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| **Autor:** | Bodin, Stéphane / Godet, Alexis / Vermeulen, Jean |
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# Biostratigraphy, sedimentology and sequence stratigraphy of the latest Hauterivian – Early Barremian drowning episode of the Northern Tethyan margin (Altmann Member, Helvetic nappes, Switzerland)

STÉPHANE BODIN[1*], ALEXIS GODET[1], JEAN VERMEULEN[2], PASCAL LINDER[1] & KARL B. FÖLLMI[1]

*Key words:* Early Cretaceous, platform drowning, phosphatization, condensation, heterozoan, Northern Tethyan margin

## ABSTRACT

During the Early Cretaceous, major palaeoceanographic changes are mirrored on the northern Tethyan carbonate platform by changes in the carbonate factory and by platform drowning. The Altmann Member of the central European, northern Alpine Helvetic thrust and fold belt, contains the sedimentary record of one of these drowning events which occurred during the Late Hauterivian – Early Barremian. It consists mainly of highly condensed beds, which are rich in glaucony and phosphates. The Altmann Member was hitherto only poorly dated. New ammonite findings and a re-evaluation of existing ammonite fauna allow to precisely date this drowning episode, starting in the *Pseudothurmannia seitzi* biozone (latest Hauterivian) and lasting until the *Coronites darsi* biozone (latest Early Barremian). These new age dates, coupled with sequence stratigraphic interpretations allow to better understand the unfolding of the drowning episode, which proceeded in two stages: The first stage consisted in an important phase of marine transgression during the latest Hauterivian, during which carbonate production was highly reduced; the second stage is recorded during the latest Early Barremian by an important sequence boundary, which is associated with a phosphatized hardground, followed by rapid sea-level rise and the deposition of outer ramp sediment associated with the backstepping of the platform. Almost the whole early Barremian is likely to be condensed in this phosphatized hardground, which is associated to a second order sea-level lowstand. The onset of the drowning event is linked to the Faraoni oceanic anoxic event, whereas during the Early Barremian, phosphatization might be the result of important winnowing during a period of highly eutrophic conditions.

## RESUME

Durant le Crétacé inférieur, les changements paléoceanographiques sont enregistrés sur la marge nord-Téthysienne par des fluctuations du mode de production des carbonates ainsi que des épisodes d'ennoiement de plate-forme. Le Membre d'Altmann, qui affleure en Europe centrale, dans les nappes plissées et charriées du domaine Helvétique, est le résultat d'un de ces ennoiements de la plate-forme carbonatée se déroulant durant l'Hauterivien tardif et le Barrémien précoce. Principalement constitué de couches fortement condensées riches en glauconie et phosphate, le Membre d'Altmann, qui peut être relié à des changements paléocéanographiques majeurs durant le Crétacé inférieur, n'a pour l'instant été que faiblement daté. De nouvelles datations biostratigraphiques basées sur des ammonites nouvellement trouvées, ainsi que sur une réévaluation de celles précédemment publiées, permettent de précisément dater cet épisode d'ennoiement de plate-forme. Celui-ci débute dans la zone d'ammonites à *Pseudothurmannia seitzi* (Hauterivien tardif) et se termine dans la zone à *Coronites darsi* (dernière zone du Barrémien inférieur). Ces nouvelles datations, couplées avec des interprétations en stratigraphie séquentielle, permettent de mieux appréhender le déroulement de cet épisode d'ennoiement de plate-forme qui se développe en deux temps : une première étape correspond à une importante phase de transgression marine durant l'Hauterivien terminal, accompagnée par une réduction importante de la production carbonatée. Une seconde étape est enregistrée durant la fin du Barrémien précoce par la formation d'un fond induré phosphaté associé à un bas niveau marin, suivie par une remontée rapide du niveau marin et le dépôt de sédiments de rampe carbonatée externe associé à une forte rétrogradation de la plateforme. De plus, la majeure partie du Barrémien précoce est condensée dans ce fond induré phosphaté associé à un bas niveau marin de second ordre. Le début de cet épisode d'ennoiement de plate-forme semble être lié à l'événement d'anoxie océanique du niveau Faraoni, tandis que durant le Barrémien inférieur, la phosphatogenèse semble être le résultat d'un important vannage des fonds océaniques durant une période d'eutrophie marine.

## 1. Introduction

The Early Cretaceous record on the Helvetic platform is characterized by several drowning episodes expressed in highly condensed and phosphatized beds (Funk et al. 1993; Föllmi et al. 1994). These beds are relatively rich in macrofossils (ammonites, belemnites, bivalves, brachiopods, sponges and echinoids) and have been the focus of several studies for nearly a century (*e.g.*, Heim 1910–1916; Goldschmid 1927; Fichter 1934; Hantke 1961; Funk 1971; Briegel 1972; Wyssling 1986; Föllmi

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[1] Institut de Géologie, Université de Neuchâtel, Rue Emile Argand 11, CP 158, 2009 Neuchâtel, Switzerland
[2] Grand Rue, 04330 Barrême, France
[*] Corresponding author. E-mail address: stephane.bodin@unine.ch

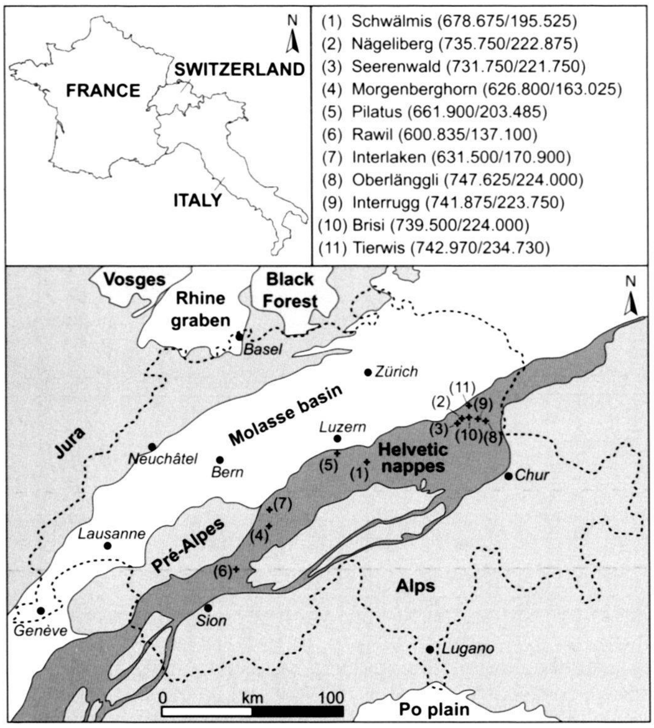


Fig. 1. Location of the studied sections and their geographical coordinates, expressed in the Swiss orthogonal coordinate system. The Helvetic realm is shown in dark grey.

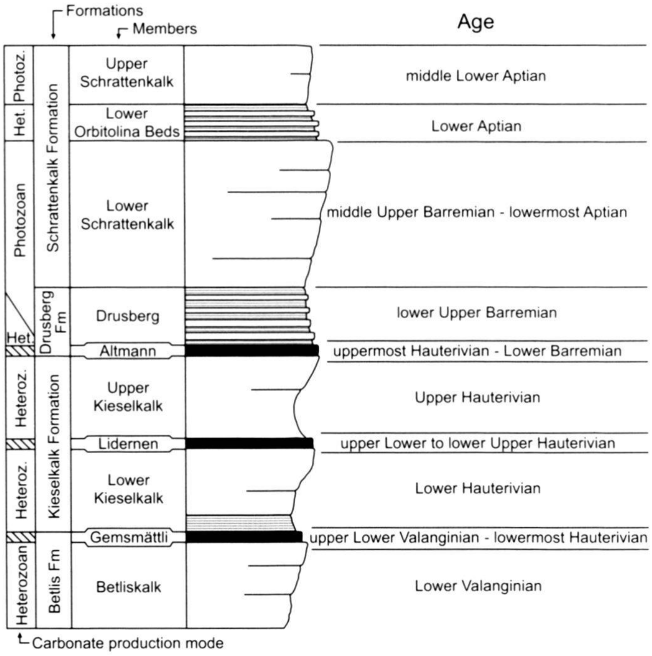


Fig. 2. Synthetic log of Helvetic platform deposits of Valanginian to Early Aptian age.

1989; Kuhn 1996; van de Schootbrugge 2001) due to their importance to date the intercalated sediments poor in biostratigraphically significant fossils.

This paper focuses on one of these condensed horizons, the Altmann Member (Mb), which separates the Kieselkalk Formation (Fm; Hauterivian) from the rest of the Drusberg Fm (latest Early to early Late Barremian). Previously, the Altmann Mb has not been dated precisely although a latest Hauterivian to earliest Barremian age was assumed (*e.g.*, Funk 1969; Briegel 1972; Rick 1985; Wyssling 1986; Funk et al. 1993; Föllmi et al. 1994). Thus, a first goal of this study is to provide a high-resolution biostratigraphy for the Altmann Mb using newly collected ammonites, as well as a reevaluation of those already collected during previous studies and stored in different museums.

The drowning horizons of the Lower Cretaceous Helvetic platform are of great interest since Föllmi et al. (1994) and Weissert et al. (1998) (see also Kuhn 1996; van de Schootbrugge 2001) have postulated links between these episodes and global palaeoceanographic events, as expressed by the carbon-isotope record. The Altmann Mb documents an episode for which no clear explanation has been yet formulated. On the other hand, major palaeoceanographic changes are present in the Tethyan realm during the Late Hauterivian – Early Barremian, such as the Faraoni oceanic anoxic event (Late Hauterivian; *e.g.*, Cecca et al. 1994; Baudin et al. 1999; Baudin 2005) and a phase of enhanced phosphorus input during the Early Barremian (Bodin et al. 2006). Using improved biostratigraphy and sedimentology of the Altmann Mb, this study aims at linking the initiation, unfolding and termination of the Altmann Mb drowning event to these major palaeoceanographic events.

## 2. Geological setting

The studied sections are located in the Helvetic nappes of Switzerland, situated in the northern part of the Alps and representing the northern Tethyan margin. This domain was thrusted, overthrusted and folded in a northward direction during Alpine orogenesis (Fig. 1). With regards to its age, almost the entire Hauterivian is represented in this tectonic unit by the Kieselkalk Fm (Fig. 2), which is divided into three members; the Lower Kieselkalk, the Lidernen and the Upper

Fig. 3. Examples of well-preserved representative ammonites from the Altmann Mb. A-D: After the study of Wyssling 1986, re-identified, Vorarlberg region, Austria (stored in the Museum of Natural history of Dornbirn, Austria); E-F: Newly collected ammonites from the Tierwis section (all the newly collected ammonites are stored at the Geological Institute of Neuchâtel). A: *Balearites aff. mortilleti*, specimen n° P9385. B: *Kotetishvilia aff. nicklesi*, specimen n° P9346. C: *Metahoplites nodosus*, specimen n° P11693. D: *Avramidiscus cf. gastaldianus*, specimen n° P6345. E: *Torcapella gr. davydovi*, bed Sa 33. F: *Emericiceras sp.*, bed Sa 33. G: *Balearites sp. gr. mortilleti*, bed Sa 16a.

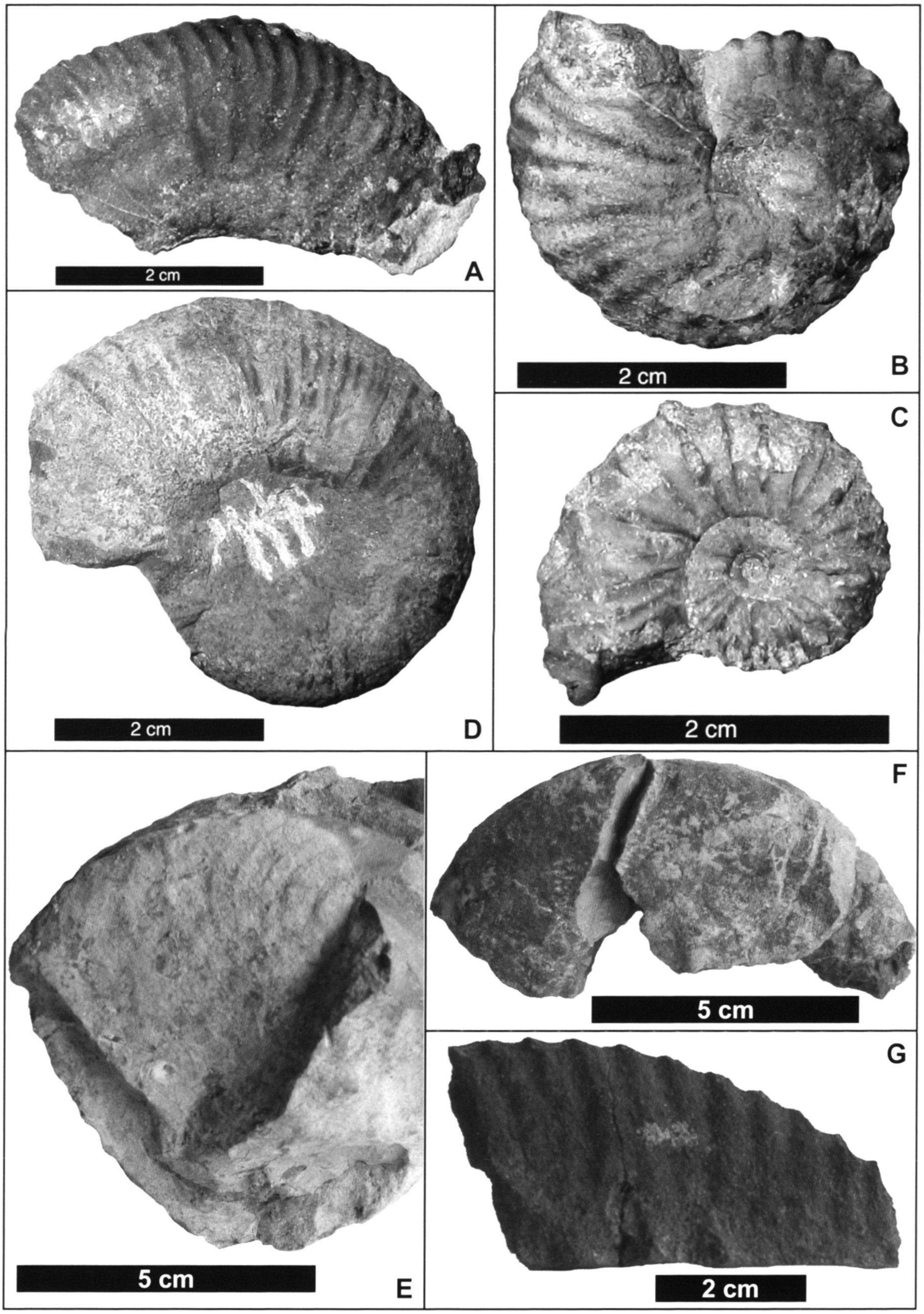

2 cm
A
2 cm
B
C
2 cm
D
2 cm
F
5 cm
G
5 cm
E
2 cm

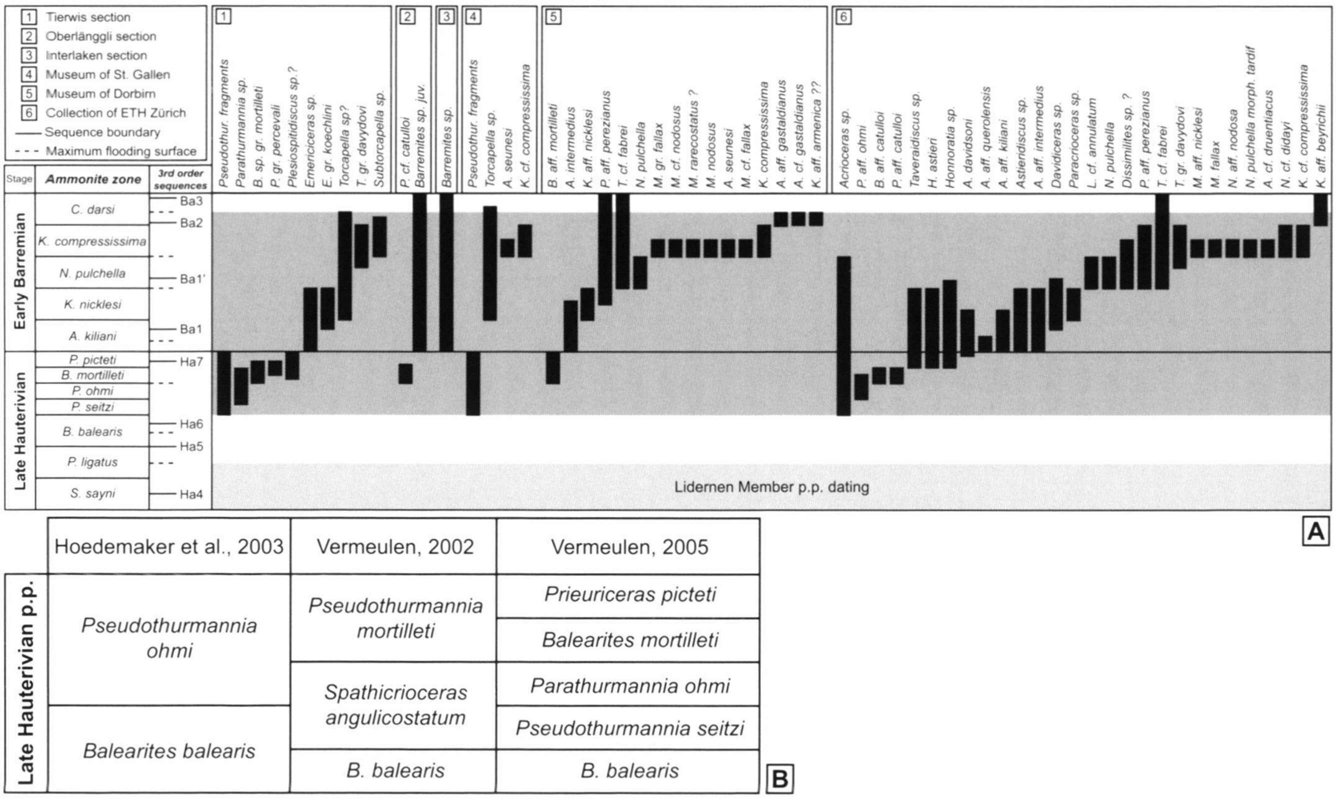
Table 1. List of identified ammonites from the Altmann Mb.

| Location | Sample | Number |
|---|---|---|
| | | |
| **This study** | | |
| Tierwis section | | |
| *Abrytusites sp.* | 1 | Sa 16a |
| *Balearites sp. gr. mortilleti* | 1 | Sa 16a |
| *Emericiceras gr. koechlini* | 1 | Sa 33 |
| *Emericiceras sp.* | 1 | Sa 33 |
| *Paraspiticeras gr. percevali* | 2 | Sa 16a |
| *Parathurmannia sp.* | 1 | Sa 16a |
| *Plesiospitidiscus sp.?* | 1 | Sa 16a |
| *Subtorcapella sp.?* | 2 | Sa 38 |
| *Torcapella gr. davydovi* | 1 | Sa 33 |
| *Torcapella sp.?* | 2 | Sa 36-38 |
| | | |
| Oberlänggli section | | |
| *Barremites sp. juv.* | 1 | Ob 2 |
| *Parathurmannia cf. catulloi* | 1 | Ob 2 |
| | | |
| Interlaken | | |
| *Barremites sp.* | 1 | int 2 |
| | | |
| **Dornbirn museum** | | |
| *Avramidiscus aff. gastaldianus* | 1 | P 11691 |
| *Avramidiscus cf. gastaldianus* | 1 | P 6345 |
| *Avramidiscus intermedius* | 1 | P 9392 |
| *Avramidiscus seunesi* | 2 | P 11675 |
| *Balearites aff. mortilleti* | 1 | P9385 |
| *Kotetishvilia aff. armenica ??* | 1 | P 9345 |
| *Kotetishvilia aff. nicklesi* | 1 | P 9346 |
| *Kotetishvilia compressissima* | 1 | P 9370 |
| *Metahoplites cf. fallax* | 2 | P 11649 |
| *Metahoplites cf. nodosus* | 1 | P 9338 |
| *Metahoplites gr. fallax* | 3 | P 9340 |
| *Metahoplites nodosus* | 1 | P 11693 |
| *Nicklesia pulchella* | 1 | P 11714 |
| *Parasaynoceras aff. perezianus* | 1 | P 6332 |
| *Torcapella cf. fabrei* | 1 | P 1615 |
| *? Metahoplites rarecostatus ?* | 1 | P 11703 |
| | | |
| **St. Gallen museum** | | |
| *Avramidiscus seunesi* | 1 | 52,4 |
| *Kotetishvilia cf. compressissima* | 1 | 52,2 |
| *Pseudothurmanniform fragments* | 1 | 51,2 |
| *Torcapella sp.?* | 1 | 55,2 |

| Location | Sample | Number |
|---|---|---|
| | | |
| **ETH Zürich** | | |
| *Acrioceras sp.* | 4 | F 7102 |
| *Anahamulina davidsoni* | 1 | W 2273 |
| *Astieridiscus sp.* | 1 | R1 |
| *Avramidiscus aff. intermedius* | 1 | F 71007 |
| *Avramidiscus aff. kiliani* | 2 | W 4876 |
| *Avramidiscus aff. querolensis* | 1 | F 71006 |
| *Avramidiscus cf. druentiacus* | 1 | W 4741 |
| *Avramidiscus gr. intermedius* | 2 | F 7102.4 |
| *Avramidiscus sp.* | 2 | F 71042 |
| *Balearites aff. catulloi* | 1 | F 71055 |
| *Balearites sp. ?* | 1 | F 71010 |
| *Costidiscus sp.* | 1 | W 4518 |
| *Davidiceras sp.* | 1 | W 5123 |
| *Dissimilites sp. ?* | 1 | W 4955 |
| *Hamulina astieri* | 1 | J 1078 |
| *Honnoratia sp.* | 4 | F 71008 |
| *Karsteniceras aff. beyrichii* | 1 | J 1043 |
| *Kotetishvilia cf. compressissima* | 2 | J 1102 |
| *Leptoceratoides cf. annulatum* | 1 | C 1042 |
| *Leptoceratoides sp.* | 1 | W 5969 |
| *Metahoplites aff. fallax* | 1 | J 1044 |
| *Metahoplites aff. nicklesi* | 2 | W 4561 |
| *Metahoplites cf. fallax* | 1 | J 1101 |
| *Metahoplites fallax* | 2 | W 4916.1 |
| *Metahoplites gr. fallax* | 1 | W 4860.1 |
| *Nickesia aff. nodosa* | 1 | W 5263 |
| *Nicklesia cf. didayi* | 1 | J 1039.3 |
| *Nicklesia pulchella* | 2 | J 1039.4 |
| *Nicklesia pulchella morphotype ta* | 2 | J 1039.1 |
| *Paracrioceras sp.* | 3 | J 1068 |
| *Parasaynoceras aff. perezianus* | 1 | F 71005 |
| *Parasaynoceras sp.* | 2 | W 4919 |
| *Pseudothurmannia aff. catulloi* | 2 | F 71011 |
| *Pseudothurmannia aff. ohmi* | 1 | W3 5135 |
| *Pseudothurmannia sp. s.l.* | 1 | W 5028 |
| *Silesites gr. vulpes* | 1 | W 4232 |
| *Taveraidiscus sp.* | 4 | F 71035 |
| *Teschenites sp. ?* | 1 | J 1011 |
| *Torcapella cf. fabrei* | 1 | W 4971 |
| *Torcapella gr. davydovi* | 7 | W 4221 |
| *Torcapella gr. fabrei* | 1 | F 71019 |

Kieselkalk Mbs (Funk 1969). The Kieselkalk Fm overlays the Gemsmättli Mb (early Late Valanginian to earliest Hauterivian; Kuhn 1996). The latest Hauterivian to early Late Barremian correspond to the Drusberg formation, which is divided into a lower part (the Altmann Mb) and an upper part (the Drusberg Mb) (cf. Bollinger 1988; Funk et al. 1993). During the Late Barremian – Early Aptian, the Helvetic platform is represented by the Schrattenkalk Fm, which is the equivalent of the Urgonian limestone facies described in many other locations in the world (*e.g.,* Arnaud et al. 1998; Lehmann et al. 1999). Gemsmättli, Lidernen and Altmann Mbs represent three successive phases of incipient Helvetic platform drowning (D1, D2 and D3 respectively, in Föllmi et al. 1994; see also Kuhn 1996 and van de Schootbrugge 2001).

The Helvetic carbonate platform morphology can be defined as a ramp (*sensu* Burchette & Wright 1992). During the Berriasian, the situation was close to a distally steepened carbonate ramp (Kuhn 1996). Rapid subsidence together with a second order sea-level rise during the Early Valanginian resulted in homoclinal ramp morphology (Kuhn 1996) until the Late Barremian and the installation of the Urgonian facies, which signaled the return to a distally steepened carbonate ramp morphology. These changes in platform morphology were accompanied by changes of the sediment-producing benthic community, from a photozoan mode (*sensu* James 1997; oligotrophic conditions) during the late Tithonian to Berriasian to a heterozoan mode (*sensu* James 1997; meso-eutrophic conditions) from the Early Valanginian to the Early Barremian. During the Late Barremian, the installation of the Urgonian platform (Schrattenkalk Fm) underlines the return of photozoans (Föllmi et al. 1994). During the Early Cretaceous, reef-related organisms such as corals, stromatoporoids and rudists characterize photozoan assemblages whereas crinoids, bryozoans, abundant sponges and the absence of reef-related organisms mark heterozoan assemblages. The condensed sediments associated with drowning deposits are characterized by the dominance of siliciclastic particles, glaucony and phosphates (*e.g.,* Föllmi et al. 1994; van de Schootbrugge 2001).



| | Hoedemaker et al., 2003 | Vermeulen, 2002 | Vermeulen, 2005 |
|---|---|---|---|
| Late Hauterivian p.p. | *Pseudothurmannia ohmi* | *Pseudothurmannia mortilleti* | *Prieuriceras picteti* |
| | | | *Balearites mortilleti* |
| | | *Spathicrioceras angulicostatum* | *Parathurmannia ohmi* |
| | *Balearites balearis* | | *Pseudothurmannia seitzi* |
| | | *B. balearis* | *B. balearis* |

Fig. 4. A. Stratigraphic range of the most significant ammonites identified in the Altmann Mb sections. Ammonite biostratigraphy zonation *sensu* Vermeulen (2005). Stratigraphic sequences after Hardenbol et al. (1998), modified by Arnaud (2005) for the latest Hauterivian – Barremian. Dating of the Lidernen Mb after van de Schootbrugge (2001). B. Correlation of the ammonite zonation of Vermeulen (2002, 2005) for the late Hauterivian with the current standard zonation (*e.g.*, Hoedemaeker et al. 2003).

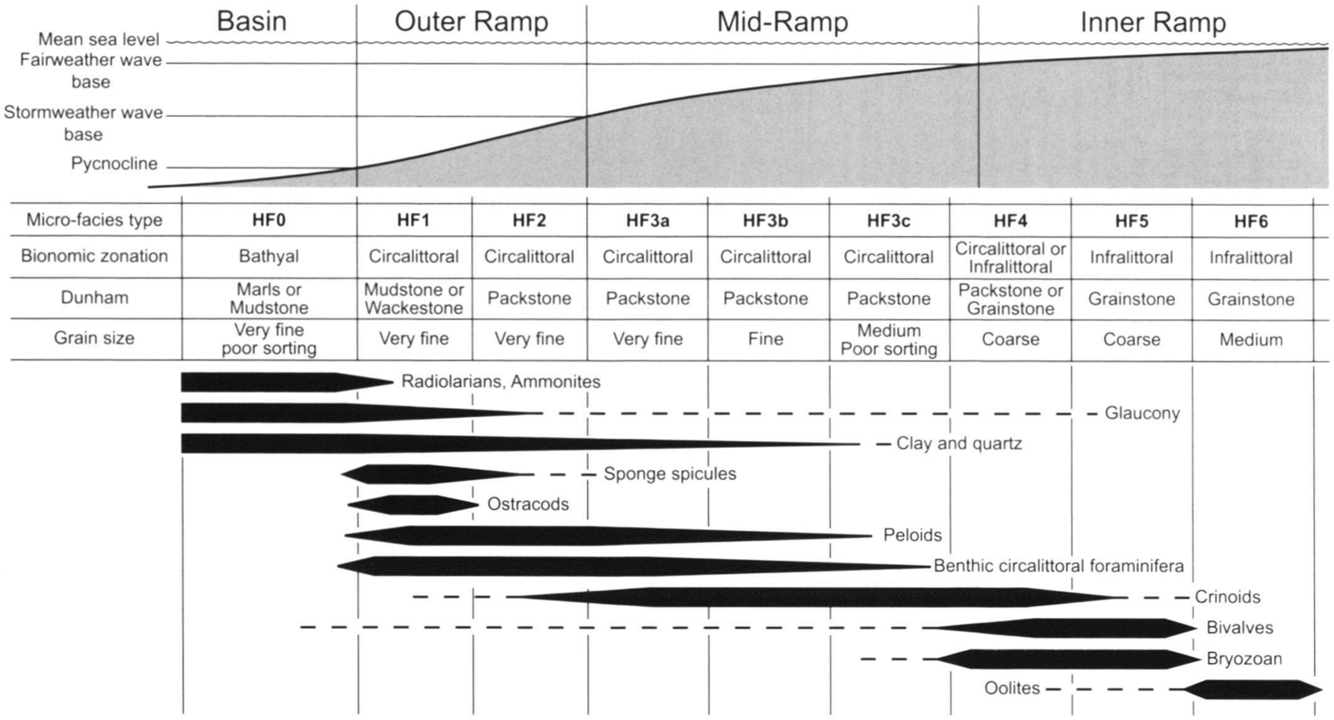
## 3. Materials and methods

Eleven sections are documented (Schwalmis, Nägeliberg, Seerenwald, Morgenberghorn, Pilatus, Rawil, Interlaken, Oberlänggli, Interrugg, Brisi and Tierwis section). The majority of the studied sections is situated in the eastern part of Switzerland (Fig. 1), in the Säntis – Churfirsten – Alvier massif, where the good quality and continuity of the outcrops allow to trace a proximal to distal transect along the northern Tethyan margin. These sections were sampled bed by bed, in order to identify high-frequency microfacies variations along the sedimentary succession. Coupled with stacking-pattern observations, these observations allow sequence-stratigraphic interpretations of the studied section.

To provide a high-resolution biostratigraphy for the Altmann Mb, a large number of ammonites were investigated, including newly collected ammonites as well as previous findings (*e.g.*, Fichter 1934; Briegel 1972; Rick 1985; Wyssling 1986; and others) that are stored in the Museums of Natural History of St. Gallen (Switzerland) and Dornbirn (Austria), and at the ETH Zürich. A total of 211 ammonites were identified. 108 of them provide accurate ages and are listed in Table 1 (see also Fig. 3). The stratigraphic position of the newly collected ammonites was precisely documented within each section in order to allow precise correlations. Combined with sequential stratigraphic interpretations, this allows to establish a markedly improved ammonite biostratigraphy of the Altmann Mb.

## 4. Biostratigraphy

The outcome of the here established improved ammonite biostratigraphy (Fig. 4) suggests that the time documented in the Altmann Mb spans from the latest Hauterivian (*P. seitzi* biozone) to the latest Early Barremian (*C. darsi* biozone). This new age determination is different from the previous ones by which a middle Early Barremian age for the end of the Altmann Mb was assumed (*e.g.*, Funk et al. 1993; Föllmi et al. 1994). Moreover, the distribution of these ammonites in time and space suggests that the biostratigraphic ages for the lower and upper limits of the Altmann Mb are synchronous (*i.e.* within the same ammonite zone) for the entire studied area. Following cyclo-stratigraphic interpretations of late Hauterivian – Barremian successions from the Vocontian trough



| Micro-facies type | HF0 | HF1 | HF2 | HF3a | HF3b | HF3c | HF4 | HF5 | HF6 |
|---|---|---|---|---|---|---|---|---|---|
| Bionomic zonation | Bathyal | Circalittoral | Circalittoral | Circalittoral | Circalittoral | Circalittoral | Circalittoral or Infralittoral | Infralittoral | Infralittoral |
| Dunham | Marls or Mudstone | Mudstone or Wackestone | Packstone | Packstone | Packstone | Packstone | Packstone or Grainstone | Grainstone | Grainstone |
| Grain size | Very fine poor sorting | Very fine | Very fine | Very fine | Fine | Medium Poor sorting | Coarse | Coarse | Medium |

Fig. 5. Distribution of the principal facies types in a schematic transect through the Helvetic ramp during the Hauterivian – Early Barremian. Bionomic zonation after the classification of Pérès (1961).

(Bodin et al. 2006), a duration of approximately 3 Myr is estimated for the time preserved in the Altmann Mb. The reduced thickness of the majority of the sections of the Altmann Mb (see below) implies that these sections are highly condensed, and the average sedimentation rate is approximately 1 m/Myr. In comparison, for the Upper Kieselkalk Mb at the Pilatus locality, an average sedimentation rate of 50 m/Myr is estimated (*e.g.,* Funk 1969; Van de Schootbrugge 2001). This difference is related to the phase of carbonate platform drowning documented by the Altmann Mb and the associated slowdown or stop of the benthic carbonate production.

## 5. Microfacies

Ten different microfacies types have been recognized in the Upper Hauterivian – Lower Barremian deposits of the Helvetic realm (Upper Kieselkalk, Altmann and Drusberg Mbs). The microfacies HF0 to HF6 are adapted from previous studies focusing on Lower Cretaceous Western Tethyan carbonate platforms (*e.g.,* Arnaud-Vanneau 1980; Schenk 1992; Wissler et al. 2003) because of the meso-eutrophic conditions prevailing on the Helvetic platform during the Hauterivian to Early Barremian. These microfacies are placed on a palinspastic transect through the northern Tethyan Helvetic homoclinal ramp (Figs. 5-6) using the carbonate ramp depositional system description from Burchette & Wright (1992). The micro-facies HFa, HFb and HFc are specific for the glauconitic- and phosphatic-rich horizons and the gravity-flow deposits within the Altmann Mb, hence a precise localization is not feasible.

### *5.1. HF0 (marls; marls - micrite)*

The rocks corresponding to this facies are finely laminated and composed of radiolaria, calcispheres, rare sponge spicules and rare beds with sparse bivalve fragments, as well as of large amounts of very small and unidentifiable bioclasts. If the conditions of preservation are good, this facies contains a macrofauna including ammonites, belemnites or fish teeth.

*Interpretation:* According to the presence of pelagic fauna, this facies is thought to represent a distal shelf deposit (hemipelagic facies).

### *5.2. HF1 (mudstone or wackestone; spicule-rich biomicrite)*

The rocks corresponding to this facies are limestones and marly limestones. It is composed of numerous sponge spicules, in addition to some very small echinoderm fragments, peloids, benthic foraminifera and rare ostracods. Sporadic fish teeth are present.

*Interpretation:* This facies may represent the outer ramp deposits below the storm-weather wave base (hemi-pelagic facies), as testified by the presence of numerous sponge spicules.

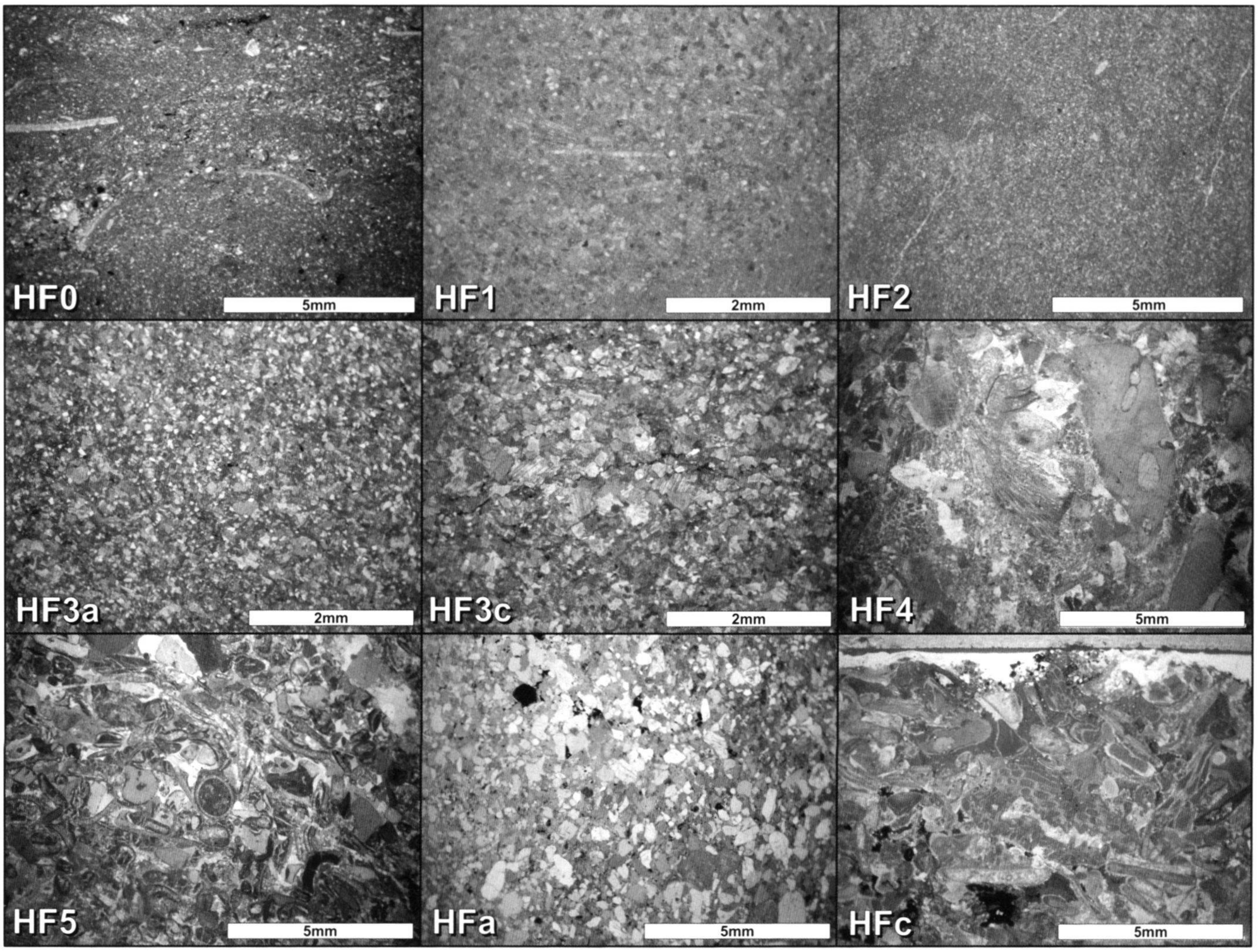


Fig. 6. Photomicrographs of micro-facies HF0-5 and HFa-c. See the text for details. **HF0**: Sample Sa38. **HF1**: Sample Sa40. **HF2**: Sample Sa23. **HF3a**: Sample Sa30a. **HF3c**: Sample Sa7. **HF4**: Sample Pil145. **HF5**: Sample Pil143. **HFa**: Sample Schwa1. **HFc**: Sample Pi1 (note the marine phreatic cement and the phosphatized matrix occurring in the top of this thin-section. Note that this is also the top of the basal hardground in this photomicrograph). Samples Pil145 and Pil143 are taken from the top of the Upper Kieselkalk Mb in the Pilatus section (after van de Schootbrugge, 2001).

### *5.3. HF2 (packstone; biopelmicrite)*

The rocks corresponding to this facies are limestones and marly limestones. It is composed of large quantities of very small echinoderm fragments, rare sponge spicules, bivalve fragments, peloids, benthic foraminifera and quartz grains.

*Interpretation:* This facies may represent the upper part of the outer ramp deposits, affected by very rare storm events, as testified by the presence of very small fragments, which were likely derived from shallower regions.

### *5.4. HF3 (packstone; crinoid-rich biopelmicrite)*

The lithology of this facies is typical for the Helvetic Kieselkalk Fm, *i.e.* crinoidal limestone or marly limestone (some chert nodules may also occur). It is mainly composed of angular crinoid fragments, small quartz grains, sparse bivalve fragments, benthic foraminifera and peloids. It is divided into three sub-facies: HF3a, 3b and 3c, taking into account the mean size of the crinoid grains, from very fine to medium grained.

*Interpretation:* The sorting of the mean size of crinoid grains may reflect redistribution of these grains during storm events. The absence of sparitic cement may, however, reflect the lack of permanent hydrodynamic currents. This facies may thus represent a middle ramp deposit, above the storm wave base and below the fair-weather wave base.

### 5.5. *HF4 (packstone or grainstone; crinoïdal and bryozoan biomicrite or biosparite)*

This facies is typical for the "Kieselkalk – Echinodermenbreccie" Mb (Funk 1969) and is expressed in relatively thick (up to 2-meters-thick) limestone beds, which are sometime cross-stratified. This facies is coarsely grained, poorly sorted, and composed of angular echinodermal and bivalve fragments, bryozoans, gastropods, peloids and rare ooids. Sparitic cements are observed.

*Interpretation:* The presence of sparitic cement in this facies hints to a deposition under quasi-permanent hydrodynamic currents. This facies is thus attributed to the transition between the upper middle and the lower inner ramp.

### 5.6. *HF5 (grainstone; coarse biosparite with rounded grains)*

This facies presents the same allochem assemblage as the previous one, with the main difference being that all the grains are well rounded. Some grains present traces of incipient ooid formation (superficial ooid).

*Interpretation:* According to the presence of rounded grains and sparitic cement, which suggests deposition under permanent agitation, this facies may have been deposited on the inner ramp, under permanent hydrodynamic currents, above the fair-weather wave base.

### 5.7. *HF6 (grainstone; oosparite or oobiosparite)*

This facies was never observed in the Hauterivian – Early Barremian of the Helvetic realm. Only indirect clues for oolithic bars are present (*i.e.* oolithes dispersed in MF4 and MF5 facies). During the Hauterivian, the presence of oolithic bars is, however, observed in the deposits of the Jura Mountains (Pierre Jaune de Neuchâtel Fm; *e.g.*, Blanc-Aletru 1995; see Fig. 1 for localization), which represent the upper part of the Helvetic ramp.

*Interpretation:* According to the presence of oolithes and sparitic cement, this facies may be representative of the inner ramp.

### 5.8. *HFa (glauconitic-rich sandstone)*

The lithology of this facies is characteristic for the highly reduced sections of the Altmann Mb (less than 2m thick). It is composed of coarse rounded quartz grains, mature glaucony grains, some phosphate and calcite grains, as well as authigenic pyrite grains. The matrix corresponds to micritic or phosphatized ooze. In the field, oblique stratifications are sometimes recognized.

*Interpretation:* The presence of numerous mature glauconitic grains, as well as phosphate and pyrite, may point to a highly condensed or an allochthonous deposit derived from a condensed deposit.

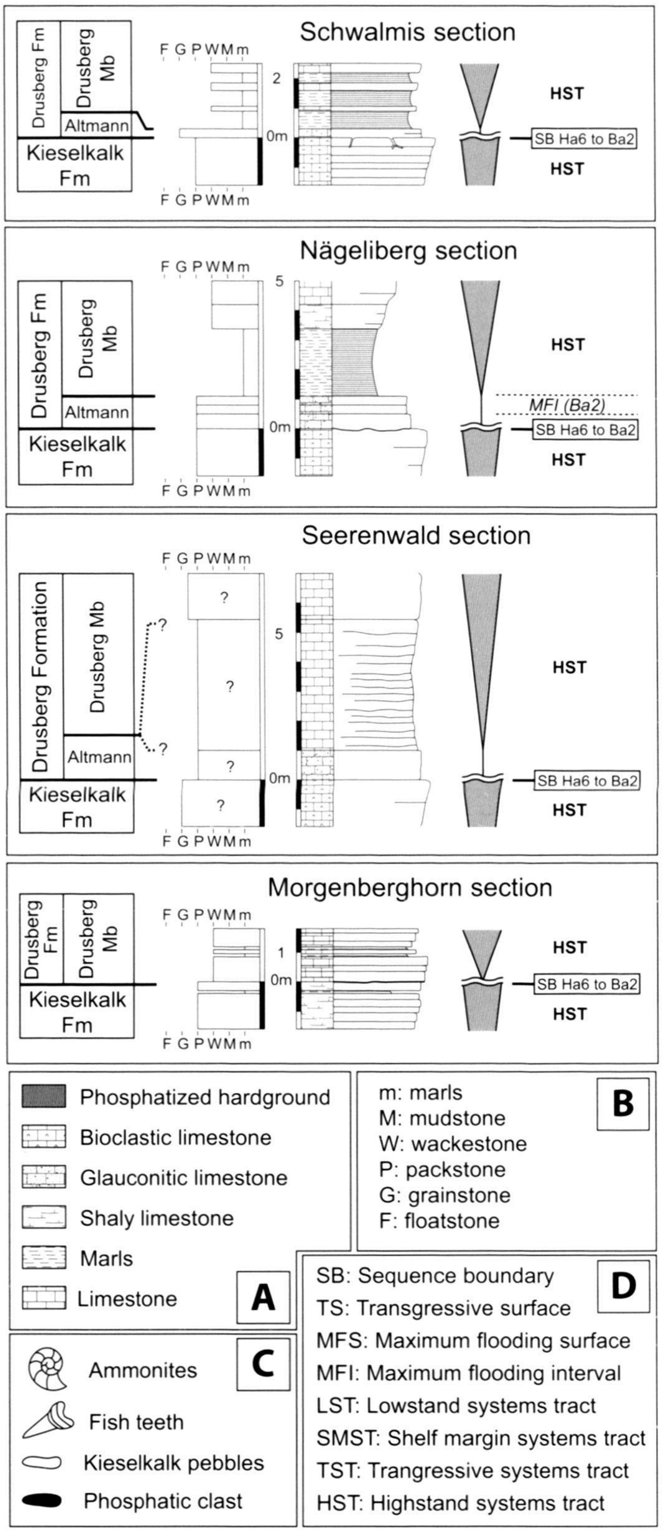


Fig. 7. Highly reduced sections or hiatus. The Seerenwald section is drawn after the description of Heim (1910–1916). A: lithology; B: Dunham classification; C: Key to fossils or nodules. D: sequence-stratigraphic terminology.

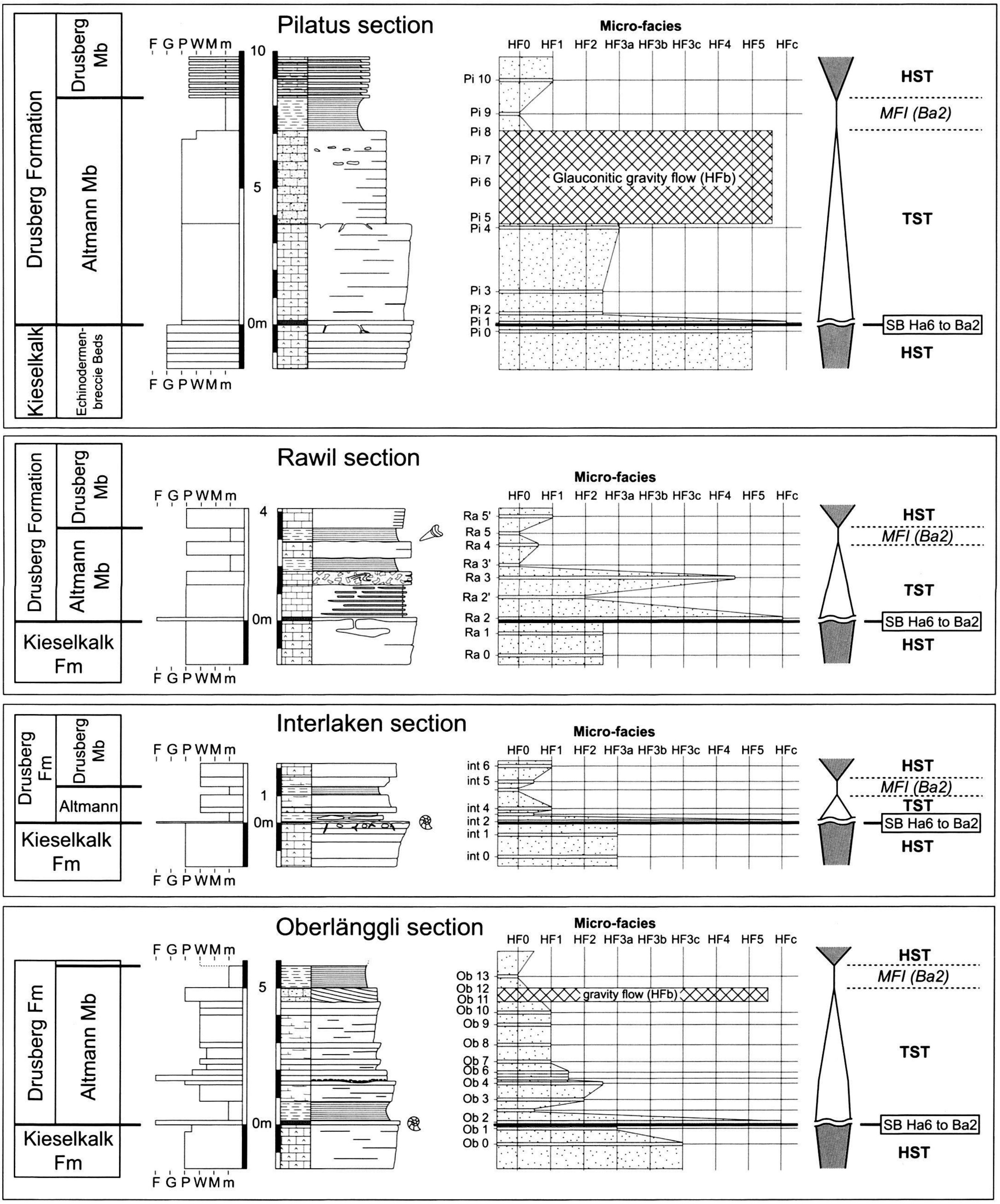


Fig. 8: Sections with a phosphatized hardground at the base. See Fig. 7 for key to abbreviations and symbols.

### *5.9. HFb (wackestone or packstone; biomicrite)*

The lithology of this facies is recognized in deposits occurring within Altmann Mb sections with phosphatized hardground at their base or with phosphatic nodules. It has the same characteristic as the micro-facies HFa. Quartz grains are, however, rare and smaller and glaucony grains (if present) are well rounded. The sorting is relatively good and many coarse crinoid grains are present. In addition, bryozoans, brachiopods and bivalve fragments, as well as small benthic foraminifera and phosphate grains are observed. The matrix is often phosphatized.

*Interpretation:* Well-rounded glaucony grains may indicate their parautochtonous origin (*e.g.*, Pasquini et al. 2004). Due to the presence of oblique stratification, as well as an erosive base below the bed presenting this microfacies, theses rocks are interpreted as gravity flow deposits.

### *5.10. HFc (phosphatized hardground)*

The macroscopic aspect of this facies differs between different sections. Similarities include the presence of macrofauna (ammonites, belemnites, bivalves, brachiopods, sponges...), as well as the presence of burrows, encrusting organisms and sometimes burrow infills below the hardground. The matrix is always composed of completely or partially phosphatized ooze. Phosphate grains, glaucony and lithoclasts are frequent, as well as grains or rock fragments reworking.

*Interpretation:* Hardground surfaces are subaquatic features. The formation of such discontinuity surfaces can be related to the lowering of the effective wave base exposing the sea floor to wave action (e.g., Immenhauser et al. 2000).

## 6. Macroscopic sedimentological aspects

The Altmann Mb is easily distinguished in the field due to its high content of glauconitic grains and the presence of phosphatic particles and crusts (Funk 1969). The distinct lithological differences between the dark colored, sandy crinoidal limestones of the subjacent Kieselkalk Fm and the grey colored hemipelagic marl – limestone alternations of the superjacent Drusberg Mb are characteristic properties that assist in the identification of the Altmann Mb. The sections of the Altmann Mb studied here are subdivided into four main types according to their thickness and lithologic pattern.

### *6.1. Highly reduced sections or hiatus*

Reduced sections and hiatus represent the majority of the Altmann Mb sections. This highly reduced type of section is characterized by the following field aspects: a total thickness < 2 meters, occasionally with an erosive base (*e.g.*, the Schwalmis and the Nägeliberg sections; Fig. 7). In some beds, oblique stratifications are observed, depending on the exposure conditions. Glaucony-rich sandstone and rare phosphatized grains characterize the facies of these beds. No datable ammonites have been found in these sections, even if some of the dispersed phosphate grains, due to their bean-shaped aspect, could be attributed to altered and phosphatized ammonite clasts. The Seerenwald section (Fig. 7) is no more accessible today, and was drawn after the precise descriptions of Heim (1910-1916). In most outcrops situated in proximal settings, the Altmann Mb is not present between the Kieselkalk Fm and the Drusberg Mb, and only an erosive surface is observed (*e.g.*, at the Morgenberghorn section; Fig. 7).

### *6.2. Sections with a phosphatized hardground at their base*

This type of section of the Altmann Mb is characterized by a thickness varying between 1 and 8 meters and by the same stacking pattern, even if some local differences exist. At the base, a phosphatized hardground rich in macrofossils is present (*e.g.*, Pilatus, Rawil, Interlaken and Oberlänggli sections; Fig. 8). The thickness of the phosphatized crust associated to the hardground varies from 2 to 15 cm. Below the hardground, burrows are observed in all sections except the one measured at the Oberlänggli locality. Above this basal horizon, a succession of alternating limestone and marls follows. In the studied sections, the Altmann Mb always ends in a marly interval, which is locally rich in fish teeth and glaucony. In the Pilatus and Oberlänggli sections, a glauconitic-rich bed occurs just below the uppermost marl interval.

### *6.3. Sections with phosphatic nodules*

Sections with phosphatic nodules are found in the Interrugg and the Brisi localities (Fig. 9). This type of section is characterized by the following field aspects: an erosive base, the presence of phosphate nodules and an obliquely stratified glaucony-rich bed (up to 60 cm thick at the Brisi locality) occurring just below an uppermost marly interval. In the Interrugg section, the poor outcrop conditions do not allow to log a complete section.

### *6.4. Expanded sections*

Expanded Altmann Mb sections are found in the Tierwis (Fig. 10), Altmann-Sattel and Fluebrig localities (*e.g.*, Funk 1969; Rick 1985). The Altmann-Sattel section is the Altmann Mb type section whereas the Tierwis section is the paratype section of the Altmann Mb (Funk 1969). At Tierwis, the Altmann Mb is approximately 35 m thick and consists of crinoidal limestones intercalated with two marly intervals; a thin and darkly colored one near the base (ca. 6 m above the Kieselkalk – Altmann boundary) and a thick second one, with intercalated layers rich in fish teeth at the top of the Altmann Mb.

The lowermost four meters of the Altmann Mb section present all the characteristics of the "Kieselkalk – Echinodermenbreccie" facies and were first attributed to the Kieselkalk Fm according to Funk (1969). The discovery of an erosive surface below these beds and the presence of a relatively high

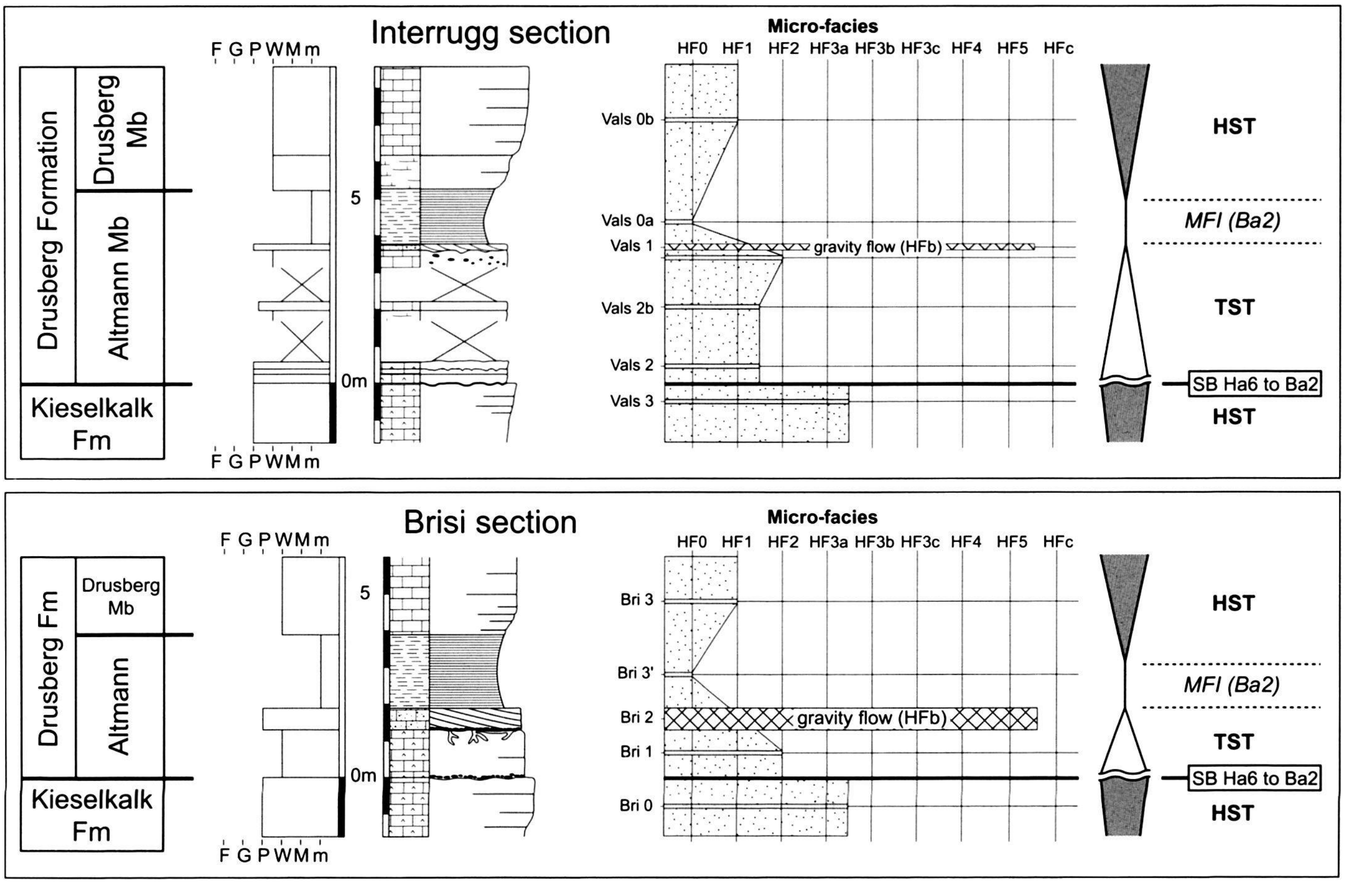


Fig. 9. Sections with phosphatic nodules. See Fig. 7 for key to abbreviations and symbols.

amount of glaucony within the limestone (contrary to the Pilatus section, which is the type section for the Kieselkalk Fm) suggest that these beds belong to the Altmann Mb. At their top, a horizon with ferric concretions and glauconitic crusts is observed (Funk 1969).

The middle part of the section is constituted by a thick crinoidal thickening-upward limestone succession (ca. 25 m) capped by *Thalassinoides*, *Ophiomorpha* and *Skolithos* burrows belonging to the *Cruziana – Glossifungites* ichnofacies (*e.g.,* Pemberton 1998; Malpas et al. 2005). A 3-meters-thick glauconitic-rich zone follows, presenting *Cruziana – Glossifungites* ichnofacies in the first meter. This zone precedes ca. 3 m of marly crinoidal limestone capped by a hardground surface. The latter is rich in macrofossils such as ammonites, oysters, sponges, belemnites and incrusting organisms, and presents many reworked rock fragments (with phosphatized outlines), burrows and traces of silicification (see Fig. 11).

The Drusberg Mb is separated from the Altmann Mb by a 1-meters-thick marly interval. The lower part of the Drusberg Mb is characterized by a thickening-upward limestone – marl alternation whereas a thinning-upward marl-dominated deposit characterizes the upper part of the Drusberg Mb.

### *6.5. Ammonite biostratigraphy in the Altmann Member*

Newly collected ammonites come from the basal hardground of the Interlaken and Oberlänggli sections (Fig. 8), and in different levels of the Tierwis section (Fig 10). The ammonites from the two first sections are phosphatized and belong to the *B. mortilleti* biozone and to the Early Barremian (Fig. 4), indicating significant periods involved in the condensation or reworking associated with the basal hardground. In the Tierwis section, the bed Sa 16b (Fig. 10), which is particularly rich in ammonites, is dated as belonging to the *B. mortilleti* biozone by *Parathurmannia sp., Balearites sp. gr. mortilleti, Paraspiticeras gr. percevali* and *Plesiospitidiscus sp.* The hardground (bed Sa 33) yields ammonites from the *A. kiliani* to the *K. compressissima* biozones (Table 1) indicating again an extended period of condensation or reworking associated to this hardground. In the upper part of the section, ammonites were found in the beds Sa 36 to Sa 38. They belong to the *K. compressissima* to *C. darsi* biozones (Table 1).

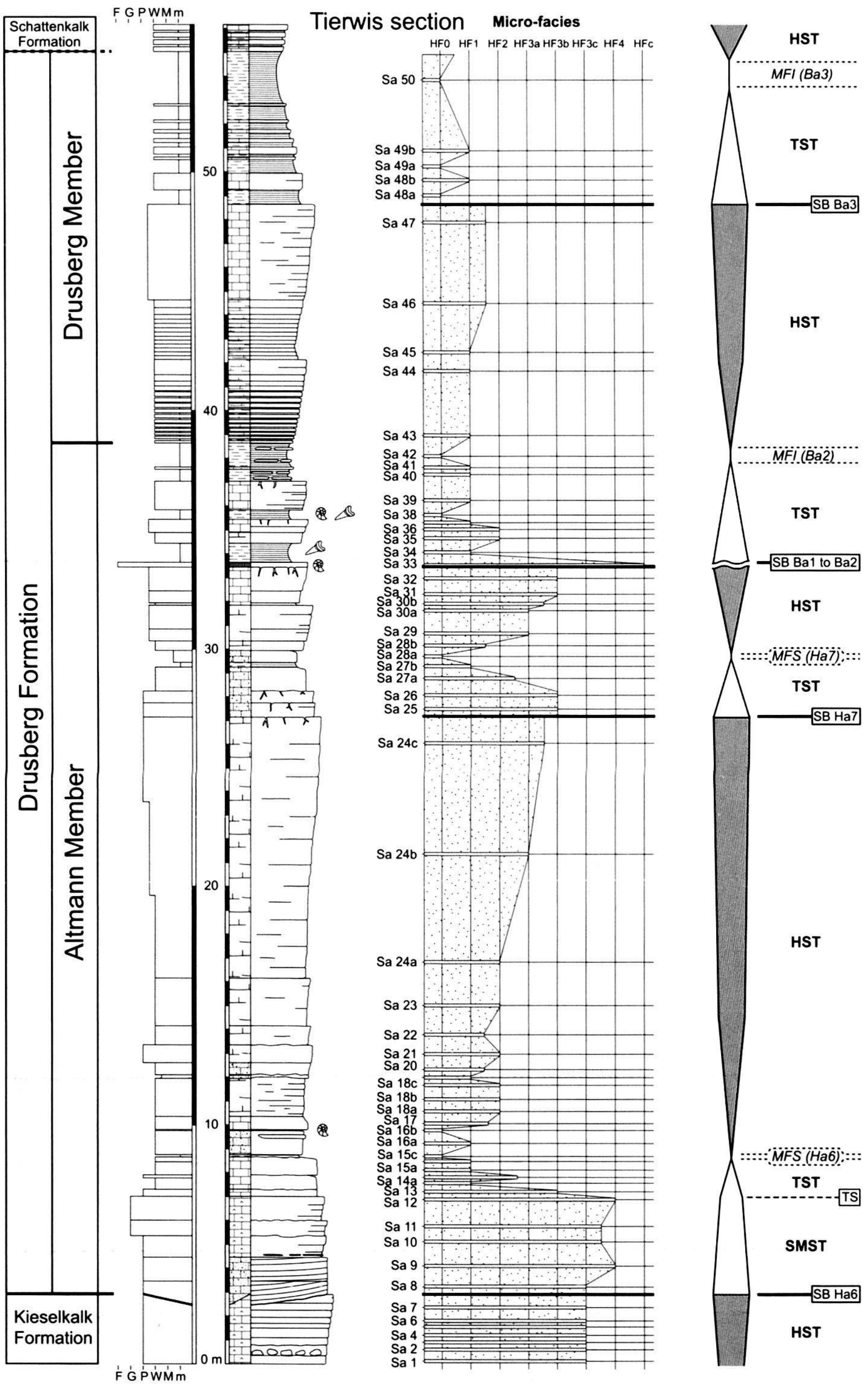


Fig. 10. Tierwis section. See Fig. 7 for key to abbreviations and symbols.

## 7. Sequence-stratigraphic interpretation

The analysis of the micro-facies temporal evolution and the stacking pattern leads to a sequence stratigraphic interpretation of the studied sections (Figs. 7–10).

In highly reduced Altmann Mb sections, sequential interpretation of the thin glaucony-rich beds is rather difficult. However, the condensed pattern of these section, as well as the high amount of glaucony, point to a deposit associated with a maximum flooding surface (MFS). In addition, the shallowing-upward stacking of the overlying Drusberg Beds (which are attributed to highstand deposits) supports this interpretation. Due to its shallowing- and thickening-upward pattern, the underlying Upper Kieselkalk Mb is attributed to a highstand deposit. No transgressive systems tract (TST) could be identified in these sections.

In sections with a phosphatized hardground or with phosphatic nodules at their base, an identified trend toward deeper facies as well as a thinning-upward stacking pattern is observed. These beds represent thus a TST. This latter overlies the Upper Kieselkalk Mb, attributed to a highstand systems tract (HST) deposit, without a recognizable sea-level fall or lowstand deposits in between. Following Schlager (1999), this SB can thus be qualified as a type 3 sequence boundary. Due to the presence of Late Hauterivian and Early Barremian ammonites in the phosphate crust of the basal hardground, this latter may be interpreted as the result of a long-period of condensation. In the Oberlänggli section, which is the most distal section studied, as indicated by microfacies variations, the first 1.5 meters consist of shallowing-upward sediments and are overlain by a phosphatic lag. These beds are interpreted as representing a first shallowing-upward parasequence associated to the TST.

In the Altmann Mb of the Tierwis section, the preserved succession is more complete, with three main sequences recorded. The Altmann Mb begins with four meters of aggrading "Echinodermenbreccie – like" limestone overlying an erosive surface. This erosive surface, which lacks any indication of emersion, may be the expression of a type 2 SB. The following deposits are thus attributed to shelf margin systems tract (SMST) deposits. This succession is capped by a thin interval of glaucony-rich marly limestone. The strong shift toward deeper facies, as well as the high content of glaucony of these deposits, is characteristic of the TST (*e.g.,* Chamley 1989; Amorosi & Centineo 1997). Between these two systems tracts, the horizon with ferric concretions and glauconitic crusts may thus be attributed to the TS. The MFS is represented by a thin dark-colored marl interval. The following HST is represented by thick shallowing- and thickening-upward marl-limestone succession.

This first main sequence is followed by a thinner second sequence. Here, no lowstand deposits are identified. The TST is thin (ca. 3m), and is marked by an enrichment in glaucony content and a shift to deeper facies. The SB is expressed as a firmground, rich in *Cruziana – Glossifungites* burrows, which may underline pauses in sedimentation (*e.g.,* Pemberton 1998) and may be transgressively modified during subsequent relative sea-level rise (*e.g.,* MacEachern et al. 1999). The HST is ca. 3.5 meters thick, and presents one shallowing-upward sequence.

The following phosphatized hardground (bed Sa 33, Fig. 10) represents a SB, above which a ca. 4 m thick TST occurs. The Altmann Mb ends within a marly interval, corresponding to a MFS. The overlying lower part of the Drusberg Mb shows two shallowing-upward deposits, attributed to the following HST.

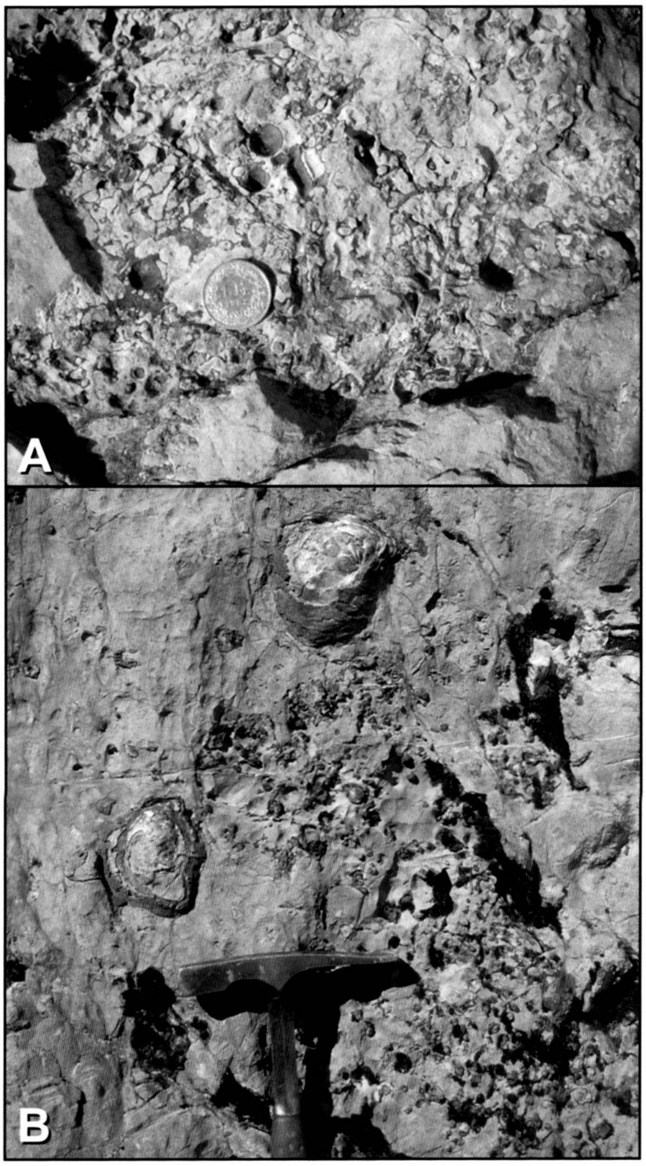


Fig. 11. Details of features at the top of the phosphatized hardground (bed Sa33, Tierwis section). A: Phosphatized burrows; B: Oysters, burrows and phosphatized nodules.

These interpretations, coupled with sequential stratigraphic interpretations of chronostratigraphically calibrated, fossiliferous basinal sections (Haq et al. 1987; Hardenbol et al. 1998; modified by Arnaud (2005) for the late Hauterivian – Barremian of the Angles section, Vocontian trough, France; Fig. 4), allow to date the identified sequences. Thus, in the Tierwis section, the Altmann Mb begins with the Ha6 sequence. The dark-colored marly interval of the MFS is thus contemporaneous with the Faraoni level documented so far only from basin sections (Cecca et al. 1994; Baudin et al. 1999). By extrapolation, the second sequence may correspond to the Ha7 sequence,

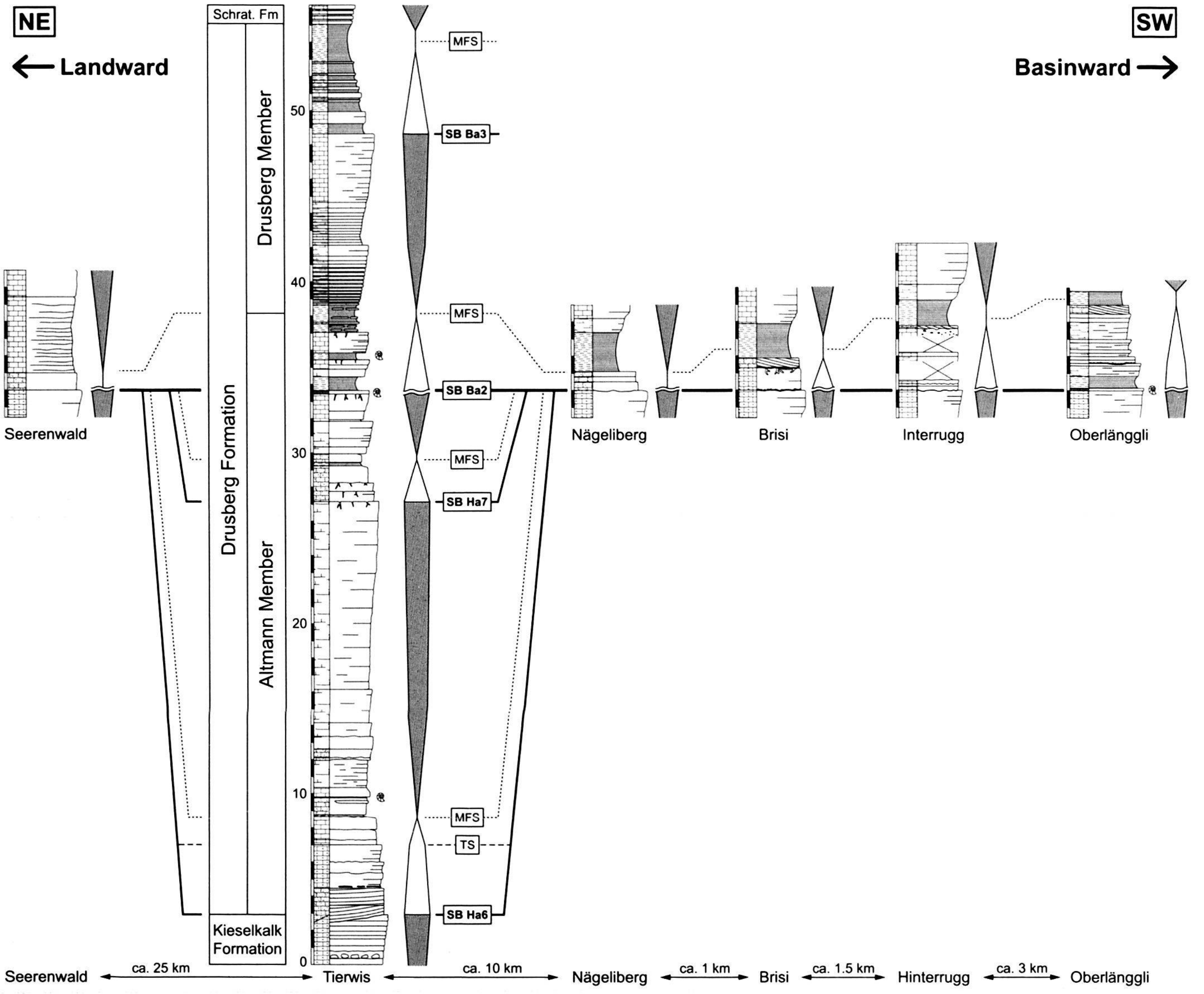


Fig. 12. Palinspastic transect along the Säntis-Churfirsten-Alvier massif with a proposed sequential correlation of sections. Note the decrease in the thickness of the Altmann Mb from basinward to landward positions (except for the Tierwis section; see text for discussion).

even if ammonite biostratigraphic dating within these beds is lacking to confirm this hypothesis. According to the presence of *Emericiceras gr. Koechlini* and *Torcapella gr. Davydovi* in the phosphatized hardground (bed Sa 33), this latter represents a time interval associated to the Ba1 and Ba1' sequences. The presence of *Subtorcapella sp.* (bed Sa 38) in the third sequence indicates that this TST deposit is dated from the *K. compressissima – C. darsi* biozone interval. In basinal sections from the Vocontian Trough, only one TST is noted during this time interval: the Ba2 TST, dated from the base of the *C. darsi* biozone. The *Torcapella sp.* found in the bed Sa 36–38, which belongs to the *K. compressissima* biozone, may thus be reworked from the underlying hardground. As a result, this confirms that Ba1 and Ba1' sequences are condensed and/or lacking in the phosphatized hardground of this section.

In sections with a phosphatized hardground or with phosphatic nodules at their base (Figs. 8–9), the temporal resolution is less good due to the absence of numerous fossil findings. However, the presence of *Barremites sp.* in the phosphatized hardground argues in favor of a Barremian age for the overlaying TST deposit. Owing to the general trends in ammonite biostratigraphy in the Altmann Mb, as well as the fact that this TST is overlain by the Drusberg Mb without any evidence of a major hiatus, this TST may thus correspond to the Ba2 TST. Consequently, the sequences Ha6 to Ba1 are lacking in these sections and/or condensed within the basal phosphatized hardground. A notable point is the fact that the Ba2 sequence lacks evidence for a LST deposit in all studied sections, as well as in the basinal section of Angles (*e.g.,* Arnaud, 2005; Bodin et al. 2006). This is compatible with the here-proposed hypothesis that the highly-condensed basal phosphatized hardground is representative of a type 3 SB.

In Fig. 12, a palinspastic transect along the Säntis-Churfirsten-Alvier massif is shown. With the exception of the Tierwis section, a small decrease in thickness of the Altmann Mb is observed toward proximal sections. This thickness decrease is related to the progressive landward disappearance of parasequences. In this transect, the important thickness of the Tierwis section, which is due to the preservation of the sequences Ha6 and Ha7, may be related to a locally, rapidly subsiding area, or the infill of an incised (sub-marine?) valley. No direct clues for both hypotheses were, however, found in the field. The observation of a synsedimentary normal fault at the top of the Altmann Mb of the Fluebrig section may argue in favor of the first hypothesis.

## 8. Depositional model

The depositional history of the Altmann Mb begins with the sequence Ha6 (Fig. 13). In the Säntis massif, a local depression (probably initiated by normal faults) led to the record of a thin SMST, followed by a very thin TST and a thick HST. The thin transgressive deposits reflect slower rates of sediment production that may be associated to the reduction of carbonate growth potential. Thus, the beginning of the "drowning episode" may correspond to the TS Ha6. During maximum flooding, the Helvetic ramp is drowned and ca. 1-m-thick, dark glauconitic-rich marls and marly limestone are deposited during the *B. mortilleti* biozone. According to cyclostratigraphic interpretations of Late Hauterivian – Barremian successions from the Vocontian trough (Bodin et al. 2006), a duration of approximately 300 kyr is likely to be condensed in this interval. During the HST, the important thickness of deposits indicates renewed carbonate production and the end of the first drowning phase in the Säntis massif. The sequence Ha7 is recorded only in the Säntis massif and is characterized by a thin TST followed by a thin HST.

The absence of Upper Hauterivian – lowermost Barremian deposits in other part of the Helvetic ramp, as well as the finding of a well-preserved phosphatized ammonite dated from the Late Hauterivian (*Parathurmannia cf. catulloi*) of the Oberlänggli section, may point to erosion, sediment starvation and/or winnowing and phosphatization along the other parts of the platform associated with this first drowning step. Following previous sea-level reconstructions (*e.g.,* Ruffell 1991; Hardenbol et al. 1998), this first drowning phase is coeval with a second order sea-level rise (Ha6 third order MFS). The observation that at the Säntis locality the carbonate platform has not been drowned during the entire Ha6 and Ha7 sequences, but only during the Ha6 TST and MFS interval, could be related to the peculiar paleogeographical setting of this locality. Indeed, the sediments preserved at this locality were likely to be deposited within a tectonically-induced depression that could have protected this part of the platform from winnowing currents.

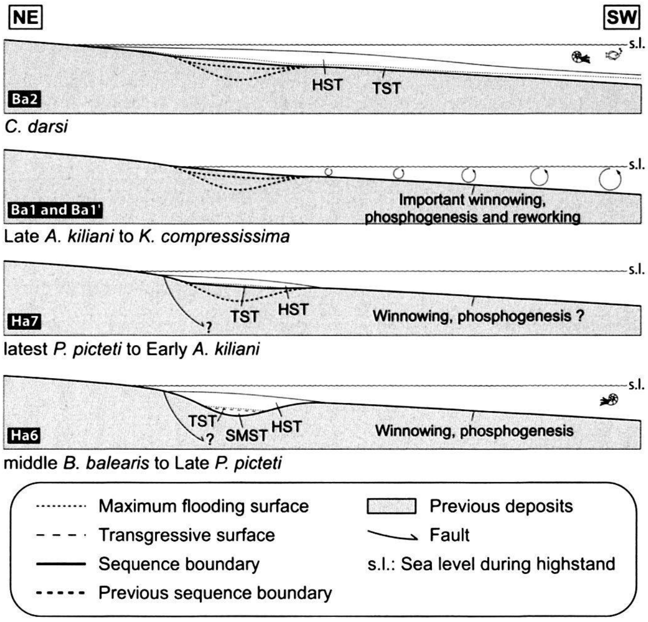


Fig. 13. Depositional model for the Altmann Mb in four successive time steps (see text for details).

The Helvetic platform preserved no major deposits during the time interval corresponding to sequences Ba1 and Ba1'. In the middle and outer ramp, the platform experienced the development of a phosphatized hardground, which is indicative of important winnowing and sediment starvation (*e.g.,* Föllmi 1996; Trappe 1998). The excellent preservation of phosphatized fossils such as ammonites or sponges may point to the effect of rapid burial and consequent phosphogenesis (Föllmi 1996). In places where no phosphatized hardground is present, an erosive surface has been observed. This feature might point to bottom current erosion and reworking. In other parts of the European continent, the Early Barremian corresponds to a second order sea-level lowstand (Ruffel 1991; Arnaud, 2005). This may imply that winnowing and phosphogenesis along the northern Tethyan realm might have take place during a long sea-level lowstand period. Hardground formation during sea-level lowstand can be related to the lowering of the effective wave base exposing the sea floor to wave action (*e.g.,* Immenhauser et al. 2000).

A second drowning phase took place during the Ba2 sequence. According to the overall backstepping pattern of the platform recorded within the Ba2 and Ba3 sequences, the SB Ba2, which is qualified as a type 3 SB, may thus be related to the TS of this Barremian second order sea-level cycle. The presence of phosphatized nodules in the TST might highlight ongoing phosphogenesis during the transgressive phase. Reworking of sediments is recorded by glauconitic-rich gravity-flow deposits in a majority of the studied sections. The deposit of a thick marly interval related to the MFS BA2, which marks the top of the Altmann Mb and which is associated to pelagic facies (HF0), documents the second drowning of the Helvetic platform. During the Ba2 HST, a great part of the Helvetic platform experienced the deposition of outer-ramp hemipelagic facies (HF1). This might indicate a strong decrease of the platform-growth area associated to the second drowning episode (back-stepping of the platform). Following Tucker and Wright (1990; p. 57), this episode can be defined as an incipient drowning stage.

Whereas sea-level change plays an important role in the Late Hauterivian – Early Barremian drowning of the Helvetic platform, it alone cannot explain the drowning of the carbonate platform. Indeed, the growth rates of carbonate platforms can easily exceed the fastest sea-level rise (*e.g.,* Schlager 1981; Hallock & Schlager 1986; Mallarino et al. 2002). One solution to resolve this apparent paradox is to reduce the growth potential of the carbonate platform through environmental stress, such as the reduction of water transparency, temperature or nutrient excess (Hallock & Schlager 1981). Bodin et al. (2006) have observed significantly high phosphorus levels in the western Tethys during the latest Hauterivian – Early Barremian. This observation might be best explained by high nutrient input correlated with the observed carbonate platform-drowning episode. On the other hand, this drowning might also have a non-negligible effect on the carbon-isotope variations of Tethyan basin sections. Indeed, following Godet et al. (2006), the high oceanic DIC resulting from this drowning may explain the rather stable trend of the $\delta^{13}C$ curve during the latest Hauterivian – Early Barremian.

The close relationship between the timing of the onset of the Altmann Mb drowning event and the Faraoni oceanic anoxic event points to a connection between these two events. Indeed, in basinal sections, the bottom water anoxia associated to the Faraoni level led to decreased phosphorus preservation in sediments and a positive feedback that led to a rise in nutrient levels in sea water (Bodin et al. 2006). This mechanism may have highly reduced the growth potential of the carbonate platform through environmental stress by nutrient excess, and induced the first step of this drowning event. During the Early Barremian, winnowing, associated to a second order sea-level lowstand and also to high nutrient level in the ocean (Bodin et al. 2006), may have induced the formation of a phosphatized hardground and the complete stop of platform growth. During the latest Early Barremian (*C. darsi* zone), the following second order sea-level transgression, which is also associated to high nutrient levels, led to the end of the hardground formation and to a second drowning step. The overall decrease in nutrient levels during the Late Barremian marks the end of the slowdown and demise of carbonate platform growth and the progressive return of a photozoan association (*i.e.* the Schrattenkalk Fm).

## 9. Conclusions

(1) Ammonite biostratigraphy shows that the Altmann Mb spans the time interval from the *P. seitzi* (latest Hauterivian) to the *C. darsi* ammonite zone (latest Early Barremian). Coupled with a detailed sequence stratigraphic interpretation of basin sections, these age data indicate that the Altmann Mb begins at the Sb Ha6 and ends within the MFS Ba2.

(2) The majority of the Altmann Mb sections records only the upper part of the Hauterivian – Barremian transition drowning event. Only some sections, mainly located in the Säntis massif, recorded evidence of a more detailed depositional history of the Altmann Mb.

(3) This may be the result of a twofold drowning. A first drowning phase is recorded in the Tierwis section (representative of the Säntis massif) and documents the Ha6 transgression, leading to the deposition of glaucony-rich black marls during the TST-MFS. These deposits are contemporaneous to the Faraoni event black-shales in basin sections (*e.g.,* Cecca et al. 1994; Baudin et al. 1999; Baudin, 2005). In the other platform areas, reworking, winnowing and phosphogenesis recorded this first drowning stage. A second phase is contemporaneous to the Ba2 transgression and is associated to a following pronounced backstepping of the carbonate factory. With the exception of the Tierwis section, the sequences Ha6, Ha7, Ba1 and Ba1' are either condensed in a phosphatized hardground or lacking. This observation is best explained by strong winnowing and bottom current-induced reworking along the northern Tethyan ramp. The Altmann Mb drowning episode ended with the Ba2 highstand and the beginning of the Drusberg Mb deposition.

(4) There is a strong coupling of this drowning event with a palaeoceanographic changes within the western Tethyan realm: the onset of the drowning episode is linked to the Faraoni oceanic anoxic event (latest Hauterivian) by platform eutrophication. During the Early Barremian, the high nutrient levels in the northern Tethys, associated with current-induced winnowing, preclude carbonate platform growth until the beginning of the Late Barremian and the progressive return of photozoans in association with a significant decrease in seawater nutrient levels (Bodin et al. 2006).

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## REFERENCES

Amorosi, A. & Centineo, M.C. 1997: Glaucony from the Eocene of the Isle of Wight (southern UK): implications for basin analysis and sequence-stratigraphic interpretation. Journal of Geological Society of London 154, 887–896.

Arnaud, H. 2005: Sequence stratigraphy interpretation. In: Adatte, T. et al. (eds.): The Hauterivian – Lower Aptian sequence stratigraphy from Jura platform to Vocontian basin: a multidisciplinary approach. Géologie Alpine, Série Spéciale "Colloques et Excursions" N° 7, 174–179.

Arnaud, H., Arnaud-Vanneau, A., Blanc-Aletru, M.C., Adatte, T., Argot, M., Delanoy, G., Thieuloy, J.-P., Vermeulen, J., Virgone, A., Virlouvet, B. & Wermeille S. 1998: Répartition stratigraphique des orbitolinidés de la plate-forme urgonienne subalpine et jurassienne (SE de la France). Géologie Alpine 74, 3–89.

Arnaud-Vanneau, A. 1980: Micropaléontologie, paléoécologie et sédimentologie d'une plate-forme carbonatée de la marge passive de la Téthys; L'Urgonien du Vercors septentrional et de la Chartreuse (Alpes occidentales). Géologie Alpine, Mémoire Hors-Série, N°11, v. 3, 19pp.

Baudin, F., Bulot, L.G., Cecca, F., Coccioni, R., Gardin, S. & Renard, M. 1999: Un équivalent du "Niveau Faraoni" dans le bassin du Sud-Est de la France, indice possible d'un événement anoxique fini-hauterivien étendu à la Téthys méditerranéenne. Bulletin de la Société Géologique de France 170, 487–498.

Baudin, F. 2005: A Late Hauterivian short-lived anoxic event in the Mediterranean Tethys: the "Faraoni Event". Comptes Rendus Geoscience 337, 1532–1540.

Blanc-Aletru, M.C. 1995: Importance des discontinuités dans l'enregistrement sédimentaire de l'urgonien jurassien: micropaléontologie, sédimentologie, minéralogie et stratigraphie séquentielle. Géologie Alpine. Mémoire Hors-Série 24, 299 pp.

Bodin, S., Godet, A., Föllmi, K. B., Vermeulen, J., Arnaud, H., Strasser, A., Fiet, N. & Adatte, T. 2006: The Late Hauterivian Faraoni oceanic anoxic event in the western Tethys: Evidence from phosphorus burial rates. Palaeogeography, Palaeoclimatology, Palaeoecology 235, 245–264.

Bollinger, D. 1988: Die Entwicklung des distalen osthelvetischen Schelfs im Barremian und Früh-Aptian. unpublished PhD thesis ETH Zürich, Zürich, Switzerland, 136 pp.

Briegel, U. 1972: Geologie der östlichen Alviergruppe (Helvetische Decken der Ostschweiz) unter besonderer Berücksichtigung der Drusberg- und Schrattenkalkformation (Unterkreide). Eclogae geol. Helv. 65, 425–483.

Burchette, T.P. & Wright, V.P. 1992: Carbonate ramp depositional systems. Sedimentary Geology 79, 3–57.

Cecca, F., Marini, A., Pallini, G., Baudin, F. & Begouen, V. 1994: A guide-level of the uppermost Hauterivian (Lower Cretaceous) in the pelagic succession of Umbria-Marche Apennines (Central Italy): the Faraoni Level. Riv. Ital. Paleontol. Stratigr. 99, 551–568.

Chamley, H. 1989: Clay Sedimentology: Berlin, Springer-Verlag, 623 pp.

Fichter, H.J. 1934: Geologie der Bauen-Brisen-Kette am Vierwaldstaettersee und die zyklische Gliederung der Kreide und des Malm der helvetischen Decken: Breträge zur Geologischen Karte, 128 pp.

Föllmi, K.B. 1989: Evolution of the Mid-Cretaceous Triad. Platform Carbonates, Phosphatic Sediments, and Pelagic Carbonates along the Northern Tethys margin. Lecture Notes in Earth Sciences 23, Springer-Verlag, 153 pp.

Föllmi, K.B. 1996: The phosphorus cycle, phosphogenesis and marine phosphate-rich deposits. Earth-Science Reviews 40, 55–124.

Föllmi, K.B., Weissert, H., Bisping, M. & Funk, H. 1994: Phosphogenesis, carbon-isotope stratigraphy, and carbonate-platform evolution along the Lower Cretaceous northern Tethyan margin. Geological Society of America Bulletin 106, 729–746.

Funk, H. 1969: Typusprofile der helvetischen Kieselkalk Formation und der Altmann Schichten. Eclogae geol. Helv. 62, 191–203.

Funk, H. 1971: Zur stratigraphie und lithologie des Helvetischen Kieselkalkes und der Altmannschichten im der Säntis-Churfirsten-Gruppe (Nordostschweiz). Eclogae geol. Helv. 64, 345–433.

Funk, H., Föllmi, K.B. & Mohr, H. 1993: Evolution of the Tithonian-Aptian carbonate platform along the northern Tethyan margin, eastern Helvetic Alps: In: Simo J.A.T., Scott R.W. & Masse J.-P. (Eds.): Cretaceous carbonates platforms. American Association of Petroleum Geologists, Special Volume 56, 387–407.

Godet, A., Bodin, S., Föllmi, K.B., Vermeulen, J., Gardin, S., Fiet, N., Adatte, T., Berner, Z., Stüben, D. & Van de Schootbrugge, B. 2006: Evolution of the marine stable carbon-isotope record during the early Cretaceous: A focus on the late Hauterivian and Barremian in the Tethyan realm. Earth and Planetary Science Letters 242, 254–271.

Goldschmid, K. 1927: Geologie der Morgenberghorn-Schwalmerengruppe bei Interlaken. Mitt. Nat. Ges. Bern 195–268.

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

Hantke, R. 1961: Tektonik der helvetschen Kalkalpen zwischen Obwalden und dem St. Galler Rheintal: Mitteilungen aus dem Geologischen Institut der Eidg. Techn. Hochschule und der Universität Zürich, Serie B, v. 16, 212 pp.

Haq, B.U., Hardenbol, J. & Vail, P.R. 1987: Chronology of fluctuating sea levels since the Triassic. Science 235, 1156–1167.

Hardenbol, J., Thierry, J., Farley, M.B., de Graciansky, P.-C. & Vail, P.R. 1998: Mesozoic and Cenozoic Sequence Chronostratigraphic Framework of European Basins. In: de Graciansky, P.-C., Hardenbol, J., Jacquin, T. & Vail, P.R. (eds.): Mesozoic and Cenozoic Sequence Stratigraphy of European Basins. Special Publication – Society for Sedimentary Geology 60, 3–13.

Heim, A. 1910–1916: Monographie der Churfirsten-Mattstock-Gruppe: Beiträge zur Geologischen Karte der Schweiz 50: Bern, 662 pp.

Hoedemaeker, P.J., Reboulet, S., Aguirre-Urreta, M.B., Alsen, P., Aoutem, M., Atrops, F., Barragan, R., Company, M., Gonzalez, C., Klein, J., Lukeneder, A., Ploch, I., Raisossadat, N., Rawson, P.F., Ropolo, P., Vasicek, Z., Vermeulen, J. & Wippich, M.G.E. 2003: Report on the 1st International Workshop of the IUGS Lower Cretaceous Ammonite Working Group, the 'Kilian Group' (Lyon, 11 July 2002). Cretaceous Research 24, 89–94.

Immenhauser, A., Schlager, W., Burns, S.J., Scott, R.W., Geel, T., Lehmann, J., van der Gaast, S. & Bolder-Schrijver, L.J.A. 2000: Origin and correlation of disconformity surfaces and marker beds, Nahr Umr Formation, northern Oman. In: Alsharhan, A.S. & Scott, R.W. (Eds.): Middle East models of Jurassic/Cretaceous carbonate systems. Special Publication – Society for Sedimentary Geology 69, 209–225.

James, N.P. 1997: The cool-water carbonate depositional realm. In: James N.P. & Clarke J.A.D. (Eds): Cool water carbonates. Society for Sedimentary Geology 56, 1–22.

Kuhn, O. 1996: Der Einfluss von Verwitterung auf die Paläozeanographie zu Beginn des Kreide-Treibhausklimas (Valanginian und Hauterivian) in der West-Tethys. unpublished PhD thesis Universität Zürich, Zürich, 380 pp.

Lehmann, C., Osleger, D.A., Montanez, I.P., Sliter, W.V., Arnaud-Vanneau, A. & Banner, J. 1999: Evolution of Cupido and Coahuila carbonate platforms, Early Cretaceous, northeastern Mexico. Geological Society of America Bulletin 111, 1010–1029.

MacEachern, J.A., Zaitlin, B.A. & Pemberton, S.G. 1999: A sharp-based sandstone of the Viking Formation, Joffre Field, Alberta, Canada: criteria for regnition of transgressively incised shoreface complexes. Journal of Sedimentary Research 69, 876–892.

Mallarino, G., Goldstein, R.H. & Di Stefano, P. 2002: New approach for quantifying water depth applied to the enigma of drowning of carbonate platforms. Geology 30, 783–786.

Malpas, J.A., Gawthorpe, R.L., Pollard, J.E. & Sharp, I.R. 2005: Ichnofabric analysis of the shallow marine Nukhul Formation (Miocene), Suez Rift, Egypt: implications for depositional processes and sequence stratigraphic evolution. Palaeogeography Palaeoclimatology Palaeoecology 215, 239–264.

Pasquini, C., Lualdi, A. & Vercesi, P. 2004: Depositional dynamics of glaucony-rich deposits in the Lower Cretaceous of the Nice arc, southeast France. Cretaceous Research 25, 179–189.

PEMBERTON, S.G. 1998: Stratigraphic applications of the Glossifungites ichnofacies: Delineating discontinuities in the rock record. American Association of Petroleum Geologists Bulletin 82, 2155.

PÉRÈS, J.M. 1961: La vie benthique. In: Océanographie biologique et biologie marine. Tome 1. Presses Universitaires de France, Vendôme. 541 pp.

RICK, B. 1985: Geologie des Fluhbrig (Kt. Sz): unter besonderer Berücksichtigung der Altmannschichten und der "Gault"-formation. Unpublished master thesis, Zürich, 83 pp.

RUFFELL, A. 1991: Sea-level events during the Early Cretaceous in western Europe. Cretaceous Research 12, 527–551.

SCHENK, K. 1992: Die Drusberg- und Schrattenkalk-Formation (Unterkreide) im Helvetikum des Berner Oberlandes. Inauguraldissertation der Philosophisch-naturwissenschaftlichen Fakultät: Universität Bern, Bern, 169 pp.

SCHLAGER, W. 1981: The paradox of drowned reefs and carbonates platforms. Geological Society of America Bulletin 92, 197–211.

SCHLAGER, W. 1999: Type 3 sequence boundaries. In: HARRIS, P.M., SALLER, A.H. & SIMO, J.A.T. (Eds.): Advances in carbonate sequence stratigraphy: Application to reservoirs, outcrops and models. SEPM Spec. Pub. 63, 35–45.

TRAPPE, J. 1998: Phanerozoic Phosphorite Depositional Systems: a dynamic model for a sedimentary resource system: Lecture Notes in Earth Sciences 76, Springer, 316 pp.

TUCKER, M.E. & WRIGHT, J.D. 1990: Carbonate sedimentology. Blackwell Science, Oxford. 482 pp.

VAN DE SCHOOTBRUGGE, B. 2001: Influence of paleo-environmental changes during the Hauterivian (Early Cretaceous) on carbonate deposition along the northern margin of the Tethys: Evidence from geochimical records (C, O, and Sr-isotopes, P, Fe, Mn). Unpublished PhD thesis, Université de Neuchâtel, Institut de Géologie, Neuchâtel (Switzerland), 268 pp.

VERMEULEN, J. 2002. Etude stratigraphique et paléontologique de la famille des Pulchelliidae (ammonoidea, Ammonitina, Endemocerataceae). Géologie Alpine, Memoire H.S. n° 42, 333 pp, Grenoble, France.

VERMEULEN, J. 2005: Boundaries, ammonite fauna and main subdivisions of the stratotype of the Barremian. In: ADATTE, T. et al. (eds.): The Hauterivian – Lower Aptian sequence stratigraphy from Jura platform to Vocontian basin: a multidisciplinary approach. Géologie Alpine, Série Spéciale "Colloques et Excursions" N° 7, 147–173.

WEISSERT, H., LINI, A., FÖLLMI, K.B. & KUHN, O. 1998: Correlation of Early Cretaceous carbon isotope stratigraphy and platform drowning events: a possible link? Palaeogeography, Palaeoclimatology, Palaeoecology 137, 189–203.

WISSLER, L., FUNK, H. & WEISSERT, H. 2003: Response of Early Cretaceous carbonate platforms to changes in atmospheric carbon dioxide levels. Palaeogeography, Palaeoclimatology, Palaeoecology 200, 187–205.

WYSSLING, G.W. 1986: Der frühkretazische helvetische Schelf in Vorarlberg und im Allgäu – Stratigraphie, Sedimentologie und Paläogeographie. Jb. Geol. Bund. 129, 161–265.

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