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A Study of the Lower Cretaceous Facies Developments in the Helvetic Border Chain, North of the Lake of Thun (Switzerland)[1]

By Martin A. Ziegler[2]

With 11 figures and 1 table in the text and 2 plates (I and II)

ABSTRACT

In an area north of the Lake of Thun, Switzerland, a well-exposed facies change of Lower Cretaceous (Barremian) age has been investigated. A localized carbonate build-up has been formed as a result of syngenetic fault movements. The vertical rock sequence illustrates a sedimentary cycle that started with a phase of submergence, as shown by transgressive sediment types. With retardation of subsidence, the production of lime sand set in and the sedimentation was then governed by a regressive regime. The Barremian sedimentary cycle finally terminated in emergence and subaerial exposure. It was possible to differentiate characteristic sediment types according to the various depositional environments. An attempt has been made to interrelate the biology with the appropriate environments.

Introduction

Cretaceous oil reservoirs in the southern part of the Persian Gulf show considerable lateral lithological variations that are related to localized carbonate build-ups. These variations are clearly reflected by the fauna. A study aimed at a better understanding of the biological changes and their interrelationship with the lithology was therefore initiated in a comparable geological province.

The excellent and easily accessible exposures in the Helvetic nappe north of the Lake of Thun in Switzerland were chosen because they furnish a good three-dimensional stratigraphic network of sections. The stratigraphic interval examined includes the top of the Hauterivian rock sequence, the Barremian sedimentary cycle and parts of the Lower Aptian.

Tectonical setting of the area investigated

The tectonic setting is shown in Fig. 1 and Pl. 1, Fig. 1. The whole area, including the crest of the Rothorn and Niederhorn as far as the Habkern Valley, belongs to one thrust sheet. It is the normal limb of a recumbent anticline which can be followed

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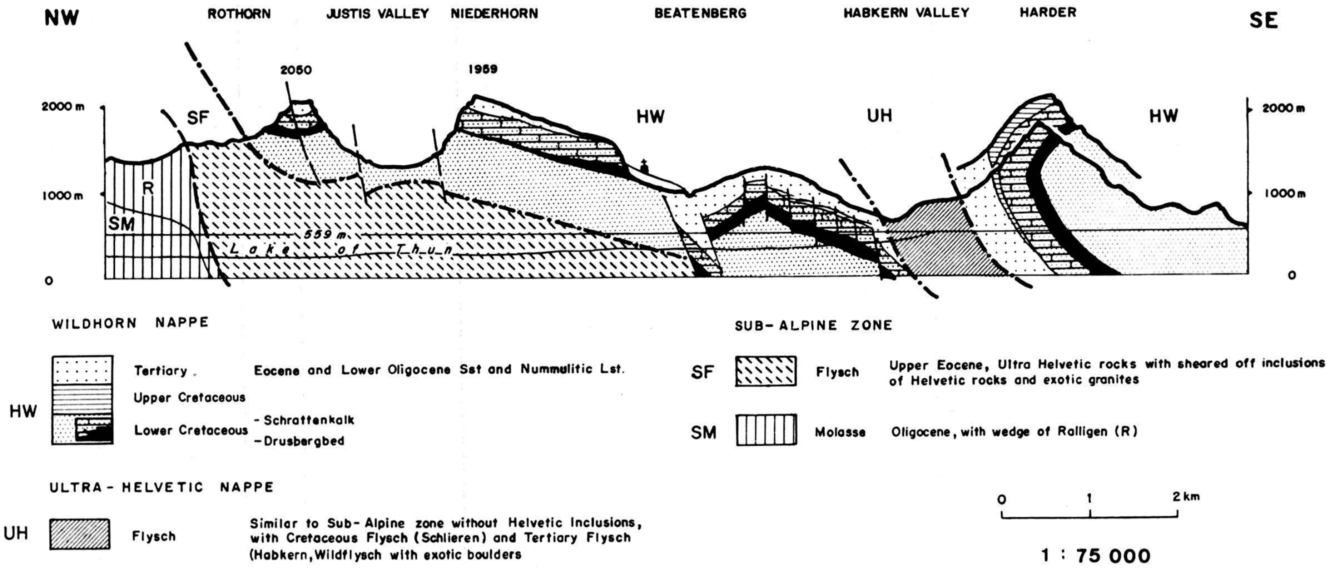

Fig. 1. Composite cross section through the mountains north of the Lake of Thun according to BECK 1938; see also Pl. 1, Fig. 1.

north-eastwards for a distance of about 50 km, as far as Lake of Lucerne. This thrust sheet, which forms a prominent morphological feature, is called the Helvetic border chain. It represents a digitation of the Wildhorn nappe (= Niederhorn-Teildecke of BECK 1911). This digitation consists essentially of Lower Cretaceous and Middle to Upper Eocene formations (the Upper Cretaceous and Paleocene are missing owing to non-deposition and to pre-Eocene erosion). It has been sheared off of its underlying strata at the level of the Valanginain limestones and marls. At Mount Harder, the Cretaceous fold is in a reversed sequence in contact with its strongly folded Jurassic core, which lies farther to the south.

The Habkern Valley, which separates a northern and a southern outcrop area of Helvetic rocks, has formed in a downfold of Ultrahelvetic sediments (mainly Flysch, see GIGON 1952). The thrust sheet as a whole lies on subalpine Flysch deposits of Upper Eocene age. North of the Alpine border, the folded and thrust subalpine Molasse is encountered.

The Niederhorn sheet dips south-eastwards and is deeply dissected by the Justis Valley. Exposures occur on the NW flank of the Rothorn crest, both sides of the Justis Valley and along the lake shore. The Mount Harder and Därlig crests also give good exposures.

The rock types of the Lower Cretaceous of the Helvetic nappes

The Lower Cretaceous rocks of the sedimentary complex overlying the Aar Massif are about 100 m thick, except where pre-Eocene erosion has removed them. They thicken rapidly towards the south and attain a thickness of about 1500 m in the higher Helvetic nappes (Säntis-, Drusberg- and Wildhorn nappes).

The predominant rocks are shallow water limestones, including oolites and calcarenites (= Urgonian facies[3]), pelletal and onkoidal limestones, as well as calcareous shales and siliceous limestones and shales. Glauconitic beds, sometimes with phosphatic fossil casts, form subdivisions in various groups and formations.

Southwards, towards the alpine geosyncline, most of the shallow water sediments pass laterally into shales or fine-grained, pelagic limestones.

Lithology of the Barremian rocks in the Helvetic realm

The Barremian rock sequence of the highest Helvetic nappes represents an intermediate facies between the basinal south-Helvetic sediments and the reduced sequence to the north. Generally, it can be subdivided from top to bottom as follows:

- Lower Schrattenkalk, partly replaced by Drusberg bed facies,
- Drusberg beds,
- Altmann beds.

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[3] Urgonian facies: light-coloured, bioclastic limestone of Barremian-Aptian age, formed by partly worn organic debris of rudists, corals, stromatoporoids, bryozoans and large nerineids. Type locality: Orgon in the south Rhône valley (France) (Int. Stratigraphic Lexicon, 1960). The term Urgonian describes a facies of mainly Toucasia (requieniid rudist) bearing limestones and associated carbonates of Barremian and Aptian age (HÄFELI 1964).

Altmann beds

The Altmann beds[4] form a relatively thin member (in maximum about 10 m thick) at the base of the Barremian interval, which is rich in glauconite and in some places in phosphate nodules. These beds represent a period of reduced deposition at the top of the upper Hauterivian cycle. The ammonites, which occur with a specific concentration in this member, indicate Barremian age. This unit, or the equivalent hard grounds and non-sequences, may be traced throughout the middle and southern Helvetic belt. It disappears only towards the axis of the geosyncline, where sedimentation was more continuous.

Such glauconite horizons are well known from the Cretaceous of the Helvetic realm; they seem to be related to rhythmic sedimentation. The interpretation of these carbonate cycles has given rise to various speculations as to the mechanism involved (ARBENZ 1919, HEIM 1921, FICHTER 1934, BRÜCKNER 1951 and 1953).

The following theories, which might explain the origin of sedimentary cycles, are pointed out:

- Tectonical control: causing episodic subsidence of a sedimentary basin, combined with uplift of the adjacent hinterland.
- Episodic subsidence in a system of a persistent subsidence; the sedimentary cycles are formed by a 'filling-in' phase subsequent to a rapid subsidence (KRYNINE 1959).
- Continuous subsidence with superimposed effects of eustatic sea level changes may cause rhythmic sedimentation (WELLS 1960); eustatic sea level changes may be produced by periodic glaciations or by alternations in the shape of ocean bottoms as a result of orogenic movements.

The position of thick glauconitic horizons in relation to the Helvetic sediment cycles is such that they are intercalated between sediments which indicate the shallowest environment of deposition of the underlying sedimentary cycle and sediments of relative deeper environment of deposition of the overlying sediment cycle.

Drusberg beds

The shaly facies in the lower part of the Barremian series is made up of Drusberg beds[5]. It is a rock sequence of dark-blue-grey, calcareous shales alternating regularly with argillaceous limestone beds up to 20 cm thick.

The thickness of the Drusberg development is variable. Depending on the shelf topography and on the position relative to the palaeo-shelf margin, it may replace

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[4] The type locality of this member is at Mt. Altmann, which is part of the Säntis range in eastern Switzerland. The Altmann beds attain a thickness varying between 0 and 20 m. Lithologically they are characterized by their nodular, green-sandy to glauconitic quartz sand development and by their specific ammonite, belemnite and oyster content; see definition in Lexique stratigraphique, 1966.

[5] The type locality of the Drusberg beds is at the Drusberg about 30 km east of Lucerne. The Drusberg formation has an average thickness of about 200 m, sporadically up to 300 m. The facies development is very similar to that of the underlying Hauterivian siliceous limestone. The lower boundary towards the Altmann beds is lithologically clearly defined, whereas the upper boundary towards the Schrattenkalk is typically facies-bound and diachronous; for definition see Lexique stratigraphique, 1966.

parts or the whole of the Schrattenkalk complex. In general the thickness of the shaly facies increases from north to south. In the autochthonous and lower Helvetic nappes, the Drusberg beds are replaced by oyster beds (so-called Sinuata beds). The Drusberg beds attain a thickness of about 50 m in the middle Helvetic facies belt and thicken to a maximum of 200–300 m farther south.

The Drusberg beds contain a monotonous, autochthonous fauna, consisting mainly of sponge spicules, very fine echinoderm fragments and some radiolarians, as reported by STAEGER (1944).

A lateral transition from Urgonian facies to the Drusberg shales is present in the higher Helvetic nappes. South of a line through Mt. Alvier in the east and Mt. Wildhorn in the west of Switzerland, the whole Barremian consists of Drusberg shale facies. This facies change is accomplished in a horizontal distance, across the strike, of less than 10 km. The lines of identical facies development run almost parallel to the Alps, i.e. W 30° S (ARN. HEIM 1921).

Schrattenkalk

The most noticeable rock type of the Barremian sedimentary cycle is the lower Schrattenkalk⁶). This limestone member forms prominent cliffs up to 300 m high (Fig. 2). The Schrattenkalk may terminate in a fully developed cycle with Urgonian facies. In this case the rudist packstone is the end stage of a grade that passes from a normal marine, bioclastic wackestone-packstone through a series of well-sorted grainstones.

Urgonian facies can be recognized in the middle Helvetic facies belt up to the Upper Aptian (= deposition of upper Schrattenkalk) where it extends farther south over deeper water sediments of Drusberg facies.

The boundary with the Aptian is typically formed by the somewhat argillaceous '*Orbitolina* beds' (named after the occurrence of *Orbitolina* cf. *lenticularis* (Blumenbach)). However, this interval cannot always be recognized and it then becomes difficult to separate the upper Schrattenkalk with the *Orbitolina* beds from lower Schrattenkalk, or to draw a boundary between Barremian and Aptian.

The Barremian facies change north of the Lake of Thun

The palinspastic cross section through the mountains north of the Lake of Thun (Pl. 2) shows in principal the distribution of Barremian sediments. In addition, in the southern part only, the Aptian facies is also displayed. The Barremian and Aptian calcareous sequence is truncated by the Eocene clastic sequence of the so-called Hohgant sandstone. This sandstone overlies the limestone sequence with low angular unconformity.

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6) Schratten, a synonym of Karren, means clints or lapies; i.e. as on a limestone surface which is irregularly corrugated and furrowed by chemical weathering. The Schrattenkalk is called after the Schrattenfluh, 20 km NE of Thun; at this locality the Schrattenkalk attains a thickness of more than 150 m and only reaches as far as the Aptian Lower *Orbitolina* beds. The lower parts of the Schrattenkalk have repeatedly revealed a glauconite horizon which has been taken as evidence of a subdivision of the Barremian sedimentary cycle in two subcycles (LIENERT 1965); see definition of Schrattenkalk in Lexique stratigraphique, 1966.

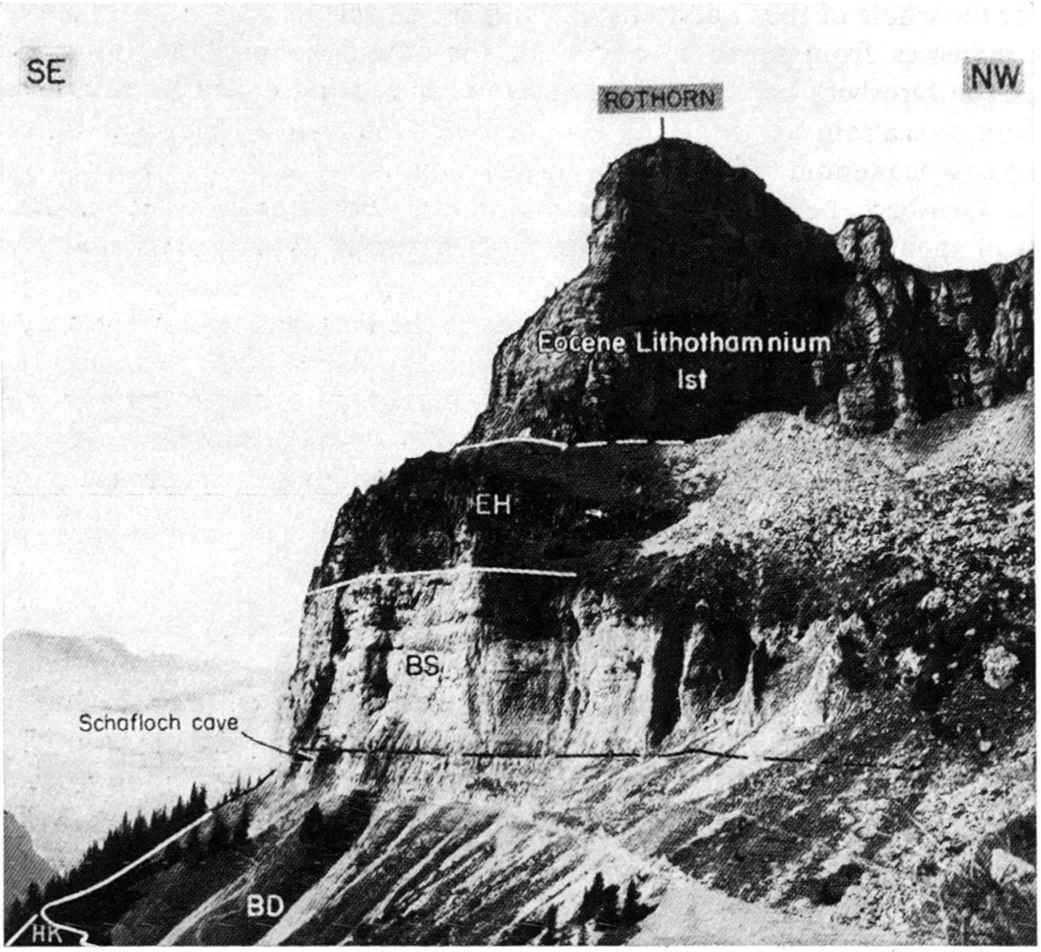

Fig. 2. View of the mouth of the Justis valley. The Rothorn shows at the base about 65 m of argillaceous Drusberg facies; the top of the Barremian sedimentary cycle is formed by packstones and grainstones of the Schrattenkalk facies. Pre-Eocene erosion has reduced the thickness of the Barremian deposits. *HK* Hauterivian Kieselkalk, *BD* Barremian Drusberg beds, *BS* Barremian Schrattenkalk, *EH* Eocene Hohgantsandstone. Section No. 1, Rothorn; picture taken from 'Vorderer Schafläger', looking towards SW.

Altmann beds

Fig. 2 on Pl. 1 illustrates the lithological development of the relevant stratigraphical sections at the Hauterivian-Barremian boundary.

Lithologically, the Altmann beds belong to the underlying Hauterivian Kieselkalk, a sponge spicular, echinoidal, bioclastic lime wackestone-packstone⁷), see Pl. I, Fig. 2. In sections most distant from the Niederhorn, the Altmann beds grade out of the Kieselkalk with a distinct increase in the glauconite content. Based on ammonite findings (FICHTER 1934) however, the Altmann beds, some 40 km farther to the NE, seem to be of Barremian age. No determinable macrofossils have been found at this horizon in the area studied.

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[7]) The rock description is based on the 'classification of carbonate rocks according to depositional texture' as proposed by R.J. DUNHAM 1961 (DUNHAM 1962).

Contrary to SCHNEEBERGER's (1927) observations, the Altmann beds are not preserved over the entire area. In the stratigraphic sections Nos. 2, 3, 6 and 7 they are missing. In Sections 3, 6 and 7 an unconformity between the Kieselkalk and the overlying Schrattenkalk has been observed (Fig. 3). At other places (Sections 1, 4 and 8) the beginning of the Altmann beds becomes more evident because of the presence of limonite crusts, hardgrounds and traces of reworking (Fig. 4). All these features seem to illustrate the unconformity observed in Sections 3, 6 and 7. Section 12 at Mt. Harder, being most distant from the Schrattenkalk development at the Niederhorn, shows the least disturbed transition from the Hauterivian Kieselkalk to the Barremian sedimentary cycle.

Section 12, Mt. Harder, is from bottom to top as follows:

1. ca. 7 m Glauconitic, massive-bedded, sponge spicular echinoderm lime packstones and grainstones with a few benthonic forams, mollusc and echinoderm fragments lying directly above irregular, wavy and decimetre-bedded Kieselkalk.
2. 0.20 m Glauconitic sponge spicular, bioclastic lime packstones with echinoderm fragments and calcispheres. The glauconite content becomes more concentrated towards the top. Glauconite-free streaks are intercalated in glauconitic shales.

Fig. 3. Unconformable contact between Hauterivian Kieselkalk (*HK*) at the base and Barremian Basisbank (*BB*) at the top. The very sharp contact cuts clearly across the Kieselkalk beds. Section No. 7, Balmholz.

Fig. 4. Hauterivian Kieselkalk breccia deposited in Altmann beds. The Kieselkalk components contain little glauconite and therefore appear as light-grey-coloured boulders, whereas the glauconite-rich Altmann sediments form the dark-grey matrix. Section No. 8, Krutbach.

3.	0.15 m	Irregularly bedded nodular layer with dark-brown-grey brecciated components, belemnites and lamellibranch fragments.
4.	0.25 m	Green, very glauconitic, calcareous shale.
5.	0.20 m	Grey, slightly glauconitic, argillaceous lime mudstone.
6.	0.70 m	Grey to grey-brown, calcareous shales, morphologically weathering back, with very thin-walled echinoderms and a few scattered pyrite cubes.
7.	4.30 m	Prominent, resistant interval subdivided by thin shale intercalations into 7 beds each about 50–60 cm thick. Fine fragmental-pelletal wackestone with belemnites, sponge spicules, echinoderm fragments and small benthonic forams, slightly dolomitic. There is little quartz and glauconite present. Pyrite occurs in concretions up to 2–3 cm in diameter.
8.	1.20 m	Calcareous shales, weathering back, with rusty, oxidized pyrite nodules.
9.	0.50 m	Cherty, fine fragmental, pelletal lime wackestone-packstone with horizontal burrows, echinoderms and probable sponge fragments. Some glauconite is present.

Nos. 1 and 2 represent the uppermost Hauterivian Kieselkalk; Nos. 3–5 Altmann beds (after Beck 1911, Nos. 2–5). Layer 3 shows the first sign of sediment condensation and is therefore considered as the base of the Altmann member. Nos. 6–9 can be attributed to the Drusberg beds.

In sections No. 3 (Bärenpfad) and No. 7 (Balmholz) a cross-bedded, highly fossiliferous grainstone (Pl. 2*B*) overlies, with low angular unconformity, the Hauterivian Kieselkalk. The Kieselkalk shows typical wavy, decimetre bedding. At the Balmholz section (No. 7) a 40 cm thick intercalation of sponge spicular Drusberg facies was observed only 5 m above the base of the Schrattenkalk.

The other sections all represent intermediate stages between the two extreme developments of section No. 12 on one hand and sections Nos. 3 and 7 on the other hand. Profiles 7 and 8 are only 500 m apart from each other but still show a pronounced difference in their sediment sequence, as shown in Pl. II, Fig. 2. This marked change is taken to suggest the presence of a syngenetic fault running roughly in a north-easterly to south-westerly direction. On the northern, up-thrown side of the fault, the top massive-bedded packstone of the Kieselkalk complex has been eroded, whereas on the down-thrown southern limb, eroded Kieselkalk boulders were able to be preserved in a glauconite-rich matrix of the Altmann beds (Fig. 4). Similar fault movements within the Helvetic realm, active since early Jurassic, had been reported by GÜNZLER-SEIFFERT (1941 and 1952) in the Bernese Oberland and by SCHINDLER (1959) in the Helvetic nappes of Glarus.

The vertical fault movements of early Cretaceous time seem to be less intensive than those of Middle Jurassic time, but were probably pronounced enough to form a lime sand producing shoal with a relief of the order of a few tens of metres.

It is postulated that the Niederhorn area represents an up-thrown block of an antithetic fault, tilting towards N–NNW, rather than a narrow centre around the Niederhorn, which is rhythmically moving up and down (SCHNEEBERGER 1927, p. 75). A horst-like configuration could also be presupposed, but no sharp NW limitation of the feature has been found yet.

Drusberg beds and lower Schrattenkalk

For early Barremian time the presence of a shoal around the Niederhorn has been postulated. This shoal serves to explain the localized development of Schrattenkalk in this area. It had already been clearly recognized by SCHNEEBERGER (1927, p. 45) that the Schrattenkalk terminates here with Urganian facies.

In the Barremian sedimentary cycle, lime sand of the type B, Pl. II, has been generated on the crest and flanks of a shoal. This sand forms, so to say, the transgressive or 'beginning clastic' phase of WILSON 1967. Areas in which this relatively thin sheet of coarse fragmental grainstone-packstone (Fig. 5) is overlain by Drusberg beds, SCHNEEBERGER (1927) calls it 'Basisbank' (base layer). The production of lime sand on the shoal afterwards kept up with further subsidence ('filling-in' phase). At that time the deposition of 'Schrattenkalk' began.

There is a gap in the stratigraphical column on the shoal between the Hauterivian and the Barremian, but it is at present impossible to judge how many of the Hauterivian and Barremian sediments are missing below and above the Altmann beds.

The rock succession in the massive Schrattenkalk is best illustrated by the cross section in Pl. II. There is a gradual change from a well-bedded packstone with a normal marine fauna (sediment type C) through cross-bedded, high energy sediments to protected, bank-interior deposits with a fauna adapted to that environment.

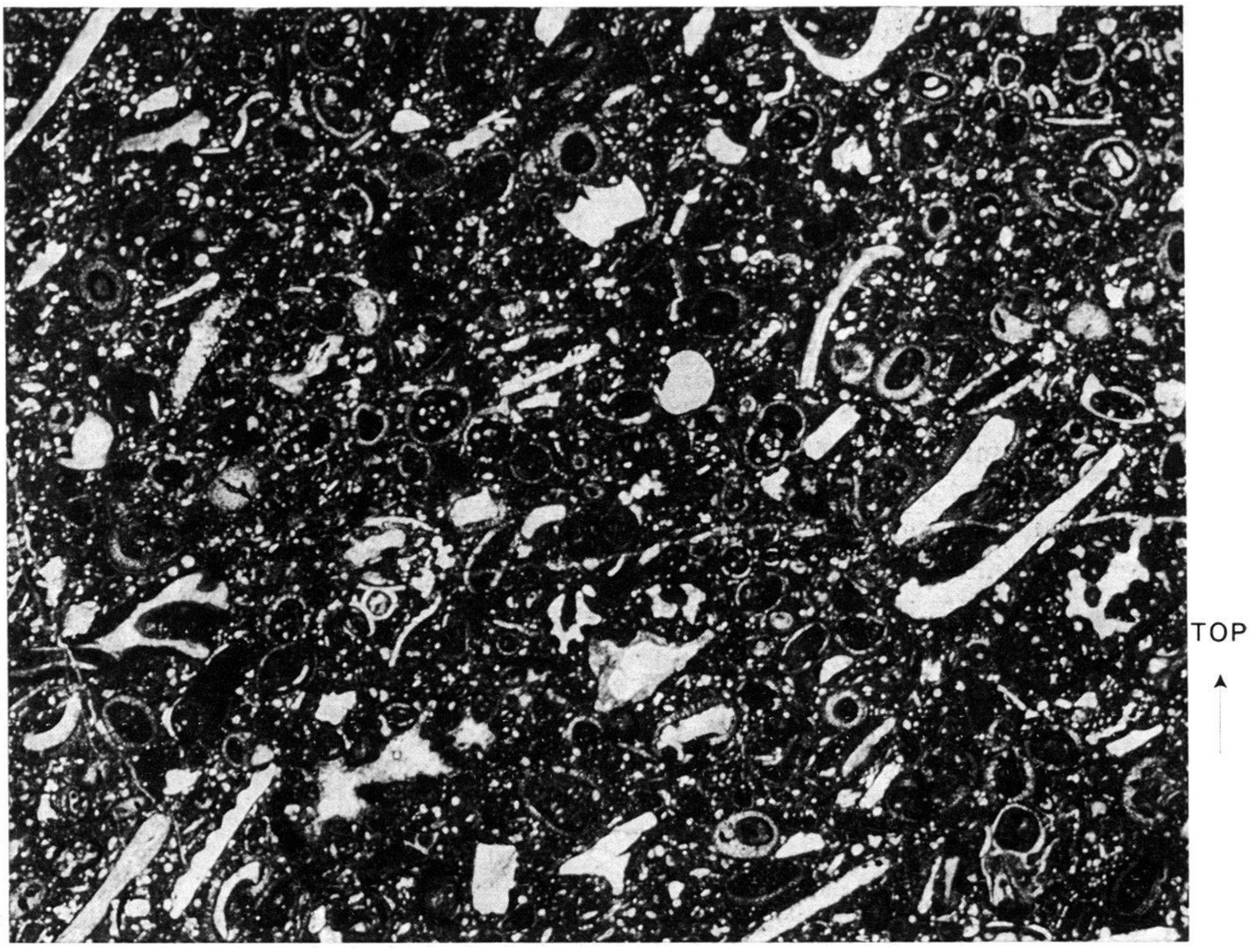

Fig. 5. Basisbank: *oolitic lime packstone.* Very fine, uncoated fragments float in a lime mud matrix. Miliolids and other benthonic forams with an average diameter up to 0.6 mm are oolitically coated. The larger (mainly mollusc) fragments show very little or no coating. It is considered that the oolitic grains are derived from a shoal and are washed by current action into sediments below wave base. The uncoated fossils seem to be autochthonous. Fossil content: fragments of echinoids, molluscs, bryozoa and dasyclad algae; benthonic forams: miliolids, lituolids, trocholinids and orbitolinids. Environment: shallow open marine. Section No. 6, Beatenbucht. Thin section, 10×.

The high energy sediments consist mainly of superficially coated oolites and worn, subangular, skeletal grainstones with a preponderance of dasyclad-algal debris. Lime sand with beach rock cementation (Fig. 6), geopetally oriented lime silt in interstices (Fig. 7) and long grain contacts (Fig. 8) have been observed in 5 different profiles, namely Nos. 2, 3, 4, 9 and 11 at two levels, in the grainstone sequence, one in the lower half and one towards the top. Similar phenomena have been noticed in rock sequences which have been intermittently exposed to air during their deposition. The lower horizon of subaerial exposure is coupled with dolomitized and brecciated sediments, whereas the upper horizon seems to relate to an interval of increased quartz silt and glauconite content.

A detailed comparison between the eastern Swiss Schrattenkalk developments and the present study might reveal whether one of these probably intermittently subaerially exposed levels is to correlate with the glauconite-rich, subcycle boundary, described by Lienert (1965).

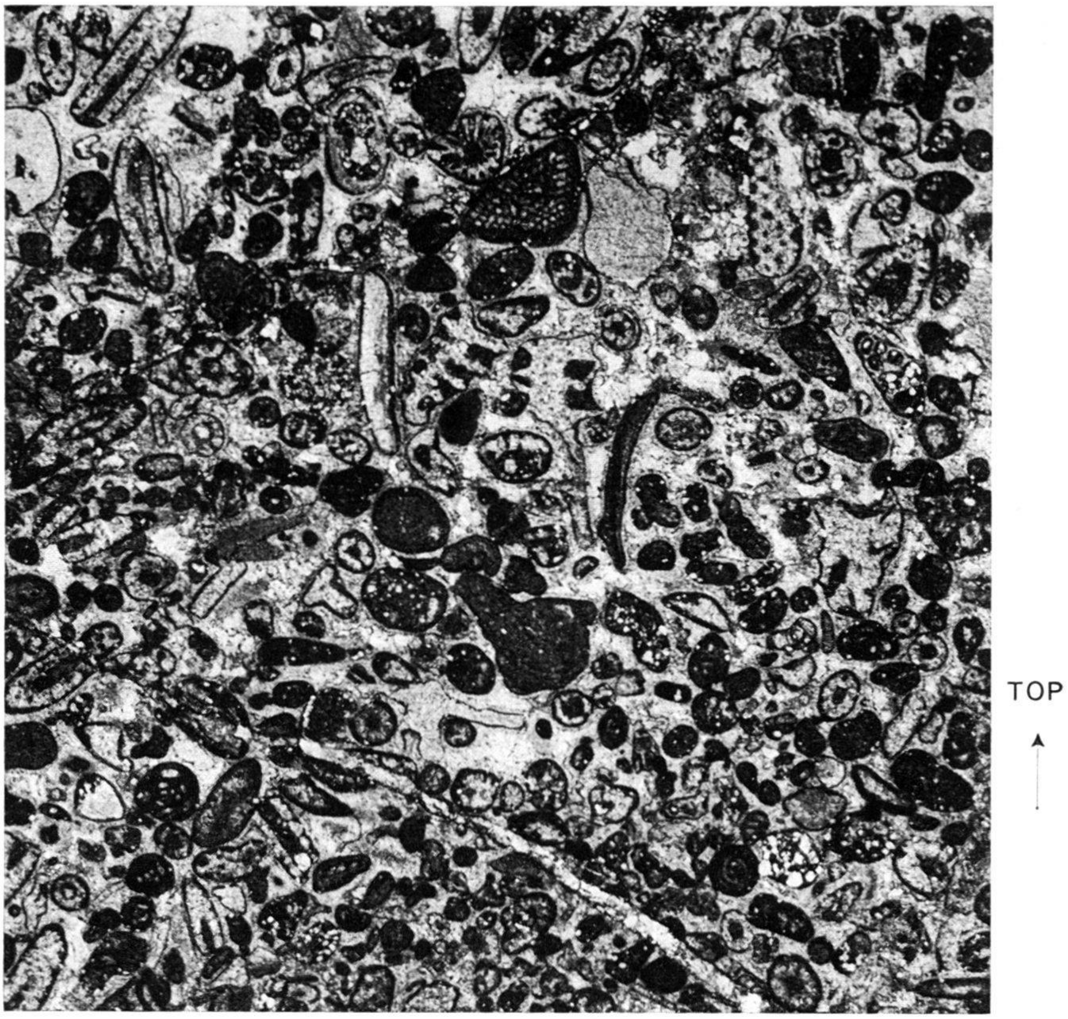

Fig. 6. Schrattenkalk: *dasyclad algal lime grainstone*. The grains are mainly worn fragments of the dasyclad alga *Salpingoporella mühlbergii* (Lorenz), with a few mollusc and crinoid fragments and worn benthonic forams such as miliolids and orbitolinids. The grains are coated by acicular drusy cement similar to that of modern beach rocks. This rock has probably been intermittently out of water. Environment: normal marine, high energy bar complex. Section No. 2, Habernlegi, Acetate peel, 10×.

The bank interior sediments are represented mainly by foraminiferal algal, pelletal wackestones and mudstones (Pl. II *G*, *H*, *I*). The most noticeable fossils in these rocks in the field are the requieniid rudist, *Toucasia* sp. (Fig. 9), monopleurid rudists (Fig. 10) and thick-walled nerineid gastropods. In some sections, farther inward on the bank, several repetitions of requieniid rudist-coquina are found (e.g. section No. 10, Spirenwald). In the topmost 5 m, before the '*Orbitolina* bed' is reached, characteristic, high-spired gastropods appear. These gastropod beds are followed by a relatively thin interval of strongly dolomitized fillings of possible mud cracks. The fauna is reduced to a few scattered, probably reworked, miliolids (Pl. II *J*).

The lowest 20 cm of the '*Orbitolina* bed' consists in sections Nos. 10 and 11 of greenish-grey mudstones which end in a foliated, carbonaceous shale with plant fragments. This mudstone shows some possible root marks or bird's-eye sedimentary structures. It is believed that the Barremian cycle is terminated by the deposition of

Fig. 7. Schrattenkalk: *skeletal lime grainstone* (*packstone*). The grains are not too well sorted and are superficially coated. Note the internal sediment which floors the pore space. The grains are made up mainly of recrystallized, mollusc and probably coral fragments. There are abundant sections through dasyclad algae (*Salpingoporella*), bryozoans, echinoderm fragments and worn conical orbitolinids. This type of sediment, in close connexion with the previously described (Fig. 6) overlying sample, could be expected in a beach complex periodically exposed to vadose conditions. Environment: normal marine high energy bar complex. Section No. 2, Habernlegi, Acetate peel, 10×.

these beds, belonging to a high intertidal to supratidal environment. The upper part of the *Orbitolina* beds is part of the new transgression of the Aptian sedimentary cycle.

The upper Schrattenkalk (Aptian) is clearly bedded in layers 5–10 cm thick, with irregularly intercalated beds up to 1–2 m thick. This formation shows at the base an almost 2 m thick argillaceous interval which here represents the '*Orbitolina* bed'. The partings often show a higher content of detrital quartz and sometimes intraformational brecciated lithoclasts. These beds are frequently intensively dolomitized towards the top. The requieniid rudists are mainly replaced by the smaller and finer-walled monopleurid rudists (Fig. 10).

Biofacies

The following principal biofacies types have been related to the various lithofacies types (Pl. II):

A *Sponge spicule, 'calcisphere' and echinoderm wackestone.*

Interpreted environment: offshore to basinal, water sufficiently deep for open-

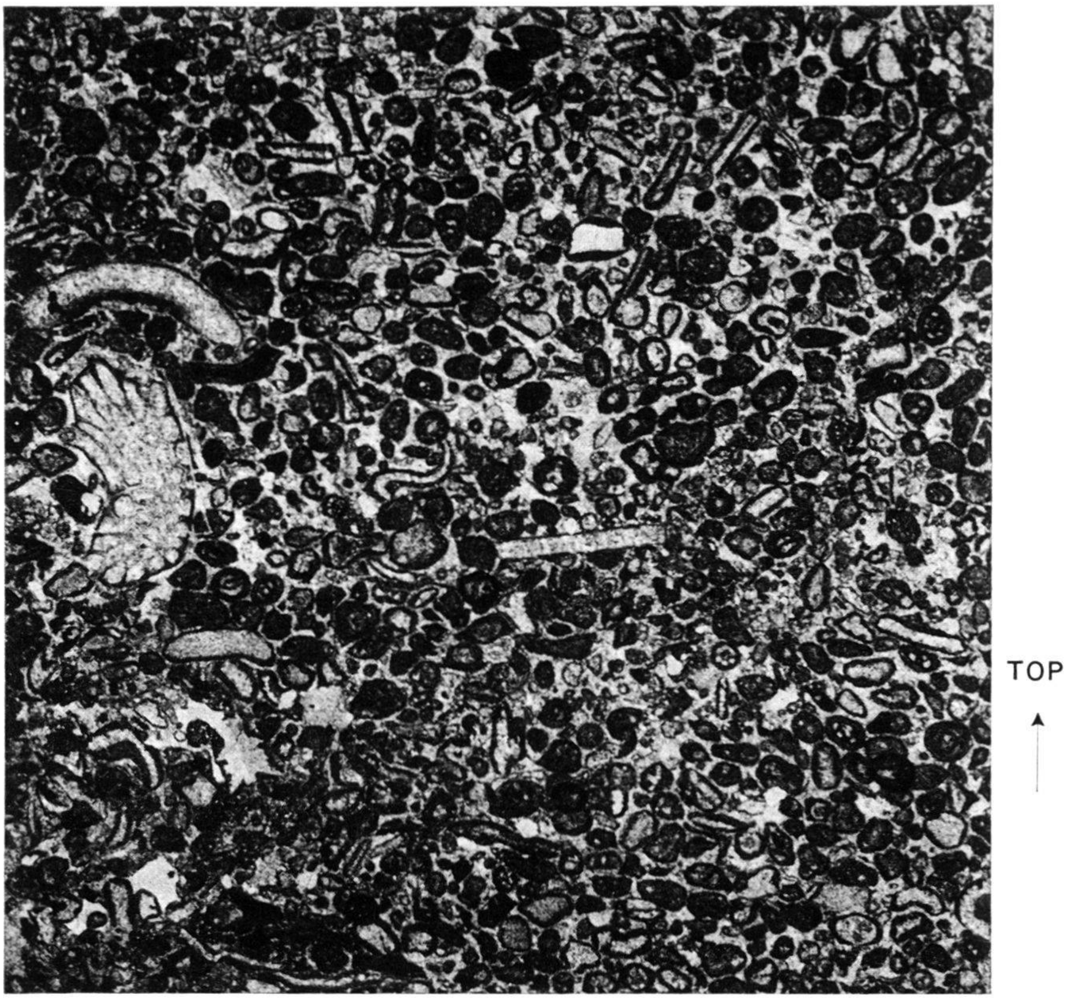

Fig. 8. Schrattenkalk: *closely packed, oolitic lime grainstone.* The oolitically coated grains show a dense packing with smooth, long grain contacts. The nuclei of the grains are made up of skeletal fragments of molluscs, echinoderms and very few benthonic forams. On the left side of the plate is a bryozoan fragment. The grains are indicative of normal marine sediments; the close packing, shown by long grain contacts, suggests a post-depositional exposure to vadose conditions. Environment: same as Fig. 7. Section No. 2, Habernlegi, Acetate peel, 10×.

marine circulation and normal marine salinity. Influences of clastics derived from the land and shoals are minor. The sediment has accumulated beneath wave base. Mixed benthonic and pelagic fauna.

B *Badly sorted, crinoid, orbitolinid bryozoan pelletal grainstone-packstone.*
Interpreted environment: normal open marine-neritic; high energy winnowed sediment. This sediment represents a type of transgressive sediment on the crest and on the flanks of a shoal with abundant and varied benthonic fauna.

C *Fine fragmental, sponge spicule, skeletal wackestone-packstone.*
Interpreted environment normal open marine, moderately shallow shelf, normal marine salinity. The sediment has accumulated below mean wave base. Some influences from sand-producing banks are present. Mixed assemblages of thin-walled molluscan and echinoderm debris.

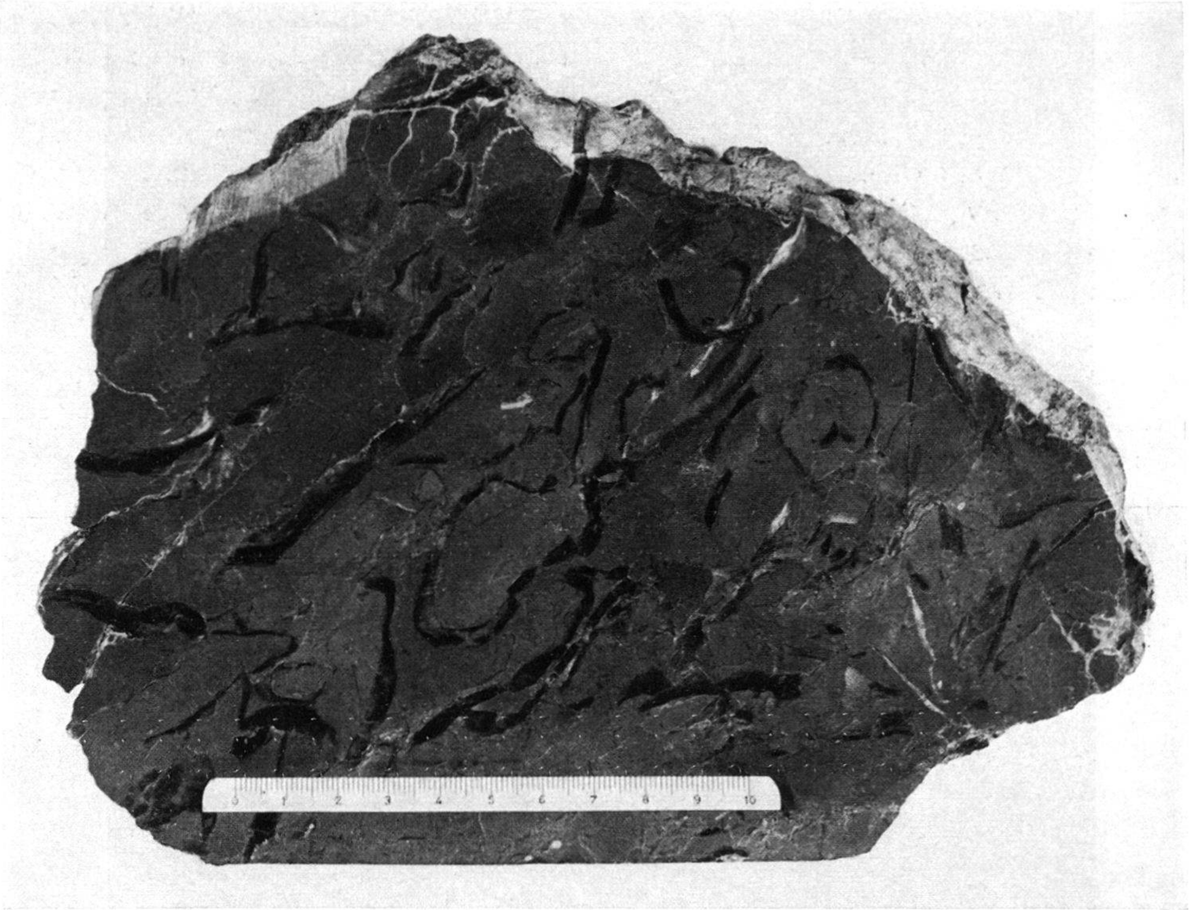

Fig. 9. Pelletoidal *Toucasia* lime wackestone-packstone. The thick-walled lamellibranchs show traces of boring organisms. Note the dark (in nature brown-black) appearance of the *Toucasia* fragments. Section No. 2, Habernlegi. Polished surface.

D *Sorted crinoid, orbitolinid, bryozoan, pelletal oolite-grainstone.*
Interpreted environment: shallow, open marine shoal, high energy oolite bar, normal marine salinity, abundant benthonic fauna.

E *Dasyclad, crinoid, gastropod oolite.*
Interpreted environment: shallow marine shoal, protected bank-interior area. The abundance of rolled and coated dasycladacean algae is indicative of very shallow marine water: probably inside an oolite or grainstone bar.

F *Coral, mollusc, bryozoan, crinoid, orbitolinid, dasyclad, oolite-grainstone.*
Interpreted environment: shallow, open marine shoal; normal marine salinity indicated by fauna, agitated water by oolitic coating of grains and worn skeletal fragments; poor sorting indicates rapid settling of the sediment.

G *Foraminifera, gastropod, onkoid, pellet wackestone-packstone with miliolids,*

H *textularids, lituolids, orbitolinids and trocholinids.*
Interpreted environment: shallow body of protected water, probably with restricted salinity and water circulation or with strong fluctuations in temperature (bank-interior sediment).

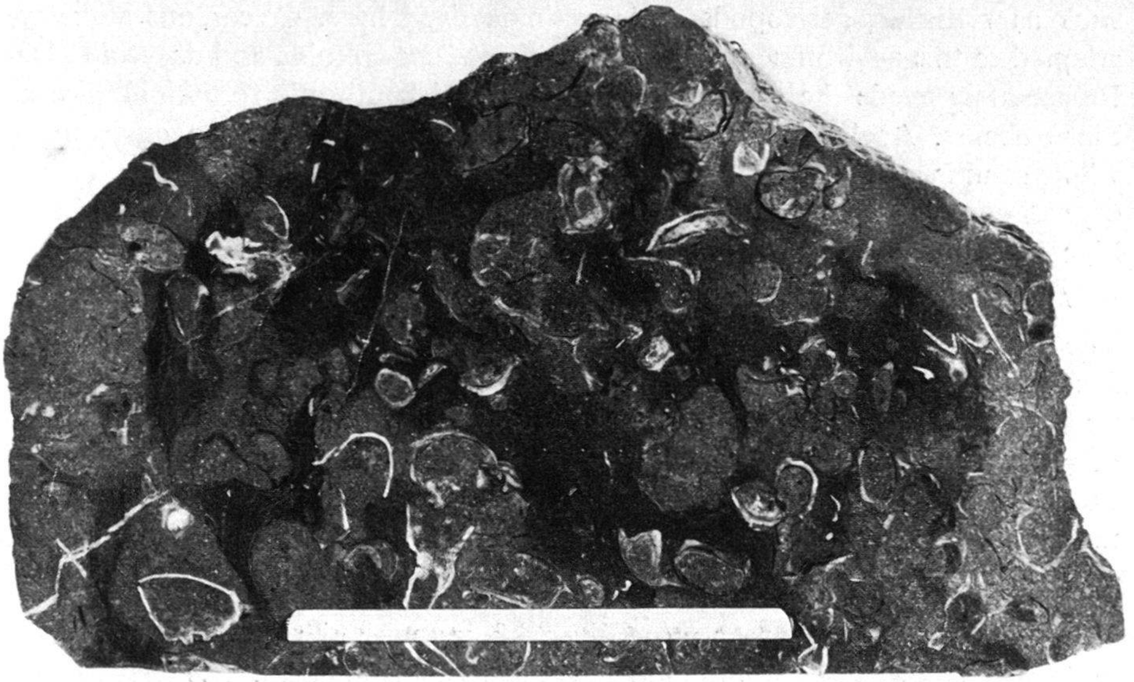

Fig. 10. Monopleurid biostromal colony in a pelletal miliolid lime packstone. Section No. 10, Spirenwald. Polished surface.

I *Rudist, miliolid, pelletal wackestone.*
Interpreted environment: shallow protected area with probably seasonal restriction in salinity, temperature and oxygenation. Requieniids occur in miliolid-rich lime wackestones and mudstones. They preferred a muddy, perhaps grass-covered bottom.

J *(Miliolid) wackestone-mudstone with possible bird's-eye structures or root marks.*
Interpreted environment: high intertidal-supratidal, restricted fauna.

Fig. 11, which is based on this study, shows an interpretation of the dead faunal-assemblage distribution on a shoal in the middle Helvetic facies realm, at the end of the Barremian depositional cycle. Fieldwork has proved that in the NW–SE extension the shoal consisted of a symmetrical distribution of environments. The fauna, which reflects the lithofacies, is similarly distributed.

The diagram clearly shows two contrasting, living environments:

a) A shallow water environment with partly restrictive living conditions inside a grainstone bank[8]). The sediments here are pelleted lime mudstone and wacke-

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[8]) Restriction of a particular environment is illustrated by the absence of whole biological groups, otherwise present under normal marine conditions. 'Blooming' of certain fossil groups, for instance miliolid forams, may also be indicative of restricted marine living conditions. Restriction may be caused by the intensity of the environmental factors (e.g. salinity, temperature, agitation and circulation) and/or the extremes of their fluctuations (personal communication of F. NOORTHOORN VAN DER KRUIJFF, K.S.E.P.L.).

stone. Large and, in spite of the protected environments, thick-walled molluscs such as rudistids, gastropods and pectinids lived here. Calcareous algae were adapted to this environment (*Bacinella/Lithocodium*-onkoids and dasyclad algae). Immediately inside the grainstone bars, a varied benthonic foraminifera assemblage occurs. Agglutinating forams seem to be confined to the environments where sand is produced, inside and outside the high energy bars, whereas cryptocrystalline, 'porcellaneous' foraminifera, such as miliolids, are preserved in both high energy and low energy environments. Sigmoilinid miliolids have been found only inside the high energy bars.

b) The normal-marine, moderately shallow shelf outside the grainstone bar shows a fauna essentially formed by fragmented echinoderms, crinoids, bryozoa, brachipods and lamellibranchs. Corals occur in limited numbers both on the outer side of the grainstone bar and at specific horizons (mainly associated with increased skeletal content) immediately inside the bars. Sponge spicules, calcispheres and fine fragments of probably floating echinoderms are found remote from the high-energy (bar) zone in what are interpreted as 'offshore (basinal?) environments'.

The high energy bar shows a more diverse fauna with elements originating from normal marine as well as from the more restricted environments. The dasyclad fragments accumulated here seem to have been washed in from the bank-interior.

Miliolids are spread over the whole shoal. The high energy sediments show a low percentage of exclusively large miliolids, whereas low energy sediments show a high percentage (about 10 times more than in high energy sediments) of individuals, ranging over all sizes, but with a dominance of small forms. It seems that in the high energy sediments the tests of dead miliolids behave like lime-sand particles but, as a result of winnowing, the smaller and lighter miliolid tests are more completely removed.

SUMMARY

This study demonstrates how a local topographical positive element, due to syngenetic faulting, rather than a shoreline or shelf edge, may initiate a carbonate build-up.

The Barremian sedimentary cycle commenced with a phase of submergence, which is reflected by a 'transgressive' sediment type. With retardation of the submergence, production of lime sand set in and the regime clearly changed to a regressive one.

The Barremian cycle terminated in emergence and probably subaerial exposure.

The vertical rock sequence through the Barremian sedimentary cycle gives an indication of the lateral facies changes that took place. In late Barremian time, for example, miliolid-requeniid pelletal wackestones pass laterally through dasyclad and coral-mollusc-grainstones, then through a cross-bedded oolite bar with orbitolinids, crinoids and bryozoans, followed by badly sorted crinoid-orbitolinid-bryozoan, pelletal packstones and end in deeper-water sediments, characterized by their higher clay content and by the occurrence of sponge spicules and possible radiolarians.

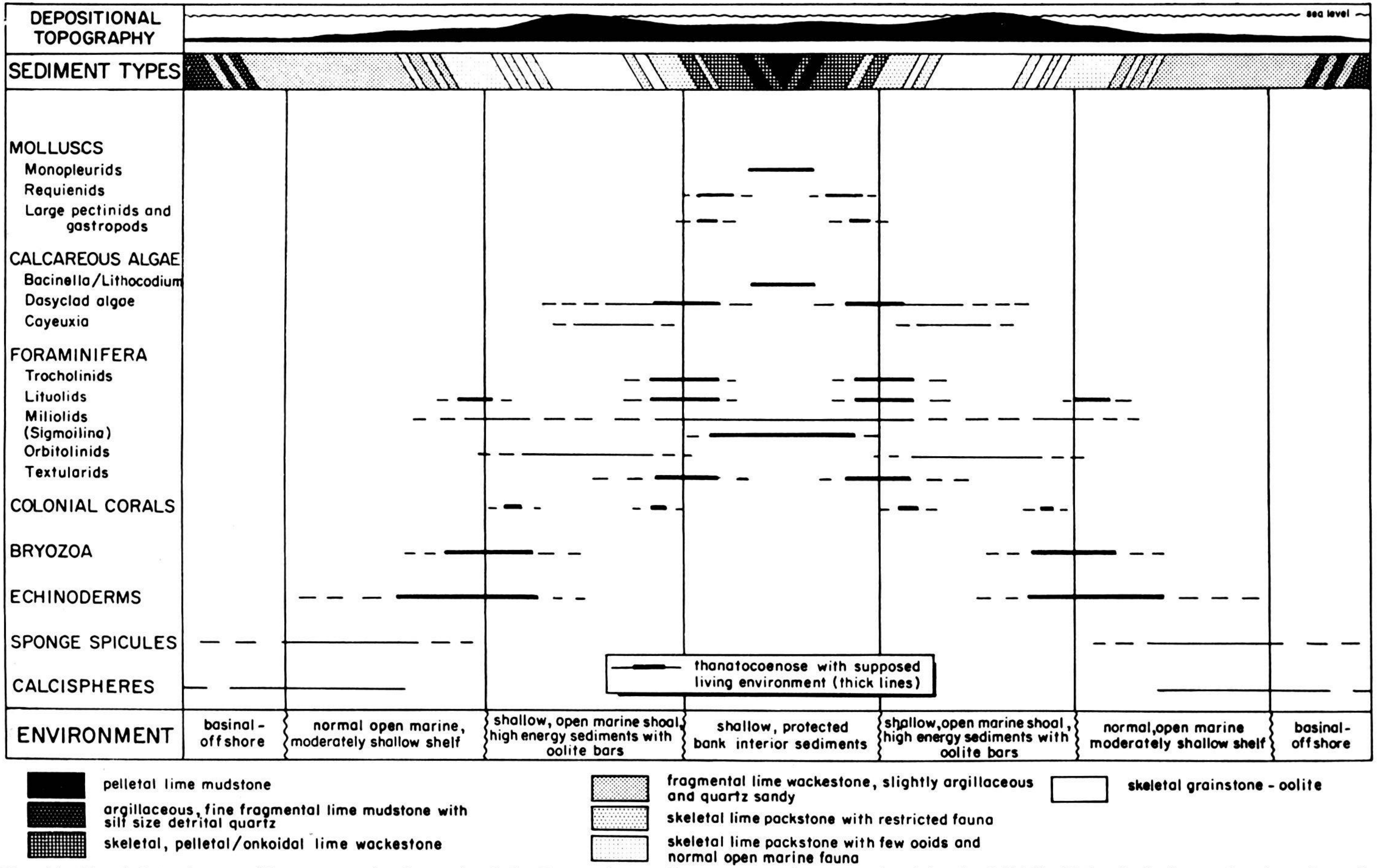

Fig. 11. Dead faunal assemblage towards the end of the Barremian sedimentary cycle on a shoal in the Middle Helvetic facies realm, based on the present investigation.

It was possible to differentiate between two contrasting living environments: one inside a grainstone complex with shallow, partly restricted living conditions and another one outside the grainstone complex, a normal marine, moderately shallow shelf.

Rudists (requieniids and monopleurids) have been observed in the shallow, protected environment inside the grainstone complex. No mound-shaped rudistid accumulations have been observed. Requieniids showed more scattered occurrence, whereas monopleurids, in their living position, showed more biostromal features.

Table 1. Location of sections.

No.	Name of section	Co-ordinates after: Landeskarte der Schweiz, sheet No. 254 (Interlaken) 1:50000
1	Rothorn	1. 625.900/175.450 2. 625.750/175.875
2	Habernlegi	1. 624.175/172.400 2. 624.150/171.900
3	Bärenpfad	1. 626.425/174.175 2. 626.500/173.900
4	Schweife	1. 628.100/176.100 2. 628.175/175.850
5	Laubenegg	1. 628.250/176.550 2. 628.425/176.350
6	Beatenbucht	623.475/170.725
7	Balmholz	625.275/170.325
8	Krutbach	625.850/170.225
9	Beatushöhle	1. 626.250/170.325 2. 625.900/170.825
10	Spirenwald	1. 626.650/172.000 2. 626.500/172.100
11	Schoren	1. 627.725/172.800 2. 627.675/173.000
12	Harder (lower portion)	1. 631.700/171.125 2. 631.575/170.950
	Harder (upper portion)	1. 631.125/171.225 2. 630.850/171.475
13	Rugen	1. 631.800/169.450 2. 631.100/169.250

Co-ordinates listed under: 1. = beginning of the section, 2. = end of the section.

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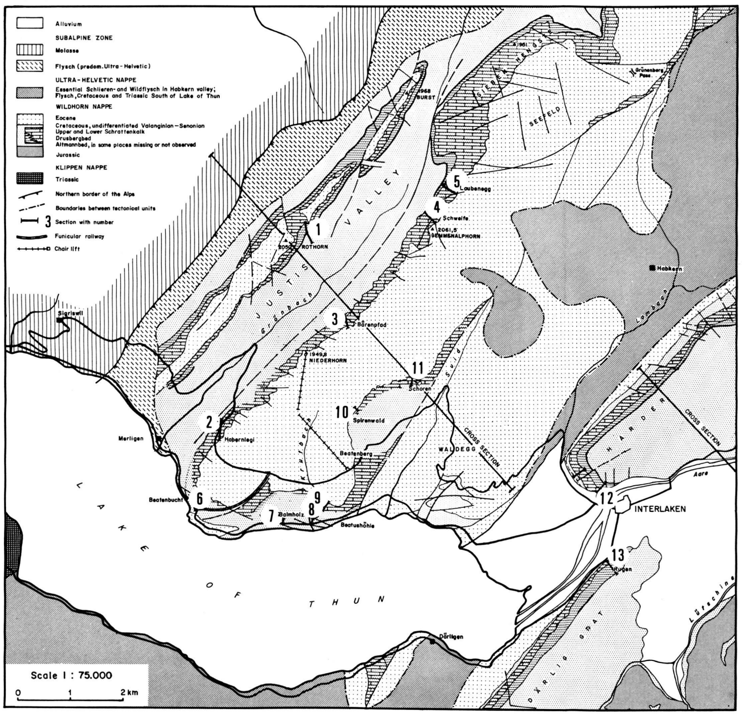

Plate I, Fig. 1. Tectonic situation of the area north of the Lake of Thun; see also cross section textfigure 1.

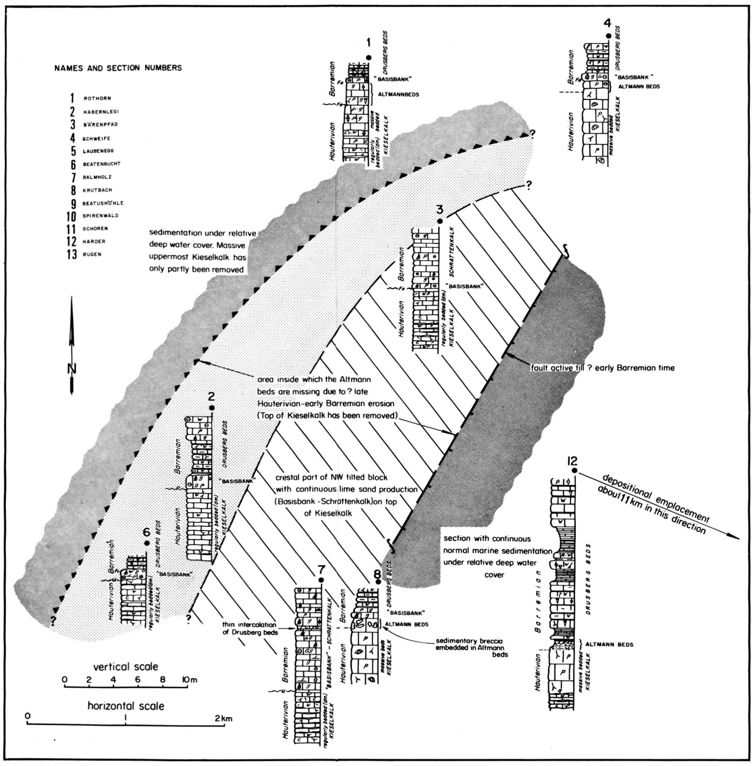

Plate I, Fig. 2. Facies development at the boundary Hauterivian-Barremian.

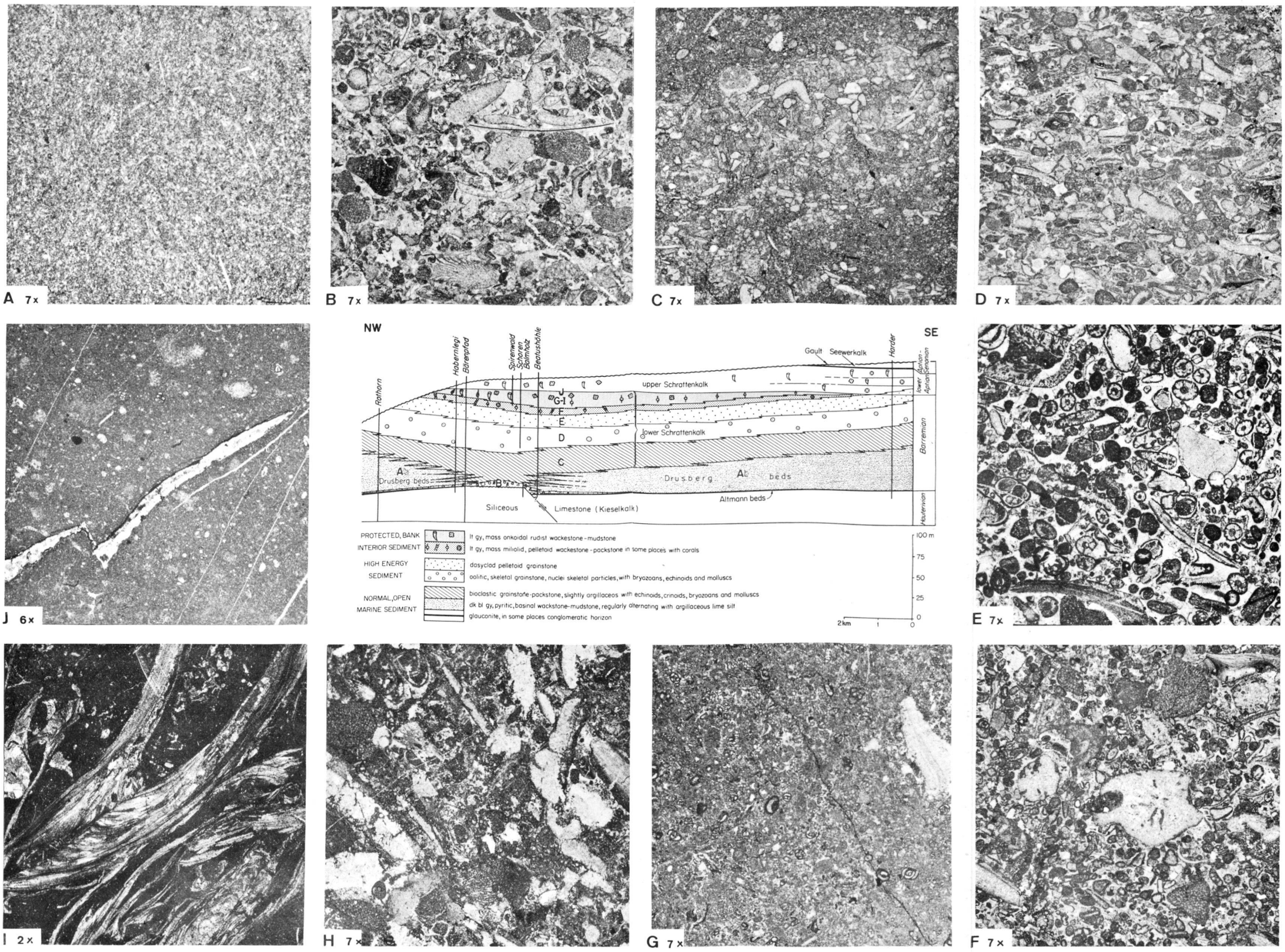

Plate II. Facies variations within the Barremian sedimentary cycle in the Wildhorn nappe north of the Lake of Thun.