Zeitschrift: Eclogae Geologicae Helvetiae
Herausgeber: Schweizerische Geologische Gesellschaft
Band: 99 (2006)
Heft: 2

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DOI: https://doi.org/10.5169/seals-169233

0012-9402/06/020175-17
DOI 10.1007/s00015-006-1187-8
Birkhäuser Verlag, Basel, 2006

Eclogae geol. Helv. 99 (2006) 175–191

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

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Key words. Stratigraphy, biostratigraphy, Kimmeridgian, Jurassic, NW Switzerland, Banné Marls, Virgula Marls, Reuchenette Formation

ABSTRACT

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

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

The new stratigraphical frame is a pre-requirement for refining correlations of sections, for reconstructing sea level fluctuations, and for quantifying synsedimentary differential subsidence.

Introduction

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

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

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

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

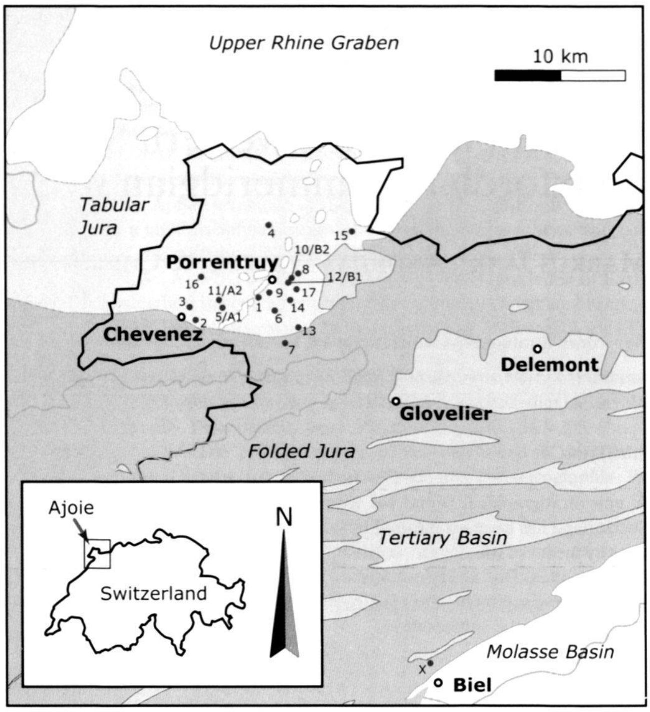

Fig. 1. Geological overview map and Swiss coordinates of locations and geological transects. Note the altitude difference (about 60 m) between the base of Coregent (A1) and the base of the Virgule Marls (A2) in Sur Combed Ronde (note: layers are ± horizontal; see Swiss geol. map 1085 St-Ursanne).

Geological Setting

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

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

Thalmann (1966) defined the Reuchenette Formation in the limestone quarry of La Reuchenette near Péry BE as a monotonous succession of bedded limestones with few and thin marl intercalations. Lime mudstone (*sensu* Dunham 1962) is the dominant lithology there, but peloidal wacke- to grainstones and some oolitic horizons occupy some prominent intervals. Coral biostromes are uncommon (Gygi & Persoz 1986). The base of the Reuchenette Formation is marked by an uneven erosion surface (Thalmann 1966) overlain by a massive 18 m thick limestone unit (Gygi & Persoz 1986). Locally a horizon with blackened lithoclasts is developed in the basal lower part (Gygi 1982, Colombié 2002). The lower 8 m of this massive unit are composed of oo-oncolitic carbonates (Verena facies). The upper 10 m are primarily mudstone with local patches of oolitic wackestone. Above this massive limestone unit, well-bedded mudstones and peloidal wacke-to grainstones with two bands of fenestrate stromatolites occur (Gygi 1982, Colombié 2002). The boundary between the massive unit and well-bedded limestones is conspicuous and it can be easily observed, whereas the horizon with blackened lithoclasts is restricted to a small part of the La Reuchenette quarry (Gygi & Persoz 1986). This sharp lithological contrast is developed between the underlying members (i.e. Porrentruy and Verena Member) and the Reuchenette Formation in all sections in the Ajoie-Region and southern and central Jura Mountains (Gygi 2000b, c). For this reason, Gygi defined the boundary between the Reuchenette Formation and the underlying Balsthal and Courgenay Formation at the base of the well-bedded limestones (Gygi 2000b, c). This boundary is visible in the quarry La Rasse south of Porrentruy (Section RG 340 of Gygi, Gygi 2000b, No. 9 in Fig. 1) and in Chemin Paulin near Courgenay (Section RG 350 of Gygi; Gygi 2000b, No. 7 in Fig. 1). The thickness of the Reuchenette Formation in terms of Gygi's boundaries is approximately 140 m at the type-section La Reuchenette.

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

Fig. 1. Coninued

Methods and Material

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

The evaluation of the Standard Microfacies Types and the facies (Fig. 3) of approximately 500 thin sections are based on the classifications of Dunham (1962), Wilson (1975), and Flügel (1982). The interpretations of thin sections and depositional environments are illustrated by "Facies-Patterns" on the right column of the figures. The term "bedding" is used to describe the internal characteristics/composition of a bed, e.g. flaser bedding, nodular bedding, cross bedding, laminated. The term "layering" is used to characterize the thickness of a bed, e.g. massive-layered (>1 m), thick-layered (0.3–1 m), thin-layered (1–3 dm), very thin-layered (<1 dm). Two geological transects (see Fig. 1; A1-A2, B1-B2) were evaluated to obtain an independent information about the regional trends in thickness.

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

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

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

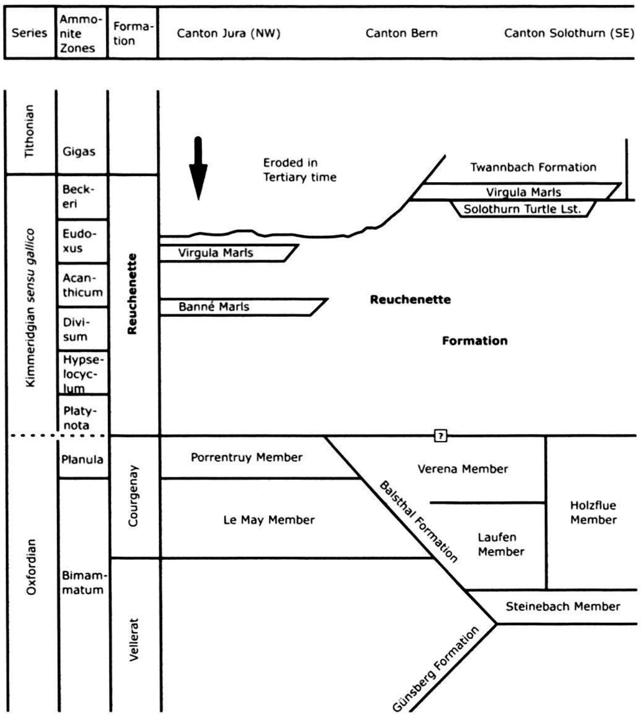

Fig. 2. Chrono-, litho- and biostratigraphical scheme for the Reuchenette Formation, based on data from Gygi (2000b), Meyer C.A. (1990, 1993) and this study. Arrow indicates position of the measured sections. The biostratigraphical position of the lithological boundary between the Reuchenette Formation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

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

Lithology

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

Porrentruy Member (top of the Courgenay Formation *sensu* Gygi 1995):

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

Thalassinoides Limestone (≈30 m) (Plate 1, a):

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

"Nautilidenschichten" (≈11 m) (Plate 1, b):

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

Lower Grey and White Limestones (≈11 m) (Plate 1, c):

This interval is composed of dm-to m-thick layers of grey and white, micritic and calcarenitic limestones with blocky fractures. *Thalassinoides* burrows are rare. Occasionally, the top is composed of stromatolitic limestones. The interval is capped by a regional hardground, which bored and biogenically encrusted by oysters.

Banné Marls (Banné Member *sensu* Marçou 1848; in Gygi 2000b, c) (≈8–9 m) (Plate 1, d):

The slightly nodular Banné Marls comprise grey dm-thick layers of marlstones, calcarenitic marls and marly limestones

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

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

with a rich fauna of bivalves associated with some brachiopods, nautilids, echinoids, vertebrate remains (e.g. turtles, marine crocodiles), *Thalassinoides* and very rare ammonites. Shelly and calcarenitic horizons, probably reworked and winnowed by storms, are intercalated and commonly separate the beds.

Nerinean Limestones (≈33 m) (Plate 1, e):

The Nerinean Limestone interval starts with dm- to m-thick layers of grey, calcarenitic limestones (≈10 m; Fig. 9), followed by significant white, blocky fracturing, dm- to m-layered, chalky, calcarenitic limestones with large gastropods (Nerineans) and stromatolite layers (see Fig. 4). To the top it grades into greenish weathered, glauconite-rich pack- and grainstones with lumachelle intercalations (Fig. 10). This part shows characteristic, strongly bored and biogenically encrusted (by oysters), regional hardgrounds and cephalopods lying on them (Fig. 5).

Virgula Marls (≈1 m) (Plate 1, f):

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

Coral Limestones (≈15 m) (Plate 1, g):

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

Upper Grey and White Limestones (≈18 m):

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

Oyster Limestones (≈17 m) (Plate 1, h):

This interval starts with massive (m-thick), calcarenitic limestones and a layer yielding Cladocoropsis *mirabilis*

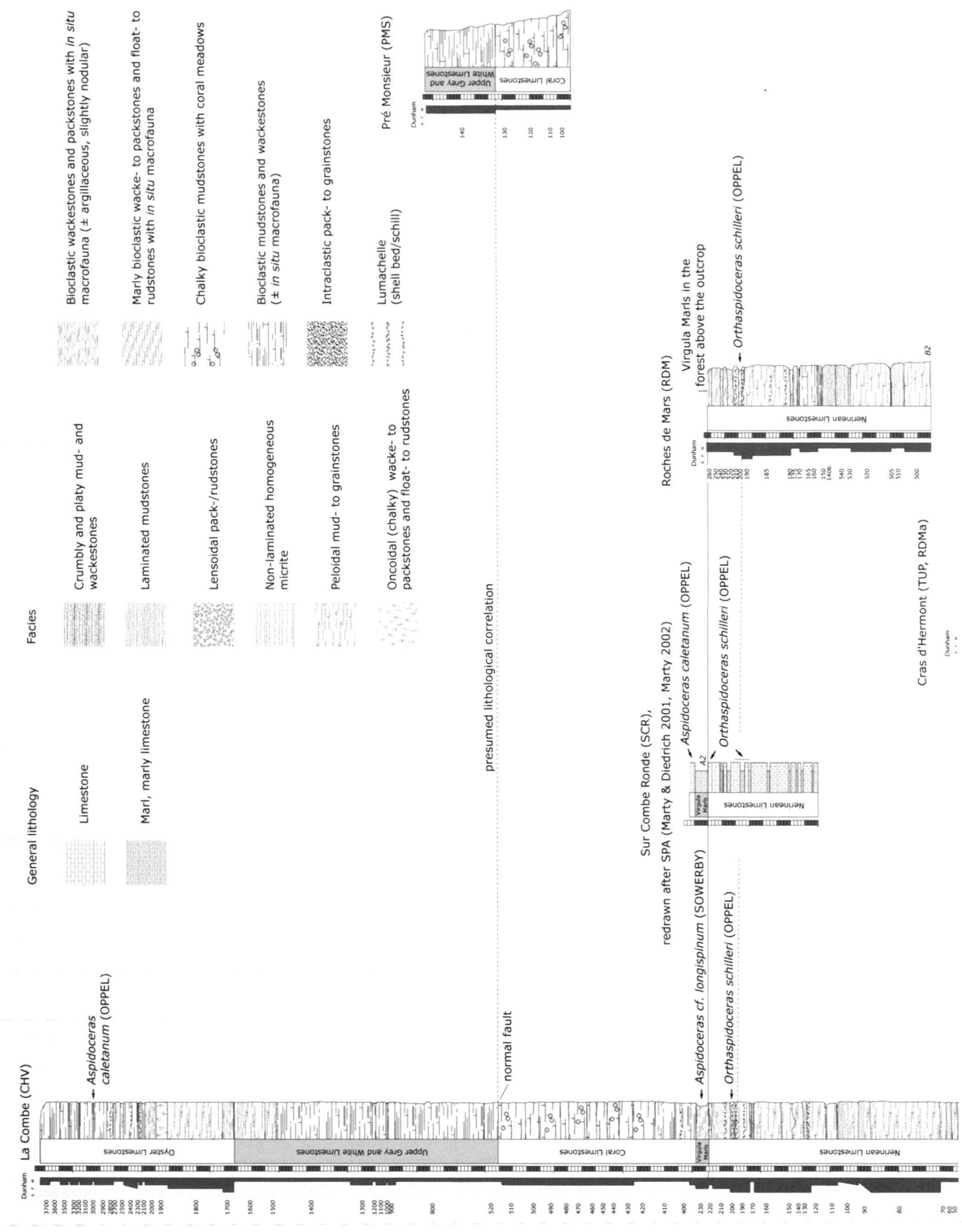
General lithology
Limestone
Marl, marly limestone
Facies
Crumbly and platy mud- and wackestones
Laminated mudstones
Lensoidal pack-/rudstones
Non-laminated homogeneous micrite
Peloidal mud- to grainstones
Oncoidal (chalky) wacke- to packstones and float- to rudstones
Bioclastic wackestones and packstones with in situ macrofauna (± argillaceous, slightly nodular)
Marly bioclastic wacke- to packstones and float- to rudstones with in situ macrofauna
Chalky bioclastic mudstones with coral meadows
Bioclastic mudstones and wackestones (± in situ macrofauna)
Intraclastic pack- to grainstones
Lumachelle (shell bed/schill)
Pré Monsieur (PMS)
Upper Grey and White Limestones
Coral Limestones
presumed lithological correlation
La Combe (CHV)
Aspidoceras caletanum (OPPEL)
normal fault
Oyster Limestones
Upper Grey and White Limestones
Coral Limestones
Virgula Marls
Nerinean Limestones
Aspidoceras cf. longispinum (SOWERBY)
Orthaspidoceras schilleri (OPPEL)
Sur Combe Ronde (SCR),
redrawn after SPA (Marty & Diedrich 2001, Marty 2002)
Aspidoceras caletanum (OPPEL)
Orthaspidoceras schilleri (OPPEL)
A2
Virgula Marls
Nerinean Limestones
Roches de Mars (RDM)
Virgula Marls in the forest above the outcrop
Orthaspidoceras schilleri (OPPEL)
Nerinean Limestones
B2
Cras d'Hermont (TUP, RDMa)
Dunham

Fig. 4.

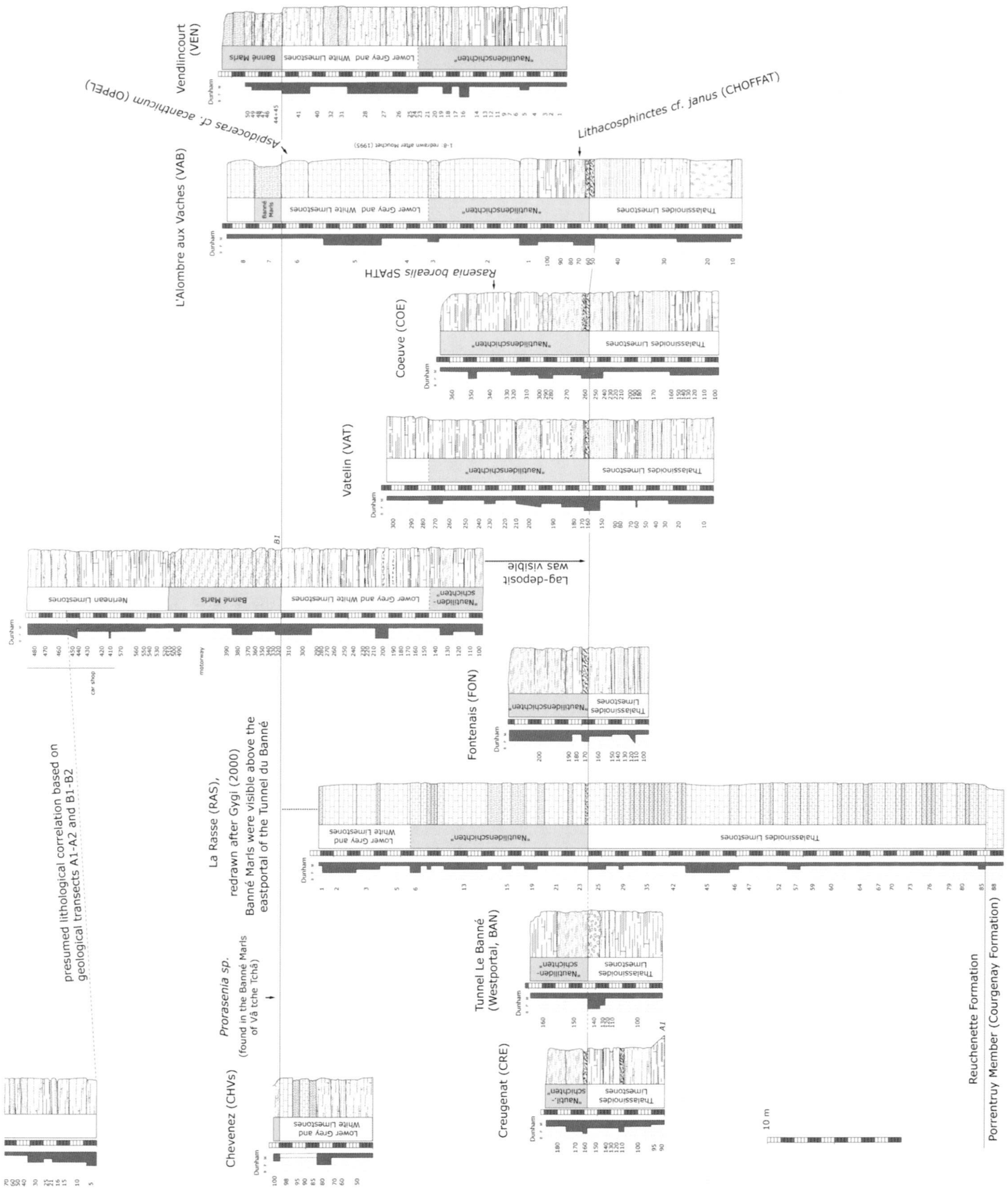

Fig. 4. Biostratigraphically subdivided composite overview for the sediments of the Reuchenette Formation in the Ajoie-Region. Detailed sections are published in PhD thesis of Markus Jank (Jank 2004).

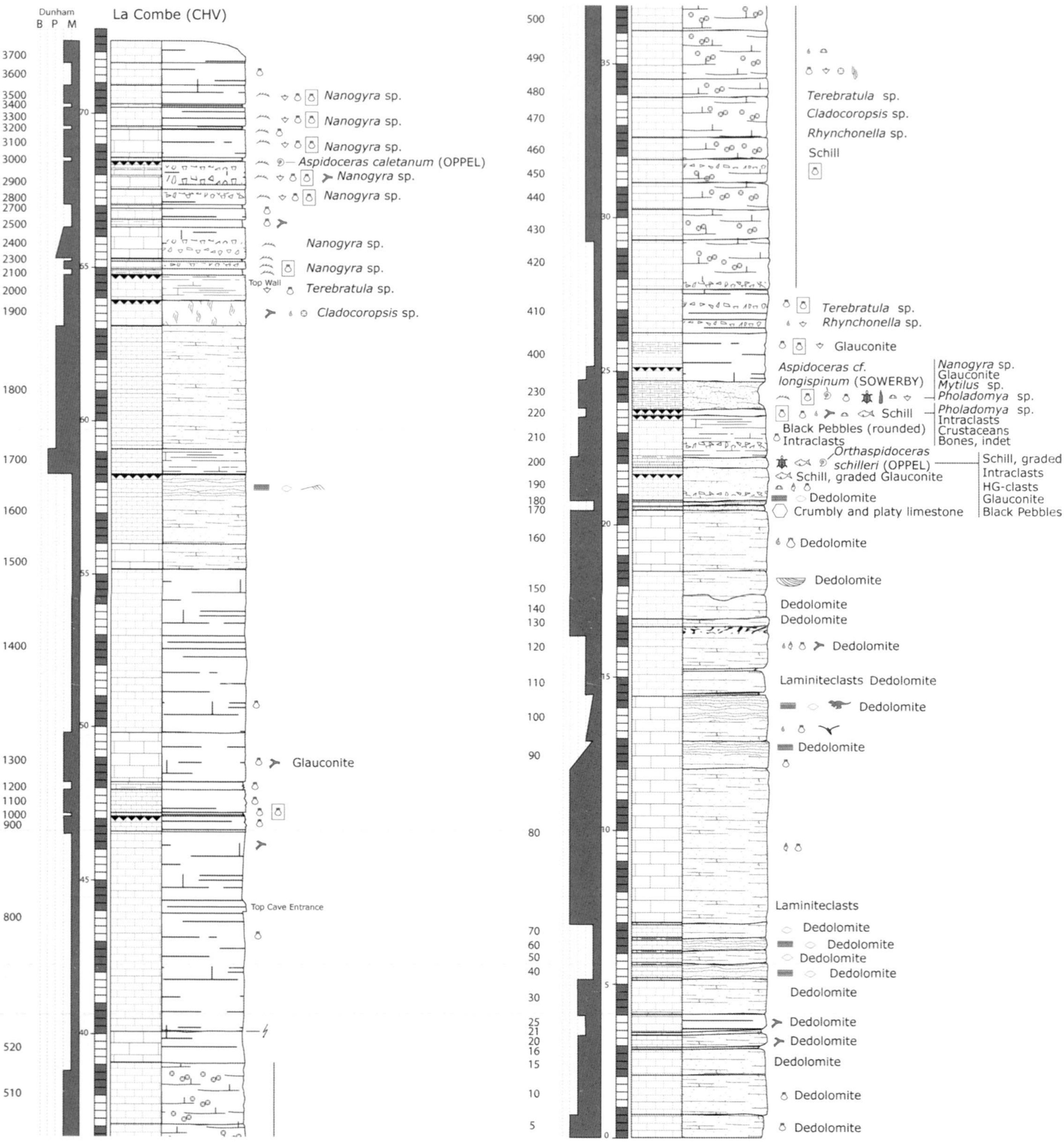

Fig. 5. Section La Combe – Bed CHV-230 are the Virgula Marls. For legend and symbols see Figs. 4 and 8.

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

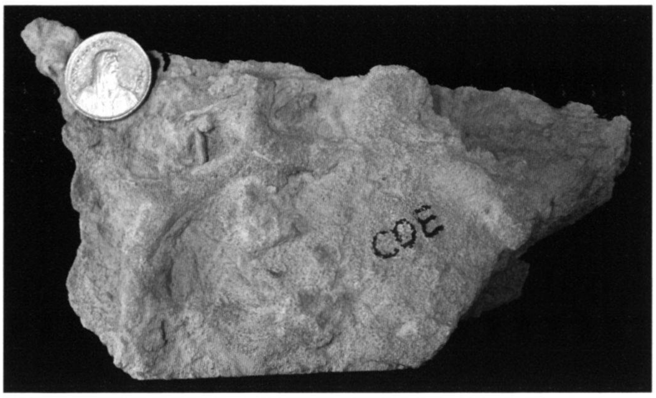

Fig. 7. Storm-lag deposit (intraclastic pack- to grainstone) with cast *Thalassinoides* (bottom side, positive hypichnia) – Important marker bed (bed COE-260, Coeuve; scale: Δ≈3 cm).

(0–6 m). It is overlain by dm-thick layers of occasionally platy, marly, fine-grained (micritic) limestones, dominated by oysters.

Biostratigraphy

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

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

Results

The stratigraphical correlation of the sections (Fig. 4) was established by the combination of lithological, facies and sedimentological criteria in combination with biostratigraphical data. This is exceptional because it is the first time that a large

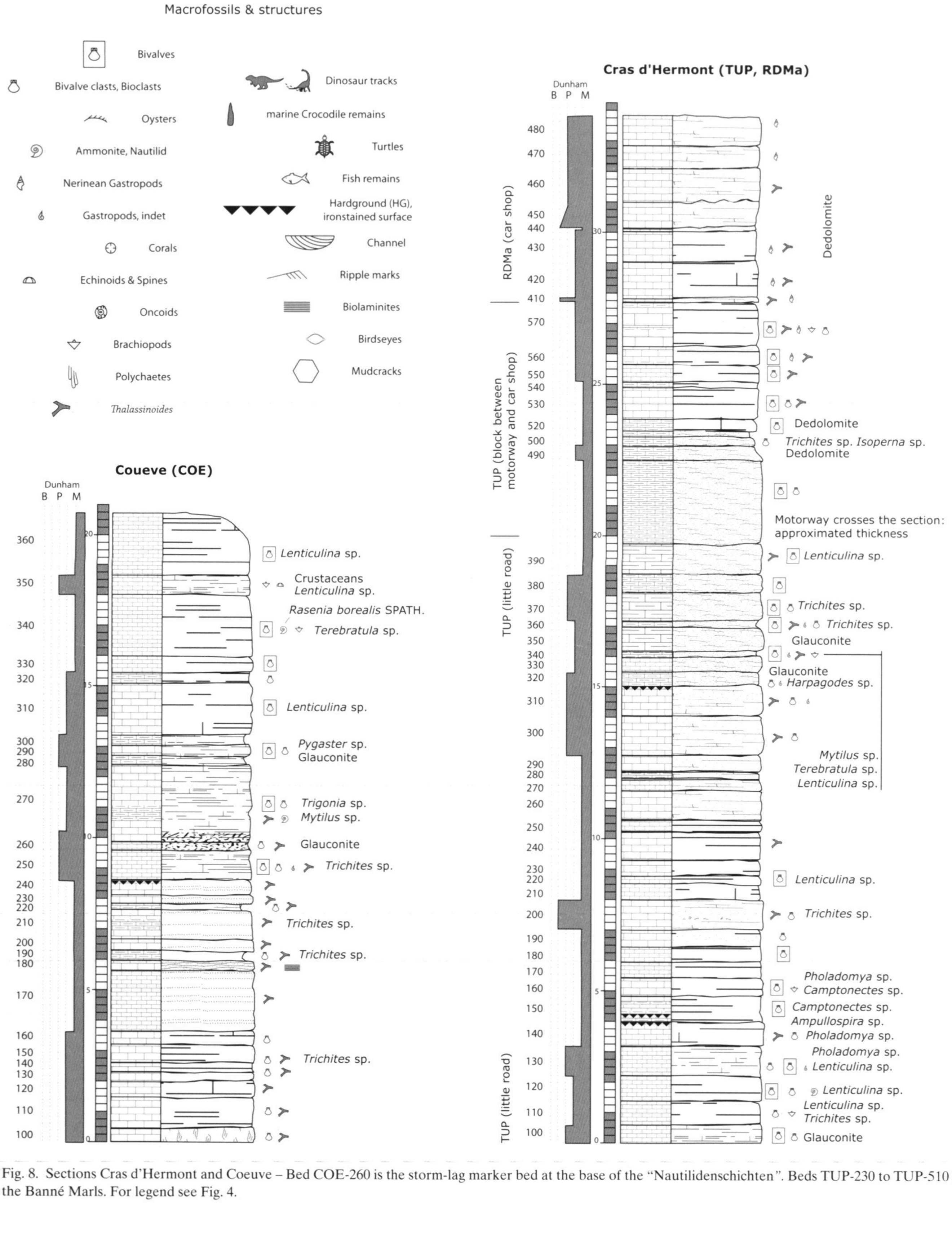

Fig. 8. Sections Cras d'Hermont and Coeuve – Bed COE-260 is the storm-lag marker bed at the base of the "Nautilidenschichten". Beds TUP-230 to TUP-510 is the Banné Marls. For legend see Fig. 4.

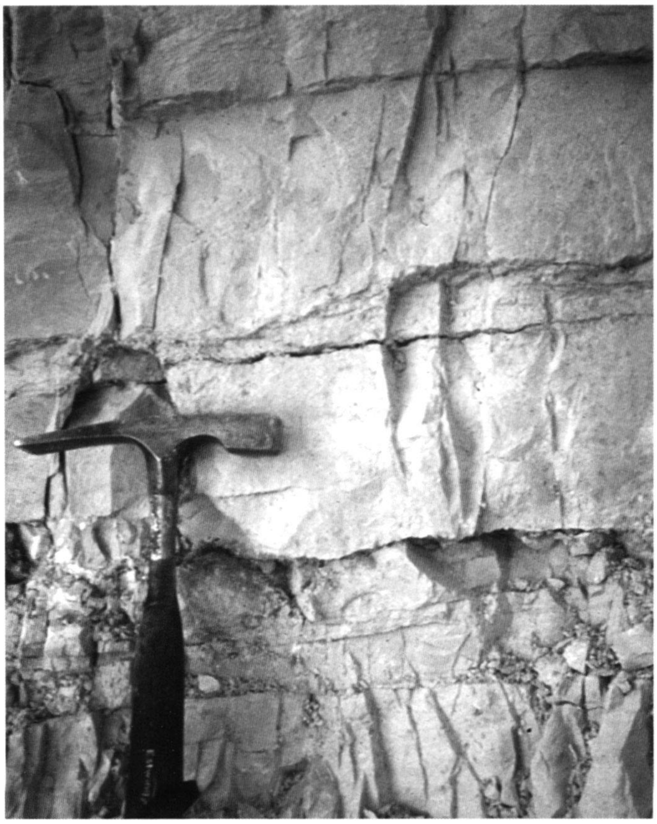

Fig. 9. Nerinean Limestones – Grey "sandy" limestone at the base of the Nerinean Limestone interval (base La Combe). Presumed lithological correlation with top Cras d'Hermont.

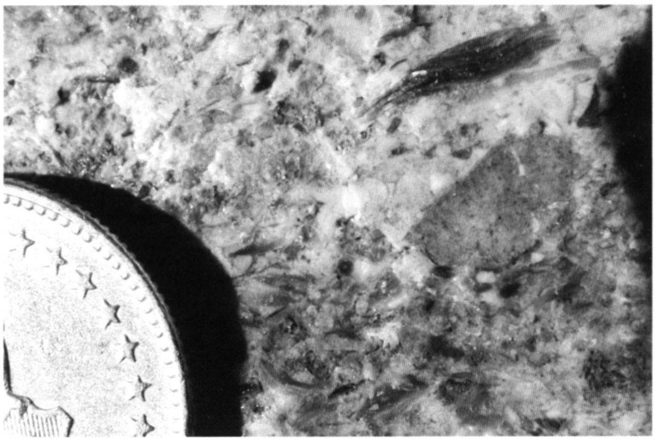

Fig. 10. Schill layer – Reworked material (right centre) from base of bed CHV-190 in shell-supported matrix (top of bed CHV-190, above hardground, La Combe; scale: Δ≈2.5 cm).

composite section of the sediments of the Reuchenette Formation can be biostratigraphically constrained by six bed-rock controlled ammonite occurrences (*in situ* collected).

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

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

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

Due to the lack of biostratigraphical data, the age of the lithological boundary (*sensu* Gygi; see above) to the Porrentruy Member remains vague. It is most probably within the Late Oxfordian (Jank 2004).

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

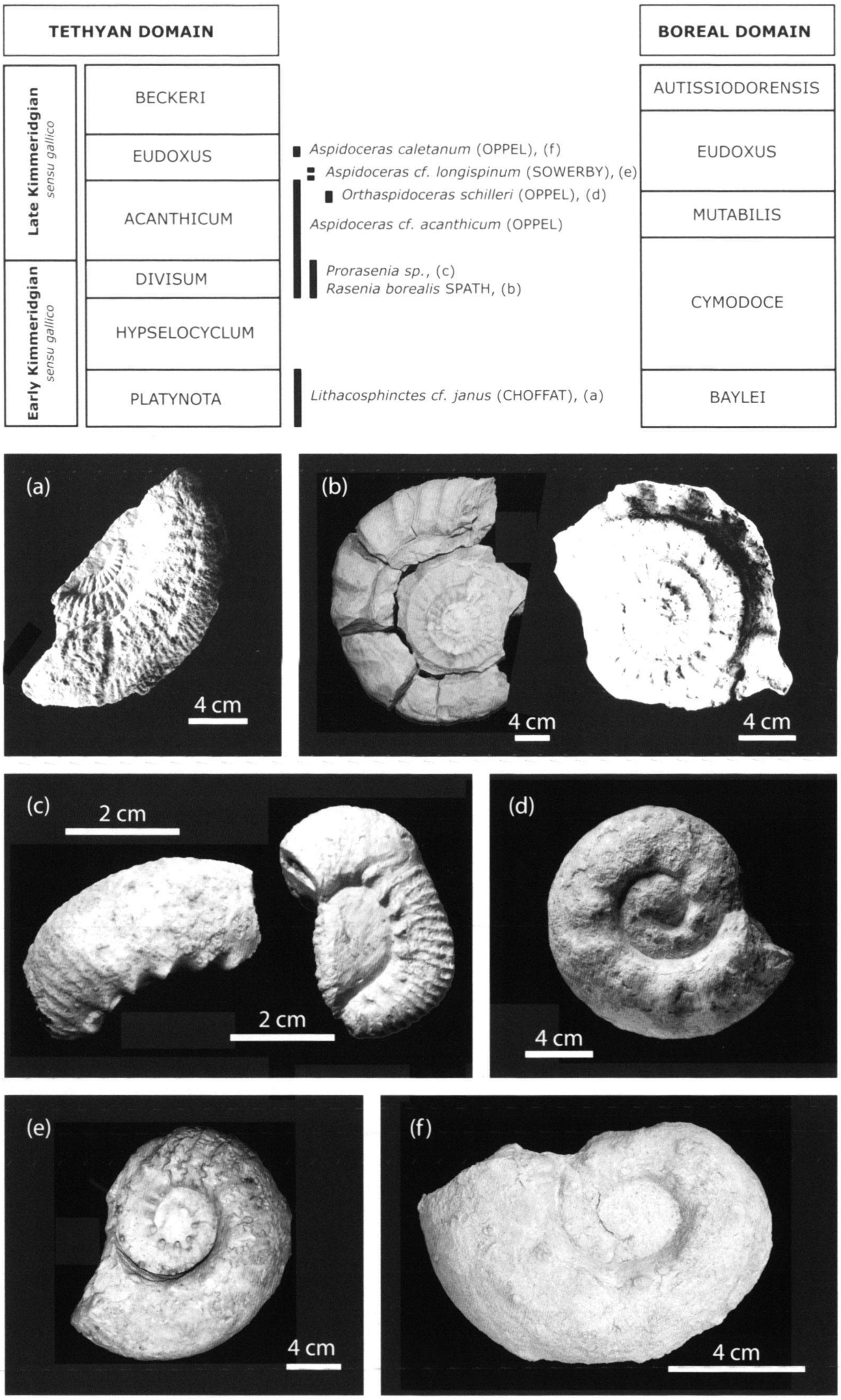

Fig. 11. Biostratigraphical frame based on ammonites. Zonation of the Kimmeridgian *sensu gallico* after Hantzpergue et al. (1997). Tethyan Domain is used *sensu* Domaine Téthysien, Province subméditerraneénne; Boreal Domain is used *sensu* Domaine Boréal, Province subboréale. All ammonites were collected *in situ*, except *Aspidoceras* cf. *acanthicum* (OPPEL) (Gygi 1995).

Exact biostratigraphical range and localities: (a) *Lithacosphinctes* cf. *janus* (CHOFFAT); Platynota-Zone; L'Alombre aux Vaches. (b) *Rasenia borealis* SPATH; Divisum-Zone; Coeuve. (c) *Prorasenia* sp.; Divisum-Zone; Vâ tche Tchâ. *Aspidoceras* cf. *acanthicum* (OPPEL); Divisum- to Acanthicum-Zone; L'Alombre aux Vaches. (d) *Orthaspidoceras schilleri* (OPPEL); Acanthicum-Zone, Lallierianum-Sub-Zone, Schilleri-Horizon; La Combe (top bed CHV-190; © SPA, photo by B. Migy), Roches de Mars and Sur Combe Ronde. (e) *Aspidoceras* cf. *longispinum* (SOWERBY); lowermost Eudoxus-Zone; La Combe. (f) *Aspidoceras caletanum* (OPPEL); Eudoxus-Zone, Caletanum-Sub-Zone, Caletanum-Horizon; La Combe and Sur Combe Ronde (limestone about 1 m above the Virgula Marls; © SPA).

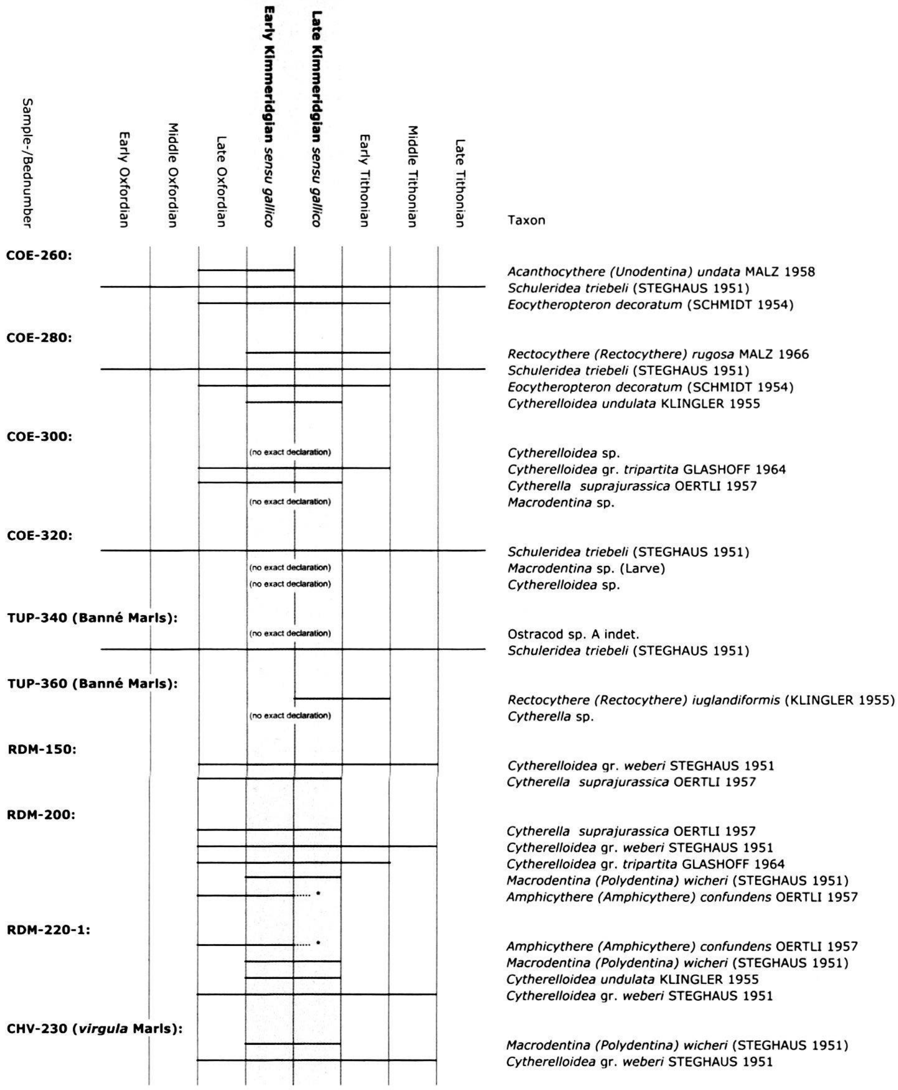

Fig. 12. Biostratigraphical framework given by range of some ostracodes. Note range of ostracode assemblage-zones vaguely agree with ammonite data. *Redrawn after Weiss (1995, 1996, 1997) and Gramann et al. (1997).

Vabenau (Mouchet 1995, 1998) (L'Alombre aux Vaches; No. 13 in Fig. 1).

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

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

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

Discussion

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

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

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

Conclusions

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

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

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

Additional Information

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

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

Apart from the sections Chemin Paulin, Bas d'Hermont, Vâ tche all sections can be found in the PhD thesis of Markus Jank (New insights into the development of the Late Jurassic Reuchenette Formation of NW Switzerland - late Oxfordian to late Kimmeridgian, Jura Mountains). A hard copy can be obtained at the library of the GPI (address: Bibliothek, Geologisch-Palaeontologisches Institut der Universität Basel, Bernoullistrasse 32, CH-4056 Basel, Switzerland); an online version is available under http://pages.unibas.ch/diss/2004/DissB_7365.htm.

Repository

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

Acknowledgments

A part of this work has been carried out in the frame of collaboration between the University of Basel and the Section de Paléontologie de la République et du Canton Jura. We are grateful to Günter Schweigert, Ulla Schudack and Lukas Hottinger for taxonomic assignment of ammonites, ostracodes and foraminifera. We thank also Bernhard Hostettler for providing very important ammonites and very helpful field trips. Thanks to the colleagues Johann Fleury, Sebastian Hinsken, Achim Reisdorf, Almar de Ronde and Kamil Ustaszewski for discussions and logistic support. Special thanks to Pascal Tschudin for discussions and providing material. André Strasser and Raymond Enay are thanked for constructive reviews of an earlier version of the manuscript. The FAG Basel is thanked for financial support.

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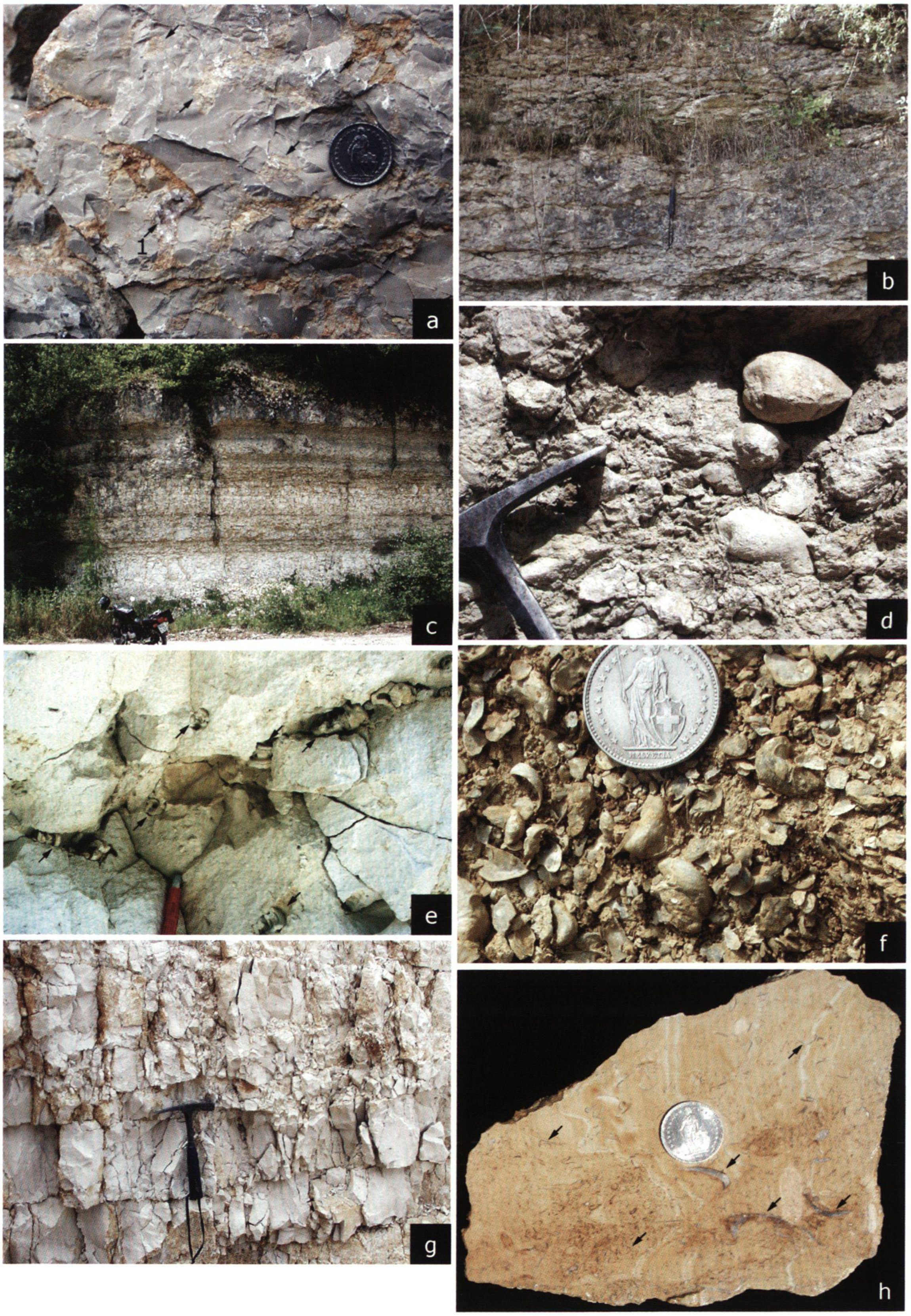
Manuscript received August 27, 2004
Revision accepted April 21, 2006
Published Online First October 13, 2006

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

Picture a: Thalassinoides Limestones – Reddish brown pseudo-oolitic material (arrows) within finer grained, grey matrix. Note the blocky cements (1) next to coarser material in the *Thalassinoides* burrows (base L'Alombre aux Vaches).
Picture b: "Nautilidenschichten" – Thick to massive marly limestones with nodular bedding (Fontenais).
Picture c: Lower Grey and White Limestones – The topmost thick limestone bed correlates with bed VEN-41 in Vendlincourt. The Banné Marls follow on the top of this bed and are rarely visible (covered) (Chevenez).
Picture d: Banné Marls – Large bivalve at the top is a *Pholadomya* sp. (Cras d'Hermont, block between motorway and car shop).
Picture e: Nerinean Limestones – Chalky Nerinean Limestone *"sensu stricto"* with internal molds of Nerinean gastropods (arrows; bed CHV-80, La Combe).
Picture f: Virgula Marls (Sur Combe Ronde).
Picture g: Coral Limestones – White chalky thin-bedded blocky fracturing limestone (La Combe). Thin marl seams separate beds.
Picture h: Oyster Limestones – Storm intercalation in bioclastic mud- to wackestone. The shell pods of *Nanogyra* sp. (arrows) and some other shells are caused by bioturbation (bed CHV-2900, La Combe).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