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A Comparative Study of the Urgonian Facies in Vorarlberg (Austria), im Allgäu (Germany) and in the Villány Mountains (Hungary)

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With 29 Text-Figures and 16 Plates

Österreich
Ungarn
Vorarlberg
Villany-Gebirge
Schrattenkalk
Nagyharsány-Kalk
Urgon

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"Tethyan Cretaceous Correlation"

Inhalt

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Vergleichsstudien zur Urgon-Fazies in Vorarlberg (Österreich), im Allgäu (Deutschland) und im Villány-Gebirge (Ungarn)

Zusammenfassung

In Vorarlberg wurde eine Reihe von Schrattenkalk-Vorkommen z.T. profilmäßig untersucht. Es sind dies der Rhomberg-Steinbruch bei Unterklien, die Illschlucht bei Feldkirch, Straßenanschnitte bei Furx und Laterns bzw. bei Übersaxen und der Bachanschnitt der Ebniter Ache. Der Schrattenkalk der Gottesackerwände im Allgäu wurde im Detail hinsichtlich seiner Faziesverteilung bearbeitet.

Im ungarischen Pendant zum Schrattenkalk – dem Nagyharsány-Kalk des Villány-Gebirges – wurden folgende Steinbrüche detailliert profilmäßig studiert: Harsány-hegy, Beremend und Vizügy.

Beruhend auf einem detailierten Faziesvergleich der österreichisch-bayerischen mit den südungarischen Urgonentwicklungen wird versucht, das Paläoenvironment und die Entwicklungsgeschichte dieser unterkretazischen Faziesentwicklungen sowie deren paläogeographische Stellung zu rekonstruieren, wobei folgende Schlußfolgerungen gezogen werden:

- Im Schrattenkalk wird eine allochthone (allodapische) und eine autochthone Faziesentwicklung unterschieden, woraus sich Zweifel über die Eigenständigkeit der Hohenemser Decke ableiten.
- Aufgrund des Fehlens von terrigenem Detritus wird geschlossen, daß zwischen der helvetischen Karbonatplattform und dem europäischen Kontinent ein seichtes Becken existierte.
- Der erhebliche Altersunterschied in den liegenden Anteilen des Nagyharsány Kalksteins der verschiedenen Vorkommen weist eher auf eine Deckenstruktur hin als auf Schuppen.
- Als Herkunftsgebiet des Deckensystems des Villány-Gebirges wird das paläozoische Gebiet der Vojvodina angenommen.
- Während der Schrattenkalk eine „shallowing upward"-Tendenz aufweist, stellt der Nagyharsány-Kalk den Beginn eines transgressiven Zyklus dar. Ähnlichkeiten besitzen die beiden Formationen lediglich in der oberen Hälfte. Trotz des erheblichen stratigraphischen Altersunterschieds und ihrer unterschiedlichen Entwicklungsgeschichte verschwanden die Karbonatplattformen des Helvetikums und Südungarns in vergleichbarer Weise. Es wird angenommen, daß ein weltweiter Meeresspiegelanstieg bzw. tektonische Subsidenz dafür verantwortlich war. Weiters wird vermutet, daß kaltes Meerwasser allmählich in südlicher Richtung in das Gebiet der Tethys eindrang.

A vorarlbergi (Ausztria), az allgäui (Németország) és a villányi-hegységi urgon fáciesek összehasonlítása

Összefoglalás

A tanulmány német és osztrák oldalról a Schrattenkalk alábbi előfordulásainak vizsgálatán alapszik: Gottesackerwände (fácies elemzés) az Unterklien melletti Rhomberg kőfejtő (részletes, szelvényszerű vizsgálat), a feldkirchi Ill-szoros (részletes, szelvényszerű vizsgálat), a Furx és Laterns közötti útbevágás (szelvényszerű, részleges vizsgálat), az Ebniter Ache völgye (szelvényszerű, részleges vizsgálat), az übersaxeni útbevágás (részszelvény).

A villányi-hegységi Nagyharsányi Mészkőnek az alábbi szelvényei kerültek feldolgozásra: harsány-hegyi kőfejtő, beremendi kőfejtő és a vízügyi kőbánya.

A fenti szelvények litológiai, ősléntytani és szöveti jellemzése alapján a két formáció őskörnyezeti és fejlődéstörténeti, valamint a térség paleogeográfiai értelmezésére is sor került. A tanulmány legfontosabb megállapításai:

- A Schrattenkalknak egy autochton és egy allochton (allodapikus) kifejlődése került elkülönítésre. Ezek alapján a szerzők megkérdőjelezik a hohenems-i takaró önálló voltát.
- A helvéti karbonát platform és az európai szárazföld között egy sekély medencét tételeznek fel a terrigén törmelék hiánya alapján.
- A Nagyharsányi Mészkő előfordulások bázis rétegeiben mutatkozó tetemes korkülönbség alapján a hegység takarós (és nem pikkelyes) felépítésére következtetnek.
- A villányi takaró rendszer forrását a vajdasági (Jugoszlávia) paleozoos zónáiban vélik megtalálni.
- Amíg a Schrattenkalk fölfelé elsekélyesedő tendenciát mutat, a Nagyharsányi Mészkő egy transzgressziós ciklus kezdetét képviseli. A két formáció nagymérvű hasonlóságot csak a formációk felső felében mutat. A korviszonyokban és a cikluson belüli helyzetben mutatkozó tekintélyes különbségek ellenére a karbonát platform eltűnése (megfulladása) azonos módon következik be. Az okot a szerzők világméretű tengerszint emelkedésben, esetleg a régió(k) tektonikus süllyedésében vélik megtalálni. Megállapítják, hogy a Tethys területére a hideg tengervíz D-felé fokozatosan nyomult be.

Abstract

On behalf of the German and Austrian sides the study is based upon the examination of the below listed occurrences of Schrattenkalk: Gottesackerwände (facies analysis), the Rhomberg quarry close to Unterklien (detailed, profil-like examination), Ill-gorge at Feldkirch (detailed, profil-like examination), road-cut between Furx and Laterns (profil-like, partial examination), the valley of Ebniter Ache (profil-like, partial examination), road-cut at Übersaxen (partial profile).

For the Nagyharsány Limestone, Villány Mts., Hungary, the following profiles were studied: Harsány-hegy quarry, Beremend quarry and Vizügy quarry.

Based upon the lithological, paleontological and textural description of the aforesaid profiles, interpretation was given for both formations in regard to palaeoenvironment and evolution history, and for the region in regard to palaeogeography. Statements of greatest importance included in the study are as follows:

- For Schrattenkalk, an allochthonous (allodapic) and an autochthonous facies were distinguished. Based upon them, the authors are doubtful as to the independence of the Hohenems nappe.
- Due to the absence of terrigenous detritus, a shallow basin is presumed to have existed between the Helvetic carbonate platform and the European continent.
- The considerable difference in age encountered in the base of occurrences of the Nagyharsány Limestone points to the fact that the Villány Mountains are not of imbricate, but of nappe structure.
- The roots of the nappe system of the Villány region is assumed to be found in the Paleozoic zone of Vojvodina, Yugoslavia.
- Whereas the Schrattenkalk shows a shallowing-upward tendency, the Nagyharsány Limestone represents the beginning of a transgressive cycle. Both formations exhibit great similarity only in the upper half of the formation. Despite the remarkable differences in stratigraphic age and position within the cycle, the carbonate platform disappeared (drowned) in similar way. The authors deem, that this was due to a worldwide sea level rise or possibily to the tectonic subsidence of the region(s). It has also been stated that the cold sea water gradually invaded towards the south into the area of the Tethys.

1. Introduction

This comparative study is part of IGCP Project 262 "Tethyan Cretaceous Correlation" and tries to find the rules of development and cessation of Urgonian-type platforms. Two formations have been chosen for comparison: the Schrattenkalk in the Helvetic zone in Vorarlberg, Austria, and the Nagyharsány Limestone Formation in Villány Mountains, Hungary.

The Schrattenkalk demonstrates the youngest Lower Cretaceous platform sediments of the European shelf incorporated into the Eastern Alps tectonic edifice in Tertiary time.

The Nagyharsány Limestone Formation is a characteristic element of the Villány-Bihar zone of the Tisza tectonic unit. The Tisza unit was part of the southern margin of the European continent during Triassic time (GÉCZY & GALACZ, 1971), and became a microplate within the Tethyan realm during Late Jurassic and Early Cretaceous time before its Urgonian episode.

The paleogeographic conditions and the duration of sedimentation of the formation in question, as well as their position in the sedimentary cycle, are considerably different.

The term Urgonian is discussed by BOLLINGER, 1988, p. 8–9. The first author (G.Cs.) wishes to broaden it for all rudistid successions following the ideas of RAT & PASCAL (1979).

The study of Schrattenkalk, launched within the Austro-Hungarian cooperation in geology started in Vorarlberg, with detailed studies on profiles of the Rhomberg quarry near Unterklien, considered as its northernmost occurrence, and of the roadcut along the Ill-gorge at Feldkirch, as a southern one, and further profiles in between at Übersaxen, Ebniter Ache and between Furx and Laterns, where the Schrattenkalk is pinching out into the Drusberg Formation. Megafauna was studied partly in the field whereas its major part was analyzed in laboratories by L. MÓRA-CZABALAY (molluscs) and A. VÖRÖS (brachiopods) on the basis of samples the authors had collected. *Orbitolina* examinations were carried out by E. KÖHLER. The rest of the microfossils was determined by I. BODROGI and D. MEHL-SALOMON. The detailed stratigraphic and microfacies studies on the Gottesackerwände close to Oberstdorf in Allgäu carried out by D. MEHL, enabled us to extend our examination considerably towards the east. In addition the recent studies by SCHOLZ (1979 and 1984) in the Allgäu should be separately mentioned here and were also used by us. For the outcrops in Vorarlberg it is useful to consult HEISSEL et al. (1967) and OBERHAUSER (1982) on the geological maps.

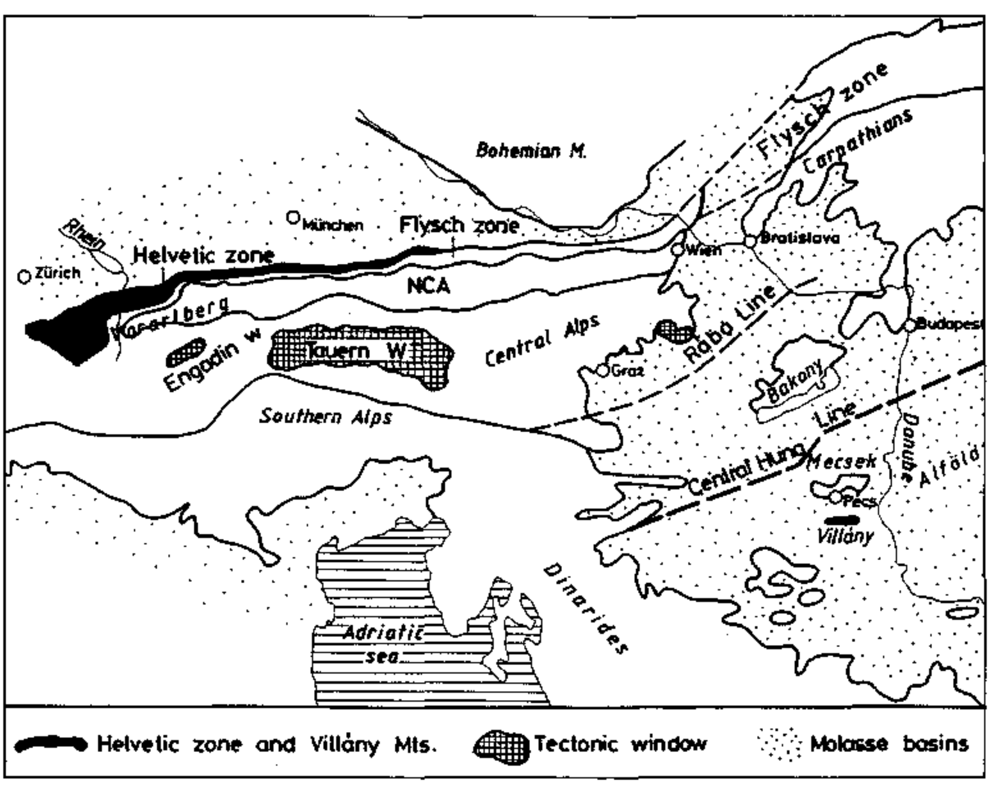
The Nagyharsány Limestone Formation was reexamined by the first author assisted by I. BODROGI and L. MÓRA-CZABALAY.

2. Schrattenkalk Formation

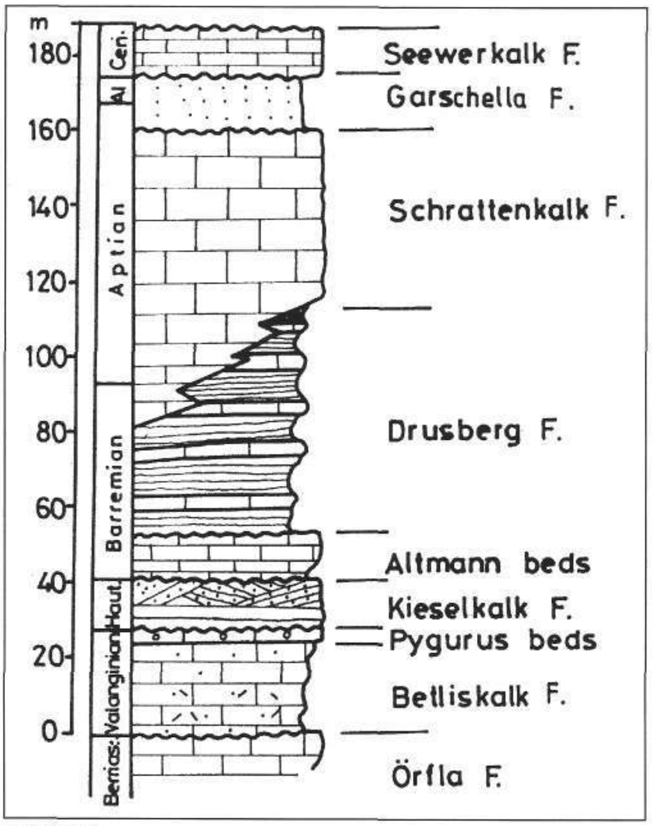
2.1. Geological Setting and Geographical Extent

The Helvetic Zone is situated in the outer zone of the Alps between the Molasse and the Rhenodanubian Flysch zones and can be traced, starting from the Western Alps, as far as Salzburg in the Eastern Alps (Text-Fig. 1). The limestone of Urgonian facies of the Helvetic zone was called Schrattenkalk by STUDER (1834). It is situated between the Drusberg Formation of shallow basin facies and the Garschella Formation of hemipelagic facies (Text-Fig. 2) and is dated as Upper Barremian–Lower Aptian since VACEK (1879) who used for it *Orbitolina*, and other fossils: see A. HEIM et al. (1933). During the last few decades several papers on the Schrattenkalk as well as on the underlying and interfingering Drusberg Formation were prepared.

Based on some profiles, ZACHER (1973) made the first examination of the microfacies, and identified three palaeoenvironmental zones, each striking roughly E–W, i.e. showing an arrangement parallel to the European margin. From the north to the south these zones are of oolitic, bioarenite-intrasparitic, and biogenic detritus supplied facies. SCHOLZ (1984) has described real bioherms (patch reefs) of coral-stromatoporoidal and chaetetidal composition in Allgäu with a few sponges and red algae. According to him these build-ups are usually underlain by various – mainly rudistid – biostromes that served as stable substrate for reef-building organisms.



Text-Fig. 1.
Location map of the study areas in Austria and Hungary.



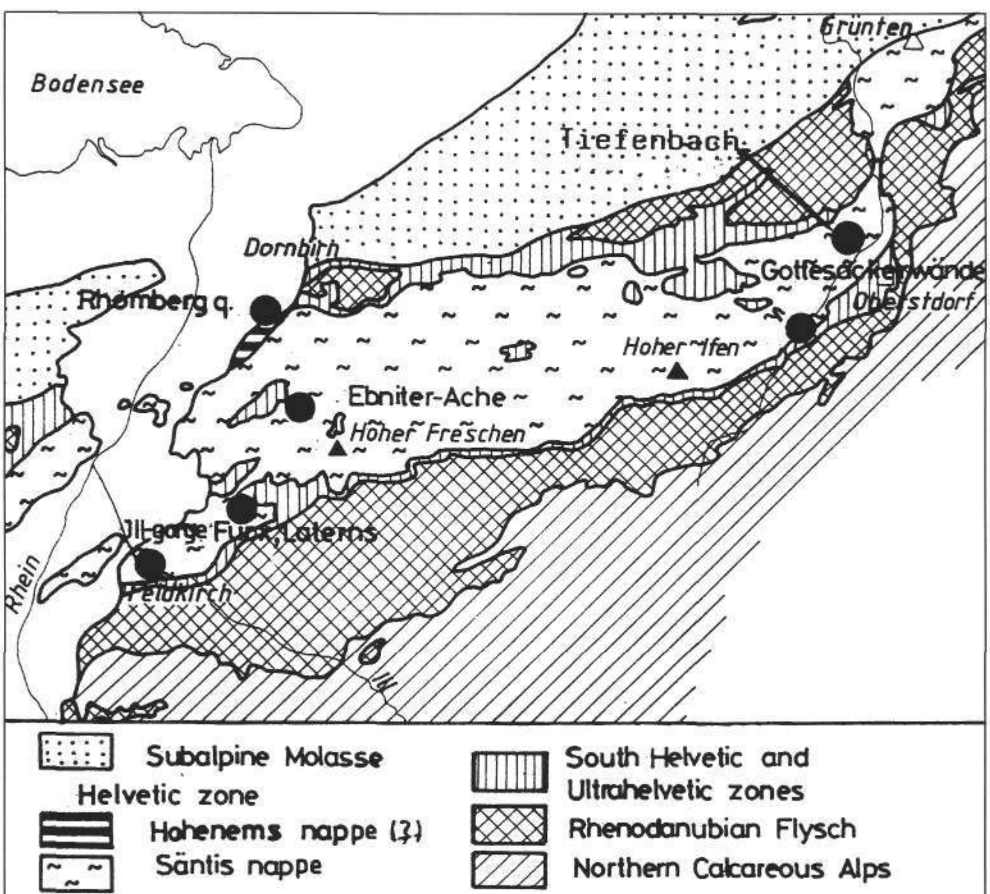
Test-Fig. 2.
Idealized sequence of Schrattenkalk in the Helvetic zone.

BRIEGEL (1972) and later FUNK and BRIEGEL (1979) furnished additional data about the areas of Vorarlberg and eastern Switzerland. They pointed out that the Schrattenkalk shows a diachronous transition into the marly sequence of the Drusberg Formation of outer shelf origin. In spite of this they found the basin of the south filled up with high energy sediments as well.

BOLLINGER (1988) studied the Barremian–Lower Aptian of the Vorarlberg-Helveticum: Drusberg Schrattenkalk- and Mittagspitz Formations and divided the Schrattenkalk into the Schrattenkalk-Orbitolinenschichten Member and Grünten Member. His shelf model shows a regressive development from Barremian to earliest Early Aptian, which is stopped by differential subsidence and a transgressive development later in Early Aptian.

In her diploma thesis SALOMON (1987) gave a detailed biofacies study of the Schrattenkalk Formation of the Gottesackerwände region and examined its underlying Drusberg Formation as well. The most important results of her palaeoecological and palaeoenvironmental examinations, relating to the Schrattenkalk and the Drusberg Formation were summarized in a separate article (SALOMON, 1990).

The resarch of the underlying formations made by WYSSLING (1986) is concluded in a reconstruction of the evolutionary history of Berriasian to Early Barremian time. The reconstruction is presented in palaeogeographical sketches. Thorough studies of the overlying formations were carried out by FÖLLMI (1989 a,b) and FÖLLMI & OUWEHAND (1987). They demonstrate the beginning of the drawning of the platform by sea level rise and the condensed phosphatic beds developed diachronously in late Early Aptian time.



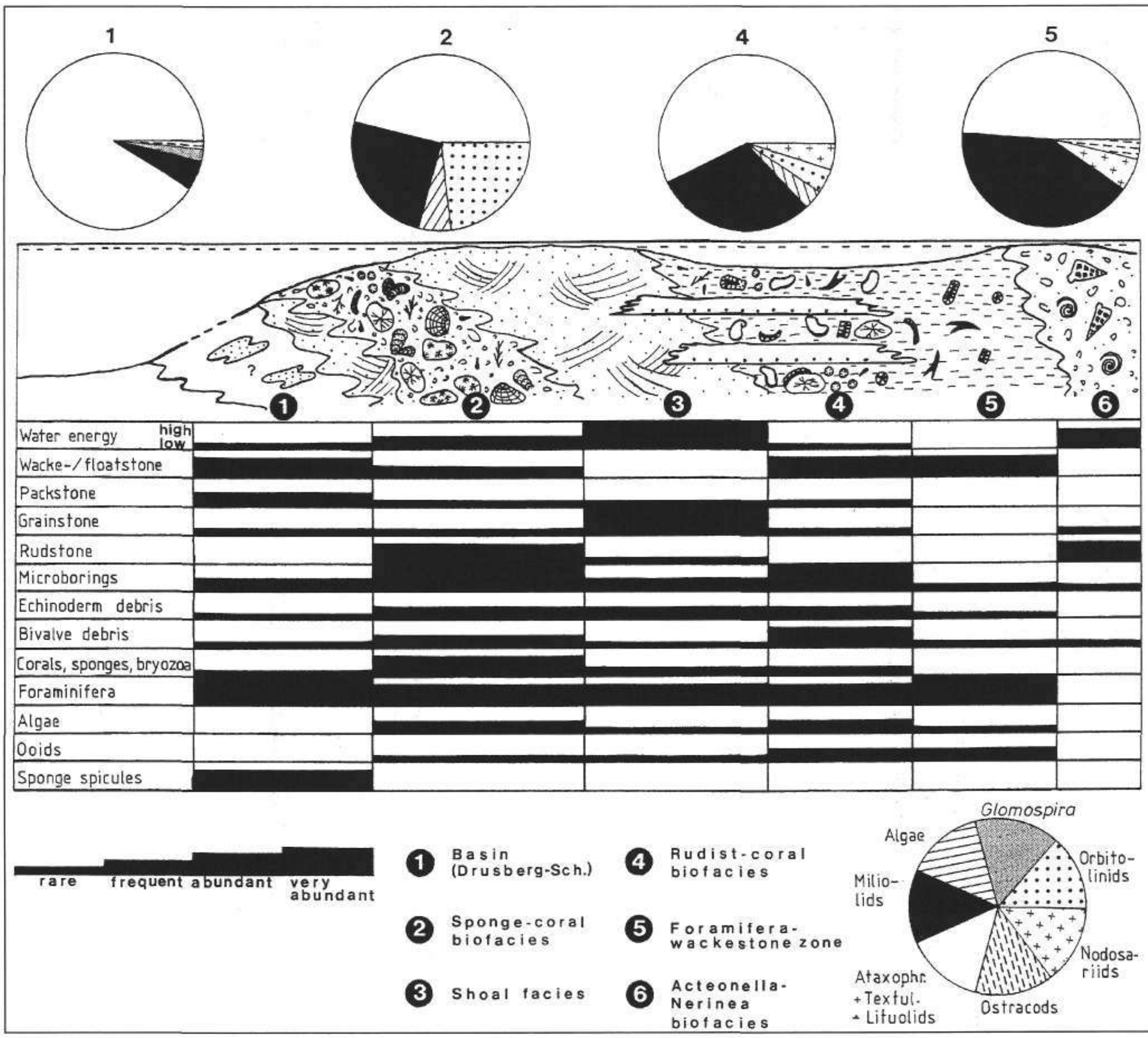
Text-Fig. 3.
Location map of Schrattenkalk with the sites of the sections studied.

2.2. Lithology, Fossil Content and Texture

2.2.1. Gottesackerwände

(for locations mentioned see Text-Fig. 3)

About the area no profile measured and described bed-by-bed is available. However, the fact that the formation found in a considerably large area is well exposed, offers suitable opportunity to identify the varied types of development. Therefore the different types of facies will be discussed here, instead of a description of the sequence. The limestone sequence is at least 90 m thick, usually of bedded, but sometimes of compact development, with bioarenitic composition, containing marly intercalations on-



Text-Fig. 4.
Idealized facies distribution of the Schrattenkalk at Gotesackerwände (after D. SALOMON, 1989).

ly sporadically. The road-cut profile at Tiefenbach in the neighbourhood of Gottesackerwände is considered by SCHOLZ (1984) as a key profile in which the highest energy environment, namely coral and stromatopora biostromes can be found in the middle of the profiles. The water energy continuously decreases both upward and downward. On the other hand, for the other profiles bioherms are described, generally from the upper part of the sequence. Although *Orbitolina* is known from several beds, the specific "Orbitolinenschichten" are missing. The top of the Schrattenkalk sequence is built up of glauconitic sandy beds which contain large arenaceous formaminifers (Pl. 6, Fig. 3). According to microfacies and to fossil associations (mega- and microfossils) different biofacies types can be distinguished at the Gottesackerwände. These are as follows:

Patch Reef Facies (Text-Fig. 4, Pl. 7)

This biofacies with sponges, algae and corals occurs mainly as reef detritus. The detritus can be considered to be para-autochthonous, in which the occurrence of large rock stocks, that were apparently not subject to any greater transport, can be observed. Rocks corresponding to this sort of biofacies are mainly of rudstone, grainstone or floatstone texture, sometimes also frame- and bafflestones occur. Their characteristic fossils include bryozoans and hemispheric corals such as *Stylina* and *Eugyra*, accompanied by coralline sponges such as *Chaetetopsis favrei*, pharetronides, and Sphinctozoa type calcareous sponges (Pl. 7, Fig. 1). In this biofacies algae show the greatest diversity. Red algae, such as *Archaeolithothamnium* (Pl. 7, Fig. 2), *Ethelia alba* (Pl. VII, Fig. 3) and *Marinella* are very frequent. Dasycladaceae, Codiaceae (*Lithocodium aggregatum*) and other green algae such as *Cayeuxia* have similar occurence. Approximately half of the foraminifera corresponds to the arenaceous forms with single shell (mainly Ataxophragmiids and Textulariids). Orbitolinas, along with the large, single arenaceous forms such as *Rheophax*, represent about one fourth of the microfauna.

Shoal Facies (Text-Fig. 4)

The main part of the Schrattenkalk at the Gottesackerwände consists of grainstone beds. The thickness of these beds varies in the range of 25 to 50 cm, but mainly attains a value as high as 2 metres. Oblique-stratified beds with thickness range of decimetre or metre can be frequently observed among them. Carbonate sand grains are medium- or wellsorted and rounded. The ooid content is low. Each grain is always a simple ooid with a large inner core and a thin radialfibrose crusting, and is likely to have been transported to this site from lagoonal environment (See also lagoonal facies). Its foraminiferal assemblage is greatly similar to that of the patch reef facies, thus enabling us to assume, that the major part of carbonate sand deposit is delivered by this facies zone.

Lagoonal Facies (Text-Fig. 4)
(a biofacies with rudists and salpingoporellas)

Rudist mounds – mainly as baffle- and floatstones with *Salpingoporella* and many miliolids – are considered to be lagoonal. Two assemblages can be distinguished:

The first one consists of *Requienia* type rudists and dendroidal corals (*Thamnastrea* and *Isastrea*) in floatstone texture, in which rare *Chaetetopsis* can also be observed. Here the diversity of algal and foraminiferal assemblages is still considerably high. This assemblage forms a transition towards the Patch reef biofacies. The other one which is of wackestone texture, contains no other megafauna than monopleurid rudists (*Agriopleura*). Other algae, except for different species of Acetabulariaea that cannot be identified more precisely, are rare. *Girvanella* appears encrusting in some cases. REITNER (1984) found that the *Monopleura* biofacies with *Girvanella* is characteristic of the inner platform area with a restricted water movement. The great amount of ooids (up to 10% of the allochems) should also be mentioned. All of them are single layered ones ("Einfachooide") like those included in the shoal facies. CAROZZI (1960) stated that this kind of ooids occur in a sedimentary environment with a relatively low energy of waving.

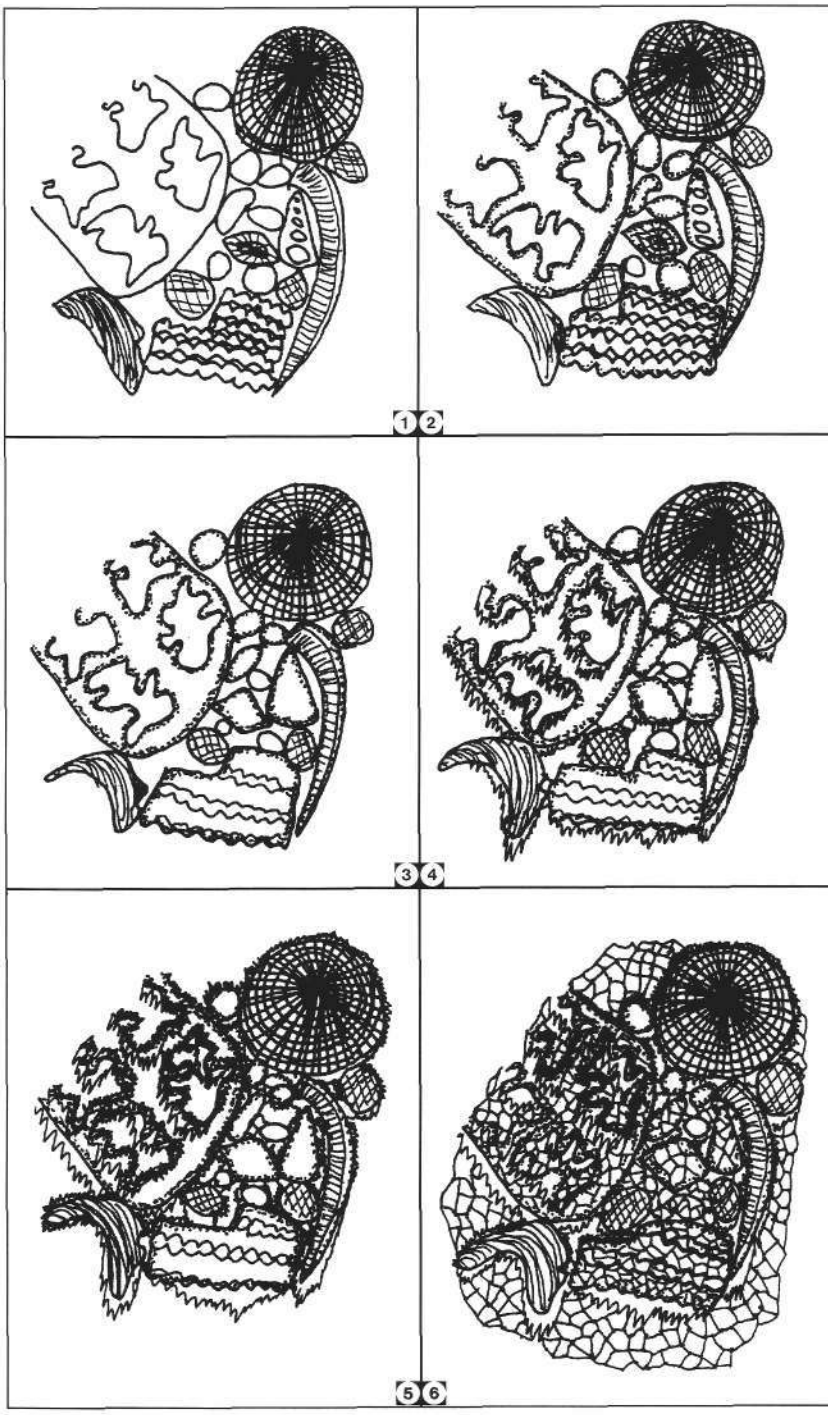
In the microfauna the proportion of Miliolidae becomes higher. *Sabaudia* and *Glomospira* are also fairly frequent. It should also be mentioned that among the Orbitolinidae, in the lagoonal environment *Orbitolinopsis* is dominant unlike other facies environment dominated by the *Palorbitolina*.

Nerinea-Actaeonella Biofacies

Nerinea and *Actaeonella* species with a size attaining even 20 cm, can be observed in the well-sorted rock of rudstone texture. Beside gastropods, also bivalve tests, coral-bryozoan and Echinodermata detritus can be identified by unaided eye.

Diagenesis with intensive dissolution can be observed in the rock. All aragonitic biogenic substances are dissolved, and there is only a micritic marginal zone (micritic envelope), probably originating from boring micro-organisms, indicating their traces.

The secondary pores developed during the diagenesis with dissolution. They are filled with marine "bladed calcite" cement, although symmetrical cement can also be recognized less frequently. The latter indicates that the deposit has been subject to the vadose zone of diagenesis, before the pores have been filled up with blockcement (PURSER, 1969). The history of diagenesis is shown in Text-Fig. 5.



Text-Fig. 5.
Presumable diagenetic history recognized in thin-sections of Gottesackerwände

It has not been clarified yet, whether the absence of microfossils is due to dissolution diagenesis, or if they were originally not present in the deposit.

Summing up: The Schrattenkalk of Gottesacker-Ifen area is characterized by an intensive bioproduction of coralline organisms (such as "Stockkorallen", stromatoporoid, sphinctozoid and calcareous sponges and *Chaetetopsis*). Particularly in the upper part of Schrattenkalk, colonies with size range of metres, of corals, *Chaetetopsis* and *Barroisia* can be observed. They were interpreted by SCHOLZ (1979) as real patch reefs. The coral organisms were frequently encrusted by various algae, thus causing formations resistant to wave actions. This represents a good corroboration for the interpretation of SCHOLZ. The high frequency of rudstone and grainstone fabrics is striking in the upper part of Schrattenkalk. Moreover, rudist mud mounds are also characteristic. A quantitative illustration of sorts of microfacies is shown in Text-Fig. 4.

The development of Schrattenkalk observed here is characterized by textures indicating high energy level.

2.2.2. Rhomberg Quarry, Unterklien

This quarry is situated at the foot of Breiterberg, at the NE end of Unterklien, in the recumbent fold limb of the Hohenems nappe (Text-Fig. 6) and is separated from the Säntis nappe represented by Eocene beds of the Haslach-Emsrütti syncline by a fault plane, on which the Breite Berg fold structure sank down more than 500 m. Strike slipe movements are also possible.

The quarry exposes the uppermost strata of Drusberg Formation of fairly calcareous development, a thin, frequently violet-spotted, glauconitic and belemnitic Garschella Formation, and a part of thick-bedded Seewerkalk (Text-Fig. 7).

The transition between the Drusberg Formation and the Schrattenkalk is gradual, whereas the boundary between Schrattenkalk and the Garschella Formation is sharp and, due to partial submarine dissolution, uneven.

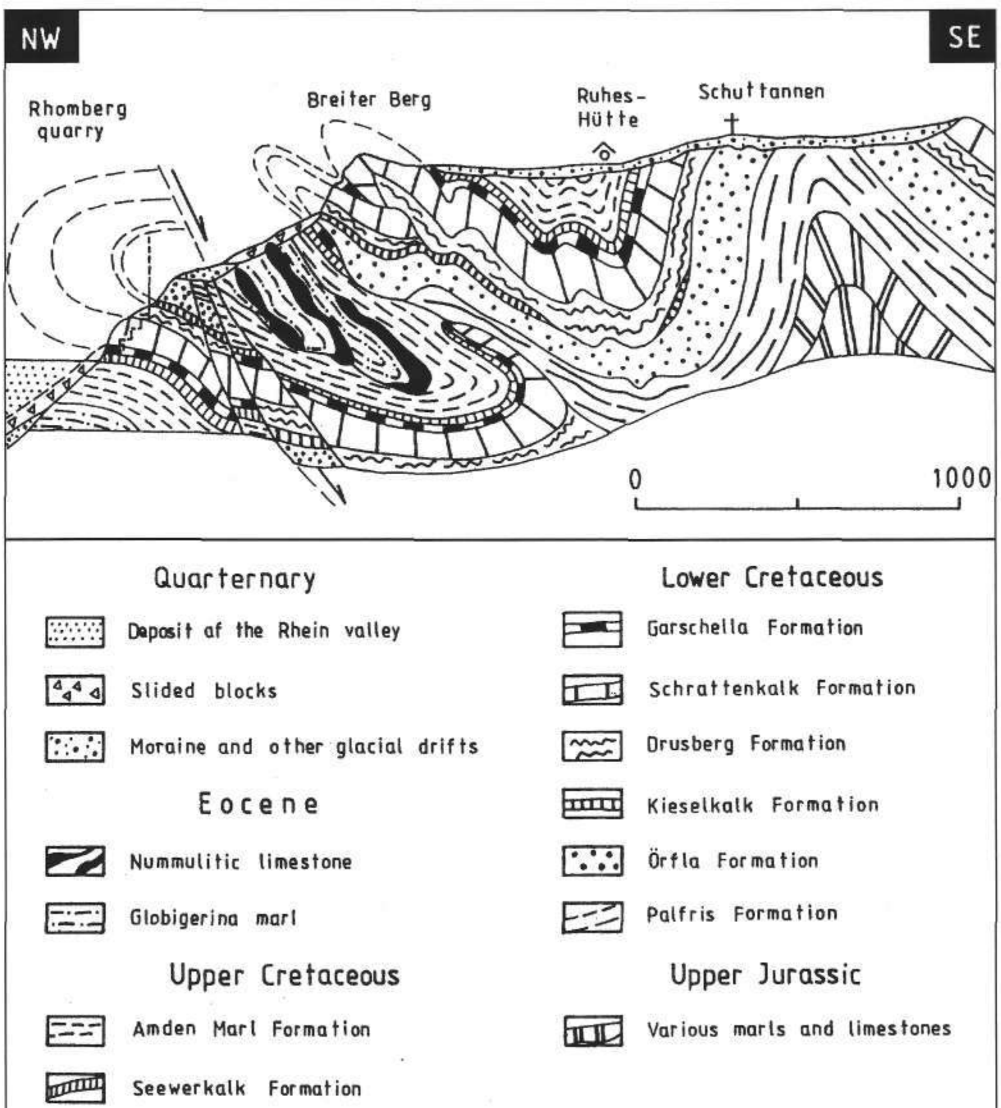
The compiled Schrattenkalk Profile to be shown here (Text-Figs. 8, 10) is composed of two sub-profiles. The larger (stratigraphically older) part is the quarry profile, whereas the smaller part was measured along the foot of the hill with steep cliff between the SW corner of the quarry and the yard of the outermost country house.

There is an overlapping of some 59 metres between the two profiles, the reliable control was ensured by the identification of a distinct *Lopha* biostrome in both profiles (Text-Fig. 9).

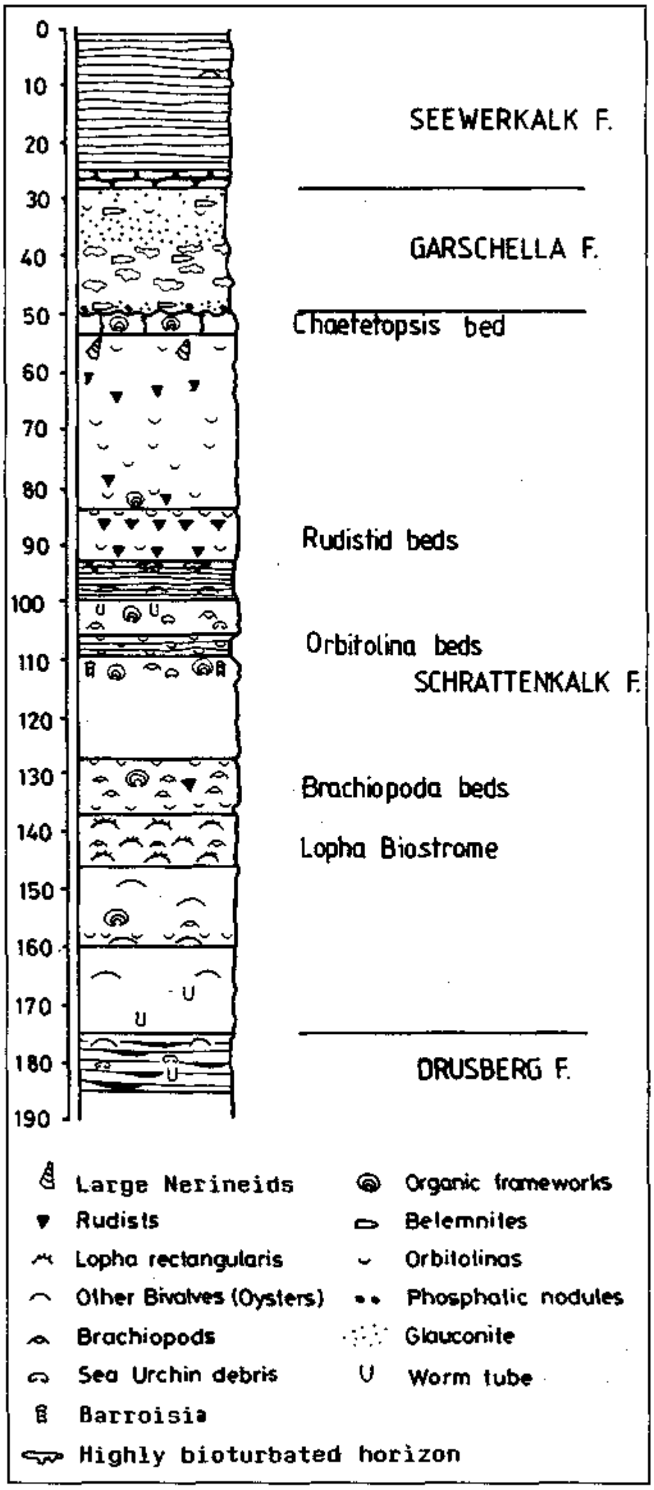
The profile has been described in detail by CSÁSZÁR, OBERHAUSER and LOBITZER (1990), therefore only a comprehensive review is given here.

In contrary to the former publication (CSÁSZÁR et al., 1990) within the Schrattenkalk of the Rhomberg-quarry profile, eight units have been distinguished.

The dark grey limestone beds corresponding to the Drusberg Formation are of flaser structure, with thin marly lenses or argillaceous bedding planes. In some horizons thick-shelled, large, gryphoidal *Ostrea* valves and sporadically thin-shelled, intact sea urchin sections are present. The most frequent fossils that can be identified from thin sections are as follow: ostracods, *Cadosina* and Echinodermata debris (Text-Fig. 11). The texture in thin section is biomicritic wackestone.



Text-Fig. 6.
Profile through Breiter Berg and Rhomberg quarry.



Text-Fig. 7.
Columnar section of the Rhomberg quarry.

It is rather difficult to distinguish the o l d e s t u n i t (I) of Schrattenkalk (samples 64 to 59) from the Drusberg Formation (No boundary can be drawn in Pl. 1, Fig. 1). The diagnostic structural features of the Lower Schrattenkalk are mainly the absence of marl-intercalated lenses and flaser type stratification. This unit is the only one in which thin elongated chert lenses can be observed. They form a horizon (around sample no. 61).

Submarine erosional contact between beds of different grain size is characteristic (Pl. 2, Fig. 1). The rock is heavily bioturbated and contains a few *Ostrea* and *Lopha* valves. Towards the younger beds, the amount of arenaceous and calcareous benthonic Foraminifera – including Miliolidae – increases. The texture in thin section is mainly pelbiomicrosparitic packstone.

The s e c o n d u n i t (II; samples 58 to 52 in Text-Fig. 11) is represented by a thick-bedded or compact, fine- or medium-grained bioclastic, or sometimes oolitic limestone of grey colour. Sometimes gradation or cross-stratification of calcareous origin can be observed (Pl. 2, Fig. 2). Text-Fig. 9 illustrates the different facies types identified in the quarry. In the SW corner of the quarry, the cross-stratification is restricted to a single bed, whereas in the NE part it is well developed in three beds. Fossils observed by unaided eye are *Ostrea*, *Orbitolina* and minor colony-forming organisms (such as coralline algae, pebble-like stromatoporoidea colonies). Microscopically, the main constituent is represented by Echinodermata test detritus and mainly arenaceous benthonic foraminifera associated sometimes with a few calcareous ones.

The percental distribution of foraminifera in sample 52 taken as a type sample is shown in Text-Fig. 10. Bryozoans are present in increasing frequency. The texture is biointrasparitic to biopelsparitic grainstone.

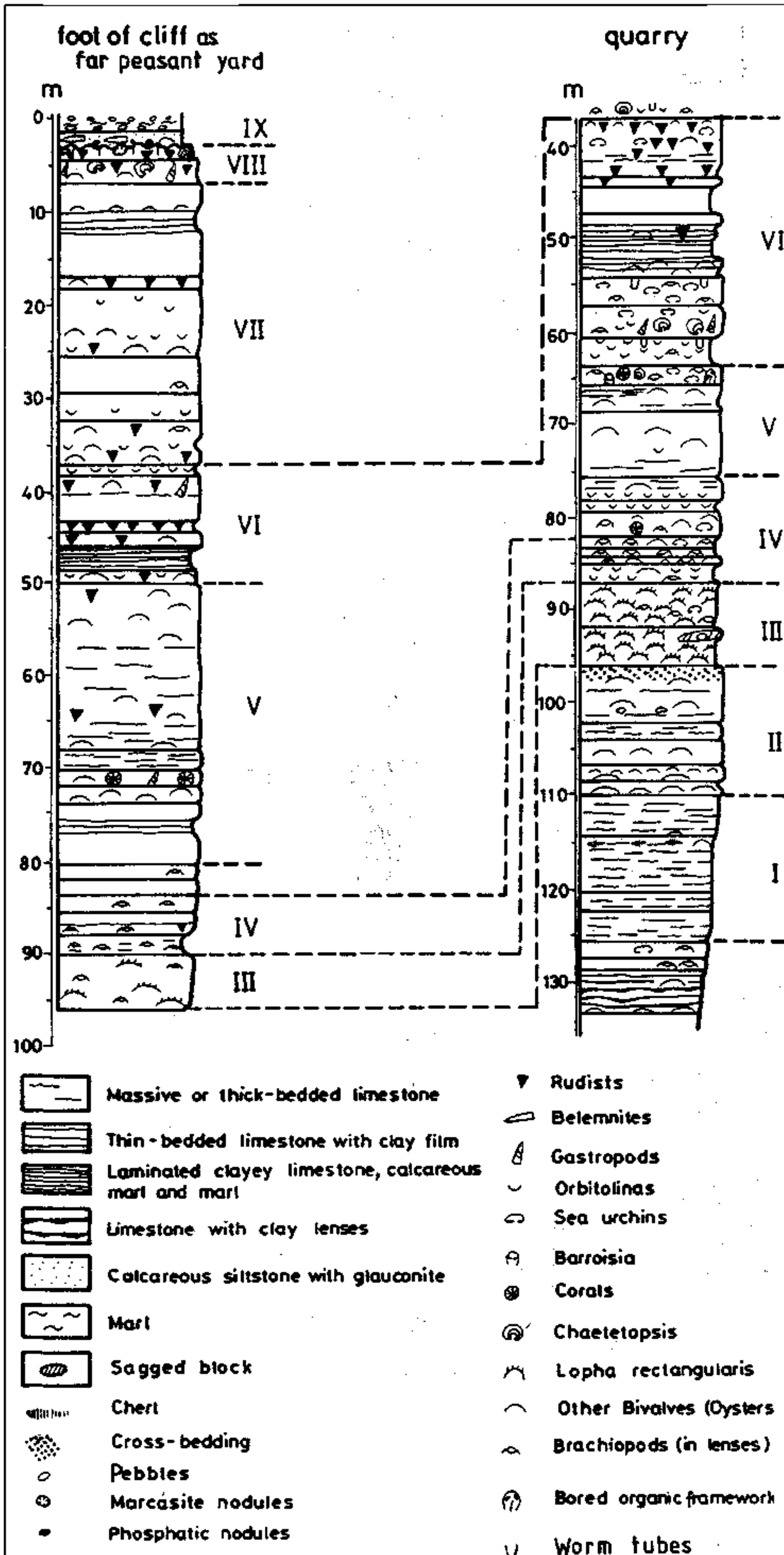
The t h i r d u n i t of the formation (III; samples 51 to 44 in Text-Fig. 11) is the *Lopha* biostrome. This rock body represents a most particular and spectacular unit of the quarry and incorporates various fossils, in addition to the characteristic *Lopha rectangularis* (Pl. 6, Fig. 1). The dark grey, sometimes black, thick-bedded limestone, with its varying argillaceous and biostrome type development is restricted to the vicinity of Unterklien. Its facies variability is strikingly high also in the quarry. As shown in Text-Fig. 9 the unified *Lopha* unit seems to disappear in NE direction through ramification, whereas its thickness decreases considerably towards the SW. Sagged blocks of grainstone or rudstone texture with the size of several metres are present within the unit (Pl. 4, Fig. 1). The texture of the *Lopha* bed ranges from wackestone to boundstone (floatstone). It should also be mentioned that for the first time the amount of bivalve test detritus exceeds that of Echinodermata tests among the biogenic constituents, indicating that a typical carbonate platform was formed during the development of this unit.

The f o u r t h u n i t (IV; samples 43 to 32 in Text-Fig. 11) is caracterized by the dominance of brachiopods (VÖRÖS in CSÁSZÁR et al., 1990). In accordance with the changes in fossil content, the limestone is darker or lighter grey and thicker or thinner bedded. Horizons rich in brachiopods are overlain and underlain by *Orbitolina* rich beds. Beside the arenaceous foraminifera in this beds also a high frequency of calcareous foraminifera can be observed. In addition to the strikingly frequent Bryozoans there are also minor algal colonies. The texture in thinsection is mainly packstone, but grainstone and wackestone are also frequent. A major part of allochems is of biogenic origin. Simple ooids with low frequency represent a permanent attendance.

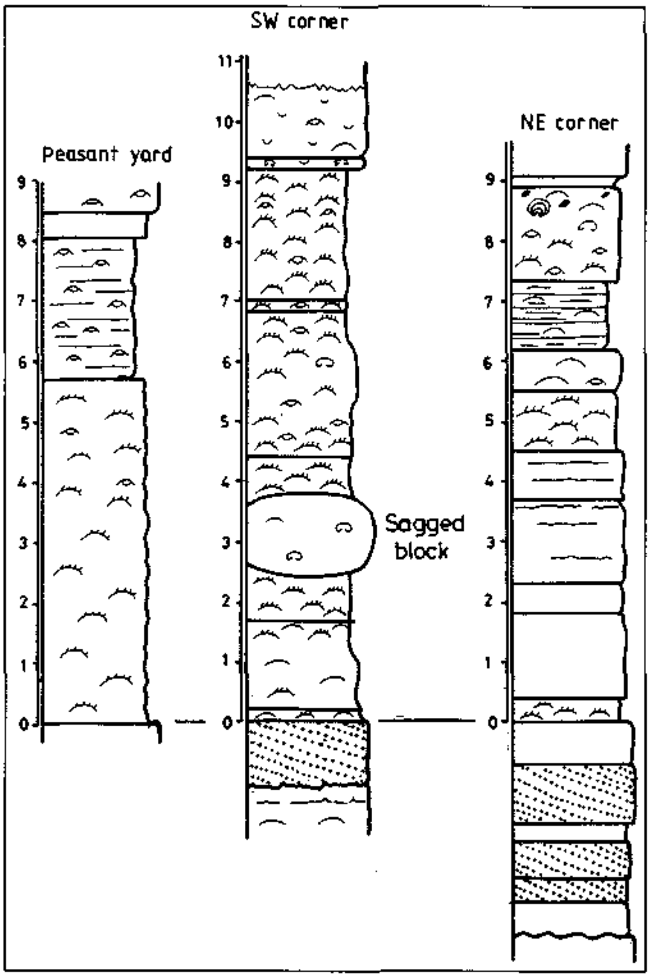
The f i f t h u n i t (V; samples 31 to 28 in Text-Fig. 11 and samples 34 to 28 of the cliff section to where the sequence continues – (Text-Fig. 12) – is of thick-bedded to compact development, light grey or sometimes brownish shade and mainly of calcareous sand facies. It has a poor megafauna, including only a few *Ostrea* valves. Towards the NW in the quarry the grain size becomes finer, the colour turns dark grey, and the clay content increases. In the 2 m thick bed of patch reef building organisms (corals, sponges –

mainly *Barroisia* and *Chaetetopsis*, coralline algae etc.), infillings of boring bivalves (frequently containing the valve itself), are very frequent. In addition, remarkable constituents are large sea urchin spines. Algae are remarkably frequent in the microfossil content of sample 28 (Text-Fig. 10). This horizon is the only one, where carapace detritus was identified from. Texture is grainstone and boundstone.

The sixth unit (VI; samples 27 to 2 in Text-Fig. 11 and 27 to 18 in Text-Fig. 12) is represented by the alternation of completely dark grey, thin-bedded calcareous marl, argillaceous limestone as well as of medium grey, poorly-sorted bioclastic limestone of compact development. At the base of the unit a relatively thick *Orbitolina* horizon is present, whereas its top part is formed by an *Orbitolina* horizon with a thickness of a few centimetres only. Rudist bivalves appear for the first time in larger amounts in the upper third of the unit. Brachipods (identified by A. Vörös, 1989) are characteristic, mainly for the deeper horizons. Here a frequent occurrence of sea urchin spines, minor coral and *Chaetetopsis* colonies can also be observed. *Ostrea* biostrome is exceptional (Pl. 2, Fig. 3). The first appearance of gastropods can be encountered. Sample 20 is taken from a poorly-stratified, sometimes cross-bedded intercalation of turbiditic origin and fine calcareous sand facies (Pl. 1, Fig. 3). At the boundary between horizons 10 and 11 the heavily bioturbated remains of a lighter grey, pelitic rock can be recognized (Pl. 2, Fig. 2 and Pl. 4, Fig. 2). In thin-sections a great amount of calcareous – mainly Miliolina species – and many arenaceous benthonic foraminifera could



Text-Fig. 8.
Schrattenkalk sequence at Unterklien.



Text-Fig. 9.
Facies changes in *Lopha* beds (Rhomberg quarry).
For legend see Text-Fig. 8.

be identified (compare Text-Fig. 10). Also a great number of Dasycladacea and ostracods and – in the uppermost part – *Bacinella irregularis* are present. In the micritic matrix of the mixed facies of bed 11, nearly three-fourth of the microfossils is Miliolidae, with the rest represented by Ataxophragmidae and Textularidae. In sparitic cement both groups show a nearly identical frequency. Its varied texture is characterized mainly by packstone.

The thicknesses of fifth and sixth units vary in the profiles of the quarry and the cliff – in accordance with the change in lithofacies.

The limestone of the seventh unit (VII; samples 17 to 5 in Text-Fig. 12) is light grey, bedded, small or medium-grained, bioclastic. At the upper boundary of the unit, stratigraphically directly beneath the bivalve biostrome a dark grey fairly argillaceous, fine-grained limestone bed was found exhibiting cross-stratification of turbiditic origin (Pl. 5, Fig. 2). Its megafauna is similar to that of the former one, but is generally poorer.

As shown by sample 7, half of the microfossils is *Salpingoporella*, one-fourth is Miliolidae, whereas the rest consists of *Orbitolina*, Ataxophragmidae and *Textularia* species as well as *Bouenia* (Text-Fig. 10). Its dominant type of texture is grainstone.

The eighth unit, (VIII; samples 1a to 4 in Text-Fig. 12) representing the youngest beds of Schrattenkalk has a thickness of 4 metres only and is of flaser type, sometimes with a nodular structure, and argillaceous intercalations. It has a diverse and rich fossil content, incorporating large *Chaetetopsis* colonies (Pl. 2, Fig. 4), coral and minor coralline algae colonies, large *Nerinea*, a great number of small gastropods, bivalves, solitary corals and rudists. Coral colonies show traces of boring organisms.

Its boundary with the Garschella Formation is formed by a condensation level where, according to SALOMON's model (1987), an alternation of sedimentation, dissolution, bioturbation and erosion took place. As a result, the surface of Schrattenkalk is uneven, bioturbated, with its detritus found in the basal beds of the overlying formation. In addition, glauconite, as well as phosphorite and marcasite nodules are also frequent here.

The microfauna content of this unit (Pl. 8, Figs. 4 and 5) does not differ essentially from that of the former one.

Due to the phenomena described above, the influence of the overlying formation can be traced down to a depth of at least 1 m and it can be observed both in textural pattern and microfossil spectrum.

The Garschella Formation is represented by grey, frequently greenish-grey, glauconitic marls with the frequent occurrence of small belemnites. It is a striking feature that only small accumulations of fossils of poor preservation can be observed along the boundary. The microfauna is determined by frequent occurrence of planktonic foraminifera.

2.2.3. Feldkirch, Upper Ill Gorge

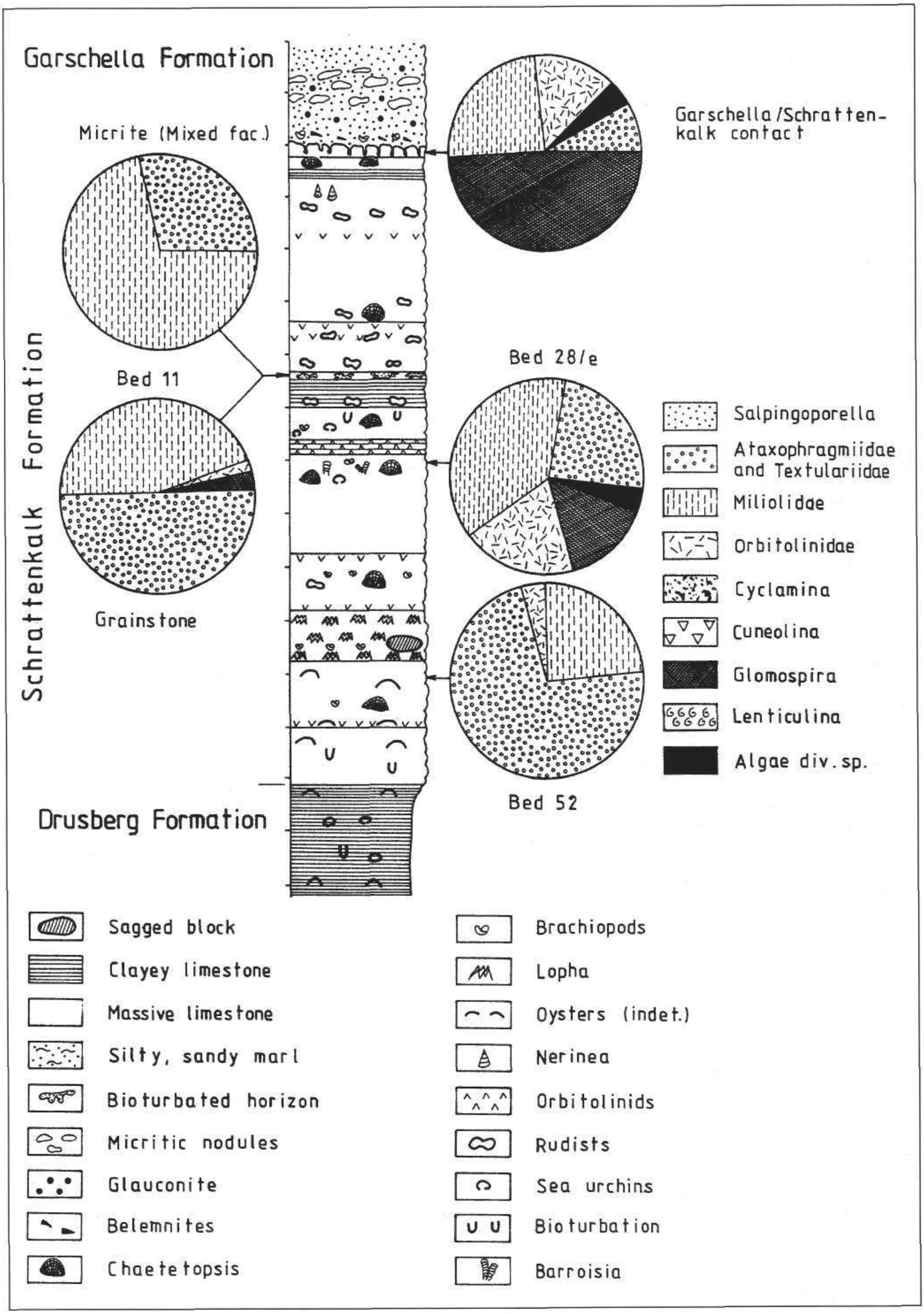
This road-cut (Text-Fig. 3), with its features essentially differing from those of the Rhomberg quarry, belongs to the Säntis nappe and exposes the sequence ranging from the Drusberg Formation to the Garschella Formation in normal tectonic position (Text-Fig. 13). It is situated along the railway line running along the right side of River Ill. The main features of the profiles are as follows (Text-Fig. 14):

- The transition between Schrattenkalk and the Drusberg Formation is gradual, with decreasing recurrences of the marly facies (Pl. 3, Fig. 2 and Pl. 4, Figs. 1 and 2).
- On account of the complete absence of megafauna and the high degree of roundedness of the frequent *Orbitolina*, the Schrattenkalk Formation (of calcareous sand facies only) is interpreted as redeposited sediment.

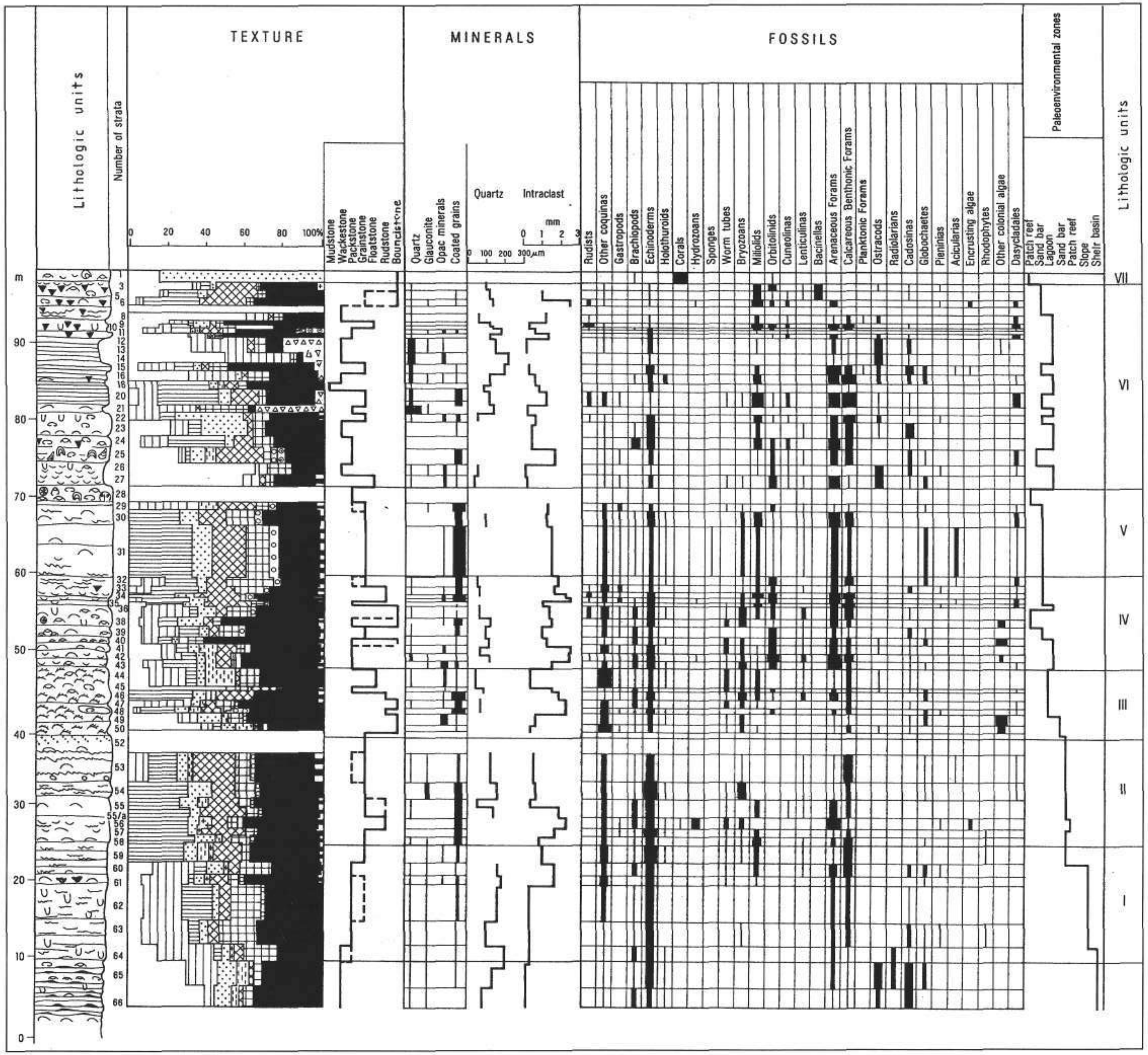
The marly Drusberg-type sediments intercalated between the Schrattenkalk beds are dark grey. Each intercalating layer shows an increase in carbonate content towards the top of the bed. The texture in thin-section is packstone and wackestone (biointrasparite and biomicrosparite). The microfauna consists of a large amount of foraminifera, mainly arenaceous ones, but sometimes arenaceous and calcareous foraminifera have approximately identical amounts (Text-Figs. 14 and 15).

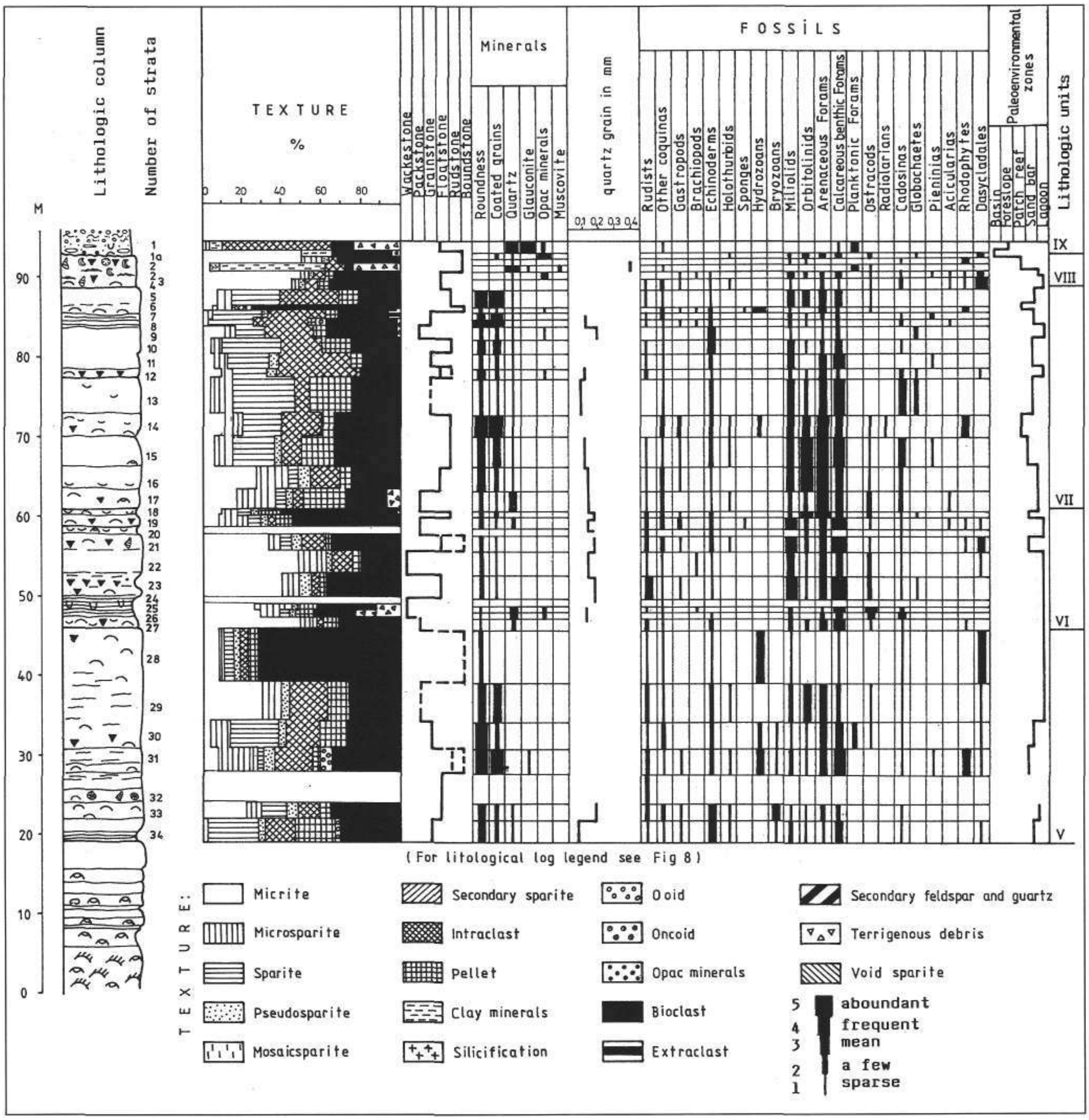
In the Schrattenkalk profile of compact or thick-bedded development the upper third part shows coarse-crystalline texture, due to recrystallization, and is, for this reason, not suitable for facies-study. In its lower two-third part a few cross-bedded layers (Pl. 3, Fig. 3), one thin chert layer

Text-Fig. 10.
Distribution of foraminifers in the Unterklien section. ➢ ➢ ➢


Garschella Formation
Micrite (Mixed fac.)
Garschella /Schratten-kalk contact
Schrattenkalk Formation
Bed 11
Grainstone
Bed 28/e
Bed 52
Drusberg Formation
Salpingoporella
Ataxophragmiidae and Textulariidae
Miliolidae
Orbitolinidae
Cyclamina
Cuneolina
Glomospira
Lenticulina
Algae div. sp.
Sagged block
Clayey limestone
Massive limestone
Silty, sandy marl
Bioturbated horizon
Micritic nodules
Glauconite
Belemnites
Chaetetopsis
Brachiopods
Lopha
Oysters (indet.)
Nerinea
Orbitolinids
Rudists
Sea urchins
Bioturbation
Barroisia

Text-Fig. 11.
Texture, mineral distribution, fossil distribution and environmental changes at the foot of the cliffs in the Rhomberg quarry.
For legend see Text-Fig. 12.





Text-Fig. 12.
Texture, mineral distribution, fossil distribution and environmental changes in the III Gorge section.

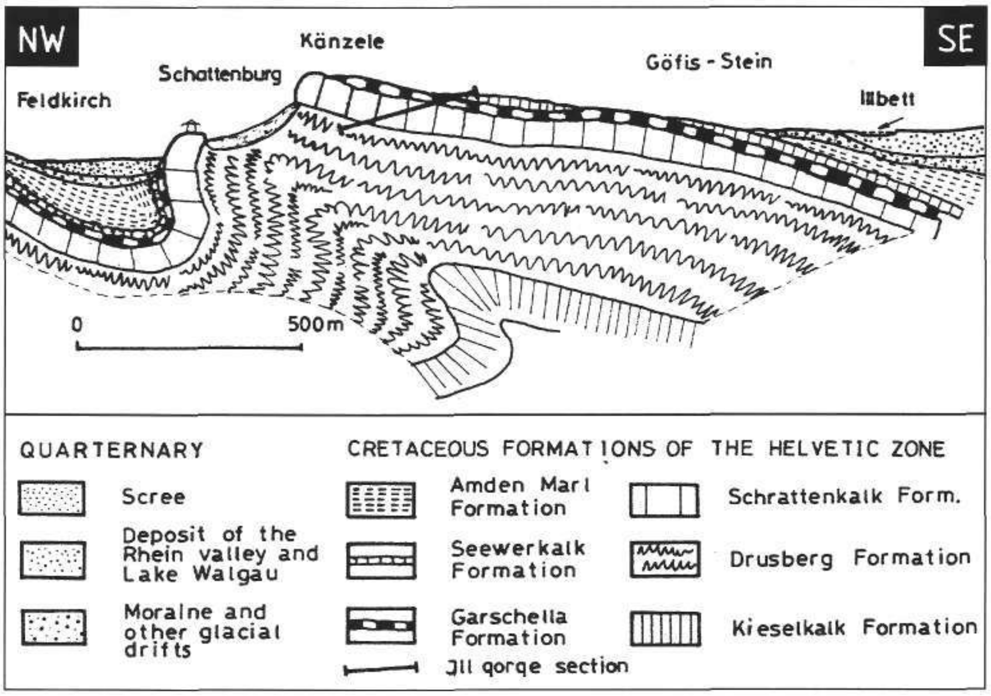
and one horizon with chert lenses are incorporated. Only a few brachiopods in poor state of preservation and a small amount of bivalve debris are included. Generally, the degree of bioturbation is heavy on the argillaceous bedding-planes and in some layers (Pl. IV, Fig. 3). The microfauna content is poor, with *Orbitolina* as its dominating element (Pl. 3, Fig. 4), although calcareous benthonic forms also occur (Miliolidae, *Lenticulina* (Text-Figs. 14,15). The amount of Echinoderm test debris exceeds, almost without exception, that of bivalve shells. The amount of detritus of bryozoans is high, whereas that of rudists is rare. The amount of Dasycladaceae, Rhodophyta, and other algae is extremely low. Texture is biointrasparitic grainstone or rudstone. Ooids generally occur in a low frequency. The amount of encrusted grains is medium or high. The degree of roundedness varies. The frequency of terrigenous grains is low and approaches 5% only rarely. Maximum grain size varies within a range of 0.1 to 0.2 mm and never attains 0.5 mm. The amount of secondary feldspar and silica grains varies between 1 to 4% in the lower part of the profile.

In the upper part of the profile the features seem to be identical with those described above, as far as the intensive recrystallization and dolomitization and the poor outcrop situation of the uppermost 4 to 5 metres allow any statement.

2.2.4. Übersaxen

A comprehensive study of further profiles was performed in order to investigate the facies change of the

Text-Fig. 13.
Location of the profile studied at Ill Gorge (Feldkirch).



Schrattenkalk towards the south within the Säntis nappe, where the trend of pinching-out of Schrattenkalk is indicated by patches becoming continously thinner. One of the related profiles is exposed by the road-cut at the upper end of the village Übersaxen, where only the basal beds are exposed enough for study (Text-Fig. 16).

The boundary between Schrattenkalk and Drusberg Formation is sharp: The dark grey-black, fairly argillaceous siltstone-marl (calcareous marl) is replaced by small- and fine-grained, bioclastic, well-bedded limestone with a grain size of a few millimetres and apparently silicified (quartzified and feldsparified). Towards the top of the profile the frequency of these grains varies up to 5 m above the boundary and then remains constant at a slightly lower value. At around 8 m the rock becomes slightly argillaceous. It may be due to this argillaceous character, that in the further part of some 50 metres along the road only scattered limestone detritus can be encountered.

The profile is poor in fossils. Only *Orbitolina* occurs in a considerable amount. A few minor *Ostrea*, only one Belemnite and one shark tooth could be recognized by unaided eyes.

In addition to the few extraclastic quartz grains, the biopelsparitic grainstone or intrabiosparitic rudstone include autochthonous plagioclase bars and quartz grains concentrated in certain fossils or intraclasts, sometimes with ooids in the latter. The microfossil assemblage consists of quartz-agglutinating *Orbitolina* (and other arenaceous foraminifera), Miliolidae, Echinoderm and sponge detritus, bryozoan and molluscan debries and a few algae like *Ethelia alba* and *Salpingoporella* sp.

2.2.5. Roadcut Between Furx and Laterns

Here the Schrattenkalk turns into a band even narrower than the one at Übersaxen. In spite of the fact that the profile of the roadcut found half-way between the two villages (Text-Fig. 16) is incomplete, only a few metres of it can be considered to be unknown (tectonic contact at the base and cover at the top). Megafossil remains have not been found, only same sponge detritus, and along argillaceous surfaces, in some cases intensive bioturbation and also *Zoophycos* can be observed. Several beds are frequently graded (partly inversely), and here and there they are pinching out laterally within a few metres (lobe sedimentation). The thickness of the beds varies in the range of 0.2 to 1.5 m. The colour is medium grey, or dark grey when more argillaceous. They consist of small to medium-grained calcareous sand. According to these lithological characters the transitional features towards the Drusberg Formation are more gradual than in the Übersaxen profile. On the basis of sedimentological features such as gradation (Pl. 5, Fig. 1) and pinching-out – the turbiditic origin of the deposits is easy to recognize, and therefore is representing a very distal region of the carbonate platform. The texture is generally biosparitic grainstone and rudstone. Packstone and floatstone textures occur only as rare exceptions. In addition to the sometimes strong silification and feldsparitization, detrital quartz and glauconite grains can also be observed.

Fossils identified from thin-sections are as follows: calcareous benthonic Foraminifera (Miliolina and *Lenticulina*), large arenaceous benthonic Forams (*Orbitolina* and *Rheophax* – Pl. VIII, Fig. 3, Text-Fig. 15), Echinoderm debris, mollusc shells, bryozoan and sponge debris, *Cadosina*, a few ostracods, red algae, brachiopods and worm tubes.

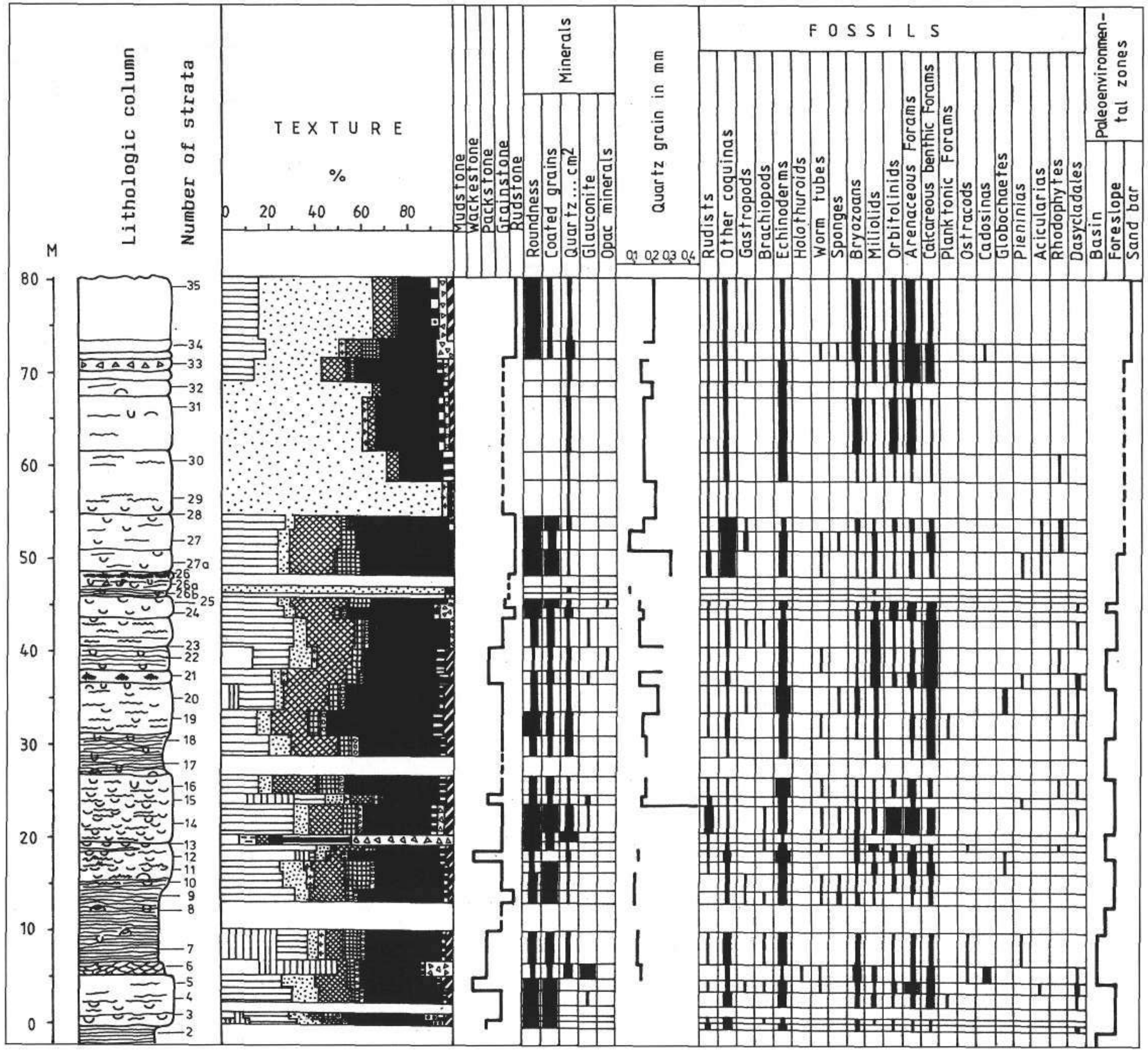
Large arenaceous foraminifers, such as *Rheophax* and *Coscinophragma* are important elements of the microfauna. The great frequency of *Coscinophragma* (a form with labyrinthine wall) raises the question of the area of origin. Sedimentary structures (soal marks or flute casts) that would refer to the direction of transport are missing even from the turbidite beds. *Coscinophragma* (Pl. VIII, Figs. 1,2) is hardly known from any of the other occurrences of Urgonian formation in Vorarlberg investigated by the authors. It should be noted, that the arenaceous forms with labyrinthine walls are rare, but whereever they occur, intensive terrigenous influence can be observed. In the upper Schrattenkalk beds of the Gottesackerwände, for example, *Choffatella* with labyrinthine walls, forms an assemblage with *Orbitolina* (Pl. VI, Fig. 3).

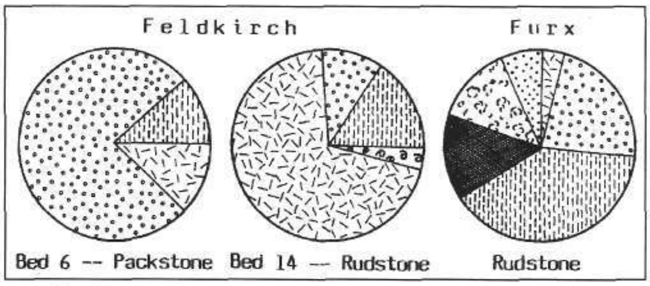
2.2.6. Ebniter Ache

(Text-Fig. 16)

The narrow zone of Schrattenkalk, crossing the rivulet, represents the southernmost development of the formation studied by us. Although its upper boundary is tecto-

Text-Fig. 14.
Texture, mineral distribution, fossil distribution and environmental changes in the Ill Gorge section.
For legend see Text-Figs. 8 and 12.





Text-Fig. 15.
Distribution of foraminifers in the sections Feldkirch (a and b) and at Furx (c).
For legend see Text-Fig. 10.

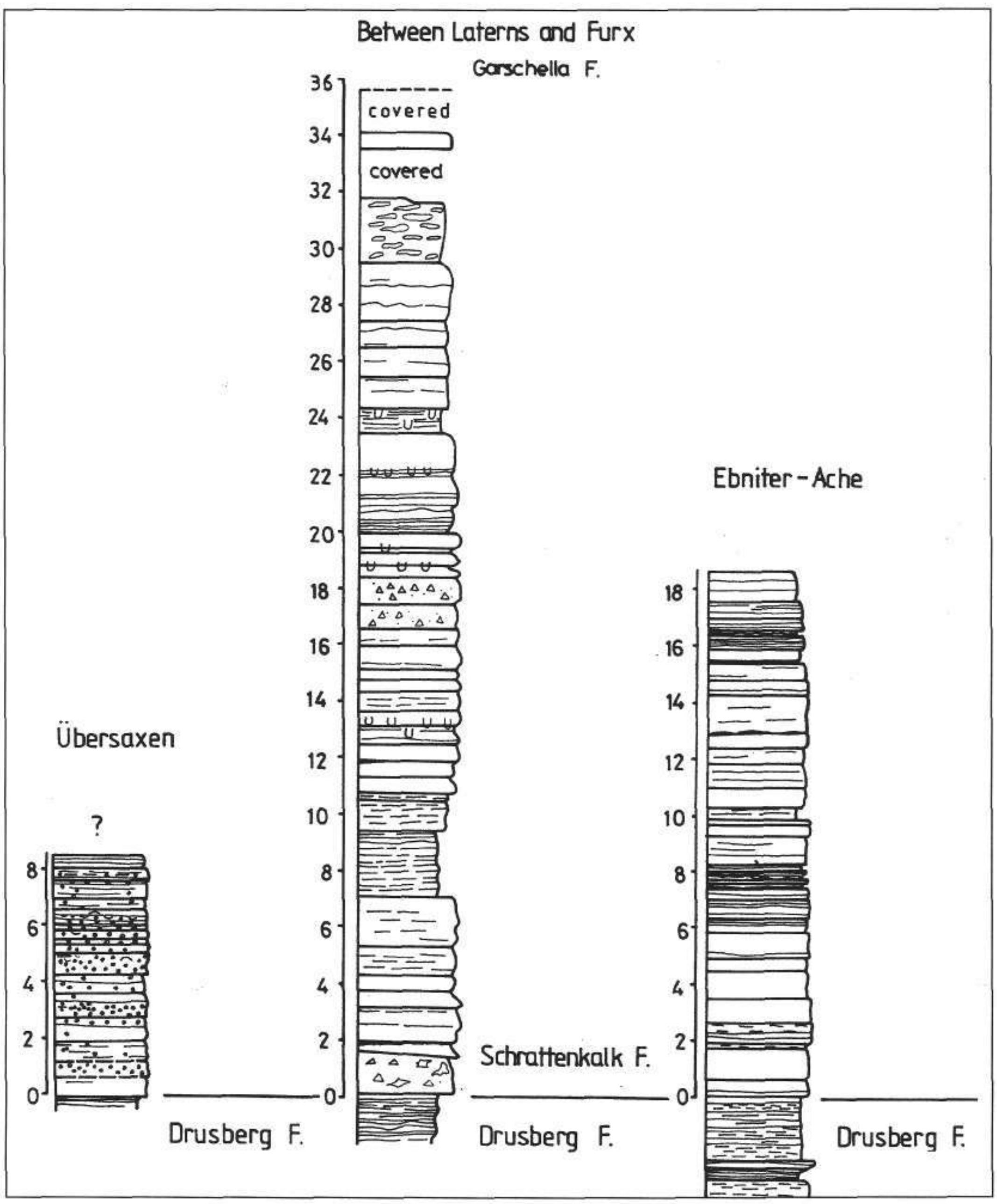
nically disturbed, the thickness can be definitely stated to be smaller than that of the former profile. It is characterized by thin- to medium-bedded, fine- to (less frequently) medium-grained, often argillaceous limestones.

The layers are generally separated by siltstone horizons, each with a thickness of a few centimetres. The Schrattenkalk can be distinguished from the Drusberg Formation on the basis of a higher carbonate content. It is overlain by a thin Garschella Formation. No megafauna was found within the sequence.

Its texture is biointrasparitic rudstone, grainstone and subordinately packstone. In some cases extraclasts (glauconite, limestone and quartz) occur in a high frequency (4 to 8%). Simple ooids are rare. Silicification appears in the cement and each sample contains a considerable amount of secondary feldspar bars.

Fossils identified from thin section, in decreasing order of frequency, are as follows: Echinoderm debris, calcareous (mainly Miliolidae, including large ones) and arenaceous benthonic foraminifera (including *Orbitolina*), minor bryozoan colonies, Dasycladaceae, bivalve shell detritus, and a large amount of *Cadosina*, sponge detritus, *Ethelia alba*, *Cayeuxia*, Ostracoda, and planktonic crinoids.

2.3. General Patterns of the Schrattenkalk Subfacies



On the basis of the sections studied, two basic types of Schrattenkalk can be distinguished: the autochthonous and the allochthonous one. The autochthonous type is characterized by a rich micro- and megafossil assemblage which can be represented by various colonial organisms in patch-reefs and mudmounds (corals, hydrozoans, *Chaetetopsis*, sponges), rudists, Echinoderm fragments, foraminifers and various kind of algae. Its texture is extremely variable, incorporating almost all types in a great frequency. The Rhomberg quarry at Unterklien and the Gottesackerwände correspond to this subfacies.

Text-Fig. 16.
Columnar sections in roadcuts at Übersaxen, between Furx and Laterns and in the Ebniter Ache valley.
For legend see Text-Fig. 8.

The allochthonous subfacies is represented by beds of carbonate sand originating from processes of reworking and redeposition of sediments and fossils from the autochthonous subfacies. Megafossils can be found in fragments only. Its microfossil content is almost identical to that of autochthonous subfacies. It has dominantly grainstone or rudstone texture. The Feldkirch profile, the road-cut between Furx and Laterns, the road-cut at Übersaxen and the exposure in the valley of the Ebniter Ache correspond to this subfacies.

2.4. Age of the Schrattenkalk

The age of this formation was assigned as early as in 1861 by GÜMBEL to the Barremian–Aptian. Even on the basis of various fossils the specialists could reveal only slight differences. ZACHER (1973) dated the beginning of the formation to the Late Barremian for the eastern part, and to the Early Aptian (Bedoulian) for the southern part. The end of the Urgonian development he stated to be isochronous in the Early Aptian. SCHOLZ (1979) assigned the formation also to the Upper Barremian–Lower Aptian, on the basis of Dasycladales, *Orbitolina* and molluscs.

In contrary to the opinion of BOLLINGER (1988, p. 39,40), who wants to start with Schrattenkalk sedimentation in Early Barremian time, we feel that the occurence of *Conorotalites bartensteini intercedens* is a sufficient proof of Middle Barremian age for the lower Drusberg beds of the northern Säntis nappe (W. FUCHS, 1971) and for the Hohenems fold at Klien (OBERHAUSER, 1969, p. A 42). "Open nomenclature stratigraphy" of orbitolinids (*Urgonina* cf. *alpillens*, *Paleodictyoconus* nov.sp.2) is in this case no definitive argument against Middle Barremian age (BETTENSTAEDT, 1958, p. 569). Therefore Schrattenkalk sedimentation seems to be not possible before Middle Barremian.

On the basis of *Orbitolinopsis buccifer* and *O. pygmea* in the Säntis nappe of Switzerland BOLLINGER, 1988, p.40, is dating the upper boundary of the formation as middle Early Aptian and at Klien in the Hohenems fold as early Early Aptian. According to FÖLLMI the oldest occurence of the Garschella formation belongs to the deshayesi-zone of the middle part of the Lower Aptian.

Therefore by Ammonites of the transgressive bed, considering some time interval for condensation, the deposition of the Schrattenkalk is likely to have stopped not later than weissi-albrechti-zone of the Early Aptian (FÖLLMI, 1989, p. 6).

The results of palaeontological examinations carried out during the last few years do not enable us to draw essentially new conclusions. Of the 302 brachipods collected from beds higher than sample No. 34 of the Rhomberg quarry, the following species were identified by A. VÖRÖS: *Lamellaerhynchia renauxiana*, *L. gillieroni* (PICT.), *L.* cf. *multicostata* BURRI, *Sellithyris* cf. *sella* (SOW.), *Loriolithyris* cf. *russilensis* (LOR.), *Symphytyris* ? sp., *Tamarella* cf. *tamarindus* (SOW.).

Based on the first three species, according to A. VÖRÖS, the examined part of the formation does not extend beyond the Barremian-Aptian boundary.

Orbitolina have been studied so far only in the younger beds of the Rhomberg quarry (samples 1–33) and in the profile measured at Feldkirch. E. KÖHLER (in CSÁSZÁR et al., 1990) has distinguished the following species: *Orbitolinopsis cuvillieri* MOULLADE, *O. debelmasi* MOULLADE, *O. kiliani* SILVESTRI, *O. pygmaea* ARNAUD-VANNEAU, *Palorbitolina lenticularis* (BLUMENBACH), *Paracoskinolina maynci* (CHEVALIER), *P. sunnilandensis* (MAYNC).

Summing up both macro- and micropaleontology, it can be stated that the Urgonian type carbonate sedimentation in the Helvetic zone of the Eastern Alps extended definitely into the Early Aptian, but did not pass the boundary between the Early and Middle Aptian, and ended by an isochronous event (SALOMON, 1990).

According to WILDI et al. (1989) features of extensional tectonics cause at that time a synsedimentary crack by drawning the platform.

3. Nagyharsány Limestone Formation

3.1. Geological Setting and Geographical Extent

Urgonian facies has developed in both larger tectonic units of the Hungarian basement (Text-Fig. 17). In the Pelso unit, belonging to the Apulian Faunal Province, the Urgonian facies (Környe Limestone and Zirc Limestone Formations) appears in two horizons of the Albian stage. It is represented in the Villány-Padurea Craiului zone of the Tisza unit by the Nagyharsány Limestone Formation.

This formation, known as the oldest Urgonian one in Hungary, is characterized by an unusual thickness of ca. 1000 metres, a slow rate of transgression (long time interval of sedimentation) and by cyclic (in some cases lofer-cyclic) appearance in the lower 100 metres. The European plate origin of the Tisza unit is accepted. Its particular sediment is the Harsány-hegy Bauxite Formation appearing as small lenses at the base of the formation. One of our aims is to find reasonable explanation for solving the contradiction mentioned above.

The formation crops out in the Villány Mountains, and in the Királyerdö (Padurea Crailui) in Transsylvania (Blid Limestone Formation). Our studies were concentrated to three quarries in the Villány Mountains (Text-Fig. 17), for two of which the erosional contact formed with the related underlying beds is also exposed (Pl. 9, Figs. 1,2). The underlying beds are represented by Upper Jurassic limestones, which show also shallow marine origin. Their occurrences are restricted to narrow imbricated zones of the Villány Mountains. Outcrops in the Lower and Middle Jurassic formations are discontinuous and punctiform.

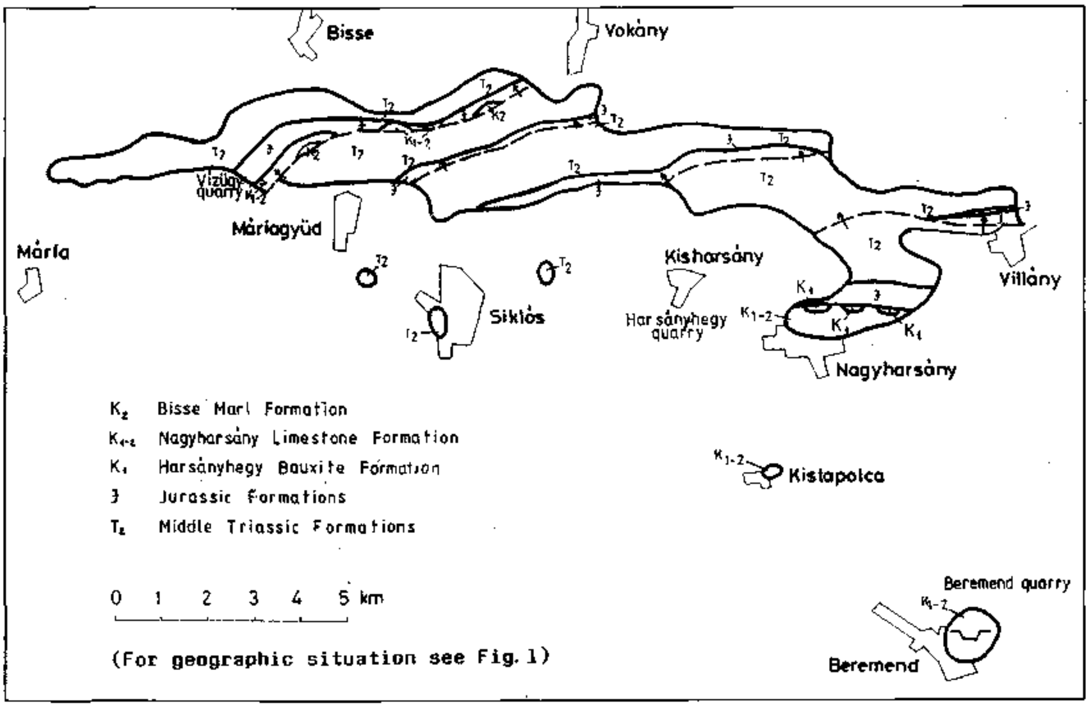
The Nagyharsány Limestone Formation is restricted only to two tectonic imbrications.

In the Tenkes imbrication, where the rudistid- and *Orbitolina*-bearing limestone has a thickness of only 30 meters, it is overlain, with a sharp boundary, but concordantly, by the Bisse Marl Formation (FÜLÖP, 1966), assigned to the Albian. In the absence of Bisse Marl the second bauxite horizon of the mountains can be found in the karstic caverns and fissures found in the surface of the Nagyharsány Limestone Formation (CSÁSZÁR & FARKAS, 1982).

On the other hand, the diverse sedimentary history of the area is indicated by the fact that borehole Bóly No. 1 drilled at a distance of a few kilometres east of the mountains penetrated the same Upper Jurassic limestones mentioned above, directly beneath the Bóly and Bisse Marl Formations of Albian–Cenomanian age.

The Nagyharsány Limestone Formation was first described and named by K. PETERS (1863). Later K. HOFMANN (1878), L. LÓCZY (1912), Gy. RAKUSZ (1937), RAKUSZ & STRAUSS (1953) and J. NOSZKY subdivided and classified this formation differently. The first detailed study was

Text-Fig. 17.
Location map of Urgonian occurrences in the Villány Mountains.



made by J. FÜLÖP (1966). A sedimentological examination of the lower one-third part of the sequence exposed in the Harsány-hegy quarry was carried out by G. CSÁSZÁR (1989).

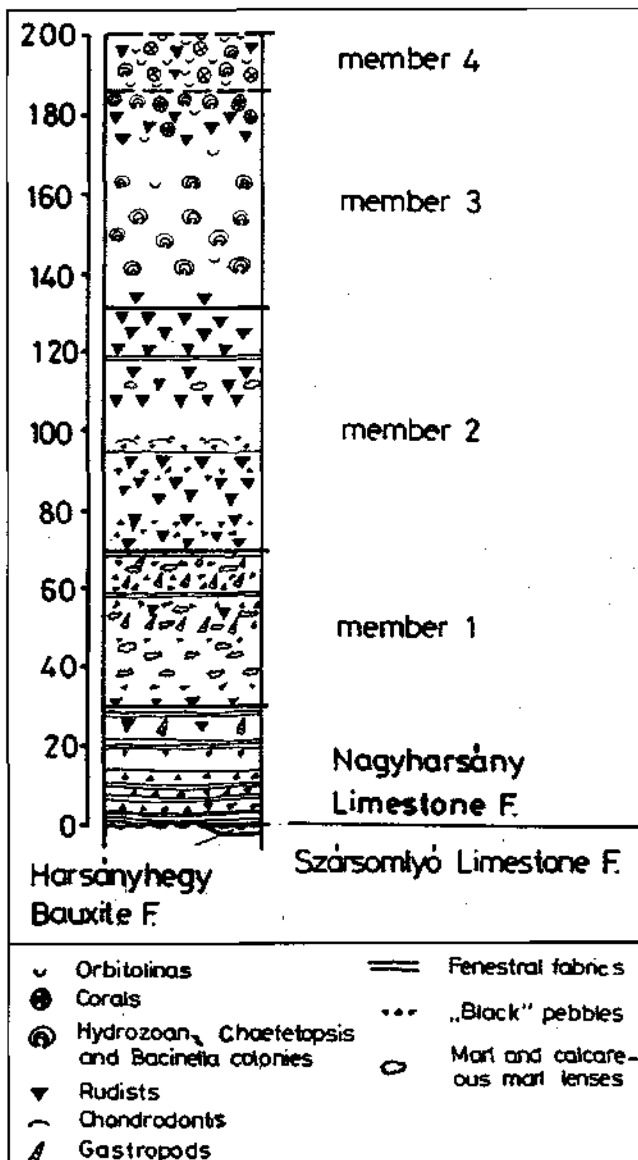
3.2. Lithology, Fossil Content and Texture

3.2.1. Harsány-hegy Quarry

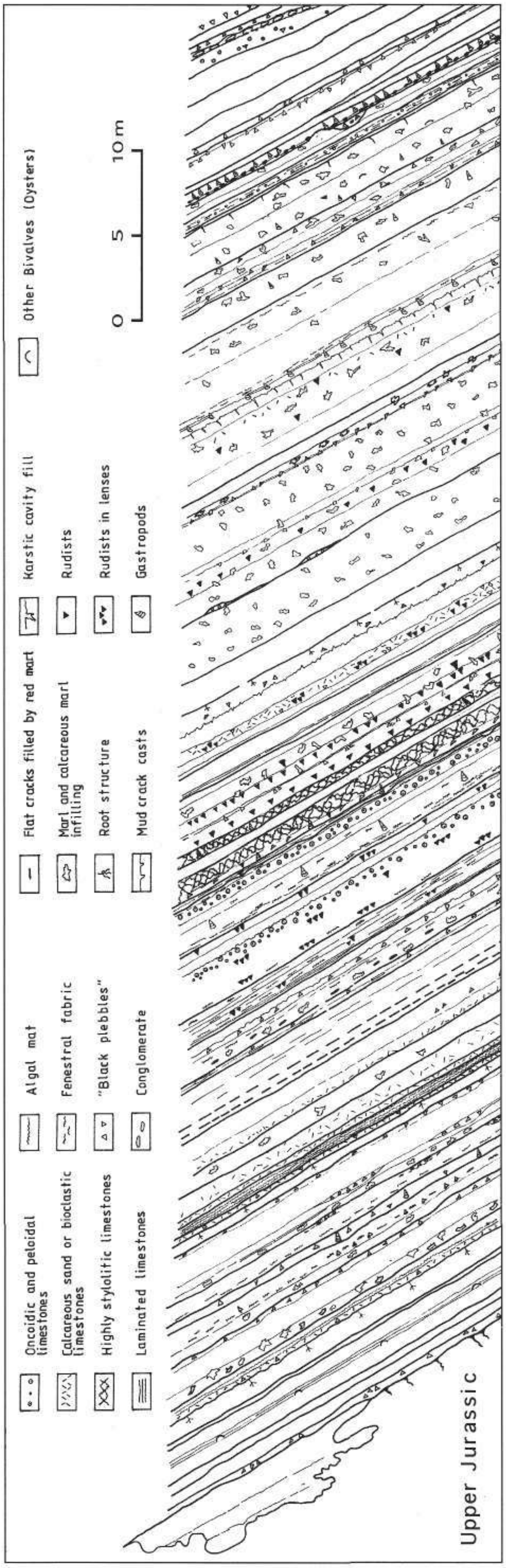
This quarry exposing Upper Jurassic and Lower Cretaceous sequences is located at the western end of Harsány-hegy. The Cretaceous part of the sequence has a thickness of 200 metres and is subdivided into four units, each of member rank (Text-Fig. 18).

Member 1

The lower, 70 m thick member is characterized mainly by cyclic development and fenestral structure (Text-Fig. 19). The limestone is thick-bedded and poor in megafossils. Its colour varies from greyish white to dark grey. The cyclic development is expressed obviously by the change in the grade of greyness (Pl. 11, Fig. 4). The alternations are of two basic types: the paling-upward and the darkening-upward ones (Text-Fig. 20). For both types, the change can be either gradual or sharp. Within the first type that version is the most frequent in this profile; the paling upward feature is more strikingly expressed. The cyclicity is well seen in regular recurrences of fenestral structures (Pl. 13, Figs. 1–3), "black pebbles" rather dark grey, or possibly pale grey (Pl. 11, Figs. 1,2 and Pl. 12, Fig. 1) and argillaceous bedding-planes, or intercalations. Here and there algal mat laminations can also be recognized (Pl. 12, Fig. 4 and Pl. 14, Figs. 1,2). Other common features of this member are pale greenish, yellowish or possibly violet-



Text-Fig. 18.
Lithostratigraphic units if the Nagyharsány Limestone Formation in the Harsány-hegy quarry (Villány Mountains).



Text-Fig. 19.
Profile in the lower member of the Nagyharsány Limestone Formation in the Harsány-hegy quarry.

coloured, irregularly-shaped marly infillings (Pl. 11, Fig. 3 and Pl. 12, Figs. 2,3) caused by bioturbation and mangrove roots. They rarely have a white calcite crust as well. Its special type is shown in Pl. 10, Fig. 1.

Despite the variegated clays and marls resembling paleosol or its proximity, real desiccation cracks are preserved rather scarcely only.

The megafauna of the first member is poor, mainly consisting of thin-shelled small gastropods (*Plesioptyxis prefleuriaui* and *Plesioplocus essertensis*, according to L. MÓRA-CZABALAY – personal communication) and 10 to 30 cm thick biostromes of minor rudists (*Requienia* ex. gr. *tortilis*, according to L. MÓRA-CZABALAY).

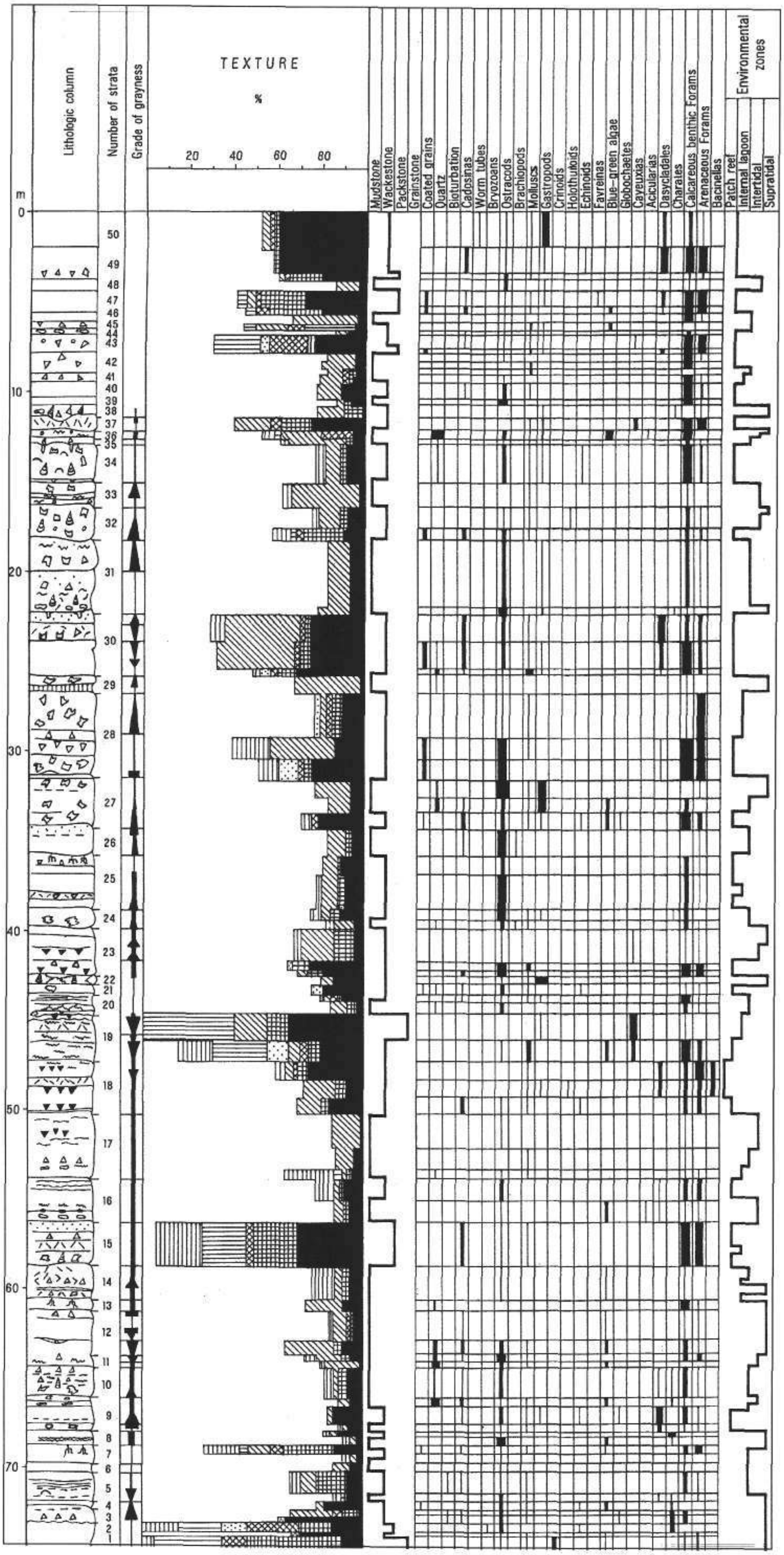
On the basis of macroscopic and microscopic observations, the lower member (Text-Fig. 19) can be subdivided into further subunits (CSÁSZÁR, 1989). As the exploitation proceeds, the quarry exhibits various lithological and palaeontological features, partly reflected by the sections studied. The examined thin sections made from an earlier profile reveal a texture of nearly exclusively mudstone or wackestone, exceptionally accompanied by a few packstone and a single grainstone. Accordingly, the allochems are of subordinate frequency. This is true also for its dominant element, the biogenic components. These facts clearly indicate a steady lagoonal, but at the same time fresh- and mixed water environment (Text-Fig. 20). The cement appearing almost permanently in the micritic matrix is the sparitic infilling of the shrinkage pores (cement B) with a 10–35 % frequency. A dominant biogenic element are benthonic foraminifera, mainly the calcareous group, especially the Miliolidae. A constant, but less frequent element is represented by Ostracoda, unidentified molluscan shells (Pl. 14, Figs. 3,4) and microgastropods. Rhythmically recurring elements are *Cadosina* and Dasycladacea, first of all various *Salpingoporella* species, but *Cayeuxia* also occurs (Pl. 15. Figs. 1,2). It should also be mentioned that the occurrence of Characea species in great frequency (Pl. 15, Fig. 3), characteristic of freshwater or possibly slightly brackish environment, is restricted to the lowermost 10 metres of the profile.

The high percental distribution of foraminifera groups is shown in Text-Fig. 21.

Member 2

The ca. 60 m thick member is characterized by a considerably greater amount and widespread occurrence of rudists. Its boundary to the former member is defined by an uneven denudation surface. The limestone is medium grey throughout the member, and – unlike the rhythmic changing in colour, characterizing the former member – colour changes occur with a lower frequency and intensity. Accordingly, the lower part of the member is medium to thick-bedded, whereas the upper half is clearly massive. In the lower half of the member the frequency of "black pebbles" is hardly lower than in the first member, although their grain size is smaller here.

"Black pebbles" are almost completely missing in the upper part of the member. An essential difference with respect to the first member is that here the pale green or yellow marl lenses of bioturbation and mangrove root origin are restricted to a few horizons only. These lithological differences are reflected also by the distribution of the megafauna. In the lower part almost only *Requienia* can be observed, frequently with biostrome feature, whereas its upper part is clearly characterized by large, generally black shelled *Toucasia*, which form frequently



Text-Fig. 20.
Texture and fossil distribution in the lower member of the Nagyharsány Limestone Formation in the Harsány-hegy quarry.
For legend see Text-Figs. 12 and 19.

biostromes. A small *Chondrodonta* bed, seemingly monospecific, can be found approximately at the boundary between the two subunits of member 2.

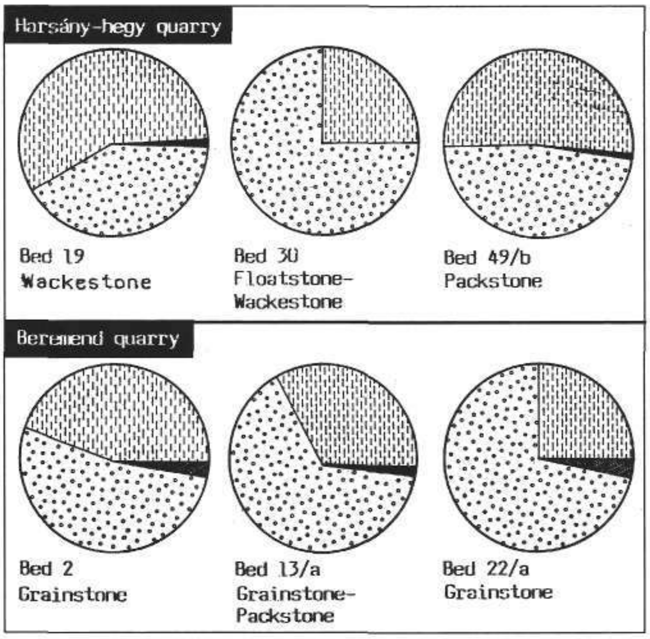
Its texture in thin-sections is packstone, and to less extent, wackestone and floatstone. The occurrence of mudstone (restricted to the lower half of the member) as well as of grainstone or rudstone is exceptional. In the upper part of the member there are only three horizons where laminoid fenestral fabrics can be observed.

Within the microfossil content the proportion of Dasycladacea (mainly *Salpingoporella* species) is considerably higher than in member 1 (Pl. 16, Fig. 2). The first microcolonies are formed by *Bacinella* sp., associated with Codiaceae. The Foraminifera content is similar to that of the previous member. *Ovalveolina* sp. (Pl. 16, Fig. 1) and Orbitolinids (Pl. 16, Fig. 3) are the only new elements in the Foraminifera assemblage of the quarry sequence.

Member 3

The major part of the approximately 55 m thick third member is undecipherably tectonized. In medium grey limestone neither rhythmic changes of greyness nor black breccia horizons are known to occur. In some tectonic blocks black-shelled *Toucasia* and small colonies unidentifiable by unaided eye can be observed.

Among variable texture-types the most common one is boundstone, although the lower part of the member is characterized by the dominance of packstone and wackestone. Floatstone, rudstone and mudstone are rare exceptions.



Text-Fig. 21.
Foraminifera distribution in the Harsány-hegy quarry and the Beremend quarries.
For legend see Text-Fig. 10.

Thin-sections reveal, that a major part of minor colonies is represented by *Bacinella* and the closely-associated Codiaceae algae. Among minor part of the colonies due to bad preservation a few corals were identified only. The foraminiferal content is slightly poorer than that of the second member. Numbers of *Orbitolina* species and individuals increased. Large Miliolina species occur mainly in samples containing no *Orbitolina*. The absence of Dasycladacea is striking.

Member 4

The youngest member of the Harsány-hegy profile is exposed in a thickness of approximately 15 metres at the southern rim of the quarry. The main feature of this thick-bedded, or massive limestone is the occurrence of beds containing disseminated *Orbitolina*, with the intercalations of horizons incorporating fasciculate corals, *Chaetetopsis* (?), rudists and other bivalves.

Owing to the incomplete condition of the profile and also to an approximately 8 m thick Pliocene fissure fill, the precise thickness of the member cannot be determined. This member is divided into two different subunits, well distinguished by fossil content and texture. The lower half is characterized by the dominance of boundstone accompanied by floatstone or packstone. Characteristic fossils of this part are *Bacinella* and the associated Codicaceae algal colonies and in some cases with colonies which due to recrystallization cannot be determined, probably Hydrozoans. *Orbitolina* is a permanent accompanying element, with a great individual number. The upper part shows almost completely wackestone texture. *Orbitolina* is found scarcely disseminated only. The matrix is fine-grained bioclastic micrite.

3.2.2. Beremend Quarry

This quarry represents the southernmost Mesozoic exposure in Hungary and is situated on the hill at the NE rim of village Beremend (Text-Fig. 17).

The most detailed data have been compiled by J. FÜLÖP (1966) on the basis of the quarry profile and a borehole drilled at the quarry. A Cretaceous rudistid limestone with a thickness of 424 m is encountered, followed by Upper Jurassic limestone with calpionellids. Neither heavily argillaceous nor tidal deposits have been described, but intercalations containing Characea can be observed above the Jurassic-Cretaceous boundary indicating freshwater influence.

Total thickness of the Nagyharsány Limestone at Beremend is approximately 450 metres. The four subdivisions of the borehole profile show similarity to the units of member rank, identified in the Harsány-hegy profile.

From the fissures and karstic caverns of the youngermost beds of the formation, CSÁSZÁR & FARKAS (1982) described a bauxite horizon, with its mineralogical composition differing from that at the base of the formation.

During the survey 3 working levels existed in the quarry (Text-Fig. 22). 6 and 16 m thick sequences are missing from the 46 m thick profile between cliffs. Because of great similarity of the cliff sequences no essentially different development can be expected in the missing parts. The limestone is thick-bedded or massive, medium grey, showing micritic texture and frequently with bituminous odour. Beside slight changes in the shades of grey colour, horizons with pale grey spots, and sometimes oncoids can be recognized. The bioclasts and calcite-spotted features are irregular and of subordinate importance.

Among the macroscopically recognizable fossils black-shelled rudists are dominant, within them the most frequent one is *Toucasia carinata*. Further, L. MÓRA-CZABALAY identified *Caprina doucillei, Requienia* ex. gr. *tortilis, Plesioptyxis prefleuriaui, P. fleuriaui, P. cretacea, Praecaprina* sp., *Chondrodonta* sp., *Monopleura* sp. and *Agriopleura* sp. Miliolina species appearing macrosopically as white spots are frequent. In addition, a few bivalve shells, sea urchin spines, and, in the lower part of the medium working level, an *Orbitolina* intercalation could be identified.

Texture in thin-section is characterized by the dominance of micritic matrix and a slight fluctuation of pellets and bioclasts among the allochems. Most frequent texture types are wackestone and packstone. Mudstone and floatstone also occur. Grainstone and boundstone are very rare.

The fossil content is rather poor, incorporating mainly arenaceous benthic foraminifera and, less common, calcareous benthonic forms, of which the most important group is Miliolina div. sp. observable by unaided eye. *Cadosina*, Ostracoda, Echinodermata tests and molluscan shell detritus are common but generally less frequent. *Bacinella* sp. and the blue-green algae, the latter seeming as intraclasts, are less frequent. Sometimes rock-forming Dasycladaceae (mainly *Salpingoporella*) and other colony-forming algae occur. Sponge spicules could be identified only in one sample.

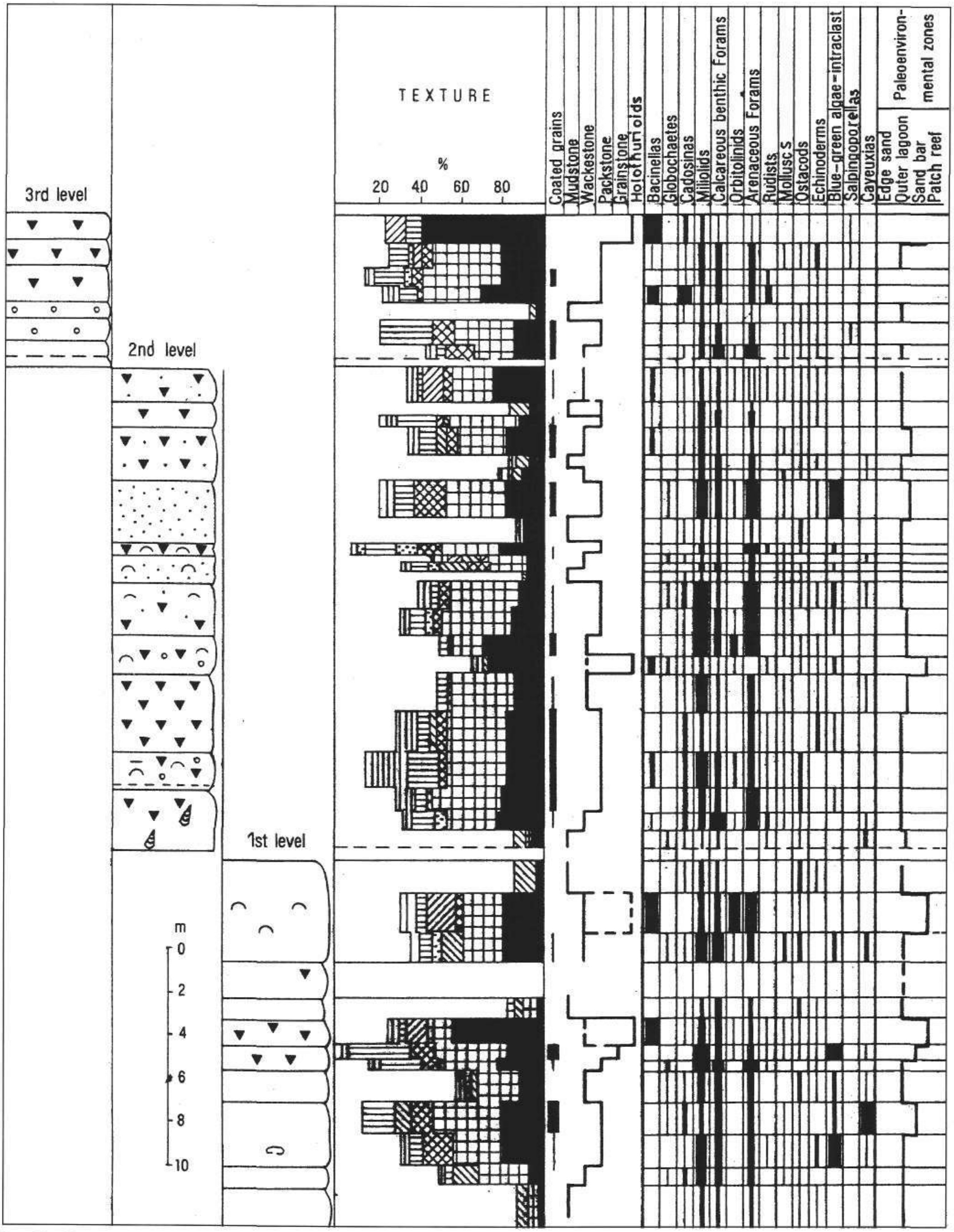
I. BODROGI identified the following foraminifera from the profile:

Calcareous benthonic forms: *Bolivinopsis rhopaloides, Derventina filipescui, Dorothia* sp., *Pseudotriloculina* sp., *Gavelinella* sp., Miliolina sp., *Nezzezatinella macovei, Nummoloculina heimi*, Nubecularidae, *Pfenderina globosa, Quinqueloculina robusta, Q. danubiana, Trocholina elongata* ?, *Spirillina minima*.

Arenaceous forms: *Ammobaculites* sp., *Arenobulimina mettae, Cuneolina* sp., *Debarina hahounerensis, Erlandia* ? *conradi, Glomospira urgoniana, Orbitolina minuta, Praeorbitolina lotzei, Ovalveolina* sp., *Pseudocyclammina minima* sp., *Rheophax* sp., *Sabaudia minuta, Textularia* sp., *Tritaxia* sp.

Among the algae the following taxa were identified by I. BODROGI: *Salpingoporella muehlbergii, S. geneviensis, Permocalculus.*

The percental distribution of foraminiferal groups made by MEHL-SALOMON is shown in Text-Fig. 21.

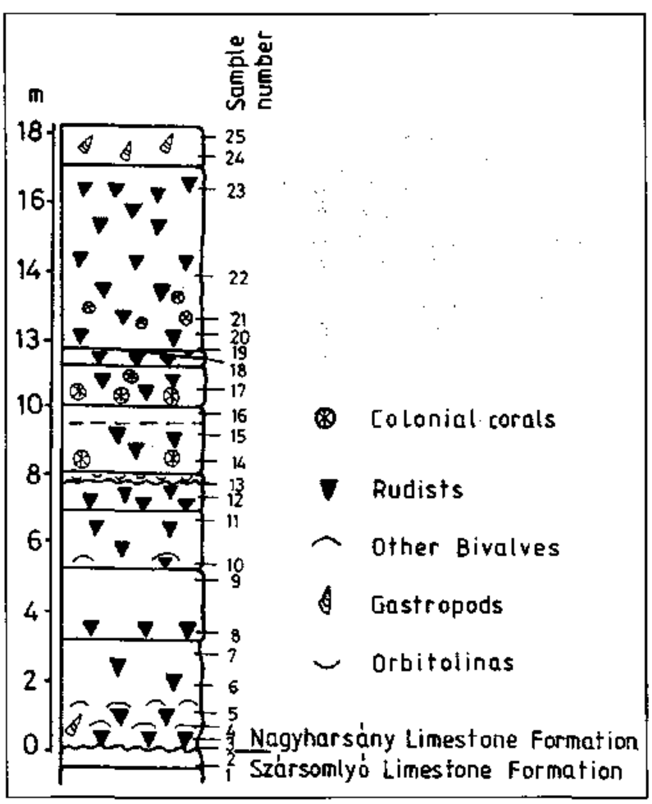


Text-Fig. 22.
Columnar section of the Beremend quarry with fossil and texture distribution.
For legend see Text-Figs. 12 and 19.

3.2.3. Vízügy Quarry (Quarry in the Szabolcs Ravine)

This quarry, being open at present, is situated west of the village Máriagyüd, on the SW slope of Tenkes hill (Text-Fig. 17). FÜLÖP (1966) described a 2 m thick limestone bed with rudists, large *Lamellotis* (current name: *Chondrodonta*) and gastropod-coral intercalations (*Calamophyllia* cf. *stutzi* and *Actinastrea* cf.aff. *konicki*) deposited on the uneven surface of a limestone assigned to the Kimmeridgian. As a result of thin-section examinations, according to identifications of K. MÉHES, *Simplorbitolina manasi* and *Orbitolina beremendensis* were found, and the sequence was dated as Early Albian.

During the survey carried out in 1988, an 18 m thick sequence cropping out from beneath the dolomite imbrication of the Middle Triassic was revealed in the SE corner of the quarry (Text-Fig. 23). The limestone is white, sometimes pinky or slightly reddish, thick-bedded to massive, generally containing disseminated small- to coarse-grained bioclasts and thin green argillaceous lenses. Its megafauna content is dominated by rudists of various size and shape: in two horizons *Chondrodonta* in living position also occur. In three horizons fasciculate corals and at the base and the top of the sequence Gastropods were observed in a very poor state of preservation. In a coarse calcareous sand bed *Orbitolina* are dominant. *Monopleura*-like rudists in living position, filled with a red calcareous marl, were found at the horizon 11.6 m. Similar red fillings could also be observed in rudists and coral branches. The thin-section examination of the sequence has not been carried out yet; therefore its exact age is unknown. However, the presence of Orbitolinas and the absence of cyclic developments, as described from Harsány-hegy quarry, indicates a transgression considered to be remarkably younger than that of the Harsány-hegy.



Text-Fig. 23.
Cretaceous sequence in the Vizügy quarry.

3.3. Age of the Nagyharsány Limestone Formation

Opinions on the age of the formation have been subject to considerable changes since the formation became known.

L. LÓCZY (1912) observed a continuous transition from the Jurassic. Gy. RAKUSZ (1937), already knowing the bauxites, assigned the formation to the Valanginian–Hauterivian. L. STRAUSZ (1952) stated, that the sedimentation was terminated by the end of the Barremian. As a result of the detailed studies NOSZKY (1959) concluded, that the sedimentation of the limestone sequence which started in the Valanginian was temporarily interrupted by marls in the Barremian and its development ended in the Albian. FÜLÖP (1966) assigned the period of bauxite development to the Valanginian–Hauterivian. He considered the beginning of limestone development to be of Barremian age for the Villány imbrication and Albian for the Tenkes imbrication. The Bisse Marl Formation, at the top of the sequence, is assigned by him to the Albian. PEYBERNES (1976) and PEYBERNES & CONRAD (1979) identified *Paracoskinolina maynci* and *Orbitolinopsis cuvilliery-kiliani*, species of *Orbitolina* and *Salpingoporella hispanica*, *S. muehlbergii*, *S. geneviensis*, *S. melitae*, *S. urladanasi*, *Cylindroporella* cf. *barnesi*, *C. elliptica*, Dasycladales algae. Based on this, they assigned the formation to the Late Barremian–Early Aptian. J. BÓNA and M. JUHÁSZ, both carrying out the palynological study of borehole drilled at the lower horizon of the quarry, close to the Miocene fissure, identified several pollen grains, from which *Crassipollis ovalis*, *Crassipollis deakae* and *C. pusztavamensis* refer to an age not older than Middle Albian, whereas M. GÁL, based on a nannoplankton flora with *Eiffelithus turriseiffeli*, dated the formation as Late Albian.

As shown before, the lower one-third of the sequence exposed on Harsány-hegy does not include those elements of the *Orbitolina* group which are the most important ones to define the age and the Dasycladales alga assemblage has only recently been approved for stratigraphical classification, thus problems associated with dating should be considered to be justified. It was a stroke of luck to find identifiable *Salpingoporella* species, in an early bed (No.9.) of the rare marine occurrences of the lower member, which is essentially of intertidal origin and was frequently subject to a subaerial condition. From here I. BODROGI identified *S. muehlbergii* and *S.* aff. *annulata* species. Based on the common occurrence of both species, the probable age of this part of the formation is Hauterivian. The situation is even more difficult, due to the fact, that *Orbitolina* species are missing in the first 125 m of the profile of Harsány-hegy quarry, and in the lower 164 m part of the borehole Beremend-No.1. Higher in the sequence of the Harsány-hegy quarry their amount increases to such a high level that in spite of the problems, their Barremian to Aptian age is doubtless.

Examinations concerning the upper limit of age of the formation are being carried out, but seemingly the carbonate sedimentation ended in the Albian.

4. Similarities and Differences between the Schrattenkalk and the Nagyharsány Limestone Formation

4.1. Lithology

Both limestone formations show variations in lithological composition and distribution.

As a result of the section studies it was ascertained that within the extent of the Schrattenkalk Formation an autochthonous and an allochthonous subfacies can be distinguished. The first one is rich in various macrofossils and its texture types comprise nearly the entire range. The latter one consists of the redeposited material of the autochthonous subfacies.

In the autochthonous type, the transition between the Schrattenkalk and the Drusberg Formation is slow and gradual, therefore it is rather difficult to draw a boundary between the two formations (see the section of the Rhomberg quarry). For the allochtonous type two variants, a proximal and a distal one, can be distinguished. As the proximal variant was still on the platform or on the upper part of the slope and it consists of poorly or medium sorted coarse-grained carbonate sand, the transitional part is characterized by the alternation of thick groups of beds of the Schrattenkalk and the Drusberg Formations (e.g. Feldkirch profile) that can be a result of sea level fluctuation.

Due to the rhythmic alternation of fairly and slightly pelitic beds and carbonate sand layers it is difficult to mark the boundary between the two formations.

With regard to the upper boundary, in the distal part of the sedimentary environment (e.g. Ebniter Ache valley) there is always a difference between the two subfacies. In the case of autochthonous profiles an intensive dissolution took place in the relatively pure limestone, leading to the accumulation of nodules. For the allochthonous type – in the material which was originally more argillaceous – the dissolution was weaker. However, in both cases phosphoritic nodules occur at the base of the Garschella Formation replacing the Schrattenkalk. These nodules origin from a phosphatic hardground, which was deposited directly after the end of Schrattenkalk sedimentation. This hardground indicates dramatic environmental changes causing the cessation of the Urgonian facies in this area. The basal bed of the Garschella Formation is, to a varying extent, silty to sandy and glauconitic. The Schrattenkalk of allochthonous subfacies is characterized throughout the formation by low glauconite content. Seldom chert is also intercalated.

The lithological composition of the Nagyharsány Limestone Formation is, as a whole, more uniform than that of the Schrattenkalk. In accordance with the transgressive character in the Nagyharsány (southern) imbrication, there is a thick succession of Lofer-cyclic patterns. The limestone is poor in fauna here, and in some cases, red or yellowish brown pelitic horizons (paleosol) can be observed. Transgrading with its younger beds such elements are missing in the northernmost imbrication.

The boundary between this formation and the Bisse Marl is not exposed. According to J. FÜLÖP (1966) a sharp contact exists between the two formations. However, lately an intensive dissolution phenomenon, as observed for the Schrattenkalk Formation, has not been recorded here either.

In a borehole drilled for hydrocarbon exploration in the Danube–Tisza Interfluve of the Villány zone, the limestone beds include marly intercalations with abundant *Orbitolina*. Thus the sequence resembles the Schrattenkalk profile of the Rhomberg quarry. It is remarkable, however, that carbonate sands with grainstone texture are negligibly rare in the Nagyharsány Limestone Formation. Its dominant texture types are wackestone and packstone. An important lithological feature of the Schrattenkalk, differentiating it from the Nagyharsány Limestone is the extremely intensive dolomitization (particularly at Feldkirch) and the occurrence of quartz and feldspar crystals of post-diagenetic origin (within several successions).

Thus, lithological and textural differences between these two formations are more expressed, than similarities.

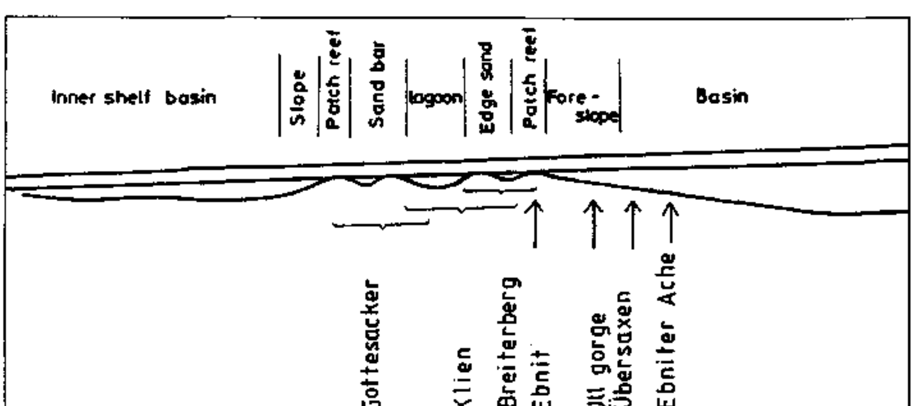
4.2. Palaeontology

Although there is a considerable time interval between the two formations (Text-Fig. 24), the Schrattenkalk can be considered to be the richer one in amount and diversity of the total fossil content. There are remarkable differences in fossil content between the members of the Nagyharsány Limestone Formation. The lower member differs strikingly from the upper part of the formation, since it is characterized by the occurrence of Characea species as well as the regular appearance of ostracods and minor Miliolinids but it is poor in other fossils. Such a facies is not present in the Schrattenkalk at all.

Elements of equal (relative) frequency in both formations as a whole, are as follows: Miliolina 3, *Cadosina* 1–2, Rudists 1–2 and Gastropods 1 (for explanation see Text-Fig. 12).

For the meaning of the relative frequency see Text-Fig. 12. The frequency of small and medium size Miliolids is almost the same in both formations, but in the Schrattenkalk also a few larger forms occur. Owing to biostrome-like appearance, the distribution of the rudists in the profiles is highly variable. Rudistid beds form a group of beds in the Nagyharsány Limestone only while those appear as separated layers or biostromes in the Schrattenkalk. Comparing the two formations on the basis of the number of rudist genera, the Nagyharsány Limestone contains *Praecaprina, Caprina* and *Eoradiolites*, in addition to *Agriopleura, Toucasia* and *Requienia*, which are common to both formations. Matheronia is the only additional genus in the Schrattenkalk to the common elements.

The palaeontological image of the two formations in relative frequency of the important fossil groups is given below as follows:



Text-Fig. 24.
Environmental zonation in the Schrattenkalk.

	Schrattenkalk	Nagyharsány Limestone
Orbitolinidae	3	1–2
Echinoderms	3	1
Brachiopods	1–3	—
Dasycladaceae	2	1
Colonial organisms I (corals, stromatoporoids *Chaetetopsis*)	2	1
Rhodophyta	1	—
Bryozoans	1–2	1
Planktonic foraminifers	1	—
Ostreids (*Lopha* and *Aetostreon*)	1–2	-
Colonial organisms II(sponges)	1–2	-

Colonial organisms characterize especially the middle and upper parts of the Schrattenkalk (compare SCHOLZ, 1984). They form considerable bioherms here. The colonial organisms of the Nagyharsány Limestone Formation have not been studied in detail yet, owing partly to their low frequency of occurrence and partly to the poor state of preservation. Concerning the sponges it is worth of mentioning that *Barroisia*, which is characteristic of some horizons of the Schrattenkalk, is only very rare in the Nagyharsány Limestone (see also BODROGI et al., 1994).

In the Nagyharsány Limestone Formation the frequency of other sponges is also negligible. Brachiopods are charactерisitic in biostromes of the Rhomberg quarry only, whereas at other places they occur only eventually and are completely missing in the Nagyharsány Limestone Formation. Only a few fossil groups occur in a higher frequency in the Nagyharsány Limestone Formation compared with the Schrattenkalk. These are as follows:

	Schrattenkalk	Nagyharsány Limestone
Bacinella	1	2–3
Ostracoda	1	2
Cayeuxia	1	1–2
Chara	—	1
Chondrodonta	—	1
Sporomorphs	—	1

As shown above, the really outstanding and positive features of the Nagyharsány Limestone Formation are the great frequency of *Bacinella* colonies and the occurrence of *Chondrodonta* bivalves.

4.3. Palaeoenvironment and Sedimentary History

4.3.1. Schrattenkalk Formation

In the Helvetic zone we find two essentially different subfacies of the Schrattenkalk. This requires a separate description and analysis. A typical example of the autochthonous type of Schrattenkalk is represented by the Unterklien profile (the Rhomberg quarry and the natural cliff; Text-Fig. 8).

As shown in Text-Fig. 24, the Drusberg Formation is considered to be a relatively uniform sediment deposited continuously in the shelf basin and on the gentle slope. Fine-grained biodetritus, which is continuously produced on the carbonate platform, was deposited here. Sedimentary structures (e.g. cross lamination, pinching out of beds – Pl. I, Fig. 4) and fine grain size indicate a distal environment and a turbiditic mode of transport. Apparently, here no essential difference existed between the relief of the basin and of the slope. The proof for the slightly dipped slope are the very rare sliding phenomena along the slope even in the transitional interval between the two formations. The biogenic production was higher than the rate of subsidence thus causing a progradation of the platform to take place. For example in the profile of the Rhomberg quarry no patch reef was developed at the base of the Schrattenkalk and the slope changed directly into sandbars where mainly grainstone and subordinately rudstone (!) type deposits were formed. The sandbar type sedimentation ended with the development of unidirectionally cross-stratified calcareous shoals indicating the appearance of an intensive stream, with a transport direction to the SE. This forset type deposit was accompanied neither by a well developed bottomset, nor by topset deposits.

After the deposition of the outer sandbar facies the sedimentation on the carbonate platform slightly fluctuated till the end of the Schrattenkalk. *Lopha* biostrome, with minor colonies of various organisms were formed in the transitional zone between the sandbar and the lagoon. The slided coarse-bioclastic blocks and one fissure filled with Ostreas within a block witness to the unevenness of the relief, and presumably to minor tectonic movements.

Subsequently, real lagoonal and calcareous sand facies alternate. Brachiopod biostromes with wackestone texture are considered as products of a very slightly agitated deeper lagoon, whereas the rudistid and *Orbitolina* limestone beds were deposited in shallow lagoons. Rich fauna was attracted by the patch reef with a large amount of boring bivalves. It is followed by transitional types of environment and varied biotopes (middle and top part in Text-Fig. 11).

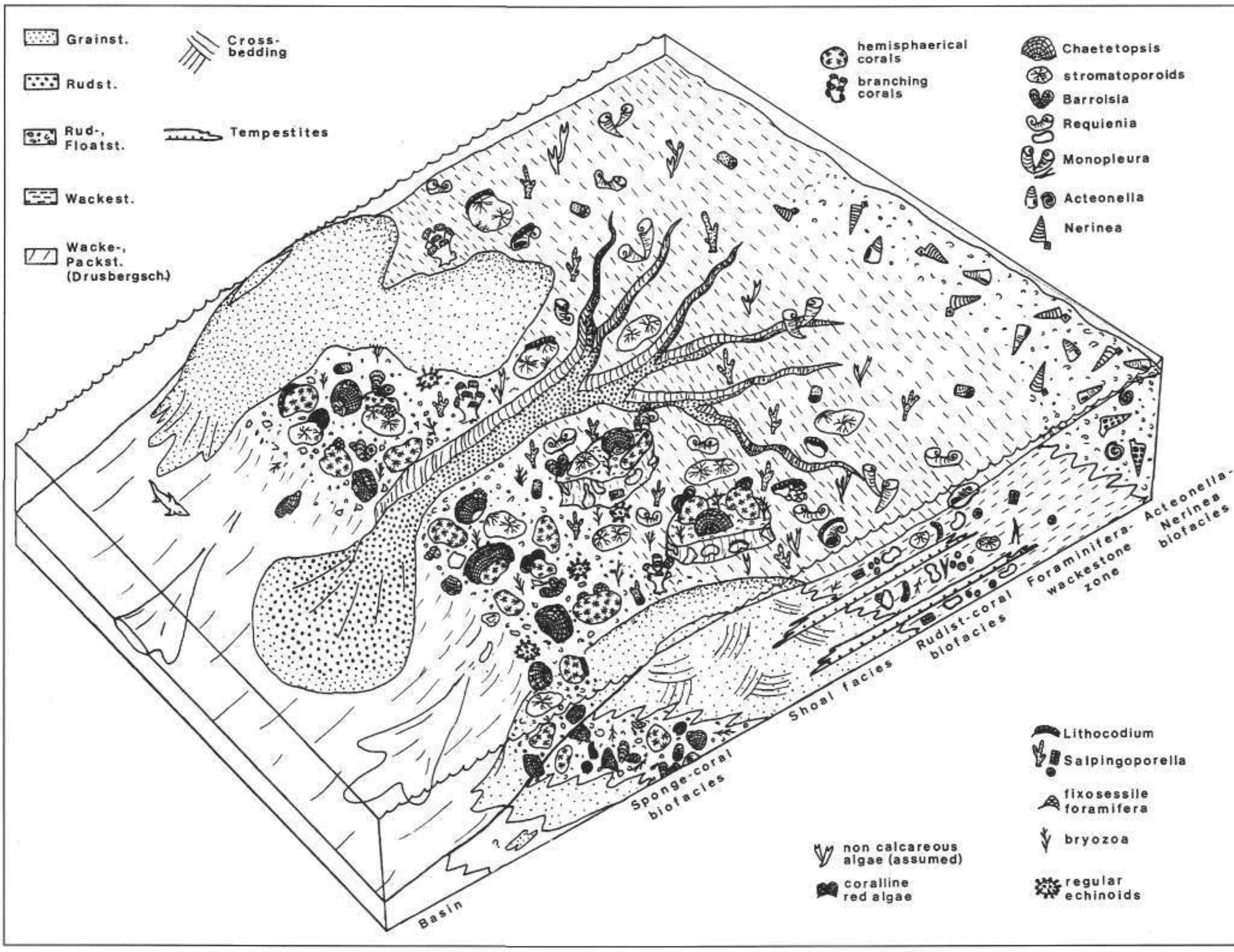
The uppermost beds of the formation were preceded by a slightly turbiditic sedimentation which is less characteristic for the carbonate platform (Pl. 5, Fig. 2.). The remnants of the micritic matrix with abundant *Salpingoporella* species in the uppermost bed of the formation is the first sign of the change in sedimentation as the micritic limestone deposited on a hardground.

A representative profile of allochthonous type sequences is well exposed in the Upper Ill-gorge near Feldkirch. Here the Drusberg Formation of basinal facies is gradually replaced by calcareous sand deposits of essentially biogenic origin, with variable grains size. It is considered to be the deposit of a platform slope which was slightly inclined. The decrease of the thickness of the Drusberg type intercalation toward the top of the Schrattenkalk profile and also their less typical Drusberg character are good evidences for the prograding platform. Crossbedding documenting a transport to the SE can also be observed. The uppermost part is considered to be a sandbar deposit. Apparently, the tendentious lithological changes throughout the profile is due not to vertical movements of the platform, but most probably due to lateral facies migration and to rhythmic changes in the transportation (sea level fluctuation).

A facies model for the Allgäu sequence (Text-Fig. 25) has been set up by SALOMON (1989). After WILDI et al. (1989) subsidence caused by extensional tectonics stops Urgonian sedimentation.

4.3.2. Nagyharsány Limestone Formation

For the Urgonian of the Tisza unit no detailed facies model of the Nagyharsány Limestone Formation is available. The generalized model of palaeoenvironments (Text-Fig. 26) considerably differs from that of the Schrattenkalk.



Text-Fig. 25.
Facies model of theSchrattenkalk based on Allgäu sequences (after D. SALOMON, 1989).

The Nagyharsány Limestone is a transgressive sequence. Two lagoons, an outer and an inner one, can be distinguished within the platform. They are separated from each other by a patch reef zone (Text-Fig. 27). The interfingering of the formation with the basin deposit is presumed.

In the Schrattenkalk sequence only one lagoon is documented, but another one may be presumed towards the coast, since no terrigenous influence is seen in the Schrattenkalk (except at the end of the formation).

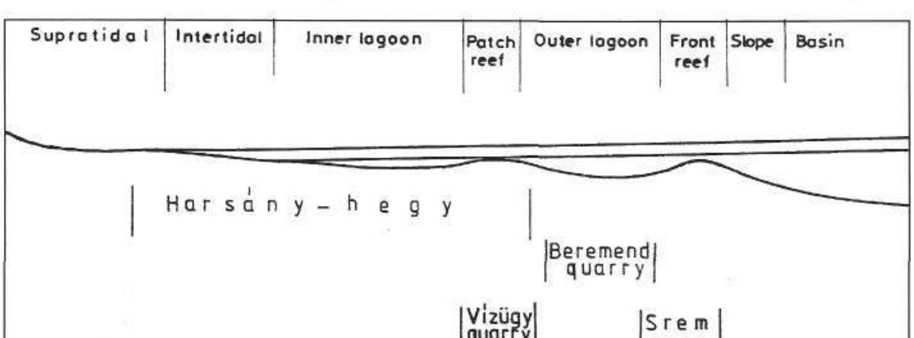
The study of the lower member of the Harsány-hegy imbrication (or better said "nappe") has documented facies zones ranging from the supratidal to the inner lagoon, whereas the upper part of the formation (Beremend) contains patch reefs and outer lagoonal zones.

The first half of the lower member in the (transgression type) Nagyharsány Formation is characterized by a rhythmic alternation of various zones as shown in Text-Fig. 20. The peculiarity of this succession is that the "path" between the highstand and lowstand positions are approximately equal, even the curves leading from the highstands to the lowstands have more smoothed and uniform shape (see environmental zones in Text-Fig. 20).

This phenomenon is probably due to the fact that instead of erosion here the sedimentation was dominant even under the supratidal conditions.

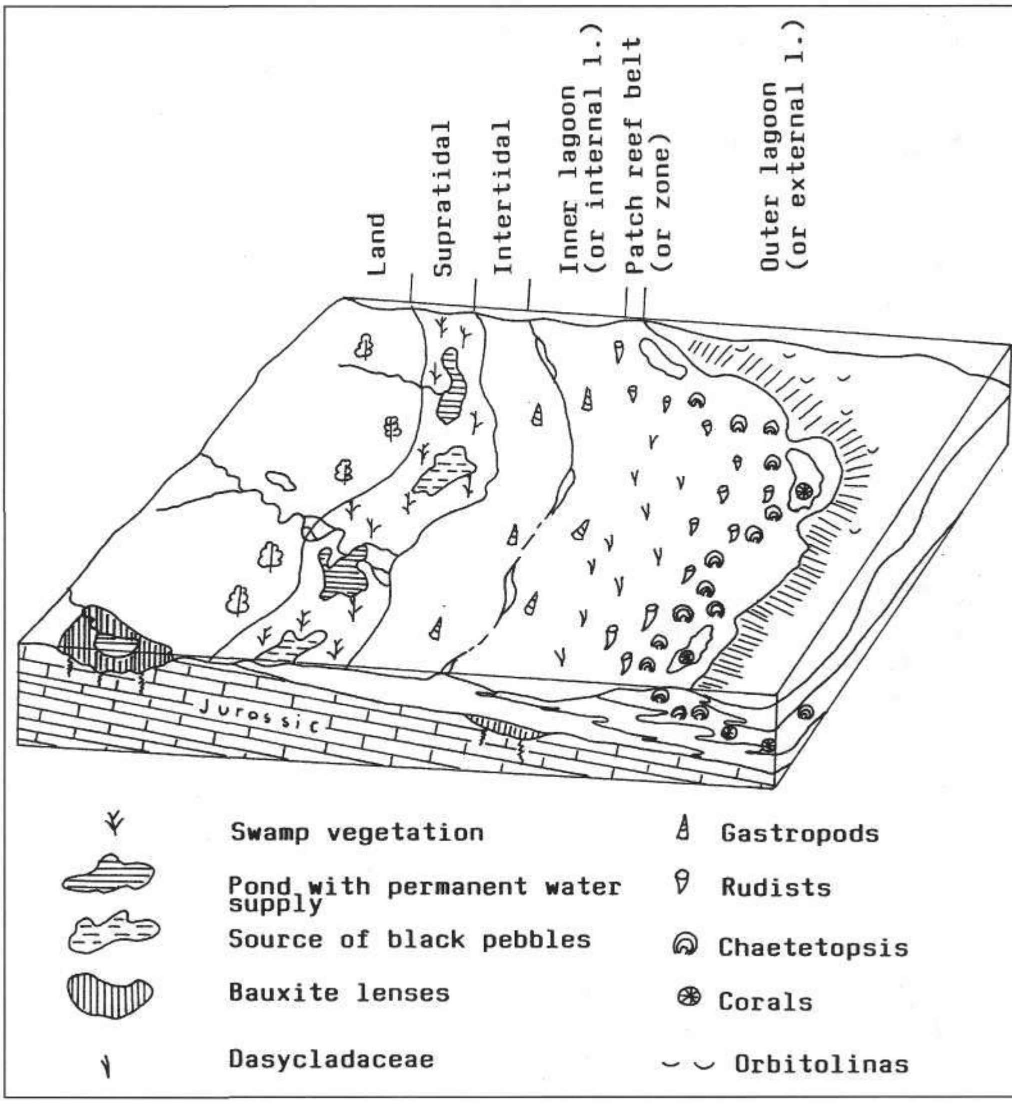
It should be stressed, particularly for the reason, that "black pebbles", which are of supratidal origin, frequently occur in the sequence.

In the upper half of the lower member which is inner lagoon by its origin as intercalation only one thin supratidal bed is known. Thus, for the lower member, as a whole, the bathymetric curve illustrates a slow and equalized trend of sedimentation.



Text-Fig. 26.
Environmental zonation of the Nagharsány Limestone Formation.

Text-Fig. 27.
Facies model of the Nagyharsány Limestone Formation.



The environmental curve shows a steady development from a fresh water/brackish towards a fully marine environment. This consequence is supported by the fact that the second member which has not been studied from microfacies point of view is characterized by thick-walled *Toucasia* type rudists.

The third member is represented by an association of various colonial organisms, and in some cases by an alternation of this fossils with rudists and Orbitolinidae. This member corresponds to lagoonal and patch reef zones. The upper member sometimes containing a greater amount of *Orbitolina*, can be considered to be a product of the outer lagoon.

Presumably, the Beremend profile also belongs to the upper member of the Nagyharsány Formation. Its succession was deposited in different parts of the outer lagoon. Sandbar deposits or a transition towards patch reef facies can be observed only rarely.

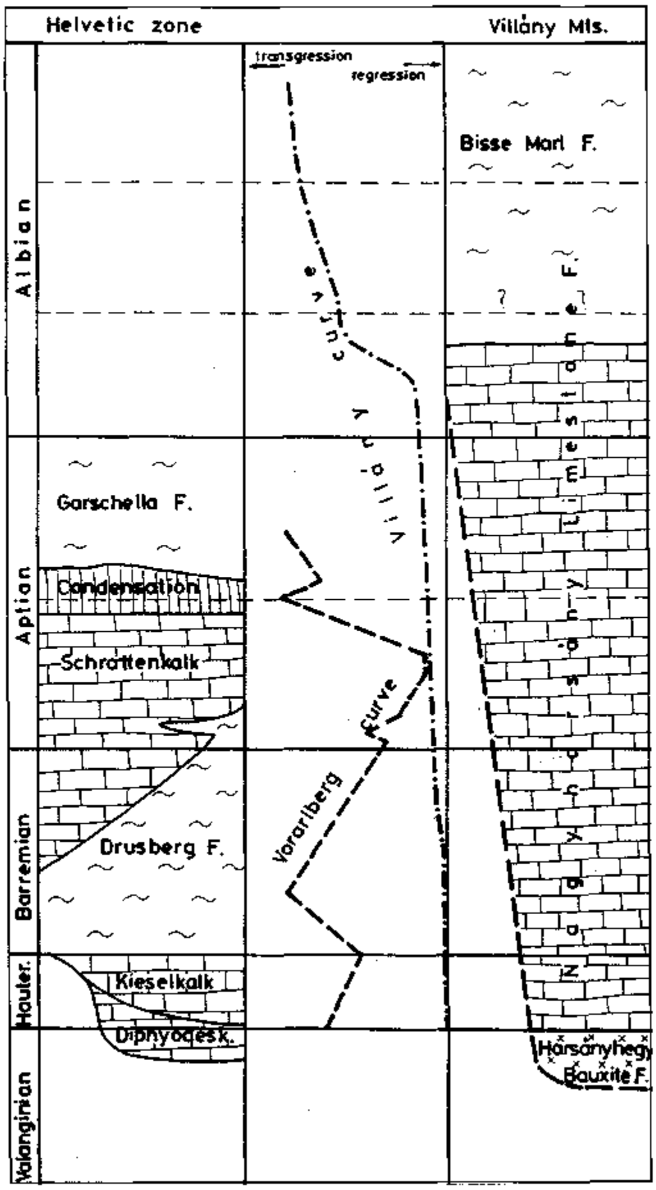
Concluding can be said that the Schrattenkalk is the product of the regressive limb of a sedimentary cycle, whereas the Nagyharsány Formation corresponds to a transgressive one. The greatest similarity between the two formations can be observed in the upper part of the profiles, where patch reefs and lagoonal facies are developed for both formations. It is due to the fact that within the Schrattenkalk the gradual shallowing-upward tendency apparently was interrupted around the middle of the profile and replaced by a subsidence accompanied by a slight oscillation. The rate of subsidence was balanced by the rate of sedimentation (Text-Figs. 11, 12). During the development of the Nagyharsány Limestone Formation the rate of subsidence was hardly any higher than the rate of sedimentation; therefore here the environment was almost constant for a long period (Text-Fig. 20). The general subsidence was interrupted twice only (after the deposition of bed No. 19 and 37) when subaeral erosion of unknown degree took place.

The equilibrium between sedimentation and subsidence rates was disturbed by a transgressive development towards the end of the Schrattenkalk. This transgressive influence was very small at the beginning (Dasycladaceae facies), then followed by a rapid subsidence, which is indicated by submarine dissolution and the production of phosphorite, glauconite and later marl. For the Nagyharsány Limestone Formation the end of the Urgonian facies is similar. The trend of subsidence accelerated and – related with the occurrence of a condensation phenomenon – the limestone sedimentation changed into silty marly development. All phenomena described above are shown by a bathymetric curve for both formations (Text-Fig. 28).

4.4. The Palaeogeographic Position of the Schrattenkalk and the Nagyharsány Limestone

The Schrattenkalk is part of the European plate (compare also CSÁSZÁR et al., 1989). Towards the E the zone is eventually replaced by the Hochstegen Zone corresponding to the Sub-Silesian zone in the Carpathians.

After LAMMERER (1988, 147) at the Lärmstange in the Tuxertal parts of the Hochstegenkalk may be of Cretaceous age and therefore the existence of metamorphosed Schrattenkalk and Drusberg beds there is possible. In the boreholes of the foreland from Upper to Lower Austria Lower Cretaceous sediments are missing. Therefore the prolongation of the Schrattenkalk toward E is eroded or



Text-Fig. 28.
Sea level curves for the Schrattenkalk and the Nagyharsány Limestone Formation.

disguised due to metamorphosis in the Tertiary. But it is possible for the Hochstegenkalk-Zone.

Isolated *Orbitolina* or *Choffatella* specimen or Urgonian klasts determinable by microfossils delivered from platforms and sedimented in turbidites from Aptian (Tristel-beds) through later Cretaceous to Paleocene–Eocene times, are present in flysches of the Rhenodanubic and other Penninic units in Allgäu (D), Rätikon (A,FL,CH) and lower Engadine window (A,CH). It is possible, that they are delivered from intrapenninic and Austroalpine sources.

In BOLLINGER's model (1988) the palaeogeographical relief of the Schrattenkalk is divided into an inner and an outer platform. Our studies allow to subdivide the inner platform. We presume that on the S and SE rims of the inner platform, in the upper quarter part of the formation above the patch reef environment the lagoonal facies is characteristic again. The inner zone of the Säntis nappe of Vorarlberg that is presumably broader than that of Hohenems nappe shows the same development as the Hohenems nappe. This confirms the assumption that these two areas are likely to have formed a unified platform.

According to the model of CSÁSZÁR and HAAS (HAAS et al., 1990) the Tisza (tectonic) unit with the Nagyharsány Limestone Formation assumed to have a palaeogeographical position far away, from the European plate by the Early Cretaceous and to have been situated along the same latitude as the Transdanubian Central Range found between the Upper East Alpine and South Alpine Zones (Text-Fig. 29). It may be due to a more southern position of the Tisza Unit, compared to the position of the Helvetic Zone, that in the latter the carbonate platform was drawned as early as the end of the Early Aptian, whereas in the Tisza Unit it existed till the beginning of the Early Albian. FUNK (1989), SALOMON (1990) and CSÁSZÁR et al. (1990) explain the cessation of the carbonate platform by the inflow of the northern, colder sea water into the Tethys region, reaching the more southern areas later (the Tisza Unit in the Early Albian, whereas the South-Alpine areas with the Transdanubian Central Range in the Late Albian).

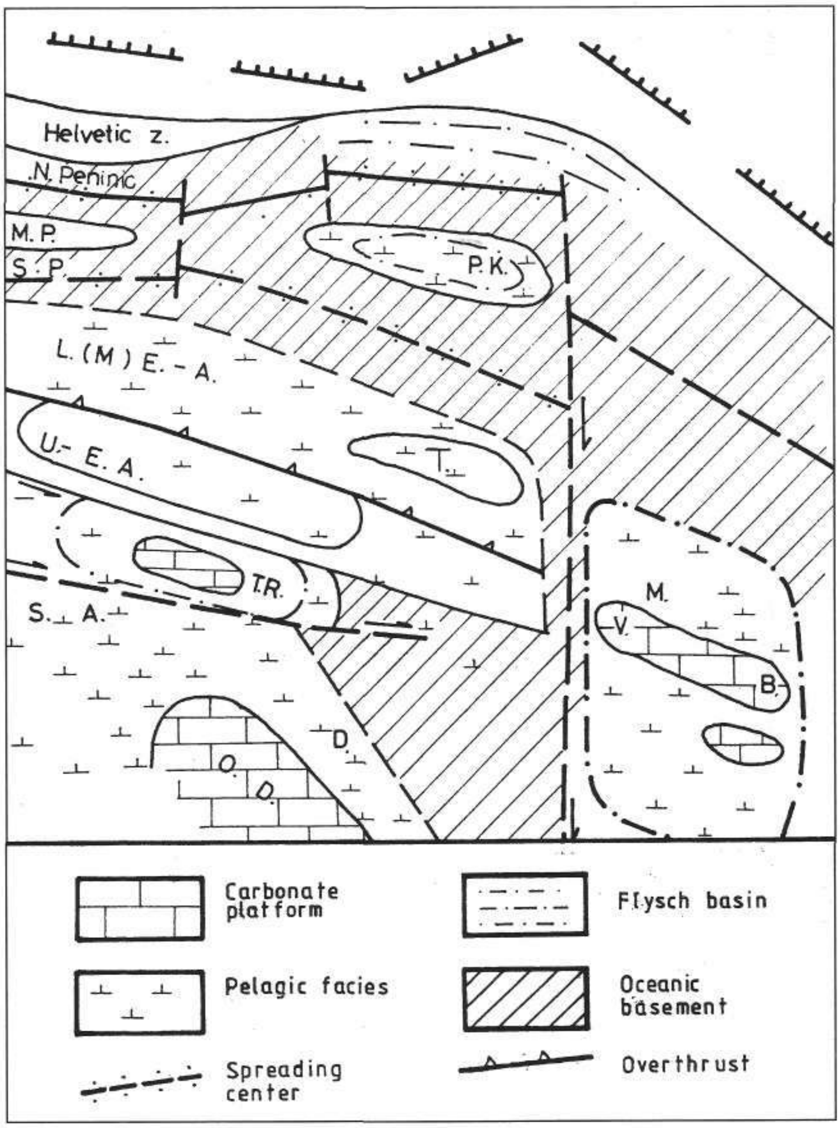
The imbricated structure of the Villány Mts. (and obviously of the zone) as well as the various facies of the Jurassic and Cretaceous formations of each imbrication suggest, that not only imbrication, but – at least partly – nappes are concerned. Accordingly, in South-Bácska in Yugoslavia a part of the Mesozoic, including the formations of Urgonian facies was mainly removed by the development of nappes, from the metamorphites that on the southernmost part of Transdanubia areas between Hungary and Vojvodina and Srem in Yugoslavia, the carbonate platform might have existed continuously. In the latter areas the rich coral development might have represented the outer reef zone on the rim of the platform, south of which deep-marine ophiolitic formations of Late Jurassic and Early Cretaceous age exposed by hydrocarbon exploration (ČANOVIĆ and KEMENCI, 1988).

Orbitolinids in breccias of Albian age from the Drauzug in Carinthia (VAN HUSEN, 1975) and new records from pebbles coming from the Calcareous Alps (HAGN, 1982, 1989 and SCHLAGINTWEIT, 1987) proof former existence of Urgonian sediments south of the Penninic realm until Late Aptian (or Albian) times.

5. Conclusions

- An autochthonous and an allochthonous succession can be distinguished within the Schrattenkalk in Vorarlberg and Allgäu. The former one is deposited on the carbonate platform, whereas the latter one comprises material derived from the platform and sedimented mainly on the flat slope or in the basin. On the basis of the facies distribution within the extent of the Schrattenkalk the existence of the Axen or Hohenems nappe at Hohenems is still in discussion. According to our studies the overturned Cretaceous succession at Unterklien can be seen as a frontal part of the Säntis nappe too (compare Fig. 6 of WYSSLING, 1984, Pl. 1, Fig. 1). This theory corresponds with the existence of deeper Helvetic units in Vorarlberg too.
- A shallow basin is supposed to have existed between the Helvetic carbonate platform and the land where the terrigenous influx deposited completely.
- The succession of the Nagyharsány Limestone Formation is subdivided into four member rank units. The lower two are known in the Nagyharsány tectonic unit only and they consist of fresh water to fully marine beds.

Text-Fig. 29.
Middle Cretaceous palaeogeographic sketch map of the Alpine zone and the Tisza unit.



- In addition to lithological differences the age of the basal beds of the formation also shows considerable differences (Hauterivian at Harsány-hegy and Albian in Tenkes tectonic unit). The age and thickness differences are sufficient evidences to presume that the Villány Mts. consist of nappes, and not imbrications only.
- The Urgonian facies of the Villány nappe system should be in close relation with the formations in the basement of the Vojvodina area. The Paleozoic zone in between the Villány zone and Vojvodina is a possible source of this nappes.
- The formation of the Schrattenkalk is a result of an upward shallowing tendency of the Helvetic zone, whereas the Nagyharsány Limestone is a transgressive succession.
- The Schrattenkalk and the Nagyharsány Limestone show significant similarities in lithology and fossil content only in the upper part of the successions.
- From a sedimentological point of view the Schrattenkalk body consists of an autochthonous and an allochthonous part, while the entire Nagyharsány Limestone is autochthonous.
- The drowning of the Schrattenkalk-platform happened in early Early Aptian and that of the Nagyharsány platform of the Villány-Bihar zone in Early Albian time.
- In spite of this considerable difference in age, the drowning process of both, the Schrattenkalk and the Nagyharsány Formation, is similar. It may be caused either by world-wide sea level rises, or by rapid subsidences.
- The palaeogeographic relation of the Helvetic (western part of European platform) and Villány zones (inside Tethys) offers an idea for the understanding of the time differences in drawning of the platforms in the northwestern part of the Tethys. According to this model the cold water proceeded from northwest of the Penninic realm, crossing intrapenninic seamounts (Tasna, Manin zone etc.) to the southeast continously and the cold water invasion was accompanied by the subsidence of the regions step by step.

Acknowledgements

The authors are grateful to Rhomberg Company for permission and supporting geological studies in their quarry in Dornbirn. Cordial thanks also to the staff of Vorarlberger Naturschau in Dornbirn, especially to Dir. Dr. WALTER KRIEG, who kindly supported our field work and museal studies in many ways.

Plate 1

Fig. 1: **Overview of the upper third level.**
Rhomberg quarry.

Fig. 2: **Highly bioturbed horizon.**
Boundary of beds 10 and 11 in Rhomberg quarry.

Fig. 3: **Turbiditic lamination of silty limestone.**
Bed No. 20 in Rhomberg quarry.

Fig. 4: **Pinching out beds.**
Rhomberg quarry (around bed No. 35).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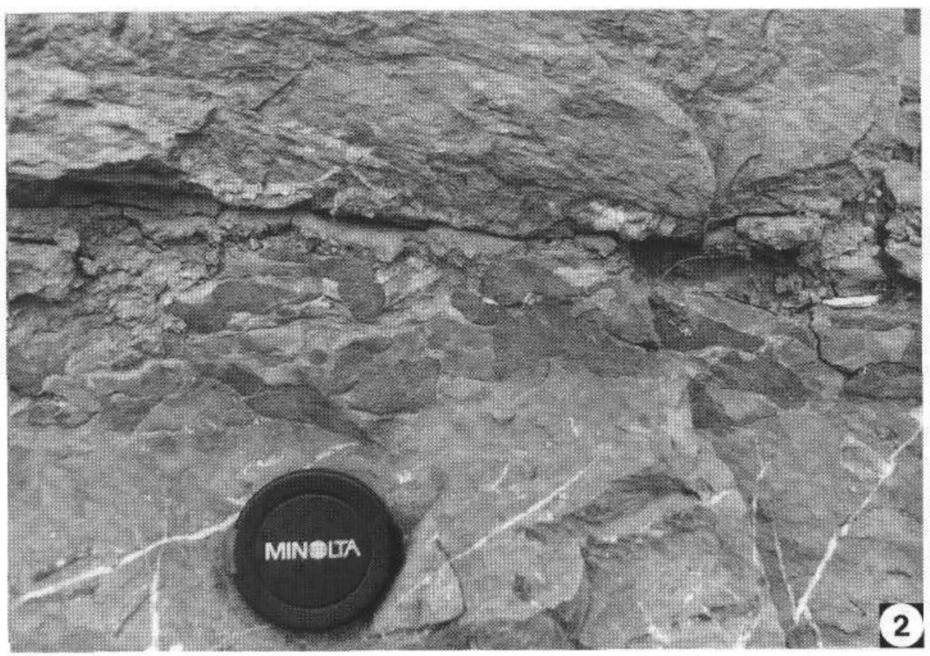
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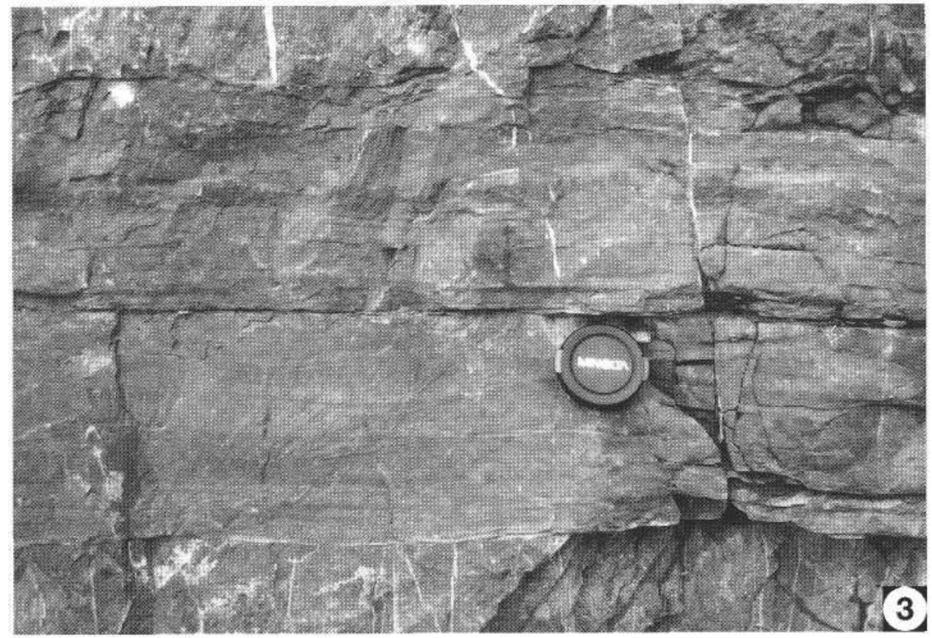
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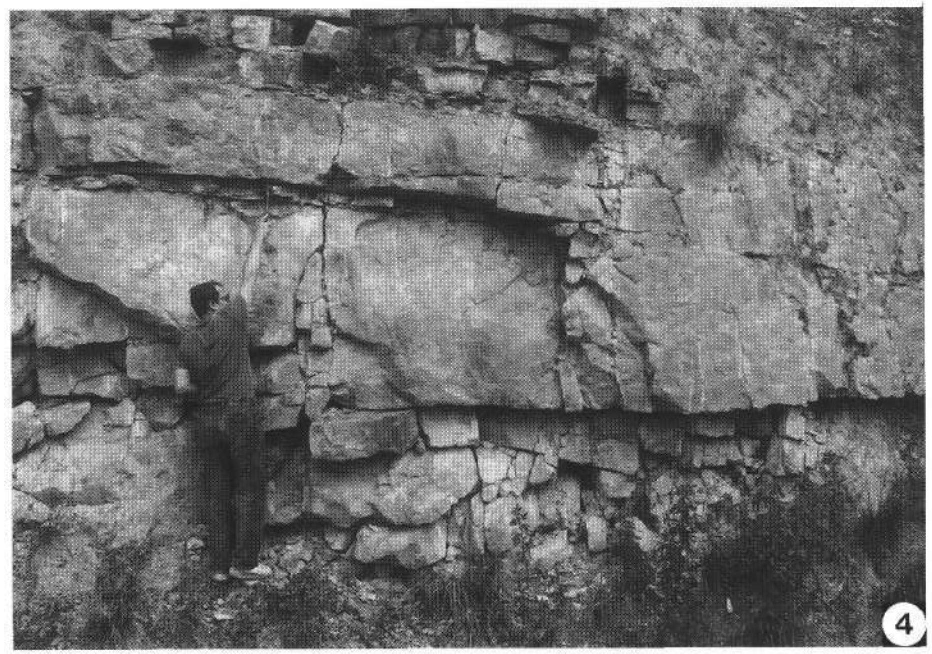
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Plate 2

Fig. 1: **Erosional contact.**
Beds 60 and 61, Rhomberg quarry.

Fig. 2: ***Lopha* beds (at the base) and cross-bedded bioclastic limestone.**
Bed No. 51 (upper part), Rhomberg quarry.

Fig. 3: ***Ostrea* biostrom.**
Bed No. 21, Rhomberg quarry.

Fig. 4: ***Chaetetopsis* colony.**
Unit No. VIII, Rhomberg quarry.


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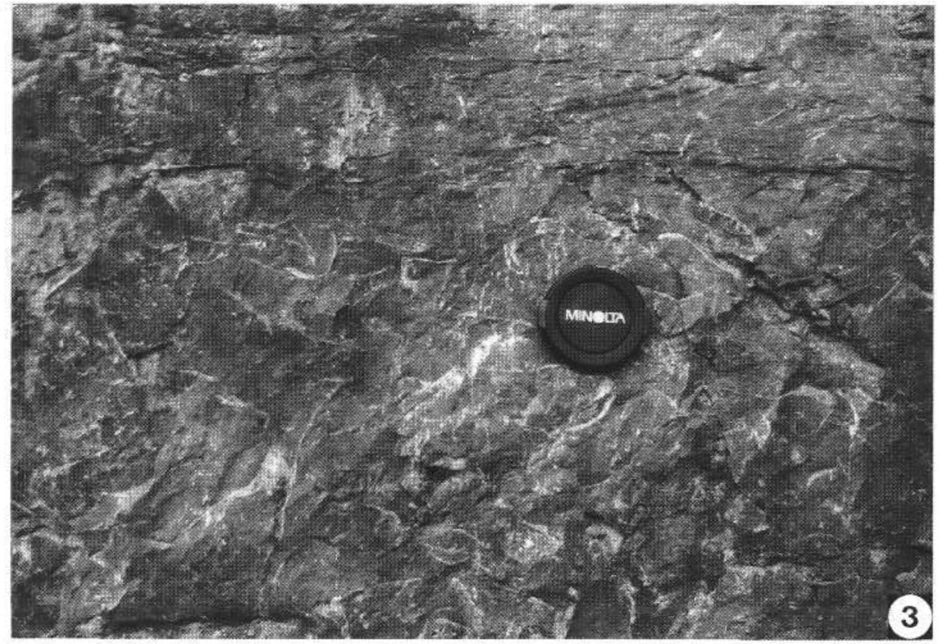
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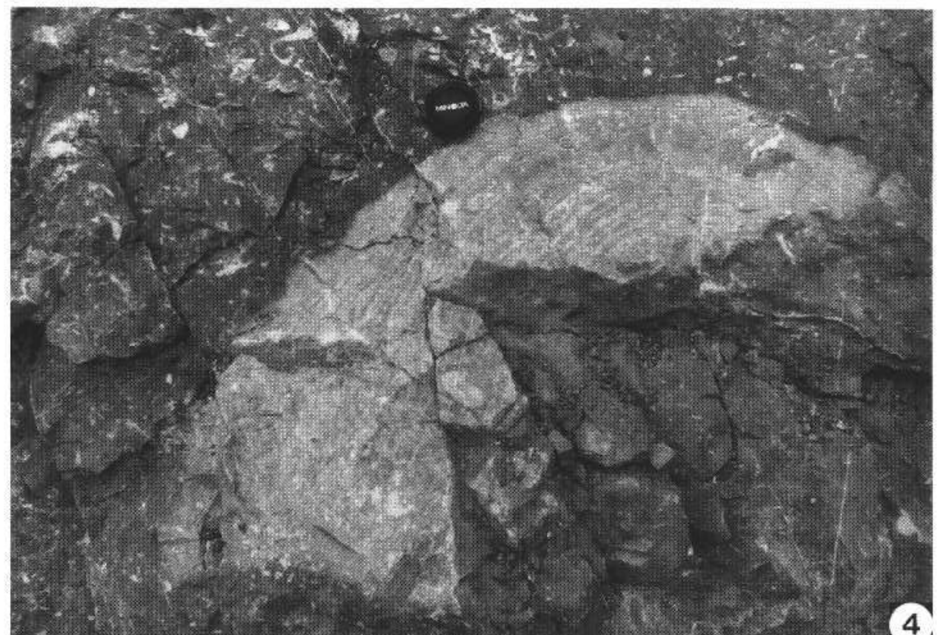
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Plate 3

Fig. 1: **Sagged block, surronded by *Lopha* beds.**
Bed 48, Rhomberg quarry.

Fig. 2: **Upper contact of the 2nd intercalation of the Drusberg beds.**
Roadcut at back Ill Gorge, Feldkirch.

Fig. 3: **Cross bedding.**
Bed 4, Ill Gorge, Feldkirch.

Fig. 4: **Coarse-grained biodetrital limestone with *Orbitolina*.**
Ill Gorge, Feldkirch.

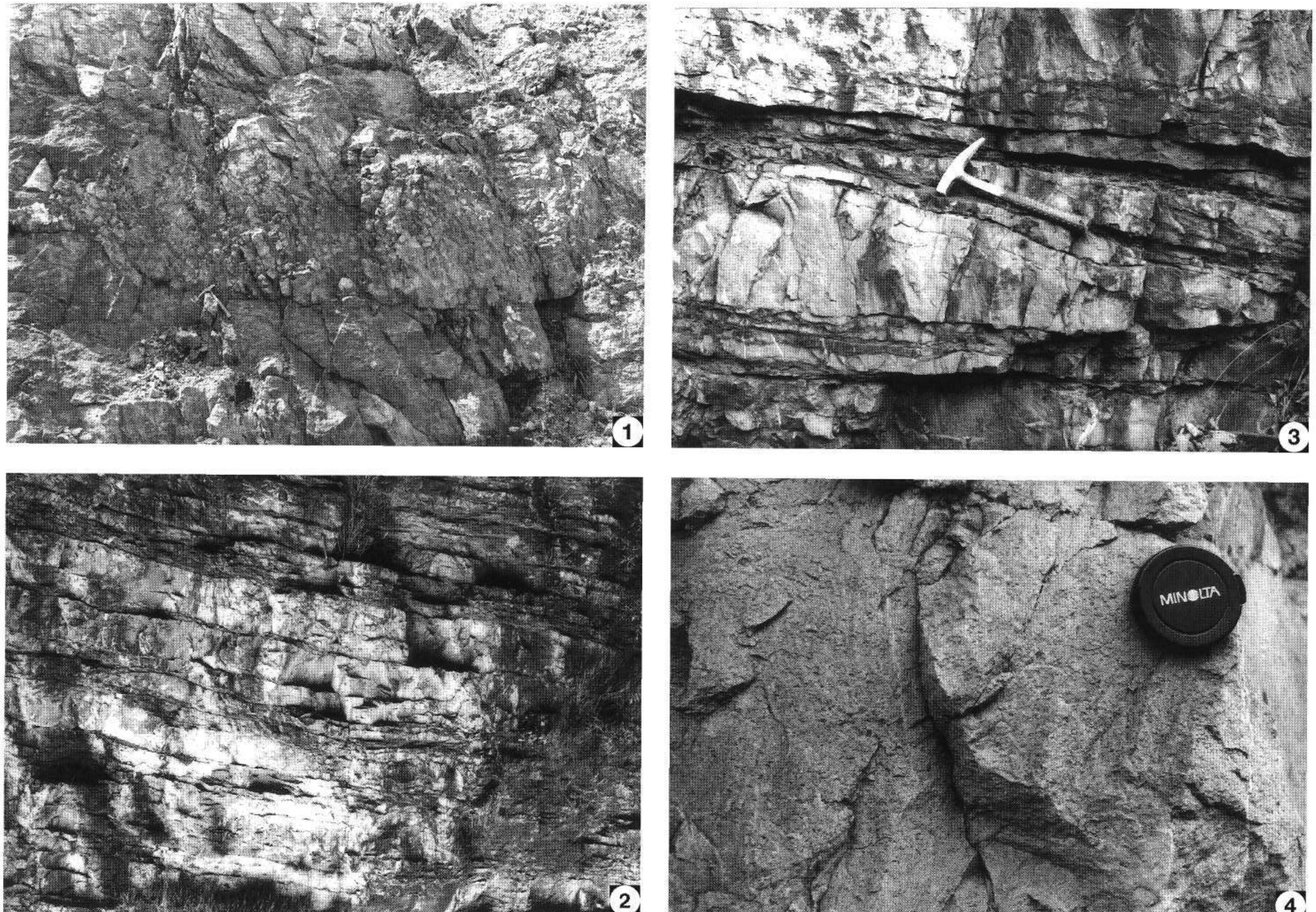
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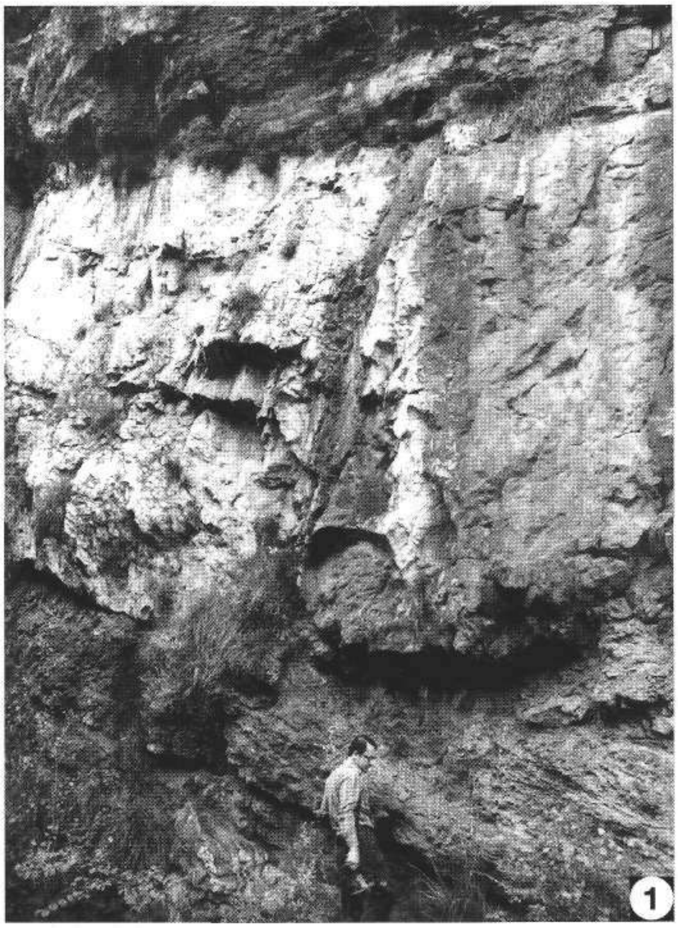
Plate 4

Fig. 1: **First appearance of the Schrattenkalk in the Drusberg Formation (lowstand systems tract).**
Ill Gorge, Feldkirch.

Fig. 2: **Lower contact of the 2nd intercalation of the Drusberg Formation in the Schrattenkalk.**
Beds 16 and 17; Ill Gorge, Feldkirch.

Fig. 3: **Empty holes of muddy and silty intraclasts and bioturbation.**
Bed 27; Ill Gorge, Feldkirch.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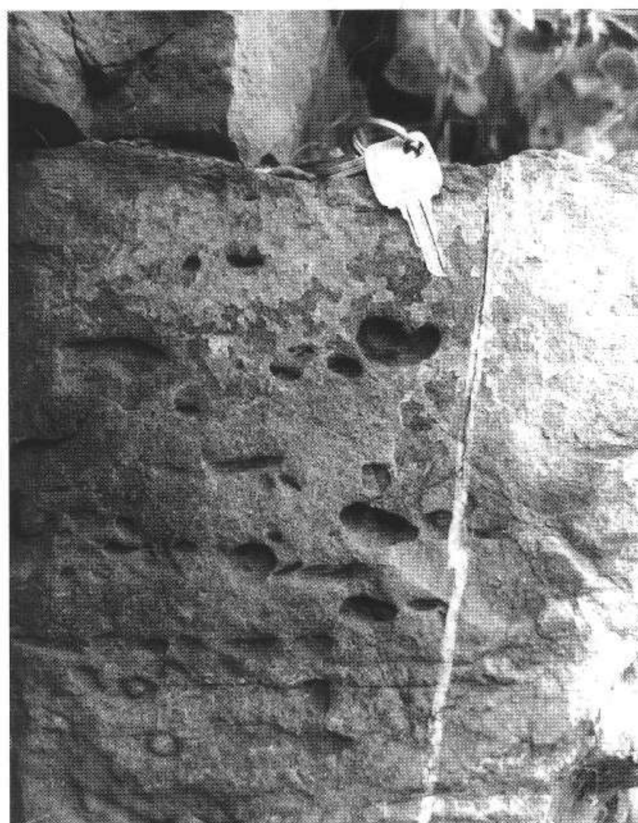
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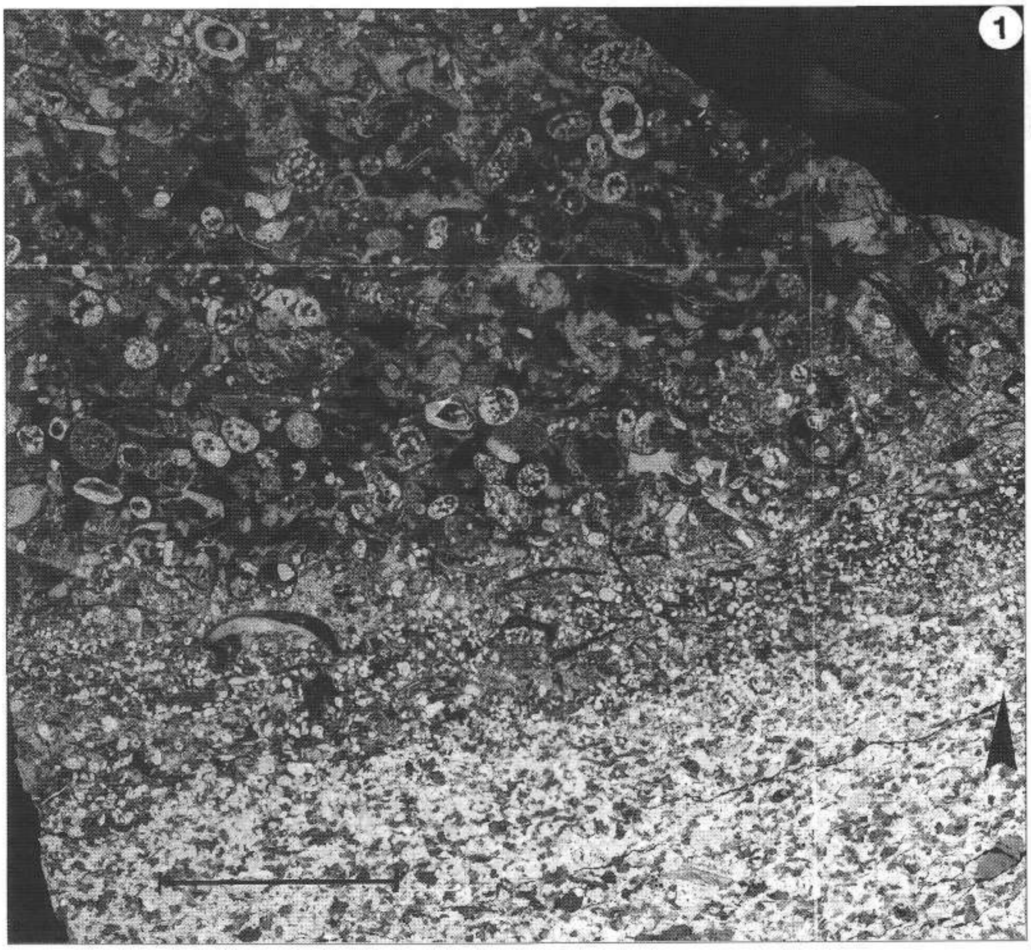
Plate 5

Fig. 1: **Graded bedding in allodapic biodetrital limestone.**
Thin-section from the road-cut between Furx and Laterns.
Negative print; scale = 1 cm.

Fig. 2: **Turbidity cross lamination.**
Thin-section of bed No. 7 of the cliff section, Rhomberg quarry, Unterklien.
Negative print; scale = 1 cm.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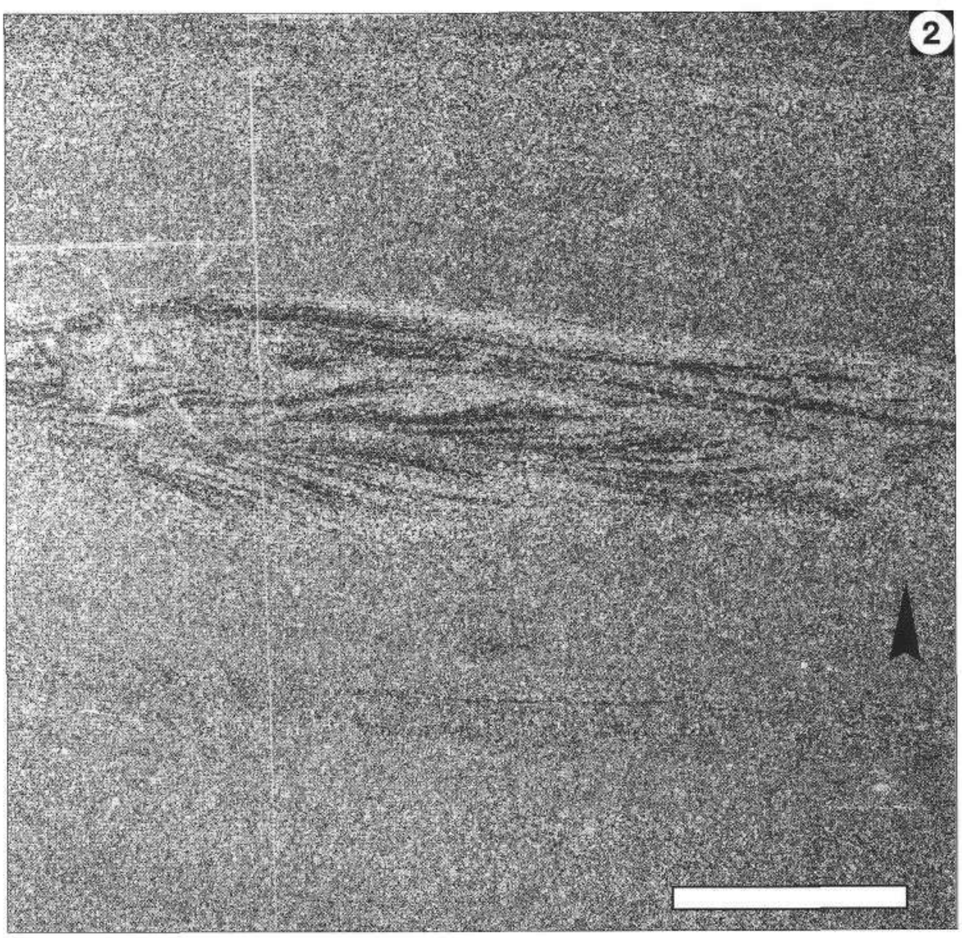
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Plate 6

Fig. 1: ***Lopha* beds with various shells, shell debris and microcolonies.**
Rhomberg quarry.
Micrograph, negative print; scale = 1 cm.

Fig. 2: **Bed No. 11 with wackestone (a) and grainstone (b) textures.**
Rhomberg quarry.
Micrograph; scale = 2 mm.

Fig. 3: ***Choffatella* sp.**
Sandy upper Schrattenkalk beds, Gottesackerwände.
Micrograph; scale = 0,2 mm.

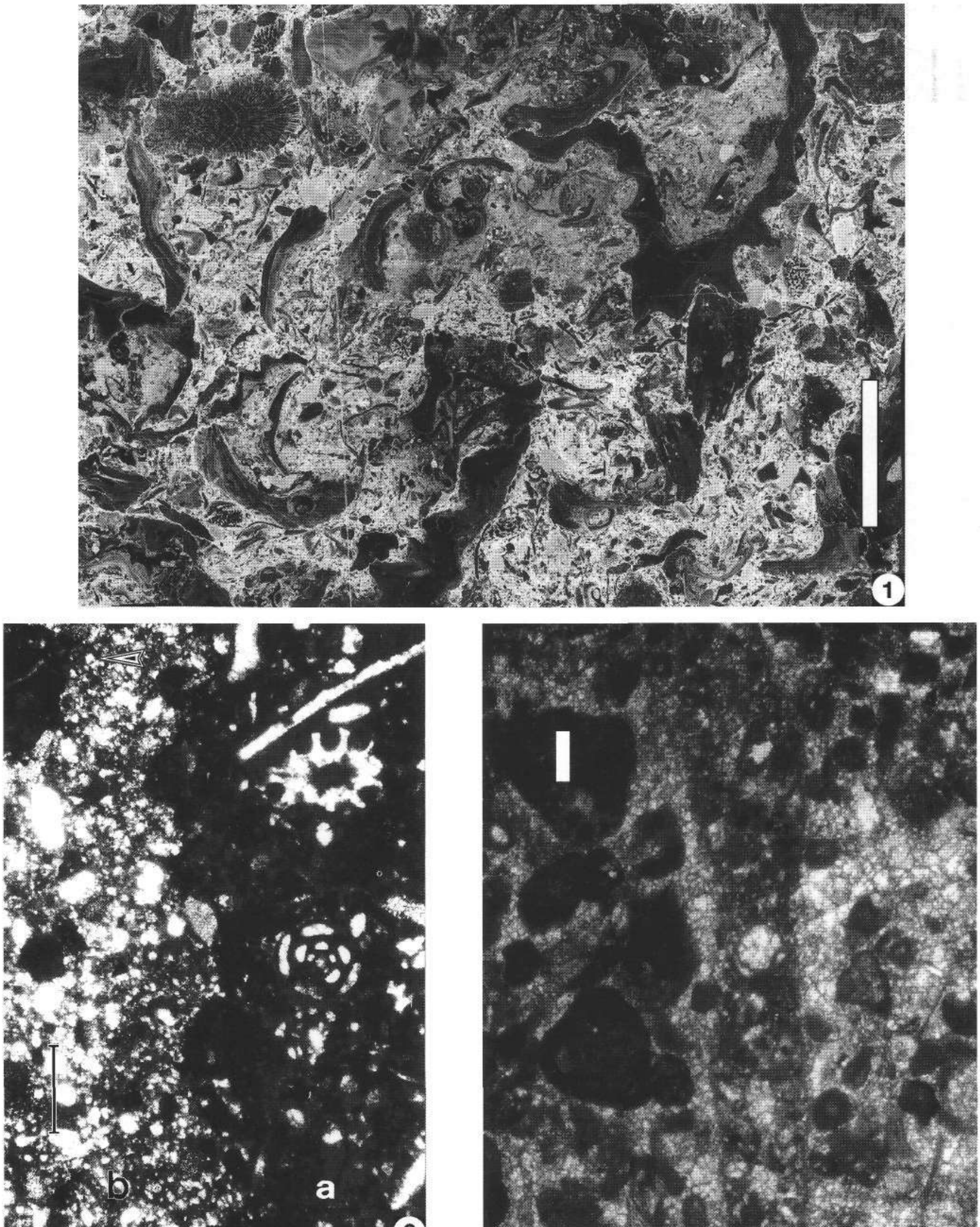
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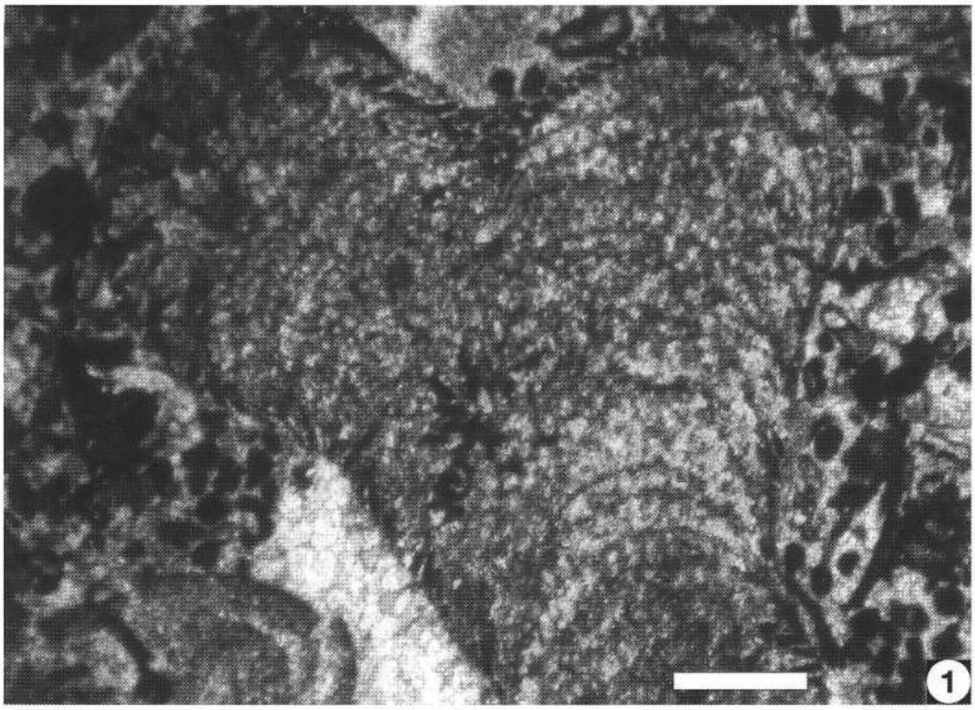
Plate 7

Fig. 1: **Sphinctozoid sponge from sponge coral biofacies.**
Gottesackerwände.
Micrograph; scale = 2 mm.

Fig. 2: ***Archaeolithothamnium* sp.,**
Gottesackerwände.
Micrograph; scale = 1 mm.

Fig. 3: ***Ethelia alba* from sponge-coral biofacies.**
Gottesackerwände.
Micrograph; scale = 0,1 mm.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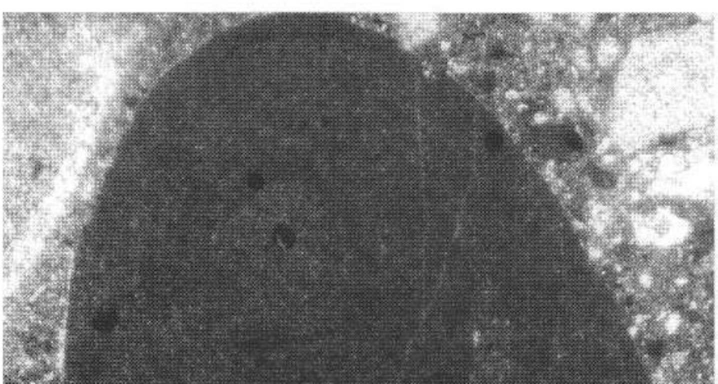
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Plate 8

Figs. 1,2: ***Coscinophragma* sp.**
Road-cut between Furx and Laterns.
Micrograph; scale = 5 mm.

Fig. 3: **Rheophax sp. with diagenetic feldspar crystals.**
Road-cut between Furx and Laterns.
Scale = 5 mm.

Fig. 4: ***Acicularia* sp. (a) and Miliolina sp.**
Contact of the Schrattenkalk and Garschella Formations.
Rhomberg quarry, Unterklien.
Scale = 5 mm.

Fig. 5: ***Orbitolinopsis* sp. (a) and Miliolina sp.**
Contact of the Schrattenkalk and Garschella Formations.
Rhomberg quarry, Unterkline.
Sclae = 5 mm.

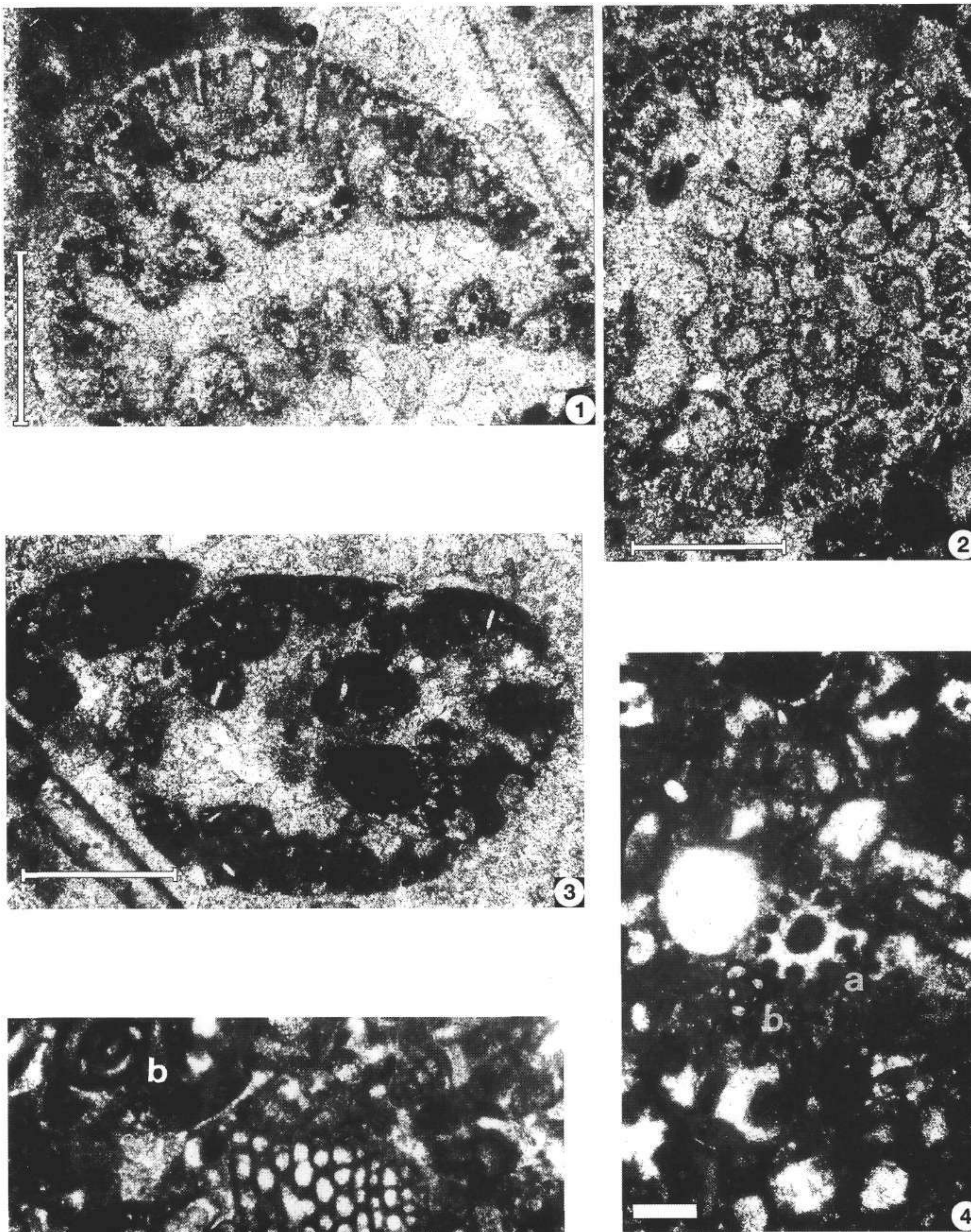
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Plate 9

Fig. 1: **Erosional contact**
between Szársomlyó Limestone Formation (Jurassic) and Nagyharsány Limestone Formation.
Harsány-hegy quarry, Nagyharsány.

Fig. 2: **Detail of the contact**
from the previous photograph.


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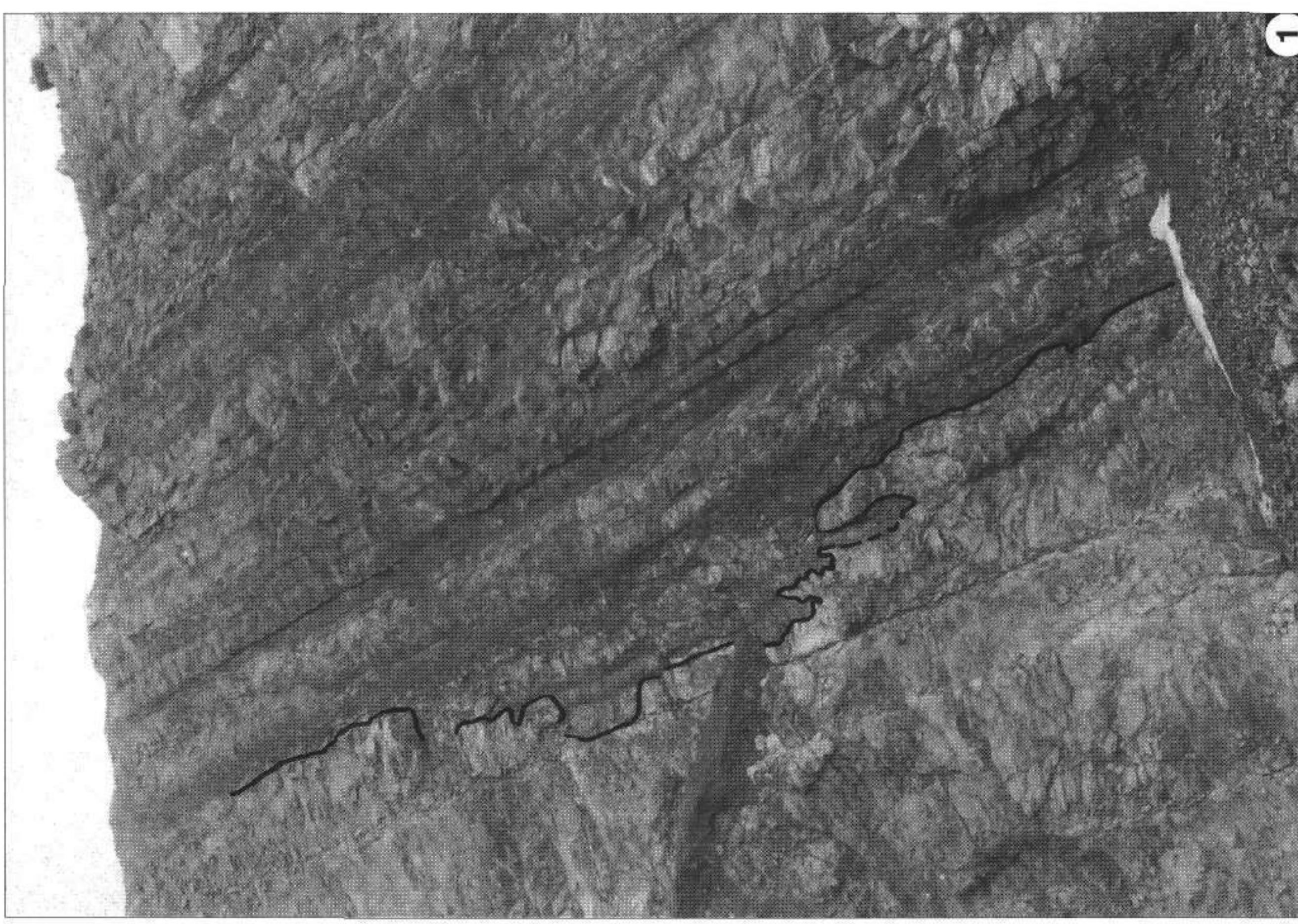
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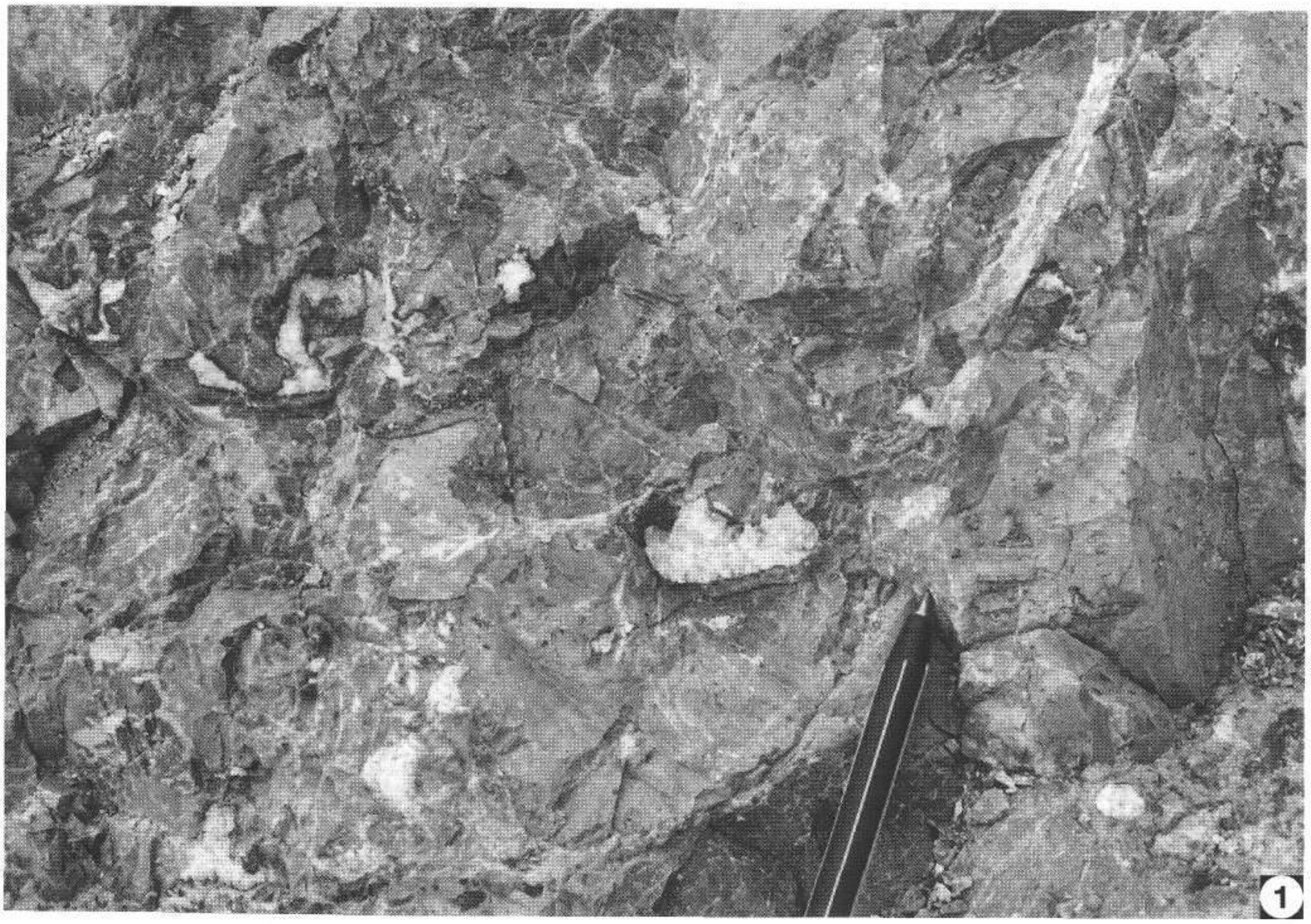
Plate 10

Fig. 1: **Calcitic infillings in Stromatactis type (?) holes.**
Note dark grey colour of the wall of the holes and rhythmic laminae at the base.
Nagyharsány Limestone Formation.
Harsány-hegy quarry.

Fig. 2: **Radical change in colour (darkness) along internal erosional contact.**
Lower member of the Nagyharsány Limestone Formation.
Harsány-hegy quarry.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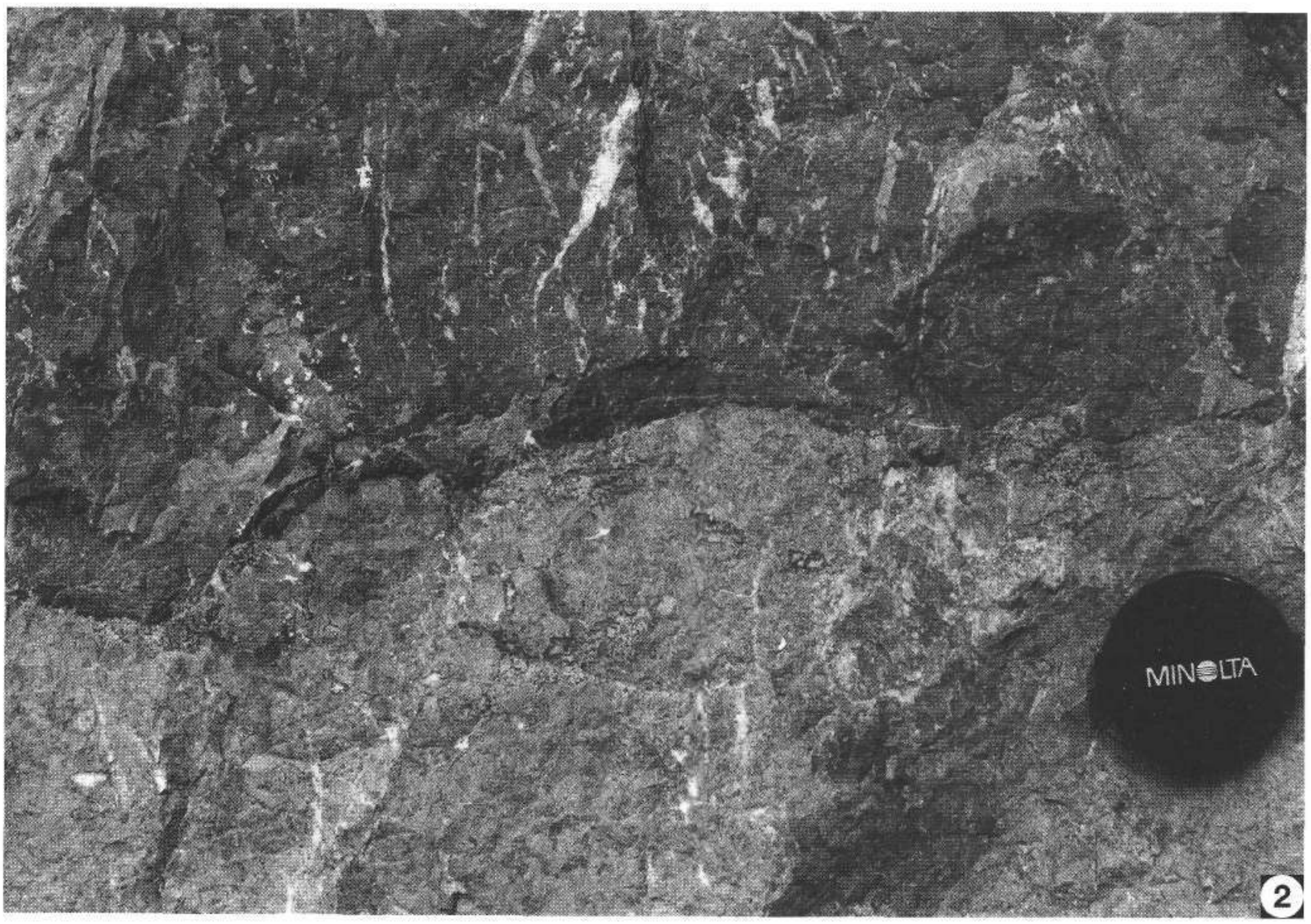

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Plate 11

Fig. 1: **Large scale synsedimentary breccia.**
Lower member (base of bed 20) of the Nagyharsány Limestone Formation.
Harsány-hegy quarry.

Fig. 2: **"Black pebbles".**
Lower member of the Nagyharsány Limestone Formation.
Harsány-hegy quarry.

Fig. 3: **Root-like features.**
Lower member of the Nagyharsány Limestone Formation.
Harsány-hegy quarry.

Fig. 4: **Sharp contact of pale-grey (above) and grey limestone (below).**
Lower member of the Nagyharsány Limestone Formation.
Harsány-hegy quarry.

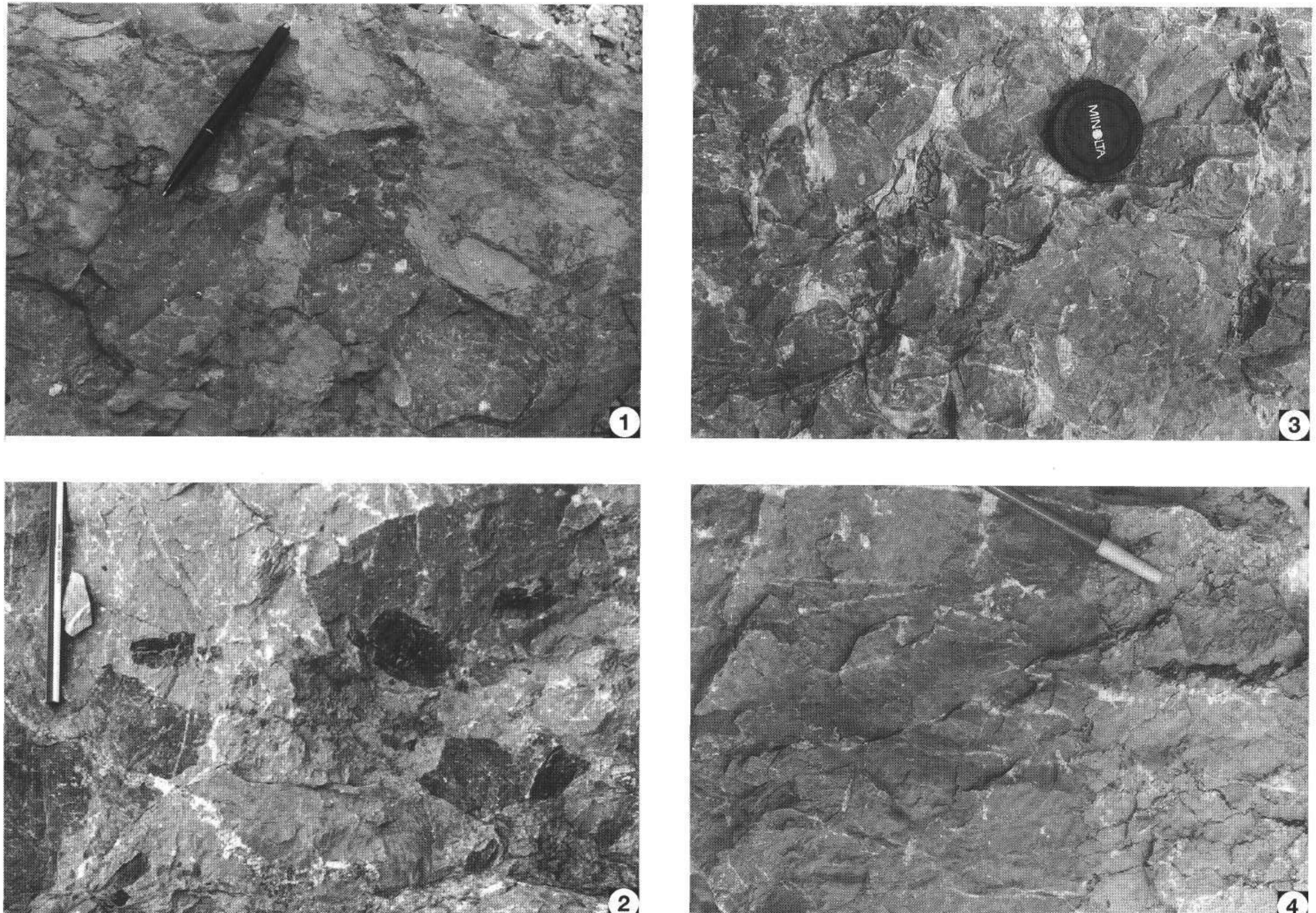
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Plate 12

Fig. 1: **Breccia, cemented by clayey mudstone (in the middle of the photograph) and Stromatactis (above).**
Lower member of the Nagyharsány Limestone Formation.
Harsány-hegy quarry.

Fig. 2: **Rounded and elongated holes filled by violet marl and calcareous marl.**
Bed No. 19, lower member of the Nagyharsány Limestone Formation.
Harsány-hegy quarry.

Fig. 3: **Unidentified formless yellowish white mudstone infillings (root structure?).**
Bed No. 23 of Nagyharsány Limestone Formation.
Harsány-hegy quarry.

Fig. 4: **Algal mat laminae.**
Lower member of Nagyharsány Limestone Formation.
Harsány-hegy quarry.

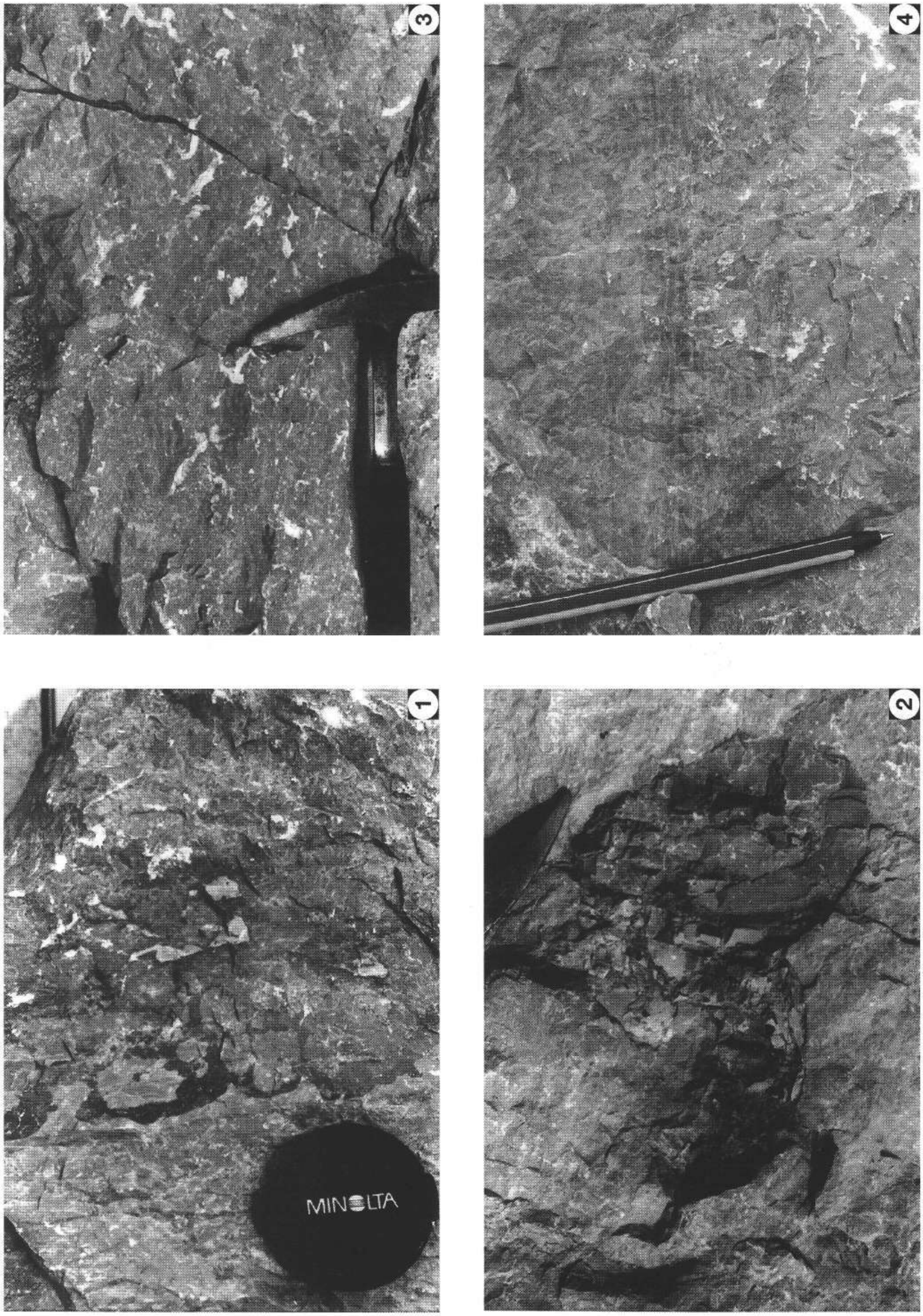
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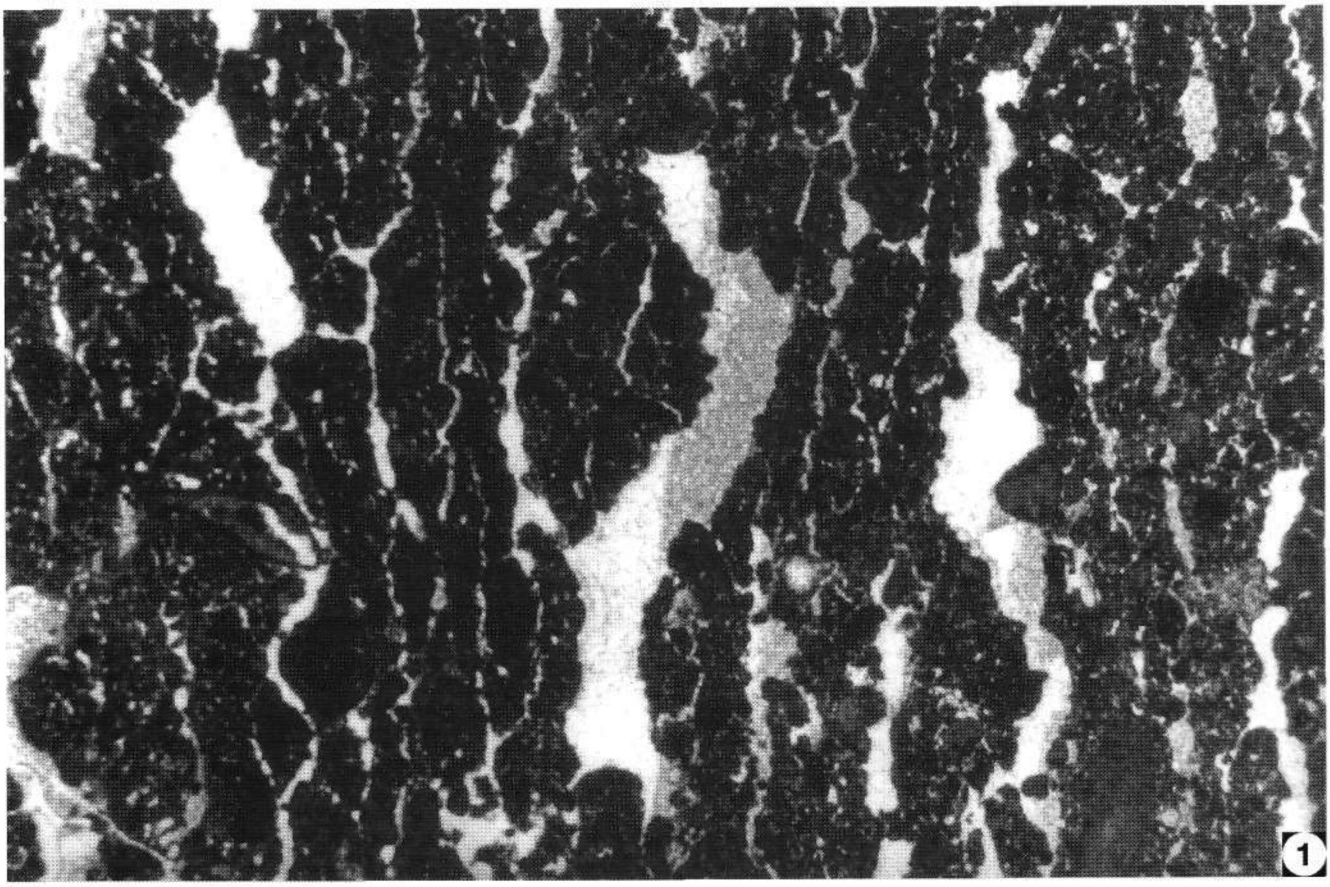
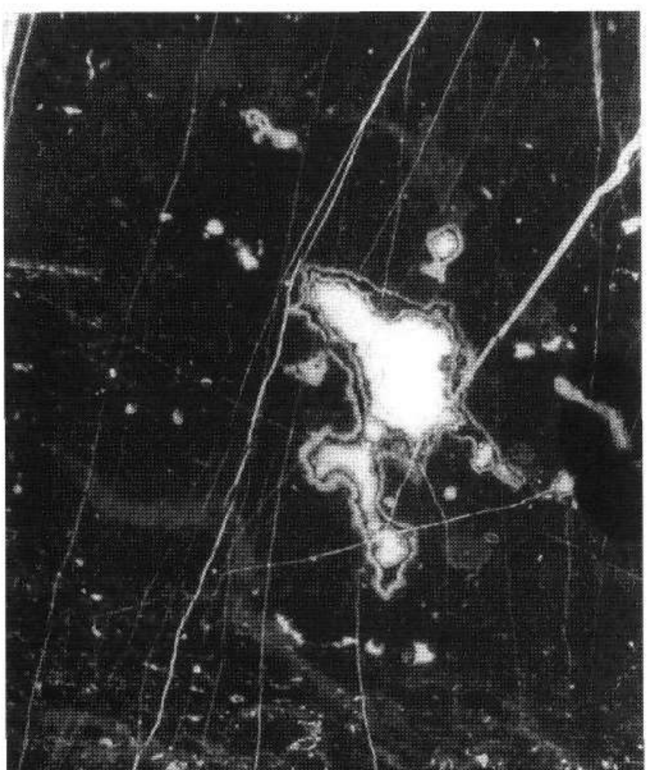
Plate 13

Figs. 1,3: **Micrographs of laminoid fenestral fabric with vadose silt.**
Lower member of Nagyharsány Limestone Formation.
Harsány-hegy quarry.
41×.

Fig. 2: **Stromatactis with infilling of several generations and stylolitic structure in the silty part of the limestone.**
Lower member of the Nagyharsány Limestone Formation.
30×.





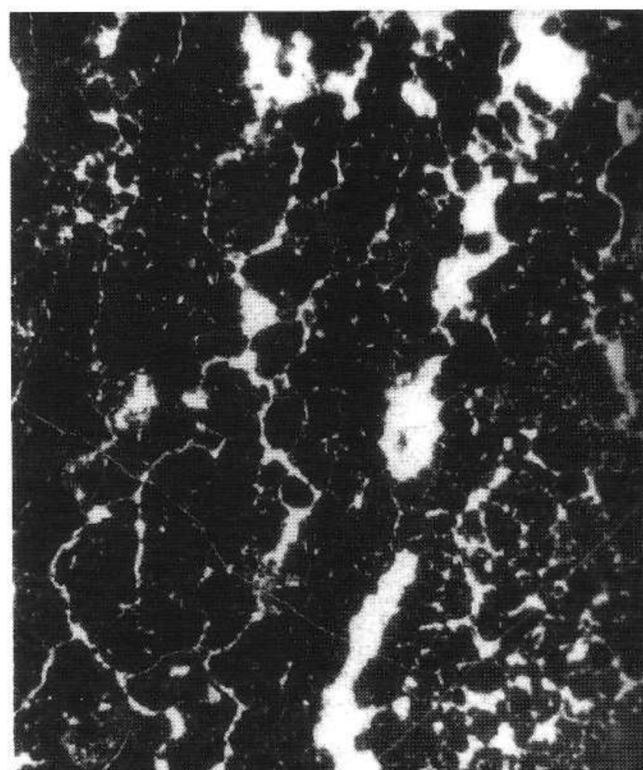


Plate 14

Figs. 1,2: **Micrographs of an algal mat intercalation.**
Lower member of Nagyharsány Limestone Formation.
Harsány-hegy quarry.
30×.

Fig. 3: **In part micritized bivalve shell fragment with forams and other bioclasts.**
Lower member of the Nagyharsány Limestone Formation.
Harsány-hegy quarry.
30×.

Fig. 4: **Oriented bivalve shells with two generation cavity infillings below of them.**
Lower member of Nagyharsány Limestone Formation.
Harsány-hegy quarry.
34×.

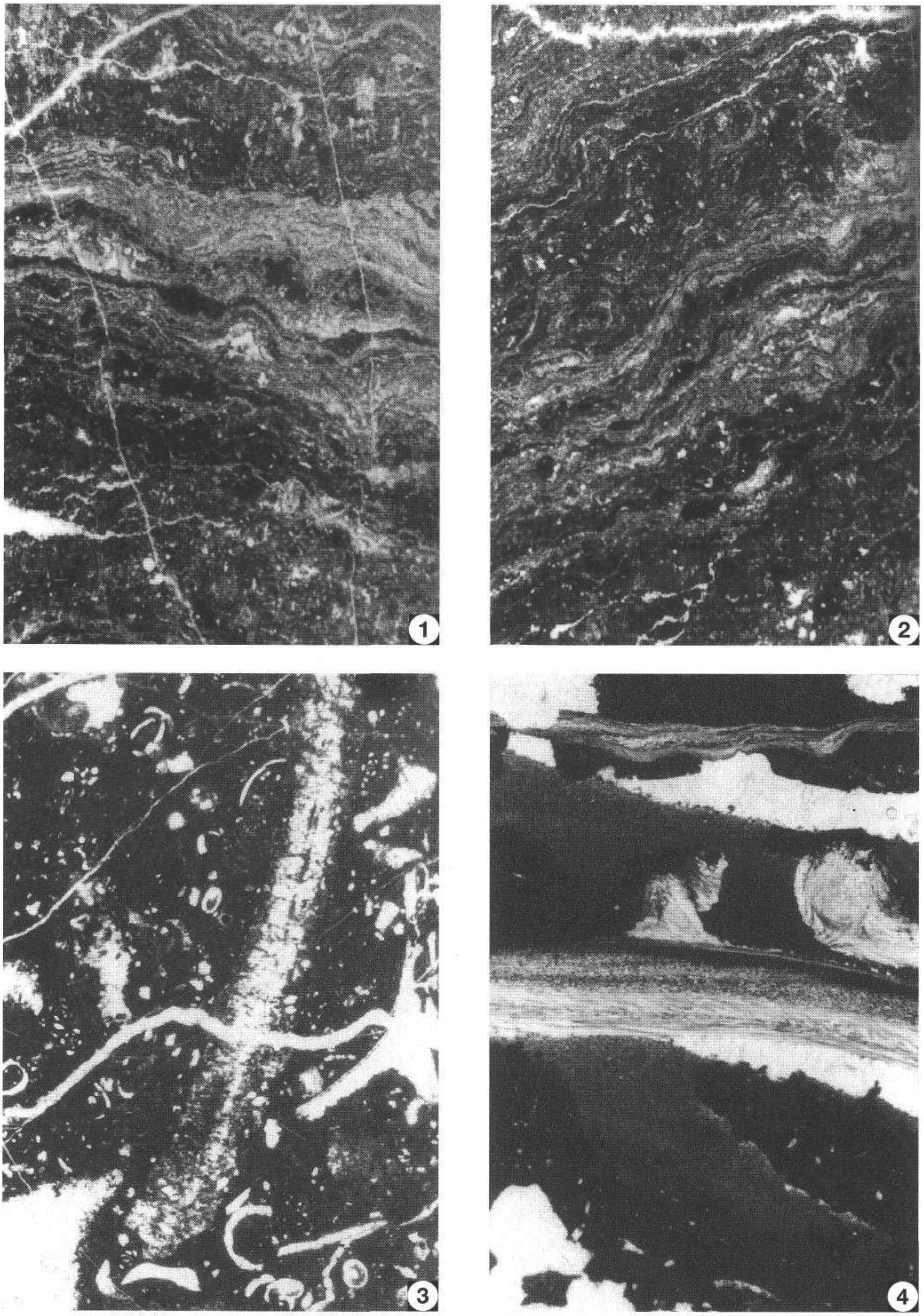

1
2
3
4

Plate 15

Fig. 1: ***Cayeuxia* grainstone.**
Lower member of Nagyharsány Limestone Formation.
Harsány-hegy quarry.
41×.

Fig. 2: ***Cayeuxia* sp. with Miliolids and other foraminifers.**
Lower member of Nagyharsány Limestone Formation.
Harsány-hegy quarry.
86×.

Fig. 3: **Characean wackestone.**
Basal beds of Nagyharsány Limestone Formation.
Harsány-hegy quarry.
41×.

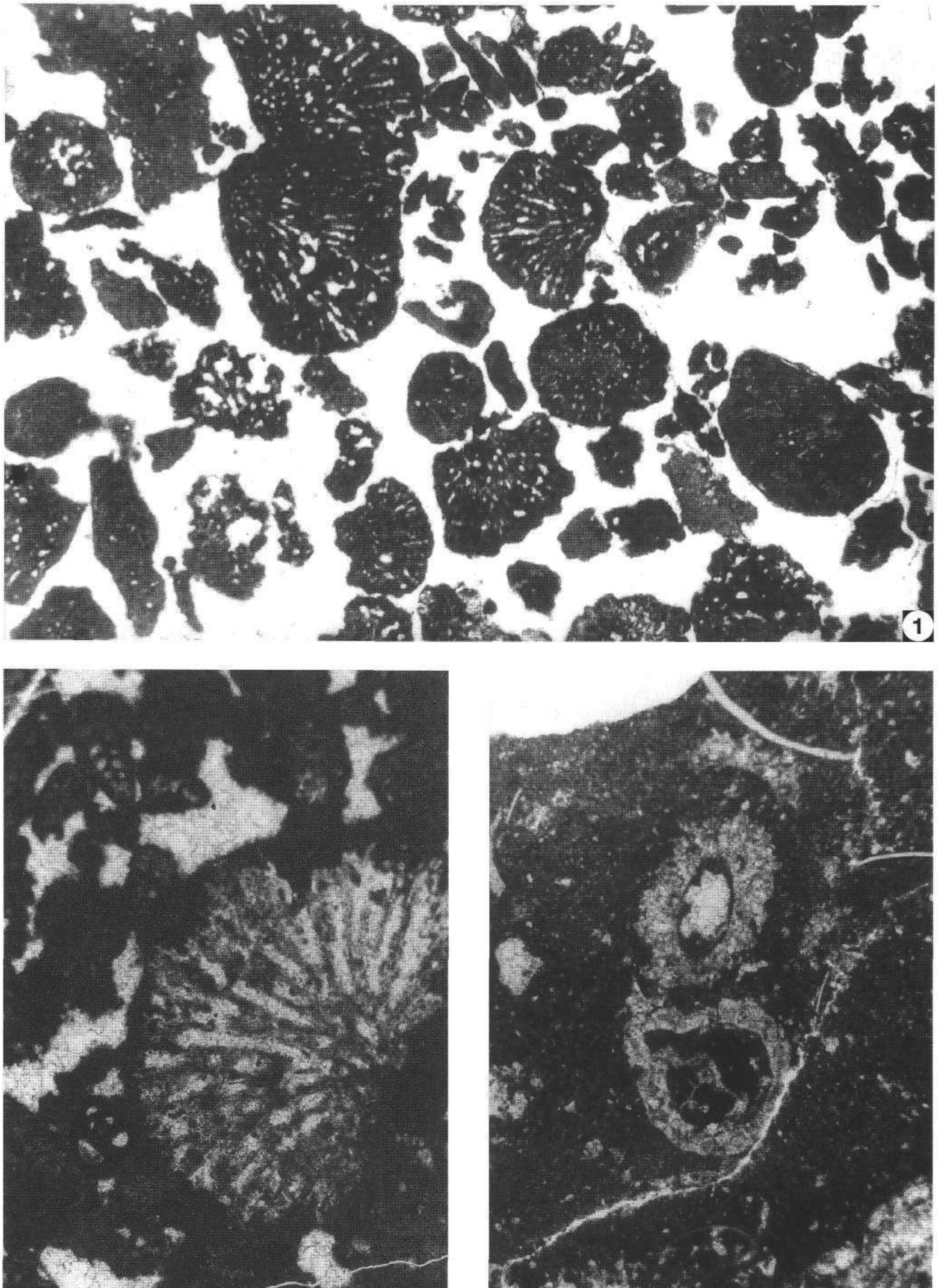
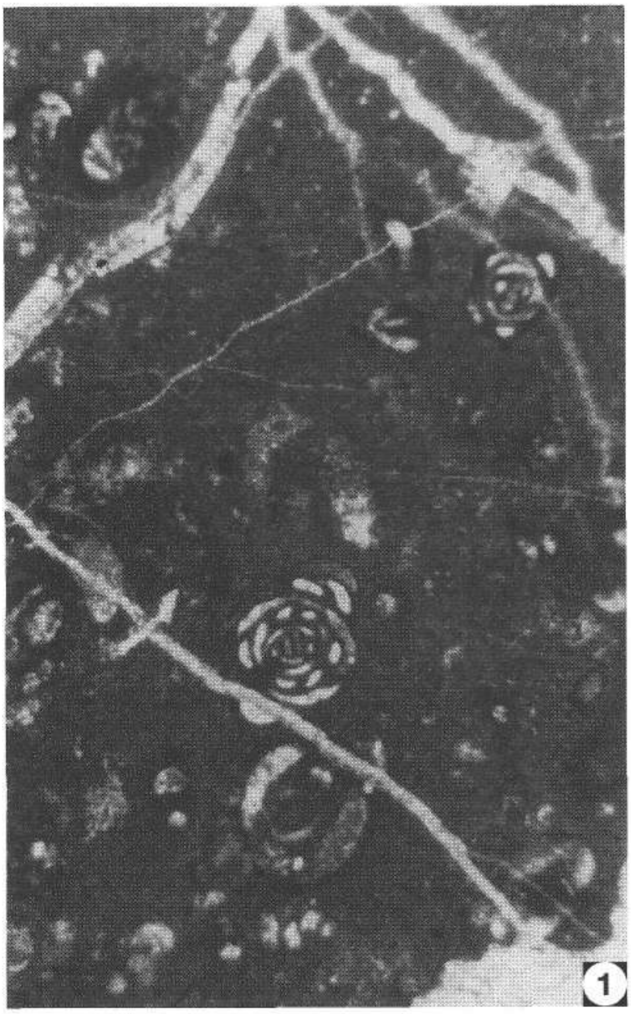

1
2
3

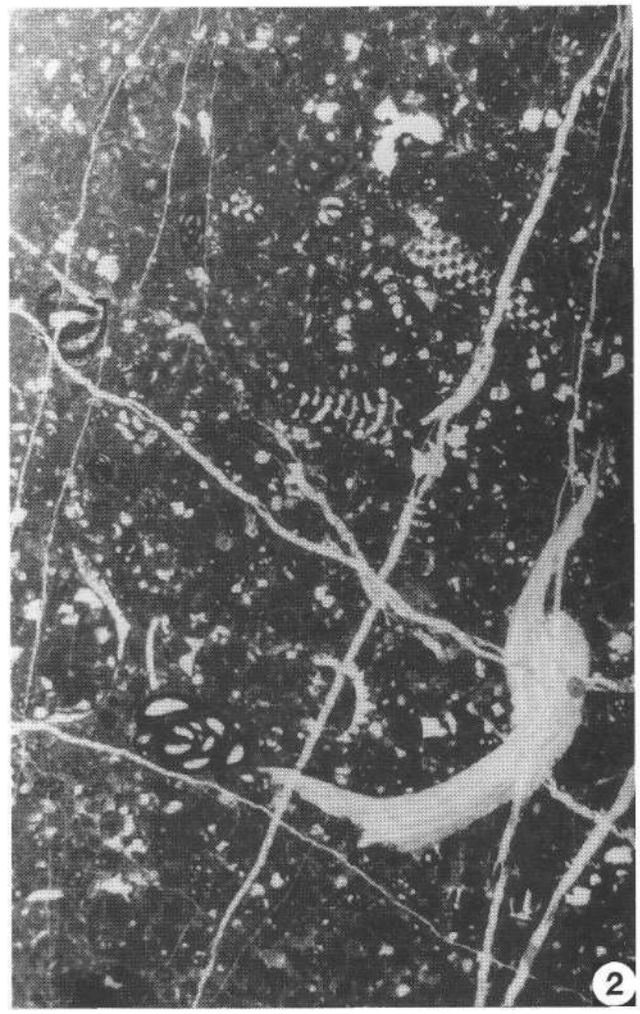
Plate 16

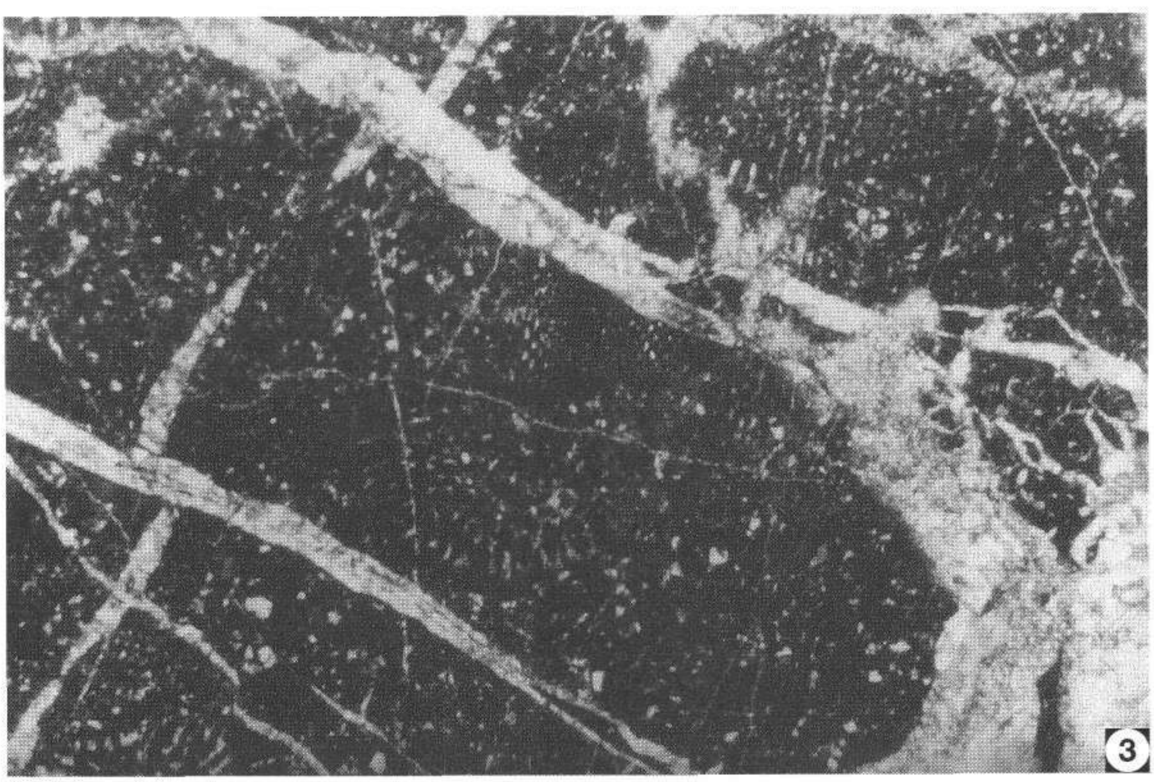
Fig. 1: **Miliolidae wackestone with *Ovalveolina* (?) sp.**
Member 2 of Nagyharsány Limestone Formation.
Harsány-hegy quarry.
86×.

Fig. 2: **Foraminifera and Dasycladales packstone with other biogenic fragments.**
Member 2 of Nagyharsány Limestone Formation.
Harsány-hegy quarry.
86×.

Fig. 3: **Orbitolinid packstone.**
Micrograph from member 3 of Nagyharsány Limestone Formation.
Harsány-hegy quarry.
86×.







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