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The Early Aptian Grünten Member: Description of a new lithostratigraphic unit of the helvetic Garschella Formation

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Key words: Helvetic Zone, Early Aptian, Grünten Member, Garschella Formation, "upper Orbitolina beds"

ABSTRACT

Early Aptian sediments mostly referred to as "upper Orbitolina beds" are known from a relatively small number of outcrop areas throughout the distal part of the Helvetic Zone of Switzerland, Austria and Germany. These sediments are here formally defined as a new, basal member of the Garschella Formation; the Grünten Member. Equivalent and correlatable sediments also exist in the Vercors region of the French Dauphinée Zone. The historical type section (holostratotype) of the Grünten Member is situated on the Grünten Mountain in southern Germany. A new type section (lectostratotype) for the Grünten Member is chosen in the better suited Bauen-Brisen area of Central Switzerland and an additional reference section (hypostratotype) is defined near the Rawil Pass in the Bernese Oberland of Switzerland. In relatively proximal settings, the Grünten Member overlies Early Aptian limestones of the Urgonian Carbonate Platform (Schrattenkalk Formation), documenting its demise and early "drowning". In relatively distal settings, it overlies the contemporary hemipelagic sediments of the Drusberg and Mittagspitz Formations. In complete successions, the Grünten Member is in turn overlain by the basal, phosphoritic Luitere Bed of the Brisi Member (Garschella Formation) documenting the continuing "drowning" of the Urgonian Carbonate Platform in the Late Aptian. The Grünten Member essentially consists of a single stratigraphic sequence, beginning with a marly base and gradually passing to crinoidal limestones at its top. Rare ammonite finds as well as sequence stratigraphic correlations suggest a late Early Aptian age (parts of the *Deshayesi* and *Furcata* Ammonite Zones). In the relatively proximal reference section of Rawil, the Grünten Member contains two phosphoritic horizons. Phosphate-enriched horizons are also known from other proximal sections of the Grünten Member.

ZUSAMMENFASSUNG

Aus einer relativ kleinen Anzahl von Aufschlussgebieten quer durch den distalen Teil der Helvetischen Zone der Schweiz, Österreichs und Deutschlands sind frühaptische Sedimente, zumeist unter dem Namen "obere Orbitolinenschichten" bekannt. Diese Sedimente werden hier, unter dem Namen Grünten-Member, formell als neues basales Member der Garschella-Formation definiert. Äquivalente und korrelierbare Sedimente existieren auch in der Vercors-Region der französischen Zone Dauphinoise. Das historische Typusprofil (Holostratotyp) des Grünten-Members liegt auf dem Grünten-Gipfel in Süddeutschland. Ein neues Typusprofil (Lectostratotyp) für das Grünten-Member wird in der besser geeigneten Bauen-Brisen Region der Zentralschweiz gewählt und ein zusätzliches Referenzprofil (Hypostratotyp) wird nahe des Rawilpasses im Berner Oberland der Schweiz definiert. In relativ proximalen Situationen überlagert das Grünten-Member frühaptische Kalke der Schrattenkalk-Plattform (Schrattenkalk-Formation), ihren Niedergang und ihr frühes "Ertrinken" dokumentierend. In relativ distalen Positionen überlagert es die gleichaltrigen hemipelagischen Sedimente der Drusberg- und der Mittagspitz-Formation. In vollständigen Abfolgen wird das Grünten-Member seinerseits durch die basale, phosphoritische Luitere-Schicht des Brisi-Members (Garschella-Formation) überlagert, welche das weitere "Ertrinken" der Schrattenkalk-Plattform im späten Aptian dokumentiert. Das Grünten-Member besteht im Wesentlichen aus einer einzigen stratigraphischen Sequenz, beginnend mit einer mergligen Basis und allmählich übergehend in einen oberen Teil aus Crinoiden-Bryozoen-Kalk. Seltene Ammoniten-Funde sowie sequenzstratigraphische Korrelationen deuten auf ein spät-frühaptisches Alter (Teile der *Deshayesi*- und *Furcata*-Ammonitenzonen). Im relativ proximalen Referenzprofil von Rawil enthält das Grünten-Member zwei Phosphorithorizonte. Phosphatreiche Horizonte sind auch von anderen proximalen Aufschlüssen des Grünten-Members bekannt.

1. Introduction

A) Subject

In the central European part of the Northern Tethyan Margin, the Early Cretaceous sediment record comprises photozoan-dominated platform carbonates, heterozoan-dominated ramp carbonates and condensed sediments. The succession of these three modes of carbonate production provides an accurate record of regional and global climate evolution during the Early Cretaceous (Föllmi et al. 1994, Weissert et al. 1998, Föllmi et al. 2006 in press). Of special interest in this context is the repeated occurrence of oceanic anoxic events both in Early and Late Cretaceous pelagic sediments, and particularly during the Aptian.

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Indeed, Aptian climate change and its sedimentary record have been closely investigated in the past few decades. Based on the excellent information provided by the pelagic and hemipelagic record (e.g. Italy, the Pacific and elsewhere), a currently popular model for the Early Aptian events suggests that extensive oceanic flood basalt volcanism (Larson 1991) in the Pacific Ocean triggered a super-greenhouse effect. This event is thought to have resulted in massive and long-lasting paleoceanographic environmental changes including the Oceanic Anoxic Event 1a with black shale deposition in the pelagic realm (Erba 1994) as well as carbonate platform demise and "drowning", condensation and authigenesis in the neritic realm (e.g. Simo et al. 1993).

In the central European part of the Northern Tethyan Margin, these events were documented by the Early Aptian demise and subsequent "drowning" of the so-called Urgonian Carbonate Platform. Unfortunately, the essential earliest part of the sedimentary "drowning" record is only documented in a relatively small number of mostly rather small outcrop areas. Although these sediments have been known for more than a hundred years, they have never been studied on a supra-regional scale and lack a formal lithostratigraphic description. Thus, the subject of this work is to describe and formally define these sediments as a lithostratigraphic unit: the Grünten Member.

B) Geographical and geological setting

The nappes of the Helvetic Zone document the Early Cretaceous sedimentary history of the European continental margin towards the Tethys (Fig. 1a). They crop out in a broad zone in the northern alpine chains, reaching from southern Germany and western Austria all the way through Switzerland (Fig. 1b). Sediments documenting the early drowning history of the Urgonian Carbonate Platform (i.e. sediments of the Grünten Member) have been observed throughout the Southern Helvetic Nappes; Figs.1b, 2). For the Barremian/Aptian, these nappes are documenting distal (i.e. paleogeographically more or less southeastern) settings near the European shelf break. They include the Wildhorn, Drusberg and Säntis Nappes (Trümpy 1969).

The sediments of the Grünten Member are of late Early Aptian age. In complete successions, they are underlain by Late Barremian and earliest Aptian limestones and marls of the Schrattenkalk, Drusberg and Mittagspitz Formations. The sediments of the Grünten Member are in turn overlain by condensed Late Aptian to Middle Cenomanian sediments from higher units of the Garschella Formation.

In the Vercors region of the French Dauphinée Zone (which represents the westward extension of the Helvetic Zone), sediments largely similar to the Grünten Member have been observed (Arnaud-Vanneau & Arnaud 1990, p. 216ff.). These sediments are labelled with the same informal name that has previously also been used for the Grünten Member (i.e. "couches supérieures à Orbitolines", English: "upper Orbitolina beds"; cf. next section). These beds display similar facies and have furnished ammonites of similar age as the here-defined Grünten Member and are therefore considered as equivalent to the Grünten Member. We therefore refer to these equivalents at different points in this paper in order to allow for a comparison.

C) History and justification of denomination

"Grünten beds":

Using the name of a geographic locality (the Grünten Mountain in the Allgäu region of southern Germany), the term "Grünten beds" (German: "Grünten-Schichten") was introduced by Arnold Heim (1919). This term is formally correct and has historical priority. It needs a small but important clarification though: In his original paper, Heim (1919) assigns the Luitere Bed of the Grünten area to his "Grünten beds". Actually, this would be in disagreement with the formal definition of the Garschella Formation (Föllmi & Ouwehand 1987) which – along with most historic studies – defines the Luitere Bed as the basal horizon of the Brisi Member. Ambiguity can be avoided though by specifing that the Luitere Bed at Grünten (and few other proximal locations) may contain reworked fossils, including ammonites, from the underlying Grünten Member. This clarification, which is in agreement with the original intentions of Heim (cf. Heim & Seitz 1934, p. 253f.) is further discussed in section 2.B.

The term "Grünten Member" was already introduced by Bollinger (1988), but it lacks a proper formal definition and erroneously includes parts of other lithostratigraphic units (i.e. the Luitere and Brisi Beds – cf. Bollinger 1988, p.33). It is important to note that the Grünten Member (as it is defined herein) is in its historical type region rather thin and condensed. We therefore propose to define a new, more complete type section (lectostratotype) in replacement of the historical type section and a further reference section in order to document the occurence of condensed phosphorite horizons.

"Upper Orbitolina beds":

Coined by Burckhardt (1896) as "obere Orbitulinaschichten" (eng.: "upper Orbitulina beds"), this term was introduced for outcrops in the Klöntal and Wäggital area of Central Switzerland (Fig. 1b) and was originally used to label a facies in the upper part of the Schrattenkalk Formation that is enriched in *Palorbitolina lenticularis* (BLUMENBACH). Despite its misleadingly similar name, this facies is completely different both from that of the Orbitolina Member (historically known as "lower Orbitolina beds") which is situated on a deeper stratigraphic level of the Schrattenkalk Formation (cf. Fig. 2), as well as from that of the Grünten Member. Only subsequently, this term was – erroneously – attributed to the sediments herein described as Grünten Member (e.g. Fichter 1934). In result, the sediments of the Grünten Member are today known under the name "upper Orbitolina beds" in most outcrop regions

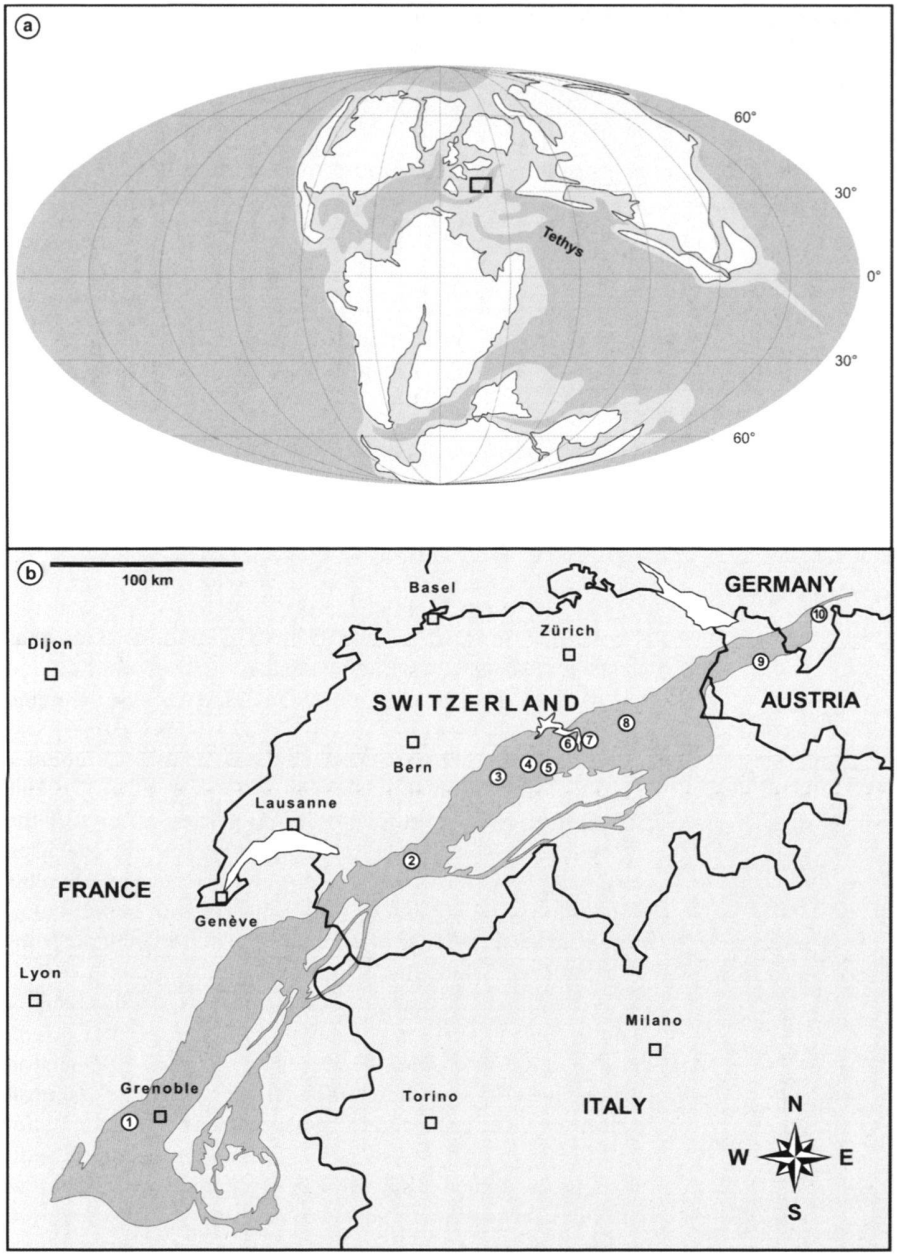

Fig. 1. A) Global paleogeography during the Early Aptian (after Blakey: http://jan.ucc.nau.edu/~rcb7). The rectangle marks the study area. B) Study area: Map of the Delphino-Helvetic Zone (dark grey, excluding the Vocontian Through). The numbered dots mark all known outcrop areas of the Grünten Member and its equivalents*: Vercors* (1), Rawil Pass (2), Brienzer Rothorn (3), Lake Sarnen (4), Engelberg Valley (5), Bauen-Brisen Range (6), Fronalpstock (7), Klöntal and Wäggital Valleys (8), Mittagspitze (9), Grünten (10). Map drawn after the tectonic map of Switzerland (Swiss Federal Office for Water and Geology) and the geologic map of the Western Alps (Gidon 1977).

(namely throughout Switzerland and in equivalent successions in the French Vercors region). Hence, while the term "upper Orbitolina beds" is not in accordance with international stratigraphic rules for referring to fossil content rather than to a locality, it is also due to its historical ambiguity that this term is inappropriate for formal use.

"Gibbsi beds":

This term (German: "Gibbsi-Schichten") was also coined by Burckhardt (1896) and was used to designate the sediments of the Grünten Member in the same, above-mentioned area of Central Switzerland. The term is based on the presence of large quantities of the brachiopod *Burrirhynchia sayni* (JACOB & FALLOT 1913; Synonymes: *Rhynchonella gibbsiana* SOWERBY, *Rhynchonella bertheloti* D'ORBIGNY) in the crinoidal limestones at the top of the Grünten Member. The term "Gibbsi beds" was often confused with the "upper Orbitolina beds" of the same author and subsequent to the publication of Fichter (1934) it was, as an apparent synonym to the "upper Orbitolina beds", no longer used (Rutsch 1964, p. 499f.). Apart from not being used in the last seven decades, the referral to fossil

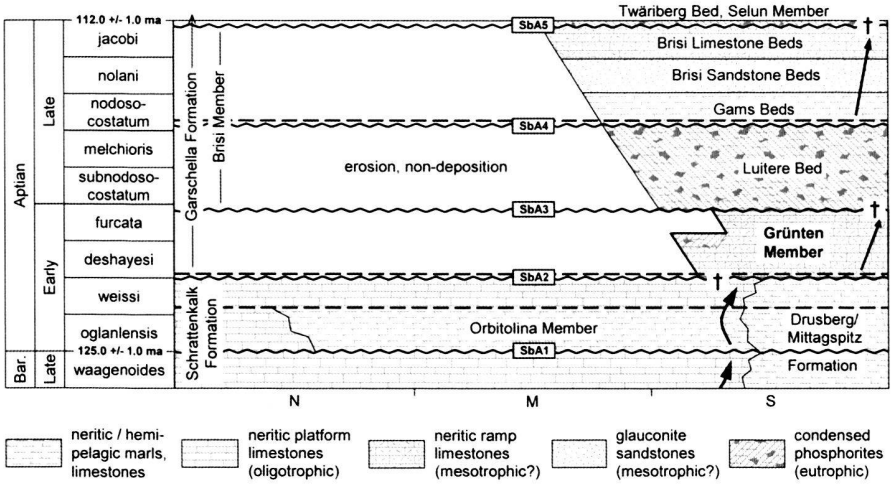

Fig. 2. Highly schematic plot of lithostratigraphic units in the Helvetic Realm against a paleogeographic north-south transect. Stratigraphic nomenclature from Föllmi & Ouwehand (1987). On the left, stages, substages (Gradstein et al. 2004) and tethyan ammonite zones (Hoedemaker et al. 2003) are given. The letters on the horizontal axis mark the Northern (N), Middle (M) and Southern Helvetic Realms (S). Wavy lines mark sequence boundaries and dashed lines mark maximum flooding surfaces (in the nomenclature of Arnaud et al. 1998). Arrows and crosses mark carbonate platform and ramp progradation and aggradation respectively demise.

names and the historical ambiguity in its use render the term "Gibbsi beds" inappropriate for formal use.

Mittagspitz Formation:

The most recently defined (partial) equivalent of the Grünten Member is the formally defined Mittagspitz Formation (Felber & Wyssling 1979) in western Austria (Fig. 1). Our study shows that its upper part ("Spatkalk Member", "Sünserspitz Mergelkalk Member", channel fillings at the top of the "Mittagspitz Member") represents a distal facies of the Grünten Member whereas its lower part (i.e. most of the "Mittagspitz Member") is equivalent to the upper part of the Drusberg Formation ("Hurstmergel" in Briegel 1972; cf. Fig. 8).

2. Formal Definition of the Grünten Member

A) General aspects

Most important references for synonyms:

1896 non obere Orbitulinaschichten – Burckhardt, p. 68 ff.
1896 Gibbsischichten – Burckhardt, p. 70 ff. (= crinoidal upper part)
1905 non Schratten-Echinodermenbreccie – Blumer, p.526 (Schrattenkalk Formation)
1919 pp. Grüntenschichten – Heim, p. 464 (without Luitere Bed)
1934 obere Orbitolinaschichten – Fichter, p. 39 ff.
1936 obere Orbitolinaschichten – Schaub, p. 352 (= crinoidal upper part)
1936 pp. Luitereschichten – Schaub, p. 352 (non Luitere-Schicht sensu Föllmi & Ouwehand 1987)
1979 pp. Mittagspitz-Formation – Felber & Wyssling, p. 689 ff.
1988 pp. Grünten Member – Bollinger, p. 45 ff. (non p. 33: Luitere and Brisi Beds!)

Definition:

The sediments of the Helvetic Zone that are mostly known as "upper Orbitolina beds" (amongst others; see section 1.C) and that are described below are formally defined under the name Grünten Member.

The Grünten Member is assigned as a new, basal member of the Garschella Formation (Föllmi & Ouwehand 1987). This affiliation is due to the lithologic and genetic affinity of the Grünten Member to the heterozoan sediments of the overlying Garschella Formation rather than to the photozoan sediments of the underlying Schrattenkalk Formation and, in particular, due to the local presence of phosphorites in proximal outcrops of the Grünten Member.

The historical type section (holostratotype) of the Grünten Member lies in the Allgäu region of southern Germany (Heim 1919). The Grünten Member is assigned a new type section (lectostratotype) in the Bauen-Brisen range of Central Switzerland. The new type section is chosen for the completeness, thickness and typical facies of the corresponding sediments in the Bauen-Brisen range, compared to the thin and partially condensed sediments of the historical type area (cf. sections 1.C, 2.B and Fig. 8). Furthermore, the Grünten Member is assigned a reference section (hypostratotype) in the Bernese Oberland region of Switzerland.

Short Description, Age:

In the most expanded sections, the Grünten Member consists of a marly base (microfacies F1, F2; cf. Fig. 7 for microphotographs and Fig. 9 for microfacies codes; nomenclature after Arnaud-Vanneau (2005), gradually passing into sandy limestones (microfacies F3) and finally to crinoidal-bryozoan limestones (microfacies F4) in its top. Judging from rare ammonite finds (presumably late forms of the genus *Deshayesites*, and *Dufrenoyia* sp.(?) see sections 2.B–D) and sequence stratigraphic correlations (cf. next paragraph), its age is late Early

Aptian and most probably restricted to parts of the *Deshayesi* and *Furcata*(?) Ammonite Zones. In equivalent sediments of the French Vercors region (Dauphinée Zone), ammonite finds include both the *Deshayesi* and the *Furcata* Zone (cf. Arnaud et al. 1998, p.32).

Stratigraphic Context:

The Grünten Member overlies the limestones of the Urgonian Carbonate Platform – i.e. the Early Aptian upper part of the Schrattenkalk Formation – in proximal to central locations and the hemipelagic Drusberg and Mittagspitz Formations (e.g. Briegel 1972, Felber & Wyssling 1979, Bollinger 1988) in distal locations of the South Helvetic Zone (cf. Fig. 8). Its base is marked by a disconformity (a hiatus with either a firmground or a hardground) which is interpreted as sequence boundary. This sequence boundary can be correlated to the Sequence Boundary SbA2 of the French Vercors region (in the nomenclature of Arnaud & Arnaud-Vanneau; for all sequence boundary codes hereafter see Arnaud et al. 1998 and cf. Fig. 2 herein). SbA2 is currently thought to coincide with the boundary between the *Weissi* and *Deshayesi* Ammonite Zones (Arnaud-Vanneau & Arnaud 1990 and pers. comm.). The top of the Grünten Member is equally marked by a disconformity which is associated with a hiatus and which is also interpreted as sequence boundary. This sequence boundary at the top of the Grünten Member is accordingly correlated to Sequence Boundary SbA3 (cf. above-cited references). SbA3 is thought to be situated near the boundary between the *Furcata* and *Subnodosocostatum* Zones (Arnaud-Vanneau & Arnaud 1990; cf. remarks in section 2.B). The Grünten Member thus essentially represents a single stratigraphic sequence of the third order. In the most complete sections, the Grünten Member is overlain by the phosphorites of the late Early to middle Late Aptian Luitere Bed (the basal unit of the Garschella Formation sensu Föllmi & Ouwehand 1987). In other places, the Grünten Member is overlain by younger units of the Garschella Formation (ibid.) or, with an angular unconformity, by the Late Cretaceous Wang Formation (in the Brienzer Rothorn area; Fig. 8).

Outcrop Situation:

The sediments of the Grünten Member crop out exclusively in the Southern Helvetic Nappes. They are confined to relatively few, mostly rather small outcrop areas that most probably represent the remains of a much larger original area of deposition that have escaped subsequent erosion. These outcrop areas reach from the extreme east of the Helvetic Zone (Grünten, southern Germany) and throughout the Austrian and Swiss Helvetic Zone with its equivalents reaching as far west as the Vercors region of the French Dauphinée Zone.

A cluster of partially related outcrop areas of the Grünten Member, including the most complete sections (e.g. the new type area) lies in Central Switzerland. The sediments of the Grünten Member reach both their maximum in thickness of over 30 metres and their maximum in completeness in paleogeographically central portions of the Southern Helvetic Realm (Bauen-Brisen lectotype area, Fronalpstock area of Central Switzerland). In a proximal direction (to the paleogeographic northwest), they rapidly diminish in thickness and progressively tend to document only the uppermost, calcareous part of the sequence (onlap pattern). There, they might be mistaken for the Brisi Limestone Beds of the Garschella Formation. In a more distal direction (to the paleogeographic southeast) the sequence of the Grünten Member remains more complete and diminishes only slowly in thickness. Here, it becomes increasingly more distal in facies (i.e. more muddy and marly) and becomes hard to distinguish from the underlying Drusberg and Mittagspitz Formations as well as from the most distal parts of the Schrattenkalk Formation. It is important to note that while the Grünten Member overlies more shallow facies of the Schrattenkalk Formation in proximal sections, in distal sections it rather overlies more distal facies of the Drusberg and Mittagspitz Formations (cf. Bollinger 1988, p.46).

The distribution of facies and thickness of the Grünten Member closely follows the morphology of the underlying Urgonian Carbonate Platform (Fig. 8): Outcrops near the rim of the Urgonian Carbonate Platform (where the Schrattenkalk Formation bears oolite-, coral-, and rudist-limestones of the microfacies F6-F8) are very thin and document only the upper, crinoidal part of the Grünten Member (microfacies F4), reflecting the small accommodation space. Outcrops on the uppermost slope of the Urgonian Carbonate Platform (where the Schrattenkalk Formation is dominated by bioclastic-peloidal grainstones of the microfacies F5) show a maximum in thickness, thus documenting the larger accomodation space. They include crinoidal grainstones, bioclastic-peloidal grainstones (without green algae) and even oolites (microfacies F4-F6; cf. Fig. 7i). Finally, in distal outcrops on the middle slope of the Urgonian Carbonate Platform (where the Schrattenkalk Formation consists of peloidal grainstones to wackestones of the microfacies F3-F2), the Grünten Member shows a slow decline in thickness, indicating a more important depth and an increasingly hemipelagic sedimentation. In the most distal sections, the sedimentary facies of the Grünten Member (spiculitic wackestones and peloidal wacke- to packstones of the microfacies F3-F1) becomes increasingly similar to the one of the underlying Schrattenkalk Formation and is therefore difficult to separate.

The equivalent "upper Orbitolina beds" of the Vercors region in the French Dauphinée Zone are an exception to this pattern; they are situated in a more proximal, lagoonal part of the drowned Urgonian Carbonate Platform. These outcrops were interpreted as incised valley fills (Arnaud-Vanneau & Arnaud 1990, p. 216ff.). They however display a facies that is largely identical to the one observed in the Grünten Member.

Here follows a list of all outcrop areas of the Grünten Member and its equivalents in the French Dauphinée Zone (with the most relevant publications on their geographic extent):

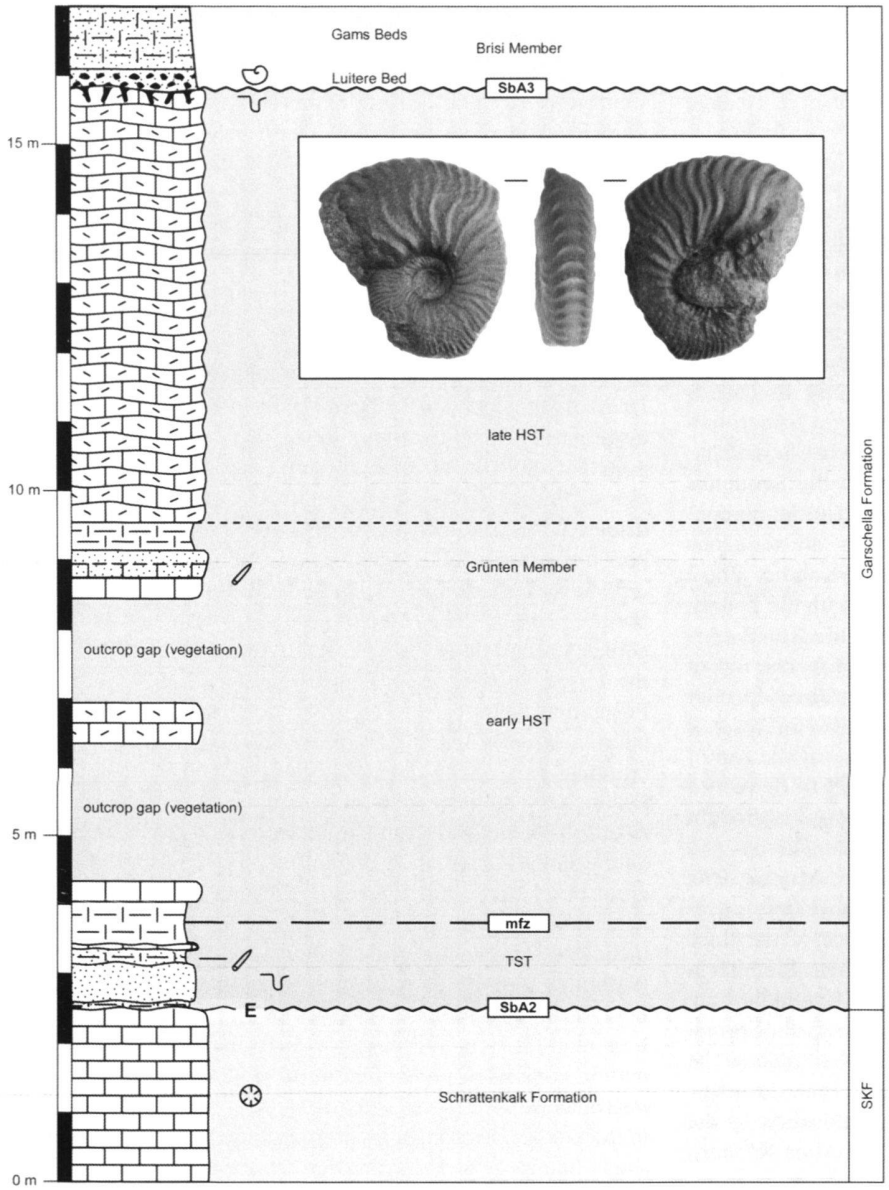

Fig. 3. Profile of the Grünten Member at the historical type section of Grünten, Germany. Note the reduced thickness of the Grünten Member at this place. Inset: Deshayesites lavaschensis KASANSKY from the Luitere Bed, maybe a reworked element from an older, not preserved phosphorite horizon within the Grünten Member (cf. Section 2.B, Fig. 8). Original size; photo: M. Delamette. For lithologic symbol key, see Fig. 8.

- Grünten Mountain, Allgäu region (southern Germany)
  Heim (1919), Gebhardt (1983)
- Mittagspitz area, Vorarlberg region (western Austria)
  Felber & Wyssling (1979), Bollinger (1988)
- Klöntal and Wäggital area, Eastern Switzerland
  Burckhardt (1896), Ganz (1912)
- Fronalpstock area, Central Switzerland
  Friedl & Zurbrügg (1988), Gigandet (2005)
- Bauen-Brisen range, Central Switzerland
  Fichter (1934), Keller (1983), Hüsser (2005)
- Engelberg area, Central Switzerland
  Hantke (1961), NAGRA (1997)
- Lake Sarnen area, Central Switzerland
  Bentz (1948)
- Brienzer Rothorn area, Bernese Oberland, Switzerland
  Jost-Stauffer (1993)
- Rawil Pass, Bernese Oberland, Switzerland
  Schaub (1936), Gainon (2001)
- Vercors region (southeastern France)
  Arnaud-Vanneau & Arnaud (1990), p. 216ff.

B) Historical Type Section Grünten

Situation:

The historical type section (holostratotype) of the Grünten Member is situated on top of the Grünten Mountain (1738 metres above sea level) near Sonthofen (Bavaria, Germany). It

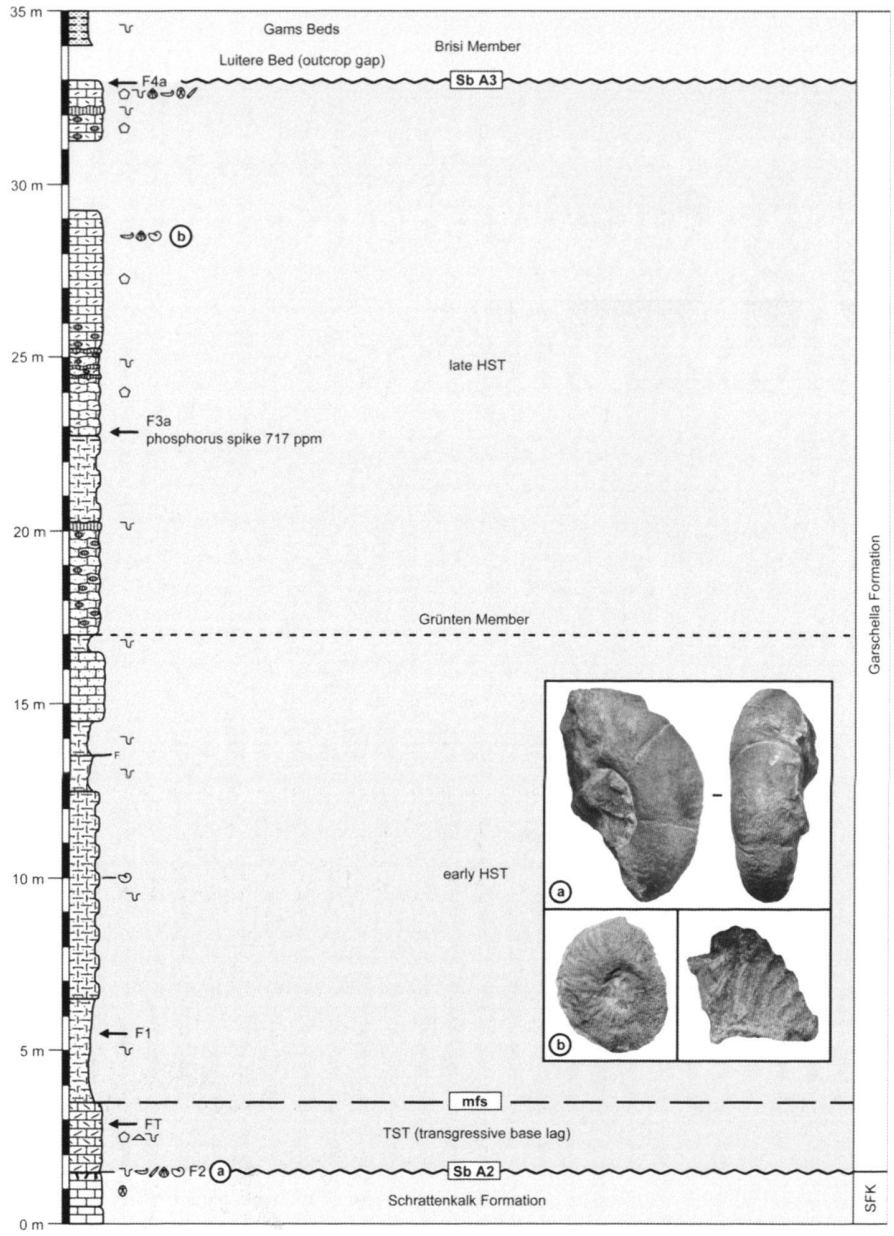

Fig. 4. Profile of the Grünten Member at the lectostratotype section of Morschfeld, Central Switzerland. Inset: A) Pseudohaploceras cf. matheroni (D'ORBIGNY) from the basal firmground (1/3 original size); B) two specimen of Dufrenoyia(?) sp. from the crinoidal upper part of the section (2/3 original size, respectively original size). Photos: M. Delamette. See also Fig. 6 for outcrop photos and Fig. 8 for lithologic symbol key.

lies in the Säntis Nappe of the Allgäu region (Southern Germany; WGS 84 coordinates: 10° 19' 10.47" E, 47° 33' 16.30" N / Swiss coordinates: 816'800/271'070; See Figs. 3, 8).

Description:

In the historical type locality, the Grünten Member measures only about 13 metres. It overlies the Schrattenkalk Formation with a hiatus forming a hardground. The base of the section consists of sandstones and sandy marls (peloidal wacke- and packstones and spiculitic wackestones of the microfacies F3-F1), passing to crinoidal limestones (grainstones of the microfacies F4) with bryozoans and small amounts of glauconite. The entire succession is poor in macrofossils and sedimentary structures; only belemnites and bioturbations are abundant. The top of the section is marked by a hiatus and is overlain by the phosphorites of the Luitere Bed.

Remarks:

A large number of ammonites from the early Late Aptian (*Subnodosocostatum* and *Melchioris* ammonite zones) have been reported from the Luitere Bed at Grünten (e.g. Heim 1919, Gebhardt 1983). However, with "*Parahoplites deshayesi var. subfissicostatus* SINZ.", respectively *Prodeshayesites fissicostatus* (PHILIPPS), both Heim (1919) and Gebhardt (1983)

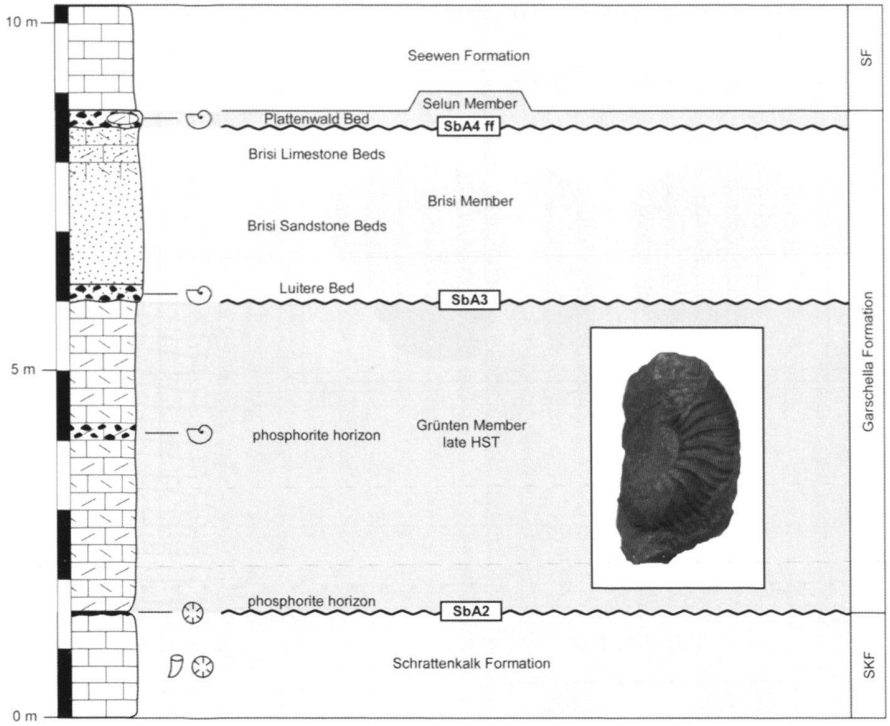

Fig. 5. Profile of the Grünten Member at the new reference section of Rawil (Bernese Oberland, Switzerland; redrawn from Gainon 2001). Note the extreme reduction of the Grünten Member in this place (including only the calcareous upper part of the complete succession) and the two phosphoritic horizons. Inset: late, indeterminable form of Deshayesites sp. from the upper phosphoritic horizon (2/3 original size). See also Fig.6 for outcrop photos and Fig. 8 for lithologic symbol key.

also mention ammonites from the earliest Aptian ammonite zone, the *Oglanlensis* Zone. If true, this would predate the Luitere Bed of the Grünten region to the upper part of the Schrattenkalk Formation elsewhere and would therefore be incompatible with the general agreement for the age of the Schrattenkalk Formation (e.g. Bollinger 1988). Unfortunately, the cited specimens of the above-mentioned authors could not be found despite intensive research in the concerning collections, so these determinations can not be verified. However, we found several ammonites of the genera *Deshayesites* and *Dufrenoyia*, including one specimen determined as *Deshayesites lavaschensis* KASANSKY (determination by Prof. T.N. Bogdanova, Univ. of St.Petersburg, Russia), which most probably indicates the late Early Aptian (*Deshayesi* Zone; Bogdanova, pers. comm.). It is probable that similar forms were earlier determined as *Prodeshayesites fissicostatus* (PHILIPPS) which would explain the seemingly anomalous age of the Luitere Bed in the Grünten area (Bogdanova, pers. comm.).

A review of the literature on a large number of outcrops of the Luitere Bed covering the entire Delphino-Helvetic Zone (mainly Föllmi 1986, Ouwehand 1987 and Delamette et al. 1997, but also Rick 1985) shows that the Luitere Bed mostly documents the two earliest ammonite zones of the Late Aptian, the *Subnodosocostatum* and *Melchioris* Zone. Only rare ammonite finds from a few outcrops document a range of phosphogenesis down to the Early Aptian *Furcata* Zone or up to the Late Aptian *Nolani* Zone. Only in two outcrops other than Grünten, ammonites older than the *Furcata* Zone are known (in western Austria; see Föllmi 1986, p. 216 and Heim & Seitz 1934, p. 229).

These observations lead to the following interpretation: The Luitere Bed is most probably relatively isochronous throughout the Delphino-Helvetic Zone, with a beginning not to far below the boundary between the *Furcata* and the *Subnodosocostatum* Zone and an end not to far above the boundary between the *Melchioris* and *Nolani* Zone (Fig. 2). The significantly older age of the Luitere Bed at Grünten and two other outcrops points to a local reworking of an older phosphorite horizon (equivalent to a phosphorite horizon contained within the Grünten Member of the Rawil section; cf. section 2.D, Fig. 8) during the deposition of the Luitere Bed, leading to an apparently anomalous age for the onset of the thus extended Luitere Bed. The bundling and mixing of phosphorite horizons by means of reworking is a frequent phenomenon in neritic phosphorites and has often caused confusion (e.g. Föllmi & Ouwehand 1987, p. 144f.). This is also observed in the reference section Rawil, where the aforementionned phosphoritic horizon within the Grünten Member and the Luitere Bed laterally merge into one single bed (Gainon 2001).

This interpretation is underpinned by the following observation: The presence of a phosphorite horizon in the Grünten Member of the relatively proximal Rawil area and the presence of a phosphorus-enriched horizon in the central outcrop of the Morschfeld section (see next section) show that such a phosphorite horizon may well have existed also in other proximal locations such as the Grünten area (Fig. 8). Thus, the correlation of these two horizons with the rock record at Grünten

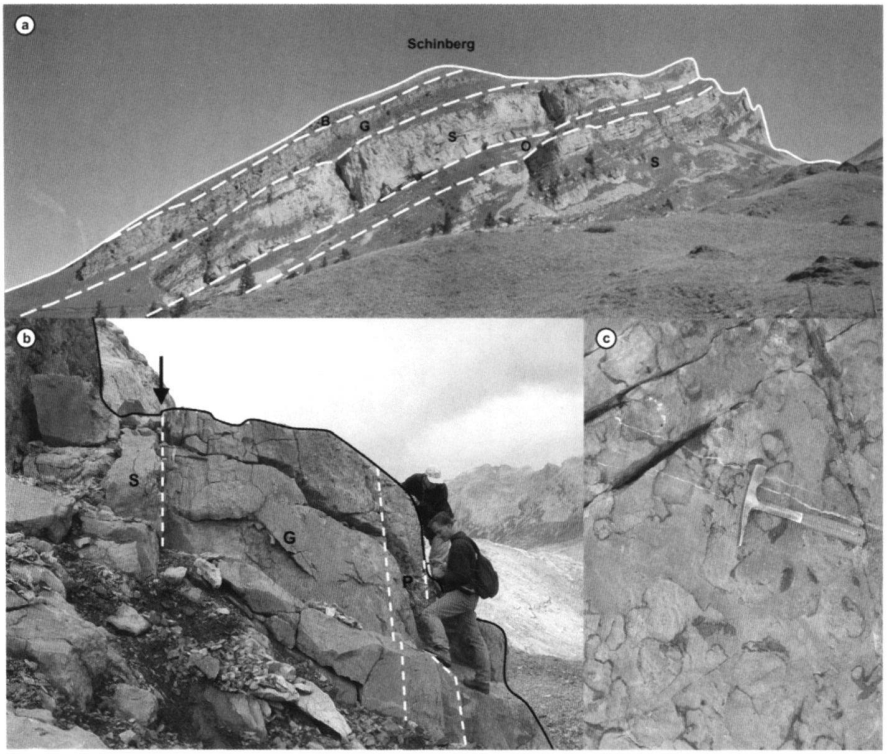

Fig. 6. *A)* Lectostratotype locality of the Grünten Member at Morschfeld in Central Switzerland. B: Brisi Member, G: Grünten Member of the Garschella Formation. S: Schrattenkalk Formation, O: Orbitolina Member of the Schrattenkalk Formation. B) Outcrop at the hypostratotype locality of Rawil displaying the lower (arrow) and upper phosphorite horizons (marked P). C) Close-up of the upper phosphorite horizon.

shows that the corresponding uppermost part of the section is probably missing in Grünten due to reworking.

These considerations also explain why the Luitere Bed of the Grünten area was attributed by Heim (1919) to his "Grünten beds". The original definition of Heim was exclusively based on the faunal elements that predate the *Furcata* Zone. So, while the Luitere Bed remains an independant lithostratigraphic unit, it is important to note that in some locations it may contain reworked elements of an older phosphorite horizon that originally belonged to the Grünten Member (i.e. a bed equivalent to the phosphorite horizon contained within the Grünten Member of the Rawil section).

C) Type Section Morschfeld

Situation:

The new type section (lectostratotype) of the Grünten Member is situated at the southward facing cliff of the Schinberg Mountain (2110 metres above sea level). It is situated in the Drusberg Nappe of the Bauen-Brisen range (Central Switzerland; WGS 84 coordinates: 08° 28' 05.48'' E, 46° 54' 57.13'' N / Swiss coordinates: 678'425/196'600; See Figs. 4, 6a, 8).

Description:

In the (lecto)type locality, the Grünten Member measures 32 meters. It overlies the Schrattenkalk Formation with a hiatus, forming a bioturbated firmground with belemnites, oysters and rare ammonoids (*Pseudohaploceras cf. matheroni* (D'ORBIGNY)). No indications for an emersion and karstification associated to the sequence boundary were observed. The firmground is covered by a centimeter-thin sandy-marly joint with small amounts of glauconite. The base of the section is overlain by 2 meters of transgressively resedimented crinoidal-bryozoan limestones with fragments of reworked sediment from the Schrattenkalk Formation (grainstones of the microfacies FT). Above follow sandy marls (wackestones of the microfacies F1) passing gradually to sandy limestones (packstones of the microfacies F3) with interbedded chert horizons (often silicified *Thalassinoides* burrows) and then to crinoidal limestones with peloids, bryozoans and small amounts of glauconite (grainstones of the microfacies F4). Whereas most of the succession is extremely poor in macrofossils, the crinoidal limestones at the top can contain huge numbers of brachiopods (*Burrirhynchia sayni* (JACOB & FALLOT 1913)), belemnites and some rare ammonites (badly preserved, doubtful forms of *Dufrenoyia(?) sp.*; might rather be late forms of *Deshayesites sp.*), pointing to a late Early Aptian age (*Deshayesi*, maybe *Furcata* Ammonite Zone). Apart from frequent bioturbation, the succession is remarkably poor in recognizable sedimentary structures. Only in the crinoidal limestones at the top, crossbeddings were noted in some outcrops of the Bauen-Brisen area (Keller 1983). The top of the section is marked by a hiatus and is overlain by the phosphorites of the Luitere Bed.

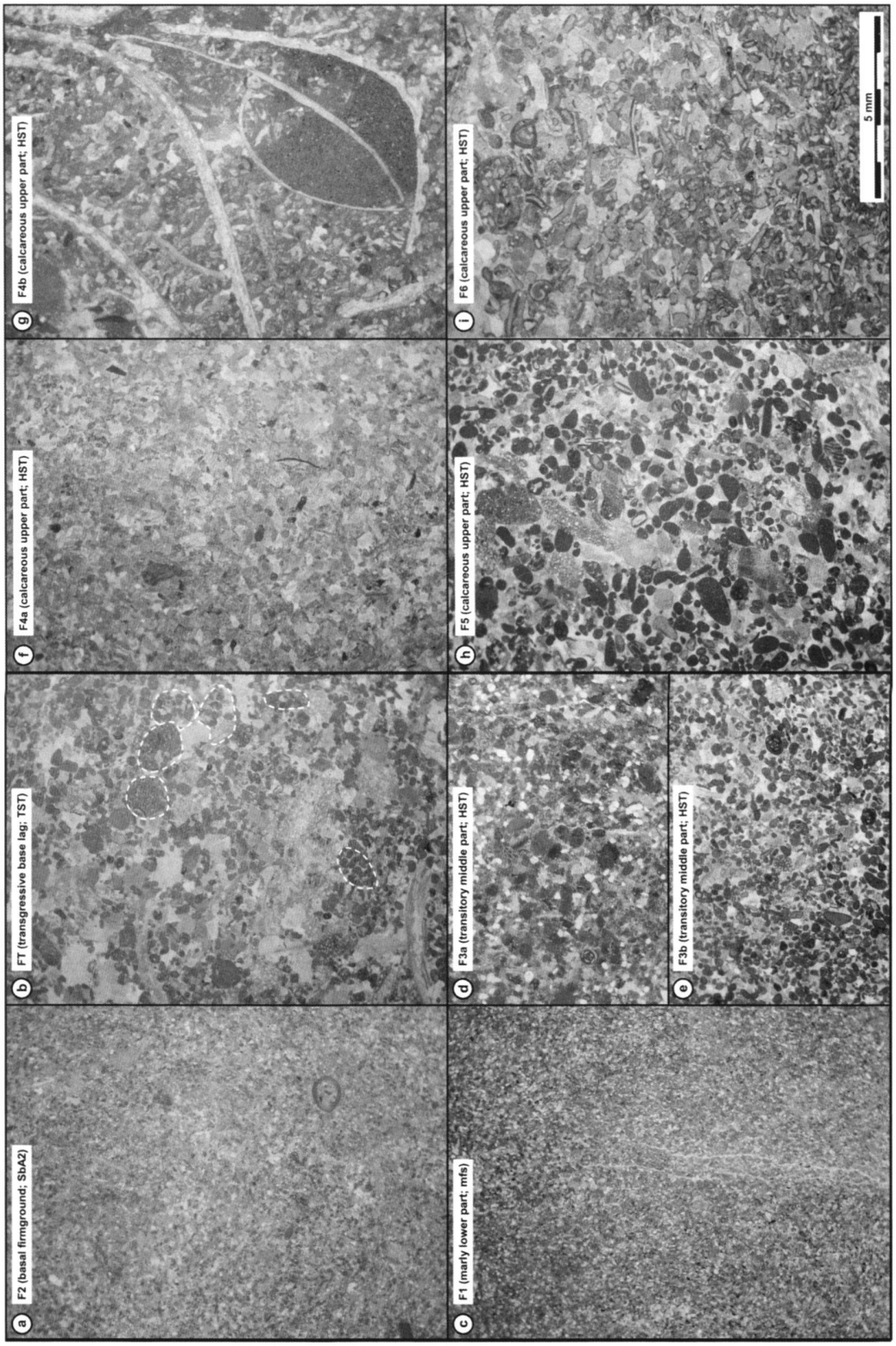

Fig. 7. Thin section photographs of typical microfacies types from the Grünten Member, given in the order of their stratigraphic succession (cf. microfacies codes in Fig. 9). Samples e, h and i are from the Huserstock section (Fronalpstock area, Central Switzerland), g is from the Gütsch section (Bauen-Brisen area, Central Switzerland), all other samples are from the lectotype section of Morschfeld (Bauen-Brisen area; cf. Fig. 2). All photos are given at the same scale (roughly 7x). The dashed lines in photo b mark extraclasts.

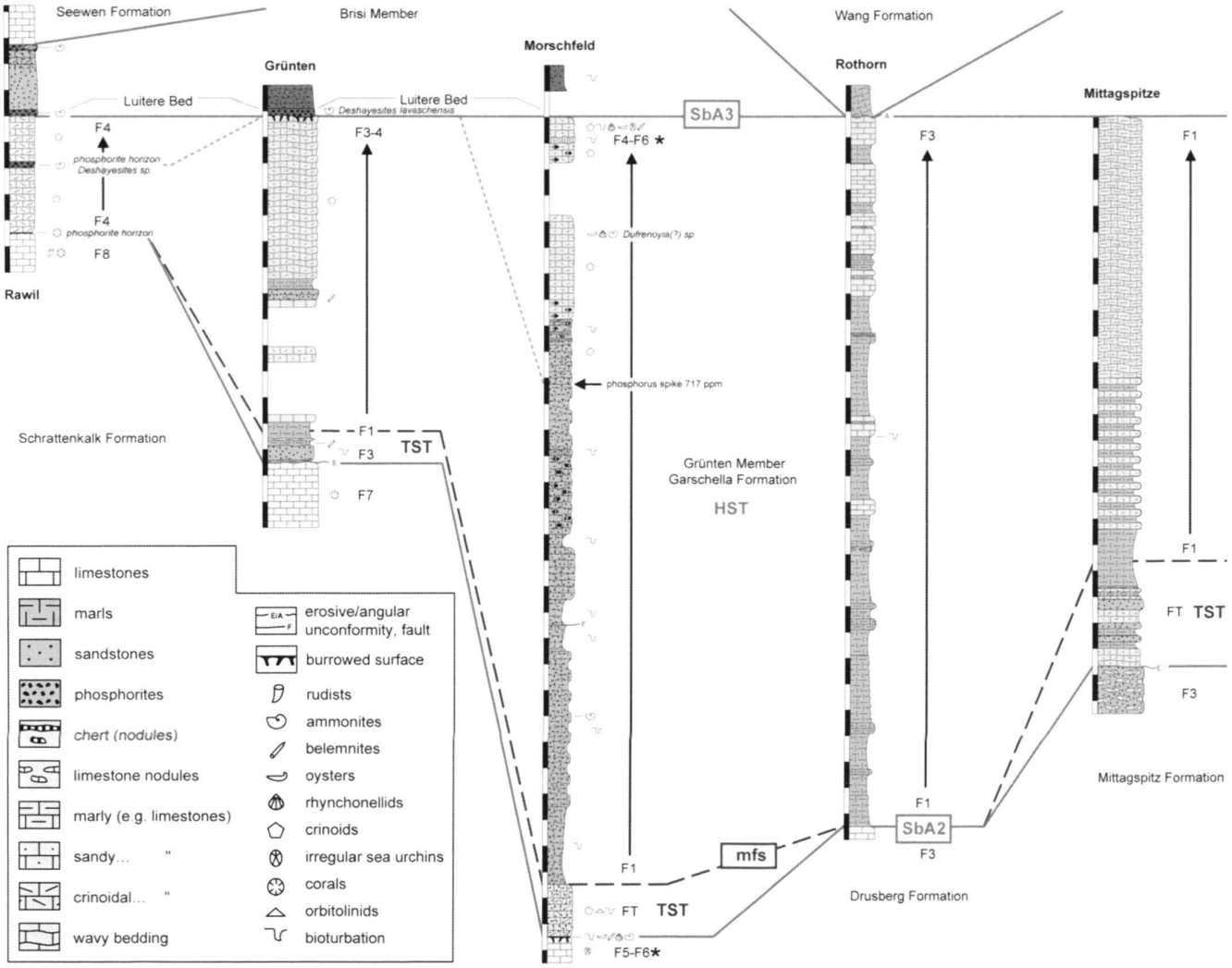

Fig. 8. Speculative lithostratigraphic correlation and sequence stratigraphic interpretation of some characteristic sections from the Grünten Member along a hypothetical transect of the distal Helvetic Realm. The profiles are aligned relative to the underlying Urgonian Carbonate Platform (as defined by the distality of the microfacies associations at the +/-isochronous time line of the sequence boundary SbA2). Relatively proximal sections are on the left, relatively distal sections on the right. The Grünten Section marks the approximate position of the Urgonian Carbonate Platform barrier. Vertical arrows mark facies trends. Microfacial information in the Morschfeld profile is supplemented by information from the Huser Stock section (marked by asterisks). Microfacial and sequence stratigraphic codes as defined by Arnaud-Vanneau (2005). The scales are in metres. Inset: Symbol key for Figs. 3–5 and 8. Microfacies codes: see Fig. 9.

Remarks:

The section has already been described by Fichter (1934), Gebhardt (2001) and Wissler (2001). To the paleogeographic northwest of the type region, the sediments of the Grünten Member progressively lose their marly lower part and thus diminish quickly in thickness. In the upper, crinoidal part of the section, a peak in phosphorus has been detected (cf. Fig. 8 and remarks in the previous section). Such a peak has also been found at a similar stratigraphic level of another, nearby section (Huser Stock section, Fronalpstock area).

D) Reference Section Rawil

Situation:

The new reference section (hypostratotype) of the Grünten Member is situated near the Plaine Morte Pass (2716 metres above sea level) in the Wildhorn Nappe (Bernese Oberland, Switzerland; WGS 84 coordinates: 07° 27' 17.58" E, 46° 22' 41.69" N / Swiss coordinates: 601'250/136'320; See Figs. 5, 6.b,c, 8).

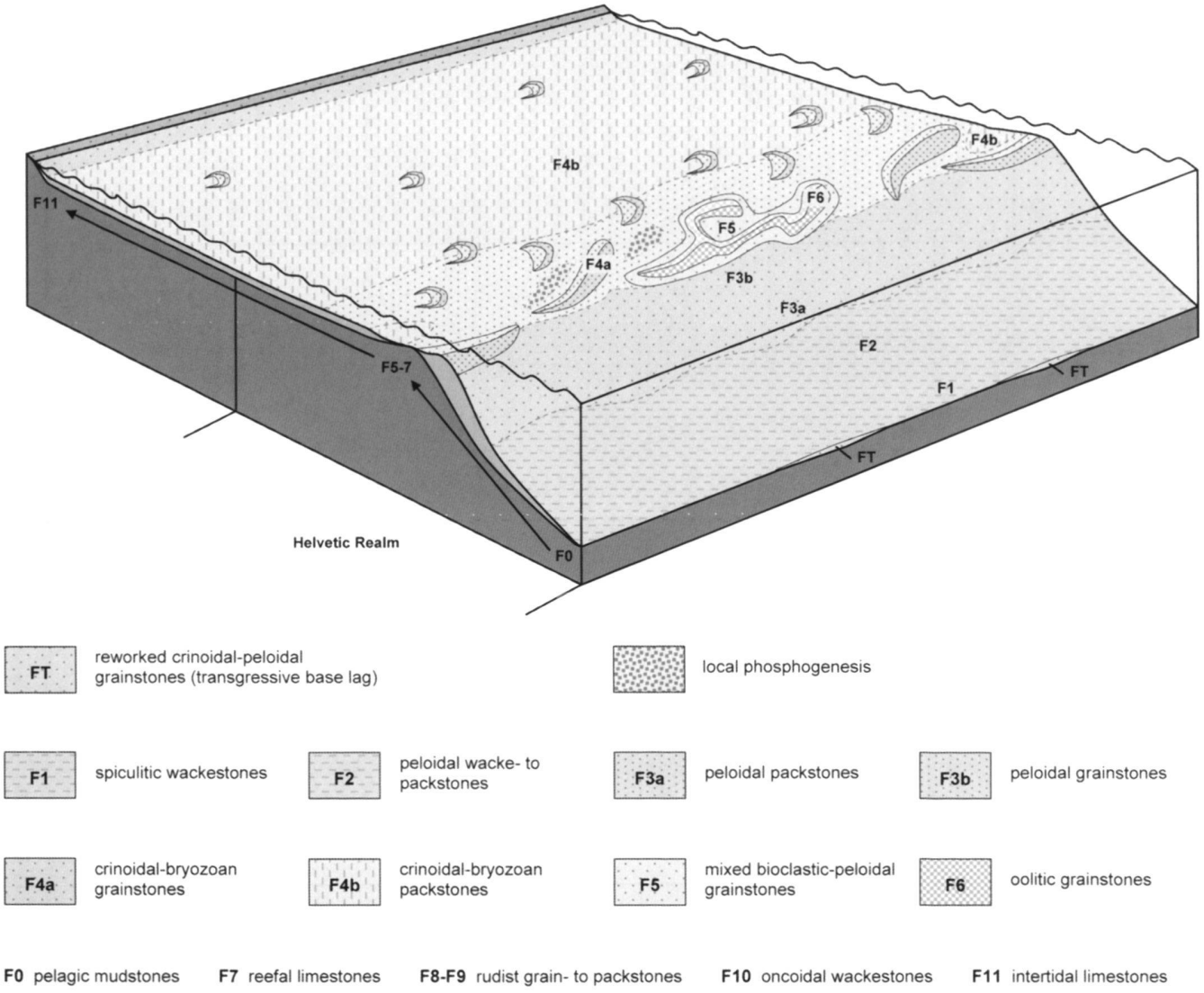

Fig. 9. Speculative, highly simplified schematic block model reconstructing the Grünten Ramp on the Northern Tethyan Margin. The underlying, demised Urgonian Carbonate Platform is marked in dark grey. Note local areas with intermittant phosphogenesis. Microfacies codes follow the nomenclature of Arnaud-Vanneau (2005); The arrows mark the microfacies trends in the underlying Urgonian Carbonate Platform.

Description:

In the Rawil area, the Grünten Member measures only 4 meters at best. It overlies the Schrattenkalk Formation with a hiatus. This hiatus is expressed by a hardground which is overgrown by incrusting corals and impregnated by phosphate. This unconformity is overlain by crinoidal limestones; i.e. crinoidal grainstones with peloids, bryozoans and small amounts of glauconite (microfacies F4). Above the middle of the succession, a second phosphorite horizon is interbedded in the limestone. Rare ammonites (late forms of *Deshayesites sp.*) from this horizon point to a late Early Aptian age (*Deshayesi* Ammonite Zone). The top of the section is marked by another hiatus which is overlain by the phosphorites of the Luitere Bed. Laterally, the Luitere Bed and the aforementionned phosphoritic bed within the Grünten Member merge into one bed. Following this trend, the Grünten Member wedges out completely within a few hundred meters (Gainon 2001).

Remarks:

The importance of the Rawil outcrop as a reference section lies in the extraordinary presence of a phosphoritic horizon within the Grünten Member, and thus predating the Luitere Bed. Furthermore, the reduced thickness of the Grünten

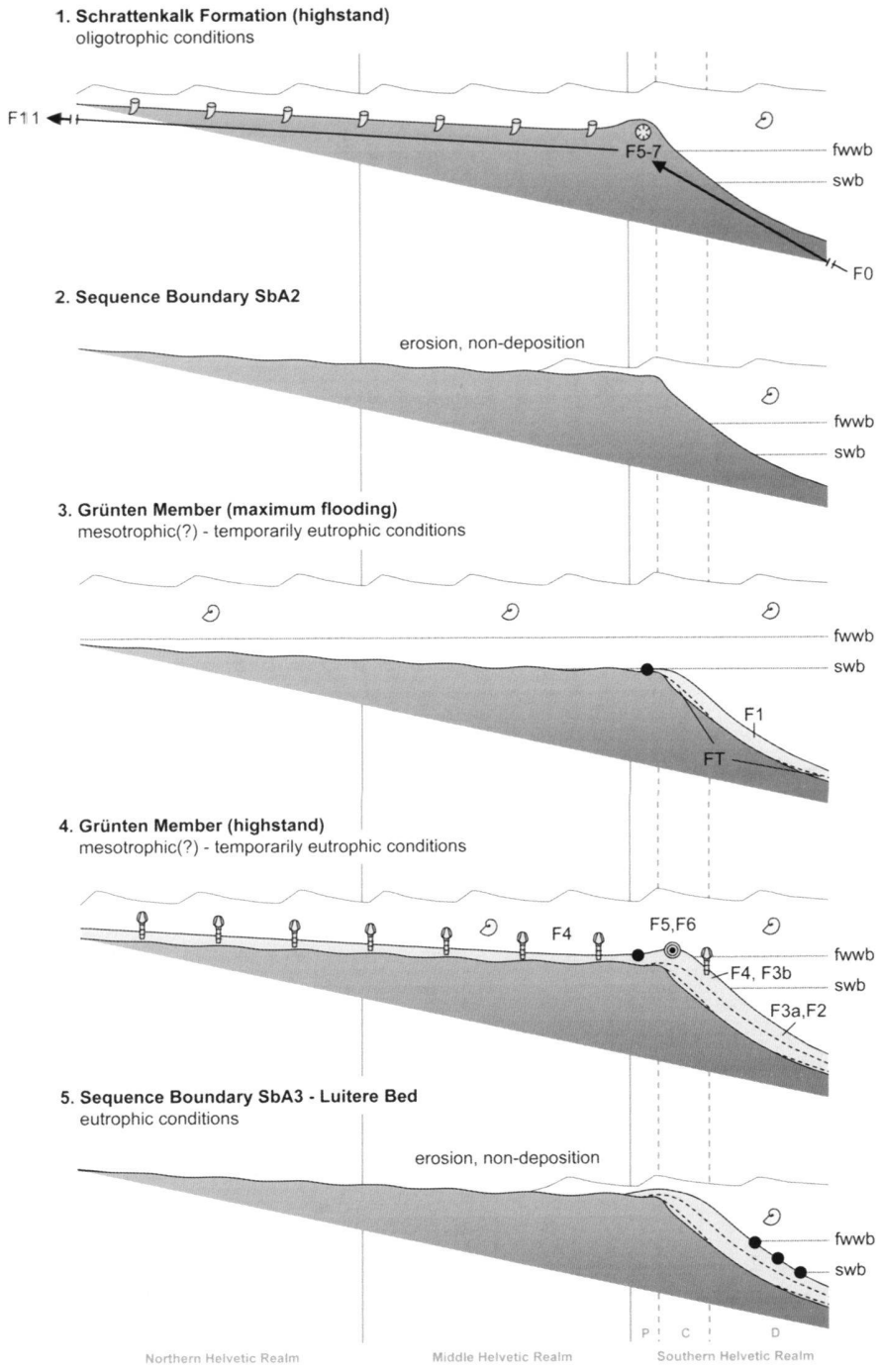

Fig. 10. Speculative, highly simplified schematic sequence depicting the demise of the Urgonian Carbonate Platform and the subsequent installation of the Grünten Ramp. Microfacies codes follow the nomenclature of Arnaud-Vanneau (2005; cf. microfacies codes in Fig. 9); the arrows mark the microfacies trends in the underlying Urgonian Carbonate Platform. The hatched horizontal lines mark the storm wave base and the fair weather wave base, the vertical dashed lines mark the proximal, central and distal parts of the Southern Helvetic Zone. Black dots mark spots with local phosphogenesis.

Member documenting only the calcareous upper part of the succession of the Grünten Member is typical for proximal outcrops of the Grünten Member. The Rawil outcrop of the Grünten Member was first described by Schaub (1936) but due to the presence of the aforementioned phosphoritic bed, he mistook the upper part of the section as a part of the Luitere Bed.

3. Discussion

The Grünten Member has been established as a new, basal member of the Garschella Formation. Its thickness and microfacies closely follow the morphology and facies of the underlying Urgonian Carbonate Platform. Based on its heterozoan-dominated sedimentary facies and especially due to the local

presence of phosphorite horizons, the Grünten Member however shows more affinities to the overlying members of the Garschella Formation, thus documenting the initial drowning phase of the photozoan-dominated Urgonian Carbonate Platform.

Based on the here presented sections (cf. Figs. 3–5 and 8), their microfacies (cf. Fig. 7) as well as their spatial and sequence stratigraphic relationships (cf. Fig. 8), the Grünten Member can be reconstructed to document distal parts of a heterozoan-dominated, distally-steepened carbonate ramp that blanketed the just demised and not yet subsided Urgonian Carbonate Platform, thus representing the remains of an originally much larger area of deposition. A hypothetical block model of the Grünten Ramp and a sequence of sketchs depicting its probable evolution are presented in figures 9 and 10.

We would like to point out the few following, noticeable observations in particular: 1) As documented by the observed crinoidal and oolitic grainstones (microfacies F4 and F6), the Grünten Ramp was rimmed by a belt of crinoidal and in some places even oolitic shoals and/or dunes. Oolites thus do not seem to be limited to photozoan-dominated settings such as reef-rimmed carbonate platforms, but rather to shallow settings. 2) The absence of lagoonal microfacies and the presence of ammonites even in the most proximal outcrops of the Grünten Member show, that the Grünten Ramp was a *much more open system than the underlying Urgonian Carbonate Platform.* 3) As illustrated by the widespread occurrence of crinoidal-bryozoan limestones (microfacies F4), the ecology of the Grünten Ramp was heterozoan-dominated even in the most proximal (respectively shallow) settings preserved. This observation is confirmed by the absence of green algae in the grainstones of microfacies F5 (the equivalent microfacies in the Schrattenkalk Formation almost always bears green algae).

The observed phosphorites within the Grünten Member are an indicator for at least short episodes of seawater eutrophication (Föllmi 1989; Föllmi et al. 1994). They might therefore be related to coeval black shale deposits in pelagic settings (e.g. the Selli Level). The demise of the Urgonian Carbonate Platform and the deposition of the Grünten Member might thus fit into the bigger picture of paleoceanographic events around the Oceanic Anoxic Event 1a.

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