse spary cement (beds VAT-150, VAT-20, COE-240, COE-170, COE-180, VAB-40, VAB-30, RAS-25; see Fig. 4). Bed surfaces are often iron stained, occasionally bored and biogenically encrusted by oysters. About 9 m below the upper boundary of this interval, a 6-7 meters thick, white, chalky limestone with oncoids and coral clasts occurs within the monotonous, grey, micritic interval (e.g. beds RAS-45 to RAS-48; Fig. 4). In La Rasse another 3-4 m thick white layer is visible, intercalated into the grey limestones (beds RAS-57 to RAS-60), as well. In Coeuve the top few meters bear a stromatolite layer.

La Combe (CHV)



Dun-ham
B G P W M
3700
3600
3500
3400
3300
3200
3100
3000
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2800
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2500
2400
2300
2200
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90
80
70
60
50
40
30
25
21
20
16
15
10
5
35
30
25
20
15
10
5
0
Nanogyra sp.
Nanogyra sp.
Nanogyra sp.
Aspidoceras caletanum (OPPEL)
Nanogyra sp.
Nanogyra sp.
Nanogyra sp.
Nanogyra sp.
Nanogyra sp.
Nanogyra sp.
Top Wall
Terebratula sp.
Cladocoropsis sp.
Glauconite
Top Cave Entrance
(Normal Fault)
Terebratula sp.
Cladocoropsis sp.
Rhynchonella sp.
Schill
Terebratula sp.
Rhynchonella sp.
Glauconite
Aspidoceras cf. longispinum (SOWERBY)
Nanogyra sp.
Glauconite
Mytilus sp.
Pholadomya sp.
Schill
Pholadomya sp.
Intraclasts
Crustaceans
Bones, indet
Black Pebbles (rounded)
Glauconite
Intraclasts
Orthaspidoceras schilleri (OPPEL)
Black Pebbles
Schill, graded
Intraclasts
HG–clasts
Glauconite
Glauconite
Schill, graded
Dedolomite
Dedolomite
Crumbly and platy limestone
Dedolomite
Dedolomite
Dedolomite
Dedolomite
Dedolomite
Laminiteclasts
Dedolomite
Dedolomite
Dedolomite
Laminiteclasts
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Fig. 5: Section La Combe – Bed CHV-230 are the Virgula Marls. For legend and symbols see Figs. 4 and 8.

Fig. 6: White chalky limestone with angular and rounded intraclasts (bed RAS-88, La Rasse; scale: coin ≈2.5 cm).

Fig. 7: Storm-lag deposit (intraclastic pack- to grainstone) with cast *Thalassinoides* – Important marker bed (bed COE-260, Coeuve; scale: coin ≈3 cm).

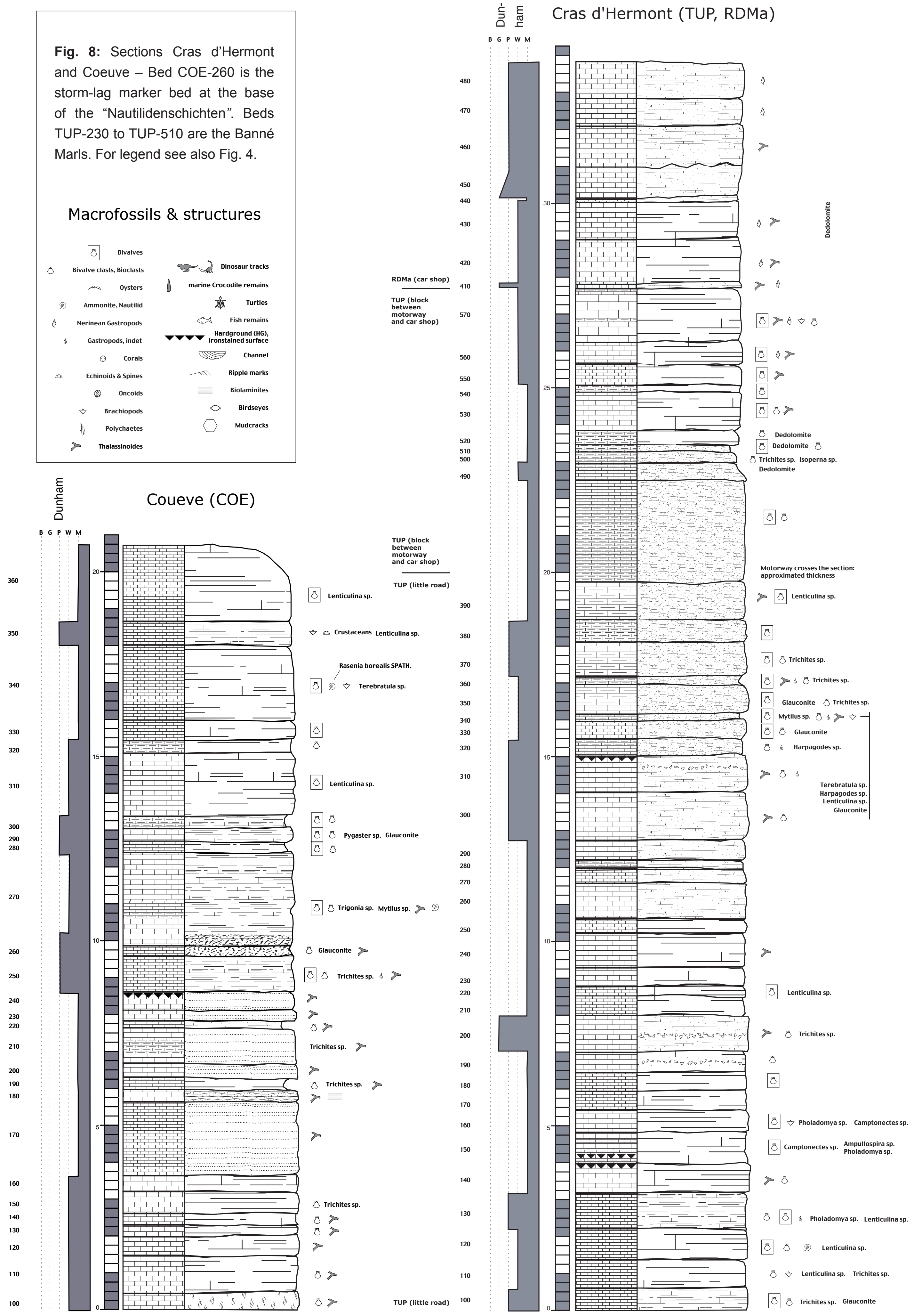
"Nautilidenschichten" (≈11 m) (Plate 1, b):
The "Nautilidenschichten" form dm- to m-thick layers. They are strongly bioturbated, marly micritic limestones and limestones with a weakly internal nodular bedding. The lower part tends to exhibit marl-limestone alternations when weathered; calcarenitic (probably storm-influenced) marly limestones alternate with bioturbated marly micritic background sediment. This interval contains a rich bivalve fauna and large nautilids (*Cenoceras sp.*). Locally, bored and biogenically encrusted (by oysters) hardgrounds are intercalated. A significant 10-15 cm thick reddish brown storm lag deposit (beds COE-260, VAT-160, VAB-50, RAS-24, PAU≈31; Fig. 4) with strongly varying fossil content marks the boundary to the underlying interval (Figs. 7 and 8). This storm material is filled into *Thalassinoides* penetrating into the underlying bed. The upper part of the grey-coloured "Nautilidenschichten" is dominated by micrite and grades into the Lower Grey and White Limestones.

Lower Grey and White Limestones (≈11 m) (Plate 1, c):
This interval is composed of dm-to m-thick layers of grey and white, micritic and calcarenitic limestones with blocky fractures. *Thalassinoides* burrows are rare. Occasionally, the top is composed of stromatolitic limestones. The interval is capped by a regional hardground, which is bored and biogenically encrusted by oysters.

Banné Marls (Banné Member *sensu* Marçou 1848; in Gygi 2000b,c) (≈8-9 m) (Plate 1, d):
The slightly nodular Banné Marls comprise grey dm-thick layers of marlstones, calcarenitic marls and marly limestones with a rich fauna of bivalves associated with some brachiopods, nautilids, echinoids, vertebrate remains (e.g. turtles, marine crocodiles), *Thalassinoides* and very rare ammonites. Shelly and calcarenitic horizons, probably reworked and winnowed by storms, are intercalated and commonly separate the beds.

Nerinean Limestones (≈33 m) (Plate 1, e):
The Nerinean Limestone interval starts with dm- to m-thick layers of grey, calcarenitic limestones (≈10 m; Fig. 9), followed by significant white, blocky fracturing, dm- to m-layered, chalky, calcarenitic limestones with large gastropods (Nerineans) and stromatolite layers (see Fig. 4). To the top it grades into greenish weathered, glauconite-rich pack- and

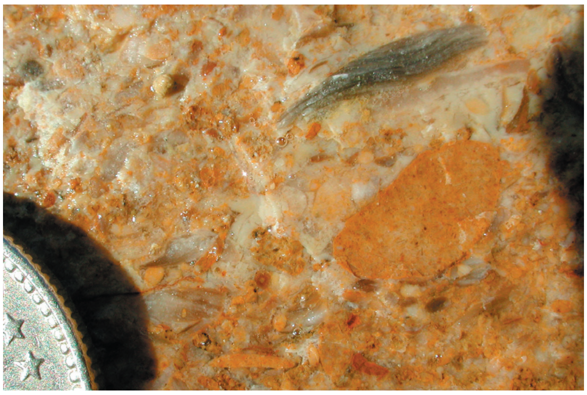
Fig. 8: Sections Cras d'Hermont and Coeuve – Bed COE-260 is the storm-lag marker bed at the base of the "Nautilidenschichten". Beds TUP-230 to TUP-510 are the Banné Marls. For legend see also Fig. 4.

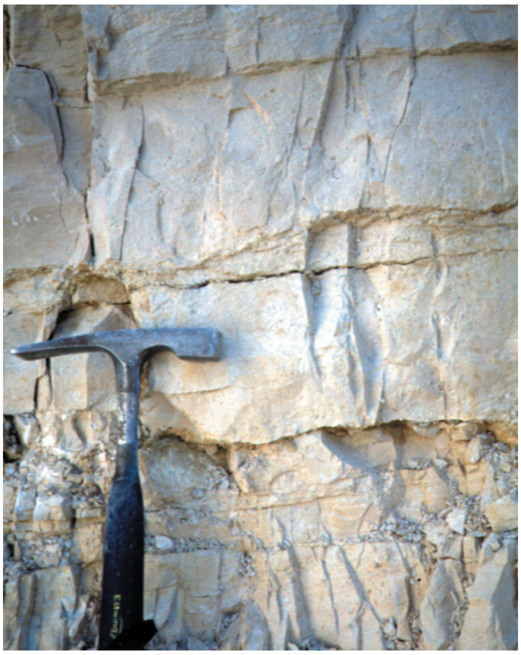


grainstones with lumachelle intercalations (Fig. 10). This part shows characteristic, strongly bored and biogenically encrusted (by oysters), regional hardgrounds and cephalopods lying on them (Fig. 5).

Fig. 9 (right): Nerinean Limestones – Grey "sandy" limestone at the base of the Nerinean Limestone interval (base La Combe). Presumed lithological correlation with top Cras d'Hermont.

Fig. 10 (left): Schill layer – Reworked material (right centre) from base of bed CHV-190 in shell- and intraclast-supported matrix (top of bed CHV-190, above hardground, La Combe; scale: coin ≈2.5 cm).





Virgula Marls (≈1 m) (Plate 1, f):
This characteristic marl interval bears a rich fauna of bivalves and cephalopods but small oysters (*Nanogyra sp.*) dominate. Vertebrate remains are often found. The marls are dark grey and form cm- to dm-thick layers. These marls correspond to the Virgula Marls mapped by Laubscher (1963).

Coral Limestones (≈15 m) (Plate 1, g):
The basal part of this interval comprises a few meters of dm-thick layers of grey, micritic limestones and intercalated bored and encrusted hardgrounds (probably regional extent). The Coral Limestones "*sensu stricto*" form a massive (m-thick) unit composed of thin- to thick-layered, blocky fracturing, white, chalky, micritic limestones with corals, terbratulid and red-brown rhynchonellid brachiopods separated by thin marl seams. The aragonitic coral skeletons were dissolved and the voids then filled with calcite (e.g. Bathurst 1971). The interval grades into the Upper Grey and White Limestones.

Upper Grey and White Limestones (≈18 m):
This monotonous micritic interval exhibits m-thick layers. It is compsed of three parts, whereas the midlle part (beds CHV-1000 to 1200 in Figs. 4 and 5) is slightly marly compared with the two other two parts. The limestones separate blocky with conchoidal surfaces. Fossils and *Thalassinoides* are sparse. A stromatolitic limestone with ripples capped by a hardground (biogenically encrusted by oysters) marks the top of this interval.

Oyster Limestones (≈17 m) (Plate 1, h):
This interval starts with massive (m-thick), calcarenitic limestones and a layer with *Cladocoroposis mirabilis* (0–6 m). It is overlain by dm-thick layers of occasionally platy, marly, fine-grained (micritic) limestones, dominated by oysters.

BIOSTRATIGRAPHY

The biostratigraphical framework is provided by seven species of *in situ* collected ammonites (Fig. 11). Early Kimmeridgian *sensu gallico* is indicated by *Lithacosphinctes cf. janus* (CHOFFAT), *Rasenia borealis* SPATH and *Prorasenia sp.* (microconche of the family *Aulacostephanidae*). *Aspidoceras cf. acanthicum* (OPPEL) indicates the Divisum- and Acanthicum-Zone (pers. comm. G. Schweigert). *Orthaspidoceras schilleri* (OPPEL), *Aspidoceras cf. longispinum* (SOWERBY) and *Aspidoceras caletanum* (OPPEL) are indicative for the Acanthicum- and Eudoxus-Zones (Late Kimmeridgian *sensu gallico*). One specimen of *Lithacosphinctes cf. janus* (CHOFFAT) was found at the base of the "Nautilidenschichten" in L'Alombre aux Vaches (bed VAB-70; Fig. 4). One specimen of *Rasenia borealis* SPATH occurred near the top of the "Nautilidenschichten" in Coeuve (bed COE-340; Fig. 4). They indicate the Platynota-Zone and the Divisum-Zone. One specimen of *Prorasenia sp.* from the base of the Banné Marls in Vâ tche Tchâ also indicates the Divisum-Zone. The exact position of *Aspidoceras cf. acanthicum* (OPPEL) is not clear, as Gygi & Persoz (1986) state that one specimen "was taken by H. and A. Zbinden from a block which fell presumably from a marly limestone 1,5 m below the Banné Marls" in L'Alombre aux Vaches (see also Gygi 1995). After Mouchet (1995), the specimen is from the marly limestone 1,5 m below the Banné Marls in L'Alombre aux Vaches. Several specimens of *Orthaspidoceras schilleri* (OPPEL) were found on hardgrounds and in glauconitic beds below the Virgula Marls (beds RDM-200, CHV-200, beds in Sur Combe Ronde around 5-8 m; Figs. 4 and 5), indicating the Schilleri-Horizon of the late Acanthicum-Zone. One specimen of *Aspidoceras cf. longispinum* (SOWERBY) was found within the Virgula Marls (bed CHV-230) and indicates the lowermost Eudoxus-Zone. Two specimens of *Aspidoceras caletanum* (OPPEL) point to the Caletanum-Horizon of the middle Eudoxus-Zone. One specimen was found in the Oyster Limestones in La Combe (bed CHV-3000), the other one in the lowermost beds of the Coral Limestones right above the Virgula Marls in Sur Combe Ronde (beds in Sur Combe Ronde around 9 m; Fig. 4).

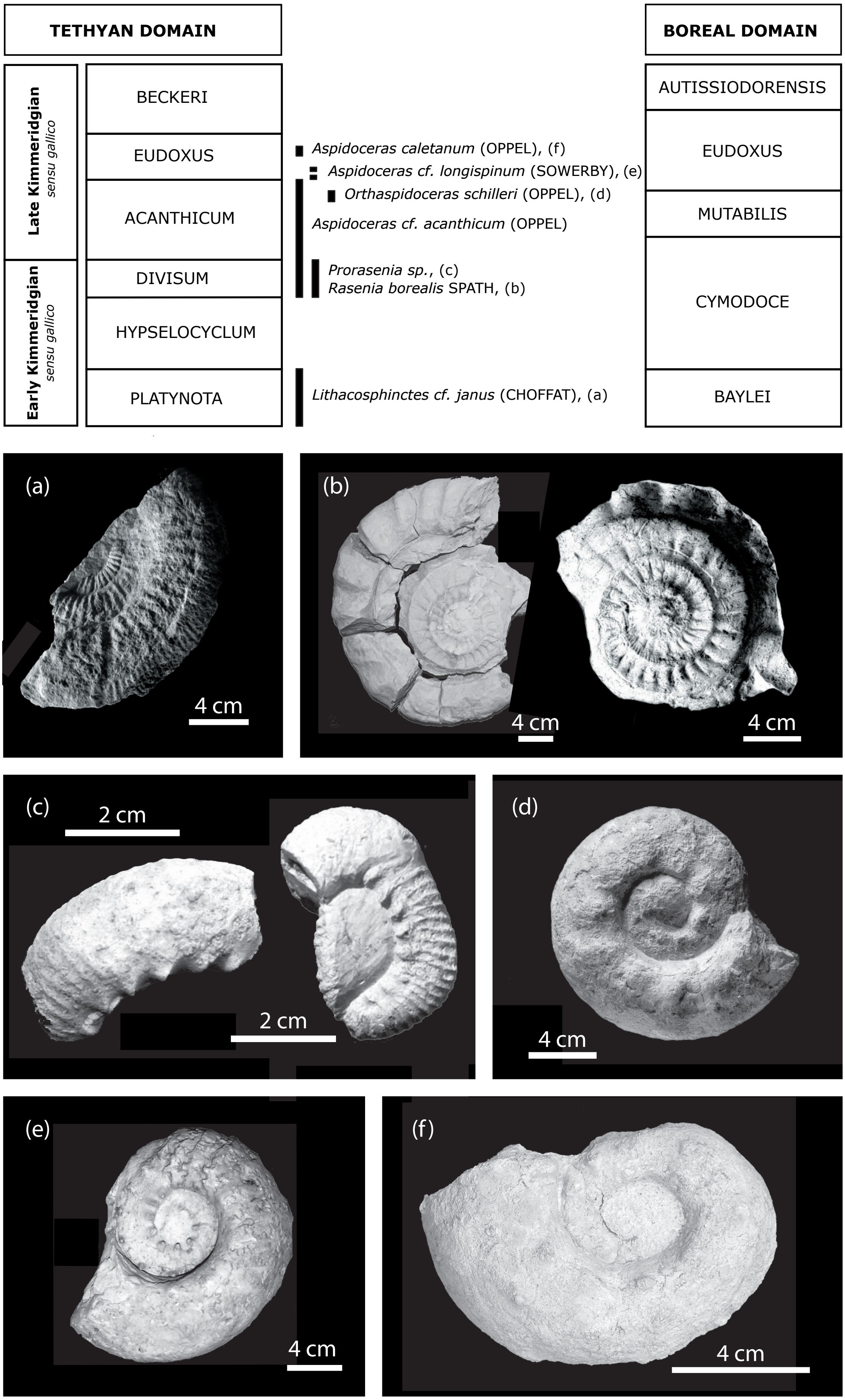
Due to low biostratigraphical resolution, ostracodes only vaguely agree with the ammonite data. They merely indicate the Early or Late Kimmeridgian *sensu gallico* (Fig. 12). Furthermore, the correlation between the ammonite-zones and ostracodes is not adequately established and remains a point of discussion (e.g. Weiss 1995), as illustrated by the biostratigraphical extension of ostracodes in beds RDM-200 and RDM-220 and the biostratigraphical position of *Orthaspidoceras schilleri* (OPPEL) also found in bed RDM-200 (Figs. 4, 11 and 12). For example, *Amphicythere (Amphicythere) confundens* OERTLI was found in Roches de Mars (beds RDM-200, RDM-220) and it appears that it is not in contradiction to *Orthaspidoceras schilleri* (OPPEL) also found in bed RDM-200 because Schudack (1994) describes a (litho)stratigraphical extension for *Amphicythere (Amphicythere) confundens* OERTLI from "Mittlerer Korallenoolith bis Unter-Kimmeridge", which corresponds approximately to the Mutabilis-Zone/parts of the Acanthicum-Zone (Weiss 1995, 1996, 1997; Gramann et al. 1997).

Fig. 11: 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).

Exacte biostratigraphical reach and localities:

Lithacosphinctes cf. janus (CHOFFAT); Platynota-Zone; L`Alombre aux Vaches (picture a). *Rasenia borealis* SPATH; Divisum-Zone; Coeuve (picture b). *Prorasenia sp.*; Divisum-Zone; Vâ tche Tchâ (picture c; foto by G. Schweigert). *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 (picture d; © SPA, foto by B. Migy). *Aspidoceras cf. longispinum* (SOWERBY); lowermost Eudoxus-Zone; La Combe (picture e; © SPA). *Aspidoceras caletanum* (OPPEL); Eudoxus-Zone, Caletanum-Sub-Zone, Caletanum-Horizon; La Combe and Sur Combe Ronde (picture f; © SPA).


TETHYAN DOMAIN
BOREAL DOMAIN
Late Kimmeridgian *sensu gallico*
Early Kimmeridgian *sensu gallico*
BECKERI
EUDOXUS
ACANTHICUM
DIVISUM
HYPSELOCYCLUM
PLATYNOTA
AUTISSIODORENSIS
EUDOXUS
MUTABILIS
CYMODOCE
BAYLEI
Aspidoceras caletanum (OPPEL), (f)
Aspidoceras cf. longispinum (SOWERBY), (e)
Orthaspidoceras schilleri (OPPEL), (d)
Aspidoceras cf. acanthicum (OPPEL)
Prorasenia sp., (c)
Rasenia borealis SPATH, (b)
Lithacosphinctes cf. janus (CHOFFAT), (a)
(a)
4 cm
(b)
4 cm
4 cm
(c)
2 cm
2 cm
(d)
4 cm
(e)
4 cm
(f)
4 cm

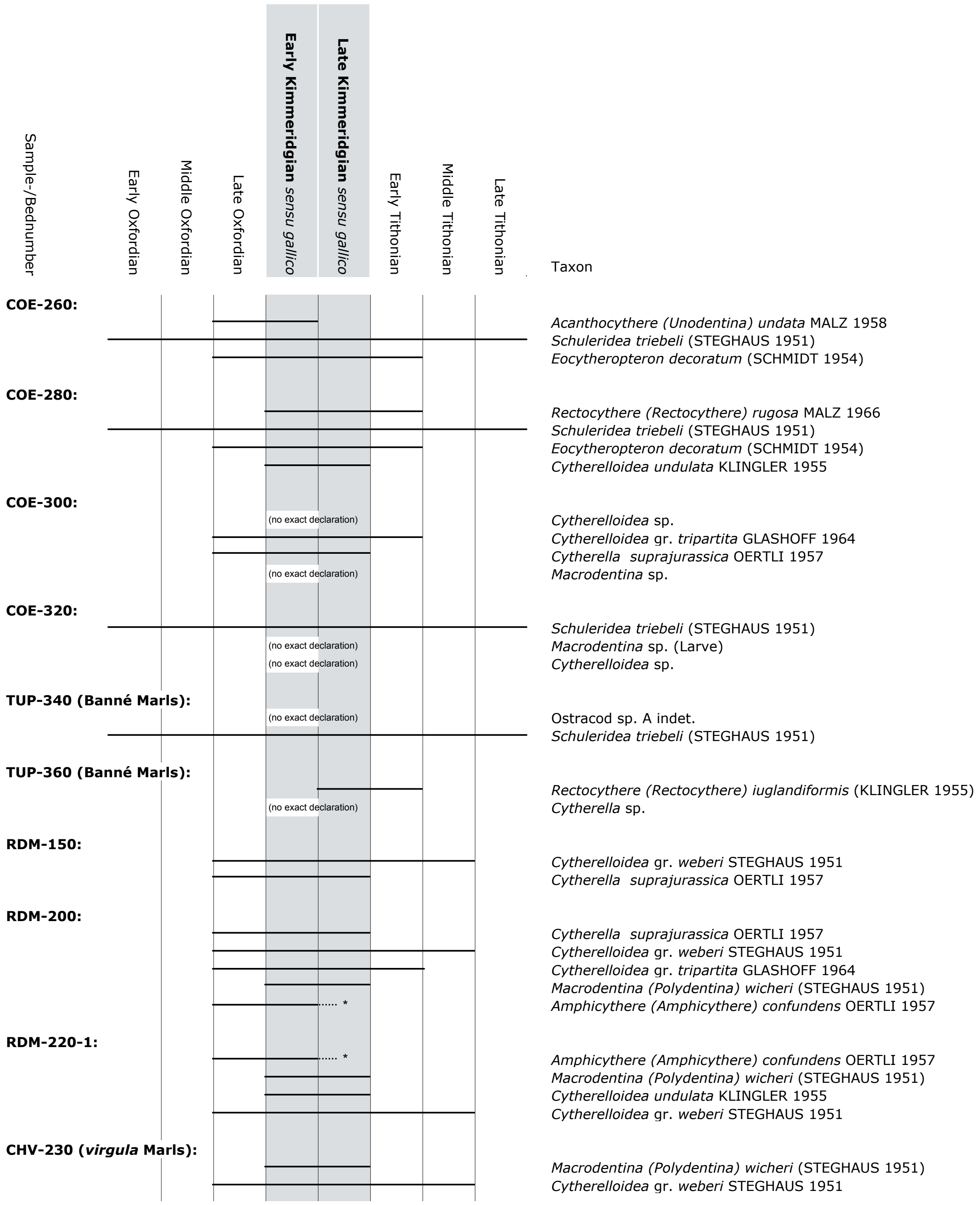


Fig. 12: Biostratigraphical framework given by range of some ostracodes. Note range of ostracode assemblage-zones vaguely agree with ammonite data. *Redrawn after Weiss (1995, 1996, 1997) and Gramann et al. (1997).

RESULTS

The stratigraphical correlation of the sections (Fig. 4) was established by the combination of lithological, facies and sedimentological criteria in combination with biostratigraphical data. This is exceptional because it is the first time that a large composite section of the sediments of the Reuchenette Formation can be biostratigraphically fixed by six "golden spikes" (*in situ* collected species of ammonites).

Marker beds provide a lithological correlation between the outcrops. The sections Coeuve, La Rasse, L'Alombre aux Vaches, Vatelin, Creugenat, Fontenais, Chemin Paulin, Cras d'Hermont and Bas d'Hermont can be exactly correlated by the reddish brown, bioturbated, intraclastic wacke- to packstone storm-lag deposit at the base of the "Nautilidenschichten". The Banné Marls connect sections La Rasse, L'Alombre aux Vaches, Chemin Paulin, Vendlincourt, Vâ Tche Tchâ and Cras d'Hermont. The sections La Combe and Cras d'Hermont are correlated by coarser grained, equally thick, calcarentic limestone beds within the Nerinean Limestone interval composed of peloidal wacke- to packstones. The second marl intercalation (Virgula Marls) allows lithological correlations between the sections La Combe, Roches des Mars and Sur Combe Ronde. The laterally homogeneous facies distribution, the vertical facies stacking pattern and lithological changes within close outcrops support these correlations.

The lithological correlation of the Virgula Marls is substantiated by the occurrence of *Aspidoceras cf. longispinum* (SOWERBY) and *Orthaspidoceras schilleri* (OPPEL) and some conspicuous hardgrounds (Fig. 5, beds CHV-190 to CHV-230). As indicated by *Prorasenia sp.* and *Rectocythere (Rectocythere) iuglandiformis* (KLINGLER), sedimentation of the Banné Marls at least started in the Divisum-Zone and probably continued in the Acanthicum-Zone. In the section La Combe *Orthaspidoceras schilleri* (OPPEL), *Aspidoceras cf. longispinum* (SOWERBY) and *Aspidoceras caletanum* (OPPEL) show that virgula-bearing sediments in the Jura Mountains differ in age. These ammonite finds also confirm that sediments between the Virgula Marls and Oyster Limestones are of Kimmeridgian age (Eudoxus-Zone) in the Ajoie-Region, as mentioned by Gygi et al. (1998), concerning Laubscher's "Portlandien" (Laubscher 1963). Furthermore ammonites show that at least three different virgula-bearing levels exist in the Swiss Jura Mountains: two in La Combe (Virgula Marls, Oyster Limestones) and one in the type-section of La Reuchenette, where they were deposited below the boundary to the Twannbach Formation (Thalmann 1966).

Considering the short time span covered by the Caletanum-Horizon the enormous thickness of the Coral Limestones and Upper Grey and White Limestones, (probably) related to an important gain in accommodation space, resulted from sea level rise and enhanced subsidence (Jank, 2004).

Due to missing biostratigraphical data, the age of the lithological boundary (*sensu* Gygi; see above) to the Porrentruy Member remains vague. It is probably within the Late Oxfordian.

The "Nautilidenschichten" correspond to the "thick limestone beds with a rich fauna of bivalves and large nautilids in the old quarry adjacent to Fontenais cemetery south of Porrentruy" (Fontenais; No. 6 in Fig. 1), the "succession above sequence boundary K1" in the quarry La Rasse (Gygi et al. 1998), as well with the lowermost part of the quarry Vabenau (Mouchet 1995, 1998) (L'Alombre aux Vaches; No. 13 in Fig. 1).

The multi-faceted facies of the sediments of the Reuchenette Formation in the Ajoie-Region represent an open to protected marine, very proximal platform setting within the Jurassic epicontinental realm of Central Europe. Facies, fauna and sedimentary structures are characteristic for shallow subtidal to supratidal settings and allow the distinction of 12 facies-entities.

Thickness estimates between the storm lag deposit at the base of the "Nautilidenschichten" (Fig. 1; point A1), the base of the Banné Marls (Fig. 1; point B1) and the base of the Virgula Marls (Fig. 1; point A2 and point B2) on the geological transects A1-A2 and B1-B2 independently confirm the thicknesses given by correlations based on marker beds. The thickness between the base of the Reuchenette Formation and the base of the Banné Marls of section Chemin Paulin (Gygi 2000b) independently corroborates the thickness between the base of the Reuchenette Formation and the base of the Banné Marls measured by correlating La Rasse, Cras d'Hermont and L'Alombre aux Vaches.

Based on all these data the thickness of the sediments of the Reuchenette Formation preserved in the Ajoie-Region is about 140 m.

DISCUSION

Evidently, the lithological correlations between the outcrops are in agreement with the biostratigraphical data. Nonetheless, the question arises, how reliable such lithological correlations are. Comparisons with modern environments are useful to illustrate the precision of such correlations, if lateral extend of facies belts, stacking patterns and event beds are considered.

Investigations of recent shallow-marine carbonate show that lateral changes in facies occur within ten's of kilometres (e.g. Harris & Kowalik 1994), i.e. a specific facies shows lateral continuity of several kilometres, at least. For example, the carbonate mud facies on the Great Bahama Bank west of Andros Island occupies an area larger than 2700 km^2 (30 km x 90 km); the pellet-mud facies an area of about 3600 km^2 (Purdy 1963a, b). In the German Muschelkalk, Aigner (1985) demonstrated that depositional cycles mainly composed of event beds correlate over ten's of kilometres and modern tempestite deposits from Hurricane Kate (1985) are blanketing the peloidal packstone environment offshore of the Caicos tidal flat (Bahamas) (Wanless et al. 1988).

For the Ajoie-Region the facies imply that the platform topography can be considered as having been rather flat. The shallow-marine sediments probably built up close to sea level, filling accommodation space, which resulted in a generally flat topography. This in turn favoured a more or less uniform lateral facies development (i.e. no significant lateral facies changes have been observed). In addition, deposition on a flat topography is highly susceptible to low-amplitude relative sea level fluctuations leading to deposition of widespread and nearly synchronous beds similar in lithology and stacking pattern (Strasser et al. 1999). As the outcrops in the Ajoie-Region are closely spaced within the range of kilometres the lithological correlations appear to be reliable, especially when compared to modern analogues. At least three easily identifiable marker beds can be traced and used for exact lithological correlations.

CONCLUSIONS

The investigations provide a data set improving the knowledge of the sedimentary history of the Reuchenette Formation in the Swiss and French Jura, because the Reuchenette Formation was initiated by Thalmann (1966) to replace the Kimmeridgian *auctorum*.

The identification of the different depositional environments within a very shallow epicontinental sea with periodic emersion, allows defining marker beds useful for lithological correlations of biostratigraphically dated intervals over small distances. The sections provide a composite overview of the sedimentary record during the (?Planula) Platynota- to the Eudoxus-Zones – nine lithological intervals, seven *in situ* collected species of ammonites, and several marker horizons. The preserved thickness of the investigated sediments in the Ajoie-Region comprises at least 140 m. It is still a matter of debate if the uppermost beds can be correlated with the type-locality (Jank, 2004). The observations also show that the boundary with the Porrentruy Member (Courgenay Formation) is still uncertain in terms of biostratigraphical age.

Nevertheless – taking into account that *in situ* index-fossils are very rare in the Kimmeridgian platform sediments of the Jura Mountains – this overview serves as a base for further refined investigations in terms of sea level fluctuations and synsedimentary differential subsidence (thickness variations and movement of depo-centres) and it offers the possibility to compare the sediments with other biostratigraphically constrained sections and outcrops in the Boreal and Tethyan realm.

ADDITIONAL INFORMATION

Fossils of the beds CRE-160 and CRE-170 in Creugenat collected and determined during a palaeontological excavation field course by the Geologisch-Paläontologisches Institut University of Basel (GPI) in collaboration with the SPA are documented in the annual reports 2000 and 2002 of the SPA ("SPA 2001"; Marty 2003). The fossils found in the Banné Marls of Vâ Tche Tchâ and the Virgula Marls of La Combe are published in the annual reports of the SPA, as well (Marty & Diedrich 2002).

As the taxonomic determination of several fossils is still under discussion see forthcoming annual reports and publications of the SPA, diploma thesis at the GPI of K. Stransky (in prep.), S. Thüring (in prep.) and R. Waite (2005.), and the huge and extraordinary collection of B. Hostettler (Fondation Paléontologique Jurassienne).

REPOSITORY

The samples, thin sections and ostracode samples of this study are stored at B. Hostettler (address: Fondation Paléontologique Jurassienne, Au Village 16, CH-2855 Glovelier, Switzerland) and the SPA (address: Office Cantonal de la Culture, Section de Paléontologie, Hôtel des Halles, Case postale 64, CH- 2900 Porrentruy, Switzerland).

ACKNOWLEDGEMENTS

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Plate 1: Characteristics of eight intervals of the Reuchenette Formation (scales: coin ≈2.5 cm, hammer, motorbike, pencil).

Picture a: Thalassinoides Limestones – Reddish brown pseudo-oolitic material (arrows) within finer grained, grey matrix. Note the blocky cements (1) next to coarser material in the *Thalassinoides* burrows (base L'Alombre aux Vaches).

Picture b: "Nautilidenschichten" – Thick to massive marly limestones with nodular bedding (Fontenais).

Picture c: Lower Grey and White Limestones – The topmost thick limestone bed correlates with bed VEN-41 in Vendlincourt. The Banné Marls follow on the top of this bed and are rarely visible (covered) (Chevenez).

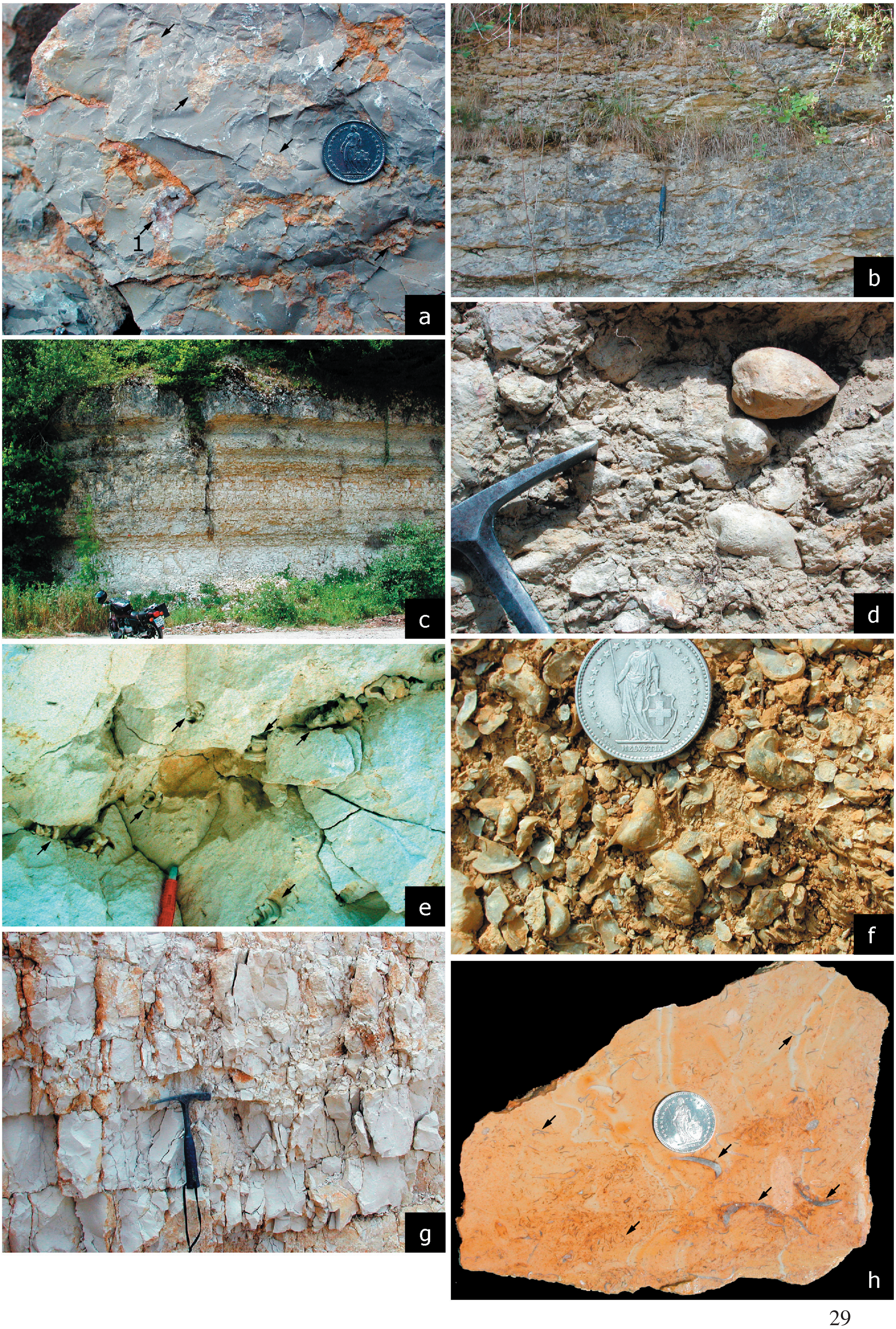
Picture d: Banné Marls – Large bivalve at the top is a *Pholadomya sp.* (Cras d'Hermont, block between motorway and car shop).

Picture e: Nerinean Limestones – Chalky Nerinean Limestone "*sensu stricto*" with internal molds of Nerinean gastropods (arrows; bed CHV-80, La Combe).

Picture f: Virgula Marls (Sur Combe Ronde).

Picture g: Coral Limestones – White chalky thin-bedded blocky fracturing limestone (La Combe). Thin marl seams separate beds.

Picture h: Oyster Limestones – Storm intercalation in bioclastic mud- to wackestone. The shell pods of *Nanogyra sp.* (arrows) and some other shells are caused by bioturbation (bed CHV-2900, La Combe).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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 –

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(submitted to Facies)

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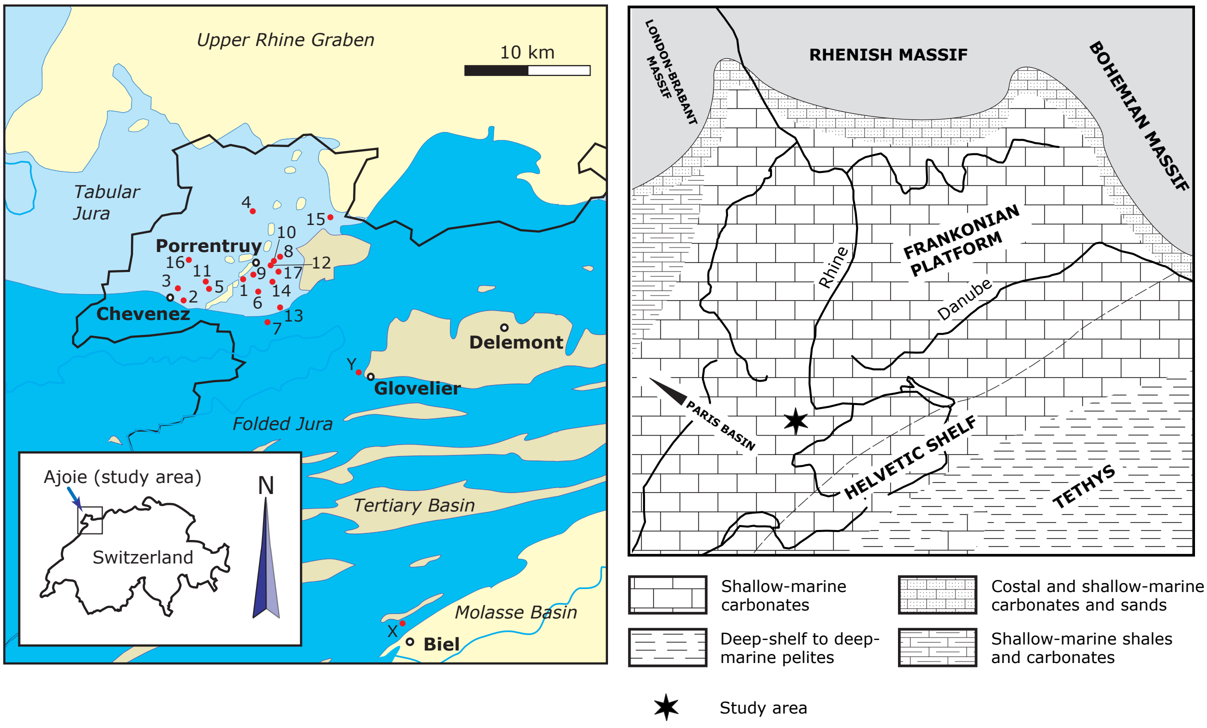
ABSTRACT

In Late Jurassic times the Swiss Jura carbonate platform occupied the transition between the Paris Basin and the Tethys and thus connects the Boreal and Tethyan realm. Up to now, the lack of index-fossils in the Reuchenette Formation prevented a reliable correlation between both areas (its sediments are are charckterised by a prominent sparseness of index-fossils). Now, seven recently *in situ* collected species of ammonites helped to establish a new sequencestratigraphical frame for the platform sediments of the Reuchenette Formation in NW Switzerland. Based on biostratigraphical data five 3rd order sedimentary sequences were assigned to the Late Oxfordian to Late Kimmeridgian. The upper three 3rd order sequences correspond to the boreal sequences Kim3 to 5 of Hardenbol et al. (1998). The deduced large-scale sea level fluctuations match those from other European regions (Spain, Russia). This biostratigraphically based sequence-stratigraphical frame is a prerequisite to refine correlations within a wider area covering the Swiss Jura and parts of adjacent France and Germany.

INTRODUCTION

Depocentres of Mesozoic sediments in the Swiss Jura Mountains appear to be related to the synsedimentary reactivation of Permo-Carboniferous basement structures (Gonzalez, 1993; Wetzel et al., 1993, 2003; Allia, 1996; Burkhalter, 1996; Pittet, 1996; Allenbach, 2002). This is also the case for the Late Jurassic Reuchenette Formation exhibiting thickness variations of up to 100 m within a maximum thickness of approximately 160 m (Gygi & Persoz, 1986; Meyer C.A., 1993). These thickness variations and the sparseness of index-fossils within the Reuchenette Formation - including the type-section in the quarry La Reuchenette near Péry BE (No. X in Fig. 1) - led to numerous different approaches on how to correlate the strata and estimate their age (e.g. Thurmann, 1832; Greppin, 1870; Thalmann, 1966; Chevallier, 1989; Meyer C.A., 1989; Gygi 2000b). Even more recent studies based on sequence-, cyclo- and mineralo-stratigraphy (Gygi & Persoz, 1986; Gygi, 1995; Mouchet, 1995, 1998; Gygi et al., 1998; Meyer M., 2000; Colombie, 2002) rely on only a few high-resolution biostratigraphical markers (i.e. ammonites). Unfortunately, most of those markers occur in different, widely spaced or very small outcrops restricting their biostratigraphical use. Consequently, the biostratigraphical data for Kimmeridgian shallow-water platform sediments were too sparse to establish a reliable (biostartigraphically dated) sequence-stratigraphical link between the Paris Basin and the Tethys (Boreal and Tethyan realm). Recently, the construction work of the Transjurane motorway in the Ajoie-Region provided new outcrops of the Reuchenette Formation. The exposures are closely spaced and well suited to study these sediments and, in addition, a considerable number of index-fossils were found (ammonites).

It is the purpose of this paper (1) to describe the depositional environments and (2) to provide an improved sequence-stratigraphical frame for the Reuchenette Formation in NW Switzerland based on a refined biostratigraphy and additional sedimentological, lithostratigraphical and microfacial data. These data are essential to define and date already established and



	Code	Sections	Coordinates		Interval(s)
1	BAN	Tunnel Le Banné (Westportal), base	571.833	250.504	top Thalassinoides Limestones, base "Nautilidenschichten"
2	CHV	La Combe (Carrière Combe de Varu), base	567.753	248.930	Nerinean Limestones... Oyster Limestones
3	CHVs	Chevenez (La Scierie), base	567.175	249.675	Lower Grey and White Limestones, base Banné Marls
4	COE	Coeuve (Carrière), base	574.725	256.075	top Thalassinoides Limestones, "Nautilidenschichten"
5	CRE	Creugenat, base	569.173	249.748	top Thalassinoides Limestones, base "Nautilidenschichten"
6	FON	Fontenais (Carrière communale), base	573.050	249.575	top Thalassinoides Limestones, base "Nautilidenschichten"
7	PAU	Chemin Paulin	573.790	247.100	Porrentruy Member… Banné Marls
8	PMS	Pré Monsieur (Carrière), base	574.887	252.262	Coral Limestones
9	RAS	La Rasse (Carrière)	572.560	250.840	Porrentruy Member… Lower Grey and White Limestones
10	RDM	Roches de Mars, base	574.372	252.021	Nerinean Limestones, (Virgula Marls)
11	SCR	Sur Combe Ronde, base Virgula Marls	568.869	250.082	top Nerinean Limestones, VirgulaMarls
12	TUP	Cras d'Hermont (base little road)	573.958	251.694	"Nautilidenschichten", Lower Grey and White Limestones
12	TUP	Cras d'Hermont (end little road)	574.108	251.750	base Banné Marls
12	TUP	Cras d'Hermont (betw. motorway and car shop)	574.058	251.797	top Banné Marls, base Nerinean Limestones
12	RDMa	Cras d'Hermont (car shop)	573.970	251.844	base Nerinean Limestones
13	VAB	L'Alombre aux Vaches (Carrière Vabenau)	574.800	248.200	top Thalassinoides Limestones... Banné Marls
14	VAT	Vatelin (Carrière)	574.300	250.500	top Thalassinoides Limestones... Lower Grey and White Lst.
15	VEN	Vendlincourt (Carrière), base	578.950	255.475	top "Nautilidenschichten"... Banné Marls
16	VTT	Vâ tche Tchâ (Combe de Vâ tche Tchâ)	568.720	252.155	Banné Marls
17	BDH	Bas d'Hermont (Carrière)	574.600	251.000	top Thalassinoides Limestones, base "Nautilidenschichten"
X	REU	La Reuchenette (Carrière)	585.890	226.240	type-section
Y	GLO	Contournement de Glovelier	581.521	242.515	

Fig. 1: Geological and paleogeographical (Kimmeridgian) overview maps (top), swiss coordinates of locations and lithological intervals (below). Palaeogeographical map aftfer Ziegler (1990, slightly changed).

newly determined sequence boundaries, to establish an integrated sequence-stratigraphical overview and to re-evaluate existing interpretations.

GEOLOGICAL SETTING

The study area (Ajoie-Region) is located at the transition from the Folded Jura Mountains to the Tabular Jura of NW Switzerland (Fig. 1). During the Late Jurassic the study area was covered by a shallow epicontinental sea (carbonate platform) between the Tethys in the south and the Paris Basin in the north and northwest (Fig. 1). Sea level fluctuations affected the platform on which mainly shallow-water limestones and some marls accumulated. The climate was subtropical at this time (e.g. Frakes et al., 1992). During the Early Tertiary or even earlier, the study area became exposed and a considerable part of the uppermost Jurassic was removed by erosion, including the Twannbach Formation, which is absent in the study area but rests on the Reuchenette Formation further to the south; it is unknown how much sediment has been eroded. A general stratigraphical overview is given in Figure 2.

METHODS, MATERIAL AND TERMINOLOGY

Detailed sedimentological, palaeontological and microfacial analyses were performed on 17 sections throughout the Ajoie-Region (Fig. 1). The evaluation of the microfacies type of approximately 500 thin sections and of the facies is based on the classifications of Dunham (1962), Embry & Klovan (1972), and Flügel (1982, 2004).

The facies and their bounding surfaces form the base for defining sedimentary cycles and sequences based on the concepts of Van Wagoner et al. (1988), Vail et al. (1991) and Strasser et al. (1999). Short-term cycles and systems tracts are numbered in relation to the number of the sequence boundary underneath, for instance, TST3 = transgressive systems tract following sequence boundary 3.

Long-term sea level fluctuations are numbered with letters (e.g. TST-A). The lowstand systems tract (LST) and transgressive systems tract (TST) are illustrated as one half-cycle. The term "bedding" is used for the internal characteristics/composition of a bed, e.g. flaser bedding, nodular bedding, cross bedding, laminated, etc.

The term "layering" is used to characterize the thickness of a bed or bed set, e.g. massive-layered (>1 m), thick-layered (0.3-1 m), thin-layered (1-3 dm), very thin-layered (<1 dm), etc.

Thin sections of oriented samples were studied by light microscopy and by cold cathodoluminescence microscopy (CITL Mark II) to evaluate diagenetic effects. To estimate the influence of meteoric diagenesis for some of these samples the isotopic composition of oxygen was measured at the isotope laboratory of the ETH Zürch. Samples for oxygen and carbon isotope measurements were taken with a dental drill from the same pieces as the thin sections, so isotope samples can be easily related

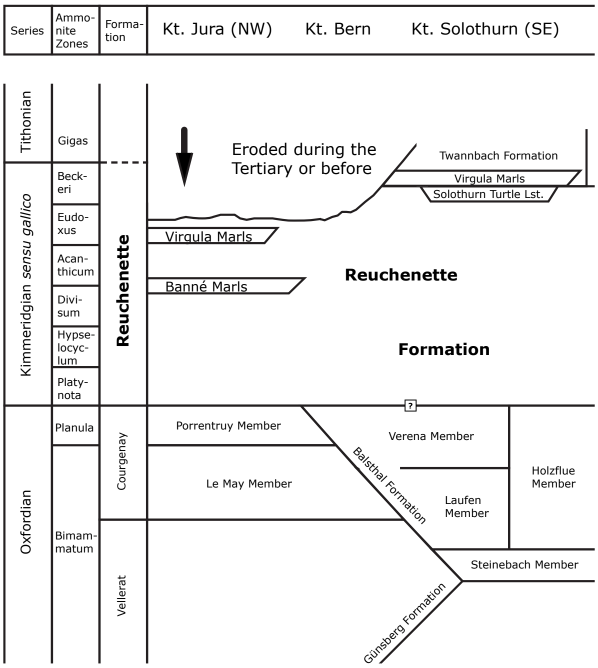


Fig. 2: Litho- and biostratigraohical sheme for the Reuchenette Formation, based on data from Meyer C.A. (1990, 1993), Gygi (2000b), Jank (2004) and this study. Arrow indicates position of the measured sections. The biostratigraphical position of the boundary between the Reuchenette Formation and the Courgenay/Balsthal Formation is still a matter of debate (Thalmann, 1966; Gygi 1995, 2000b; Colombie, 2002).

to the microscopically defined limestone domains. The isotopes were measured by a VG Isogas PRISM mass spectrometer. Isotope compositions are expressed in notation as per mil deviations from the international PDB carbonate standard. Analytical precision based on routine analysis of the internal standard (Carrara Marble) was ±0.10‰ for delta 18O and ±0.05‰ for delta 13C.

To illustrate the thickness-development and the subsidence-history, the decompaction factors of Moore (1989), Goldhammer (1997), and Matyszkiewicz (1999) were used (decompaction factor * thickness = initial thickness, when deposited; for details see Fig. 9). The available accommodation space was estimated as suggested by Strasser et al. (1999).

Due to the limited space in publications five long and (if possible) ammonite-bearing sections (La Combe, La Rasse, Cras d'Hermont, L'Alombre aux Vaches, Vendlincourt; No. 2, 9, 12, 13, and 15 in Fig. 1) have been selected to illustrate the results. The sections La Rasse (No. 9 in Fig. 1), Chemin Paulin (No. 7 in Fig. 1) and parts of L'Alombre aux Vaches (No. 13 in Fig.1) are already measured and described by Mouchet (1995, 1998) and Gygi (2000b). They were reinvestigated and partly extended.

BIOSTRATIGRAPHY

The evaluation of sea level changes in terms of relative time is based on eight *in situ* collected species of ammonites (see biostratigraphical frame Fig. 3). A detailed discussion of the ammonites would be beyond the scope of this paper; biostratigraphical details of the

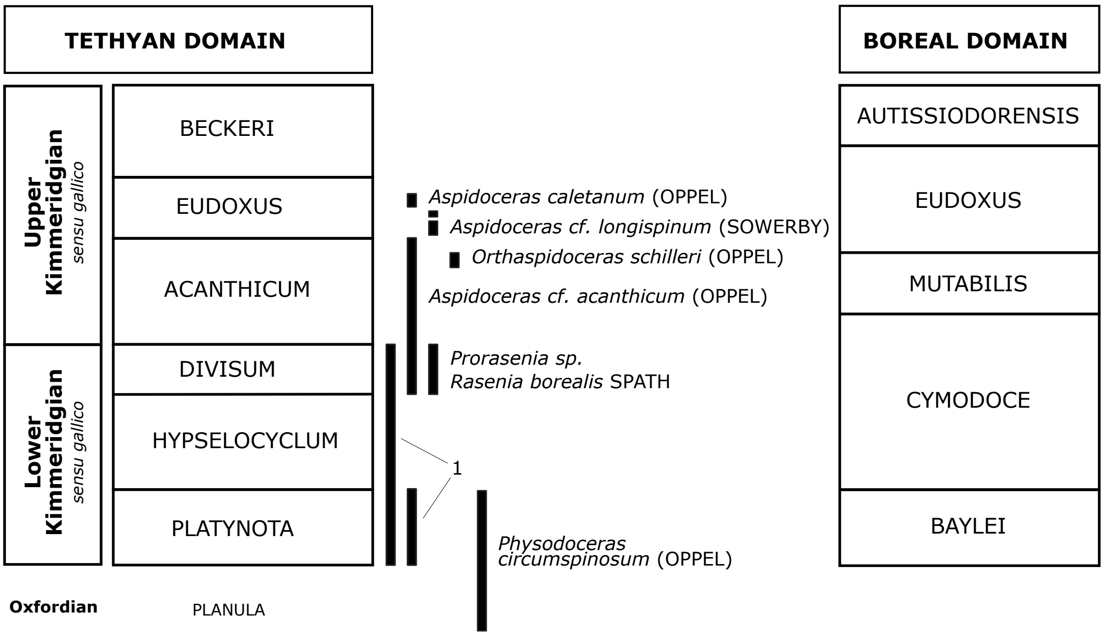


Fig. 3: Biostratigraphical frame based on ammonites.
Zonation of the Kimmeridgian *sensu gallico* after Hantzpergue et al. (1997). Tethyan Domain is used *sensu* Domaine Téthysien, Province suméditerraneénne; Boreal Domain is used *sensu* Domaine Boréal, Province subboréale. All ammonites were collected *in situ*, except *Aspidoceras cf. acanthicum* (OPPEL) (Gygi, 1995).

Biostratigraphical reach and localities:
1: *Lithacosphinctes cf. janus* (CHOFFAT); Platynota-Zone (according to Schweigert) 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.

ammonites of the studied sections are discussed in Jank (2004) and Schweigert et al. (in prep.). Gygi & Persoz (1986) and Gygi (1995, 2000b, 2003) give further information about index-fossils found in the Reuchenette Formation.

LITHOLOGY

In the study area the preserved part of the Reuchenette Formation is subdivided into nine intervals. Characteristic lithological features including colour, fossils and composition are used for naming them.

In the Ajoie-Region the Porrentruy Member (= top member of the Courgenay Formation *sensu* Gygi, 1995) is overlain by the Reuchenette Formation (Fig. 2). The Porrentruy Member is composed of massive-layered, white, calcarenitic to micritic, chalky limestones with Nerinean gastropods, small oncoids and coated intraclasts. The latter two occasionally display brownish rims.

The **Thalassinoides Limestones** form the base of the Reuchenette Formation. They consist of monotonous, thick- to massive-layered, well-bedded, bioturbated, grey, micritic limestones that contain some bioclasts and reddish-brown or greyish, coarse-grained pseudo-oolites (mainly rounded intraclasts and peloids) within pockets, patches or strings within a micritic matrix. Thin- to thick-bedded layers commonly show abundant *Thalassinoides* and iron-stained bed surfaces, and fracture conchoidally. The burrows are in many cases filled with coarse-grained rounded intraclasts and peloids (pseudo-oolites). Some massive-layered white chalky limestones are intercalated.

The overlying **“Nautilidenschichten”** has a conspicuous 10-15 cm thick reddish-brown storm-lag deposit at its base that has a strongly varying fossil content with occasional ammonites and/or large nautilids (e.g. *?Paracenoceras ingens n. sp.* (holotype); Tintant et al., 2003). The “Nautilidenschichten” consist of thick- to massive-layered, strongly bioturbated, marly limestones and limestones with a weak internal nodular bedding. The lower part tends to exhibit marl-limestone alternations when weathered; calcarenitic, storm-influenced marly limestones alternate with bioturbated marly micritic background sediment. Locally, some bored and biogenically encrusted hardgrounds occur.

The “Nautilidenschichten” grade upward into the **Lower Grey and White Limestones**. They are composed of thin- to thick-layered, grey and white, micritic and calcarenitic limestones. The interval is capped by a regionally bored and biogenically encrusted hardground.

The overlying **Banné Marls** form a prominent marl intercalation. They 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. Intercalated shelly and calcarenitic horizons, that in many cases separate the beds, probably result from reworking and winnowing by storms.

The overlying interval, the **Nerinean Limestones**, starts with thin- to thick-layered, grey, calcarenitic limestones followed by white, thick- to massive-layered, chalky limestones with Nerinean gastropods, bioloaminite-layers and dinosaur foot prints. At the top it grades into greenish weathering, glauconitic, coarse-grained calcarenitic limestones. These greenish sediments show characteristic, strongly bored and biogenically encrusted, regional hardgrounds that contain cephalopods.

On top, the dark-grey, thin-layered **Virgula Marls** interval contains a rich fauna of bivalves and cephalopods, but small oysters dominate. Vertebrate remains, such as plesiochelid turtles and marine crocodiles, and coaly plant remains were often found.

Overlying the Virgula Marls, the **Coral Limestones** form an interval with some metres of thin-layered, grey, micritic limestones at their base that are overlain by the Coral Limestones *sensu stricto*. These are a massive unit composed of thin- to thick-layered, white, chalky, micritic limestones with re-crystallized corals and conspicuous red-brown shelled rhynchonellid brachiopods; (Fig. 17/4) separated by thin marl seams.

This interval grades into the **Upper Grey and White Limestones**. This thick- to massive-layered, monotonous, micritic interval is separated by a slightly coarse-grained, marly intercalation. The limestones break blocky with conchoidal fractures. Body fossils and *Thalassinoides* are sparse.

The **Oyster Limestones** form the uppermost interval. The base consits of calcarenitic limestone and a layer with *Cladocoroposis mirabilis*, that is overlain by thin layers of occasionally platy, marly, fine-grained (micritic) limestones, dominated by oysters.

FACIES AND DEPOSITIONAL ENVIRONMENTS

Facies 1: Cast and filled *Thalassinoides*-tubes

In the studied sediments, *Thalassinoides* generally comprises unwalled tubes, but their sharp outlines and their passive fill suggest a lining. The burrows are mainly horizontal, rather than vertical to subvertical. The fill differs in composition from the host sediment and in many cases records the preceding sedimentological development. There are a few layers wherein *Thalassinoides* tubes contain coarse block cement (Fig. 11/6) that is indicative of an incomplete fill of at least some tubes' segments.

Interpretation: The observed *Thalassinoides* are comparable to burrows of recent *Alpheus crassimanus* that lives in intertidal to shallow-subtidal lime mud in shallow lagoons in tropical areas (e.g. Farrow, 1971). *Thalassinoides* is regarded a part of the environmentally wide-ranging Glossifungites ichnofacies and is common in firmgrounds such as dewatered compacted mud, colonized under relatively low energy conditions (Bromley, 1975; Frey & Seilacher, 1980; Pemberton & MacEachern, 1995; MacEachern & Burton, 2000). Dewatering may result from burial of offshore mud. When the overlying sediments are stripped off by submarine erosion during a lowering of the wave-base, the firm substrate is exposed on the seafloor and available for colonization by the trace makers. Sediment indurations may also be a result of retarded sedimentation and oxidation of organic matter leading to cementation (Wilson & Palmer, 1992). Both real soft sediment infauna and many epifaunal organisms avoid such cohesive substrates. Burrowers excavate open tunnels in the firm sediment and leave behind traces such as *Thalassinoides*. The burrows commonly remain open and are subsequently filled with coarser grained shallow-water sediments (Fig. 11/1), which can be related to the downward shift in sea level (Handford & Loucks, 1993). Furthermore, *Thalassinoides* are known to potentially demarcate sequence boundaries, transgressive surfaces and transgressively modified sequence boundaries (MacEachern & Burton, 2000); according to Burns & Hooper (2001), abundant *Thalassinoides* filled with coarse material (in this study commonly intraclastic pack- to grainstones) represent periods of omission associated with both transgressive ravinement surfaces and downshift surfaces. The coarse-grained components are derived from both storm-generated lag deposits and more laterally extensive shore face erosion associated with fluctuations in relative sea level (Burns & Hooper, 2001). *Thalassinoides*-producers could have excavated their burrows through a thicker coarse-grained lag as outlined by Seilacher (1967), Frey & Seilacher (1980) and Pemperton & Frey (1985).

Additionally, washed out and cast trace fossils can be used to identify and quantify storm-erosion (Fig. 15/3) (e.g. Wetzel & Aigner, 1986), because trace fossils show a characteristic depth-zonation within the sediment. Storm-transported material occurring within *Thalassinoides*–tubes suggests their passive fill by wave pumping during waning storms (Tedesco & Wanless, 1991).

Facies 2: Intraclastic pack- to grainstones and lumachelle (shell beds)

Reddish and grey intraclastic pack- to grainstones form thin-bedded bioturbated sand sheets (Fig. 15/3), pseudo-oolitic fill in *Thalassinoides*-tubes (Fig. 11/1), or amalgamated and mixed relicts (reworked Facies 2) in micritic background sediment (Fig. 11/2). In the latter case components occur in patches dispersed throughout the sediment producing a floating grain texture (rounded intraclastic material having a pseudo-oolitic appearance); argillaceous parts are heavily affected by stylolites. Moderately to well sorted, abraded (rounded) and coated, reworked material (intraclasts) dominates the composition. Coatings and boundaries of grains in some cases exhibit brownish colours. Shell debris is also generally worn and rounded, and coarse-grained calcarenites are commonly much more abundant than medium-grained calcarenites (Fig. 11/3). Regular (e.g. *Hemicidaris mitra*) and irregular sea urchins (e.g. *Pygurus blumenbachi*), coral clasts, large gastropods and some large nautilids also occur in such layers. Locally the pack- to grainstones are selectively dolomitised (now preserved as dedolomite), and stained by Tertiary clays (carstification) and are, therefore, clearly visible. Cast *Thalassinoides* are common on lower surfaces of calcarenitic pack- to grainstone sheets filling an erosional relief (Fig. 15/3). Thickness variations in such layers are common. Commonly intraclastic pack- to grainstone sheets are also accompanied by conspicuous surfaces that show evidence for colonisation. These surfaces form firmgrounds below calcarenitic sheets (burrowed by *Thalassinoides*). The top of the sheets were colonized by byssally attached (e.g. *Mytilus sp., Camptonectes sp.*) and semi-infaunal bivalves (e.g. *Trichites sp.*) or bored and encrusted (Fig. 11/1).

The lumachelle layers consist of generally well-bedded, thin-layered bioturbated float- and rudstones containing bioclasts (bivalves, corals, echinoderms, etc). Lumachelles form separate layers, amalgamations or indistinct horizons (mixed into the background sediment). The large bioclasts are commonly well preserved, unabraded and disarticulated. Bioturbation usually churns the original bedding and led to the formation of pseudointraclasts. Underneath such layers high-relief bored and biogenically encrusted hardgrounds and reworked pebbles occur.

Interpretation: Lumachelle and intraclastic pack- to grainstones are interpreted as storm deposits. According to Wilson (1975) and Flügel (1982, 2004), intraclastic pack- to grainstone sheets may represent lags in washout zones and represent distal, shallow deposits. They indicate slow average sedimentation rates (condensation, winnowing) and are represented as single or multi-event layers. This is supported by brownish colouring, corrosion and abrasion of some coatings of the intraclasts (Fig. 11/4) and reflects transport and their exposure at the sediment-water interface for some time (Bathurst, 1966; Millimann, 1974). Observations in the recent support this interpretation (e.g. Ball, 1967; Hine, 1977; Aigner, 1985). Accordingly, the intraclastic pack- to grainstone beds are interpreted to have been deposited by storms and moved as traction bedload. The floating grain texture characterized by coarse grains concentrated in patches dispersed throughout micritic (background) sediment is attributed to soft-ground burrowing communities (Burns & Hooper, 2001), suggesting input by storm and bioturbation (biofacies mixing, Tedesco & Wanless, 1991). Often storm-influenced bed surfaces either show evidence for post-event colonisation by boring endofauna and/or epi- and infauna (Aigner, 1985). Genetically intraclastic pack- to grainstones and shell beds are closely related to each other; shell beds are also genetically related to bioclastic wacke- and packstone (see below).

Facies 3: Bioclastic mud- and wackestones (± *in situ* macrofauna)

Typical are thin-bedded, carbonaceous or argillaceous, bioclastic mudstones and wackestones that exhibit slightly nodular bedding and fine wispy laminae. Skeletal material is present in all states of preservation from complete shells to intensely micritised grains. The microfacies is mainly composed of randomly orientated, angular bioclasts and sponge spicules in a lime-mud matrix (Fig. 12/1). Thin sections further show thin-shelled bivalves, echinoderm fragments, foraminifera (e.g. *Alveosepta jaccardi, Lenticulina sp., Nautiloculina sp.*), rare algae (e.g. *Solenoporacea sp.*), and peloids. Macrofaunal elements are epi- and infaunal bivalves (e.g. oysters, *Trichites sp., Mytilus sp., Camptonectes sp., Pholadomya sp.*), brachiopods (*Sellithyris subsella*; Sulser & Meyer, 1998; "*Terebratula sp.*", "*Rhynchonella sp.*"), echinoderm fragments, small gastropods and rare cephalopods. Locally, randomly orientated components and pseudo-intraclasts occur.

Interpretation: The fine-grained texture of bioclastic mud- and wackestones is interpreted as indication of subtidal deposits accumulated under episodic turbulence below the fair-weather wave-base in an open platform area. Randomly distributed bioclasts and pseudo-intraclasts imply bioturbation. Large nautilids point to an open marine influence. Background sediments were deposited from suspension. Owing to its strong micritisation and moderate to good rounding, imported storm-transported material from shallow environments is clearly distinguished from background sediments that are dominated by sponge spicules. The nodular texture is a result of a combination of bioturbation and compaction, although bioturbation seems to be the dominant factor for development of nodularity (e.g. Kennedy, 1975; Werner, 1986). Thick packages (as in Vendlincourt, Vatelin and L'Alombre aux Vaches) of this facies type probably accumulated in open lagoonal platform environments. Limestones with normally articulated *Nanogyra* specimens in low density, which probably inhabited the soft sea floor, are interpreted to represent the more or less undisturbed habitat of the oysters below the storm wave-base (e.g. Fürsich & Oschmann, 1986a,b).

Facies 4: Chalky bioclastic mudstones with coral meadows

Chalky bioclastic mudstones (locally with floatstone texture) are white and thin- to thick-layered. Wispy marl seams separate beds. Generally, this facies is poor in species but rich in specimens. Macro-components are patch reefs (coral meadows), solitary corals, *Sellithyris subsella, Terebratula sp., Rhynchonella sp.* (red-brown-shelled) and some bivalves. The corals (e.g. *?Calamophilliopsis sp., ?Cyathophora sp., ?Stylina sp., ?Ovalastrea sp.*) are of tuberoid and small dendroid shape, re-crystallised and therefore difficult to determine (Fig. 17/4). The corals dominate the faunal assemblage; some of them show borings by lithophaga bivalves. Brachiopods are also very abundant and often show geopetal fills. Sea urchin spines, bivalves and gastropods (e.g. *Harpagodes oceani*) are less common. Bioclastic aprons are developed around coral meadows. Angular bivalve shells, echinoderm fragments, serpulids, algae clasts (*Marinella sp., Cayeuxia sp.*), sponge spicules, oncoids, ?stromatoporids (*Cladocoroposis mirabilis*) and foraminifera (*Pseudocyclamina sp., Alveosepta jaccardi, Lenticulina sp.*) in a lime-mud matrix can be seen under the microscope. In La Combe a 10 m high complex composed of stacked coral meadows interfingering with the surrounding micritic beds was visible.

Interpretation: The chalky mud- and wackestones with coral meadows are interpreted as shallow and quiet, stenohaline facies (Flügel, 1982, 2004, Leinfelder et al, 1994) deposited under episodic turbulence (fine-grained matrix, poorly sorted and large angular bioclasts). The brachiopods might have lived on the corals (Werner, 1986). Beauvais (1973) named these beds biostromes, as they display a lower diversity in genera and species than bioherms. The corals probably settled on a muddy bottom where they could only survive if sedimentation was less rapid (Leinfelder et al., 1994); otherwise they would have been buried. According to Werner (1986) plocoid (e.g. *Stylina sp., Ovalastrea sp.*) and ceroid (e.g. *Cyathophora sp.*) corals lived on soft sediment, as well as *Harpagodes oceani*. The deposition of this facies is inferred to have occurred in a normal marine, quiet, shallow lagoon below fair-weather wave-base.

Facies 5: Marly bioclastic wacke- to packstones and float- to rudstones with *in situ* macrofauna

This facies solely comprises the Banné Marls and the Virgula Marls. The marly bioclastic wacke- to packstones are dark grey and thin-layered with internal nodular bedding. A rich macrofauna occurs in a marly lime-mud matrix. Individual and distinct trace fossils are rare in the thoroughly bioturbated parts. Nevertheless remnants of sedimentary layering (especially in the Banné Marls) occur as alternations of fossil-/shell-rich marls with less fossiliferous beds or bioturbated marls. Dominant macrofossils are *in situ* epi- and infaunal bivalves such as *Anchura sp., Apporhais sp. and Pholadomya sp.* (in the Banné Marls) and/ or monospecific oysters (i.e. *Nanogyra sp.* in the Virgula Marls). Furthermore, gastropods, sea urchins, brachiopods, vertebrate remains, and cephalopods, and scarce lithoclasts, pseudo-intraclasts, and coaly plant-fragments occur (pers. comm. B. Hostettler, D. Marty).

Thin sections show angular components composed of thin-shelled bivalves, echinoderm fragments and bioclasts (Fig. 12/6).

Interpretation: The marly bioclastic wacke- to packstones and float- to rudstones formed under intermittent, moderate turbulence (Folk, 1959, 1962); in quiet marine lagoon or bight below fair-weather wave-base is inferred. Cephalopods point to a connection to open marine areas. The mass occurrence of oyster shells, bivalves and shell-layers, a high amount of marl (clay content), coaly plant fragments, and common vertebrate remains imply protected, land-near conditions, occasionally affected by storm-deposition or winnowing. The Banné Marls and the Virgula Marls were episodically reworked by storms or affected by runoff from land. Alternatively either open marine and terrigenous material was deposited.

Storm reworking may have led to episodically low rates of sedimentation as documented by composite shell beds in more offshore deeper waters (Fürsich & Oschmann, 1986a).

Facies 6: Bioclastic wacke- and packstones with *in situ* macrofauna (±argillaceous, slightly nodular)

These thin- to thick-layered wacke- and packstones show internal, slightly nodular bedding and contain a rich macrofauna. Marly parts display an increased amount of coarse components (fauna and clasts). In some instances faint bedding is observed. The boundaries of nodules are gradational and consist of indistinct clay seams. Large, angular and rounded bioclasts, coated grains, peloids and macrobiota within a lime-mud matrix dominate. The matrix contains sponge spicules. Sorting and rounding is moderate to good. Micritisation of components comprises coating to complete destruction of original structures (e.g. Fig. 12/2). Calcarenitic grains are dispersed throughout, producing a floatstone texture. *Thalassinoides* occurs as well, but individual and distinct burrows are extremely rare in thoroughly bioturbated parts. The macrofauna comprises brachiopods, sea urchins, bysally attached and infaunal bivalves (e.g. *Pholadomya sp.*), locally oyster shells and gastropods. Locally semi-infaunal and epifaunal biota (*Trichites sp., Rhynchonella sp.*) are concentrated in coarse, marly horizons. Thin sections further show foraminifera (*Alveosepta jaccardi, Lenticulina sp., Nautiloculina sp.*) and ostracodes.

Interpretation: The bioclastic wacke- and packstones are interpreted to have formed in a normal marine inner shelf setting near skeletal shoals. This facies documents the interaction between storm- and background-accumulation next to shell shoals. Sea urchins imply normal marine conditions.

Nodular wacke- and packstones interbedded with indistinct marl layers indicate deposition under intermittent to calm conditions. Biogenic sedimentary structures and randomly distributed components and pseudointraclasts point to bioturbation and thus sufficient oxygenation. Storm-imported clasts are rounded and worn (Fig. 12/3, 4) and markedly differ from *in situ* clasts (Fig. 12/5). Storm influence is indicated by large angular parautochthonous bivalve clasts, as well. The argillaceous and carbonaceous zones are differentially compacted and probably were enhanced during further burial. The varying nodular texture appears to have formed during diagenesis in response to the bioturbate texture (e.g. Kennedy, 1975; Werner, 1986). Beds of pervasively burrowed and bioturbated wackestones with a considerable proportion of lime mud probably accumulated under quiet conditions below fair-weather wave-base. Extensive bioturbation and storm-imported material usually obliterated the original *in situ* facies, which is represented by rare nodular limestones with sponge spicules.

Bioclastic pack- to grainstones with rounded intraclasts and micritised bioclasts (Fig. 12/3, 4) imply wash-over sedimentation from sand shoals under strong wave agitation. The wash-over material in more quiet areas of the lagoon indicate mixing of biofacies and input by storms (Tedesco & Wanless, 1991). The coarse-grained components represent storm-generated lag deposits, *in situ* storm-generated reworking (short transport) or are derived from extensive shore face erosion. According to Aigner (1985) shelly pack- to grainstones are interpreted as near-shore shallow skeletal banks and shell shoals interfingering with mud-and wackestones. Therefore, bioturbated, massive skeletal packstones indicate a relatively unprotected environment next to shell shoals, which were episodically affected by storms.

Facies 7: Oncoidal (chalky) wacke- to packstones and float- to rudstones
White, thin to thick layers contain mainly oncoids (Fig. 15/4), pseudo-intraclasts and large Nerinean gastropods either floating or in grain-to-grain contact within a lime mud or fine-grained "clastic" matrix. Other large bioclasts are corals and bivalves. The components are randomly distributed throughout the beds. The large components range in size from millimetrs to centimeters. Sorting and rounding is moderate to good. Micritised rims on bioclasts are common. *Thalassinoides* filled with coarse block cements are occasionally present. Furthermore peloids and echinoderm fragments occur. Centimetre-sized *Cladocoropsis mirabilis* fragments were found in La Combe (Fig. 13/1).
Interpretation: Frequently occurring oncoids imply restricted conditions. According to Flügel (1982) and Wilson (1975) oncolitic wacke- or floatstones are typical of shallow, relatively quiet backbank environments where they form on edges of ponds and channels in protected lagoons; coarse-grained oncoidal limestones point to moderately high energy in very shallow water. Centimetre-sized *Cladocoropsis mirabilis* also suggests a clear and warm shallow marine environment (Champetier & Fourcade, 1967).

Facies 8: Peloidal mud- to grainstones
Thin- to thick-layers of intensely bioturbated, peloidal mud- to grainstones contain some macrofauna (e.g. *Camptonectes sp., Trigonia, sp.*, Nerineans; Fig. 11/8) and bioclasts (and occasionally ooids) (Fig. 13/4, 6). Internally they are fairly homogenous or faintly parallel bedded; bed-parallel stylolite seams enhanced bedding. Some beds show an enrichment of miliolids (Fig. 13/5) or Nerineans. Peloids often merge to a micritic matrix (clotted texture). Thin sections further show thin-shelled bivalves, echinoderm fragments, foraminifera (e.g. *Alveosepta jaccardi, Lenticulina sp., Nautiloculina sp.*), occasionally algae (*Solenoporacea sp.*), sponge spicules and coated grains. Locally the beds became indurated; firmgrounds, burrowed by *Thalassinoides*, or hardgrounds, bored or encrusted by shells. Cast *Thalassinoides* are common. Bioturbation led to a wide range of textures (wacke- to grainstone) and then indicates sufficient oxygenation. Rounded intraclasts may occur in small pockets or in zones of coarser packstone within a fine matrix.
Interpretation: Small peloids are interpreted as fecal pellets (Flügel, 1982, 2004), the large ones either as algae clasts or micritised ooids (Koch et al. 1994). Pelsparites are deposited in warm and shallow-water with slight circulation. The fecal-pellet rich pack- to grainstones would represent warm, shallow-water with only moderate water circulation (Flügel, 1982, 2004, Volk et al., 2001). The mud- to wackestone texture indicates more restricted circulation and deeper water, comparable to the pellet-mud-facies on the Great Bahama Banks west of Andros Island, which is formed under minimal water energy, increased salinity in 2-6 m water depth (e.g. Flügel, 1982). According to Sellwood (1986) peloidal mud- to grainstones represent a stable and muddy lime-sand habitat shoreward of an active sand shoal. The enriched Miliolids imply fluctuating salinity (e.g. Flügel, 1982).
According to Werner (1986) Nerinean layers generally are associated with a pronounced sedimentological facies change, commonly from lower to higher water energy (e.g. from stromatolitic mudstones to peloidal pack-to grainstones between layers CHV-70 and 80 in La Combe; Fig. 4). In this study (mass-occurring) Nerineans probably acted as opportunists occupying a new developed habitat rather than a certain biotope (Wieczorek, 1979).

Facies 9: Non-laminated homogeneous micrite
Very thin-bedded, non-laminated and homogeneous, occasionally marly, thin-layered mudstones contain few well-preserved, unabraded and disarticulated angular bioclasts and some macrofauna. Clasts commonly show no micritisation. *Thalassinoides* are filled with coarse block cement or coarse-grained sediment (Fig. 13/7).
Interpretation: Homogeneous mudstones are ascribed to (hyper-saline) tidal ponds (Wilson, 1975) as they are always dveloped within a succesion of inter- to supratidal sediments. The

homogeneous composition and texture, and the few clasts probably point to tidal ponds or protected shallow bights and lagoons with a normal marine influence (compare Werner, 1986). Skeletal material has been exposed to transport and abrasion only briefly. *Thalassinoides* were filled with coarse material during storms or by wave pumping (Tedesco & Wanless, 1991).

Facies 10: Lensoidal pack-/rudstones
A lens shaped channel-like body (Fig. 13/2) of peloidal, bioclastic or intraclastic pack-/rudstones, about 1 m thick and tens of metres wide was found intercalated into well-bedded limestones in Tunnel Le Banné. This body is composed of several amalgamated thin, discontinuous layers. Many of these amalgamated layers consist of coarse-grained peloidal packstones; others show crude fining-up packages of skeletal packstones. Some rounded limestone clasts occur (Fig. 13/3), some of them are clearly derived from the underlying sediment indicating erosion while others seem to be imported (e.g. *Cayeuxia* clasts).
Interpretation: The geometrical and lithological relationship to the sediments below and above and the material of the lensoidal body suggest a channel in a tidal flat or shallow-subtidal environment. Similar channels have been described by Seilacher (1982) and Aigner (1985) and were interpreted as storm surge or rip channels.

Facies 11: Laminated mudstones
Laminated mudstones display wavy to parallel, sub-millimetre thick micritic laminae. Some laminae are fenestral, others are slightly domed or pinch-and-swell like. Components are sparse and macrofauna is nearly absent. Occasionally dedolomite and locally bioclasts and fecal pellets occur within the laminated texture. Some horizons display mud cracks (Fig. 15/2), birds eyes, key stone vugs, sheet cracks, small ripples or dinosaur foot prints. *Thalassinoides* filled with coarse block cement occur locally. This facies type is closely associated with facies type 12, crumbly and platy limestones (see below).
Interpretation: Laminated mudstones are interpreted as biolaminites/stromatolites because of their sedimentological structures. Abundant fenestral pores like birds eyes and sheetcracks are characteristic for the intertidal zone, as reported from the recent by Shinn (1983a,b). Mudcracks and tracks indicate emersion/supratidal conditions.

Facies 12: Crumbly and platy mud- and wackestones
Crumbly and platy mudstones and wackestones are reddish-grey or greenish-grey. They consist of a lime-mud matrix with some clay, microspar, occasionally dedolomite and quartz; slight flaser bedding in very thin- to thin bedded layers may occur (Fig. 17/2). Macro- (shells) and microfaunal (foraminifera, ostracodes) remains are very rare. Some horizons exhibit mud cracks and sheet cracks. Some thin sections display a clotted or pelsparitic microtexture composed of fecal pellets and peloids (Fig. 13/8). Vertebrate remains occur occasionally. This facies only forms very thin sheets at the top part of the Nerinean Limestone interval.
Interpretation: Crumbly and platy mudstones and wackestones accumulated on supra- to intertidal mud flats or marshes as evidenced by their stratigraphical relationship to cyanobacterial laminites, mud cracks and fenestral facies. Mud flats were episodically flooded. Mud cracks and other indicators of emersion and the paucity of marine fauna point to a supra- to intertidal origin. Pelsparitic microtextures within crumbly and platy laminated limestones are interpreted as being intertidal and having formed under episodic water agitation.

FACIES ASSOCIATIONS

The shallow-water, inner-platform setting of the investigated sediments exhibits 12 facies types, which are grouped into four major facies associations (Tab. 1).
Facies 1 and 2 are not considered as facies *sensu stricto*, which indicate a certain depositional environment, because they occur in almost every other facies association (see above).

Nonetheless they are outlined as own facies association (*Thalassinoides* and storm sediment association), because they are genetically closely linked to each other, occasionally they dominate within a bed, and then they have sedimentological and (especially) sequence-stratigraphical importance.

The abundance and high diversity of skeletal fauna in facies 3 to 6 implies normal marine conditions and distinguishes them from the facies in supratidal, intertidal and restricted platform areas. Therefore these facies are grouped into the open lagoon and bight association.

The low diversity and the high abundance of some skeletal fauna and bioturbation in facies 7 to 10 imply restricted marine conditions. These facies were deposited under moderately turbulent water at depths of a few metres and less. They take part in the shallow-subtidal to intertidal, restricted platform facies association.

The quasi-absence of fauna and frequent emersion features in Facies 11 and 12 indicate very restricted conditions in a supra- to intertidal environment in which cyanobacterial activity is important. They are outlined as supra- and intertidal platform area association.

SEQUENCE-STRATIGRAPHIY

Facies, bed-thickness and grain-size were used to define trends; systems tracts are often expressed as several metres to a few tens of metres thick packages (e.g. Pittet & Strasser, 1998; Tab. 1, Fig. 5), which are limited by laterally persistent bounding surfaces (bounding discontinuities). In epicontinental settings often bounding surfaces are replaced by intervals, so-called turn-arounds (e.g. Strasser et al., 1999; Pawellek & Aigner, 2003). The stacking of such packages in combination with the hierarchy of the bounding discontinuities and facies changes were used to separate 3rd order sea level cycles, which (presumably) are superimposed on 2nd order cycles.

In terms of the above outlined characteristics in response to sea level fluctuations the following 3rd order cycles are defined:

Sea level cycle SC 1 (≈ 20 m; Fig. 14)

Sequence boundary SB1 is indicated by a marked lithological change, which is excellently visible at the base of the La Rasse section. This change separates massive-layered, white, chalky, shallow-subtidal, oncoidal limestones (facies 7, Porrentruy Member; Fig. 11/7) from grey, micritic, slightly marly, intertidal and shallow-subtidal, peloidal limestones (facies 8). This change also can be seen in the section Contournement de Glovelier (No. Y in Fig. 1; Jank, 2004). Unfortunatelly, the lack of further easily accessible beds in Chemin Paulin and La Rasse does not allow a more precise description of the first cycle. Nevertheless, the bed-thickness trend at La Rasse (Fig. 14) displays two thickening-upward packages (bed RAS-87 to 79 and 66 to 45) and a thinning-upward package (bed RAS-78 to 67). The same trend in thickness and even in coloring occurs at the contemporaneous Contournement de Glovelier section (Jank, 2004), where these trends clearly cover a lowstand, transgressive and highstand systems tract (LST1, TST1 and HST1; Jank, 2004). Additionally the lowstand corresponding to sequence boundary K1 and the associated lowstand sediments of Gygi et al. (1998) lie within LST1 of this study.

Sea level cycle SC 2 (≈ 30 m; Fig. 15/1)

Sequence boundary SB2 is marked by a clear break and change in sedimentation from white chalky limestones (facies 7) to grey micritic limestones (facies 8) in the upper part of the Thalassinoides Limestones. The grey, micritic deposits, which are mainly composed of homogeneous and peloidal limestones compose LST2. They show mass occurrence

Tab. 1: Facies, depositional environments and characteristics of systems tracts.

No.	Facies	Bathymetry	Depositional environment	Facies association	Developm. of facies	Systems tracts		
						LST	TST	HST
1	Cast and filled *Thalassinoides* -tubes	shallow subtidal (storm wave-base) to intertidal	lagoon	*Thalassinoides* and storm sediment association	–	√	√	
2	Intraclastic pack- to grainstones (-layer)	shallow subtidal (storm wave-base) to intertidal	lagoon	*Thalassinoides* and storm sediment association	–	√	√	
2	Lumachelle (shell bed)	shallow subtidal (storm wave-base) to intertidal	lagoon	*Thalassinoides* and storm sediment association	–		√	√
3	Bioclastic mud- and wackestones (± *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		√	√
4	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				√
5	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	<== basinward migration of facies (regression) landward migration of facies (transgression) ==>		√	√
6	Bioclastic wacke- and packstones with *in situ* macrofauna (± argillaceous, slightly nodular)	shallow subtidal	open lagoon, next to shell shoals	open lagoon and bight association			√	√
7	Oncoidal (chalky) wacke- to packstones and float- to rudstones	(very) shallow subtidal	restricted and relatively quiet lagoon	restricted platform association				√
8	Peloidal mud- to grainstones	intertidal and shallow subtidal	restricted, shallow lagoon and tidal flat	restricted platform association		√		√
9	Non-laminated homogeneous micrite	intertidal and very shallow subtidal	tidal pond and protected, quiet, very shallow bight or lagoon	restricted platform association		√		
10	Lensoidal pack-/rudstone	intertidal	storm surge channel or rip channel in a tidal flat environment	restricted platform association		√		
11	Laminated mudstones	supratidal and intertidal	restricted plarform areas	supratidal and intertidal platform area association		√		√
12	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) overly SBs and form during maximum regression. **Features:** Mud cracks, birds eyes, erosion surfaces, raggioni, tepees, small-scale ripples,dinosaur foot imprints, tidal channels. 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, chephalopods. 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.

of "sand-filled" *Thalassinoides*, numerous minor iron-stained surfaces and ferruginous reworked material, which forms mm- to cm-thick blankets on bed surfaces (Fig. 11/1) or is concentrated in patches (floating grain texture) in the background sediment. Beds thicken upwards (e.g. Fig. 16/1, 3 below the "Nautilidenschichten"). Their composition indicates erosion and condensation in a storm-influenced, inter- to shallow-subtidal setting. These sediments themselves were repeatedly reworked (regressive erosion surfaces). Stromatolitic limestones in Coeuve (No. 4 in Fig. 1) and a channel in Le Banné (No. 1 in Fig. 1) indicate this lowstand as well. In most sections a conspicuous horizon (e.g. beds VAB-40, RAS-25) rich in *Thalassinoides*, which contain considerable amounts of coarse spary calcite cement, also points to very shallow conditions (Fig. 11/6). The cements show delta 18O values between –7.6‰ and –5.1‰ PDB (delta 13C from –4.5‰ to –0.3‰ PDB). Such an isotopic composition is typical for the interaction between early meteoric and marine diagenesis (e.g. Immenhauser et al., 2003).

Transgressive surface ts2 is marked by a prominent, grey or reddish intraclastic pack- to grainstone sheet (e.g. bed VAB-50; Fig. 15/1), which separates the preceding reworked limestones (top Thalassinoides Limestones) from the grey, argillaceous and slightly nodular "Nautilidenschichten". This sheet accumulated as a proximal storm-lag, as suggested by *Thalassinoides* casts on the lower side of the sheet, which fills an erosion relief (Fig. 15/3). The reworked grains exhibit brownish, corroded and abraded coatings and boundaries, which imply discontinuous sedimentation, transport and exposure at the sediment-water interface for some time (e.g. Bathurst, 1966: Millimann, 1974). They formed during transgression when the sea reworked either the previous sequence boundary or the sediments that accumulated during lowstand after the formation of the sequence boundary (ravinement erosion surface). According to Brett (1995) highly corroded, fragmented remains are typical of erosive lowstand or early transgressive conditions and lags consisting of corroded particles typify often highly condensed sections. Transgressive systems tract TST2 is made-up by the "Nautilidenschichten", which are composed mainly of slightly glauconitic, open marine, bioclastic wacke- and packstones with minor iron-stained bed surfaces. They clearly show higher abundance and diversity of fauna, than within the underlying deposits. The lower part is an extremely bioturbated and highly fossiliferous alternation of limestones and marly limestones, in which marly parts contain an increased amount of coarse fossil debris and clasts. Cephalopods indicate a connection to the open sea. A thinning-upward trend in the "Nautilidenschichten" (Fig. 16/1, 3, 4; between ts2 and mfs2) and lithological change from peloidal and homogeneous to bioclastic limestones indicate a deepening; a fining-upward trend indicates a decrease of hydrodynamic energy.

During transgression carbonate production could not keep pace with the generated accommodation space as indicated by the decrease in bed-thickness and in the amount of storm-influenced and winnowed sediments. Additionally the preservation of complete fragile regular and irregular sea urchins with spines at the base of the "Nautilidenschichten" (found in beds CRE-160 and 170 in Creugenat; No. 5 in Fig. 1) are characteristic of marginal environments, which are too deep to be disturbed by storm waves, but still shallow enough to be occasionally inundated by pulses of rapid storm-generated sediments (Brett, 1995).

Maximum flooding surface mfs2 is marked by the transition from the "Nautilidenschichten" into the fine-grained Lower Grey and White Limestones. Highstand systems tract HST2 comprises a thinning-, coarsening- and shallowing-upward trend (Fig. 16/2, 4) and documents a progressive loss of accommodation space (Fig. 5). Maximum flooding and the concomitant loss of carbonate production at the time of largest generation of accommodation space occurred in the vicinity of bed VAB-3 (and corresponding levels) as indicated by a minor facies change (Mouchet, 1998), thin layers, condensation (hardground) and intact multi-element skeletons (e.g. Brett, 1995). The transition from transgression to highstand marks a maximum flooding zone (mfz2) rather than a maximum flooding surface *sensu stricto*, as for example indicated by the facies development in Vatelin (Fig. 6) and Vendlincourt. *Lithacosphinctes cf. janus* (CHOFFAT) (or *Perisphinctidae indet.* respectively) has been

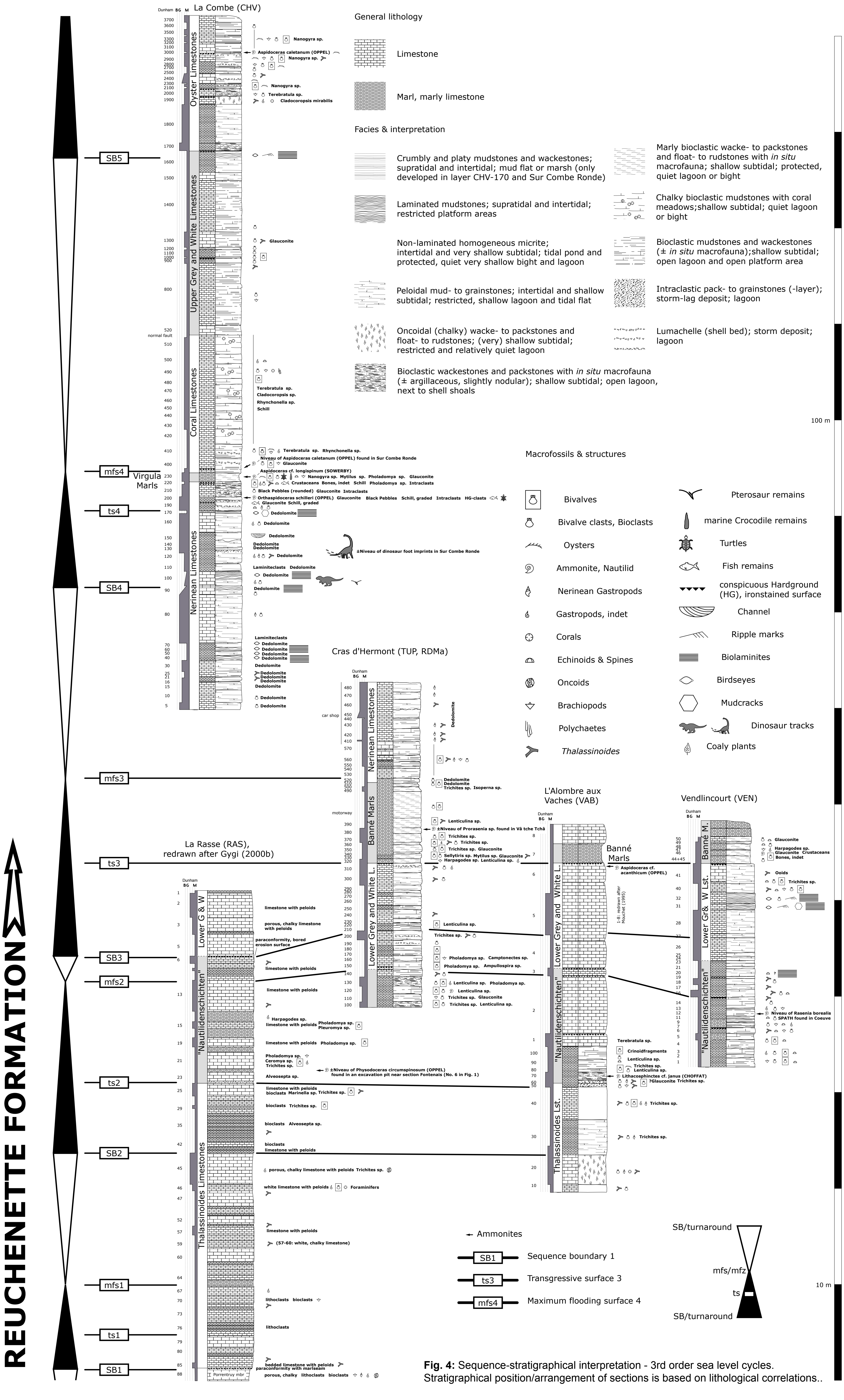
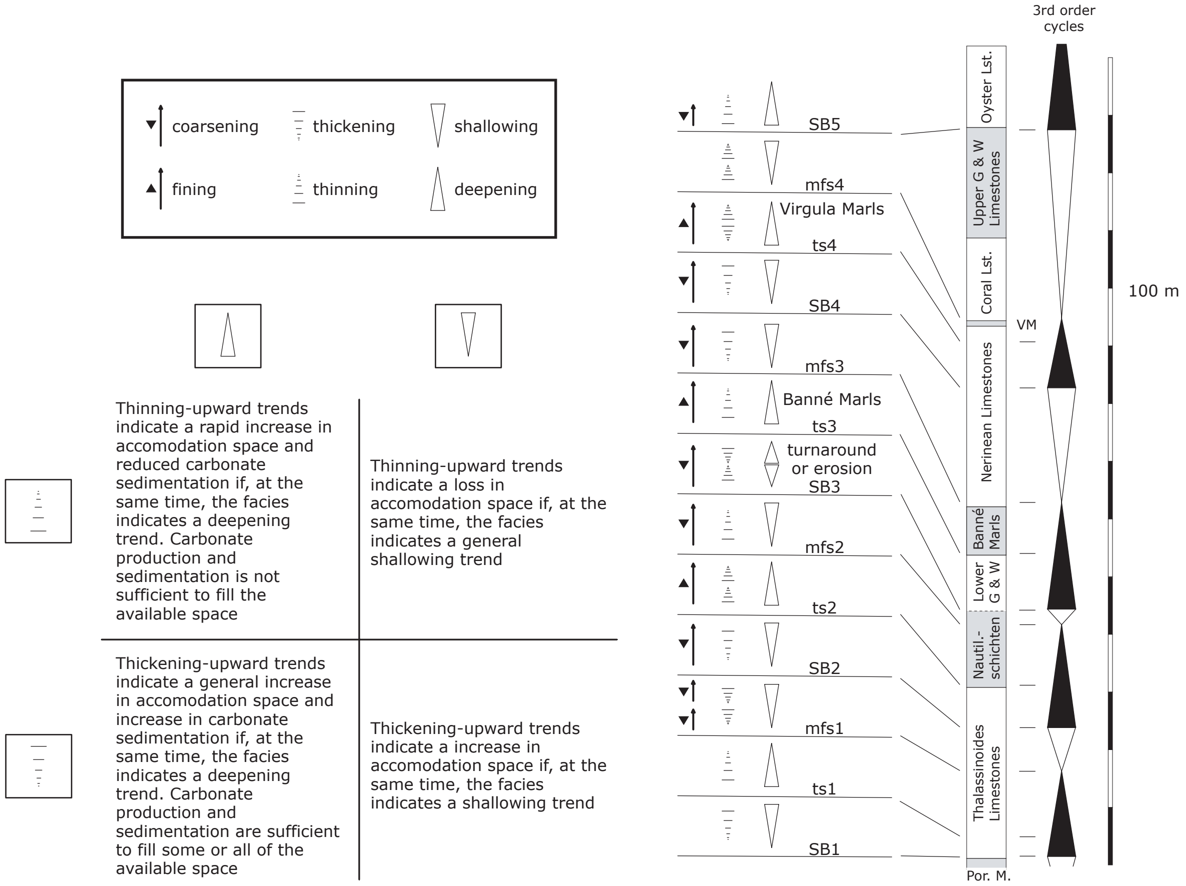


Fig. 4: Sequence-stratigraphical interpretation - 3rd order sea level cycles. Stratigraphical position/arrangement of sections is based on lithological correlations..

found at the base of TST2 in bed VAB-70. *Physodoceras circumspinosum* (OPPEL) was found within the same level in an excavation pit near Fontenais (pers. comm. B. Hostettler; next to No. 6 in Fig. 1). *Rasenia borealis* SPATH has been found in Coeuve (bed COE-370; Fig. 11/5) pointing to the Divisum-Zone.

Sea level cycle SC 3 (≈ 30 m; Fig. 15/1, 16/2, 4, 17/1)
Two thick stromatolite-layers (beds VEN-31 and 32; top Lower Grey and White Limestones) with ripple marks, birds eyes, mud cracks (Fig. 15/2, 16/2) and iron-stained laminae are considered as sea level lowstand deposits. Such a composition, which is observed only in Vendlincourt, indicates slow accumulation (emersion subsequently followed by condensation) and the onset of a slightly rising sea level as slightly deeper deposits covered the mud cracks. As the transition from falling to rising sea level is gradual and displays low sedimentation, this interval indicates a turnaround rather than a sequence boundary *sensu stricto*. A continuous facies-turnaround occurs at the same level in L'Alombre aux Vaches (Mouchet, 1995, 1998). At Cras d'Hermont the corresponding quasi macrofossil-free interval is interpreted as the turnaround but there is no evidence for emersion. At La Rasse bored erosion surface (Gygi et al. 1998) overlain by a coarsening-upward trend indicates the pronounced sea level fall at SB3. Consequently a kind of lowstand *sensu stricto* is solely visible in La Rasse.
The onset of transgressive systems tract TST3 is marked by transgressive surface ts3 with an encrusted hardground. On top of it rest the slightly glauconitic Banné Marls. The composition



Thinning-upward trends indicate a rapid increase in accomodation space and reduced carbonate sedimentation if, at the same time, the facies indicates a deepening trend. Carbonate production and sedimentation is not sufficient to fill the available space

Thinning-upward trends indicate a loss in accomodation space if, at the same time, the facies indicates a general shallowing trend

Thickening-upward trends indicate a general increase in accomodation space and increase in carbonate sedimentation if, at the same time, the facies indicates a deepening trend. Carbonate production and sedimentation are sufficient to fill some or all of the available space

Thickening-upward trends indicate a increase in accomodation space if, at the same time, the facies indicates a shallowing trend

Fig. 5: General development of grain-size, thickness and facies. The implied development of the accomodation space is modified after the concept of Strasser et al. (1999).

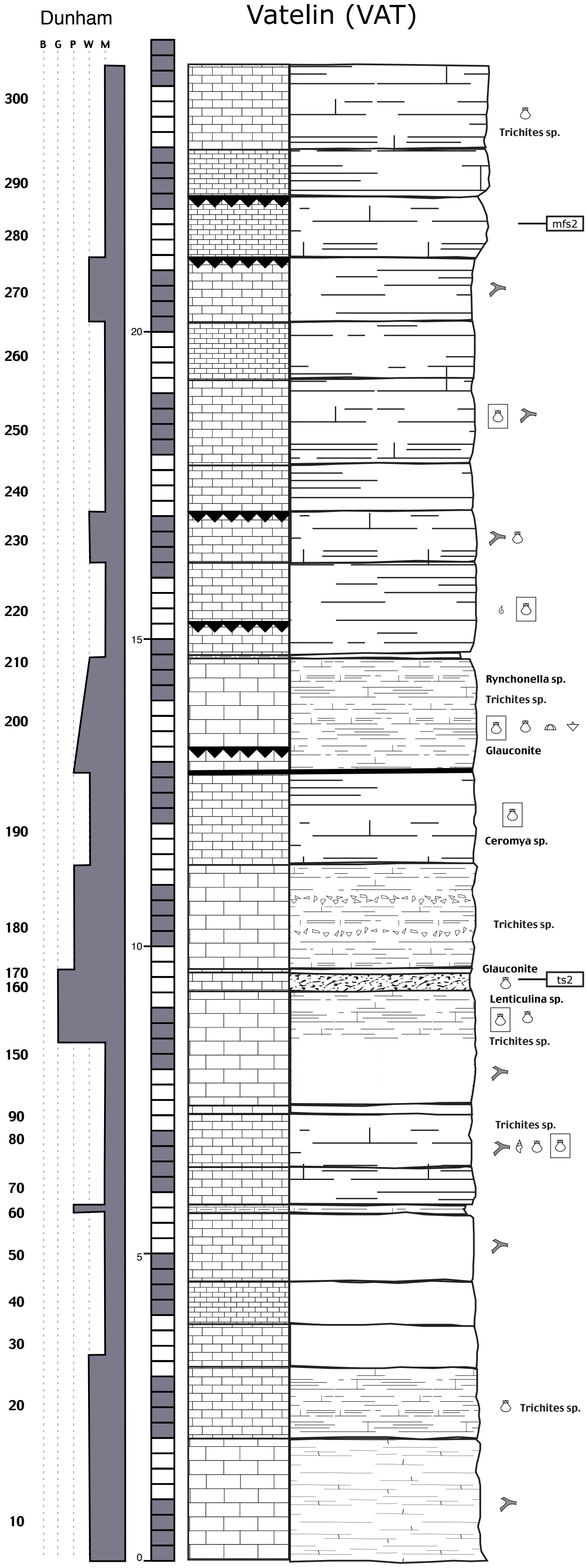


Fig. 6: Section Vatelin. The numbers on the left side of the grey-white scale label meters. For legend see Figure 4.

of the Banné Marls varies between slightly nodular marlstones and marly limestones. They contain a rich macrofauna and cephalopods and intercalated shelly and calcarenitic horizons (probably reworked and winnowed by storms). The lithology points to a near-land, quiet marine lagoon or bight below the fair-weather wave-base and documents a conspicuous increase of water depth. The Banné Marls represent a time of rapid creation of accommodation space and hence, reduced carbonate accumulation (e.g. Strasser et al., 1999; Fig. 5). They are dated by *Prorasenia sp.* that was found in Vâ tche Tchâ (No. 16 in Fig. 1).

Towards the top of the Banné Marls deposition, carbonate accumulation started to re-establish. The base of the Nerinean Limestones marks the maximum flooding surface mfs3. The highstand systems tract HST3 is represented by the lower part of the overlying Nerinean Limestones and it is composed of fine bioclastic limestones, which change into increasingly coarse peloidal packstones with stromatolites and birds eyes. The lithology of HST3 implies a continuous decrease of water depth accompanied by a continuous increase in grain-size (coarsening-upward trend) and finally emersion features. Concomitantly the diversity of the fauna decreases. A slightly progressive increase of accommodation space is reflected by a weak thickening-upward trend (Fig. 5). Locally high-energy deposits such as bioclastic and peloidal winnowed pack- to grainstones with some ooids and oncoids are intercalated.

Sea level cycle SC 4 (≈ 50 m; Fig. 17/1, 18/1, 2)

A pronounced low sea level and break in sedimentation in lowstand systems tract LST4 is indicated by stromatolitic and peloidal limestones accompanied by tidal channels, birds eyes mud cracks and dinosaur foot imprints; some of these deposits became reworked and form intraclasts (e.g. top bed CHV-120).

Calcite-cement rays, which look like raggioni (Mutti, 1994) on a stromatolitic limestone with very small tepees and desiccation cracks in Roches de Mars (bed RDM-140), point to palaeocarst and a very low sea level. LST4 displays a progressive shallowing- and thickening-upward trend finished by a crumbly and platy mudstone with mud cracks (Fig. 17/2). As there is no significant change in composition at the transition from high- to lowstand, this development marks a turnaround rather than a sequence boundary *sensu stricto*.

Transgressive surface ts4 (bed CHV-190) is marked by the distinct onset of (partially graded) lumachelle or worn and rounded bioclastic and peloidal pack- to rudstones with large intraclasts (Fig. 12/8), hardground clasts, invertebrate remains and black pebbles (Fig. 12/7). Such highly corroded, fragmented remains are typical for erosive lowstand or early transgressive conditions and high condensation (e.g. Strasser, 1984; Brett, 1995). In combination with the onset of glauconite sedimentation and several significant hardgrounds it is considered as early part of transgressive systems tract TST4. Further up-section a fining- and thickening-upward trend implies a deepening but still under strongly storm-influenced, shallow-subtidal conditions. The condensed and richly fossiliferous Virgula Marls (Fig. 17/3), which accumulated in a subtidal, protected, near-land setting, are interpreted as late TST4 that developed during a long lasting transgression of the shoreline and low sediment accumulation. The onset of the early transgression is dated by *Orthaspidoceras schilleri* (OPPEL), the intensified creation of accommodation space during deposition of the Virgula Marls by another specimen of *Orthaspidoceras schilleri* (OPPEL), and by *Aspidoceras cf. longispinum* (SOWERBY) and *Aspidoceras caletanum* SPATH.

The Virgula Marls are followed by a slightly marly and iron-rich bed (bed CHV-400) incorporated into the base of the Coral Limestones that documents the re-establishment of limestone sedimentation. This is interpreted as maximum flooding surface mfs4. The iron impregnation resulted from condensation attributed to reduced carbonate production around mfs4. Highstand systems tract HST4 is made up by the extremely thick Coral Limestones and the Upper Grey and White Limestones (Fig. 17/1; Fig. 18/1, 2), which are mainly composed of a homogeneous very thick subtidal, coral bearing and bioclastic limestones without any significant vertical facies variability. At the top of the Upper Grey and White Limestones white bioclastic and peloidal mudstones are capped by a stromatolitic mudstone with ripple marks, birds eyes and iron-stained laminae (bed CHV-1600). HST4 comprises a general shallowing-upward trend accentuated by two progressive thinning-upward trends. According to Sarg (1988) a constant bed-thickness within a thick homogeneous succession, like that of the Coral Limestones, characterises the transition from transgression to early highstand. The enormous thickness of HST4 (≈35 m), the constant bed-thickness and the low facies variability of the Coral Limestones and the Upper Grey and White Limestones within a wide area are probably a result of enhanced subsidence, which balanced deposition rate and reduction of accommodation space.

Sea level cycle SC 5 (Fig. 18/2-4)

The stromatolitic mudstone with ripple marks, birds eyes and iron-stained laminae at the top of the Upper Grey and White Limestones are interpreted as sequence boundary SB5. The peloidal and oncoidal pack- and grainstones at the base of the Oyster Limestones then represent the lowstand systems tract LST5 formed in a shallow-subtidal setting with high hydrodynamic energy. Slightly nodular marly limestones with numerous iron-stained minor surfaces and some hardgrounds follow (beds CHV-2000 to 3700). These are composed of intensively bioturbated, oyster-dominated, bioclastic mud- to wackestones alternating with thin marly intercalations. A subtidal, low-energy environment is inferred; cephalopods imply open marine conditions. They are interpreted as part of the incomplete transgressive systems tract TST5. LST5 and TST5 display an initial thickening-upward followed by a thinning-upward trend with progressive fining and deepening (Fig. 18/2-4, Fig. 5). The numerous iron-stained surfaces indicate condensation. The initial creation of accommodation space was partly compensated by high carbonate production; in a second phase of evolution, carbonate production was probably unable to keep pace with the created accommodation space (TST5). In bed CHV-3000 the Caletanum-Horizon is indicated by Aspidoceras caletanum (OPPEL).

INTERPRETATION

Vertical rhythmic changes of facies and inferred depositional environment allowed distinguishing five sea level cycles. Each of them consists of a basal transgressive interval followed by a regressive one.

SB3 and SB5 have been biostratigraphically dated by *Rasenia borealis* SPATH, *Prorasenia sp.* and *Aspidoceras caletanum* (OPPEL) to the Divisum-Zone and Caletanum-Horizon (Eudoxus-Zone) respectively (Fig. 7). Based on the assumption that these cycles are similar in duration, the time calibration (compare Hardenbol et al., 1998) of the sequence boundaries SB3 and 5 with estimated time duration of about 1.4 my for cycles SC3 and 4 led to an average of about 0.7 my duration for these sea level cycles. Therefore the cycles SC1 to 5 are interpreted as 3rd order sea level cycles *sensu* Van Wagoner et al. (1988) and Vail et al. (1991). Additionally 0.7 my cycle-duration roughly corroborates the ages of the sequence boundaries SB1, 2 and 4 proposed by the other ammonites (see below).

The persistent vertical rhythm of stacked systems tracts along with the presence of emersion features indicate that periodic change of accommodation played an important role in their formation (compare Strasser, 1991). In addition, in some of the systems tracts a number of higher-order rhythms were clearly identified as for example visible in L'Alombre aux Vaches, where TST2 is composed of several bed sets, or La Combe where HST4 is composed of two thinning-up bed sets. As in average one cycle is assumed to have lasted for about 0.7 my, the duration of transgressive and regressive successions may fall within the Milankovitch long eccentricity band (400 ky). Furthermore the 3rd order rhythms comprise several beds and bed sets, which may indicate the possible influence of the precession (20 ky) and obliquity (40 ky), and short eccentricity (100 ky) Milankovitch cycles (e.g. Fig. 18/1, 2).

SB1 and SB2 can be assigned to the Planula- (late Oxfordian) and Platynota-Zone (Early Kimmeridgian) because of the find of *Physodoceras circumspinosum* (OPPEL). At the same level, however, *Lithacosphinctes cf. janus* (CHOFFAT) occurs (compare Biostratigraphy). Assuming an average cycle length of 0.7 my, SB2 probably lies within the Platynota-Zone. Then mfs2 would lie within the Hypselocyclum-Zone. As mentioned above SB3 is within the Divisum-Zone. *Rasenia borealis* SPATH and *Prorasenia sp.* justify placing ts3 (at the base of the Banné Marls) into the Divisum-Zone (see position of ammonites in Fig. 4). Because Prorasenia sp. also occurs within the Banné Marls the sedimentation of the Banné Marls started within the Divisum-Zone; their upper boundary, however, still needs to be biostratigraphically defined. Mfs3 and SB4 fall into the

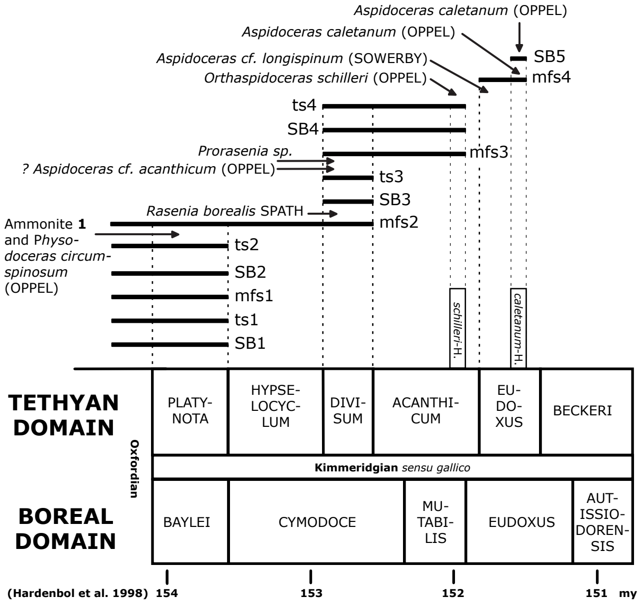


Fig. 7: Possible maximum time ranges of SBs, ts' and mfs' derived from ammonites. Note that SB3, ts3 and SB5 are most precisely dated. The age-assignment of SB1 to ts2 is based on only specimen of *Physodoceras circumspinosum* (OPPEL). The two possible ages given by ammonite 1 (see above) are not considered. Nevertheless, the age assigment given by *Lithacosphinctes cf. janus* (CHOFFAT) agrees with those given by *Physodoceras circumspinosum* (OPPEL).

Acanthicum-Zone if the cycles are of roughly similar duration. *Orthaspidoceras schilleri* (OPPEL), indicating the Schilleri-Horizon (Upper Acanthicum-Zone), was found 2 m above ts4 and on the hardground directly beneath the Virgula Marls (Marty et al., 2003). Accordingly, ts4 is assumed to be within the Schilleri-Horizon. The base of the Virgula Marls is dated to the Schilleri-Horizon (upper Acanthicum-Zone) by a second specimen of Orthaspidoceras schilleri (OPPEL) as well; the lowermost Eudoxus-Zone is indicated by *Aspidoceras cf. longispinum* (OPPEL) (also found in the Virgula Marls); the top of the Virgula Marls is assigned to the Caletanum-Horizon (upper Eudoxus-Zone) by *Aspidoceras Caletanum* (OPPEL), which was found in the first limestone layer above the Virgula Marls (pers. comm. D. Marty). Mfs4 and SB5 lie also within the Caletanum-Horizon, indicated by another specimen of *Aspidoceras caletanum* (OPPEL).

The 2nd order sea level fluctuations are believed to be clearly identifiable, only when the development in Oxfordian and Tithonian times is also taken into consideration which would be, however, out of the scope of this paper. Nevertheless the deposits around and between SB3 and SB4 represent a very thick regressive depositional succession as indicated by birds eyes, mud cracks and dinosaur foot imprints. Therefore these deposits are interpreted as lowstand (LST-B) presumably belonging to a 2nd order sea level cycle (SC-B; Fig. 8), which begins with SC 3 and 4. The depositional sequences SC 1 and 2 are interpreted as the preceding 2nd order cycle SC-A from the Planula- to Divisum-Zone; the transgressive peak being in the Hypselocyclum-Zone („Nautilidenschichten“). The general facies distribution of SC-A shows a fining- followed by a coarsening-upward trend with the inflexion point

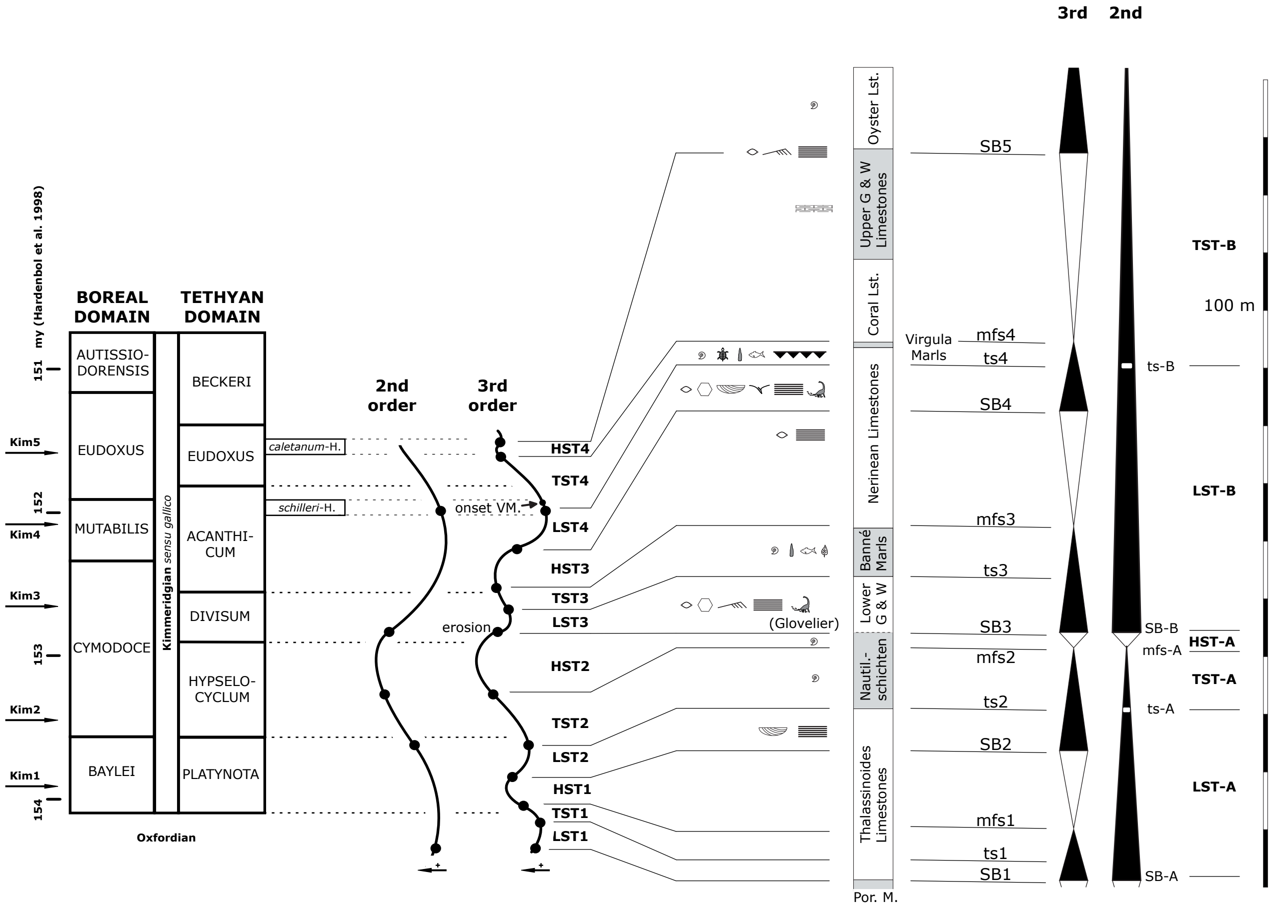


Fig. 8: Systems tracts of the Reuchenette Formation in comparison to chronometric time, tentative relative sea level trend and thickness. Kim1 to 5 are the Boreal sequence boundaries after Hardenbolet al. (1998). For legend see Figure 4.

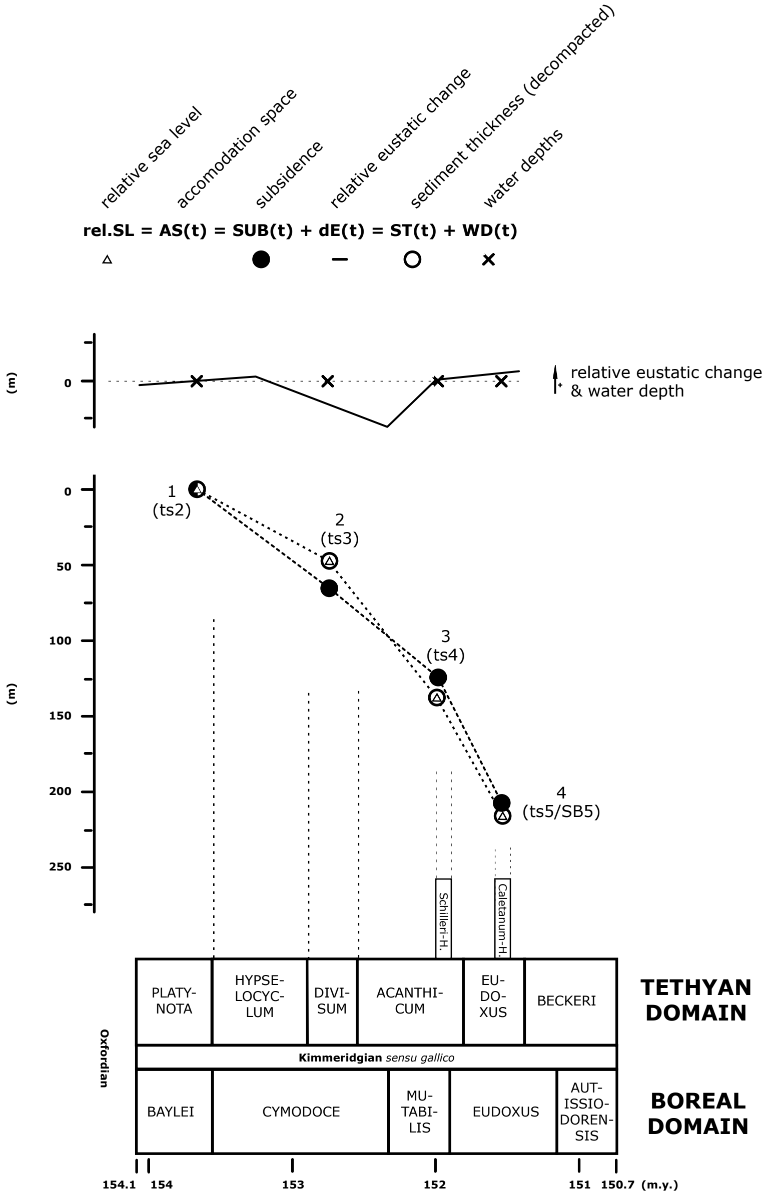


Fig. 9: Accomodation space, subsidence and sediment thickness between ts2 and ts5. Note the point where relative sea level rise gets ahead of subsidence coincides with point of maximum regression in the curve of eustatic change, i.e. the following accomodation space is additionally provided by eustic sea level rise (besides the subsidence).
Approximated decompaction factors: marl x3, limestone x2 (based on Moore, 1989; Goldhammer, 1997; Matyszkiewiez, 1999). Chronometric time scale according to Hardenbol et al. (1998). Relative eustatic changes according to Sahagian et al. (1996; Russian Craton).

	"position"	thickness difference (m)	thickness differnce ,decompacted (m)	thickness development ,decompacted (m)	water depth (m)	relative eustatic change (m)
1	4 m below ts2 in Coeuve (stromatolite)	0	0	0	0	0
2	4 m below ts3 in Vendlincourt (stromatolite with birdseyes and mudcracks)	24	48	48	0	-17
3	ts4 in La Combe (crumbly and platy mudstone with mudcracks)	8 (marl) & 33	90	138	0	15
4	ts5/SB5 in La Combe (stromatolite with birdseyes)	1 (marl) & 37	76	214	0	3

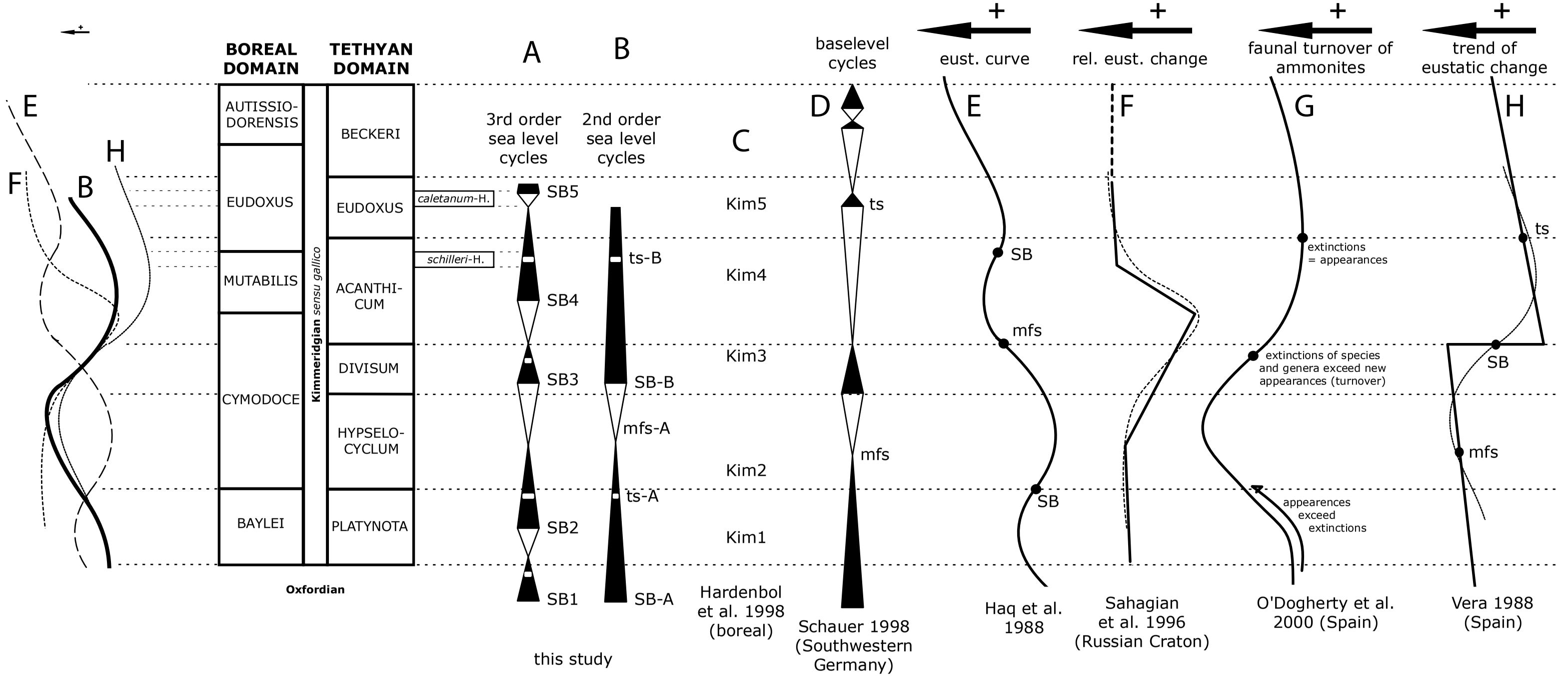


Fig. 10: Right side: Comparison of this work (A, B) with other studies (Relative changes of E, F, G & H are not to scale; thin and small stippled line in F and H: interpreted sinus-curve). The general trend of Sahagian et al. (F), O'Dogherty et al. (G) and Vera (H) "fits" with the "2nd" order trend of this study. Haq et al.`s short term curve (E) extremely differs in the lower part (Hypselocyclum-Zone). Number and ages of Boreal sequence boundaries Kim1 to 5 of Hardenbol et al. (C) partly match with those of this study (especially Kim3 to 5); discontinuities of Schauer (D) are occassionally different. As mentioned in the text differences are most probably due to limited biostratigraphical resolution and data and the calibration of the biostratigraphical schemes used in the different studies. Schauer's differences are probably due to the different investigation methodes (baselevel concept). Left side: "2nd" order trend of this study (B) crossed with the curves of Haq et al. (E) Sahagian et al. (F) and Vera (H) in the Divisum-Zone.

located around mfs2/mfs-A. The lithology around mfs-A (TST2 and HST2) corresponds to the maximum development of open platform facies and is regarded as the maximum flooding zone of this 2nd order sequence. LST-A and TST-A show a trend to increasingly open platform facies, up to a maximum around mfs-A. LST-B is recorded by significant hydrodynamical, sedimentological and faunal modifications towards near-land or terrestrial conditions as indicated by for example black pebbles, coaly plants (pers. comm. D. Marty), crocodile teeth within the Banné Marls (Marty & Diedrich, 2002), dinosaur foot imprints and sub-aerial erosion. Therefore, the Banné Marls are considered as 3rd order, transgressive, probably condensed, intercalation within a 2nd order, shallowing-upward lowstand (LST-B; Fig. 8). The development following SB4 probably indicates the beginning of the second 2nd order transgression TST-B.

The thickness of the studied sediments markedly exceeds the depositional water depths and therefore, additional accommodation space must have been provided during deposition (Wetzel et al., 2003). Additionally, subsidence was not synchronous (Fig. 9). For example, the increased thickness between ts4 and ts5 during a moderate eustatic rise (Fig. 9) first led to long lasting condensation (represented by the Virgula Marls) and then to very thick deposits that formed within a short time interval (Caletanum-Horizon, compare Fig. 8). Correspondingly, after initial underfill of the created accommodation space, sediment accumulation drastically increased. Such a stacking-pattern can be attributed to an aggradational or weakly retrogradational parasequence set in a transgressive systems tract (Van Wagoner et al., 1988). Considering the short time span covered by the Caletanum-Horizon the enormous thickness of the Coral Limestones and Upper Grey and White Limestones, (probably) related to an important gain in accommodation space, resulted from sea level rise and enhanced subsidence (Wetzel et al., 2003).

DISCUSSION

The sea level fluctuations deduced in this study are in good agreement with several other investigations (e.g. Vera, 1988; Sahagian et al., 1996; Hardenbol et al., 1998; O'Dogherty et al., 2000; Fig. 10) but markedly differ from those of Haq et al. (1988) and Schauer (1998). The sequence boundaries SB3 to 5 of this study match well the boreal sequence boundaries Kim3 to 5 of Hardenbol et al. (1998) (Fig. 10). A significant eustatic minimum, which is enclosed by two prominent eustatic maxima interpreted for the Russian Craton by Sahagian et al. (1996) fits well with the 2nd order trend of this study; the maxima are within the Hypselocyclum- and Eudoxus-Zones and the minimum within the Acanthicum-Zone. The ammonite-faunal turnover-curve of the Betic Cordillera of Spain of O'Dogherty et al. (2000) also mirrors the 2nd order sea level trend of this study. For example, the culmination of the development of new genera and species in the Hypselocyclum-Zone coincides with mfs-A. The following decrease of diversity and the start of recovery is in accordance with this study as well. The age of the turnover coincides with SB-B and recovery approximately with the onset of TST-B. Vera's (1988) trend of eustatic change also represents a significant analogy, which is represented by two eustatic sea level rises separated by a prominent sequence boundary (at the transition Divisum-Acanthicum-Zone). Pittet & Strasser (1998) have also demonstrated that spanish and swiss sea level fluctuations correlate well in Oxfordian times. Schauer's and Haq et al.'s curves only partly match those of this study. The obvious and occasionally rather prominent mismatches between the studies might depend on limited biostratigraphical resolution, limited biostratigraphical data and (especially) the difficult calibration of biostratigraphical schemes used in the different studies (e.g. boreal, tethyan, subboreal, etc.).

CONCLUSIONS

New biostratigraphical data, facies and sequence stratigraphical analysis of the late Jurassic Reuchenette Formation in the Ajoie-Region (NW Switzerland) led to the identification of 3rd order relative sea-level fluctuations that are superimposed on a presumably 2nd order sea level trend. Additionally, considering that high-resolution biostratigraphical data are very rare in the platform carbonates of the Reuchenette Formation, this study provides an improved (more precisely dated) insight into the development of Kimmeridgian sea level changes in NW Switzerland. The data of this study form a reference frame for a comparison/correlation with adjacent areas.

(1) Five sedimentary sequences have been interpreted as result of 3rd order relative sea level cycles for the Late Oxfordian to Late Kimmeridgian *sensu gallico* time interval. The SBs lie in the Planula-, Platynota-, Divisum-, Acanthicum and uppermost Eudoxus-Zone. SB3 to 5 coincide with the boreal sequence boundaries Kim3 to 5 of Hardenbol et al. (1998). The influence of the Boreal realm is partly corroborated by ammonites, which are typical for the Boreal realm *sensu stricto* (but Tethyan ammonite occur as well; compare Schweigert et al., in prep.).

(2) The sequence boundaries SB1 and SB2 may, but do not have to, be assigned to the boreal sequence boundaries of Hardenbol et al. (1998) due to the different interpretation of ammonites found in the lower Reuchenette Formation. Therefore SBs traceable over large distances might provide a reference to rectify biostratigraphy.

(3) The first two 3rd order cycles are superimposed on a 2nd order transgressive-regressive sea level cycle, the mfs being in the Hypselocyclum-Zone. Dinosaur foot prints, erosion, birds eyes and mud cracks mark a pronounced 2nd order lowstand in the Acanthicum-Zone (3rd order cycles three and four). A second 2nd order transgression begins probably with the fourth 3rd order cycle.

(4) Minimum accommodation space resulted in local exposure and very shallow-water to supratidal deposits. The increasing sea level rise during TSTs led to the most prominent lithological changes on top of condensed suites indicated by marly deposits and winnowing. Maximum floodings resulted in the highest rates of carbonate production (Handford & Loucks, 1993) and led to the deposition of thick- and massive-layered relatively deep open shallow-marine carbonates.

(5) The preservation of (parts of) fossils appears to be related to the systems tracts; highly corroded, fragmented remains are typical of erosive lowstands or early transgressive conditions. Intact multi-element skeletons characterise rapid background sedimentation during highstands and ferruginous lags of corroded particles and fossils typify condensed sections. Skeletal accumulations develop during intervals of low sediment input. Starved accumulations and winnowed shell beds may indicate transgressions.

(6) Synsedimentary differential subsidence modifies the lithological expression of sea level fluctuations. The sea level fluctuations are superimposed on differential synsedimentary subsidence; this led to a repeated reorganization of the depositional environment, favouring shifts of the facies belts and the establishment of specific settings.
Enhanced subsidence within the Caletanum-Horizon (Eudoxus-Zone) led to the formation of extremely thick, homogeneous packages.

ACKNOWLEDGEMENTS

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Fig. 11: Late Oxfordian to late Kimmeridgian platform carbonates of NW Switzerland: *Thalassinoides* and storm sediment association (Pics 1-4, 6), macrofossils (Pics 5, 8) and indicator for reduced sedimentation (Pic. 7).

Pic. 1: Intraclastic storm-lag deposit (reddish), developed as incipient hardground, covering a grey micritic limestone-firmground and filled into *Thalassinoides* burrows (arrow). (Scale: coin ≈2.5 cm; Bas d'Hermont).

Pic. 2: Storm sediment (brown) biomottled with bioclastic soft-sediment-mudstone - Storm material is composed of ferruginous reworked material, peloids and rounded and micritised bioclasts. The bioclastic mudstone partly forms pseudointraclasts. (Scale bar: 5 cm; bed VAT-180, Vatelin).

Pic. 3: Intrabioclastic pack-to grainstone - Components are composed of intraclasts (from reworked peloidal limestones) and worn and rounded bioclasts. (Scale bar: 1 mm; bed COE-270, Coeuve).

Pic. 4: Intraclastic pack- to grainstone deposited as tempestite indicating lag deposition - (1) bioclastic mudstone intraclast, (2) peloidal mudstone intraclast, (3) abraded intraclast. (Scale bar: 1mm; bed COE-260, Coeuve).

Pic. 5: *Rasenia borealis* SPATH in a bioclastic mudstone. (Bed COE-340, Coeuve)

Pic. 6: Conspicuous horizon composed of Thalassinoides filled with coarse-grained spary cement. (Bed VAT-150, Vatelin).

Pic. 7: Porrentruy Member – Brown rimmed oncoids and intraclasts in a white chalky limestone. According to Flügel (1982) ferruginous rims on oncoids occur when sedimentation begins to lag or is interrupted. (Scale: coin ≈2 cm; bed RAS-88, La Rasse).

Pic. 8: Large gastropods (Nerineans) in coarser grained peloidal limestone; found a few meters below the Virgula Marls in Sur Combe Ronde.


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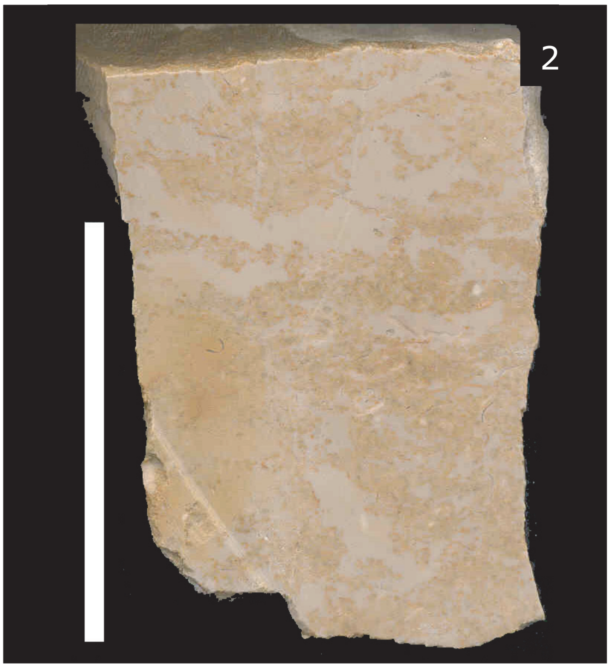
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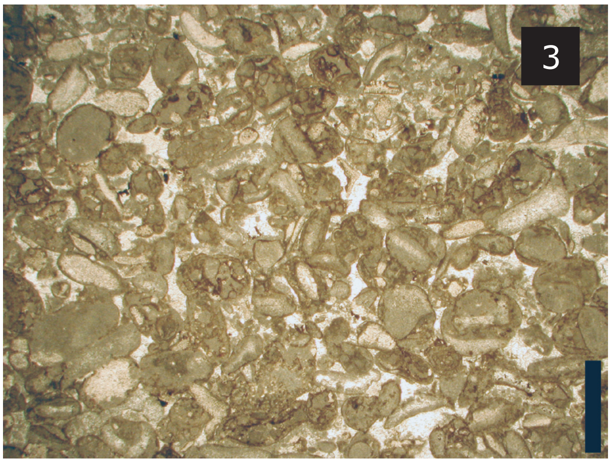
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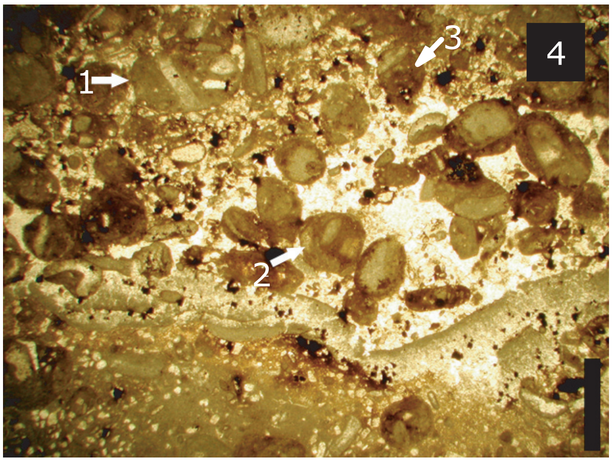
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Fig. 12: Late Oxfordian to Late Kimmeridgian platform carbonates of NW Switzerland: Facies types (Pic. 1-6) and storm sediments (Pics 7, 8).

Pic. 1: Bioclastic mudstone composed of angular bioclasts and spongerhaxen. (Scale bar: 1 mm; bed TUP-110, Cras d’Hermont).

Pic. 2: Bioclastic packstone with rounded micritised components and peloids mixed with bioclastic mudstone (top right corner) due to storm input and bioturbation. Elongated big clast in the center (arrow) probably shows microbial coating. (Scale bar: 1 mm; bed COE-350, Coeuve)

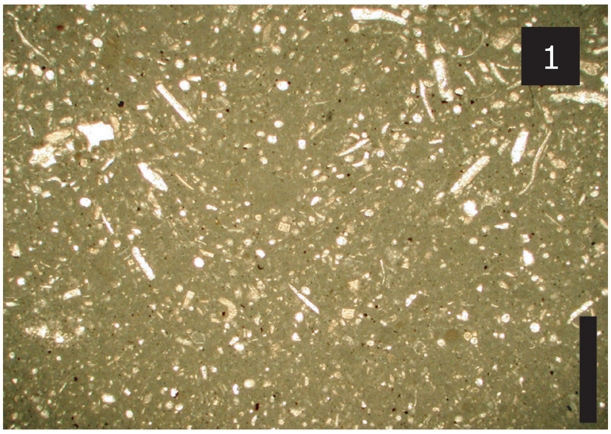
Pic. 3 and 4: Bioclastic packstone with large rounded bivalve clasts and rounded reworked material (intraclast, see close up Pic. 4). Some micritised bioclasts show no trace of the original shell structure. Casts (arrows) formed by complete solution of probably aragonite shell, followed by precipitation of cement into the void at a later date. The intraclast shows dedolomite rhombs (orange) in a fecal-pellets-packstone texture. Note abrasion of intra particles. This means the grain must have been “lithified” at the time of reworking and might also be interpreted as an extraclast. (Scale bar: 1 mm; bed CHV-200, La Combe).

Pic. 5: Bioclastic wacke- to packstone with small angular bioclasts and reworked material (brown rimed). Original background sediment (bioclastic mudstone) can be seen in bivalve. (Scale bar: 1 mm; bed CHV-210, La Combe).

Pic. 6: Bioclastic mud- to wackestone composed of angular and some micritised bioclasts. (Scale bar: 1 mm; bed VEN-46, Vendlincourt).

Pic. 7: Black Pebbles (arrows) in Schill layer - Black bivalve shells are oysters. (Length of large black pebble is about 2 cm; bed CHV-200, La Combe).

Pic. 8: Large intraclast (reworked and rounded) from the base of bed CHV-190 deposited at the top of the same layer above a hardground in a glauconitic storm schill bed. (Scale: coin ≈3 cm; top of bed CHV-190, La Combe).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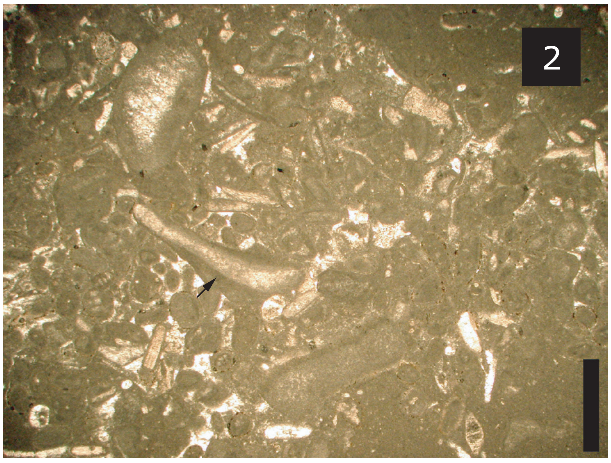
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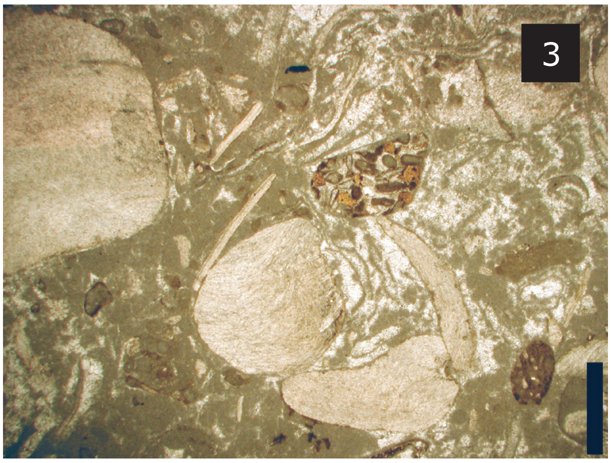
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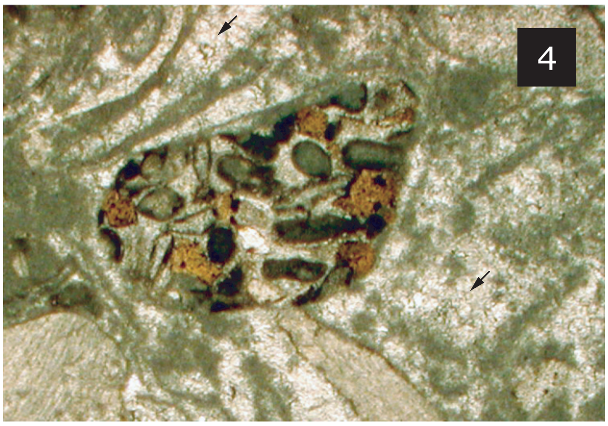
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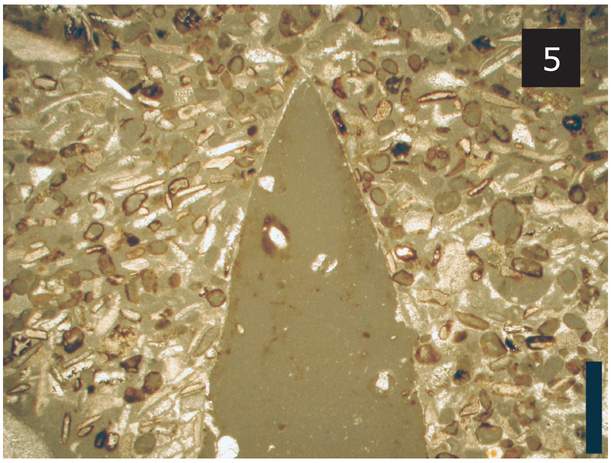
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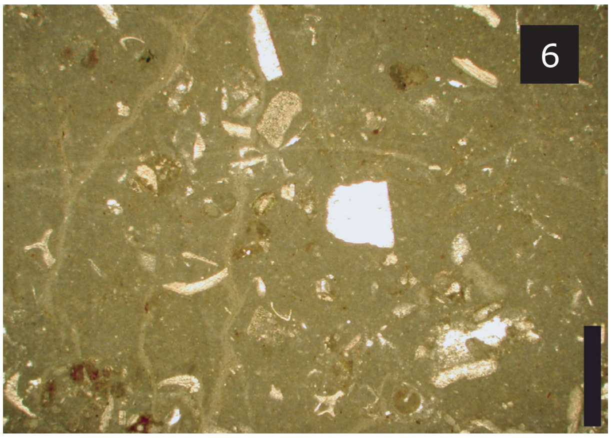
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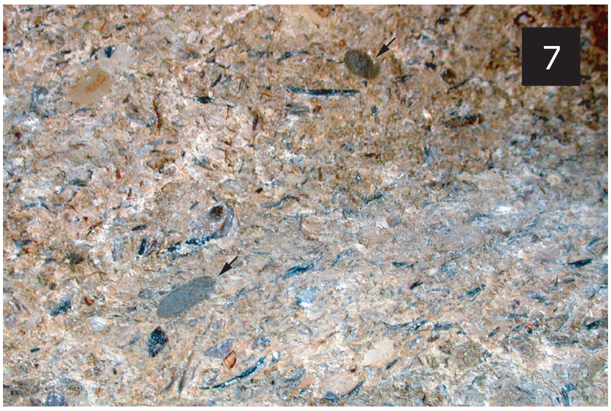
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8

Fig. 13: Late Oxfordian to Late Kimmeridgian platform carbonates of NW Switzerland: Facies types.

Pic. 1: *Cladocoropsis mirabilis* in peloidal packstone matrix. Note peloids merge to micrite. (Scale bar: 1 mm; bed CHV-1900, La Combe).

Pic. 2 and 3: Channel intercalated into well bedded limestones. Unit is composed of several amalgamated noncontinuous lensoidal sheets. Sample from channel infill (Pic. 4) shows a crude fining-up sequence following an erosion surface (1). Note reworked and rounded channel-background-sediment (2) mixed with different clasts (e.g. *Marinella sp.* (3)). (Scale bar Pic. 3: 20 cm, length of sample in Pic. 4 is about 10 cm; bed BAN-140, Tunnel Le Banné).

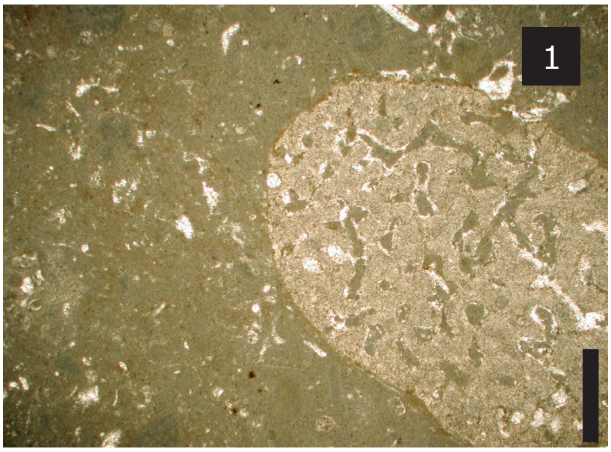
Pic. 4: Peloidal wacke- to packstone with large matrix-dedolomite-rhombs (arrows) - Individual peloids are for the most part indistinct. The dedolomite crystals have cloudy centers and clear rims, some are multi zoned - a commonly observed feature. (Scale bar: 1 mm; bed CHV-140, La Combe).

Pic. 5: Peloidal packstone with miliolids (arrows) - Peloids (fecal pellets and larger peloids) build a grain-supported texture with some fenestrae. (Scale bar: 1 mm; bed VEN-27, Vendlincourt).

Pic. 6: Peloidal grainstone with large peloids/intraclasts and small fecal pellets. (Scale bar: 1 mm; bed CHV-80, La Combe).

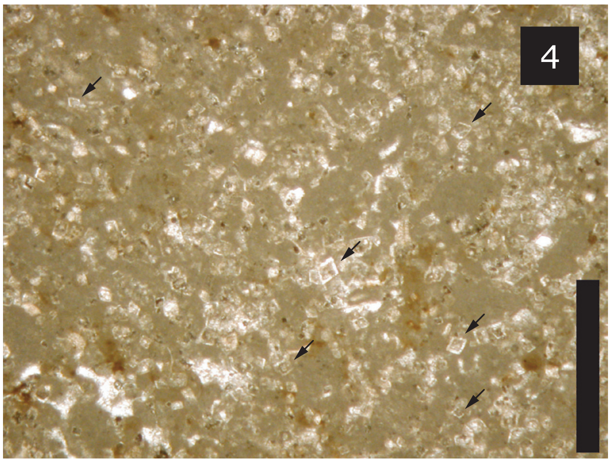
Pic. 7: *Thalassinoides* in homogenous mudstone filled with coarser grained material. (Scale bar: 1mm; bed COE-240, Coeuve).

Pic. 8: Crumbly and platy mudstone – Irregular laminated alternation of fine peloidal (probably fecal pellets) sediment and carbonate mud separated by sheet parallel fenestrae. They probably correspond to decay of organic matter. Note larger peloids in centre of photograph (arrows). (Scale bar: 1 mm; bed CHV-170, La Combe).


1


2


3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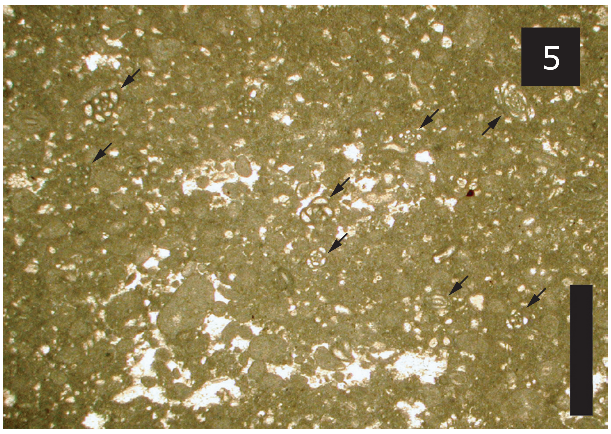
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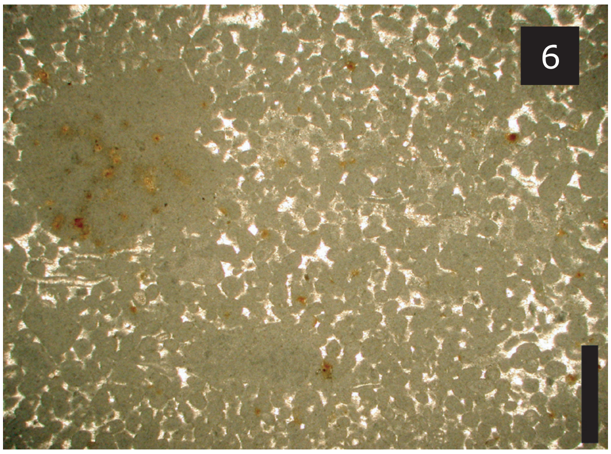
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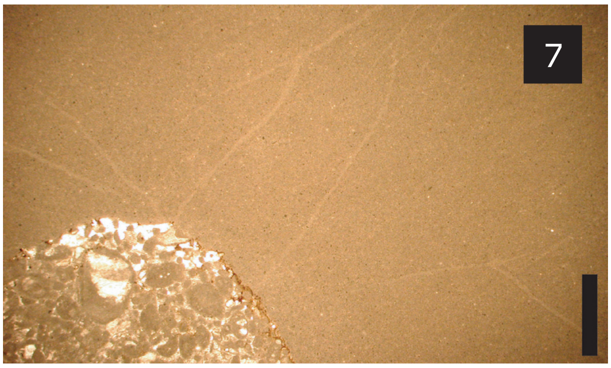
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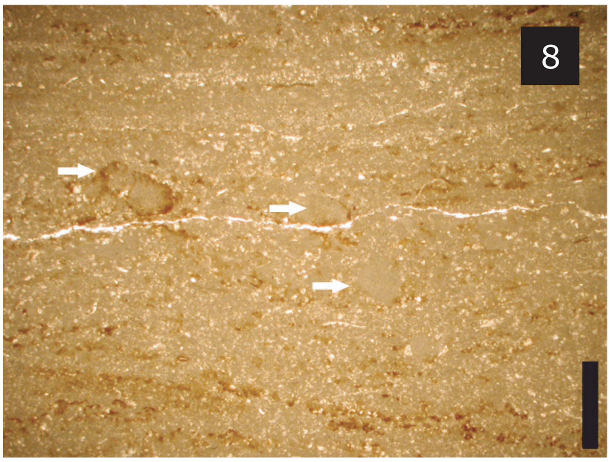
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Fig. 14: Overview of the lower part of the quarry La Rasse. Lines mark the thickness- and color-trend.


ts2
RAS-45
SB2
RAS-66
RAS-67
mfs1
RAS-78
RAS-79
ts1
RAS-87
Porrentruy Member
SB1

Fig. 15: Position of discontinuities SB2 to mfs3 (Pic. 1) and typical sedimentological and lithological features (Pics 2-4).

Pic. 1: Quarry L'Alombre aux Vaches – SB2 is placed on top of the white, chalky limestones in the top part of the Thalassinoides Limestones (bed VAB-20). The transgressive surface ts2, on top of bed VAB-50, and maximum flooding surface mfs2 have been recorded in the Nautilidenschichten; sequence boundary SB3, ts3 and mfs3 in the Lower Grey and White Limestones and on top of the Banné Marls.

Pic. 2: Mudcracks in laminated and wavy stromatolites - The level of bed VEN- 31 in Vendlincourt corresponds to the third bed below ts3 on Pic. 1 and Fig. 16/4, respectively.

Pic. 3: Bottom side of intraclastic pack- to grainstone sheet with cast *Thalassinoides* deposited as tempestite indicating erosion and lag deposition – This sheet correlates with bed VAB-50 in Pic. 1. (scale: coin ≈3 cm; bed COE-260, Coeuve).

Pic. 4: Oncoidal wackestone – Oncoid in the right bottom corner shows attached or encrusted bioclasts. Bioclasts act as nuclei. Sample was taken from the white, chalky limestone below SB2 (compare Pic. 1). (Scale bar: 1 mm; bed VAB-20, L'Alombre aux Vaches).


1
mfs3
ts3
SB3
mfs2
ts2
SB2
Thalassinoides L.
Intraclastic pack-grainstone strom-lag; VAB-50
White, chalky limestone; VAB-20
"Nautilidenschichten"
Lower Grey and White L.
Banné Marls
Ner. L.


2


3
C9E

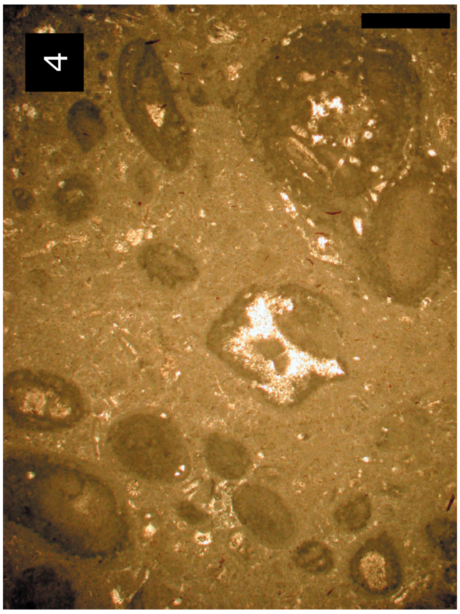
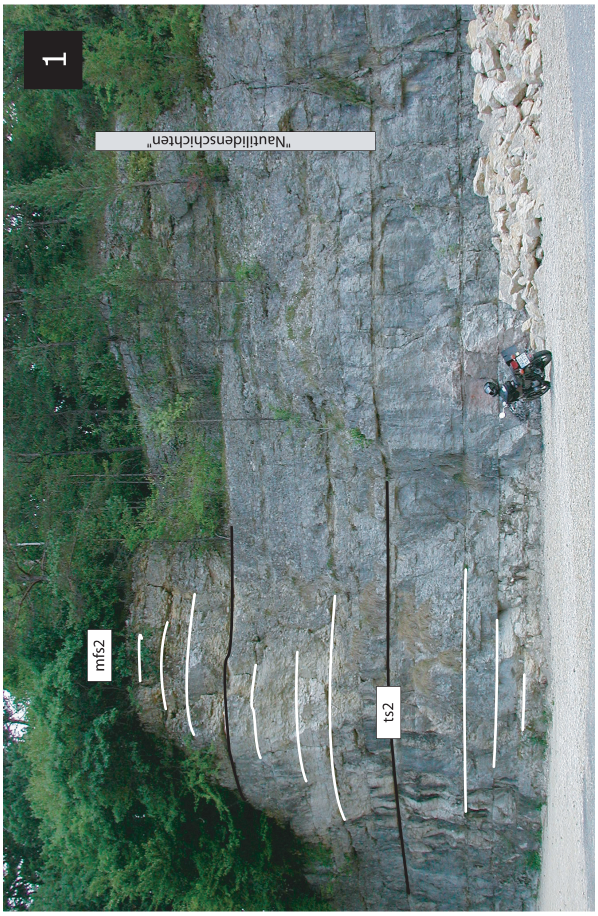
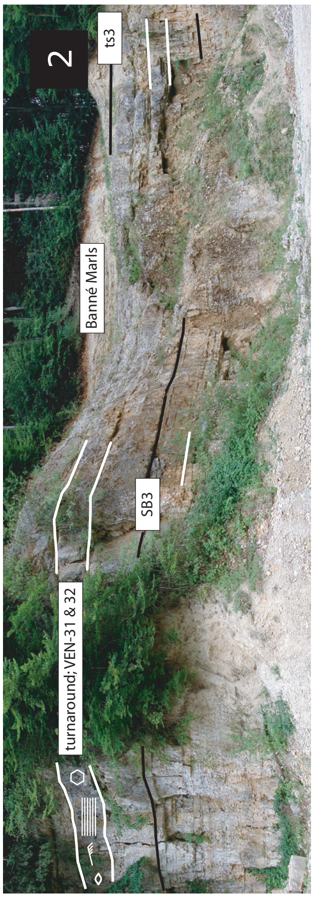
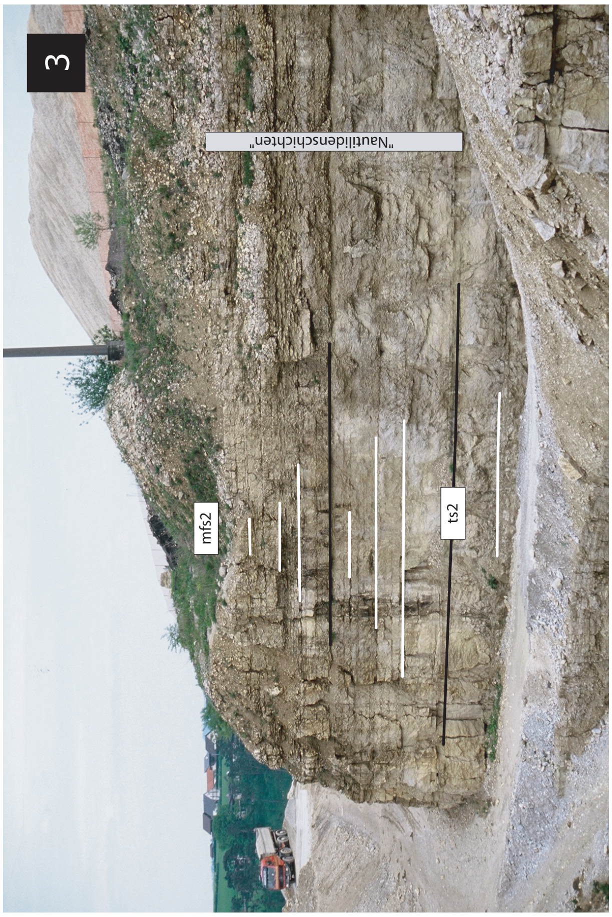

4

Fig. 16: Thickness trend of the “Nautilidenschichten” and Lower Grey and White Limestones in Bas d’Hermont (Pic. 1), Vendlincourt (Pic. 2), Vatelin (Pic. 3) and L’Alombre aux Vaches (Pic. 4). Below ts2: thickening-upward; between ts2 and mfs2: thinning-upward; between mfs2 and SB3: thinning-upward; between SB3 and ts3: thinning-thickening-upward.


1
"Nautilidenschichten"
mfs2
ts2


2
ts3
Banné Marls
SB3
turnaround; VEN-31 & 32


3
"Nautilidenschichten"
mfs2
ts2

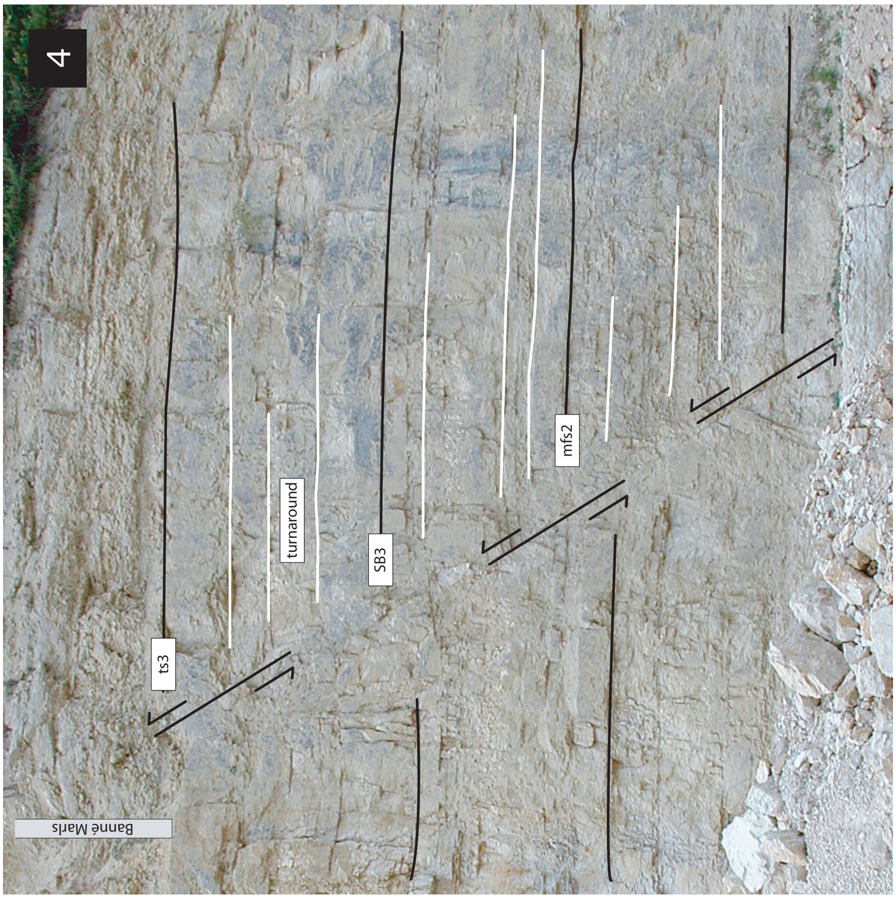
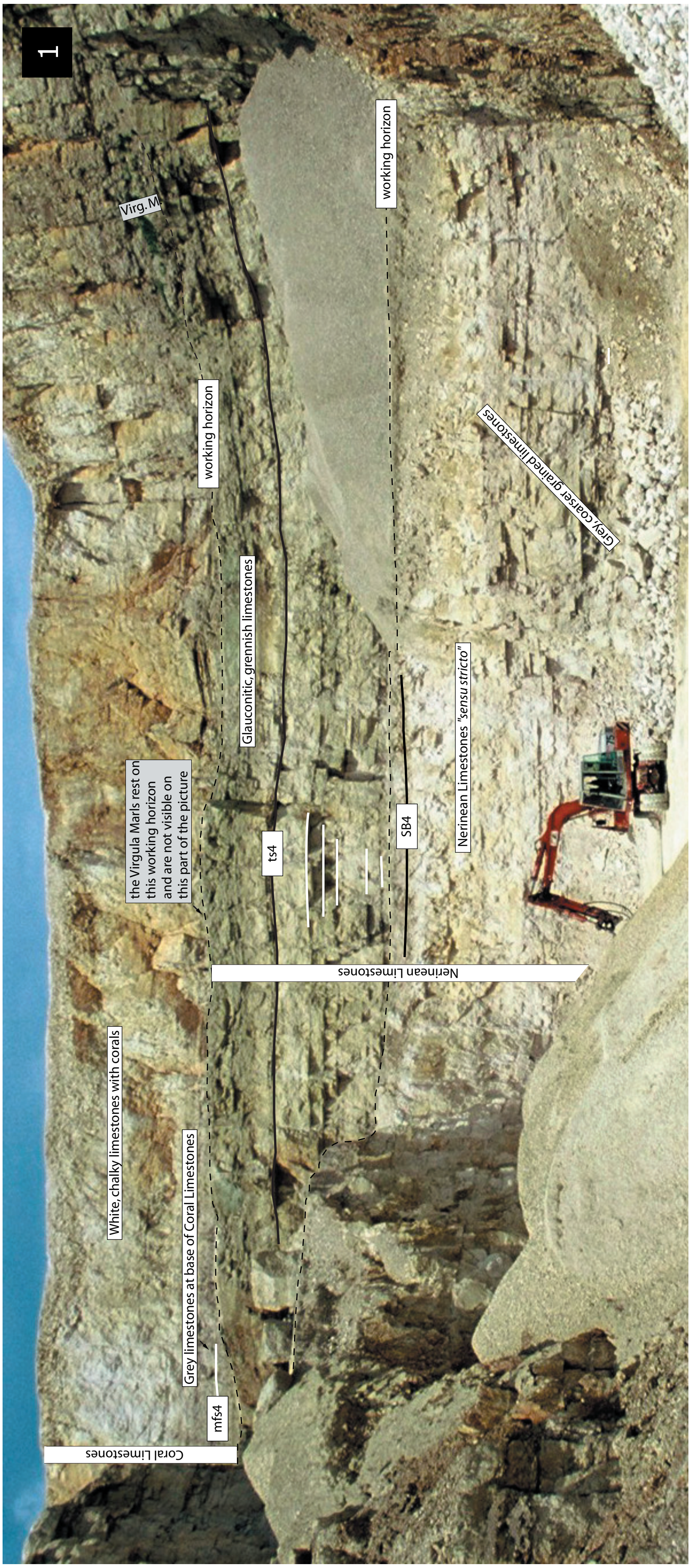

4
Banné Marls
ts3
turnaround
SB3
mfs2

Fig. 17: Position of discontinuities SB4 to mfz4 (Pic. 1) and typical sedimentological and lithological features (Pics 2-4).
Pic. 1: Lower part of the quarry La Combe – Sequence boundary/turnaround 4 can be observed at the base of several biolaminitic limestones with birds eyes in the upper part of the outcropping Nerinean Limestones. A very thin bed of crumbly and platy mudstone (Pic. 2) at the boundary to the glauconitic top part of the Nerinean Limestones marks ts4. Maximum flooding zone 4 is located at the transition between the Virgula Marls and the ferruginous lower few meters (grey colored) of the Coral Limestones. A close-up of the conspicuous Virgula Marls is shown in Pic. 3.

Pic. 2: Crumbly and platy mudstone with mudcracks and mud polygons with curling-up edges. (Bed CHV-170, La Combe).

Pic. 3: Virgula Marls. (scale: coin ≈2,5 cm; Sur Combe Ronde).

Pic. 4: Cast of ?*Stylina sp.* (scale: coin ≈2,5 cm; Coral Limestones, La Combe).

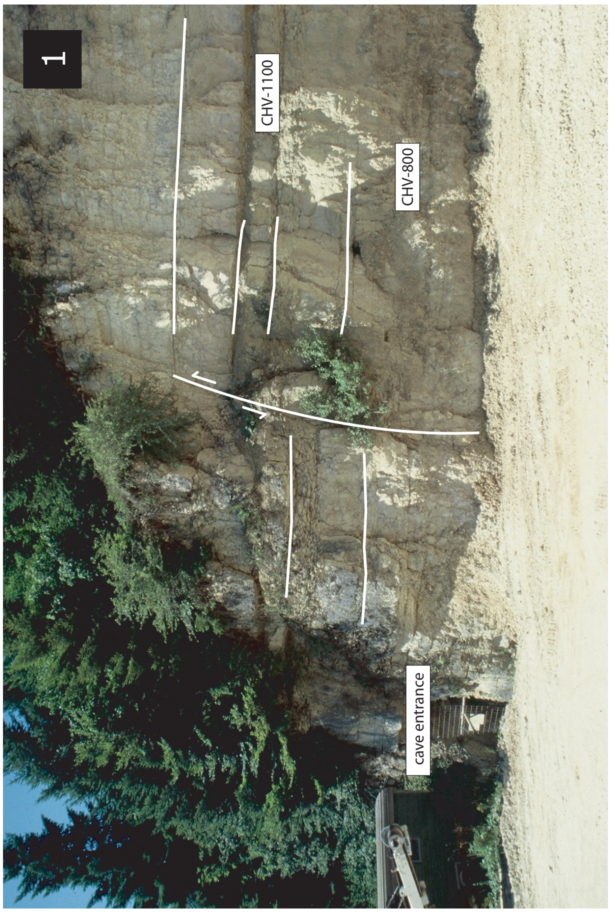

1
Coral Limestones
mfs4
Grey limestones at base of Coral Limestones
White, chalky limestones with corals
the Virgula Marls rest on this working horizon and are not visible on this part of the picture
Virg. M
working horizon
Glauconitic, grennish limestones
ts4
Nerinean Limestones
SB4
Nerinean Limestones "*sensu stricto*"
working horizon
Grey, coarser grained limestones

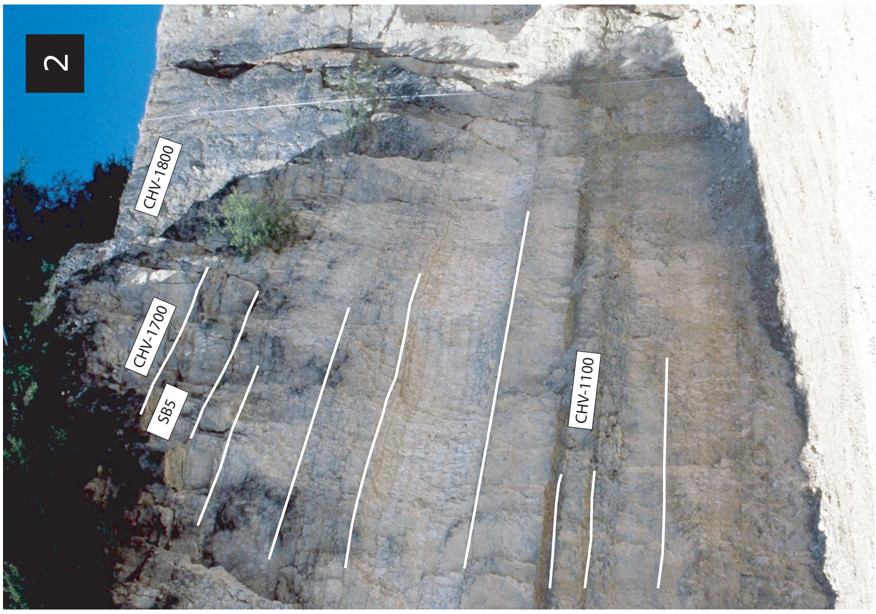

4

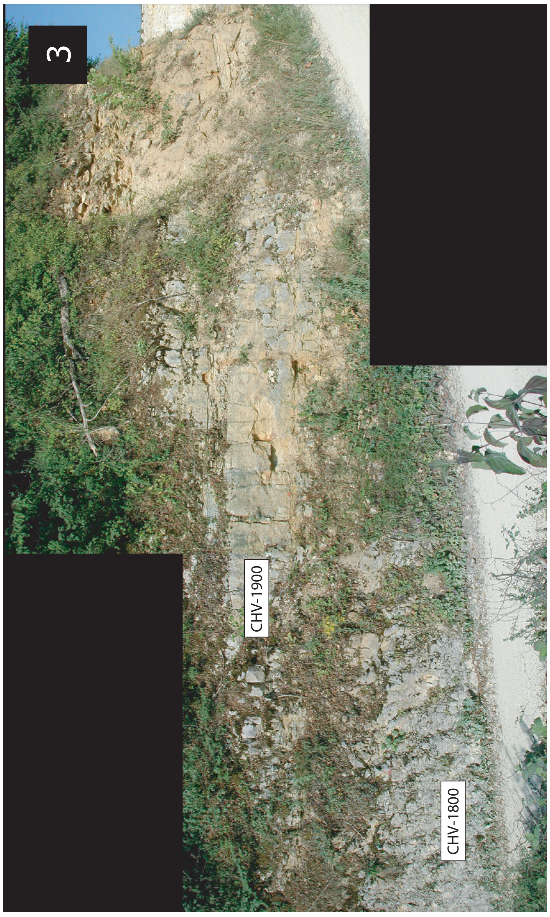

3


2
10 cm
CHV-3-1-130.25

Fig. 18: Upper part of the quarry La Combe. HST4 displays two thinning-upward trends. The upper trend reveals two thinning-upward bed sets (Pic. 1, 2). LST5 and “TST5” display increasingly marly deposits and thinner beds (Pic. 3, 4).


1
CHV-1100
CHV-800
cave entrance


2
CHV-1800
CHV-1700
SB5
CHV-1100


3
CHV-1900
CHV-1800


4
CHV-3000 with *Aspidoceras caletanum* (OPPEL)

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

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(submitted to Sedimentary Geology)

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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, 2004). 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.

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 CA, 1989; Gygi, 2000b). Even recent studies based on sequence-, cyclo- and mineralo-stratigraphy rely on only a few (if any) high-resolution biostratigraphical markers (Gygi & Persoz, 1986; Gygi, 1995; Mouchet, 1995, 1998; Gygi et al., 1998; Meyer M, 2000; 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.

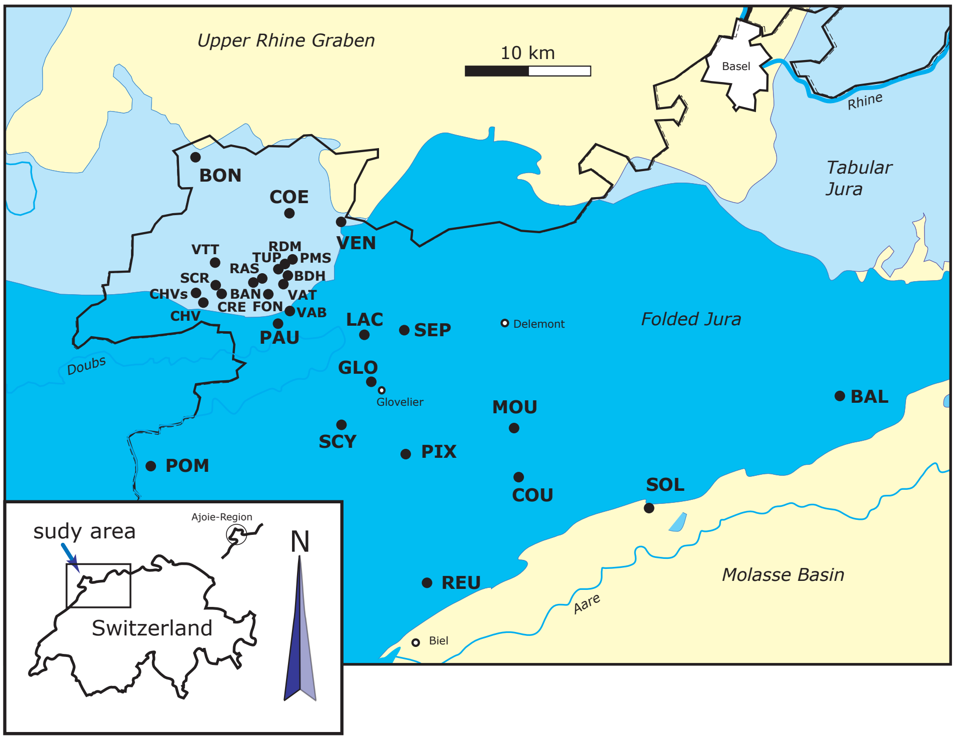


Fig. 1: Major geological units and swiss coordinates of sections and outcrops.

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, 2000b; 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.

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 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).

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).

	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 (2000b), 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 Limestones	Gygi (2000b), 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 White Limestones	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 & 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 separated*	Gygi (2000b), Colombié (2002)
	23	REU	La Reuchenette (Carrière) - type-locality	585.890	226.240	*not defined, merely the "southern" Virgula Marls are separated*	Thalmann (1966), Mouchet (1995, 1998), Gygi (2000b), Colombié (2002)
	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 are separated*	Meyer (1990, 1993, 1994, 2000), Meyer & Jordan (2000), Gygi (2000b)
	26	BAL	Region around Balsthal			*not defined*	Gygi (2000b)
	27	LAC	La Coperie	580.849	246.243	*not defined, merely the Banné Marls are separated*	Gygi (2000b)
	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*	-

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 prep.) and illustrated in Figure

4. Gygi & Persoz (1986) and Gygi (1995, 2000b, 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, 2000b,c), Gygi & 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 (2000b), Colombié (2002) and Jank (2004). The characteristics and the compilation of the sequence-stratigraphical interpretations of Gygi et al. (1989), Gygi (2000b), Colombié (2002) and Jank (2004) are given in Figures 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 & 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).

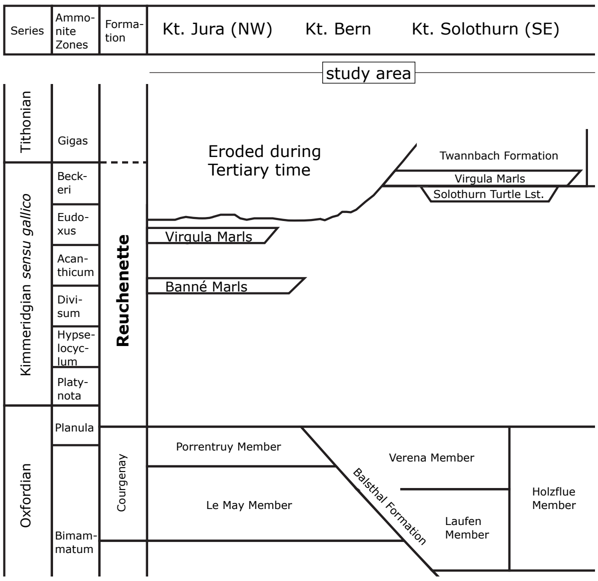


Fig. 2: Litho- and biostratigraohical scheme for the Reuchenette Formation, based on data from Meyer C.A. (1990, 1993), Gygi (2000b) and Jank (2004).The associated thickness-relation in the Ajoie- (Kt. Jura) and Solothurn-Region are not to scale (difference about 100 m; compare introduction).

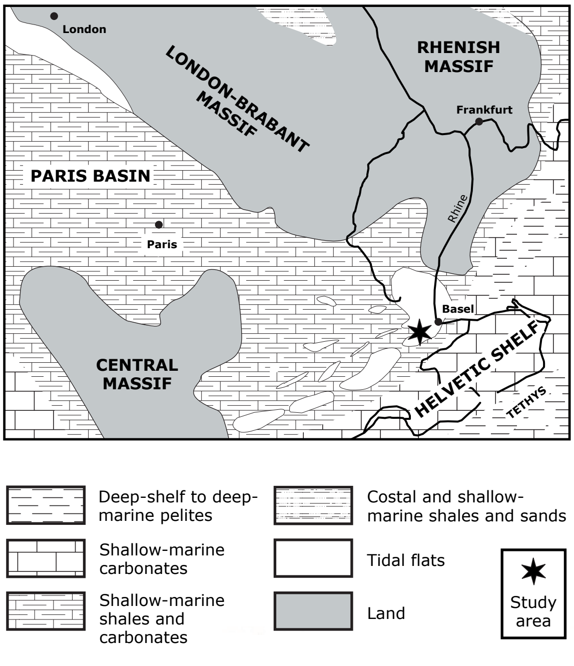


Fig. 3: Kimmeridgian paleogeographical map (Divisum- and Acanthicum-Zone). Compiled after Ziegler (1990), Meyer C.A. & Lockley (1996), Marty et al. (2003) and this study.

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.

- 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 (Fig. 5 and 7):

(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 & Gressly 1859; in Gygi, 2000c) grades laterally into the Courgenay Formation (i.e. Porrentruy *sensu* Gygi 1995) (Gygi, 2000b).

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 & 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; Gygi, 2000b; 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 & 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 2000b,c; Fig. 7). For this reason, Gygi & Persoz (1986) and Gygi (2000b,c) 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 and coated intraclasts (Gygi, 2000b; 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 & Persoz (1986) and Gygi (2000b,c) is developed as described above (Fig. 5). This lithological boundary coincides with sequence boundary SB1.

(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 (Fig. 5 and 7).

(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) Banné Marls and mineralostratigraphical horizon D1
The sections in the Ajoie-Region, at Moulin de Séprais, Contournement de Glovelier and Gorges de 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 2000b, c) comprise grey, thin- to thick-layered, slightly nodular marlstones,

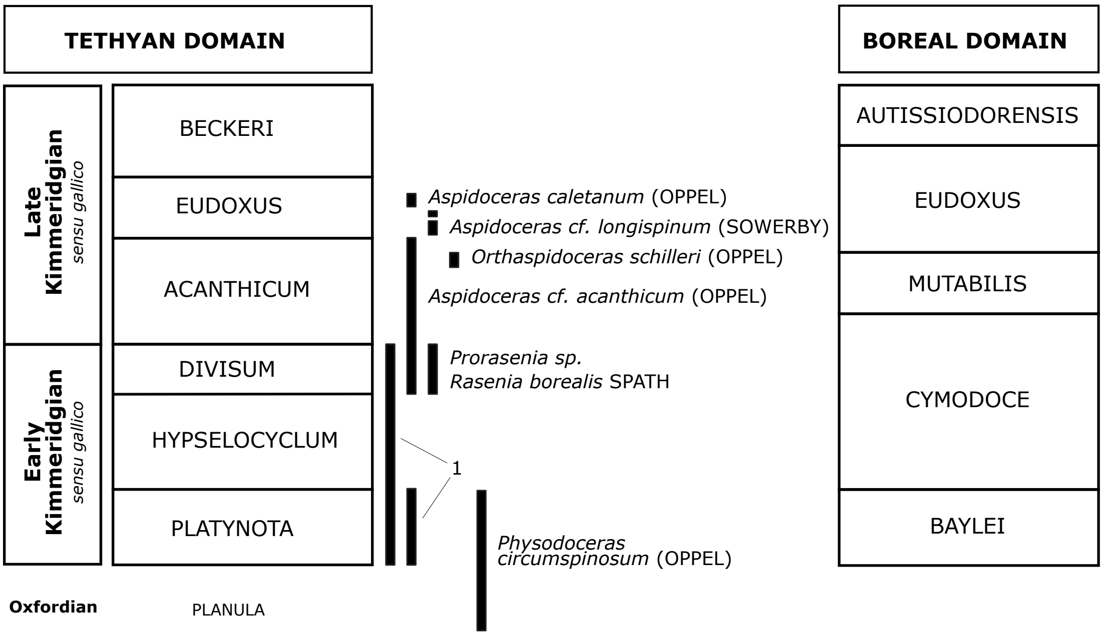


Fig. 4: Biostratigraphical frame based on ammonites.
Zonation of the Kimmeridgian *sensu gallico* after Hantzpergue et al. (1997). Tethyan Domain is used *sensu* Domaine Téthysien, Province subméditerraneénne; Boreal Domain is used *sensu* Domaine Boréal, Province subboréale. All ammonites were collected *in situ*, except *Aspidoceras cf. acanthicum* (OPPEL) (Gygi, 1995).

Biostratigraphical reach and localities:
1: *Lithacosphinctes cf. janus* (CHOFFAT); Platynota-Zone (according to Schweigert) 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.

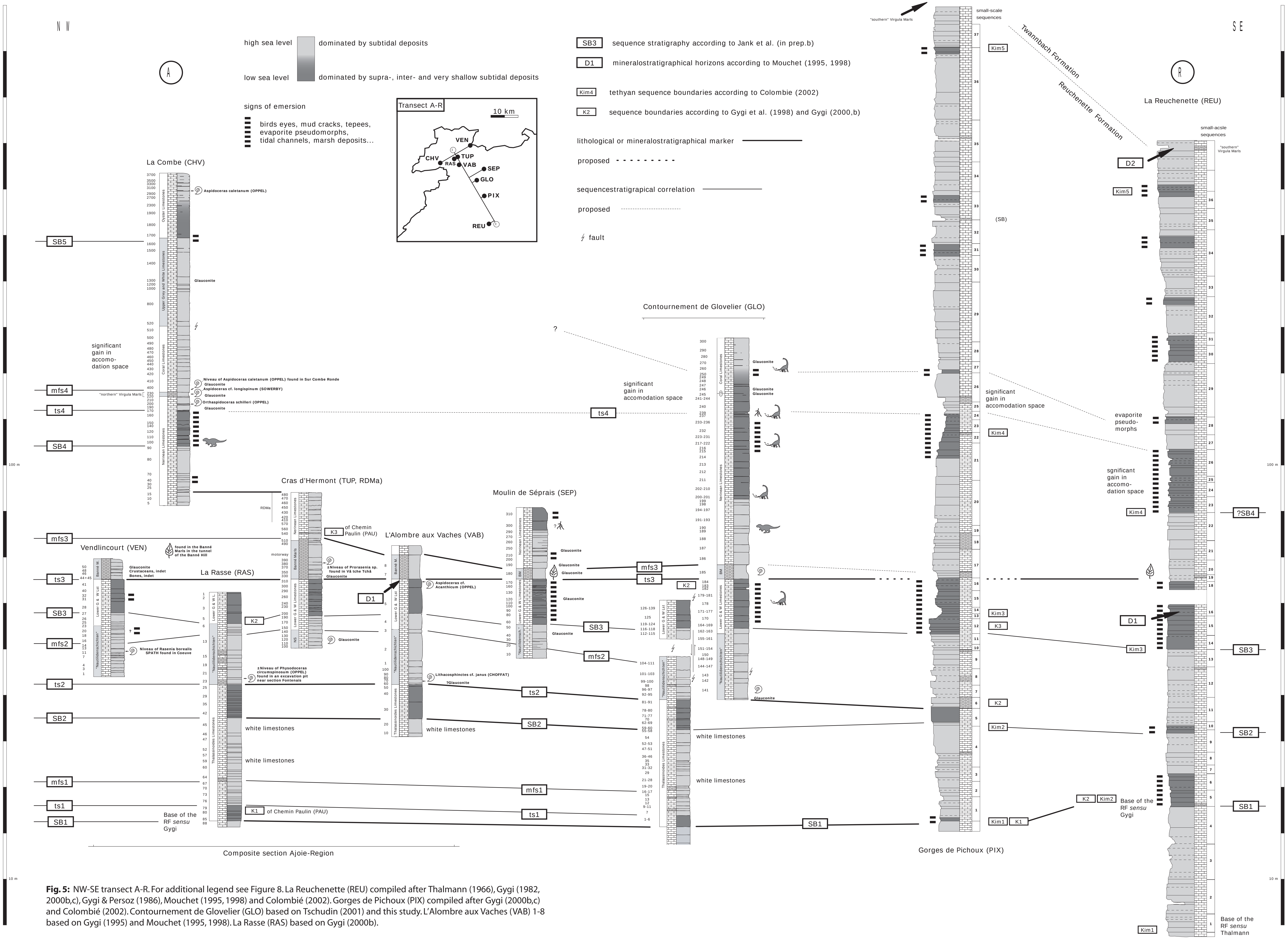


Fig. 5: NW-SE transect A-R. For additional legend see Figure 8. La Reuchenette (REU) compiled after Thalmann (1966), Gygi (1982, 2000b,c), Gygi & Persoz (1986), Mouchet (1995, 1998) and Colombié (2002). Gorges de Pichoux (PIX) compiled after Gygi (2000b,c) and Colombié (2002). Contournement de Glovelier (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 (2000b).

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 around D1 are well correlateable 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).

(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; Fig. 5 and 7) but they are younger than the "northern" Virgula Marls (Gygi et al., 1998; Jank; 2004).

Systems tracts			Facies	Bathymetry	Depositional environment	Facies association	Developm. of facies
LST	**TST**	**HST**					
√	√		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	<== basinward migration of facies (regression) landward migration of facies (transgression) ==>
	√	√	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	
√			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

Fig. 6: Facies and facies characteristics of the systems tracts of the Reuchenette Formation (compiled after Gygi et al., 1998; Colombie, 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.

The "northern" Virgula Marls are exactly correlateable between the closely spaced sections at La Combe, Roches des Mars and Sur Combe Ronde (No. 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 & Hantzpergue, 1973; Chevallier, 1989). The vertical facies changes above and below these Virgula Marls are also correlative to each other (Jank, 2004).

- 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.

(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 marine platform conditions below the fair weather wave-base and high-energy conditions in tidal flat areas (Gygi et al., 1998; Gygi, 2000b; Colombié, 2002 and 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

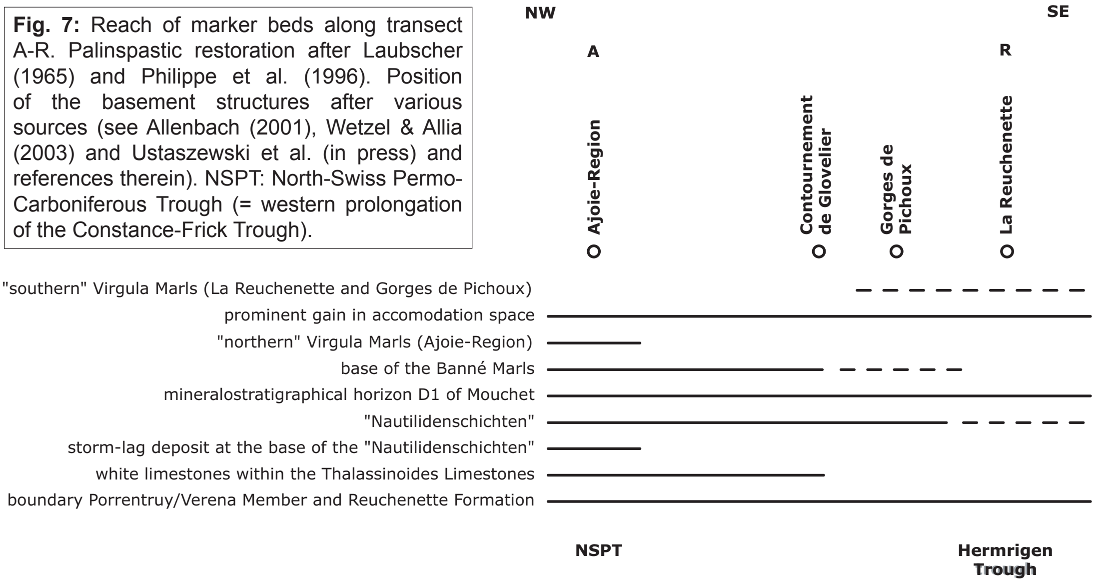
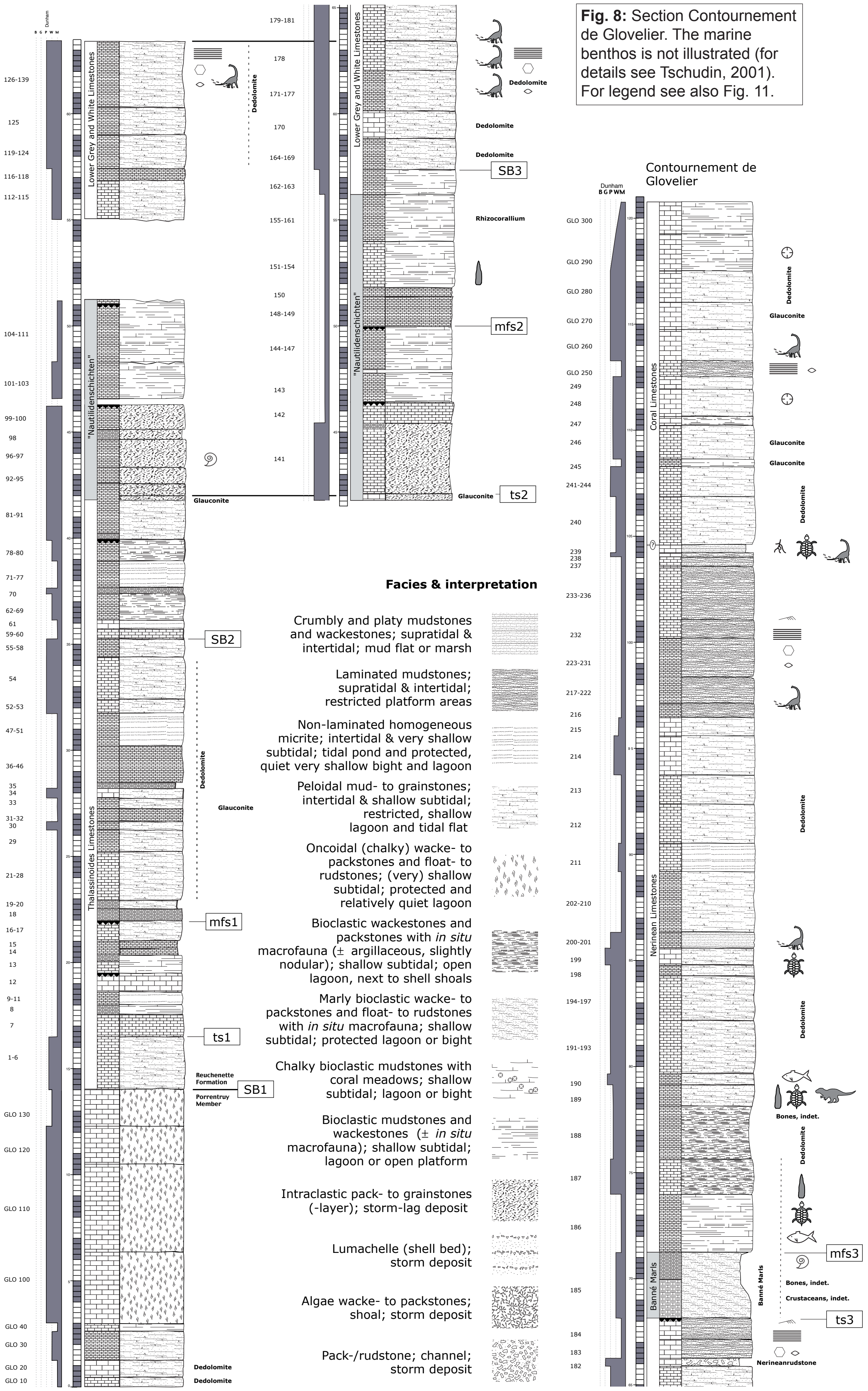


Fig. 7: Reach of marker beds along transect A-R. Palinspastic restoration after Laubscher (1965) and Philippe et al. (1996). Position of the basement structures after various sources (see Allenbach (2001), Wetzel & Allia (2003) and Ustaszewski et al. (in press) and references therein). NSPT: North-Swiss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

Fig. 8: Section Contournement de Glovelier. The marine benthos is not illustrated (for details see Tschudin, 2001). For legend see also Fig. 11.



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

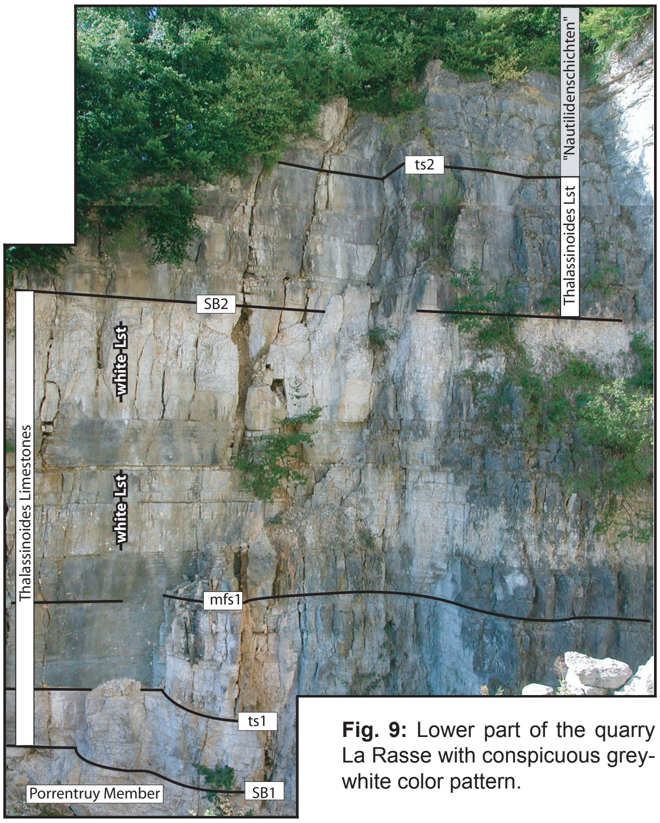


Fig. 9: Lower part of the quarry La Rasse with conspicuous grey-white color pattern.

(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 & Hantzpergue, 1973 or Marnes de 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, more calm 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., 2004). Therefore a protected, normal-marine depositional environment is postulated for the Banné Marls (Jank, 2004; Chevallier, 1989), probably in an intra-platform bight.

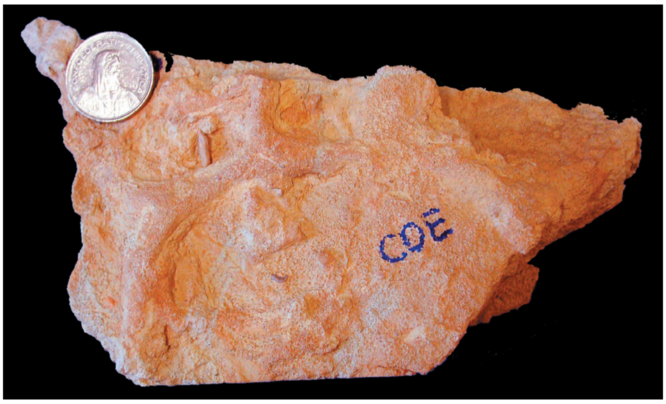
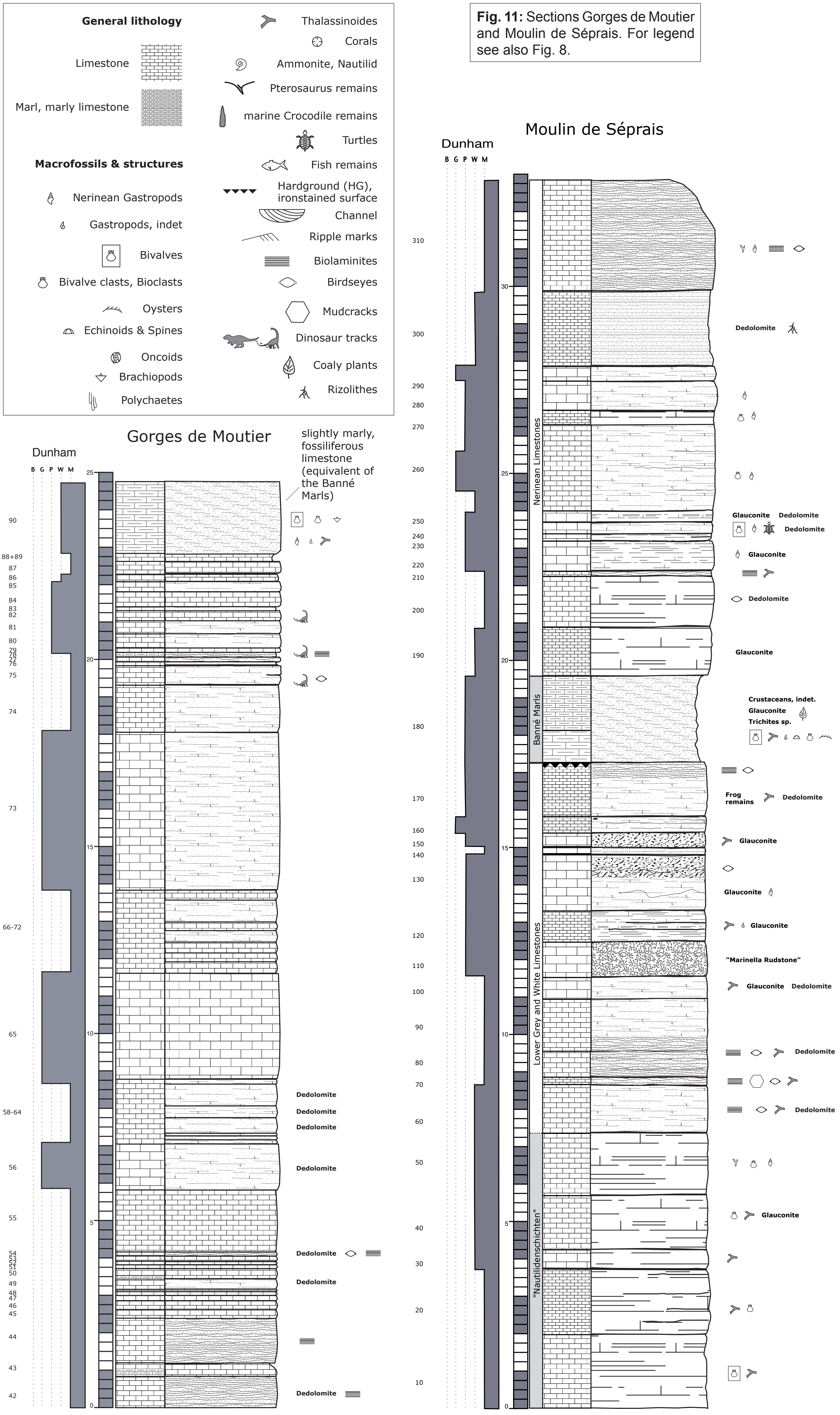


Fig. 10: Storm-lag deposit at the base of the "Nautilidenschichten". Bottom side of intraclastic pack- to grainstone layer with cast *Thalassinoides* (positive hypichnia) deposited as tempestite, indicating erosion followed by lag deposition. The occurrence of this storm sheet is restricted to the Ajoie-Region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

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



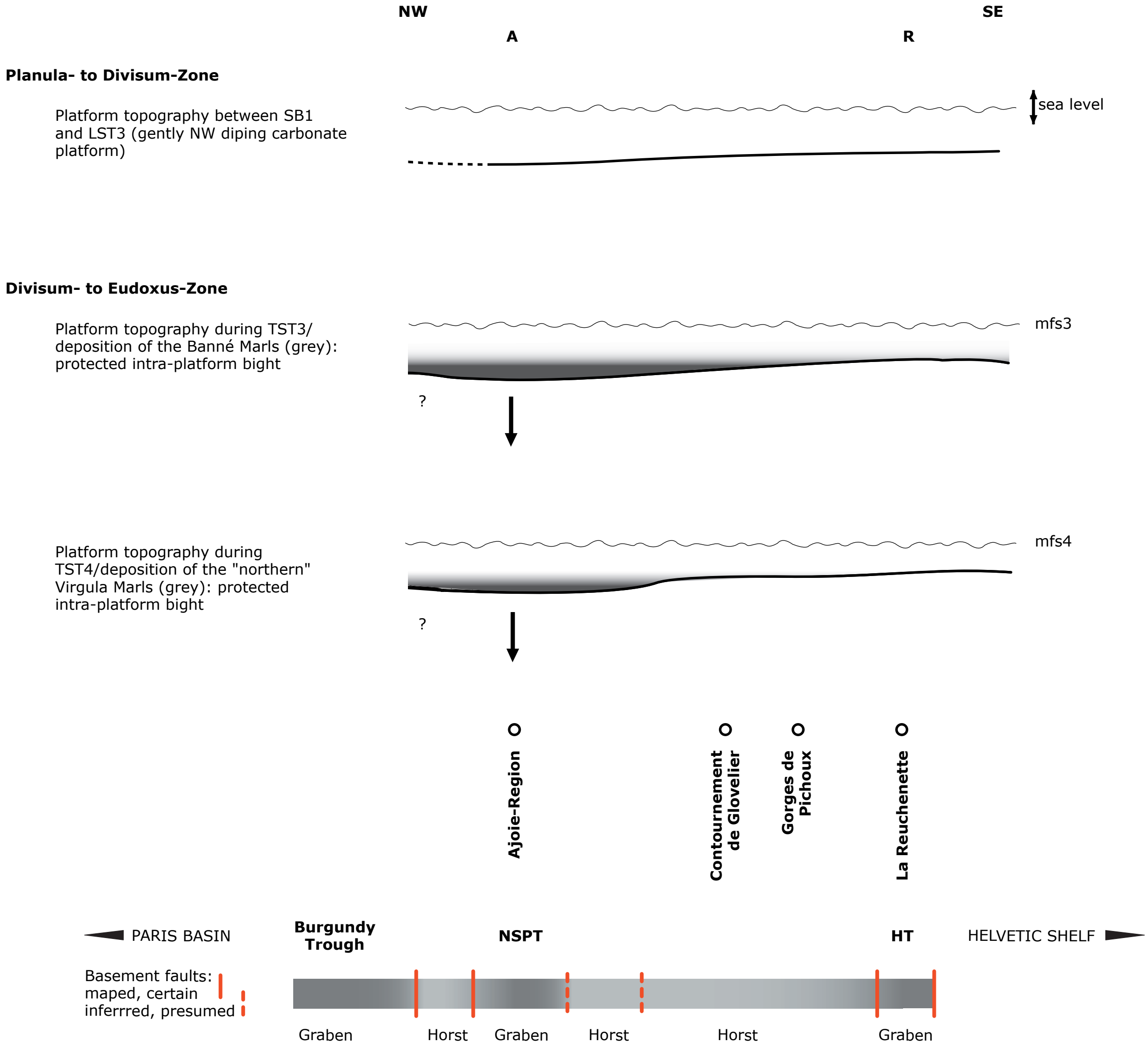


Fig. 12: Schematic platform topography for selected time intervals and/or facies between the Ajoie-Region (A) and the type-locality La Reuchenette (R) . Arrow indicates positions of enhanced synsedimentary subsidence. Palinspastic restoration after Laubscher (1965) and Philippe et al. (1996). Position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

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 at 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) occuring at different levels in the sediments of HST3 and LST4 in different sections (compare Fig. 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

No.	Code	Sections	Coordinates		Thickness Banné	Literature
7	PAU	Chemin Paulin	573.790	247.100	6 m	Gygi (2000b)
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. (2001)
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 (2004)
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 (2000b)
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)

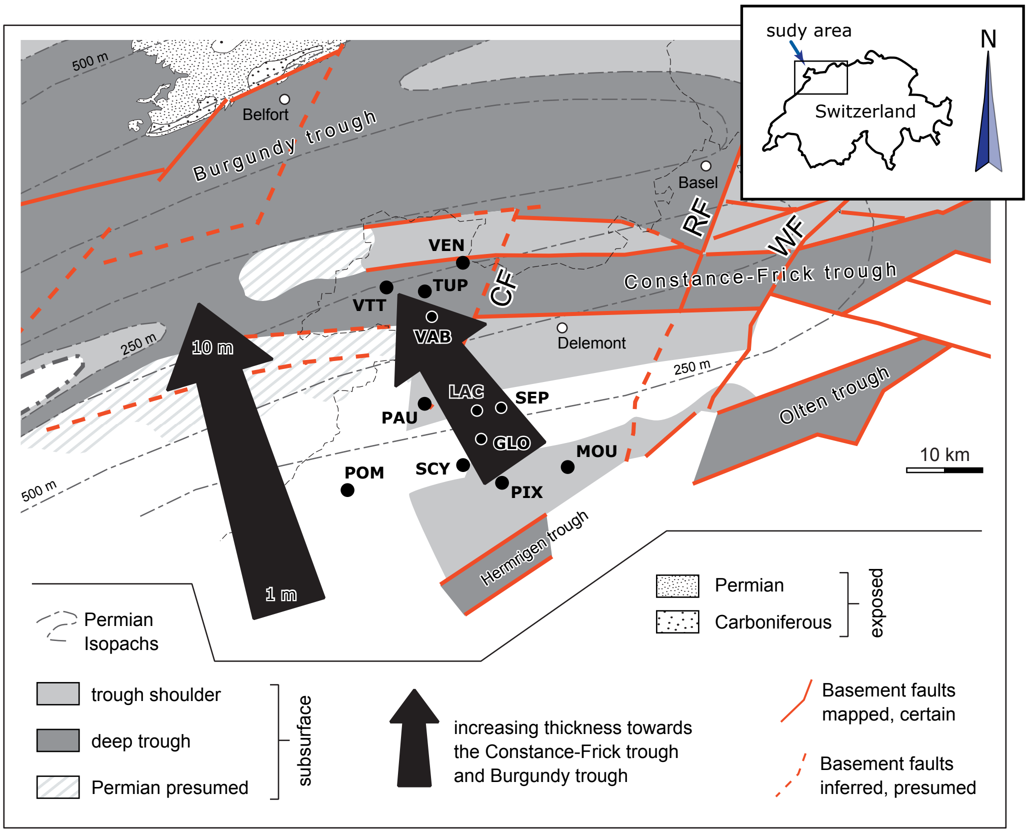


Fig. 13: Thicknesses of the Banné Marls and their lateral equivalents plottet above Palaeozoic basement structures. The thickness distribution for "West of the Ajoie-Region" (left arrow) is from literature and based on a thickness-distribution map. Exact coordinates do not exist. Palinspastic restoration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

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" Virgula Marls restricted to the Ajoie-Region and the region west to it (Contini & 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 Figure 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.

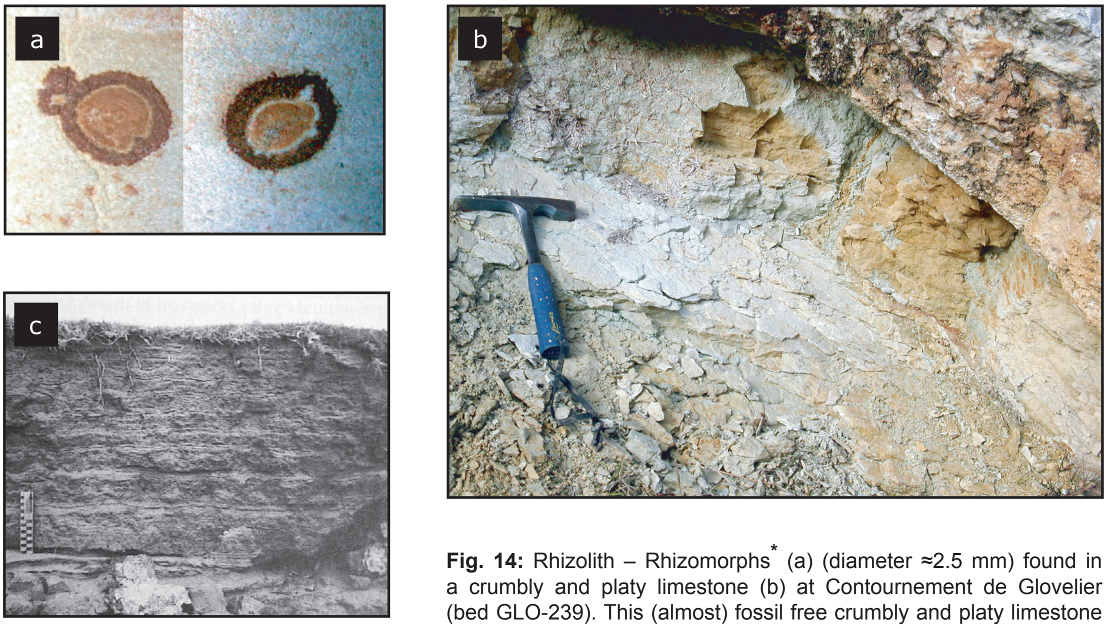


Fig. 14: Rhizolith – Rhizomorphs* (a) (diameter ≈2.5 mm) found in a crumbly and platy limestone (b) at Contournement de Glovelier (bed GLO-239). This (almost) fossil free crumbly and platy limestone appears quite abruptly above emerged stromatolites (note the mud cracks (b)). It is comparable with modern 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.

DISCUSSION

- 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 (2000b), 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 (2000b) 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, 2000b). 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 prep.), 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-

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

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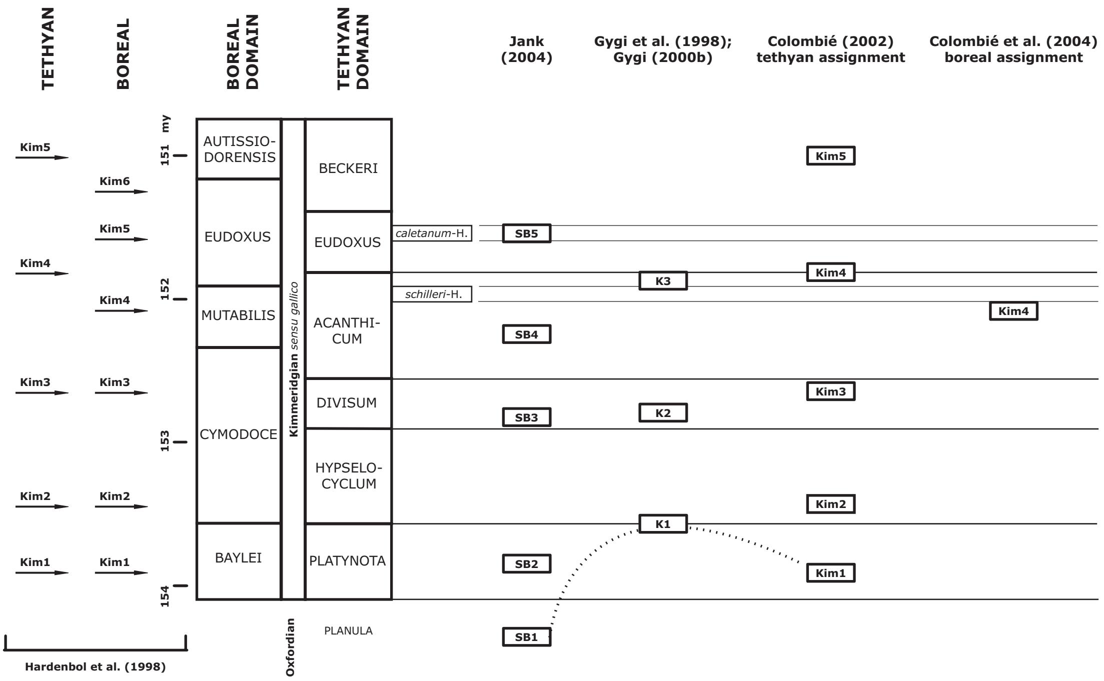
* Rhizomorphs are interpreted as fossilized roots of plants. They probably come from Gymnosperms (Conifers, Seedferns, Cycads, etc.). Equisetaleans and fern rhizomorphs can be almost certainly ruled out because they have a completely different structure. Cycads, Ginkgos, etc. usually grew in delta plains, 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).

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

CORRELATIONS

Jank (2004)	This study	Gygi et al. (1998); Gygi (2000b)			Colombié (2002); Colombié et al. (2004)	
Ajoie-Region	Contournement de Glovelier and Moulin de Séprais	Ajoie-Region	Contournement de Glovelier	Gorges de Pichoux and La Reuchenette	Gorges de Pichoux	La Reuchenette
mfs5						
TST5						
ts5						
LST5						
SB5	?SB5					
HST4	?HST4					
mfs4	?mfs4					
TST4	?TST4					
ts4	?ts4					
LST4	LST4				?Kim4	
SB4	SB4	K3				?Kim4
HST3	HST3					
mfs3	mfs3					
TST3	TST3					
ts3	ts3					
LST3	LST3		K2	K3	Kim3	
SB3	SB3	K2				Kim3
HST2	HST2					
mfs2	mfs2					
TST2	TST2					
ts2	ts2					
LST2	LST2			K2		
SB2	SB2				Kim2	SB between cycle 9 & 10
HST1	HST1					
mfs1	mfs1					
TST1	TST1					
ts1	ts1					
LST1	LST1	K1		K1	Kim1	Kim2
SB1	SB1					

AGES



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 (2000b) 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 (2000b) 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).

- 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 & Noack, 1997; Ustaszewski et al., in press). 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 & 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

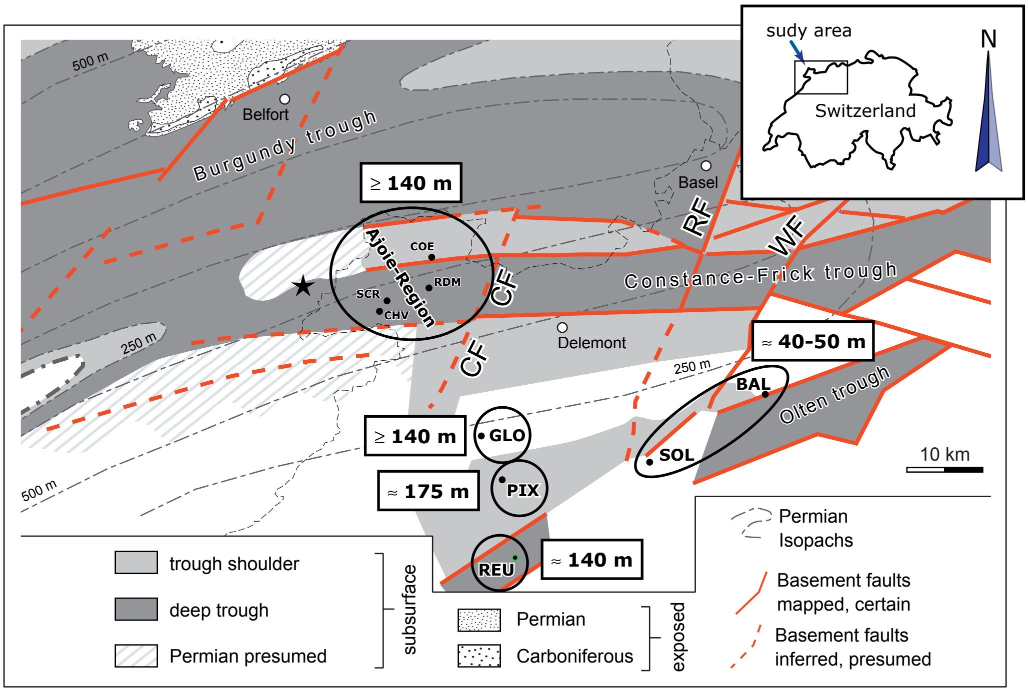


Fig. 17: Thicknesses of the Reuchenette Formation plottet above Palaeozoic basement structures. Thickness increases west of the Rhenish Fault (RF) and Caquerelle Fault (CF). The different Virgula Marls occur in the Ajoie-Region (localities CHV, RDM, SCR) and west of it in the region of Montbéliard (star; Contini & Hantzpergue, 1973; Chevalier, 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 & Allia (2003) and Ustaszewski et al. (in press) and references therein). WF: Werra Fault. For codes of localities see Figure 1.

sediments between the Ajoie-Region and La Reuchenette (variation up to 100 m; Meyer C.A., 1993; Fig. 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 intra-platform basins and swells. The subtle

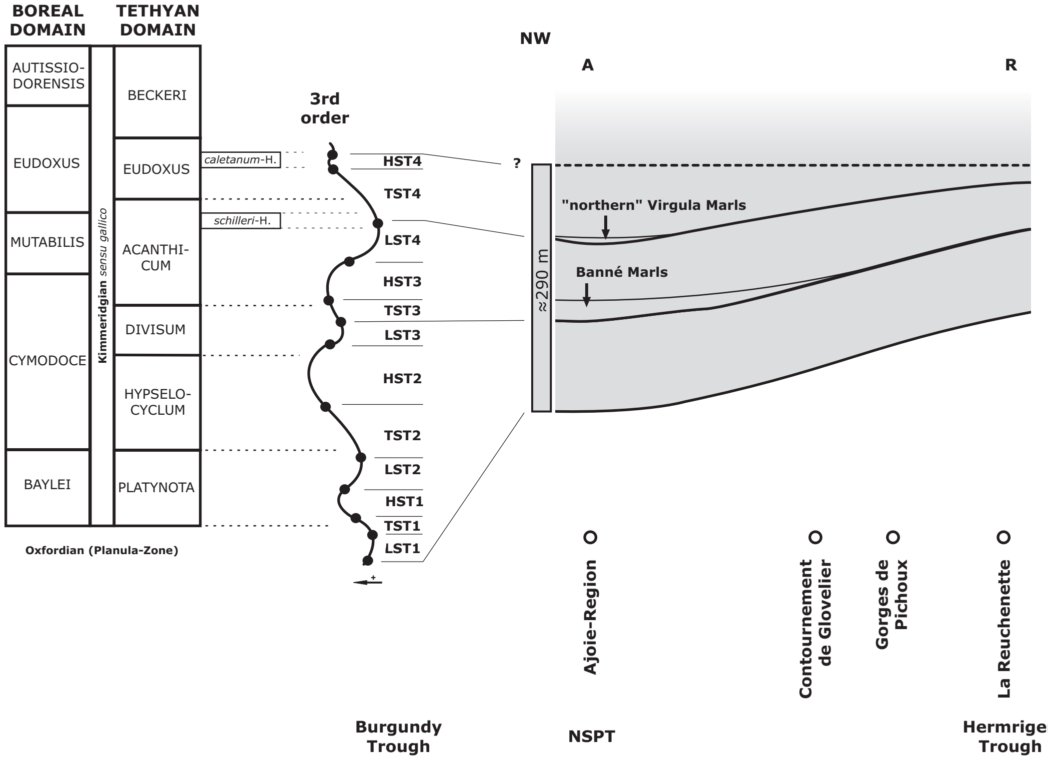


Fig. 18: Schematic decompacted NW-SE section across the study area between the Ajoie-Region (A) and the type-locality La Reuchenette (R) for selected time intervals. Across the North-Swiss Permo-Carboniferous Trough (NSPT) thickness significantly increases. Note that the section was drawn by interpolating between outcrops. Tentative sea level curve after Jank et al. (2004b). Approximated decompaction factors: marl x3, limestone x2 (based on Moore, 1989; Goldhammer, 1997; Matyszkiewiez, 1999). Palinspastic restoration after Laubscher (1965) and Philippe et al. (1996). Position of the basement structures after various sources (see Allenbach (2001), Wetzel & Allia (2003) and Ustaszewski et al. (in press) and refernces therein).

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 & Lockley, 1996; Diedrich, 2004; Fig. 2).

CONCLUSIONS

Lithology, marker beds, facies, bio- and sequence-stratigraphy allow defining intervals useful for lithological and sequence-startigraphical 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 sections.

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 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.

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 than 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.

GENERAL CONCLUSIONS

The presented data improve the knowledge of the sedimentary history of the Reuchenette Formation in the Swiss and French Jura because the Reuchenette Formation was initiated by Thalmann (1966) to replace the Kimmeridgian auctorum without changing its boundaries and "fixing" the sediments biostratigraphically with all consequences for its correlation. The new data on lithology, marker beds, facies, bio- and sequence-stratigraphy allow defining intervals useful for lithological and sequence-startigraphical correlations over large distances and hence, offer new biostratigraphically-dated insights into the development of the Kimmeridgian carbonate platform, at the transition between the Boreal and Tethyan realms.

In particular, 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 new established and biostratigraphically well dated reference section in the Ajoie-Region. Therefore, also 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 sections and shorter distances.

At a platform scale, the vertical facies development and the position and the number of sequence boundaries – traceable over large distances – support the correlations by marker beds that allows to refine and improve former age-assignments of the sequence boundaries.

Regarding the sequence-stratigraphical composition of investigated sediments five sedimentary sequences have been interpreted as result of 3rd order relative sea level cycles for the Late Oxfordian to Late Kimmeridgian sensu gallico time interval. The sequence boundaries lie in the Planula-, Platynota-, Divisum-, Acanthicum and uppermost Eudoxus-Zone. Sequence boundaries SB3 to 5 coincide with the Boreal sequence boundaries Kim3 to 5 of Hardenbol et al. (1998) and as the base of the Reuchenette Formation coincides with SB1, it can be assigned to the Late Oxfordian Planula-Zone.

The sequence boundaries might also provide a reference to rectify biostratigraphy because sequence boundaries SB1 and SB2 may, but do not have to be assigned to the Boreal sequence boundaries Kim1 and 2 of Hardenbol et al. (1998) due to the different interpretation of ammonites found in the lower Reuchenette Formation. The influence of the Boreal realm is partly corroborated by ammonites, which are typical for the Boreal realm sensu stricto (but Tethyan ammonite occur as well; compare Schweigert et al., in prep.).

The first two 3rd order cycles presumably are superimposed on a 2nd order transgressive-regressive sea level cycle, the maximum flooding surface being in the Hypselocyclum-Zone. Dinosaur foot prints, erosion, birds eyes and mud cracks mark a pronounced 2nd order lowstand in the Acanthicum-Zone (3rd order cycles three and four). A second 2nd order transgression begins probably with the fourth 3rd order cycle. These large scale sea level fluctuations match those from Russia and Spain.

Regarding the composition of the sediments the preservation of (parts of) fossils appears to vary in relation to the systems tracts: Highly corroded, fragmented remains are typical of erosive lowstands or early transgressive conditions, intact multi-element skeletons characterise rapid background sedimentation during highstands, and ferruginous lags of corroded particles and fossils typify condensed sections. Skeletal accumulations develop during intervals of low sediment input. Starved accumulations and winnowed shell beds may indicate transgressions.

Additionally, minimum accommodation space resulted in local exposure and very shallow-water to supratidal deposits. The increasing sea level rise during TSTs led to the most prominent lithological changes on top of condensed suites often indicated by marly deposits and winnowing. Maximum floodings resulted in the highest rates of carbonate production and led to the deposition of thick- and massive-layered relatively deep open shallow-marine carbonates. Consequently these sediments bear no significant marker beds traceable over large distances and biostratigraphical markers in the top part of the sections in the Gorges de Pichoux and La Reuchenette, which might confirm the proposed sequence-stratigraphical correlations between the Ajoie-Region, Contournement de Glovelier and these sections. Nevertheless the gain in accommodation space (indicated by thick bedded sediments), biostratigraphically assigned to the Late Eudoxus-Zone (Caletanum-Horizon) in the Ajoie-Region, can be used for an approximated correlation at platform scale.

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 might have significantly affected the deposition of the sediments of the Reuchenette Formation. The interplay of sea level changes and synsedimentary differential subsidence acrosss these structures led to a repeated reorganization of the depositional environment and is documented by the lateral facies pattern and the associated platform topography. Evidence is given by conspicuous thickness and facies variations across Late Palaeozoic structures.

During the Planula- to Divisum-Zone time interval 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 than 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 short wave-length 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 this time interval.

Contrasting, during the Divisum- and Acanthicum-Zone a prominent basin-and-swell morphology with intra-platform basins developed. This morphology is probably related to increased synsedimentary differential subsidence across Late Palaeozoic basement structures and lower sea level and presumably “separated” the Paris Basin from the Tethys. In addition enhanced subsidence within the Caletanum-Horizon (Late Eudoxus-Zone) during HST4 led to the formation of extremely thick, homogeneous packages on the platform. Dinosaur tracks in lowstand deposits might indicate that these swells were used to traverse between the Central Massif and the London-Brabant Massif.

As common in scientific research, some questions got answered but many others arose and remain unanswered. In this paragraph I would like to give some hints for further investigations on Kimmeridgian sediments in NW Switzerland and adjacent France.

For example, strontium isotope analyses on unaltered fossils from different stratigraphical levels above the Banné Marls/transgressive surface ts3 might improve and confirm, in combination with the known ammonites (given by Gygi’s researches and this study), the proposed sequence-stratigraphical correlations. Few fossiliferous and biostartigraphically exactly dated sediments of the Ajoie-Region might be used as reference levels. Additionally, the upper boundary in the type-section La Reuchenette might then be dated and traced across the platform.

As the “northern” Virgula Marls are not developed in the area of Goumois (located at the French-Swiss border, own field observations) and the level of the Banné Marls in the Gorges de La Lou (eastern France) indicates erosion (Mouchet, 1995, 1998), these data might also provide the possibility to refine the correlations and locate/predict the Late Paleozoic basement structure further to the southwest of the study area in western Switzerland and adjacent France.

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Education

2000-2004	Ph.D. in Geology (University of Basel) *New insights into the Late Jurassich Reuchenette Formation of NW Switzerland (late Oxfordian to late Kimmeridgian, Jura Mountains)*; supervised by Prof. Dr. A. Wetzel, PD Dr. Ch. A. Meyer and Prof. Dr. R. Koch
1994-2000	Diploma in Geology (University of Erlangen-Nürnberg) *Fazielle, lithostratigraphische und hydrogeologische Betrachtung an Malmbohrkernen nördlich von Gräfenberg (Nordbayern)*; supervised by Prof. Dr. R. Koch *Geologische Kartierung im Ostalpinen Altkristallin südlich des Gumriauls bei Sillian/Osttirol/Oesterreich*; supervised by PD Dr. B. Schulz
1994	Allg. Hochschulreife (Abitur), Simon-Marius Gymnasium Gunzenhausen/Bavaria/Germany.With the core subjects mathematics, (organic) chemistry and geography.

Specialities

Reconstruction of shallow marine environments, shelf and platform evolution and architecture, facies evolution and sequence architecture from multi-parameter data sets (seismic facies analysis, thin-section petrography, macro- and microfacies analysis, mapping and (well-) logging, stratigraphical correlation), subsidence analysis and biostratigraphy.

Practical training and professional activities

2003	June: Field trip to Wilhelmshaven (North sea); focusing on (recent) sedimentology, sea level fluctuations and biofacies in the wadden sea.
2000-2004	Ten months of field work in the Jura Mountains (Switzerland and France) for my PhD thesis.
2000-2003	Teaching assistant (lectures, exercises, field and mapping trips) in sedimentology, macro- and microfacies analysis, introduction to geosciences, historical geology, palaeontology, palecology, collecting and preparation. Field trips involving sedimentology, neo-tectonics, ichnology and palaeontology of the Jura Mountains, the Upper Rhine Graben Area, the Molasse Basin and the Alps. Palaeontological dig in Creugenat (Ajoie-Region, Swiss Jura). Co-organizer of international meetings.
1999	Mai-August: Fieldwork in the region of Gräfenberg/Bavaria/Germany for my degree in geology and palaeontology. June, July: Hydrogeological consultant for the community of Gräfenberg. January, May: Facies and lithofacies analysis of fluvial and shallow marine sandstones; with field trips and logging exercises (Prof. Dr. I. B. Singh, Lucknow University, India).
1998	November, December: Practical training at RWEDEA in Hamburg/Germany (E&P geology). September: Field trip of three weeks in Iran involving geology, palaeontology and culture of Iran. August, September: Diploma mapping in the Austrian Alps (Sillian/Osttirol/Austria). March, April: Field trip to SW USA involving phanerozoic, palaeogeographical evolution of the Greater Death Valley Region, Four Corners District, Basin and Range Province (interaction between Antarctica, Siberia, Laurentia) based on sequence stratigraphy; interaction between neo-tectonics and sedimentation (geomorphology).
1997	March: Field trip of three weeks in Morocco involving sedimentology, palaeontology and recent geology.
1996	September, October: Practical training at Geobüro Sichermann in Osternohe/Bavaria/Germany (consulting bureau for applied geology and hydrogeology).
1995-2004	Field trips (160 days) in (recent) sedimentology, sequence stratigraphy, petroleum geology, neo-tectonics, palaeontology, volcanology, mineralogy, applied geology and hydrogeology to Austria, Czech Republic, France, Germany, Hungary, Iran, Morocco, Romania, Spain, SW USA and Switzerland.

Seminars and specialized courses

2002	Seismic facies analysis and sequence stratigraphy (Prof. Dr. G. Eberli, RSMAS University of Miami, USA). Quantification of sedimentary processes (Prof. Dr. A. Strasser et al. University of Fribourg, Switzerland).
1999	Permeability and porosity of carbonates (Dr. R. Sobbot, University of Erlangen-Nürnberg).
1998, 1999	Sedimentology and biofacies of fluvial and shallow marine environments (Prof. Dr. R. Höfling, University of Erlangen-Nürnberg).
1998	Analysis and interpretaion of borehole wire lines (Prof. Dr. R. Koch, University of Erlangen-Nürnberg). Diagenesis and microscopy of sandstones (Prof. Dr. R. Koch, University of Erlangen-Nürnberg). Sedimentary structures and fabrics; from turbidity systems to glacial structures (Prof. Dr. W. Buggisch, University of Erlangen-Nürnberg). (Micro-)facies analysis, standard microfacies types, depositional environments und facies models of limestones (Prof. Dr. E. Flügel, Prof. Dr. B. Senowbary-Daryan, Prof. Dr. R. Koch, University of Erlangen-Nürnberg).
1997, 1998	Petroleum geology (Prof. Dr. P. Kehrer, BGR Hanover, Germany). Diagenesis and microscopy of limestones (Prof. Dr. R. Koch, University of Erlangen-Nürnberg).
1996, 1997	Lithostratigraphy, seismic stratigraphy und sequence stratigraphy (PD Dr. M. Keller, Prof. Dr. R. Koch, Dr. E. Samankassou, University of Erlangen-Nürnberg). Geophysics I & II (PD Dr. F. Heider, University of Erlangen-Nürnberg). Terrestrial sediments (Prof. Dr. W. Buggisch, University of Erlangen-Nürnberg). Brittle tectonics (Dr. A. Petereck, University of Erlangen-Nürnberg). Heavy mineral analysis (Prof. Dr. G. Nollau, University of Erlangen-Nürnberg).

Associated fields

2002, 2003	Introduction to geographic information systems GIS (lecturers in geology and geography, University of Basel).
2001, 2002	Mathematical methods and modeling in geosciences (Prof. Dr. W. D. Skala et al., FU Berlin, Germany).

ANNEX

Detailed sections and additional photographs of outcops are presented in this paragraph. They consist of further evidence that was used to create a comprehensive model of the Reuchenette Formation , but that did not have place within the three manuscripts. They were not included in the publications due to the limited space in scientific journals.

Key to profiles

General lithology

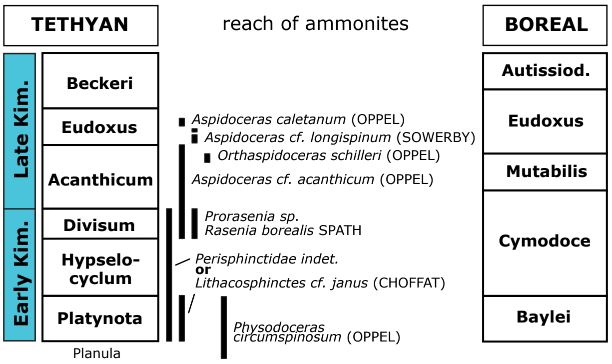
- ▦ Limestone
- ▩ Marl, marly limestone

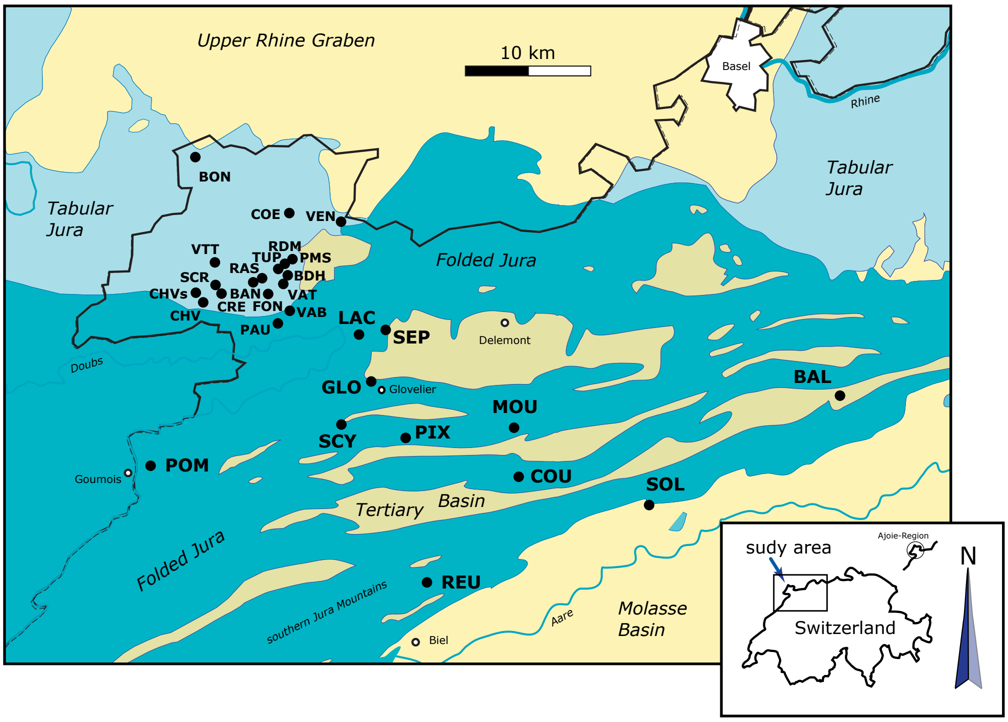
Facies & interpretation

- Crumbly and platy mudstones and wackestones; supratidal and intertidal; mud flat or marsh
- Laminated mudstones; supratidal and intertidal; restricted platform areas
- Lensoidal pack-/rudstones; storm surge channel or rip channel in tidal falt environment
- Non-laminated homogeneous micrite; intertidal and very shallow subtidal; tidal pond and protected, quiet very shallow bight and lagoon
- Peloidal mud- to grainstones; intertidal and shallow subtidal; restricted, shallow lagoon and tidal flat
- Oncoidal (chalky) wacke- to packstones and float- to rudstones; (very) shallow subtidal; restricted and relatively quiet lagoon
- Bioclastic wackestones and packstones with *in situ* macrofauna (± argillaceous, slightly nodular); shallow subtidal; open lagoon, next to shell shoals
- Marly bioclastic wacke- to packstones and float- to rudstones with *in situ* macrofauna; shallow subtidal; protected, quiet lagoon or bight
- Chalky bioclastic mudstones with coral meadows;shallow subtidal; quiet lagoon or bight
- Bioclastic mudstones and wackestones (± *in situ* macrofauna);shallow subtidal; open lagoon and open platform area
- Intraclastic pack- to grainstones (-layer); storm-lag deposit; lagoon
- Lumachelle (shell bed); storm deposit; lagoon

Macrofossils & structures

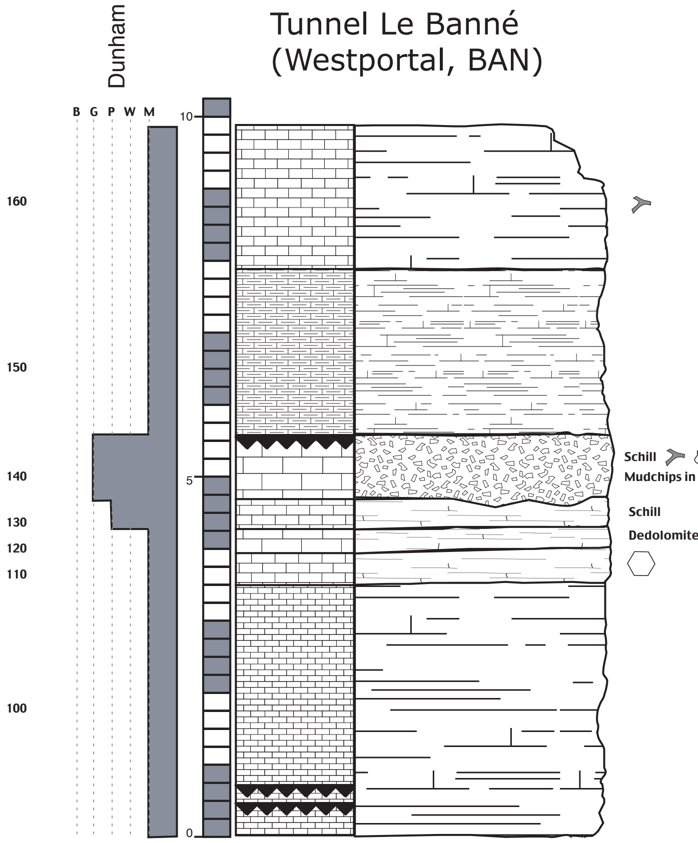
- Bivalves
- Bivalve clasts, Bioclasts
- Oysters
- Ammonite, Nautilid
- Nerinean Gastropods
- Gastropods, indet
- Corals
- Echinoids & Spines
- Oncoids
- Brachiopods
- Polychaetes
- *Thalassinoides*
- Pterosaur remains
- marine Crocodile remains
- Turtles
- Fish remains
- ▼▼▼▼ conspicuous Hardground (HG), ironstained surface
- Channel
- Ripple marks
- ≡ Biolaminites
- Birdseyes
- ⬡ Mudcracks
- Dinosaur tracks
- Coaly plants



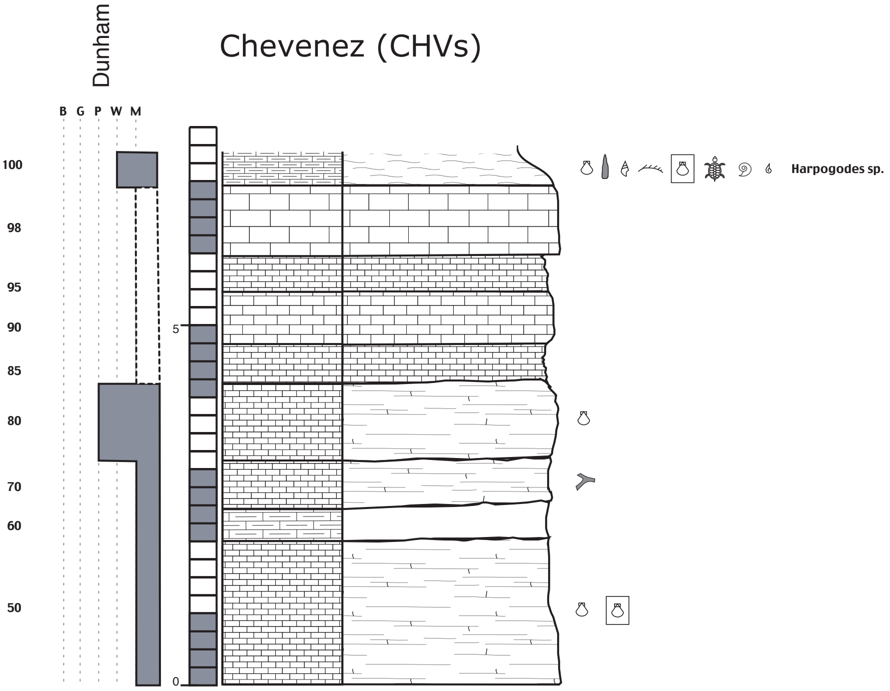


Code	**Sections**	**Profiles**	**Pictures**
BAL	Region around Balsthal	-	-
BAN	Tunnel Le Banné	Annex	Annex
BDH	Bas d'Hermont	-	Chapter II, Fig. 16/1
BON	Boncourt	-	Annex
CHV	La Combe	Chapter I, Fig. 5	Chapter II, Fig. 17/1, Fig. 18
CHVs	Chevenez	Annex	Chapter I, Pl. 1/c
COE	Coeuve	Chapter I, Fig. 8	Annex
COU	Gorge de Court	-	-
CRE	Creugenat	Annex	Annex
FON	Fontenais	Annex	Annex
GLO	Contournement de Glovelier	Chapter III, Fig. 8	Annex
LAC	La Coperie	-	-
MOU	Gorges de Moutier	Chapter III, Fig. 11	-
PAU	Chemin Paulin	-	-
PIX	Gorges de Pichoux	Chapter III, Fig. 5	Annex
PMS	Pré Monsieur	Annex	Annex
POM	Les Pommerats	-	Annex
RAS	La Rasse	Annex	Annex; Chapter II, Fig. 14
RDM	Roches de Mars	Annex	Annex
REU	La Reuchenette	Chapter III, Fig. 5	-
SCR	Sur Combe Ronde	-	-
SCY	Saulcy	-	-
SEP	Moulin de Séprais	Chapter III, Fig. 11	Annex
SOL	Region around Solothurn	-	-
TUP	Cras d'Hermont	Chapter I, Fig. 8	Annex
VAB	L'Alombre aux Vaches	Annex	Chapter II, Fig. 15/1, Fig. 16/4
VAT	Vatelin	Chapter II, Fig. 6	Annex; Chapter II, Fig. 16/3
VEN	Vendlincourt	Annex	Chapter II, Fig. 16/2
VTT	Vâ tche Tchâ	-	-

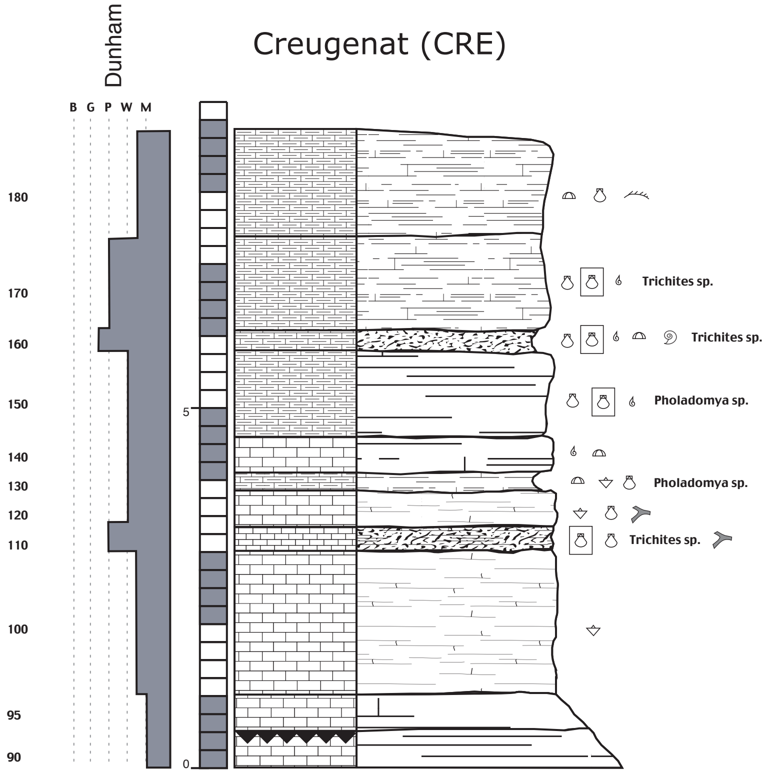
Tunnel Le Banné (Westportal, BAN)



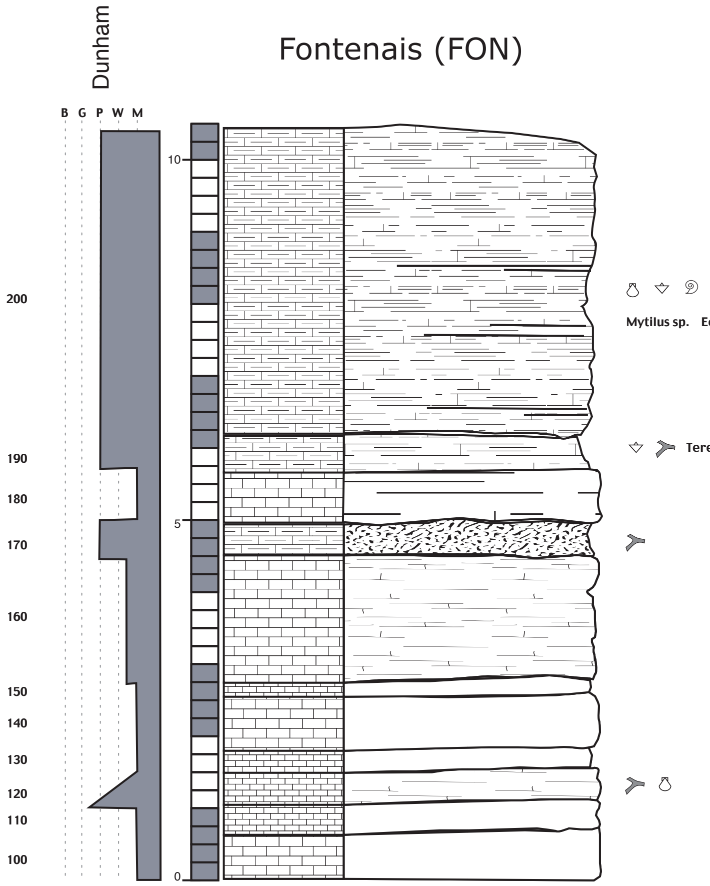
Chevenez (CHVs)

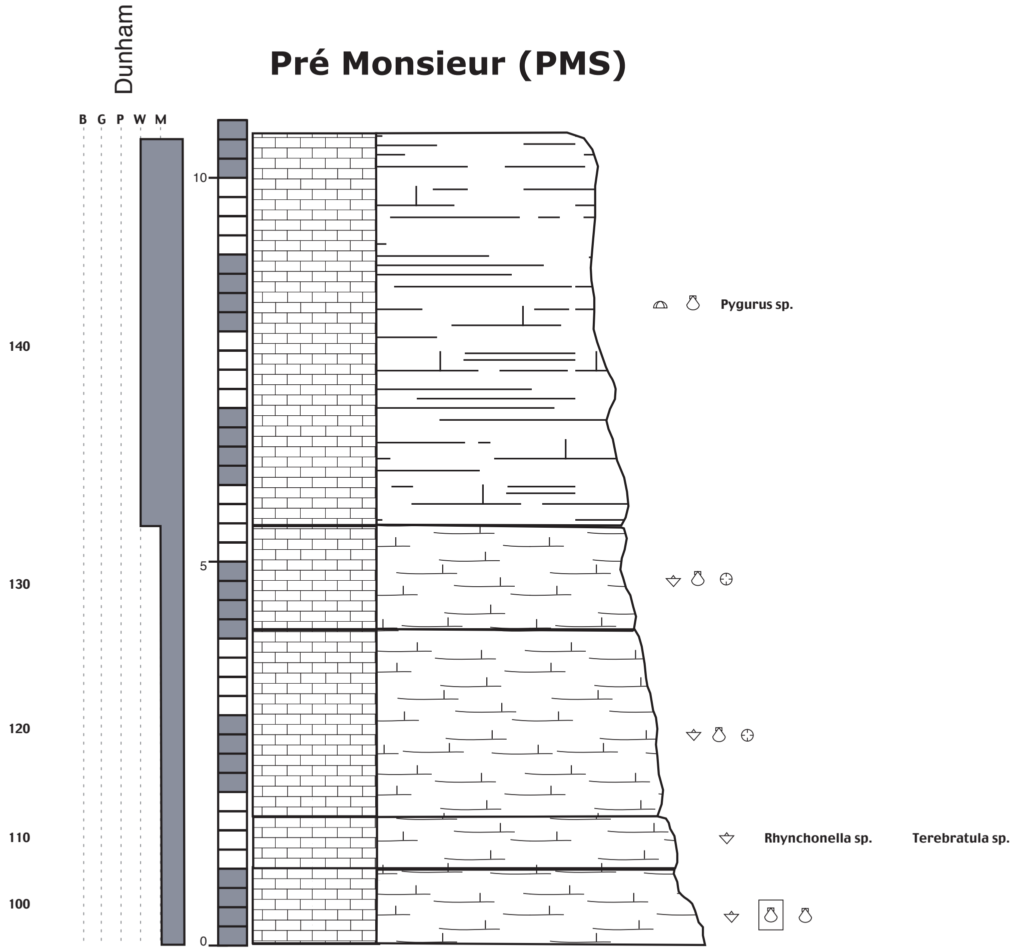


Creugenat (CRE)

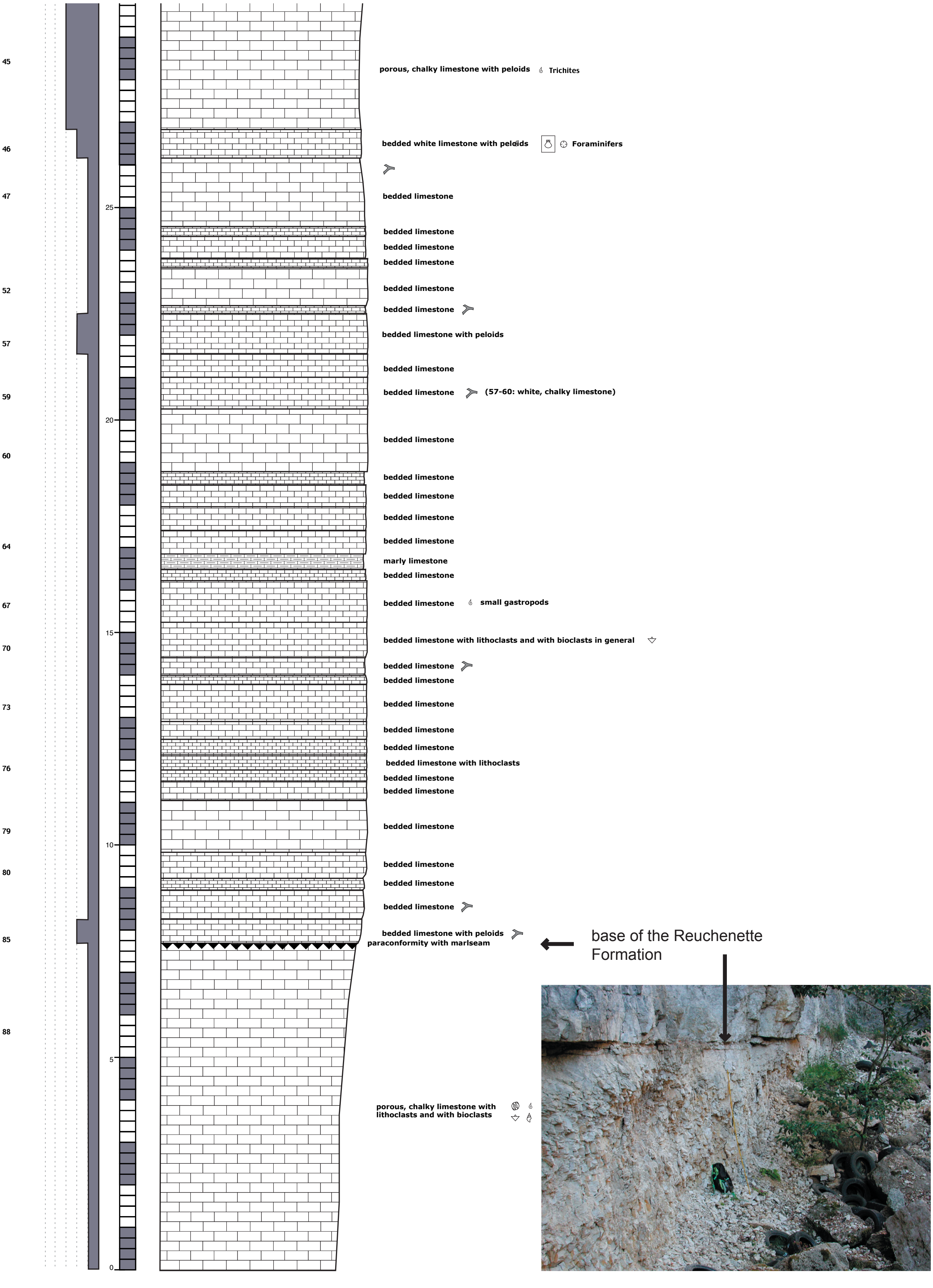


Fontenais (FON)

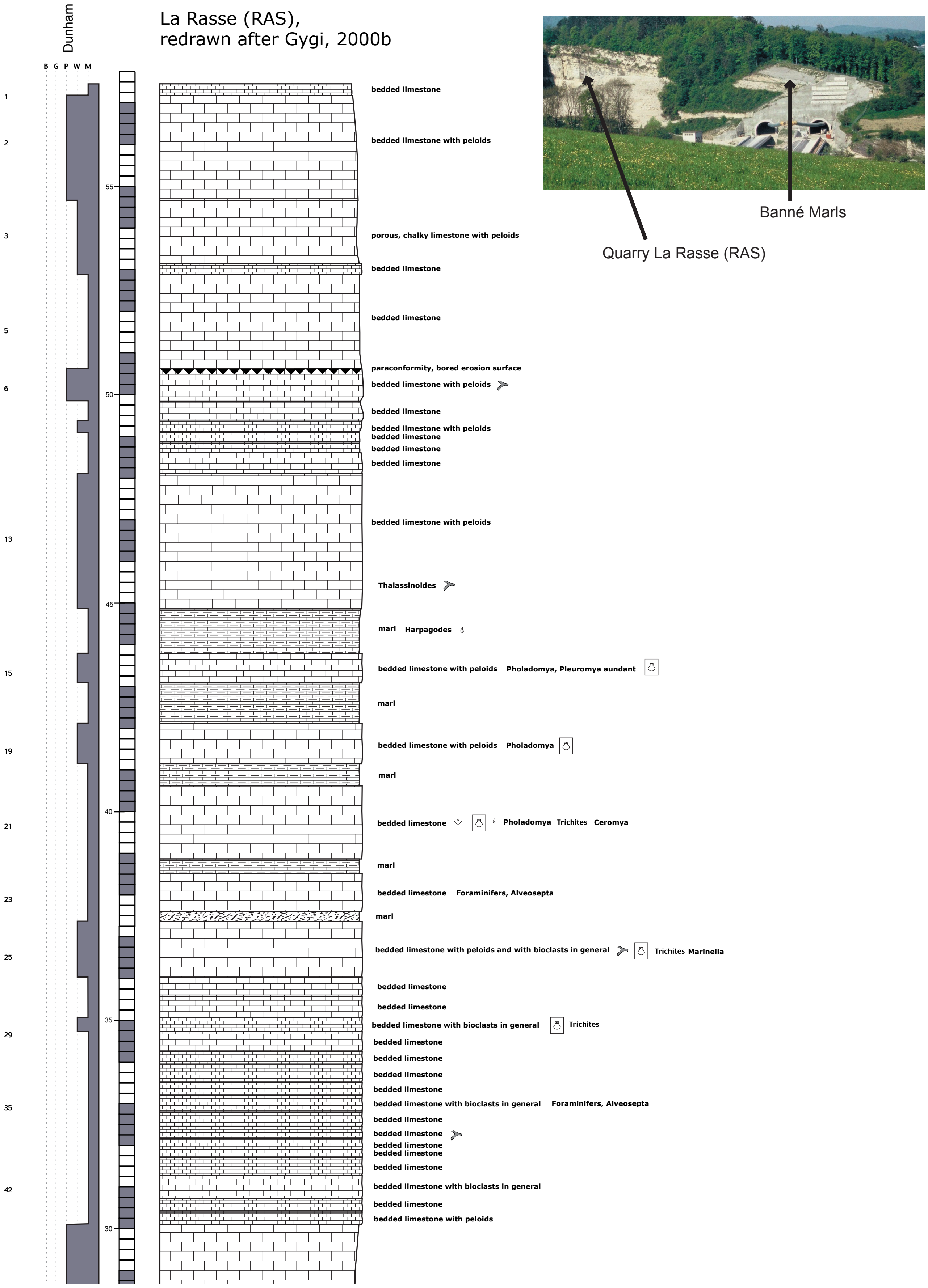



Dunham
Pré Monsieur (PMS)
B G P W M
10
5
0
140
130
120
110
100
Pygurus sp.
Rhynchonella sp.
Terebratula sp.

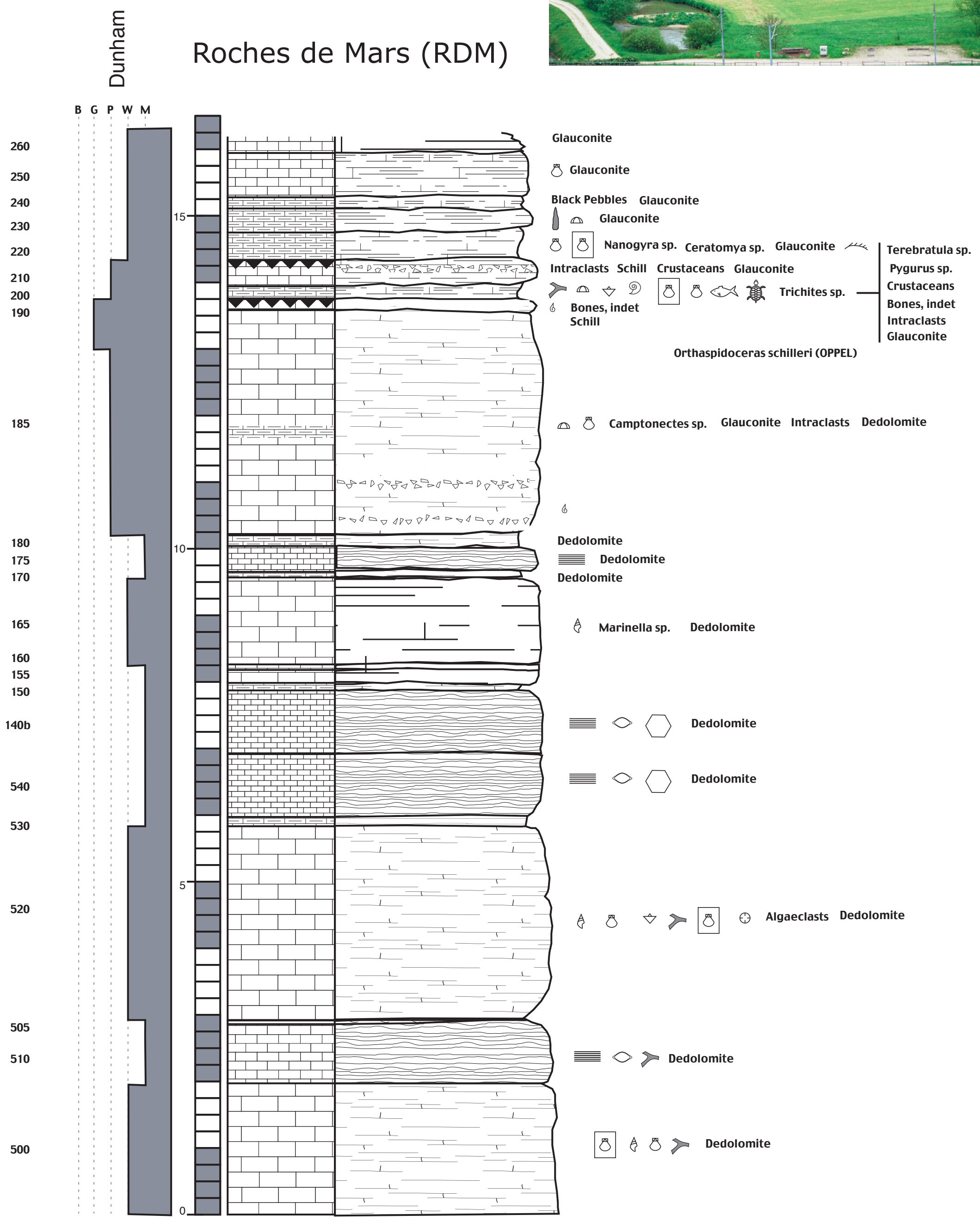
Lower part of La Rasse (RAS)

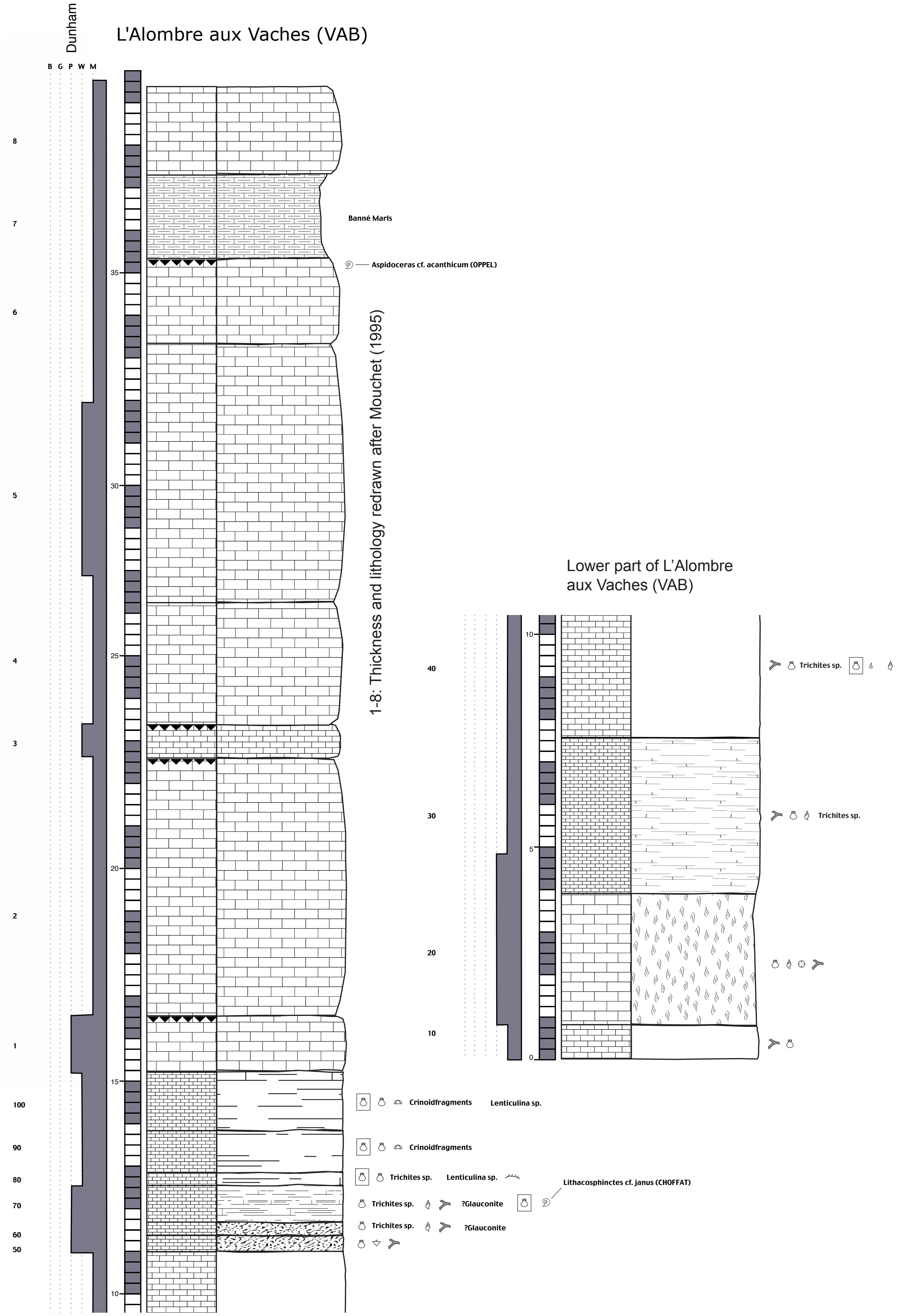


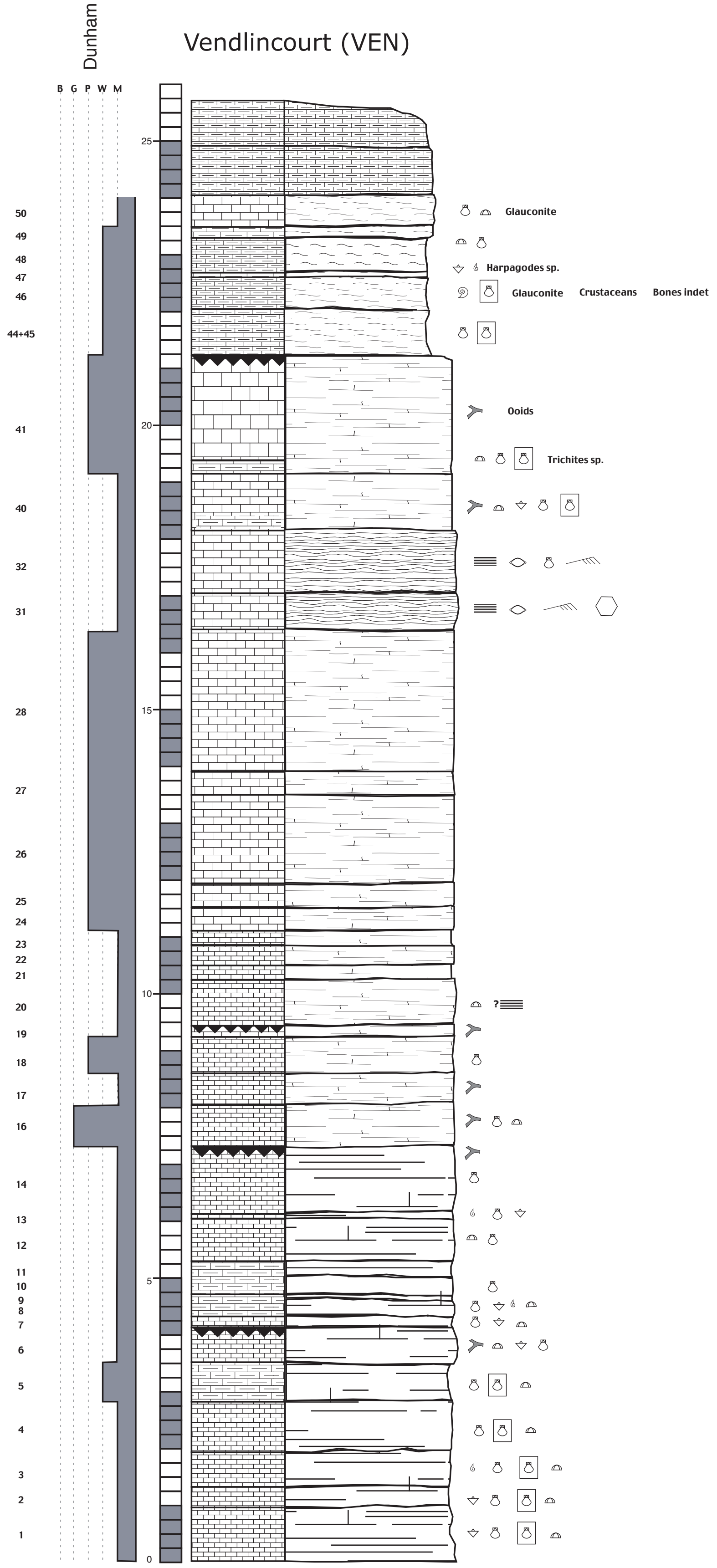
La Rasse (RAS),
redrawn after Gygi, 2000b



Roches de Mars (RDM)

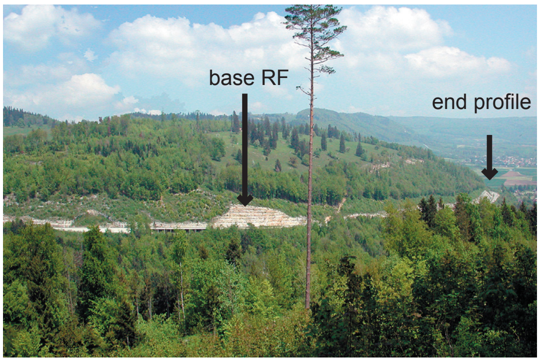



Dunham
L'Alombre aux Vaches (VAB)
B G P W M
8
7
6
5
4
3
2
1
100
90
80
70
60
50
35
30
25
20
15
10
Banné Marls
Aspidoceras cf. acanthicum (OPPEL)
1-8: Thickness and lithology redrawn after Mouchet (1995)
Crinoidfragments
Lenticulina sp.
Crinoidfragments
Trichites sp.
Lenticulina sp.
Lithacosphinctes cf. janus (CHOFFAT)
Trichites sp.
?Glauconite
Trichites sp.
?Glauconite
Lower part of L'Alombre aux Vaches (VAB)
40
30
20
10
10
5
0
Trichites sp.
Trichites sp.


Vendlincourt (VEN)
Dunham
B G P W M
50
49
48
47
46
44+45
41
40
32
31
28
27
26
25
24
23
22
21
20
19
18
17
16
14
13
12
11
10
9
8
7
6
5
4
3
2
1
25
20
15
10
5
0
Glauconite
Harpagodes sp.
Glauconite
Crustaceans
Bones indet
Ooids
Trichites sp.
?

Boncourt (BON)

Coeuve (COE)



Section Contournement de Glovelier (compare also picture to the right).

Base of the Reuchenette Formation in Contournement de Glovelier (note the colour change next to the person).

Cast horizontal *Thalassionoides* in the Thalassionoides Limestones in Contournement de Glovelier (bed GLO-34)

Base of the Reuchenette Formation in Gorges de Pichoux (PIX). Note the conspicuous bed-thickness change.

Banné Marls in Les Pommerats (POM)

Moulin de Séprais (SEP)

Cras d'Hermont (base little road). The three pictures show the "Nautilidenschichten"

Cras d'Hermont (little road)

Cras d'Hermont (between motorway and car shop)

Vatelin (VAT)

Cave in La Combe

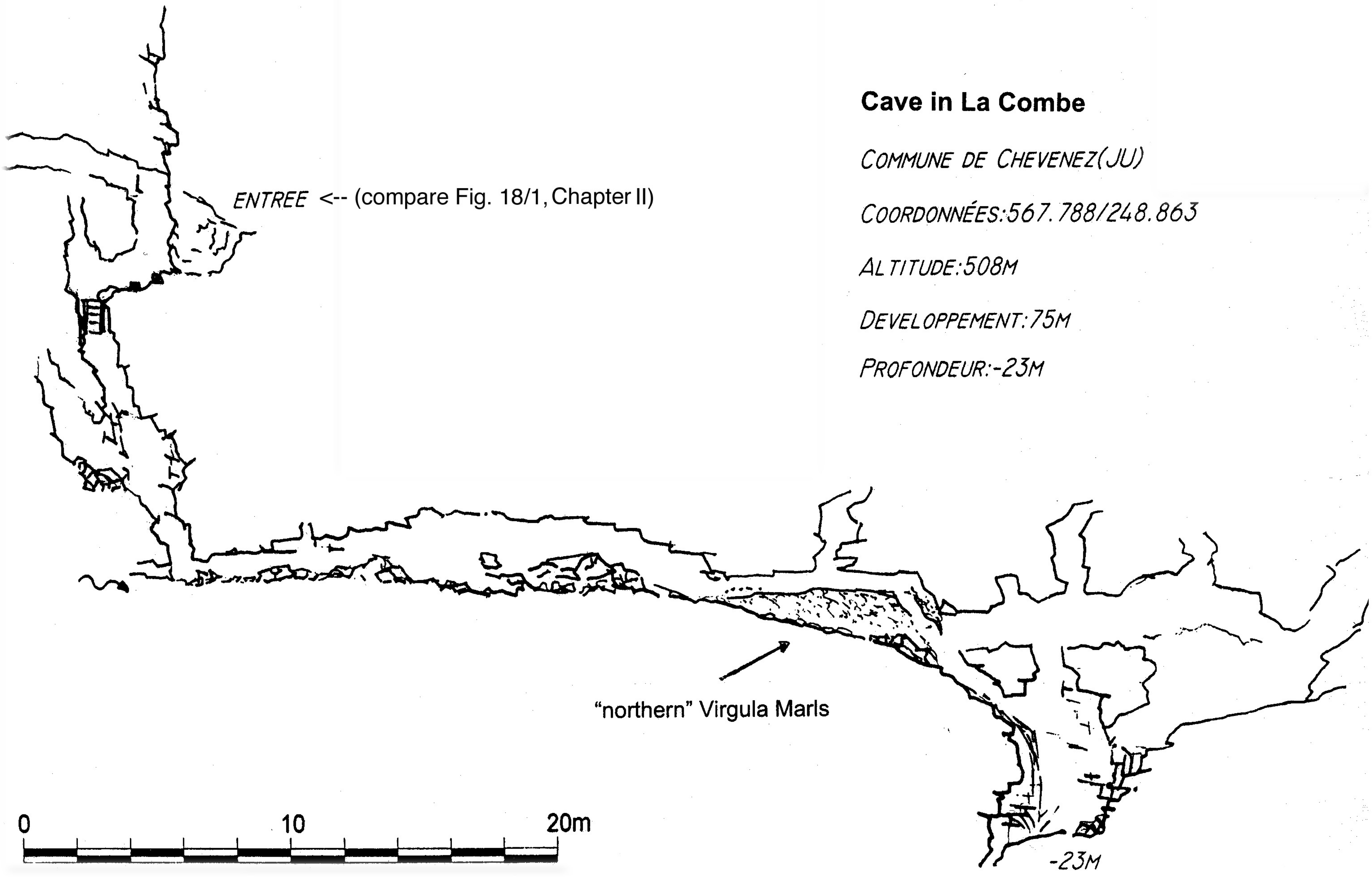
COMMUNE DE CHEVENEZ(JU)

COORDONNÉES:567.788/248.863

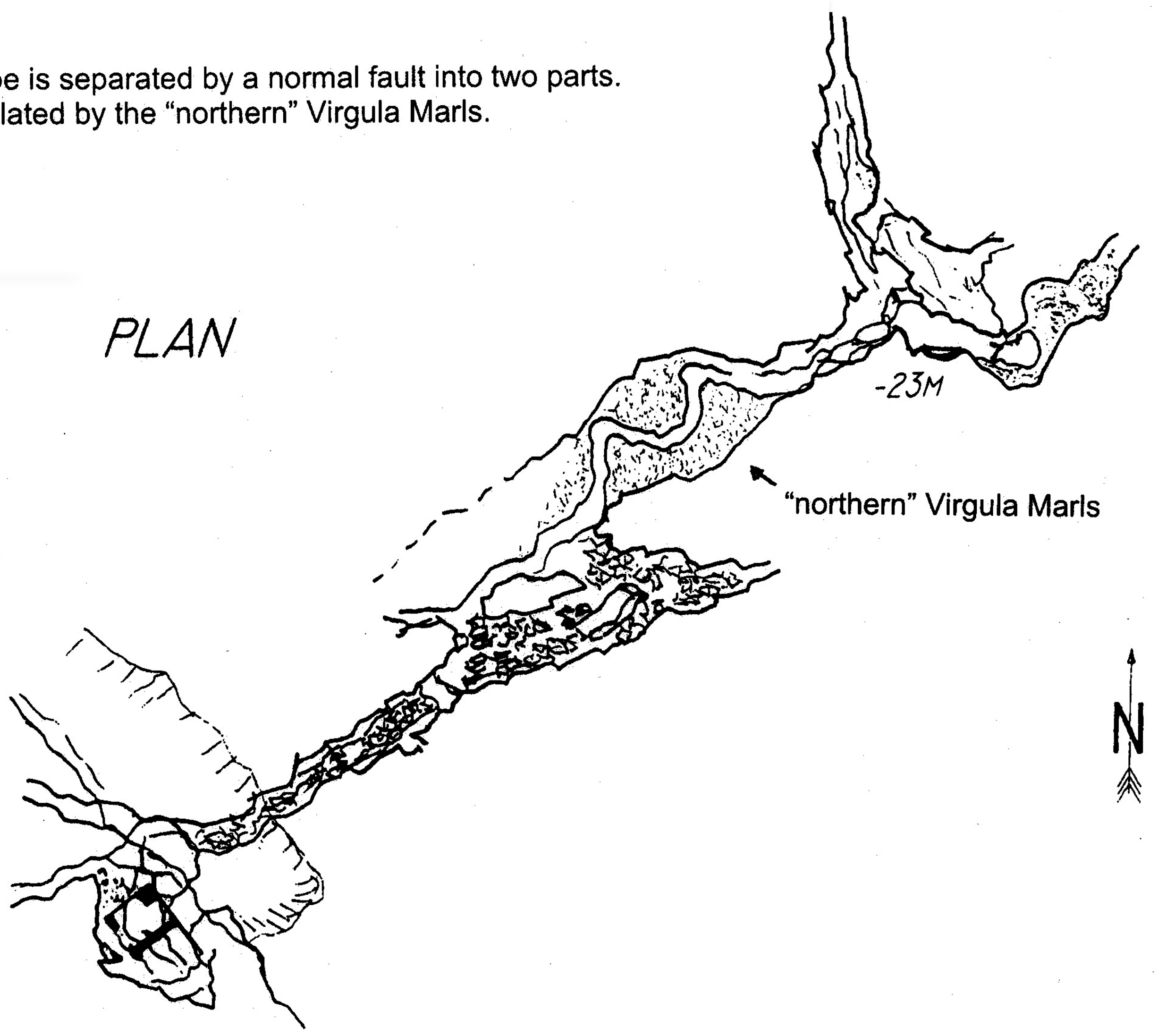
ALTITUDE:508M

DEVELOPPEMENT:75M

PROFONDEUR:-23M



The log in La Combe is separated by a normal fault into two parts.
These can be correlated by the "northern" Virgula Marls.



TOPO:GSP/II.1998