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Synsedimentary tectonics in an epicontinental sea: A new interpretation of the Oxfordian basins of northern Switzerland

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Keywords: Oxfordian, subsidence, Paleozoic, sea-level, facies, paleowaterdepth, sequence stratigraphy

ABSTRACT

Synsedimentary tectonics rather than autocyclic processes influenced the architecture of Oxfordian basins of northern Switzerland. Sea-floor topography constitutes swells and depressions that subsided differentially as a result of the Pan-European stress-field reorganization taking place during the Late Jurassic. Linked to the reactivation of basement faults, relief reversals during the Oxfordian led to shallow environments becoming deep, while previously rapidly subsiding areas became stable and were filled by sediments, resulting in shallow environments. Palinspastically restored facies maps and basin cross-sections reveal that the facies boundaries and depocenters were spatially related to reactivated Paleozoic faults seated in the basement. As a consequence, the assumption that the Mesozoic of northern Switzerland reflects a period of tectonic quiescence needs to be revised. Furthermore, it is evident that tectonics played a major role in defining the paleoenvironments subordinately influenced by eustatic sea-level. While tectonic movements were indeed unspectacular, reinterpretation of the Oxfordian facies nevertheless clearly shows that the opening of the North Atlantic and Tethyan Oceans affected the depositional domains situated between these two areas of extension.

ZUSAMMENFASSUNG

Die Architektur der Füllung der nordschweizer Oxford-Becken wurde eher durch synsedimentäre Tektonik als durch autozyklische Prozesse gesteuert. Der Ablagerungsraum gliederte sich in Becken und Schwellen, welche als Resultat des sich während des späten Juras reorganisierenden paneuropäischen Spannungsfeldes differentiell subsidierten. In Verbindung mit der Remobilisierung von Brüchen im Grundgebirge, führte Reliefumkehr während des Oxfordiums zur Vertiefung ehemals flacher Ablagerungsräume, während vormalig schnell subsidierende Gebiete stabil und als Resultat der Auffüllung mit Sedimenten zu Flachwassermilieus wurden. Palinspastisch rekonstruierte Fazieskarten und Beckenprofile zeigen, dass die Faziesgrenzen und Depozentren räumlich an reaktivierte paläozoische Störungen im Basement gebunden waren. Die Annahme, dass das Mesozoikum der Nordschweiz eine tektonische Ruheperiode darstellt, muss daher revidiert werden. Darüberhinaus wurde deutlich, dass tektonische Bewegungen eine wichtige Rolle bei der Abgrenzung der Paläoablagerungsräume spielten, welche ihrerseits untergeordnet von eustatischen Meeresspiegelschwankungen beeinflusst wurden. Obwohl die tektonischen Bewegungen an sich unspektakulär waren, zeigt die Reinterpretation des Oxfordiums deutlich, dass die Öffnung des Nordatlantiks und der Tethys die zwischen diesen beiden Extensionsgebieten gelegenen Ablagerungsräume beeinflusste.

Introduction

Up to the present, the Jurassic (including the Oxfordian) of northern Switzerland (Fig. 1) has been regarded as a period of tectonic quiescence (e.g. Diebold 1990), most likely due to the lack of contrary outcrop evidence of syndepositional tectonic features, such as those indicating a platform break-up. In fact, seismic records do not display marked facies or thickness changes, therefore linking the geometry of the Oxfordian formations to syndepositional tectonic activity could not be established (e.g. Laubscher 1986). In recent years sedimentologists have become increasingly aware of the effects of differen-

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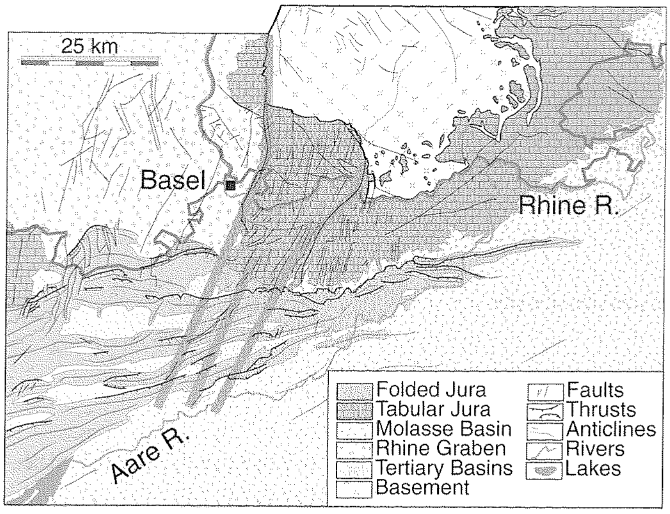


Fig. 1. The study area is situated in the Swiss Jura Mountains. Major geological and structural elements are the Molasse Basin to the south of the range and the Tabular Jura, Black Forest and Rhine Graben to the north. High-lighted as bold gray lines are the Rhenisch Lineament, which coincides with the eastern Rhinegraben masterfault, and the Wehra-Zeininger Fault.

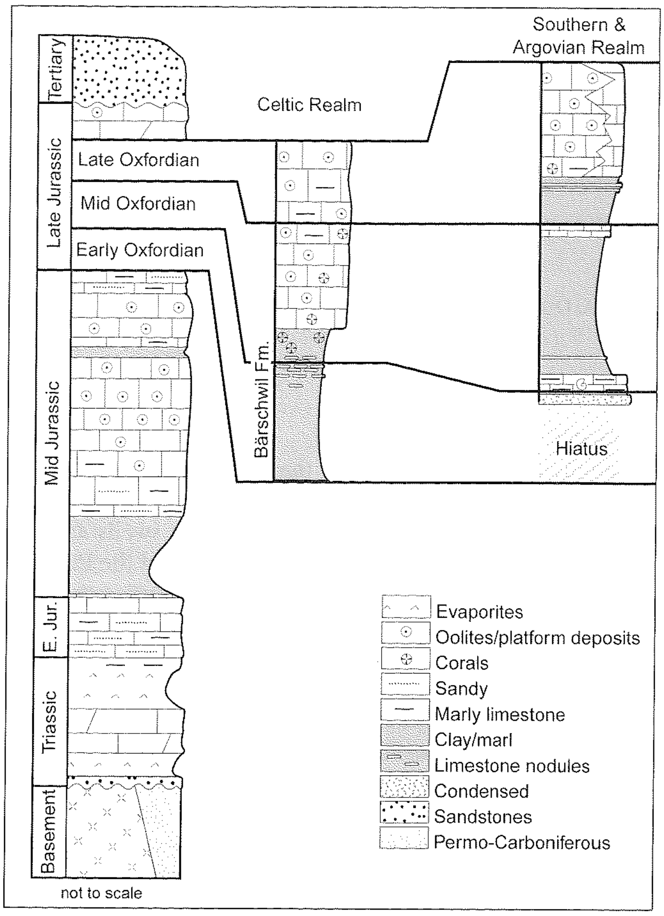


Fig. 2. Idealized section of the sedimentary cover of northern Switzerland. Two depositional realms can be identified in the Oxfordian deposits; the Celtic which is situated in the north-west of the study area and the Argovian in the remaining study area. The Celtic realm includes the Sequanian and Rauracian facies used by earlier authors.

tial subsidence related to large-scale tectonic events on the depositional environments of the Jura Mountains (Allia 1996; Burkhalter 1996; Wetzel & Allia 2000) and have increasingly used sequence stratigraphy to decipher the depositional history (Burkhalter 1995, 1996; Pittet & Strasser 1998). The combined effects of eustasy and tectonism are both recorded in the sedimentary record and differentiating the two can be very problematic (e.g., de Wet 1998; Robin et al. 1998). Similarly to eustasy, very large-scale tectonic events such as the opening of the North Atlantic and Tethys, will have long-range effects on the depositional systems linked to the area where the event took place (de Graciansky et al. 1998). Central Europe, being located between the North Atlantic and Tethys, had a high potential to be affected by the extensional tectonics in those realms, although its relatively rigid continental crust would have reacted passively. However, deep-reaching faults could be reactivated if placed in an appropriate stress field at times of major extensions, as has been demonstrated in other areas (Lowe 1985; Færseth 1996; de Wet 1998). Such deeply rooted faults formed during the Late Paleozoic when a megashearzone developed between the Ural and Appalachian mountain ranges (Arthaud & Matte 1977) and grabens and halfgrabens were formed (e.g. von Raumer 1998).

In recent years, a series of Paleozoic troughs has been identified in the basement underlying the Jura Mountains and Molasse Basin (Matter 1987; Diebold 1988; Diebold & Noack 1997). Other studies have demonstrated the effects of these troughs on Mesozoic sedimentation (Wetzel et al. 1993; Allia 1996; Burkhalter 1996; Allenbach 2001a; Allenbach 2001b) and the tectonic build of the Jura Mountains (Laubscher 1986; Küehni 1993; Philippe 1995; Diebold & Noack 1997; Laubscher & Noack 1997). The major trough-bounding faults lie beneath the southern foot of the Jura Mountains and along the northern edge of the folded Jura Mountains.

For the Oxfordian, increased subsidence has been recorded for southern central Europe (Wildi et al. 1989; Loup 1992) but to date the coincidence of significant lateral variations in facies and accommodation space with basement structures has not been recognized for the study area. Therefore, the model of Gygi (1969, 1986) for the Oxfordian basin fill in northern Switzerland relies on autocyclic processes which form sea-floor topography along with significant changes in relative sea-level. Alternatively, differential subsidence could explain the same depositional features of these basins and it would no longer be necessary to assume large paleo-waterdepths or a continuously rising sea-level, since accommodation space is being formed simultaneously with deposition by differential subsidence. In fact new sequence stratigraphic data and eustatic sea-level curves (Haq et al. 1987; Rioult et al. 1991; de Graciansky et al. 1998; Pittet & Strasser 1998) display only minor sea-level fluctuations during the Oxfordian being on the order of 30 m (Haq et al.

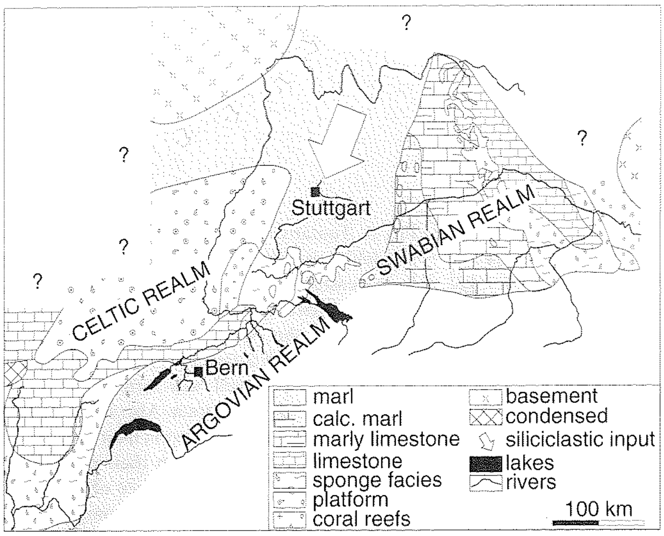


Fig. 3. Paleogeographic map of the Jura Mountains and adjoining areas during the Mid Oxfordian. The study area lies in an epicontinental sea north of Tethys and is characterized by platforms and shallow basins. Compiled from (Ziegler 1962; Debrand-Passard & Courbouleix 1984; Meyer & Schmidt-Kaler 1989) and own observations.

1987) to 15 m during the Middle Oxfordian (Pittet & Strasser 1998). Sea-level rises of this range cannot provide the space to accommodate up to 260 m of compacted deposits. Therefore differential subsidence becomes a plausible alternative to the autocyclic model. It is the purpose of this paper to demonstrate the potential of differential subsidence to explain the spatial distribution of lithofacies and the variations of sediment thickness deposited during the Oxfordian of northern Switzerland.

Geological Situation and Methods

During the Mesozoic the area of today's Jura Mountains were flooded by a shallow epicontinental sea in a subtropical climate (Fig. 2). Spread over Europe are a number of crystalline highs from which siliciclastic sediments were derived, resulting in a mixed carbonate-siliciclastic system (e.g. Pittet & Strasser 1998). Within the Oxfordian of Switzerland, eastern France and southern Germany two major domains can be distinguished. Based on older texts the terms "Celtic" for the platform and "Argovian" for the mud dominated realm are used to differentiate the general facies domains (Fig. 3) but they are unsuitable for stratigraphic purposes. The Celtic realm consists of three formations, the Bärschwil Formation at the base overlain by the St. Ursanne and the Vellerat Formations (Fig. 4). In detail the Bärschwil Formation consists of three members. From base to top these are the Renggeri Beds, Terrain à Chailles and Liesberg Beds. This formation attains thicknesses of up to 160 m and thins-out to zero towards the east and south. The Renggeri Beds are composed of mudstones with frequent occurrences of pyritized fauna (mainly ammonites) and pyritized wood. Sedimentary structures are primary lamination and some bioturbation. The Terrain à Chailles is similar to the Renggeri Beds, yet with continuous bands of micrite nodules interbedded in the mudstones. The Liesberg Beds are again muddy yet with numerous dish-shaped corals encrusted by serpulids, abundant crinoids and other fauna (Lauer 1985).

With the onset of the St. Ursanne Formation, a carbonate platform is established, which features some lateral facies variations especially at its base. Along the platform margin micrites with varying amounts of bioclasts (mudstone to wackestone) occur contrasting to the platform interior where oolites and patchreefs are found. Along the seaward edge of the St. Ursanne platform thick successions of micrite of the Pichoux Formation form the coeval sediments.

Lateral facies variations become more pronounced within the Vellerat Formation: the Vorbourg Member changes from micrites in the interior platform to sandbars and patchreefs along the platform edge. Despite these variations within the member, it is easily recognizable in the field due to distinct lithofacial changes in comparison to the St. Ursanne Forma-

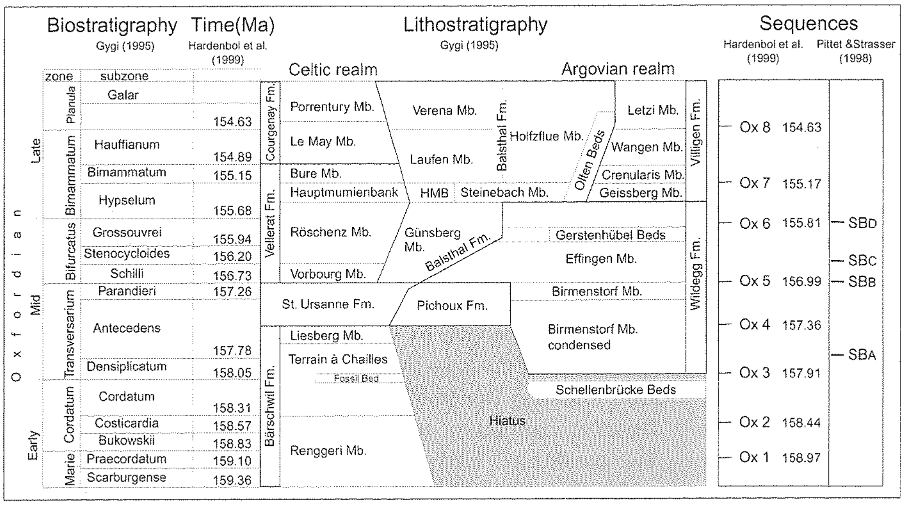


Fig. 4. Bio- and lithostratigraphy used in this study, redrawn from Gygi (1995). To the right are the sequence stratigraphic horizons of Pittet & Strasser (1998); SB refers to sequence boundaries. Also shown are the absolute ages and sequence boundaries of Hardenbol et al. (1998). Discrepancies between the two sequence interpretations are discussed in the text.

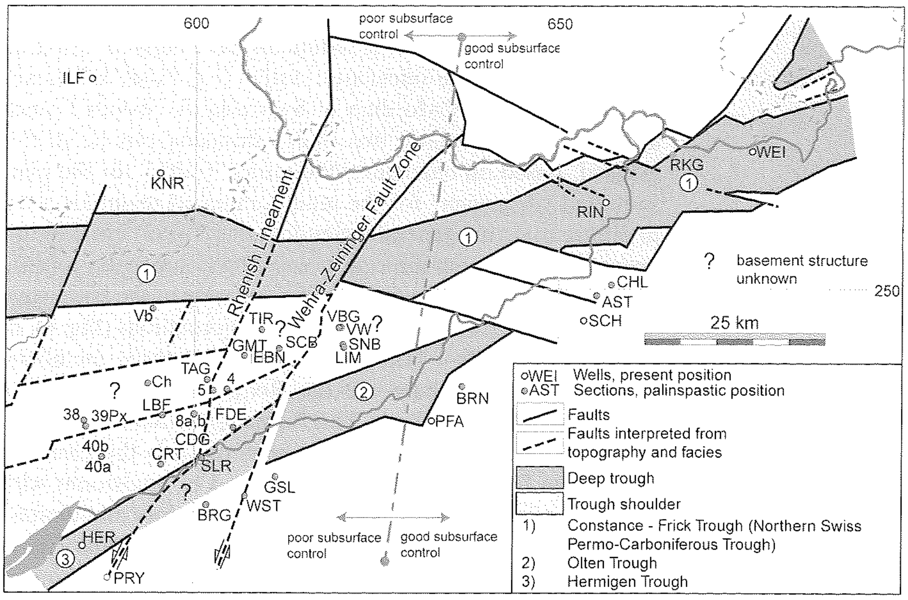


Fig. 5. Tentative map of the Paleozoic troughs and faults situated below the sedimentary cover. In the eastern study area, the Paleozoic troughs were identified through seismic exploration undertaken by the Nagra. Towards the west, the Hermrigen trough is the only one recognized on a seismic line. The well was terminated before reaching the Paleozoic strata. Also shown are the sections referred to in the text in their palinspastic positions. Wells are shown in their present day positions as they provide evidence of the Paleozoic beneath the Mesozoic cover (compiled from Matter et al. 1987; Matter et al. 1988; Diebold & Naef 1990; Naef & Diebold 1990; Laubscher & Noack 1997; Pfiffner et al. 1997).

tion. The Röschenz Member (formerly known as Natica Beds; Gygi 1995) is a thin (up to 30 m) stack composed of complex variations of platform carbonates and marls. Detrital quartz is very common (10-40%) in some beds, occasionally forming sandstones. Plants (Pittet 1996; van Konijnenburg - van Cittert & Meyer 1996; Allenbach & van Konijnenburg – van Cittert 1997) and terrestrial vertebrates (Meyer et al. 1997) occur in this member. In contrast, the Argovian realm is represented by muddy sediments (Wildegg and Villigen Formations), except for its basal part. Upsection follows the Hauptmumien Bank, a distinct oncolite which is a synchronous marker bed (Gygi & Persoz 1986; Pittet & Strasser 1998) covering most of the study area.

In the Early and early Middle Oxfordian of the eastern Argovian realm non-deposition prevailed, resulting in the condensed Schellenbrücke Beds and the Limonitic Crust (Fig. 4). Along the margin of the Early Oxfordian mudstones of the Celtic realm, thin accumulations of marl occur, overlain by the micrites of the distal Pichoux Formation. Further east in the study area the coeval Birmenstorf Member contains a very rich fossil fauna consisting mainly of siliceous sponges (Oppliger 1915) and ammonites. Associated are belemnites, crinoids, sea-urchins, brachiopods, gastropods and fish remains. Overlying the Birmenstorf Member and Pichoux Formation follows the Effingen Member. This member is a uniform succession of mudstone and marl alternations with occasional influxes of detrital quartz. The Effingen Member is subdivided into Upper (UEF) and Lower (LEF) members by the calcareous Gerstenhübel Beds, which become increasingly bioclastic towards the Celtic platform. They correlate with the patch reefs and the oolite sand bars of the Günsberg Member which at that time prograded over the north-western Effingen basin. As in the Celtic realm, the Hauptmumien Bank and coeval oolitic Steinebach Beds are developed.

The differentiation into facies domains, one Celtic, consisting of continuous shallow-water carbonates and the other, Argovian, characterized by marls, raises the question of which factors affected this facies pattern. Evidently, subsidence was of importance, because sediment thickness exceeds the depositional waterdepth. To decipher the effects of differential subsidence, sediment accumulation patterns in terms of thickness and facies were studied by using isopach maps (Bitterli 1992), subcrop maps of the Late Paleozoic structures (Fig. 5) and subsidence analysis, in addition to detailed lithostratigraphic sections. These were correlated by biostratigraphic (Gygi 1995) paleoecological and sequence stratigraphic criteria. A high-resolution sequence stratigraphic model (Pittet 1996) describes the response of the environment to Milankowitch cycles and provides a detailed facies analysis of the Middle Oxfordian Röschenz Member. From that study the longer-term sequence stratigraphic boundaries are used within this paper.

Previous basin models

The currently accepted depositional and facies pattern was worked out and described in detail by Gygi (1981, 1986, 1990, 1995), Gygi & Persoz 1986 and Gygi et al. (1998). He interpreted the Early Oxfordian as pro-delta muds (Gygi 1986) in front of a landmass situated further to the north-west (Gygi et al. 1998; fig. 9). Paleo-waterdepth at the base of these muds was estimated to have been at least 80 m in this area. According to Gygi a positive relief formed in response to continuing accumulation of these muds so water depth decreased and the facies graded into a coralline and mud facies (Liesberg Member), finally allowing the Middle Oxfordian carbonate platform (St. Ursanne Formation) to establish itself on the prodelta muds. The condensed Early Oxfordian succession in the Argovian realm (Schellenbrücke Beds, Limonitic Crust and condensed

Birmenstorf Member) is the result of starvation (Gygi 1986; Gygi et al. 1998), since nearly all of the sediment was deposited to the north-west (Gygi 1986) but water-depth was the same as in the north, according to (Gygi 1981) 80 to 100 m. The hard substrate and clear water (interpreted from the lack of sediment) should have been an ideal facies for corals (Gygi 1981). However, the only filter-feeders encountered are brachiopods and sponges. The absence of current dependent filter-feeders such as corals is regarded by Gygi (1981) as evidence for slack bottom currents and a lack of light due to depth. After the platform in the Celtic realm began to prograde, mud deposition was transferred further to the south-east into the Argovian realm forming marl-limestone alternations (Effingen Member). Towards the late Middle Oxfordian the carbonate platform rapidly prograded over the now partially filled Effingen basin. This progradation is recorded by the advance of the coral bioherms situated on the platform margin. The numerous micrite beds are interpreted as prograding clinothems (Gygi 1986) which lie parallel to the slope relief.

Alternatively, Bolliger & Burri (1970) considered synsedimentary tectonics and foresaw differential subsidence occurring along basement blocks which alternately formed or diminished accommodation space. They attributed the Early Oxfordian mudstones thinning out to the south and east to the rotation of blocks in the basement (Bolliger & Burri 1970; fig. 30).

Basement structures and database

The basement of the study area is structured by Late Paleozoic fault-bounded troughs which strike ENE to E-W (Fig. 5). A further major tectonic element is the Rhenish Lineament, which coincides with today's eastern Rhinegraben masterfault and the Wehra Zeininger fault zone (Boigk & Schöneich 1974; Ziegler 1990; Allenbach 2001a). The major faults bordering the Permo-Carboniferous trough display varying orientations; approximately ENE east of the Rhenish Lineament and south of the Jura Mountains and almost east-west north of the Jura Mountains and west of the Rhenish Lineament (Diebold 1990; Diebold et al. 1992).

Within the context of this paper it is important to point out that the Permo-Carboniferous trough infill was certainly of only minor importance because the trough fill was already compacted; during the Permian the trough was inverted and about 1000 to 1500 m of sediment were eroded (Kempter 1987; Schegg & Leu 1998). In addition, the Late Paleozoic geothermal gradient was higher thereby enhancing lithification. Therefore differential subsidence due to compaction of trough-fill sediments is ruled out during the Mesozoic, because up to the Oxfordian less than half of the eroded thickness was deposited (600 m; Diebold et al. 1992). Further compaction will not occur until the amount of overburden achieved before inversion is reached again. Accommodation space formed by differential compaction of underlying Mesozoic strata is also highly unlikely since most of the compaction is achieved during deposition, especially in limestones.

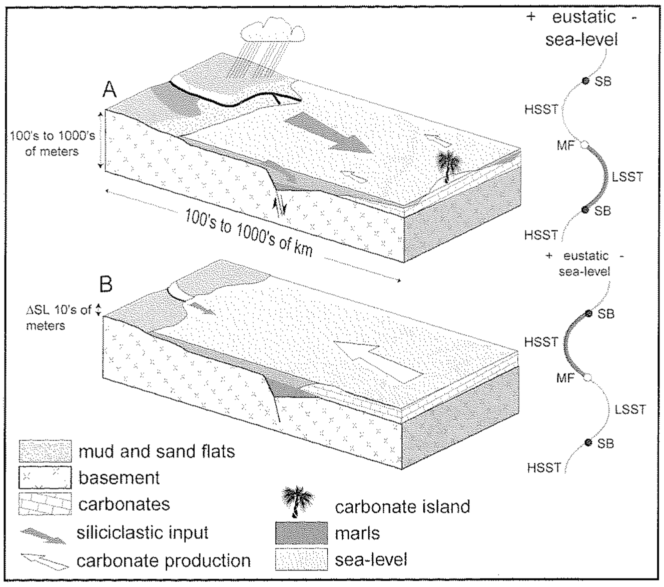


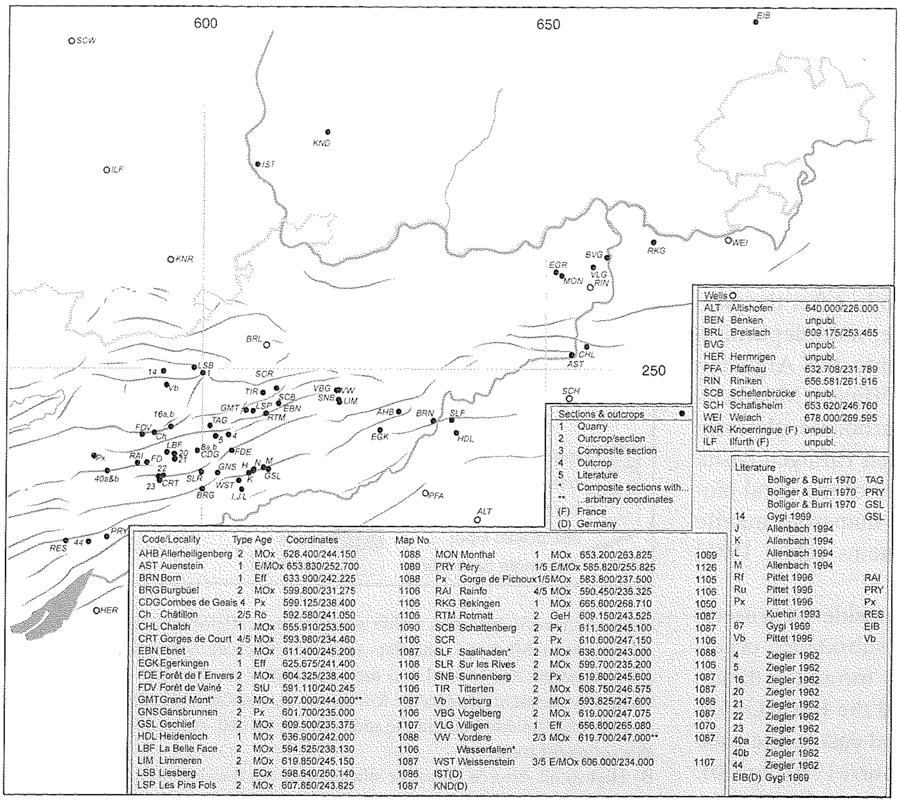
Fig. 6. Sediment dynamics within a sequence stratigraphic scenario.
A) Lowstand. Mud and sand flats as well as basement/siliciclastic deposits become exposed, are eroded and the siliciclastics are brought into the depositional environment. Due to the low sea-level, carbonate production is reduced and siliciclastics dominate in the sedimentary record. A reactivated trough acts as a sediment trap.
B) Highstand. Source areas for siliciclastics are flooded thereby reducing the amount of siliciclastics brought into the depositional environment. Parallel to the rising sea-level, carbonate production picks up again and dominates in the sedimentary record.

Palinspastic restoration of analyzed sections on facies maps and isopach maps was undertaken using Laubscher's (1965) data. The amount of shortening is greatest along the southern foot of the Jura Mountains and decreases gradually towards the unfolded Tabular Jura in the north of the study area.

The biostratigraphy and lithostratigraphy of the Late Jurassic in northern Switzerland has been established by Gygi (e.g. 1986, 1995) and is well documented, especially within the Effingen basin. The sequence stratigraphy used in this study relies mainly on a modified model of Pittet & Strasser (1998) which conforms well with the Hardenbol et al. (1999) chart. Major discrepancies are found in SBA of Pittet & Strasser (1998), which probably corresponds to Ox3 and SBC (Fig. 4). While SBC (Pittet & Strasser 1998) does not appear on the Hardenbol et al. (1998) chart, it does occur in the study area (see below). Possibly this sequence boundary is only of local importance or it reflects a 400 ky cycle (Strasser, Fribourg, 2001, pers. comm.). Determining its formation and distribution is beyond the scope of this study.

Timing of subsidence pulses and depositional patterns

A time frame is essential to understand the geometrical development of facies belts. For this purpose biostratigraphic data, sequence stratigraphic analysis and input of siliciclastics were



Wells ○		
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BEN	Benken	unpubl.
BRL	Breislach	609.175/253.465
BVG		unpubl.
HER	Hermrigen	unpubl.
PFA	Pfaffnau	632.708/231.789
RIN	Riniken	656.581/261.916
SCB	Schellenbrücke	unpubl.
SCH	Schafisheim	653.620/246.760
WEI	Weiach	678.000/269.595
KNR	Knoerringue (F)	unpubl.
ILF	Ilfurth (F)	unpubl.

Sections & outcrops ●	
1	Quarry
2	Outcrop/section
3	Composite section
4	Outcrop
5	Literature
*	Composite sections with...
**	...arbitrary coordinates
(F)	France
(D)	Germany

Code/Locality	Type	Age	Coordinates	Map No.					
AHB Allerheiligenberg	2	MOx	628.400/244.150	1088	MON Monthal	1	MOx	653.200/263.825	1069
AST Auenstein	1	E/MOx	653.830/252.700	1089	PRY Péry	1/5	E/MOx	585.820/255.825	1126
BRN Born	1	Eff	633.900/242.225	1088	Px Gorge de Pichoux	1/5	MOx	583.800/237.500	1105
BRG Burgbüel	2	MOx	599.800/231.275	1106	RAI Rainfo	4/5	MOx	590.450/236.325	1106
CDG Combes de Geals	4	Px	599.125/236.400	1106	RKG Rekingen	1	MOx	665.600/268.710	1050
Ch Châtillon	2/5	Ro	592.580/241.050	1106	RTM Rotmatt	2	GeH	609.150/243.525	1087
CHL Chalch	1	MOx	655.910/253.500	1090	SCB Schattenberg	2	Px	611.500/245.100	1087
CRT Gorges de Court	4/5	MOx	593.980/234.460	1106	SCR	2	Px	610.600/247.150	1106
EBN Ebnet	2	MOx	611.400/245.200	1087	SLF Saalihaden*	2	MOx	636.000/243.000	1088
EGK Egerkingen	1	Eff	625.675/241.400	1108	SLR Sur les Rives	2	MOx	599.700/235.200	1106
FDE Forêt de l' Envers	2	MOx	604.325/238.400	1106	SNB Sunnenberg	2	Px	619.800/245.600	1087
FDV Forêt de Vainé	2	StU	591.110/240.245	1106	TIR Titterten	2	MOx	608.750/246.575	1087
GMT Grand Mont*	3	MOx	607.000/244.000**	1087	Vb Vorburg	2	MOx	593.825/247.600	1085
GNS Gänsbrunnen	2	Px	601.700/235.000	1106	VBG Vogelberg	2	MOx	619.000/247.075	1087
GSL Gschlief	2	MOx	609.500/235.375	1107	VLG Villigen	1	Eff	656.800/265.080	1070
HDL Heidenloch	1	MOx	636.900/242.000	1088	VW Vordere	2/3	MOx	619.700/247.000**	1087
LBF La Belle Face	2	MOx	594.525/238.130	1106	Wasserfallen*				
LIM Limmeren	2	MOx	619.850/245.150	1087	WST Weissenstein	3/5	E/MOx	606.000/234.000	1107
LSB Liesberg	1	EOx	598.640/250.140	1086	IST(D)				
LSP Les Pins Fols	2	MOx	607.850/243.825	1087	KND(D)				

Literature		
	Bolliger & Burri 1970	TAG
	Bolliger & Burri 1970	PRY
	Bolliger & Burri 1970	GSL
14	Gygi 1969	GSL
J	Allenbach 1994	
K	Allenbach 1994	
L	Allenbach 1994	
M	Allenbach 1994	
Rf	Pittet 1996	RAI
Ru	Pittet 1996	PRY
Px	Pittet 1996	Px
	Kuehni 1993	RES
87	Gygi 1969	EIB
Vb	Pittet 1996	Vb
4	Ziegler 1962	
5	Ziegler 1962	
16	Ziegler 1962	
20	Ziegler 1962	
21	Ziegler 1962	
22	Ziegler 1962	
23	Ziegler 1962	
40a	Ziegler 1962	
40b	Ziegler 1962	
44	Ziegler 1962	
EIB(D)	Gygi 1969	

Fig. 7. Most of the studied outcrops are situated in the folded Jura Mountains. Due to poor exposure of the Oxfordian in the Tabular Jura, surface data are restricted to quarries. Numbered sections are those of Ziegler (1962). All locations are shown in their present day positions. A comparisson with Fig. 5 will give the reader an indication on the amount of latteral displacement caused by the folding of the Jura Mountains.

used. In a mixed siliciclastic - carbonate system the introduction of siliciclastics into the depositional environment offers a certain control on the timing of coeval deposits on the platform and the basin (e.g. Gygi & Persoz 1986; Pittet 1996). Especially useful are quartz sands derived from exposed continental areas (Bolliger & Burri 1970). The siliciclastics may enter the depositional area during a lowering eustatic sea-level when potential source areas became exposed, weathered and eroded (Fig. 6). Resulting siliciclastics were then introduced into the environment thereby reducing carbonate production and siliciclastic deposition could dominate. During a rising eustatic sea-level (Fig. 6) exposed basement is flooded and erosion decreases, allowing carbonate production to resume as accommodation space and ecological conditions suitable for carbonate production develop (Schlager 1992). Alternatively, the relative drop in sea-level could be of tectonic origin (uplift of basement), but erosion, weathering and introduction of siliciclastics are identical to the first model. In this scenario, eustatic sea-level has little or no effect. Therefore, the episodic occurrence of siliciclastics into a carbonate environment offers a certain time control, even though the mechanism itself may remain unknown.

Once siliciclastics (especially detrital quartz) are introduced, they should occur in both the calmer platform environments as well as the deeper basin. Similarly, increased carbonate production on the platform should also be documented in the basin by an increase in the carbonate content.

Section descriptions

To evaluate the effects of differential subsidence, numerous sections were measured, sampled, interpreted and correlated (Fig. 7). Complete sections, with a low resolution, are shown in the correlations further below. In addition to the complete, correlated sections some detailed parts are shown to illustrate typical features and the characteristics of correlation horizons.

Gschlief and Weissenstein (Wildegg and Balsthal Formations)

The Upper Callovian is represented by bioclastic, ooidal ironstones overlain by a marly ooidal ironstone layer containing small ammonites and belemnites. Above the Upper Callovian deposits follow slightly more than 5m of Lower Oxfordian clays, interrupted by a carbonate mudstone interval with a ferroan top (Fig. 8b). The base of the clays includes a number of carbonate nodules (casts of *Thalassinoides* burrows?) and ferroan ooids in the lower 30 cm. Upsection follow 9m of carbonate mudstones with thin marly partings belonging to the Birmenstorf Member. Of these, the bottom 15 cm are intensely bioturbated and somewhat ferroan with richer occurrences of fossils in comparison to the remainder of the section. While the same fauna occurs in this area, it is less abundant than in the typical Birmenstorf facies of Auenstein (see section Auenstein below). Further components are detrital quartz and glauconite. Towards the top of the Birmenstorf Member two separate layers of detrital quartz occur. Above a brief marly interval of the Lower Effingen Member, a first calcareous unit with tempestites crops out followed by a second marly interval again overlain by calcareous marls with tempestites. The remainder of the Wildegg Formation at this location is obscured by vegetation and scree.

The Günsberg Member of the Weissenstein section commences some 100 meters above the Birmenstorf Member. Corals dominate the lithology with peloid and bioclastic packstones found between the corals, as is typical for this member. A brief siliciclastic interval in the form of sandy shales defines the top of the reef environment (Fig. 8c). Above this siliciclastic horizon the section reverts to platform carbonates beginning with peloid, ooidal and bioclastic packstones. The top of the sections is formed by oolitic sandbars of the Steinebach Member.

Interpretation

While greatly reduced in thickness, the Lower Oxfordian of this locality is similar to the situation found in the clay pit of Liesberg (Gygi et al. 1998; fig. 5). In general, the succession from oolitic ironstones (Late Callovian) to clays (Early Oxfordian) corresponds to an omissional discontinuity *sensu* Burkhalter (1995). This implies non-deposition due to a land-ward shift of the depocenter during a rapid rise of sea-level (op. cit.). This sea-level rise coincides with a eustatic sea-level rise shown on the curve of Haq et al. (1987). Carbonates found in the Birmenstorf Member were shed from the platform (St. Ursanne Formation) during the Late Transversarium chron. Introduction of quartz grains and clays into the environment, parallel with a cessation of carbonate production, is interpreted as due to a rapid drop in sea-level (SBB or Ox5 of Hardenbol et al. 1998) which marks the top of the Birmenstorf Member.

The uppermost Effingen Member includes tempestites with components derived from the nearby platform. Coral patch-reefs of the Günsberg Member nucleate on these beds in response to a rising sea-level while some marl deposition continues. Upsection the reefs are found in peloid wacke- and packstones, again interpreted as highstand deposits. These are overlain by a thin, sandy mudstone interval above which packstones and finally grainstones are found. This sharp facies change from reefs to mudflats is interpreted as caused by a drop in sea-level corresponding to SBD (Fig. 8c) and represents the east-ward extension of the mud and sandflats of the Péry locality (see below). Stratigraphically the horizon corresponds to the Röschenz Member. Again similarly to the Burgbuel and Péry sections (see below), carbonate production picks up again after this break in production and carbonate sandbars are re-established as accommodation space is provided by a transgression.

Auenstein (Wildegg Formation)

Deposited on Callovian sandbars, the condensed Schellenbrücke Beds and Limonitic crust of the late Early Oxfordian are overlain by the Birmenstorf Member in its typical assemblage of marls and micrites rich in sponges and ammonites (Fig. 9). Crinoid roots are occasionally found on the sponges. Other fauna includes brachiopods, belemnites, fish remains, echinoderms and gastropods. With the onset of the Effingen Member fossils become sparse. Within the Lower Effingen Member a series of stacked channels crops out; internal structuring is virtually absent, apart from some lags, but channel geometry displays a paleoflow to the west. The remainder of the Effingen Member consists of marl - limestone alternations apart from a ferroan sponge crust on a ca. 50 cm thick limestone bed. The Gerstenhübel Beds (shown below) are approximately 16 m thick at this location and are featureless apart from occasional traces of *Chondrites*, pyrite trails and marly partings. The Upper Effingen Member is again a marl - limestone alternation with a number of carbonate-rich intervals. Situated 10 m over the top of the Gerstenhübel Beds a 5–10 cm thick mudstone bed is capped by a limonite/pyrite crust up to 3 mm thick. Its top is bioturbated by horizontal *Thalassinoides* burrows and vertical borings. Internally the crust contains ripples formed by detrital quartz and pyrite grains (Fig. 10). Mineralized ammonites up to 1 cm in diameter occur additionally. Towards the top of the section up to 10cm thick tempestites composed mainly of detrital quartz become fairly abundant.

Interpretation

The sheer abundance of macrofossils within the Birmenstorf Member is indicative of slow sedimentation. Due to sediment being continuously swept from this area, condensation and minor deposition prevail. The diverse fauna encountered in the Birmenstorf Member suggests a hospitable environment to a wide range of species, many of which are sessile filter feeders dependent on currents, crinoids and sponges for instance. With the onset of rapid marl deposition in the Effingen Member, fauna becomes scarcer. Considering the fact that Late Callovian deposition on this location was on a swell (Bitterli 1977), the reduced deposition during the Early Oxfordian is attributed to a persistence of this swell (c.f. Gygi 1986). Sedimentologically, the reworked sediments of the oldest Oxfordian deposits of the Argovian realm support this interpretation (Allenbach 2001b), as also stated for similar deposits in SW Germany (Ricken 1985). Furthermore, paleontologically the sponge communities of the Birmenstorf Member in France were interpreted by Gaillard (1983) as having formed on submarine swells rather than in deep, starved basins. Within this context the separation of the Early Oxfordian basin of the Jura Mountains and the Early Oxfordian Sub-Alpine basin of southern France is important: These two depositional domains are separated by a swell characterized by condensed deposits (Fig. 11).

The series of channels encountered in the Lower Effingen Member are interpreted as the lowstand deposits laid down after SBB (Ox5 of Hardenbol et al. 1998). During a relatively

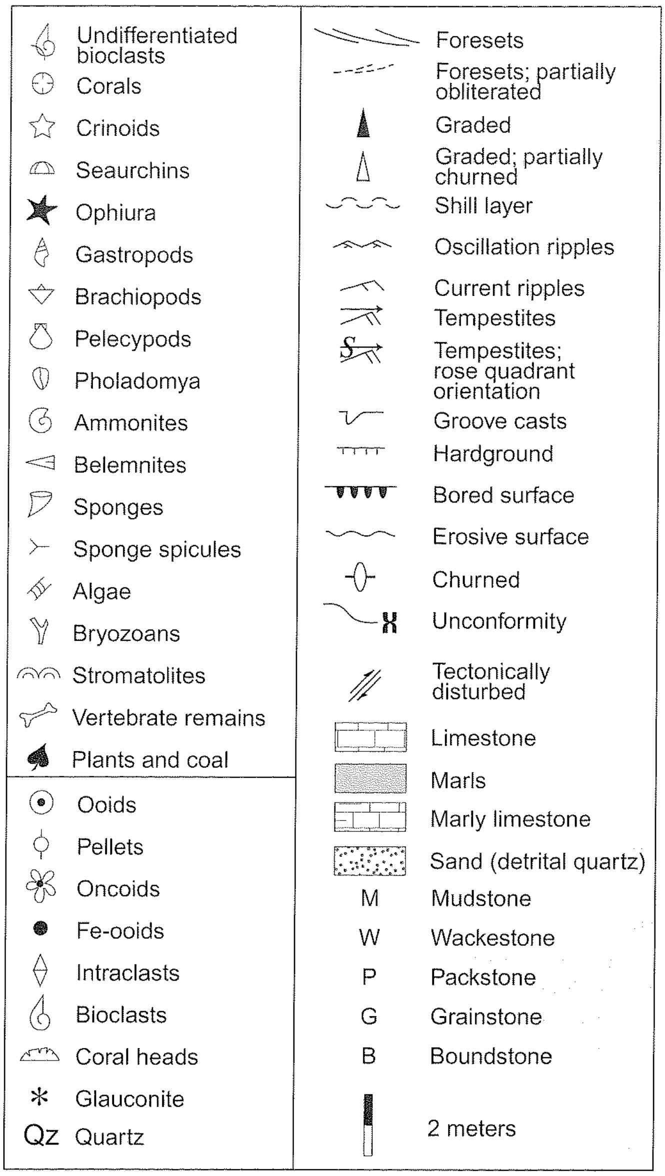


Fig. 8a. Key to symbols and patterns used in the stratigraphic sections (Figs. 8, 9, 11–15). Only the significant parts of complete sections are illustrated as detailed sections; scale bars in meters. Numbered section-meters indicate meters above base of a section.

low sea-level, tidal run-off from shallower environments incised channels into the sea-floor matching the observed paleocurrent direction. Upsection the rocks become increasingly calcareous, reflecting a transgression up to the sponge crust which is interpreted as a period of non-deposition due to maximum flooding (MFC of Pittet & Strasser 1998) while the limestones above are regarded as highstand carbonates washed off the platform. Further mud deposition up to the Gerstenhübel Beds corresponds to a further regression and low-stand. The thick limestones of the Gerstenhübel Beds indicate a highstand with increased carbonate production. The presence of both *Thalassinoides* burrows and borings found in the hardground above the Gerstenhübel Beds has a multi-phase history: deposition – bioturbation and erosion – burial and lithification – exhumation – mineralization and boring. The erosion and exhumation phases especially are indicative of a shallowing of the environment rather than a deepening as suggested by Pittet (1996). Therefore, in this study, this horizon is seen as a type 2 sequence boundary (SBD) rather than a maximum flooding surface.

Titterten (Pichoux and Vellerat Formations)

The Pichoux Formation forms the lower part of the Titterten section and is composed of a fairly thick succession of gray to beige micrites, peloid wacke- to packstones and corals (Fig. 12). The corals are a loose assemblage of coral heads embedded in a micrite matrix. Upsection corals and pellets as well as bioclasts increase in amount. A wavy, irregular surface forms the top of the Pichoux Formation. The overlying Vellerat Formation begins with the Vorbourg Member. It is composed of pack to grainstones including ooids, pellets, bioclasts, detrital quartz and lithoclasts and is of an orange-beige color. The remainder of the section is formed by the Röschenz Member beginning with marls at the base containing occasional thin wacke- to packstone tempestites, followed by a succession of grainstones and patch reefs. These are in turn overlain by marls containing thin beds of peloid and bioclastic grainstones. A second marly interval with intercalated thin wacke- to packstones follows. It is capped by the oolitic grainstones and mudstones of the Hauptmumienbank.

Interpretation

The shift from open marine micrites to coralline deposits of the Pichoux Formation reflects the transgressive trend during the late Transversarium chron (Pittet & Strasser 1998), as carbonate production increases and reefs of the St. Ursanne Formation prograde slightly over the Pichoux Formation mudstones. The following grainstone assemblages of reworked, worn allochems and intraclasts indicate a regressive trend leading to a shallower environment between the top of the Pichoux Formation and lower Vorbourg Member. The irregular surface encountered at the top of the Pichoux Formation is interpreted as an erosive sequence boundary (SBB of Pittet & Strasser 1998; Ox5 of Hardenbol et al. 1998). During deposition of the Vorbourg Member a sea-level rise led to more agitated conditions on the platform indicated by the deposition of grainstones. The following marl interval of the Röschenz Member documents a significant input of siliciclastics (Fig. 6) deposited in muddy lagoons on the platform (Gygi & Persoz 1986; Pittet & Strasser 1998). This change from high energy conditions encountered in the Vorbourg Member to muddy lagoons documents a drop in sea-level (SBC of Pittet & Strasser 1998) leading to protected and even restricted conditions on the platform (op. cit.). Open conditions prevail again as sand bars and

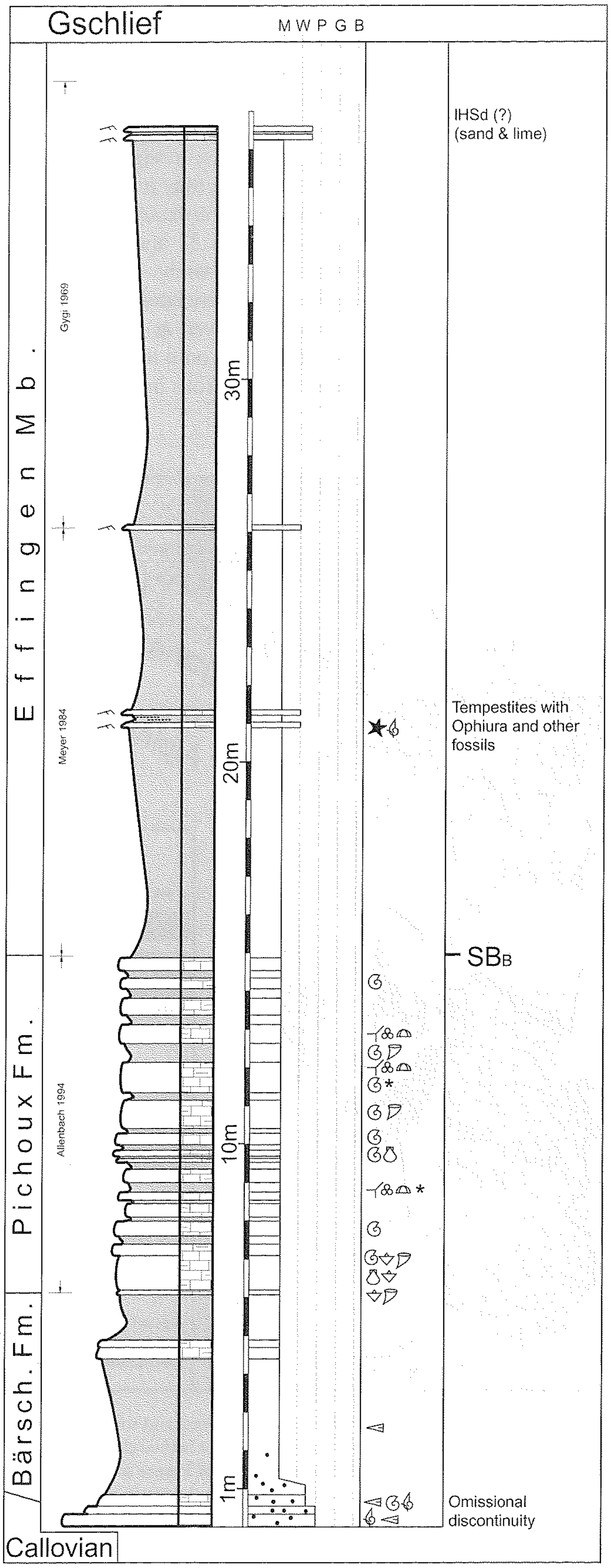


Fig. 8b. In the Gschlief section both the Bärschwil Formation of the Early Oxfordian, which thins out to the south, and the Effingen Member of Mid Oxfordian basin are exposed. Compared with the coeval Birmenstorf Member of the Auenstein section, the fossil content, while similar, is not as rich within the Pichoux Formation. Carbonate content was derived from the coeval St. Ursanne Formation. Following SBB (Ox5 of Hardenbol et al. 1998) the clay content increases and the Effingen Member was deposited. The ophiura-bearing tempestites of the Lower Effingen Member are interpreted as coeval with the channels of the Auenstein section (see below). Compiled from Gygi (1969), Bolliger & Burri (1970), Meyer (1984), Allenbach (1994) and new observations.

patch-reefs are re-established on the platform due to a renewed flooding of the platform (MFC of Pittet & Strasser 1998). A further regressive phase within the Röschenz Member is indicated by further mudflat and muddy lagoon deposits (SBD of Pittet & Strasser 1998; Ox6 of Hardenbol et al. 1998).

Péry (Wildegg, Balsthal and Vellerat Formations)

This section commences with ca. 5m of dark gray clays of the Lower Oxfordian Bärschwil Formation overlain by ca. 35 m of well bedded gray micrites with marly partings belonging to the Pichoux Formation (see below). These rocks consist mainly of

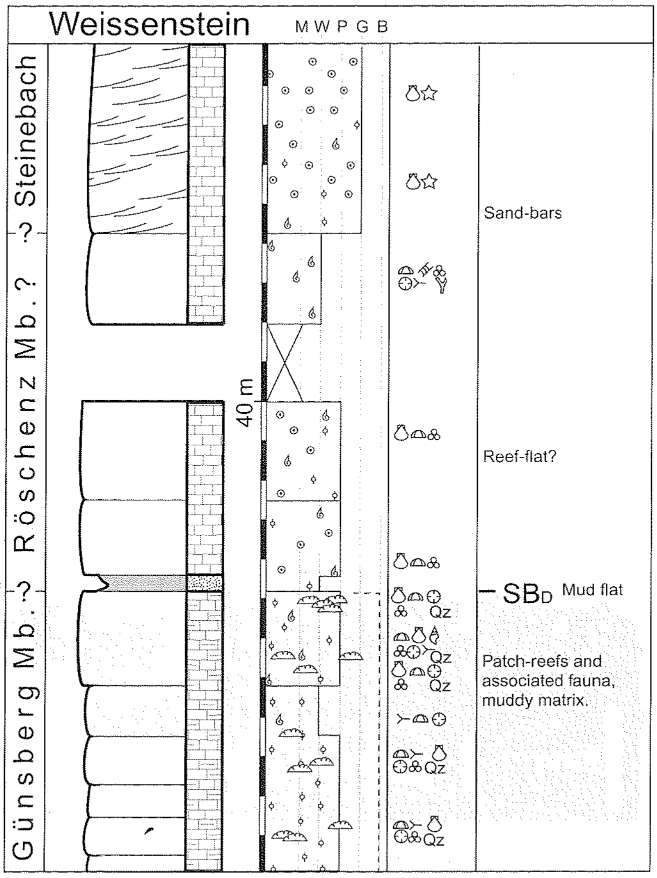


Fig. 8c. In the Weissenstein section SBD is recognized by the thin sandy, marl layer and low-energy carbonates overlying the patch-reef facies, before reverting to high-energy, marginal platform conditions of the Steinebach Member.

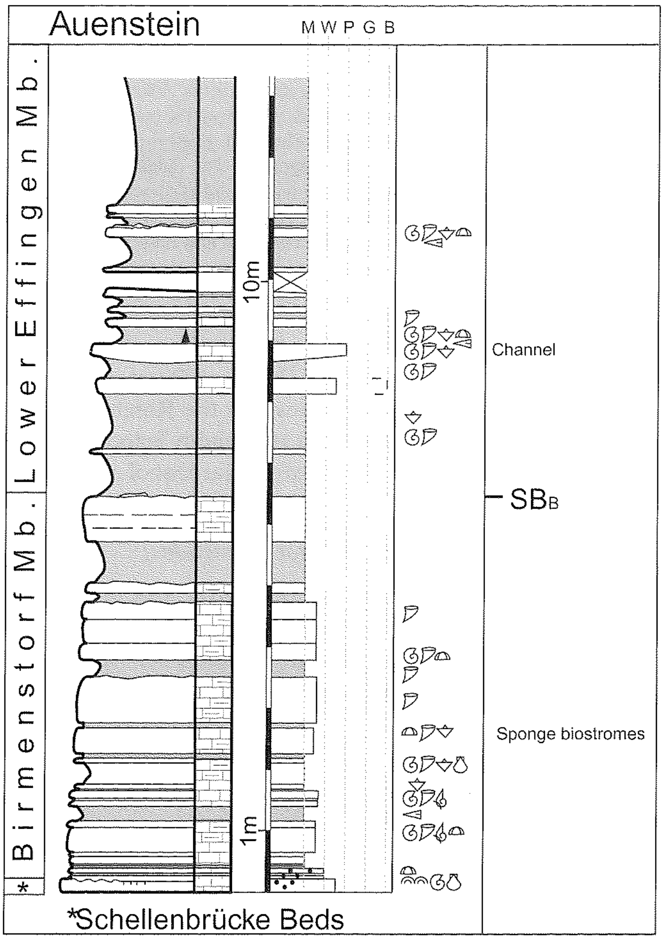


Fig. 9. Auenstein is the most distal section illustrated. At the base of the section lies the condensed Limonitic Crust and Schellenbrücke Beds interpreted as condensation through by-passing on a submarine swell. Carbonate muds of the Birmenstorf Member were derived from the coeval St. Ursanne and Pichoux Formations. SBB (Ox5 of Hardenbol et al. 1998) is placed along the top of the Birmenstorf Member which coincides with an increase in marl deposition. The channels encountered in the Lower Effingen Member are interpreted as low-stand deposits usually not preserved on the platform.

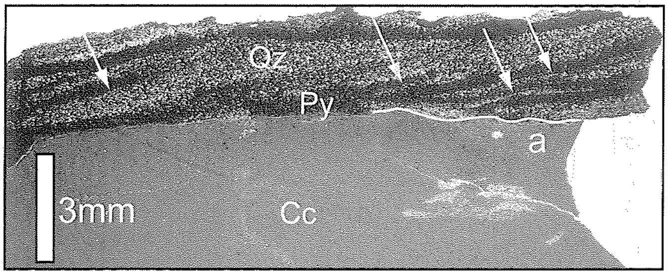


Fig. 10. Hardground overlying the Gerstenhübel Beds of the Auenstein section. The bed is composed of a churned carbonate mudstone (Cc). Over an erosive top (a), lies a ferroan tempestite composed of detrital quartz grains (Qz) and pyrite (Py) in the pore spaces. The siliciclastic layers are arranged in current ripple foresets (white arrows).

mudstones along with some bioclastic and peloid wacke- to packstones. A hardground covered by a thin marl layer forms the top of the formation. Upsection the Effingen Member starts with a thin-bedded, calcareous unit. Continuing upsection (Fig. 13) a number of newly described sandy tempestites, graded event beds, pot casts, channels and a hardground occur. Tempestites are frequent at this locality, they are usually thin (< 5cm), bioturbated beds and display remnants of laminae and/or current ripples. Between meters 32 and 39 (Fig. 13) nearly all of the beds encountered are sandy, ferroan, up to 15 cm thick tempestites. They feature erosive bases, groove casts, both uni- and bidirectional foresets as well as occasional pot casts. Near meter 44, a firmground rests on a thick mudstone. The firmground is documented by numerous imprints of large

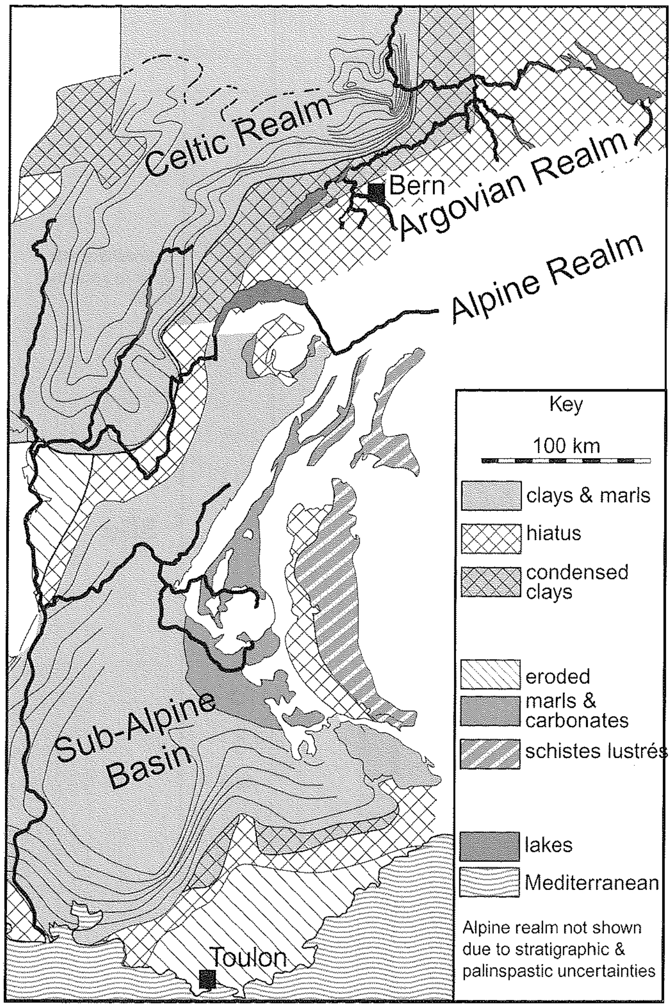


Fig. 11. Map showing the basin realms of Switzerland and south-east France during the Early Oxfordian. Thick accumulations of basinal clays are found in the Sub-Alpine basin of France and in the Jura of France and Switzerland. Between the two basins lies a large area of condensed deposits which stretches into the Swabian and Helvetic realms, which were formed on a swell. Compiled from Ziegler (1962), Debrand-Passard & Courbouleix (1984) and own observations.

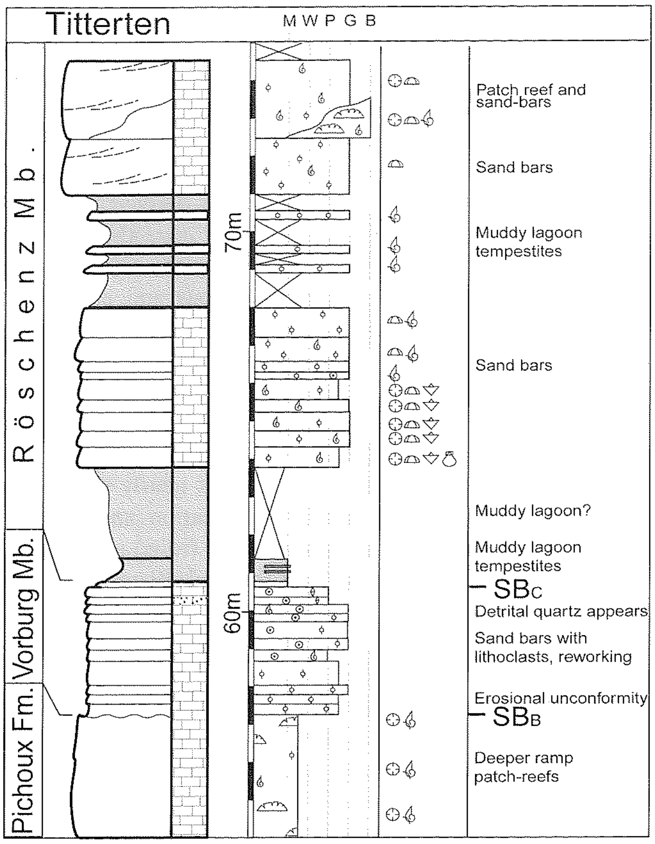


Fig. 12. Section Titterten is one of the few sections measured in which SBB (Ox5 of Hardenbol et al. 1998) can be identified by an erosional unconformity and a sharp lithofacial change from deeper platform patch-reefs of the Pichoux Formation to carbonate pack-and grainstones of the Vorbourg Member. Low-stand deposits are not preserved. Following SBC muddy lagoons are encountered of the interior platform.

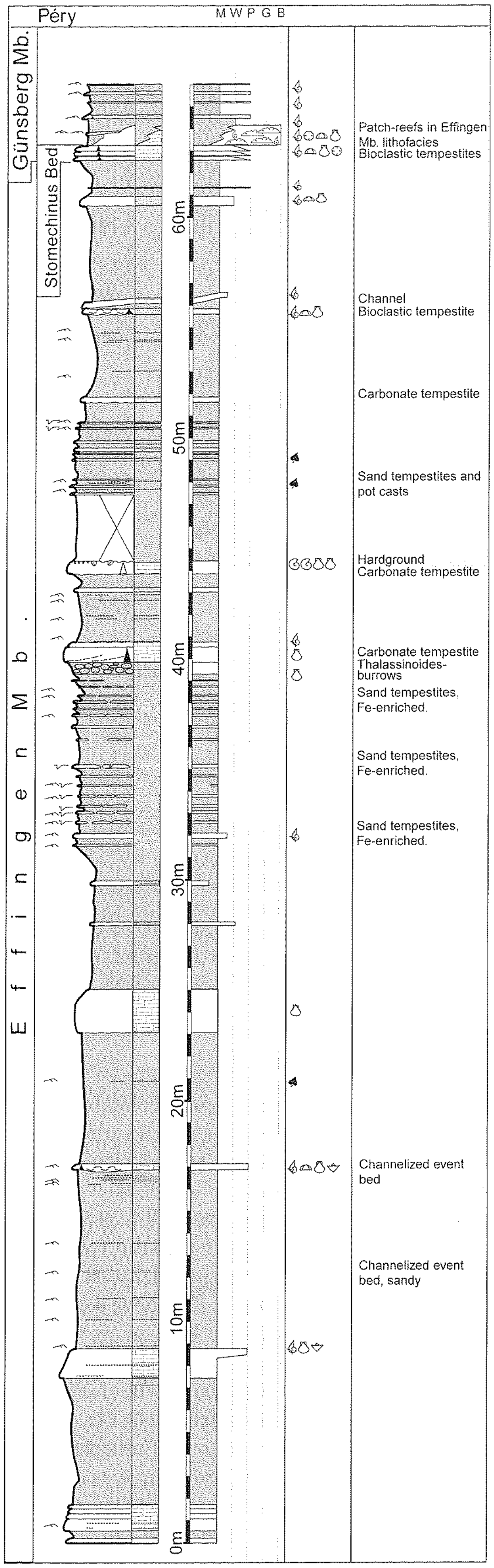


Fig. 13. Deposits of the upper part of the Effingen Member in the Péry section frequently contain sandy tempestites and even amalgamated sandstone layers. Sedimentary structures such as current ripples and groove casts indicate a paleoslope to the south. Other structures such as bi-directional current ripples and pot-casts reveal that the paleo-waterdepth was never far from the storm wave base and occasionally even above the storm wave base. In comparison to other sections (i.e. Weissenstein and Auenstein), the Effingen Member of Péry contains the most detrital quartz indicating its proximity to the source area.

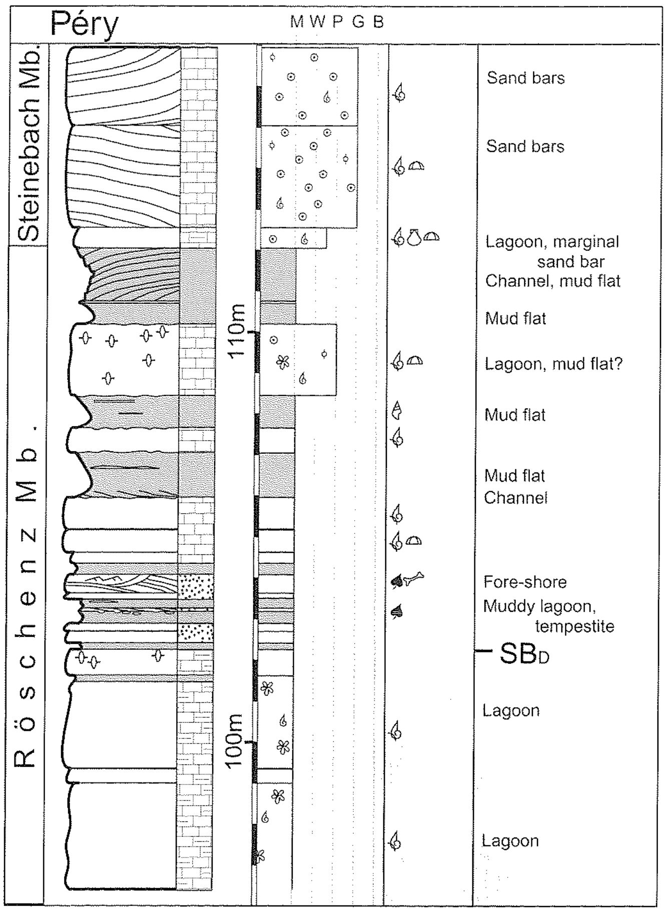


Fig. 14. The Péry section (continued approximately 35 m over Fig. 13) shows late high-stand lagoonal deposits of the lower Röschenz Member which are then covered by shallow-water marls and sandstones following SBD. The shift from patch-reefs over oolites of the Günsberg Member (not figured) to lagoons foreshore environments and mud flats documents a major regression. A transgressive trend is documented by the re-installation of carbonate sand bars of the Steinebach Member.

ammonites (20 cm in diameter), *in situ* pholadomyas that protrude from the bed top and borings; a ferroan crust is not developed. Close to meter 48, tempestites become amalgamated. Laterally marl beds may occur tucked in between the sandstones indicating laterally varying erosive forces. Internally these beds are laminated and do not reflect paleocurrent directions. Groove casts, however, have a N-S polarity. A second tempestite interval occurs around meter 50. Above meter 56 a shale interval with six inclined mudstone beds at its base is found overlying a graded, biodetrital tempestite. Of these inclined beds three dip to the south and three to the north. Upsection marls dominate and further biodetrital beds are encountered. The three graded biodetrital packstones (including coral fragments) located at meter 63 are the first indicators of the advancing platform. These beds are known as the "*Stomechinus* Beds" among collectors after the occurrence of the seaurchin *Stomechinus*. The first patchreefs of the Günsberg Member nucleate on these beds. Between the patchreefs of the lower Günsberg Member, marl sedimentation continued and was deposited between the individual patchreefs. Numerous biodetrital gutters also lie between the patchreefs within the marly lithofacies. Furthermore, huge inter-reef channels over 20m wide and over 15m deep occur. These are mainly filled with quartz sand, marls and some carbonate detritus (mainly bioclasts derived from the reefs). Internally the sediment forms 10 to 20cm thick graded beds featuring climbing ripples. Upsection the reefs of the Günsberg Member become more numerous and are finally replaced by oolites of the upper Günsberg Member. The onset of the Röschenz Member is marked by a distinct lithological change to oncolitic and bioclastic pack- to wackestones. Within the Röschenz Member, a further change in facies is encountered with the appearance of sandstones and mudstones (Fig. 14). A sandstone bed which attains a thickness of nearly one meter features foresets, low-angle cross-stratification and internal scouring. Plant remains (leaves, stems and fruits) are concentrated within thin layers throughout this bed. Bones and teeth of vertebrates were also recovered. Upsection oncolitic wacke- and packstones crop-out along with marl sequences structured in foresets. Over the uppermost marls of the Röschenz Member follow further oncolitic and bioclastic deposits which are covered by the oolites of the Steinebach Beds. Along the base of the Steinebach Beds patch-reefs buried beneath the oolites are also encountered. Two distinct units can be differentiated within the oolites; a lower with foresets dipping to the NW and higher with foresets dipping to the WSW.

Interpretation

The Pichoux Formation attained its considerable thickness of 35m due to the neighboring platform having supplied considerable amounts of carbonate during the transgressive and highstand stages of the late Transversarium chron. The hardground at the top of the Pichoux Formation is interpreted as a sequence boundary (SBB; Ox5 of Hardenbol et al. 1998) due to the sudden influx of siliciclastics into the environment. It is overlain by the initially relatively calcareous lower part of the Effingen Member. These carbonates probably correspond to the coeval Vorbourg Member and represent transgressive to late highstand deposits. Marl deposition of the lower Effingen Member is in all likelihood linked to SBC. With respect to the paleo-environment further upsection, the numerous thin, sandy tempestites, occasionally containing coal fragments, and chanellized event beds indicate proximity to a shallow platform, evidence of which is not encountered in the eastern Argovian realm (sections VLG, AST, CHL; Fig. 7). The bidirectional foresets of tempestites (meter 32) suggest deposition near the stormwave base (Seilacher & Aigner 1991). This is also true for pot casts (Aigner 1985), which altogether indicates a regressive trend. The firmground encountered near meter 44 of the section displays a multiphase history: the vague remains of grading, along with an erosive base, suggest that this was originally an event bed, later partially bioturbated and colonized by deep-burrowing pholadomyas. These were then were partially exhumed by an erosional event which reflects continuing lowstand conditions.

Upsection the curiously inclined mudstone beds found over a bioclastic event bed (meter 56) are interpreted as the cut bank of a meandering channel marking the final stages of the lowstand. As of this level, decrease of the tempestite frequency implies a deepening of the environment, yet the three amalgamated carbonate tempestites of the Stomechinus Beds indicate the nearby platform. It is noteworthy that throughout the whole 1 km wide quarry the first patch-reefs of the Günsberg Member all nucleate on the Stomechinus Beds without any sign of progradation. It appears that the reefs nucleated nearly instantaneously. Continuing siliciclastic influx within the patch-reef facies might be the result of alternate periods of mud deposition and coral growth. Available accommodation space was filled, as is implied by the find of *in situ* sphenophytes (Gee et al., in press) in pockets of siliciclastic deposits between the patch-reefs. These plants are indicative of subaerial conditions. The climbing ripples encountered within the channels indicate continuous and ample siliciclastic supply. Dominant current direction is to the SSE. Rocks recovered from the scree of this interval show ladder-ripples known from the intertidal zone. With the appearance of oolite sandbars of the Upper Günsberg Member a sea-ward carbonate platform margin is fully established. The oncolitic and bioclastic mudstones of the lagoonal lower Röschenz Member are a response to a shallowing of the environment as accommodation space was filled. Within these deposits, Pittet (1996) interprets a shift from an open lagoon to a semi-confined lagoon as the platform progrades. The marls and sandstones of the upper Röschenz Member indicate a substantial change in the environment. In general these are interpreted as mud and sand flats (e.g. Pittet 1996) associated with SBD (Ox6 of Hardenbol et al. 1998). The tabular low-angle cross-stratified and internally scoured sandstone beds are near-shore deposits. In comparison with modern analogues, plant remains and terrestrial vertebrate remains imply the nearby presence of emergent terrains. A tidal channel meandering through the mudflats is interpreted from the accretionary foresets encountered in the top-most marls reflecting a low sea-level. The top of the section is composed of black, lagoonal oolites over which prograde the oolites of the Steinebach Beds. The reefs situated in the base of the Steinebach Member are the first indicators of the renewed formation of accommodation space as sea-level rose again. It appears that the oolites rapidly buried the reefs during the ensuing highstand. The presence of these reefs indicates that sedimentation was reduced over a certain amount of time, allowing for their growth.

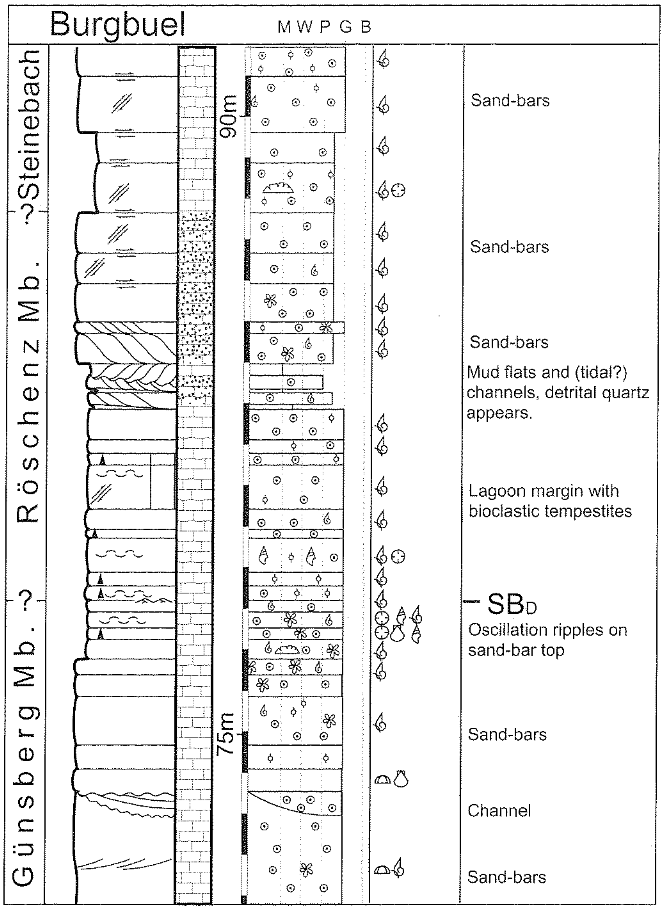


Fig. 15. Section Burgbuel deposited on the platform margin. Shallow-water carbonates prevail throughout the interval figured. The top of the Günsberg Member is placed along a horizon containing wave ripples on top of a sandbar. This interval coincides with SBC. Upsection a shift to somewhat more protected environments occurs as can be recognized in the faunal composition and the increase in schill-layers. Very shallow conditions are recognized in the mud flats and channels in which detrital quartz appears. The remainder of the section consists of carbonate sandbars as the platform margin is re-established.

Burgbuel (Balsthal Formation)

The Burgbuel section begins with coral patch reefs in a skeletal carbonate mud matrix followed by the peloid pack and grainstones of the Günsberg Member (see below). A stretch of tunnel with concrete walls obscures the following 14m. Judging by the exterior cliffs, the covered rocks are calcareous, yet unstable possibly due to a higher clay content, probably similar to the lower Günsberg Member of Péry. Upsection follow peloidal and oolitic sand bars displaying mainly south-vergent and occasionally north-vergent foresets (Fig. 15). Towards the top of the Günsberg Member bioclast content, including corals and oncoids, increases. Detrital quartz indicates an incipient facies change. Allochems remain assembled as sand bars dominated by south-vergent foresets. The top of the Günsberg Member is placed along a horizon containing oscillation ripples on top of a carbonate sand bar. The Röschenz Member continues with grainstones yet the occurrence of gastropods and other bioclasts assembled in graded event beds reflect a marked facies change from the oolitic and peloid sandbars of the Günsberg Member below. Within the upper Röschenz Member, a 1m thick interval containing three mudstone beds

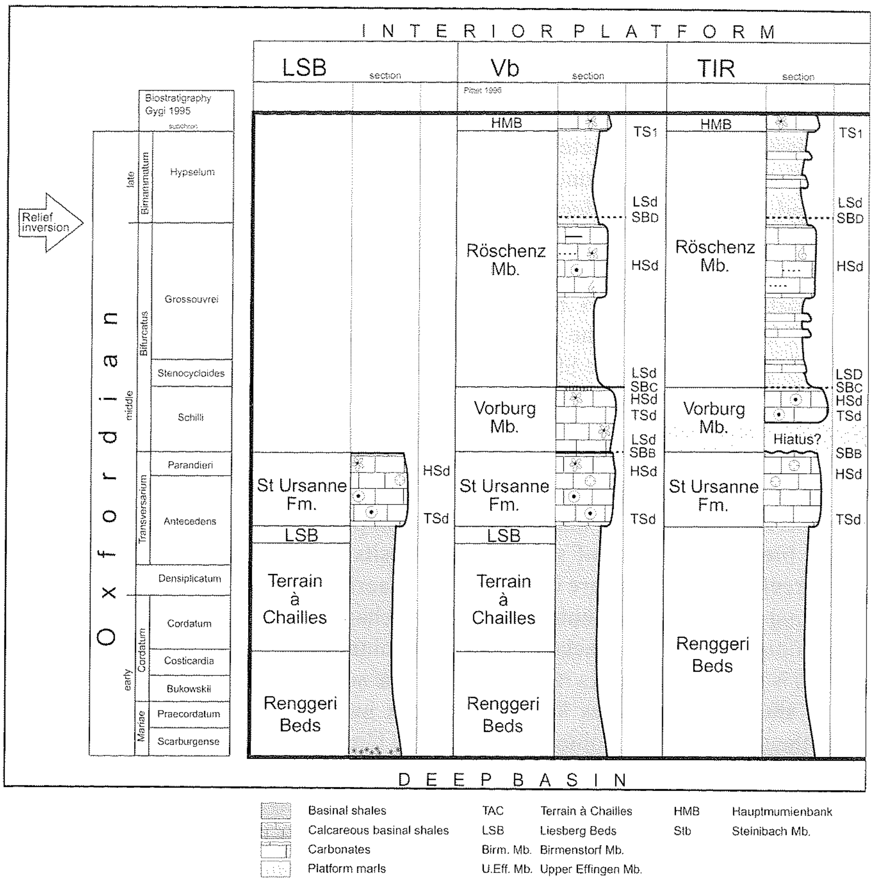


Fig. 16. Correlation of significant lithostratigraphical sections based on sequence stratigraphic interpretations. The sequence boundaries SBB (Ox5 of Hardenbol et al. 1998), SBC and SBD (Ox6 of Hardenbol et al. 1998) in sections Vb and PRY correspond to those of Pittet & Strasser (1998). Transgressive deposits usually document a shift from low to higher energy environments, while high-stand deposits generally show a shift from open environments to more confined, even restricted, environments. In the basin these trends are barely recognizable. However, carbonate dominated deposits derived from highstand surplus (on the platform) can still be recognized in the basin. Compared with the platform, low-stand deposits have a higher preservation potential in the basin. The hiatus in section TIR are not verified biostratigraphically, yet it seems likely that these intervals (low-stand deposits) are not preserved on the platform. SBD (Ox6 of Hardenbol et al. 1998) appears to coincide with an interval of minor subsidence over the whole study area. Relief inversion refers to the approximate stratigraphic level where accelerated subsidence shifts from the Celtic to the Argovian domain.

separated by ferroan pack- and grainstones is the only major deviation from the sandbars and grainstones seen in most of this section. Allochems appear worn, feature micrite envelopes and are embedded in a dolomite matrix. Within this brief interval both north and south vergent foresets occur. Upsection the remaining deposits are again peloidal and oolitic sandbars with dominantly south-vergent foresets. The top of the Röschenz Member is placed just below the first patch-reefs of the Steinebach Member embedded in pack- and grainstones.

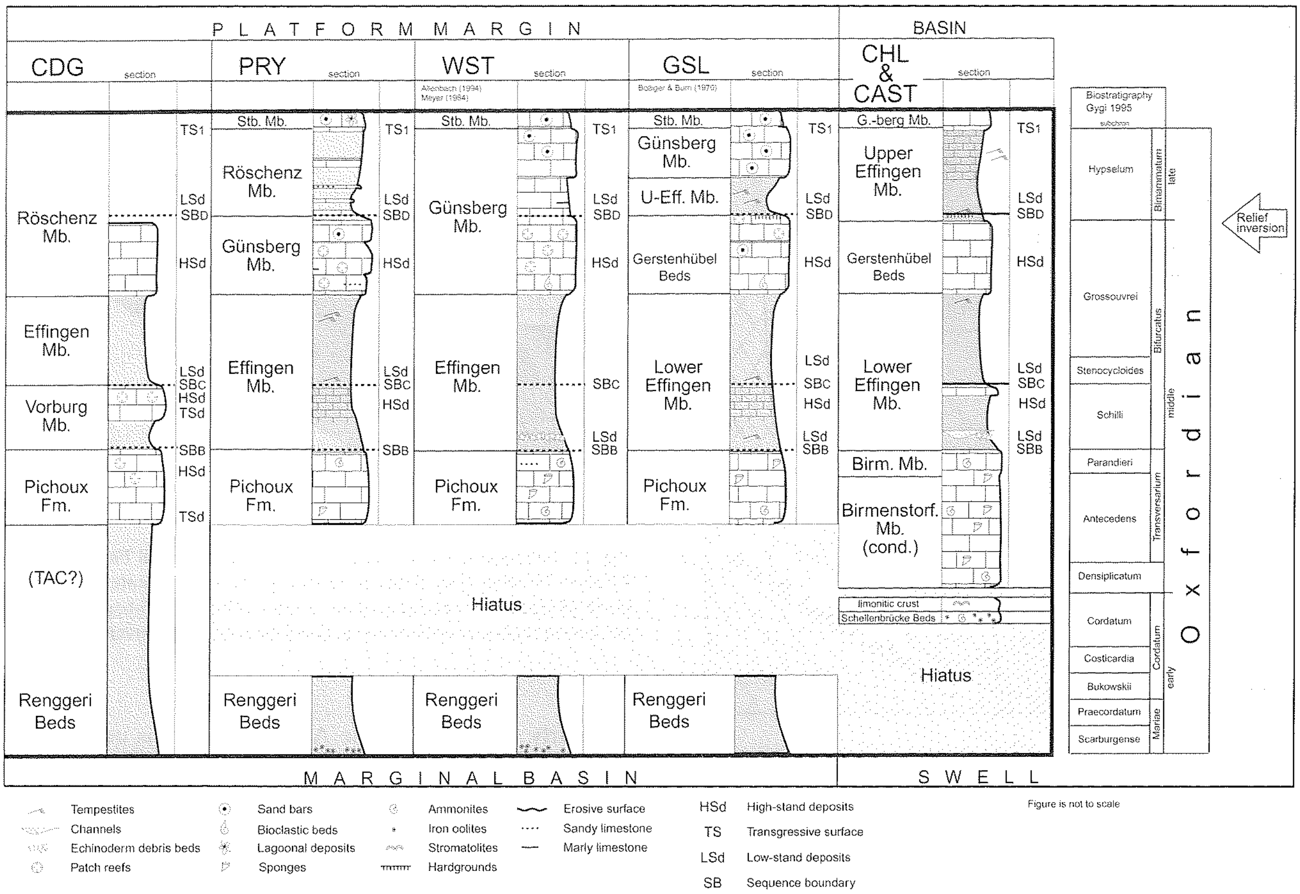
Interpretation

The corals at the base announce the advance of the carbonate platform as is typical for the boundary between the Effingen Member and Günsberg Member, as carbonate production begins to increase in response to a transgressive interval. With the onset of the carbonate sandbars even shallower environments of the platform margin are established. The increase of bioclasts and oncoids in the upper Günsberg Member along with the change to somewhat thinner beds indicate a shift to less exposed environments as well as a decrease in the rate of carbonate production and depositional characteristics of a dropping sea-level. With the oscillation ripples and mud drapes found overlying a sandbar, the shallowest interval thus far is attained (SBD). While grainstone deposition continues, the increased presence of oncoids and gastropods suggest the incursion of lagoonal components into these sediments during a lowstand. The thin mudstone beds as well as the thin, ferroan beds containing worn and abraded allochems represent a period of minor deposition in a shallow environment with the mudstones being interpreted as carbonate mudflats formed during a lowstand. The converging paleocurrent orientations deduced from the foresets may be of tidal origin. Above this brief interval, carbonate production and deposition increases rapidly in response to a renewed transgression. This is documented by the reappearance of carbonate sand bodies and even small patch reefs as marginal platform conditions are again established. Detrital quartz appears within grainstones in the lowermost meters of this segment (meter 88 in Fig. 15). These are interpreted as being washed out of a more protected environment to the north as the platform became flooded.

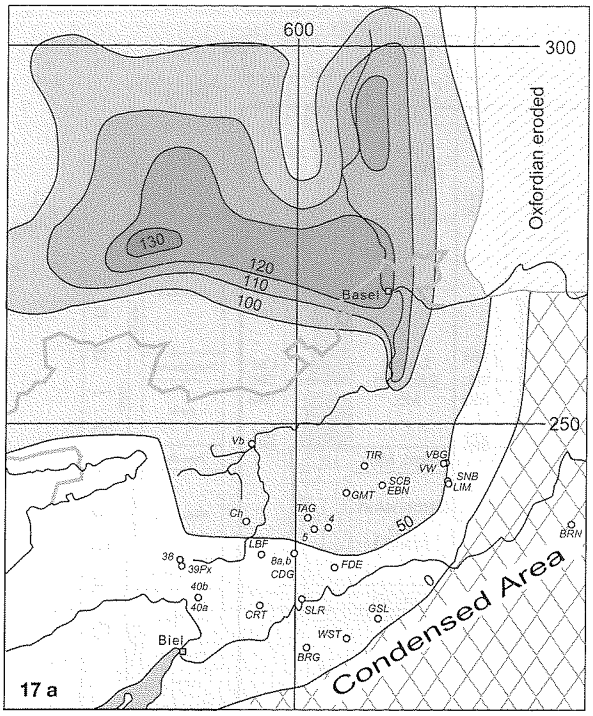
Interpretation

Sequence stratigraphy

The sequence stratigraphic horizons deduced above were used - within a defined biostratigraphic frame – for the correlation of the sections studied (Fig. 16). During the upper half of the



Transversarium chron carbonate deposition occurred throughout the study area while the St. Ursanne and Pichoux Formations and Birmenstorf Member formed. The carbonate in the deeper environments originated from the platform on which carbonate production starts up at times of a rising or high sea-level and was swept into the basin by waves or currents. This scenario has been proven valid for the study area (Pittet 1996) and elsewhere (Sarg 1988). A sea-level drop led to formation of the SBB (Ox5 of Hardenbol et al. 1998) represented by an erosion surface in section Titterten (Fig. 12) and the introduction of detrital quartz in most other sections. It is, in all probability, synchronous with the quartz and karst horizon of the Franconian Alb described by Gröschke & Fay (1981). Furthermore, the hardground in the Péry section (top Pichoux Formation) very likely reflects reduced deposition during a lowered sea-level. Above SBB (Ox5 of Hardenbol et al. 1998), lowstand deposits are found in the Effingen basin while coeval deposits are unknown from the platform due to the lack of accommodation space. Channel incision (section Auenstein, Fig. 9), crinoid debris beds (section CHL in Fig. 7) and ophiurid-bearing event beds (section Weissenstein, Fig. 8b) represent basinal lowstand deposits following SBB. A rise in sea-level allows carbonate production on the platform to start up again, leading to the deposition of the Vorbourg Member. Again, a concomitant increase in carbonate can be recognized in the basin deposits of the Péry and Weissenstein sections, but the carbonate content clearly decreases with increasing distance from the platform where most of the carbonate is produced. Carbonate production on the platform diminished with or just before SBC and siliciclastics again invaded the depositional system. On the platform muddy lagoons of the Röschenz Member developed and in the basin the marly lower Effingen Member. A renewed transgressive interval in the Late Bifurcatus chron led to the widespread deposition of carbonates and once again carbonate content increased, represented by the Gerstenhübel Beds which were deposited during this interval. Paleowaterdepth probably remained shallow, as is indicated by reworked and bored lithoclasts found in the Gerstenhübel Beds of the basin margin (section RTM; Fig. 7). Towards the platform these beds become increasingly bioclastic (sections LIM, WST; Fig. 7) or even oolitic (section GSL, Fig. 7). The next sequence boundary (SBD; Ox6 of Hardenbol et al. 1998) led to a renewed invasion by siliciclastics. Within the interior platform muddy lagoons with graded washover tempestites (sections SCB, EBN, TIR, TAG, MTR, Fig. 7), at times even restricted muddy lagoons (Px, MTR, Fig.7) and sand and mudflats (MTR, Px, Vb, Fig. 7) formed. With the onset of a further transgression during the mid Hypselum subchron carbonate



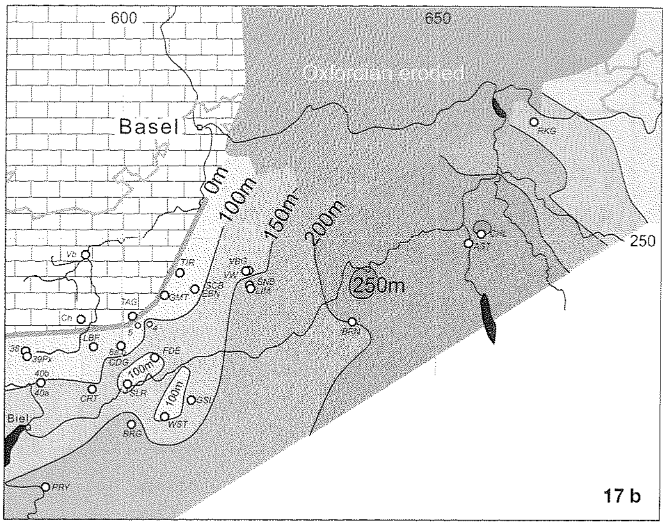


Fig. 17. Palinspastic reconstruction of both the Bärschwil Fm. (Fig. left) and Effingen Member (Fig. right). Note that the basin depocenters shift from the north (Bärschwil Formation) to the south (Effingen Member) over time and the coeval shallower environments also follow this relief inversion.

production begins to increase again and the oncolitic Hauptmumienbank and oolitic Steinebach Beds accumulated.

As outlined above, four horizons are used in correlating the Lower and Middle Oxfordian successions; three are sequence boundaries that are associated with siliciclastic deposits on the platform and in the basin (SBB, SBC and SBD of Pittet & Strasser 1998). The lowest horizon (SBB; Ox5 of Hardenbol et al. 1998) and its significance had already been recognized by Bolliger & Burri (1970) who correlated the appearance of quartz above the St. Ursanne Formation with quartz layers on, or near, the top of the Birmenstorf Member in the basin. This lithologic correlation was verified biostratigraphically (Gygi & Persoz 1986) and supports the siliciclastic input model described above. The fourth horizon is a transgressive surface (TSD1 of Pittet & Strasser 1998) preceding the Hauptmumienbank and Steinebach Beds. Subordinate, less extended correlation horizons are only recognizable on the platform or in the basin.

Accommodation space and differential subsidence

Using facies patterns and shallowing-up trends, changes in accommodation space can be determined. Thicknesses of individual formations reflect available accommodation space if the top consists of shallow-water sediments. In terms of sequence stratigraphy, non-deposition is interpreted as a lack of accommodation space, or in some cases as an effect of by-passing (Schlager 1992). Non-deposition in a deep basin starved of sediment as suggested by Gygi (1986) and Gygi et al. (1998) for the Early Oxfordian of the Argovian realm is unlikely. Since the mudstones of the Celtic basin are separated from the Subalpine basin by a belt of condensed deposits (Fig. 11), a submarine swell which experienced by-passing is the more logical explanation. Since the amplitude of sea-level fluctuations was less than the thickness of the shallowest formations, most of the accommodation space must have been provided by synsedimentary subsidence. In striving to differentiate tectonic from eustatic controls on accommodation space Robin et al. (1998) found that short range variations (wave length < 150 km) are certainly tectonic in origin while the long range variations (> 500 km) are eustatic (even though a tectonic origin cannot be completely ruled out). The Callovian-Oxfordian boundary is condensed over a large part of the European craton (> 500 km) and even beyond, giving a strong indication of a eustatic control. However, the change in depocenter location from the Bärschwil Fm. (Fig. 17a) to the Effingen Mb. (Fig. 17b) indicates that there was accommodation space shift from the Celtic to the adjacent Argovian realm. This is a short range shift and thereby implies tectonic control.

A transect covering the Middle Oxfordian across the Paleozoic Hermrigen Trough (Fig. 18, 19) illustrates the coincidence between the basement structures and sediment thickness and hence, accommodation space. During the later Transversarium chron the relief from the platform to the basin was probably not pronounced. Carbonate produced on the platform was swept into the neighboring basin and is now seen as the bioclastic and peloid Pichoux Formation (section Px; Figs. 7 and 19). In the basin the allochem content decreases with increasing distance from the platform (section PRY). With the onset of the Bifurcatus chron, the marls of the Effingen Member invaded the basin (section PRY, Fig. 13), while shallow

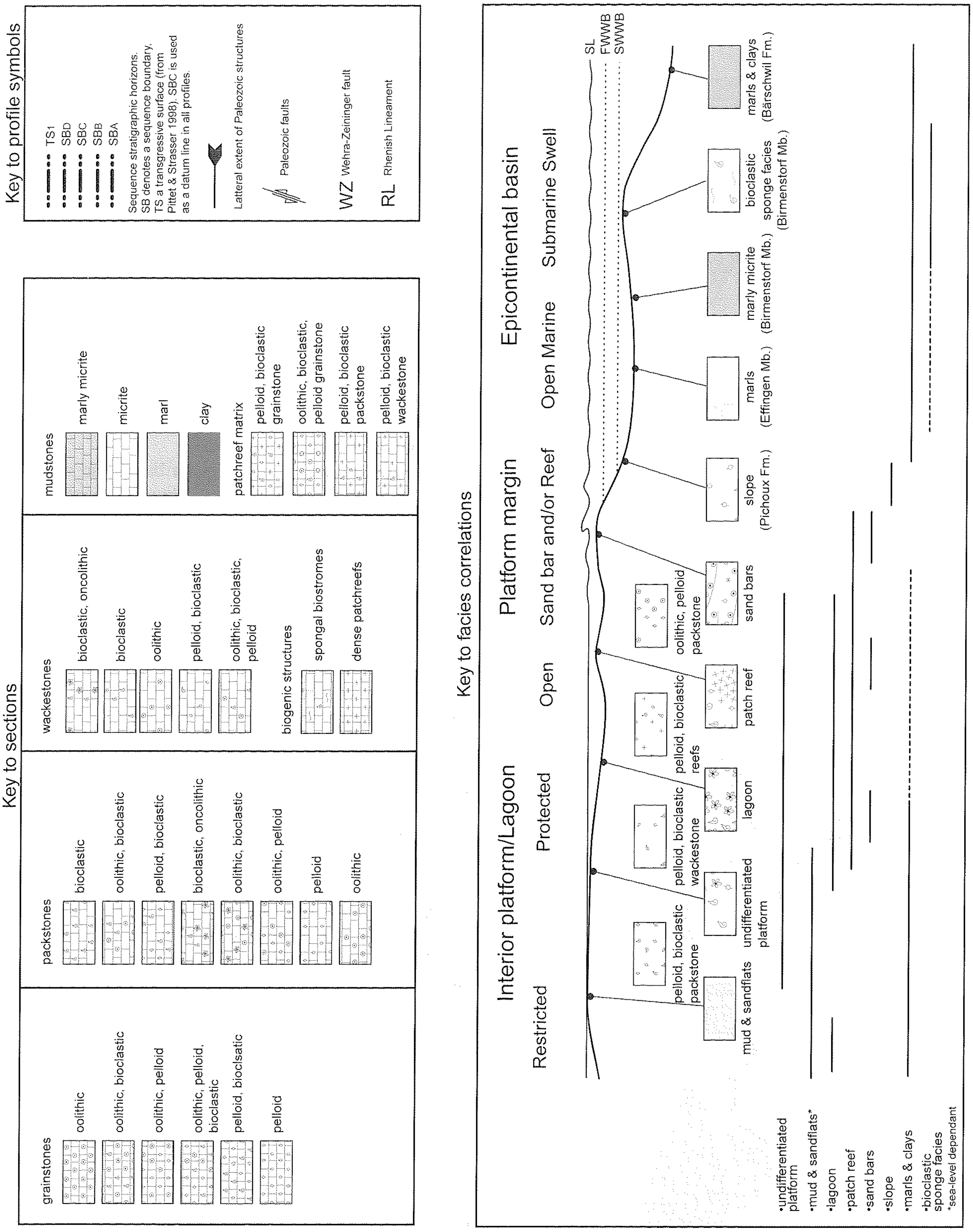
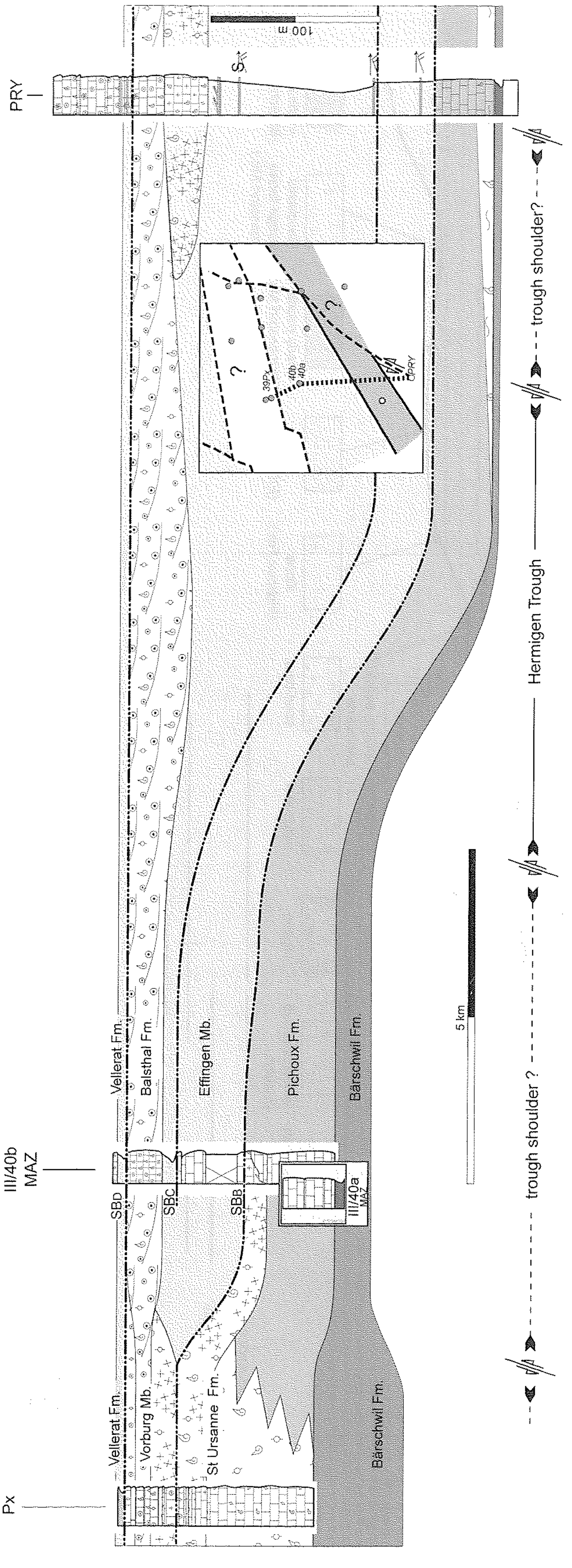


Fig. 18. Key to symbols and patterns used in Figs. 19–22 and Plate 1.



water deposits dominate on the platform (section Px). A correlation parallel to the one mentioned above shows a nearly identical history (Fig. 20). Again slight progradation can be recognized towards the top of the St. Ursanne Formation as reefs are established above the Pichoux Formation. Additionally, the Lower Oxfordian basin deposits thin out towards the south. When seen together these correlations make clear that both basin fills thin out in the vicinity of the Paleozoic Hermrigen trough as the Early and Middle Oxfordian basins overlap. Towards the end of the Transversarium chron, sea-level dropped, yet patchreefs of the St. Ursanne Formation (late Transversarium) did not prograde further than the northern trough margin where mudstones accumulated, documenting a greater paleo-waterdepth south of the trough-bounding fault. Thin deposits of Early and Middle Oxfordian age imply low rates of subsidence throughout this time span at the SLR locality (Fig. 20). Below this locality, the Rhenisch Lineament and the Paleozoic Hermrigen and Olten Troughs intersect which might have inhibited subsidence.

Profiles parallel to the Effingen basin also show distinct variations of facies and thickness above Paleozoic structures (Pl. 1). The thickness of the Effingen Member between Péry (PRY) and Gschlief (GSL) suggests fairly uniform subsidence. Thick successions of corals and oolites of the Günsberg Member terminate in the vicinity of the Weissenstein section (WST). Accumulation of such a thick shallow-water succession during a falling sea-level implies continuing increased rates of subsidence between Péry and the Weissenstein.

Profiles parallel to the strike of the Paleozoic troughs display only minor facies and thickness variations (Figs. 21 and 22). In these profiles it becomes evident that the Rhenisch Lineament is the major facies-defining structural element: The thick shallow-water deposits in section TAG (Fig. 22) document the creation of accommodation space by locally accelerated subsidence along the Rhenisch Lineament. In fact, the Rhenisch Lineament separates the Celtic and Argovian realms. East of the lineament storm layers occur in the Upper Effingen Member of the marginal basin while the Röschenz Member of the platform is encountered to the west.

During the Oxfordian the zone of increased subsidence shifted to the south. During the Early Oxfordian the Celtic realm subsided and the Bärschwil Formation accumulated whereas in the Argovian, Swabian and Helvetic realms a condensed facies formed. During the Early Middle Oxfordian sub-

Fig. 19. Profile of the Mid Oxfordian platform to basin transition over the Paleozoic Hermrigen Trough (inset). During the Early Oxfordian differential subsidence dominates in the northern domain and the Bärschwil Formation is deposited. During the Late Transversarium chron the St. Ursanne Formation does not prograde further than the northern Hermrigen trough shoulder. As subsidence shifts southward during the Transversarium chron, accommodation space for the Effingen Member is produced over the Hermrigen Trough. See Figure 8 for key. All sections are palinspastically corrected. Datum line is SBD (Ox6 of Hardenbol et al. 1998).

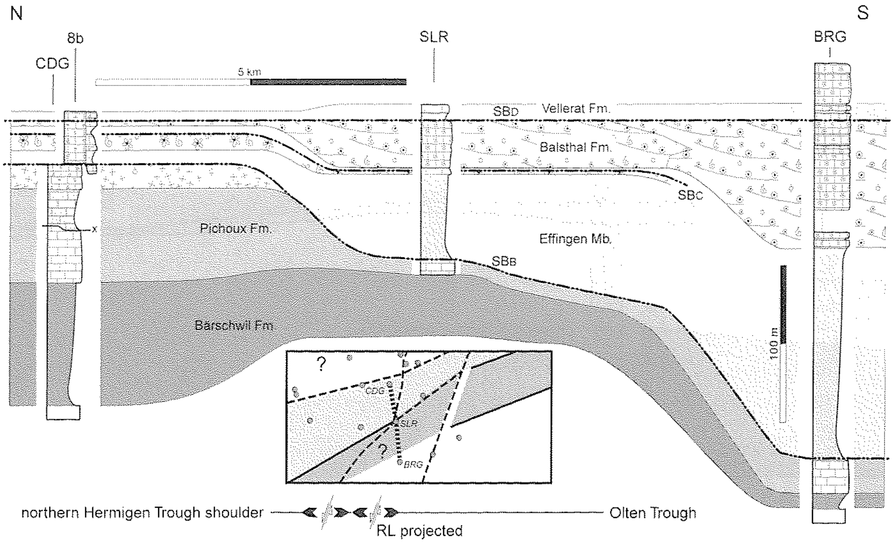


Fig. 20. During deposition of the Effingen Member only limited accommodation space is formed in the north while the Paleozoic Hermrigen and Olten Troughs (inset) rapidly subside, forming accommodation space. Reefs nucleate over the Pichoux Formation in the more proximal environments to the north. See Figure 8 for key. All sections are palinspastically corrected. Datum line is SBD (Ox6 of Hardenbol et al. 1998).

sidence remained high in the Celtic realm preventing carbonate platform progradation. During the Early Bifurcatus chron, subsidence started to accelerate in the eastern Argovian realm and accommodation space for the Effingen Member was created. At the end of the Bifurcatus chron acceleration of subsidence shifted further eastward and southward resulting in the thick marl deposits found in the eastern Argovian realm and underneath the Molasse Basin. Such a shift of the area of enhanced subsidence was previously, albeit less clearly, worked out by Trümpy (1969).

Subsidence controlled sediment accumulation

The southeastward shift of the area of enhanced subsidence shown above and the wavelength (e.g. Robin et al. 1998) of the subsiding area suggests tectonic influence. To evaluate that, palinspastically restored isopach and facies maps of the Early and Middle Oxfordian were compared to the known Late Paleozoic structures in the basement (Fig. 5). In fact, the basin margins follow tectonic elements in the basement (Allenbach, 2001a, b). Of importance are the Rhenisch Lineament and faults bounding the Northern Swiss Permo-Carboniferous Trough system (Fig. 5). The Oxfordian basin to platform transition follows the Rhenish Lineament on a nearly north-south strike and the PCT lineament on a NE-SW strike – with depocenters located on both sides of these tectonic elements (Figs. 5 and 17).

The spatial coincidence of isopach maxima with known basement structures suggests a synsedimentary tectonic control on sediment accumulation. Consequently, the Lower Oxfordian mudstones (Bärschwil Formation) are better interpreted as basinal rather than pro-delta sediments. Furthermore, the depocenter of the Lower Oxfordian mudstones spatially coincides with the depocenters of the Middle Triassic (Bitterli 1992), Aalenian (Allia 1996) and Callovian (Bitterli 1977) sediments. Consequently, in the Argovian realm, the condensed Lower and Middle Oxfordian cannot represent a "starved basin", because deeper areas occur to the north and south, thereby rendering the area of condensed facies a swell. Within the study area two similarities in the depositional pattern between the Callovian and Early Oxfordian can be recognized; isopach maxima and minima of both successions coincide and the Late Callovian in the Argovian realm has already been interpreted as deposited on a swell (Bitterli 1977).

Similarly to the Argovian realm, the Lower Oxfordian of the Swabian Alb, Franconian Alb and Helvetic Shelf (with exceptions) either represents a hiatus or is condensed. This constitutes a large area of non-deposition where condensed facies formed in shallower water relative to the basins in which muds accumulated. In achieving non-deposition by keeping sediment in suspension, the water column remains turbid, thereby possibly excluding colonization by corals. Apart from turbidity, other mechanisms which keep corals from colonizing an environment are known, such as ecological stress by other organisms and nutrient excess (Hallock & Schlager 1986). Nutrient excess may result from nutrients derived from landmasses or by plankton blooms which occurred over the wide expanses of the Helvetic Shelf where suboxic carbonates and marls accumulated at that time (Trümpy 1969). Ecological stress may have been caused by sponges. Therefore, the non-occurrence of corals in this facies is in fact a poor indicator of great waterdepth.

The significance of siliciclastics

The origin and transport of the detrital siliciclastics, especially quartz grains, encountered in the Oxfordian deposits has been frequently discussed (Ziegler 1962; Bolliger & Burri 1970; Ricken 1985; Kugler 1987; Gygi 1990; Pittet 1996), yet remains unresolved. They certainly have a continental source, crystalline basement or its lowermost sedimentary cover. During the Oxfordian a number of Hercynian crystalline massifs were exposed (Ziegler 1990) and were thus potential source areas,

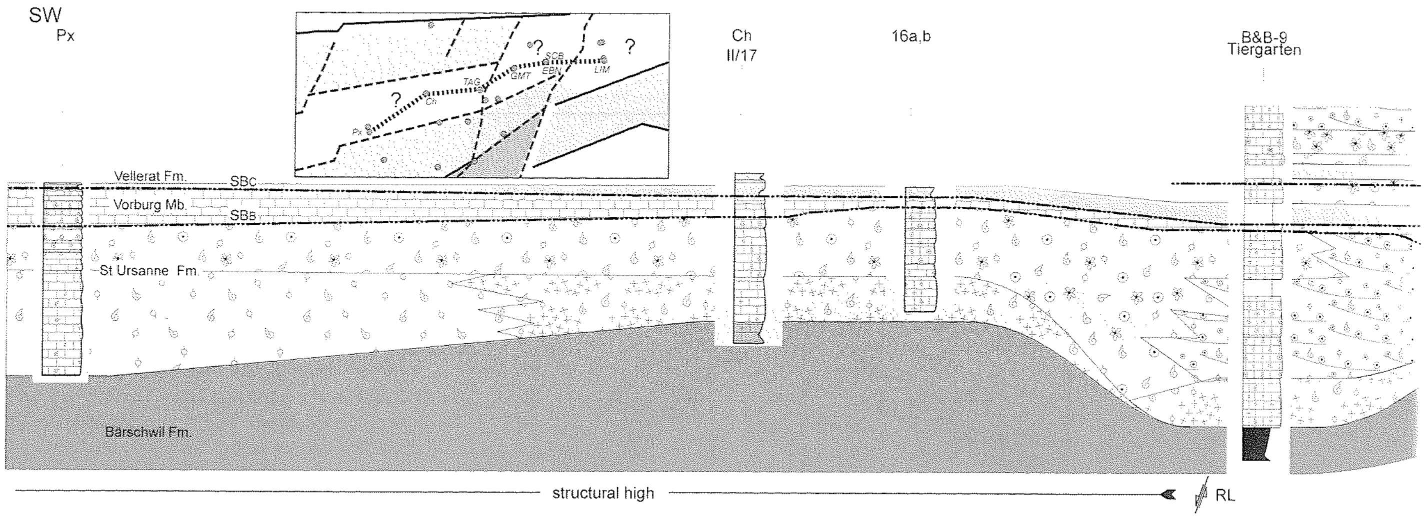


Fig. 21. This profile lies more or less parallel to the Paleozoic trough orientation (inset). Evident is the fairly homogenous platform to the west of the Rhenish Lineament, while accommodation space is provided east of it during deposition of the Effingen Member Note the sharp facies change from reefs to marls to the east of section TAG, which takes place along the Rhenish Lineament (R.L). See Figure 8 for key. All sections are palinspastically corrected. Datum line is SBD (Ox6 of Hardenbol et al. 1998).

such as the London-Brabant Massif, Bohemian Massif, Massif Central and Scandinavian Shield.

Bolliger & Burri (1970) suggested aeolian transport from the Rhenish Massif. Yet SEM images of the quartz grains do not show convincing structures on the grain surfaces, such as frosting (Krinsley & Doornkamp 1973), which would substantiate this idea.

Stratigraphically, quartz is encountered in the Bärschwil Formation, Wildegg Formation (especially in the lower and uppermost Effingen Member) and in the Röschenz Member. Within the uppermost Effingen Member as well as in the Röschenz Member sandstone beds are encountered, occasionally containing plant remains. Paleogeographic maps of the Late Jurassic of southern Germany (Meyer & Schmidt-Kaler 1989) show extensive mudflats surrounding the coastal Rhenish Massif during the Middle Oxfordian (Fig. 3). Such an environment offers ideal conditions for the reworking and subsequent transport of muds and sands. Since the siliciclastics are already present as loose grains, the transfer into the basin requires time-spans comparable to ammonite subchrons (Slingerland et al. 1994; Tucker & Wright 1990), in particular during relative low-stands, when the unlithified mudflats become easily reworkable.

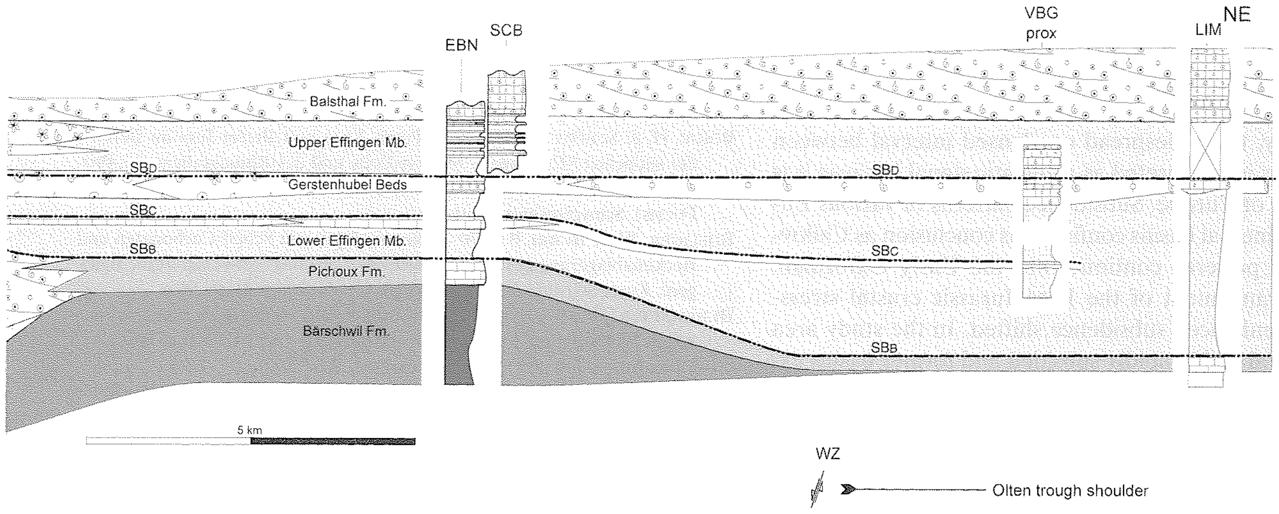
The spatial distribution of the detrital quartz shows a distinct preferential area of deposition more or less restricted to the Celtic realm (Fig. 3), where the shallowest and most restricted Oxfordian facies are encountered. Detrital quartz is most common within the tempestites of the Effingen Member along the platform margin and the grain-size of the quartz diminishes from the NW to the south and east (Bolliger & Burri 1970 and own observations).

During the Stenocycloides through Hypselum subchrons, siliciclastic deposition is encountered in both the Effingen Member and mixed-system deposits of the Röschenz Member which include the highest quartz content. Because the grain-size of the quartz diminishes from the NW to the south and east (Bolliger & Burri 1970 and own observations), the source area of the quartz was located to the north or north-west of the study area, a fact further substantiated by paleocurrents measured from quartz-bearing tempestites. This trend has already been recognized by previous authors who envisaged the Vosges as a possible source area (Ziegler 1962).

Introducing siliciclastics from a distant source area requires a number of factors which have to coincide; a relative drop in sea-level in the source area in order to expose the source rocks, a climate favorable for weathering and eroding exposed rocks (Pittet & Strasser 1998) and very importantly, but usually not reconstructable, the relief of the source area. This later factor may tie relative changes in sea-level to relief-forming processes in the source area.

Conclusions

A shift of the area of enhanced subsidence led to thick accumulations of sediment regardless of sea-level fluctuations during the Oxfordian. At times of eustatic low-stand, developing depocenters were preferentially filled with siliciclastics eroded in distant source areas (Callovian Clay, Renggeri Beds and Effingen Member). High-stands, on the other hand, left successions of calcareous platform deposits. The geographic recurrence of depocenters above Paleozoic troughs, and/or facies boundaries spatially related to Paleozoic faults are known for Triassic, Aalenian, Bajocian, Bathonian, Callovian and Oxfordian deposits in northern Switzerland. These are strong indicators that the depositional environments were largely influenced by the reactivation of the Paleozoic basement structures.



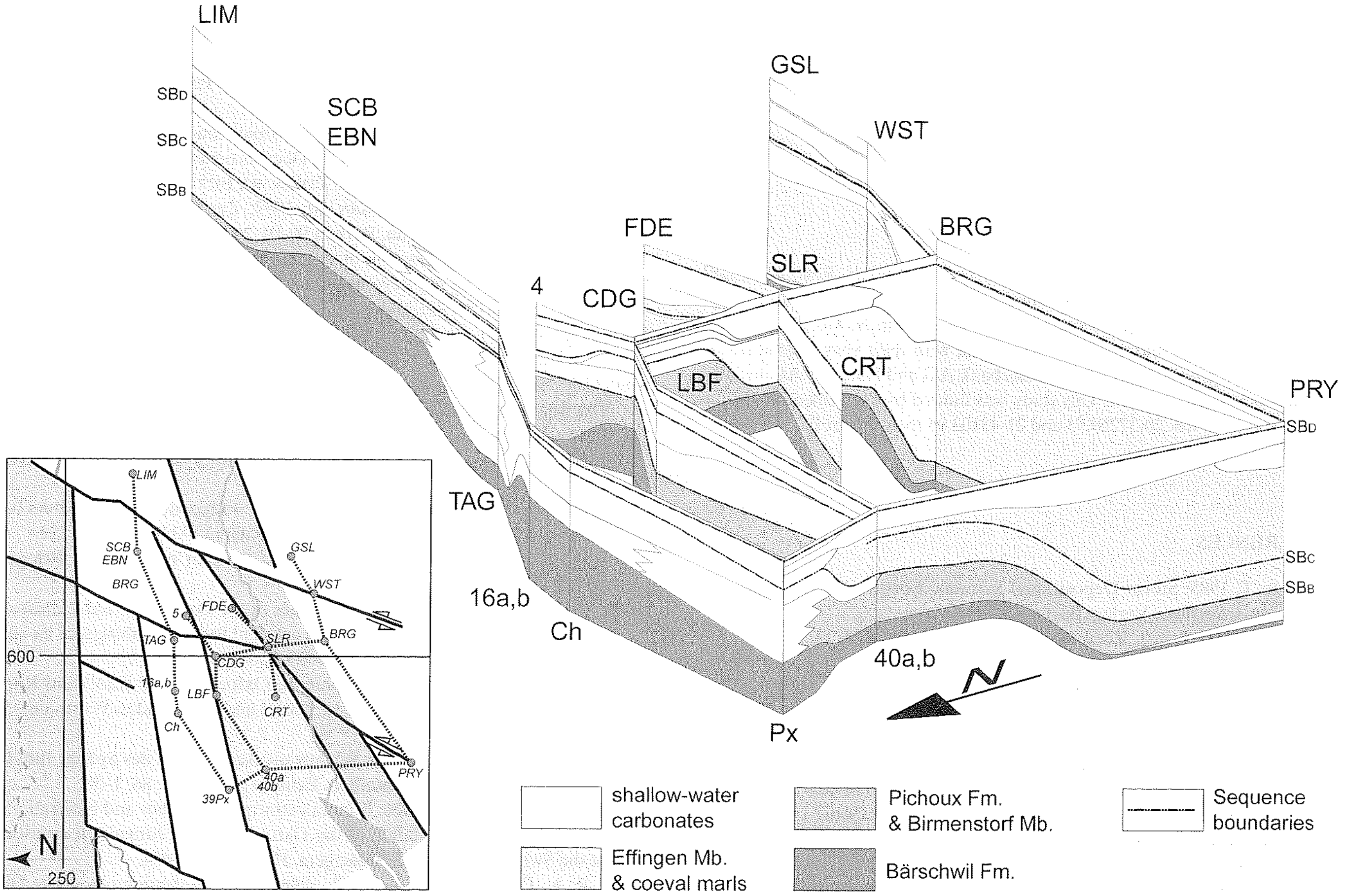


Fig. 22. This three-dimensional fence diagram shows the influence of Paleozoic faults (inset and Fig. 5) on the Mid Oxfordian environment. The profiles correspond to Figures 19–21 and Plate 1 and their positions are shown in the inset. Accommodation space is provided by differential subsidence along trough masterfaults, while the Rhenisch lineament and northern Hermrigen trough masterfault also act as major facies-defining structures.

Comparison of the Early Oxfordian with the Upper Callovian shows that similar facies patterns developed within similar areas during both substages. Therefore, the Bärschwil Formation is regarded as a continuation of the basinal Callovian Clays. Similarly, the widespread condensed interval between both formations is interpreted as a eustatic signal because it is seen over most of Europe. Subsidence patterns of various European epicontinental basins confirm this conclusion as Callovian subsidence patterns continue into the Early Oxfordian. With the rearrangement of the Late Jurassic crustal stress-field, areas of enhanced subsidence shifted. In the study area former structural highs rapidly subsided and former basins experienced decelerated subsidence rates. This effect is seen in the shift of depocenters from the Celtic to the Argovian realm during the Early Bifurcatus chron.

On the platform there are some features indicative of very shallow-water to inter-tidal facies, such as plant roots (Pittet 1996) and desiccation cracks (Gygi & Persoz 1986). Considering that paleowaterdepth in the coeval basin is estimated have been between 30 and 70 m, higher subsidence rates under the basin are the only variable for forming the required accommodation space in that area (Allenbach 2001b). Superimposed on the subsidence-dependent depositional styles, eustatic sea-level also leaves a signal. Depending on the sea-level, facies boundaries (and basin margins) shift basinward or landward, resulting in parallel yet displaced facies boundaries, as is seen in the Early and Middle Oxfordian basin margins.

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REFERENCES

Aigner, T. 1985: Storm Depositional Systems. Lecture Notes in Earth Sciences 3, Springer Verlag, Berlin, 174 p.

Allenbach, R. & van Konijnenburg – van Cittert, J. H. A. 1997: On a small flora with araucariaceous conifers from the Röschenz Beds of Court, Jura Mountains, Switzerland. Eclogae geol. Helv., 90, 571–579.

Allenbach, R. P. 1994: Geology of the Balmberg and surrounding area. Unpubl. M.Sc. Thesis, University of Bern, 142 p.

Allenbach, R. P. 2001 a: Mesozoic facies relationships and the age of the Upper Rhinegraben Lineament. Tectonophysics, in review.

Allenbach, R. P. 2001 b: The ups and downs of „Tectonic Quiescence“; a case study from the Oxfordian of northern Switzerland. Sediment. Geol., in press.

Allia, V. 1996: Sedimentologie und Ablagerungsgeschichte des Opalinustons in der Nordschweiz. Ph.D. Thesis, University of Basel, 185 p.

Arthaud, F. & Matte, P. 1977: Late Paleozoic strike-slip faulting in southern Europe and northern Africa: Result of a right-lateral shear zone between the Appalachians and the Urals. Geol. Soc. Amer. Bull. 88, 1305–1320.

Bitterli, P. H. 1977: Sedimentologie und Paläogeographie des oberen Doggers im zentralen und nördlichen Jura. Ph.D. Thesis, University of Basel, 131 p.

Bitterli, T. 1992: Zur Anwendung der tektonischen Materialbilanz im östlichen Faltenjura. Ph.D. Thesis, University of Basel, 170 p.

Boigk, H. & Schöneich, H. (1974) Perm, Trias und älterer Jura im Bereich der südlichen Mittelmeer - Mjösen-Zone und des Rhinegrabens. In: Proceed. of an Intern. Rift Symposium, 60–71. (Ed. by J. H. Illies & K. Fuchs). Schweizerbart, Stuttgart.

Bolliger, W. & Burri, P. 1970: Sedimentologie von Schelf-Carbonaten und Beckenablagerungen im Oxfordien des zentralen Schweizer Jura. Beitr. geol. Karte Schweiz, NF 140, Schweiz. Geol. Komm. Bern, 96 p.

Burkhalter, R. M. 1995: Ooidal ironstones and ferruginous microbialites: origin and relation to sequence stratigraphy (Aalenian and Bajocian, Swiss Jura mountains). Sedimentology 42, 52–74.

Burkhalter, R. M. 1996: Die Passwang-Alloformation (unteres Aalénien bis unteres Bajocien) im zentralen und nördlichen Schweizer Jura. Eclogae geol. Helv. 89, 875–934.

De Graciansky, P.-C., Hardenbol, J., Jacquin, T. & Vail, P. R. 1998 Mesozoic and Cenozoic sequence stratigraphy of European basins. Soc. Sediment. Geol. Spec. Publ. 60, 781.

de Wet, C. B. 1998: Deciphering the sedimentological expression of tectonics, eustasy and climate: a basinwide study of the Corallian Formation, southern England. J. Sediment. Res. 68, 653–667.

Debrand-Passard, S. & Courbouleix, S. 1984: Synthèse Géologique du Sud-Est de la France, Bur. Rech. Géol. Min., Mem. 126, Orléans, 615.

Diebold, P. 1988: Der Nordschweizer Permokarbon-Trog und die Steinkohlefrage der Nordschwiez. Vjsch. natf. Ges. Zürich 133, 143–174.

Diebold, P. 1990: Die tektonische Entwicklung der Nordschweiz. Nagra Informiert 90/2, 47–55.

Diebold, P. & Naef, H. 1990: Der Nordschweizer Permokarbontrog. Nagra informiert, 90/2, 29–36.

Diebold, P. & Noack, T. 1997: Late Paleozoic troughs and Tertiary structures in the eastern Folded Jura. In: Deep structure of the Swiss Alps: results of the NRP 20 (Ed. by O. A. Pfiffner), Birkhäuser, Basel, 59–63.

Diebold, P., Naef, H. & Ammann, M. 1992: Zur Tektonik der zentralen Nordschweiz. Nagra Techn. Bericht 90–04, Nagra, Wettingen, 140–141.

Færseth, R. B. 1996: Interaction of Permo-Triassic and Jurassic extensional fault-blocks during the development of the northern North Sea. J Geol. Soc. (London) 153, 931–944.

Gaillard, C. 1983: Les biohermes a spongiares dans l'Oxfordien de Jura Meridonal. Ph.D. Thesis, Université Claude-Bernard, 515 p.

Gee, C. T., Meyer, C. A. & v. Konijnenburg - v. Cittert, J. H. A. in press: The first unequivocal sphenophytes from the Late Jurassic of north-western Switzerland (Late Oxfordian Vellerat Formation) – Paleobotany and implications for facies interpretation. In: Festschrift F. Schaarschmidt (Ed. by H. Kemp). Senckenberg Courier.

Gröschke, M. & Fay, M. 1981: Ein Paläokarst mitteloxfordischen Alters bei Flintsbach in Niederbayern. N. Jb. Geol. Paläont. Abh. 161, 133–152.

Gygi, R. A. 1981: Oolitic iron formations: marine or not marine? Eclogae geol. Helv., 74, 233–254.

Gygi, R. A. 1986: Eustatic sea level changes of the Oxfordian (Late Jurassic) and their effect documented in sediments and fossil assemblages of an epicontinental sea. Eclogae geol. Helv. 79, 455–491.

Gygi, R. A. 1990: Die Paläogeographie im Oxfordium und frühestem Kimmeridgium in der Nordschweiz. Jh. geol. Landesamt Baden-Württemberg 32, 207–222.

Gygi, R. A. 1995: Datierung von Seichtwassersedimenten des Späten Jura in der Nordschweiz mit Ammoniten. Eclogae geol. Helv. 88, 1–58.

Gygi, R. A. & Persoz, F. 1986: Mineralostratigraphy, litho- and biostratigraphy combined in corellation of the Oxfordian (Late Jurassic) formations of the Swiss Jura range. Eclogae geol. Helv. 79, 385–454.

Gygi, R. A., Coe, A. L. & Vail, P. R. 1998: Sequence stratigraphy of the Oxfordian and Kimmeridgian stages (Late Jurassic) in northern Switzerland. In: Mesozoic and Cenozoic Sequence Stratigraphy of European Basins. (Ed. by P. C. de Gracianski, J. Hardenbol, T. Jacquin & P. R. Vail), Soc. Sediment. Geol. Spec. Publ. 60, 527–544.

Hallock, P. & Schlager, W. 1986: Nutrient excess and the demise of coral reefs and carbonate platforms. Palaios 1, 389–398.

Haq, B. U., Hardenbol, J. & Vail, P. R. 1998: Chronology of fluctuating sea levels Since the Triassic. Science 235, 1156–1167.

Hardenbol, J., Thierry, J., Farley, M.B., Jacquin, T., De Gracianski, P.C. Vail, P.R., 1998: Mesozoic and Cenozoic Sequence Chronostratigraphic Framework of European Basins. In: P.C. de Graciansky, J. Hardenbol, T. Jacquin & P.R. Vail (Editors), Mesozoic and Cenozoic Sequence Stratigraphy of European Basins. Soc. Sediment. Geol. 86 p.

Kempter, E. H. K. 1987: Fossile Maturität, Paläothermogradienten und Schichtlücken in der Bohrung Weiach im Lichte von Modellberechnungen der thermischen Maturität. Eclogae geol. Helv. 80. 543–522.

Krinsley, H. K. & Doornkamp, J. C. 1973: Atlas of Quartz Sand Surface Textures. Cambridge University Press, Cambridge, 91 p.

Küehni, A. 1993: Strukturgeologische Untersuchungen in der Chasseral-Kette südlich von Corgémont/Sonceboz (BE). Unpubl. MSc. Thesis, Universität Bern.

Kugler, C. 1987: Die Wildegg-Formation im Ostjura und die Schilt-Formation im Östlichen Helvetikum; ein Vergleich. Ph.D. Thesis, University of Zürich, 209 p.

Laubscher, H. 1965. Ein kinematisches Modell der Jurafaltung. Eclogae geol. Helv. 58, 231–318.

Laubscher, H. 1986: The eastern Jura: relations between thin-skinned and basement tectonics, local and regional. Geol. Rdsch. 75, 535–553.

Laubscher, H. & Noack, T. 1997: The deep structure of the Basel Jura. In: Deep structure of the Swiss Alps: Results of the NRP 20 (Ed. by O. A. Pfiffner), Birkhäuser, Basel, 54–58.

Lauer, S. 1985: Terrain à Chailles und Liesberg Schichten (Oxfordien des Zentralen Schweizer Jura) im Aufschluss Liesberg. Unpublished MSc. Thesis, University of Basel, 69 p.

Loup, B. 1992: Mesozoic subsidence and stretching models of the lithosphere in Switzerland (Jura, Swiss Plateau and Helvetic realm). Eclogae geol. Helv. 85, 541.572.

Lowe. 1985: Ouachita trough: Part of a Cambrian failed rift system. Geology, 13, 790–793.

Matter, A. 1987: Faziesanalyse und Ablagerungsmillieus des Permokarbons im Nordschweizer Trog. Eclogae geol. Helv., 80, 345–367.

Matter, A., Peters, T., Isenschmid, C., Bläsi, H.-R. & Ziegler, H.-J. 1987: Sondierbohrung Rininken – Geologie. Nagra Technischer Bericht 86–09, Nagra, Baden, 198 p.

Matter, A., Peters, T., Bläsi, H.-R., Meyer, J., Ischi, H. & Meyer, C. 1988: Sondierbohrung Weiach - Geologie. Nagra Technischer Bericht 86–01, Nagra, Baden, 438 p.

Meyer, C. A. 1984: Palökologie und Sedimentologie der Echinodermenlagerstätte Schofgraben (mittleres Oxfordian, Weissenstein, Kt. Solothurn). Eclogae geol. Helv. 77, 649–673.

Meyer, C. A., Allenbach, R. P. & Graf, K. (1997) The Late Jurassic vertebrate record of northern Switzerland – new discoveries and interpretations. In: 2nd European workshop in European vertebrate paleontology, Quillan, France.

Meyer, R. K. F. & Schmidt-Kaler, H. 1989: Paläogeographischer Atlas des süddeutschen Oberjura (Malm). Geol. Jb. 155 A, 77 p.

Naef, H. & Diebold, P. 1990: Tektonik des östlichen Tafeljuras und der angrezenden Molasse. Nagra informiert 2/90, 37–46.

Oppliger, F. 1915: Die Spongien der Birmensdorferschichten des Schweizerischen Jura. Abh. Schweiz. Paläont. Ges. 40, 32 p.

Pfiffner, O. A., Erard, P. F. & Stäuble, M. 1997: Two cross sections through the Swiss Molasse Basin. In: Deep Structure of the Swiss Alps: Results of the NRP 20 (Ed. by O. A. Pfiffner, P. Lehner, P. Heitzmann, S. Mueller & A. Steck), Birkhäuser, Basel, 64–72.

Philippe, Y. 1995: Rampes latérales et zones de transfert dans les chaînes plissées: géometrie, conditions de formation et pièges structuraux associés. Ph.D. Thesis, Université de Savoie, 272 p.

Pittet, B. 1996: Contrôles climatiques, eustatiques et tectoniques sur des systèmes mixtes carbonates-siliciclastiques de plate-forme: exemples de l'Oxfordien (Jura suisse, Normandie, Espagne). Ph.D. Thesis, Université de Fribourg, 256 p.

Pittet, B. & Strasser, A. 1998: Long-distance correlation by sequence stratigraphy and cyclostratigraphy: examples and implications (Oxfordian from the Swiss Jura, Spain and Normandy). Geol. Rdsch. 86, 852–874.

Ricken, W. 1985: Epicontinental Marl Limestone Alternation: Event Deposition and Diagenetic Bedding (Upper Jurassic, Southwest Germany). In: Lecture Notes in Earth Sciences, 1 (Ed. by U. Bayer & A. Seilacher), Springer, Berlin, 127–162.

Rioult, M., Dugué, O., Jan du Chêne, R., Ponsot, C., Fily, G., Moron, J.-M. & Vail, P. R. 1991: Outcrop sequence stratigraphy of the Anglo-Paris Basin, Middle to Upper Jurassic (Normandy, Maine, Dorset). Bull. Centre Rech. Exploration-Produdction Elf-Aquitaine 15, 101–194.

Robin, C., Guillocheau, F. & Gaulier, J.-M. 1998: Discriminating between tectonic and eustatic controls on the stratigraphic record in the Paris basin. Terra Nova 10, 323–329.

Sarg, J. F. 1988: Carbonate sequence stratigraphy. Soc. Sediment. Geo. Spec. Publ. 42, 155–181.

Schegg, R. & Leu, W. 1998: Analysis of erosion events and paleogeothermal gradients in the North Alpine Foreland Basin of Switzerland. In: Basin Modelling: Practice and Progress, (Ed. by J. Düppenbecker & J. E. Iliffe) Geol. Soc. Spec. Publ. 141, 137–155.

Schlager, W. 1992: Sedimentology and sequence stratigraphy of reefs and carbonate platforms. AAPG, Tulsa, 71 p. p.

Seilacher, A. & Aigner, T. 1991: Storm Deposition at the Bed, Facies and Basin Scale: the Geologic Perspective. In: Cycles and Events in Stratigraphy (Ed. by G. Einsele, Ricken, W. & Seilacher, A.), Springer, 377–382.

Slingerland, R., Harbaugh, J. W. & Furlong, K. P. 1994: Simulating clastic sedimentary basins. Prentice Hall, New Jersey, 220 p.

Trümpy, R. 1969: Die helvetischen Decken der Ostschweiz: Versuch einer palinspastischen Korrelation und Ansätze zu einer kinematischen Analyse. Eclogae geol. Helv. 62, 105–142.

Tucker, M. E. & Wright, P. V. 1990: Carbonate Sedimentology. Blackwell, Oxford, 482 p.

van Konijnenburg - van Cittert, J. H. A. & Meyer, C. A. 1996: Some plant remains from the Natica Beds (Oxfordian) of the Swiss Jura mountains. Eclogae geol. Helv. 89, 1117–1136.

von Raumer, J. F. 1998: The Paleozoic evolution in the Alps: from Gondwana to Pangea. Geol. Rdsch. 87, 407–435.

Wetzel, A. & Allia, V. 2000: The significance of hiatus beds in shallow-water mudstones: an example from the Middle Jurassic of Switzerland. J. Sed. Res. 70, 170–180.

Wetzel, A., Allia, V., Gonzalez, R. & Jordan, P. 1993: Sedimentation und Tektonik im Ostjura. Eclogae geol. Helv. 86, 313–332.

Wildi, W., Funk, H., Loup, B., Amato, E. & Huggenberger, P. 1989: Mesozoic subsidence history of the European marginal shelves of the alpine Tethys (Helevtic realm, Swiss Plateau and Jura). Eclogae geol. Helv. 82, 817–840.

Ziegler, M. A. 1962: Beiträge zur Kenntnis des unteren Malm im zenralen Schweizer Jura. Ph.D. Thesis, University of Zürich, 82 p.

Ziegler, P. A. 1990: Geological Atlas of Central and Western Europe. Shell Internationale Petroleum Maatschapij, The Hague, 239 p. and 56 encl.

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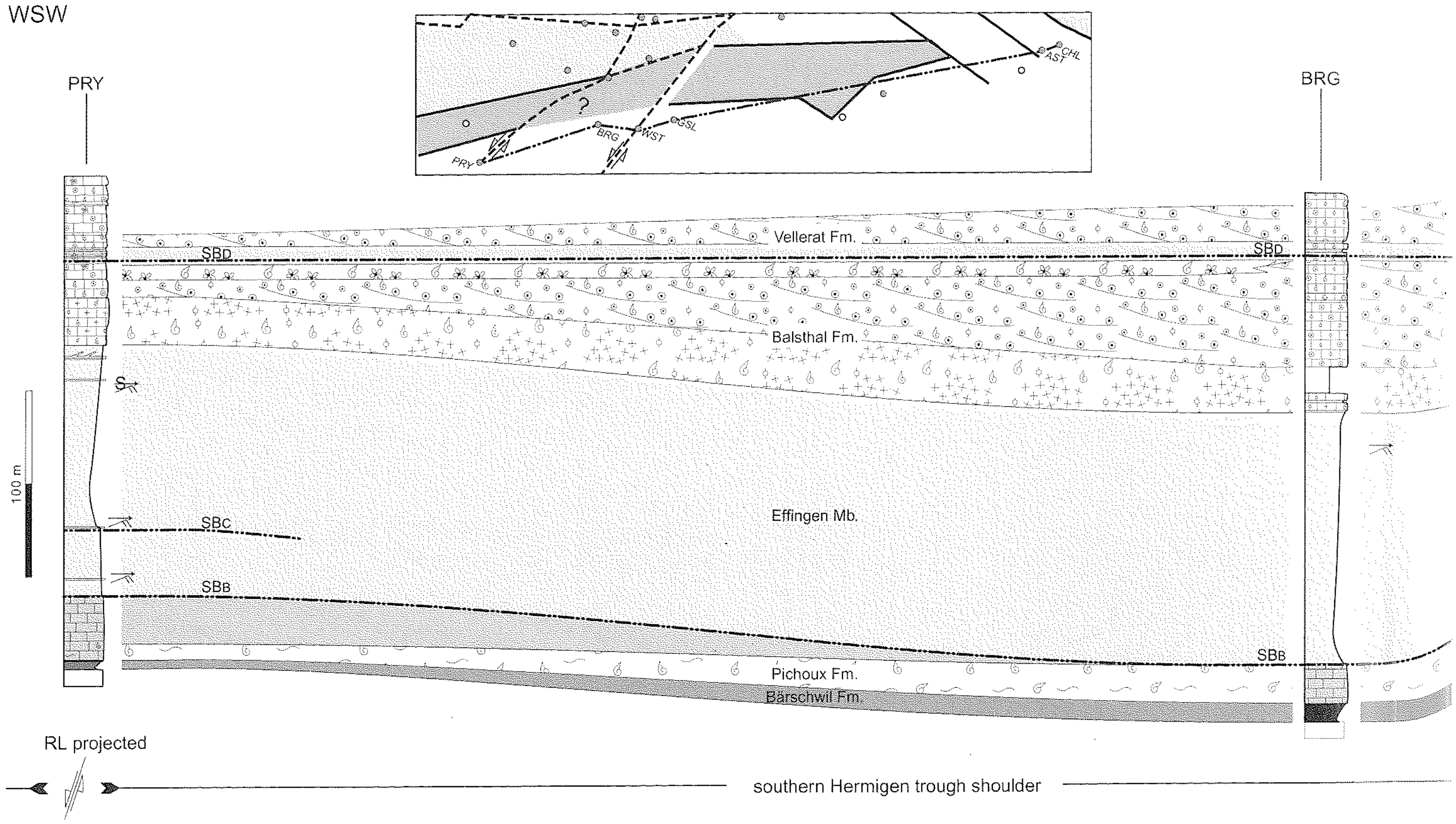
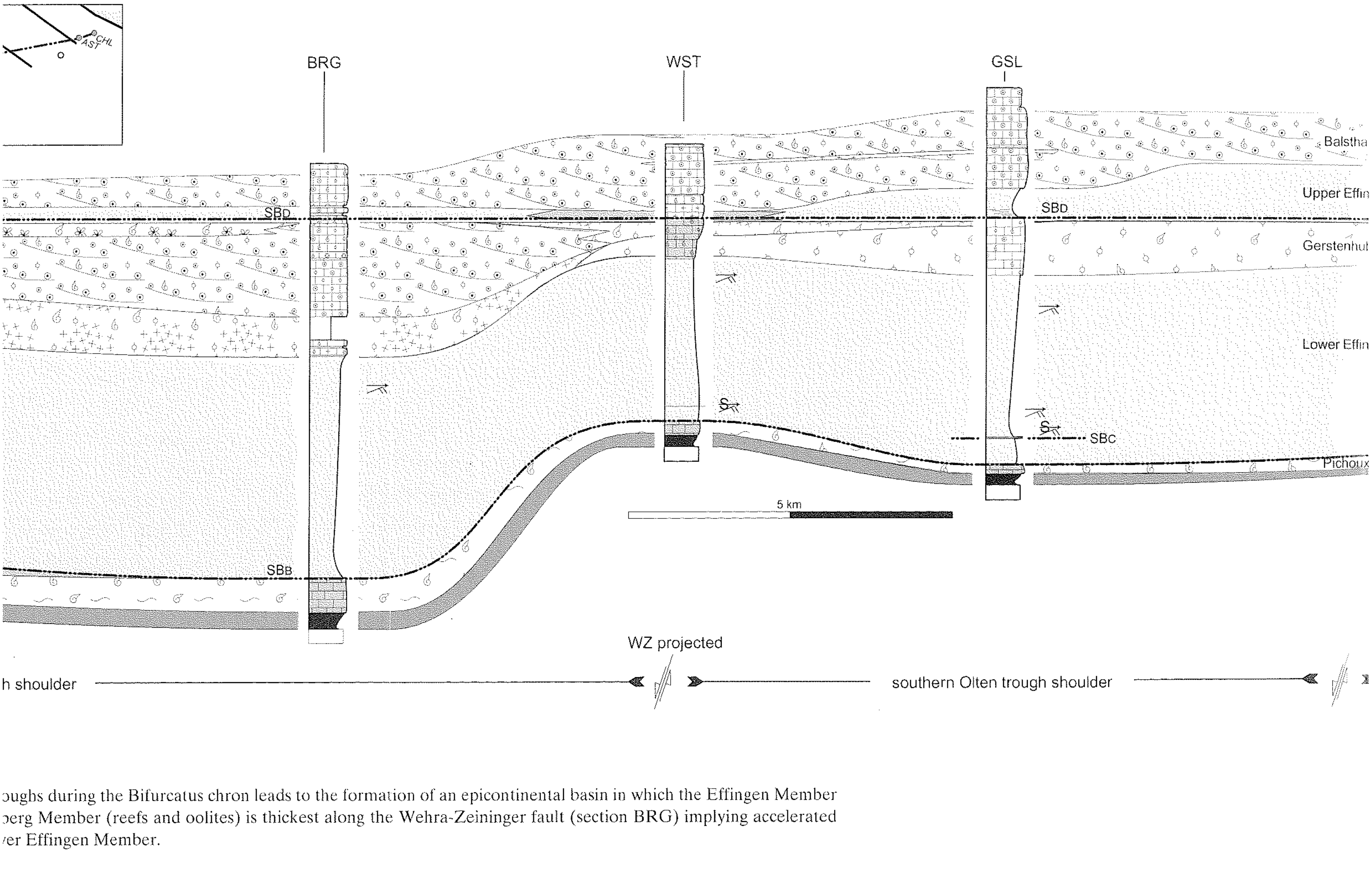
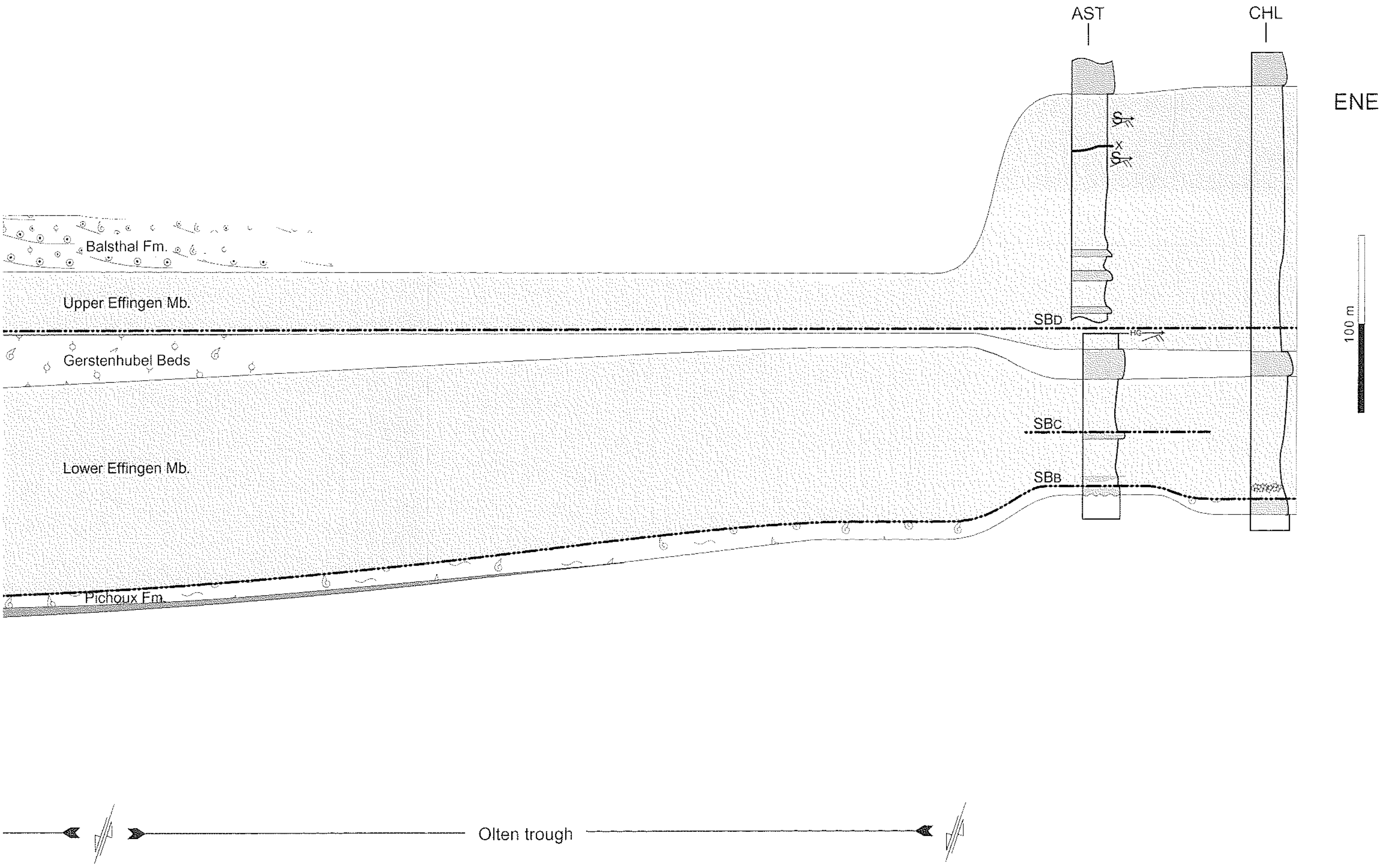


Plate 1: Profile parallel to the Paleozoic troughs (inset). Differential subsidence along the Hermrigen and Olten troughs during the Bifurcatus chron leads to the formation of
was deposited. Note the marginal reefs which reach from the west to the Weissenstein (section WST). The Günsberg Member (reefs and oolites) is thickest along the Wehr
subsidence in that area. To the east (section AST), the inherited Callovian swell can be recognized by the thin Lower Effingen Member.



oughs during the Bifurcatus chron leads to the formation of an epicontinental basin in which the Effingen Member berg Member (reefs and oolites) is thickest along the Wehra-Zeininger fault (section BRG) implying accelerated er Effingen Member.


AST
CHL
ENE
Balsthal Fm.
Upper Effingen Mb.
SBD
HG
Gerstenhubel Beds
SBC
Lower Effingen Mb.
SBB
Pichoux Fm.
100 m
Olten trough