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Günter Trabold

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Sedimentology, Sequence Stratigraphy and Biostratigraphy

Günter Leo TRABOLD

Genève 1996

ISSN 1012-2990

Section des Sciences de la Terre

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intitulée :

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Sédimentologie, biostratigraphie, stratigraphie séquentielle."

La Faculté des Sciences, sur le préavis de Messieurs J. CHAROLLAIS, professeur ordinaire et directeur de thèse (Département de géologie et paléontologie), R. SCHROEDER, professeur et codirecteur de thèse (Université de Francfort), A. STRASSER, professeur (Université de Fribourg) et C. STROHMENGER, docteur (BEB, Hanovre), autorise l'impression de la présente thèse, sans exprimer d'opinion sur les propositions qui y sont énoncées.

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RESUME

Le but de cette étude sédimentologique et biostratigraphique est de définir l'évolution des paléoenvironnements des Calcaires urgoniens du domaine delphino-helvétique, de part et d'autre de la vallée de l'Arve, pour la période comprise entre l'Hauterivien supérieur et l'Aptien.

Trois coupes ont fait l'objet de recherches particulièrement poussées: dans la zone la plus interne du massif des Bornes *stricto sensu* (Rocher de Cluses), dans la chaîne des Aravis (Bella Cha et Grande Forclaz), massif de Platé (Flaine). Dans ces régions, l'étude de la mise en place de la plate-forme urgonienne à l'Hauterivien supérieur et au Barrémien inférieur a conduit à reconnaître trois domaines marins (hors des domaines subaériens): le talus, la plate-forme externe et la plate-forme interne. Au sein de ceux-ci, sept milieux de dépôt ont été définis: milieu de bassin et de pente, marin ouvert (circa- et infralittoral), lagon plus ou moins ouvert et protégé, lagunaire à lacustre, et milieu "transgressif". Ces différents environnements sont caractérisés par 23 types de microfaciès, recensés et décrits dans ce travail.

L'étude biostratigraphique et l'analyse séquentielle ont permis de proposer un découpage des dépôts de cette plate-forme carbonatée, complètement inédit. La nouvelle biozonation basée sur les orbitolinides, proposée par SCHROEDER & *al.*, et calée sur l'échelle des ammonites, constitue un nouvel outil stratigraphique, en tout cas pour les dépôts de l'Hauterivien supérieur et du Barrémien inférieur. De ce fait, les unités reconnues dans les différentes coupes de Calcaires urgoniens ont été datées à la zone d'ammonites près, ce qui autorise la corrélation des milieux carbonatés de plate-forme avec ceux qui caractérisent le bassin. D'autre part, les nouvelles connaissances acquises en stratigraphie séquentielle permettent de proposer des coupures au sein du grand cycle régressif de 2ème ordre qui débute à l'Hauterivien inférieur (fin de la Zone à Radiatus) et se termine au Barrémien supérieur (Zone à Feraudi). En effet, un certain nombre de séquence de 3ème ordre ont été reconnues et identifiées en se fondant soit sur des critères basés sur l'évolution des milieux de dépôt, soit sur des données paléontologiques (échinides, ammonites, orbitolinides), soit sur des connaissances à la fois sédimentologiques et paléontologiques.

Ainsi dans la coupe des Calcaires urgoniens du Rocher de Cluses, ont pu être identifiées les séquences Ha6, Ha7 et Ba1, Ba2, Ba4, Bd1, Bd2; ici a donc été mis en évidence l'absence de dépôts durant les périodes des séquences Ba3 et Ba5. A Flaine, les séquences ont été reconnues pour Ha7, Ba1, Ba2, Ba4 et Ba5; la séquence Ba3 étant peut être représentée par quelques mètres de sédiments. Dans la chaîne des Aravis, les coupes de Bella Cha et de la Grande Forclaz ont permis de reconnaître respectivement les séquences Ha5, Ha6, Ha7, Ba1, Ba2 et Ha5, Ha6, Ba1, Ba2, Ba3, Ba4, Ba5.

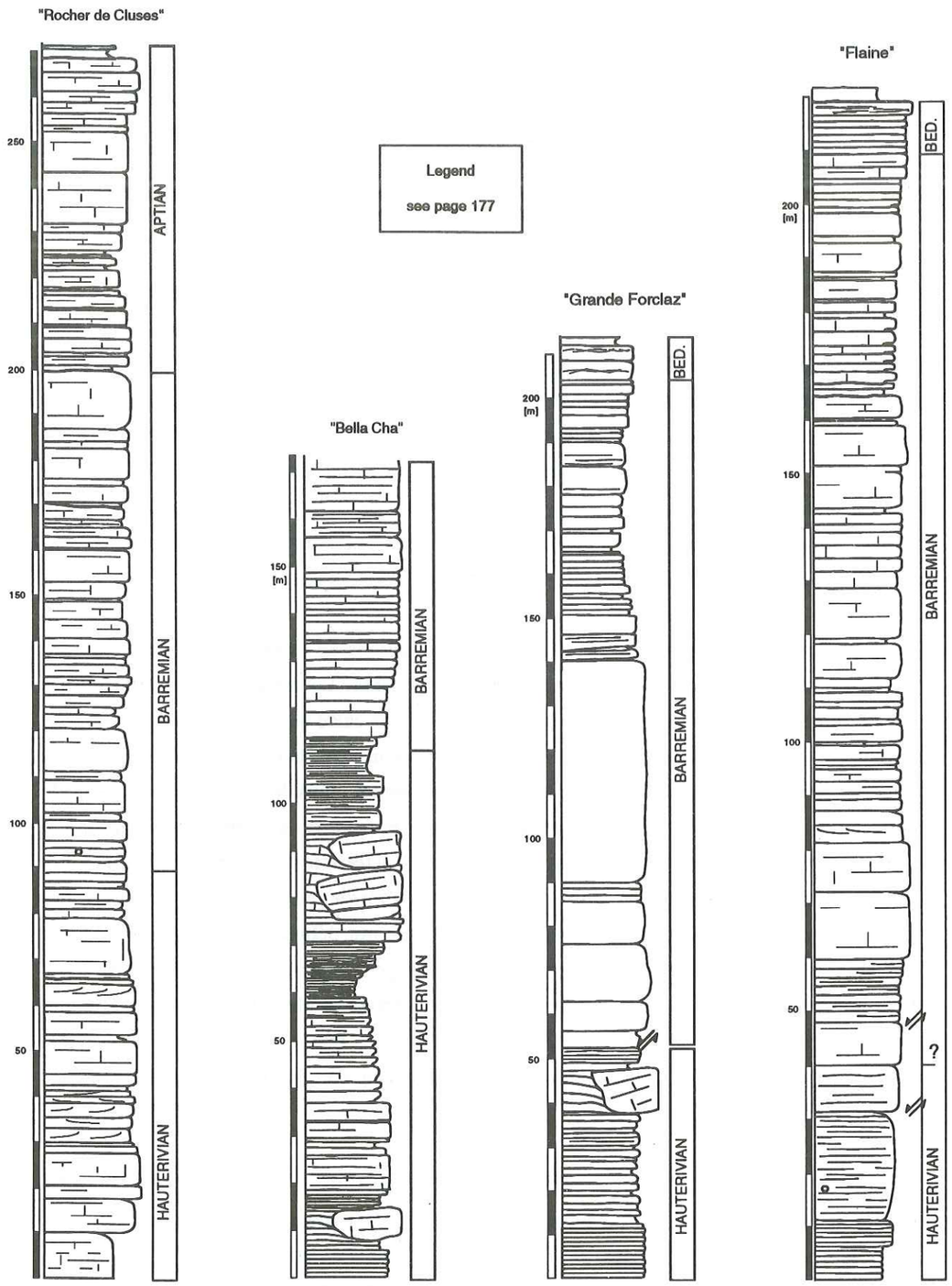

Fig. R.1. Coupes synthetiques: (a) "Rocher de Cluses" (Massif des Bornes), (b) "Bella Cha" et "Grande Forclaz" (Chaîne des Aravis) et (c) "Flaine" (Massif de Platé).

ABSTRACT

Part I

Development of the Urgonian limestones in the delphino helvetic realm. (Sedimentology, Sequence Stratigraphy and Biostratigraphy)

The aim of this study is to delineate the paleoenvironmental and paleogeographical evolution of Late Hauterivian - Early Aptian shelf deposits developed on the European passive margin of the Ligurian Tethys. The study was focused on the sedimentological, sequence stratigraphical and biostratigraphical development of the *Urgonian limestones.*

Based on the investigation of numerous stratigraphic sections in the northern Subalpine Chains (Western Alps, SE-France) the shelf can be divided into 3 paleogeographic units: **muddy shelf, outer-platform** and **inner-platform.** These units can be differentiated into 7 distinct depositional environments: (1) basin, (2) slope, (3) open marine shallow-complex, (4) open lagoon, which can be subdivided into a transitional zone (4a) and a slightly protected lagoon (4b), (5) protected to semi-restricted lagoon, (6) lacustrine/brackish and (7) "transgressive". These depositional units themselves are characterized by 23 microfacies-/facies types basic units.

The stratigraphic record displays a vertical succession of large-scale- and medium-scale depositional sequence stacking patterns.

The whole record of the investigated stratigraphic sections is part of a **large-scale depositional** sequence. This shows a shallowing-upward (regressive) tendency where the hemipelagic slope facies and the shallow-marine *Urgonian platform* prograded over the pelagic silty to marly limestones of the Dauphinois Basin. This shallowing-up is considered as part of a 2nd order cycle terminating with the maximum regression in the Upper Barremian.

Medium-scale depositional sequences (on average 40 m thick) are interpreted as 3rd order sequences (sensu Vail *et al.* 1991) built up by prograding, aggrading and backstepping stacking patterns. The age of the sequences has been established by means of benthic orbitolinid foraminifera, echinids, and ammonites, which make it possible to correlate the sequences in a chronostratigraphic framework.

Part II

Gravity submarine mass movements, relative sea-level changes in late Hauterivian to early Barremian delphino-helvetic deposits (Aravis mountains).

In the SW-NE trending Aravis mountains, which are situated in the northern Subalpine Chains (SE-France), two horizons of carbonate mass flow deposits are well exposed. These deposits or "lentils" consist of large slide and slump blocks (up to several hundreds of meters large) embedded in a matrix of conglomerates, micrite and fine-grained carbonate particles.

Microfacies analysis indicates that the matrix and most of the megablocks are composed of circalittoral particles derived from the slope. Some of the megablocks are built up by shallow-water platform carbonates.
Gravity mass flows in the Aravis region are probably the result of tectonic instability during the Lower Cretaceous. These gravity mass flows are considered as lowstand deposits, and they were transported into the basin during a sea-level fall via gravity sliding, slumping and debris flows from both the slope and the prograding Urgonian platform. A succession of hemipelagic carbonate packages overlie the mass flow horizons and suggest a deepening of the depositional environment. They are interpreted as transgressive and highstand deposits, separated by well developed maximum flooding-surfaces. This 3rd order cycle is developed twice and represents the so called "Transition Zone" (Détraz *et al.* 1986). These two 3rd order cycles are embedded between the pelagic Hauterivian "Kieselkalk" and the shallow-water Urgonian platform carbonates. The shallowing-up from the pelagic Hauterivian "Kieselkalk" unit through to the shallow-water Urgonian limestones is part of a 2nd order cycle terminating with the maximum regression in the Upper Barremian.
Ammonite, echinid and orbitolinid biostratigraphy suggests a Late Hauterivian to Early Barremian age for the studied section. Biostratigraphic and sequence stratigraphic investigations made it possible to compare the results with the Lower Cretaceous cycle chart proposed by Clavel *et al.* (1992).

GENERAL OUTLINES AND AIMS OF THE STUDY

For generations of geologists, the **Urgonian limestones** have been used for sedimentological and paleontological works (e.g. Paquier 1900).
Since the "eighties", when the concepts of sequence stratigraphy became popular, the Urgonian platform was again subject to the attacks of sedimentologists.
In the Vercors and Chartreuse massifs, the platform outcrops laterally and exhibits the transition to the Vocontian Basin in the SE. For this reason, most of the recent studies on the Urgonian platform were derived from this domain (Arnaud-Vanneau & Arnaud 1990, Clavel *et al.* 1994, Hunt & Tucker 1993, Jaquin *et al.* 1991).
In the northwestern part of the Subalpine Chains, in the **Bornes Massif**, **Platé Massif** and **Aravis mountains**, where this study was carried out, the Urgonian limestones outcrop only vertically. Only in the Aravis mountains, slope and platform carbonates can be laterally observed over distances of several hundred of meters.
This work focuses on a detailed definition of **microfacies types** in order to interpret the depositional environments.
The interpretation of the **depositional paleoenvironments** is based on sedimentological features in the field and by a petrographical information (microfacies types).
The determination of **Orbitolina-foraminifers** is essential for this study. Orbitolinids are the only indicator fossils on the shallow water platform which allow a detailed biostratigraphic zonation and the recognition of third-order sequences (Clavel *et al.* 1993, 1994).
Sequence stratigraphic interpretations are based on field evidence, and the correlation of depositional environments in an isochronic framework. Obtained sequence stratigraphic results are correlated with the interpretations of Clavel *et al.* (1992, 1993, 1994) who defined a cycle chart for the Lower Cretaceous in SE-France.
Finally, the **paleogeographic history** will be reconstructed based on recognized depositional environments and sequence stratigraphic interpretation.

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Chapter 1: INTRODUCTION

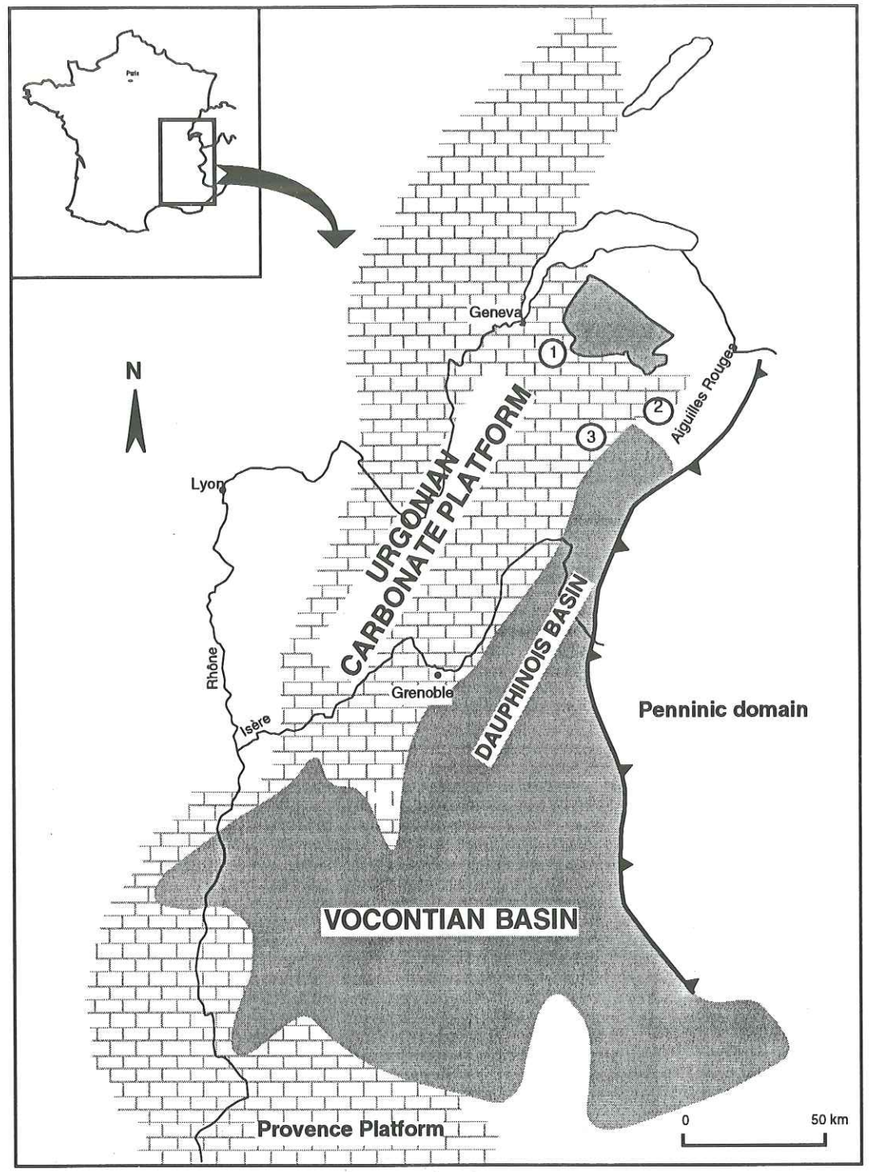


Fig. 1.1. Paleogeographic situation of the Urgonian carbonate platform, Vocontian Basin, and Dauphinois Basin during the late Hauterivian to early Aptian (modified after Debrand-Passard *et al.* 1984). (Numbers 1 to 3 indicate the study areas: (1) Bornes Massif, (2) Platé Massif and (3) Aravis Chains).

1.1 Geological setting

In the western Alps, during the late Hauterivian to early Aptian, the Urgonian platform developed along the European continental margin whilst the Ligurian Tethys was opening (Fig. 1.1). Passive margin sedimentation was dominated in response to relative sea level and/or oceanic major changes.
Along the continental margin, the late Jurassic to Early Cretaceous "breakup" was accompanied by large displacements along major lineaments. Two of them are the "Isère fault" and the "Durance fault", which trend SE-NW and separate three distinct paleogeographic domains (Arnaud-Vanneau & Arnaud 1990): the Jura-Bas Dauphiné platform to the northwest, the Dauphinois or Vocontian Basin to the central domain, and the Provence platform to the south (Fig. 1.2.).

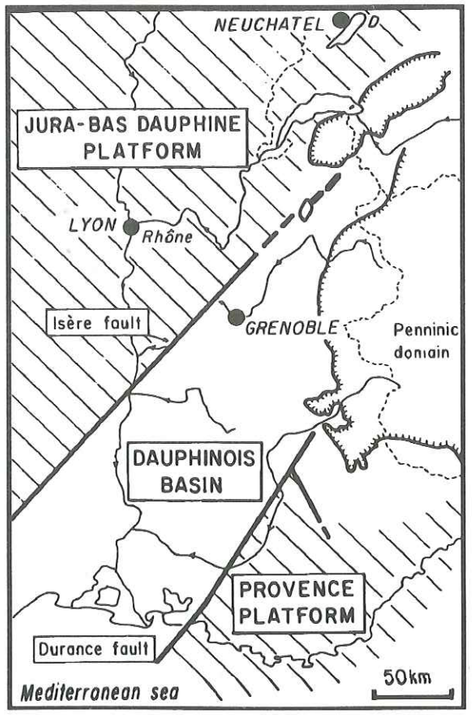


Fig. 1.2. Location of the stable and subsident domains. The Jura-Bas Dauphiné platform and the Provence platform correspond to stable areas, the Dauphinois Basin was an highly subsident domain (After Arnaud-Vanneau & Arnaud 1990).

During the Berriasian in the northern Subalpine Chains, the relatively stable platform developed into a rimmed shelf, while the highly subsident basin was filled with thick series of hemipelagic sediments. From the Valanginian to the early Hauterivian in the northern Subalpine Chains the shelf margin was drowned by the deposition of hemipelagic sediments on a ramp dipping slightly towards the SE.
Overlying this early Hauterivian inherited paleotopograhy extended from the former Jura platform to the external part of the Dauphinois Basin, the Urgonian carbonate platform was progressively deposited during the early Hauterivian to early Aptian.

The installation of the Urgonian carbonate platform developed during the lower to basinal upper Hauterivian in the French-Swiss Jura domain (Clavel *et al.* 1994). From this area, the platform extended and prograded in two principal directions: (1) from the West to the East and (2) from the Northeast to the Southwest (Clavel *et al.* 1987, reviewed in Clavel *et al.* 1994).

1.2 Geographical and geological framework

The study area is situated in the Haute-Savoie, France, and covers the tectonic units of the northwestern Bornes Massif, Platé Massif and the Aravis mountains . The study realm is bordered by the Jura mountains in the north and northwest, and limited by the Prealps in the northeast. The crystalline units: Aiguilles Rouges Massif, external Belldonne Massif and the Mont-Blanc Massif form the southern to southeastern boundary (Fig. 1.3).

1.2.1 Bornes Massif

The Bornes Massif forms the frontal mountain range in the northeastern part of the French Subalpine Chains between the Arve valley and the Lake of Annecy. The Subalpine Chains make the foreland fold/thrust belt of the Western Alps. The Bornes Massif is considered as a succession of anticlines and synclines disturbed by a series of fractures and thrusts (Charollais *et al.* 1988) provoked during the alpine orogenic phase.
For a review on the Bornes Massif, see Charollais *et al.* (1988) and references therein.
Historical works: Bütler (1928), Maillard (1889), Moret (1934), Parejas (1938), Sarasin (1902).
Recent works: Charollais (1963), Charollais & Lombard (1966), Charollais *et al.* (1988).

1.2.2 Aravis Chains

The SW-NE trending Aravis mountains are situated between the Arve valley (NE) and the Col des Aravis (SW). They represent the subalpine border in the southeast of the Bornes Massif (Charollais *et al.* 1988). The Aravis mountains form the southeast flank of the *Thônes-Synclinal.* The flank is inclined in a northwestern direction.
Historical works: Haug (1895), Moret (1934), Parejas (1925), Ritter (1897).
Recent works: Rosset (1957), Détraz *et al.* (1986), Détraz (1989), Villars (1991)

1.2.3 Platé Massif

The Platé Massif is intercalated between the Bornes Massif and Aravis mountains in the southwest and the Haute-Giffre in the northeast. Structurally, the massif is connected with the Aravis mountains in the southwest and separated by the Arve valley. Ayrton (1972) and Pairis *et al.* (1973) described the allochthonous character of the Platé Massif (recently discussed in Epard 1990).
Historical works: Collet (1943), Lillie (1937), Moret (1920)
Recent works: Breton (1972), Ayrton (1972), Pairis (1975)

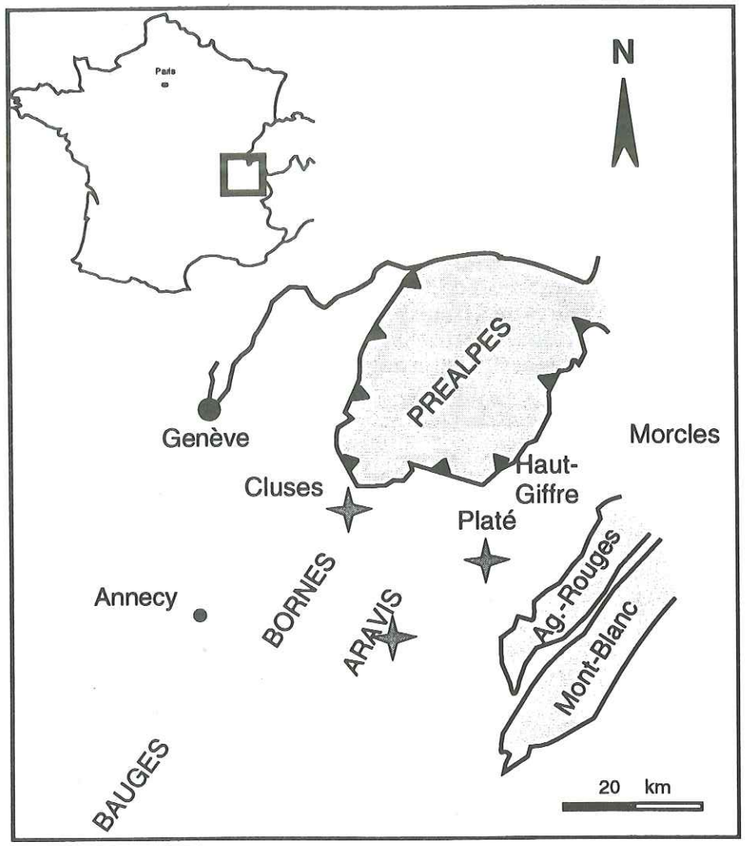


Fig. 1.3. Location map of studied areas.

1.3 Structural geology

The origin of the different tectonic units: Bornes, Aravis, Haut-Giffre, Platé, and in the Helvetic realm: Dents du Midi, Morcles, Diableretes and Wildhorn, and their relationships are not clear and still open to discussion.
Controversy exists concerning whether the Bornes, Aravis, and Platé massifs belong to the same or different tectonic units and if they are related to the northeastern Helvetic nappes: Dents du Midi, Morcles, Diableretes and Wildhorn.
Moret (1934) and Collet (1943) interpreted the Platé Massif as a prolongation of the Morcles Nappe and related these units to the para-autochthonous Bornes Massif.
Pairis *et al.* (1975) proposed the same tectonic origin for the Platé, Haut-Giffre, Morcles and Aravis massifs.
Clavel *et al.* (1987) and Epard (1990) supposed that the two flanks of the "Thônes-syncline" (the northwestern flank corresponds to the Bornes Massifs and the southeastern flank to the Aravis) were never separated over long distances and belong to the same tectonic unit.
Other authors, for example Chaplet (1992) and Doudoux *et al.* (1982), supposed different tectonic origins of these units. Chaplet (1992) suggested that the

"Thônes-syncline" represents a large-scaled failure over which the "Aravis Nappe" is thrusted onto the external "Bornes Nappe".
For detailed discussion, see Chaplet (1992), Charollais & Liermier (1967), Collet (1943), Doudoux *et al.* (1982), Epard (1990), Huggenberger & Wildi (1991) Moret (1934), Pairis (1975), Ramsay (1989), Tardy & Doudoux (1984),
For a review of the structural relationship of the different units see Charollais *et al.* (1988).

1.4 Palinspastic reconstruction

Following the results of Charollais *et al.* (1988) and Epard (1990, pers. comm.) it is assumed, that the Bornes Massif, the Aravis Chains and Platé Massif belong to the same tectonic unit. The Borne Massif (including the anticline "Rocher de Cluses") is considered to be para-autochthonous and was submitted to only minor northward transport. The allochthonous Aravis and Platé massifs, however, are considered to have their origins in the south to southeast and that initial distances were reduced by folding movements (Fig. 1.4. a and b). It is assumed, that original relative distances were reduced by a factor 1.5 to 2 (Charollais pers. comm. 1992, Epard pers. comm. 1994).

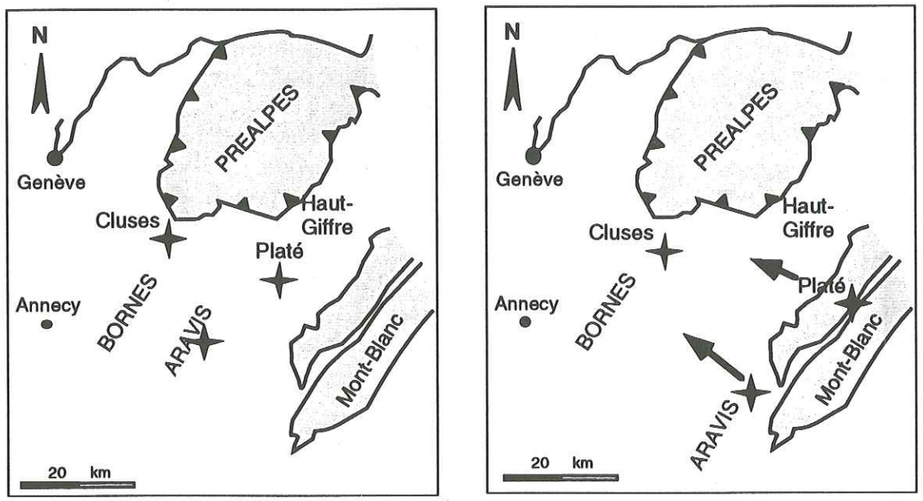


Fig. 1.4. (a) Present localities of studied areas; **(b)** original localities of studied areas.

Chapter 2: METHODS

2.1 Sampling
Fourteen sections with approximately 1050 samples were studied. All samples have been taken with consideration of the stratigraphic orientation and in "fresh" conditions to eliminate alterations by weathering.

2.2 Preparation
Most samples have been sawed perpendicular to bedding and polished with corundum-powder.

2.3 Thin sections
Approximately 800 thin sections have been made in the laboratory of the Department of Geology and Paleontology, Geneva.

2.4 Acetate peels
About 1000 acetate peels have been made and described after Folk (1959, 1962) and Dunham (1962).

2.5 X-ray diffraction analysis
XRD analysis of the clay fraction were performed by J.F. Deconinck ("Laboratoire de Dynamique sédimentaire et structurale", Lille, France) using a Philips diffractometer (PW 1730) with CuK-alpha radiation. XRD. (For further description see chapter 6 CLAY MINERALS.
The method of sample preparation is described in detail in Holzapffel (1985).

2.6 Carbonate Content
The carbonate contents of most of the samples were determined by using the "carbonate-bomb" method (Müller & Gastner 1971), the relative error being about 2-5% (Dunn 1980).

2.8 Microscopy
Thin sections were analyzed with a Leitz Vario Orthomat microscope. Photos were documented with an AGFA APX 25 ASA.

2.7 Scanning electron microscopy
Scanning microscopic analysis were performed by R. Martini (Institut de Géologie et Paléontologie de Genève) using a "geol 6400"-Scanning Microscope.
Working conditions:
Electron beam: 15 KV at 100 mA
Photography: Black-white Kodak, Plus-X-Pan

2.8 Cathodoluminescence microscopy
Instrument: 8200 MK II made by Technosyn, Cambridge, GB
Working conditions:
Electron beam 16 KV at 60 mA, chamber of observation with a residual pressure of 80 mTorr.

Chapter 3: LITHOSTRATIGRAPHY

3.1 Siliceous limestones ("calcaires siliceux", "calcaires gréseux à miches").

This 400 to 650 m thick formation is composed of thick sandy limestone beds containing sponge spicules and silty to sandy shales. The uppermost part of the formation is characterized by a marly to micrite limestone, rich in glauconitic pellets and platform derived material. This uppermost "Hauterivien" is described as facies type 18 (chapter 8 MICROFACIES AND FACIES TYPES).
The siliceous limestone formation exhibits a southward thickening; from 400 m in the Bornes Massif to 650 m in the Aravis Chains (Charollais *et al.* 1988, Muller 1985).

3.2 Transition zone; "couches de transition"(Détraz *et al.* 1986); "zone de transition" (Conrad 1968)

For detailed description see Charollais *et al.* (1966), Conrad (1969), Froidevaux (1976), Muller (1985), Pairis (1975), Revil (1911), Rivano-Garcia (1978), Rosset (1957).
This stratigraphic unit displays a transition of stratal pattern between the underlying hemipelagic siliceous limestones and the overlying Urgonian platform carbonates. Sediment composition and outcrop development indicate a transition between deep-marine and shallow-marine depositional environments.
In this study the "couches de transition" in the Aravis realm were of particular interest, because they include one or two horizons of mass flow deposits (see chapter 10 SUBMARINE MASS FLOW DEPOSITS).

3.3 The "Urgonian" limestones

3.3.1 History

It was in 1850 that d'Orbigny defined the "substage" "Urgonien", named after the reference section in Orgon, Apilles, southeast France. With this subdivision he distinguished chalky rudist limestones from the differing under and overlying units. Stratigraphically, d'Orbigny suggested that the new substage belonged to the Upper Neocomian (between the Neocomian s.s. and the Lower Aptian).
Just after d'Orbigny had introduced the term "Urgonien", confusion and misunderstanding followed concerning its use and definition. For a period it was uncertain whether the new terminology would be practiced in a facial, stratigraphical or lithological sense.
Kilian (1910, 1915) specified that the term "Urgonian" should only be used as a facies type (with varying character). According to Kilian, the "Urgonian" is only developed in southeastern France from the Provence to the Jura mountains, crossing the Subalpine Chains and the eastern border of the Massif Central. Its age ranges from the Hauterivian (Lexique strat. int.) to the Lower Aptian. Clavel *et al.* (1993) defined for the "rudist limestones",

from the *Orgon* stratotype, a chronological extension only within the basinal Upper Barremian; the *Barremese*-ammonite zone.
Paquier (1900, 1905) subdivided the Urgonian limestones into a "masse inférieure" and a "masse supérieure", separated by the "première zone des marnes à Orbitolines" (Lory 1846, see below). To integrate the historic definition of the "Urgonian" and the different facies and lithological developments, Leenhardt (1883) and Masse (1976) proposed the following terminology.

Leenhardt:	calcaires inférieurs	U1
	calcaires à *Requienia*	U2
	calcaires supérieurs	U3
Masse:	calcaires urgoniens	s.l.
	calcaires urgoniens	s.s.

According to Masse (1976), the Urgonian limestones s.l. are composed of fine grained bioclastic limestones with chert and locally glauconite. Vertically they grade into argillaceous or medium grained limestones. They may also consist of medium to coarse grained carbonates or oolites.
The Urgonian limestones *s.s.* consists of inner-platform carbonates characterized by rudist-reefs and micrite rich units.
Recently, Arnaud-Vanneau & Arnaud (1990, their Fig. 5) proposed a subdivision of the "Urgonian limestone formation" into a "lower member" and "upper member", separated by the "lower *Orbitolina* beds". According to these authors, the Urgonian limestone formation is of Late Barremian (BA2) to late Early Aptian (AP1) age.
For further reading see Clavel *et al.* (1993). This work contains a reviewed detailed discussion about the history, recent works and new data on the Urgonian limestones.

3.3.2 The use of "Urgonian" limestones in this study:

In this study, the term "Urgonian limestones" includes all stratal packages deposited on the shallow water shelf which built up the carbonate platform. These upper Hauterivian to early Aptian deposits are well separated from the underlying hemipelagic slope deposits and from the overlying "Grès verts helvetiques" (also "Helvetic Greensandstones") (Delamette 1994).

3.4 "Couches à Orbitolines inférieures" ("lower *Orbitolina* beds")

The term "première zone des marnes à Orbitolines" was created by Lory (1846). In general these micrite deposits are used to divide the Urgonian limestones into a lower and upper unit (see above e.g. Paquier 1900, Arnaud-Vanneau *et al.* 1990). The age of these sequences were determined as basal Aptian in the northern Subalpine Chains (Arnaud-Vanneau *et al.* 1990). Arnaud-Vanneau *et al.* interpreted these *Orbitolina* beds as (tidal?) channel sediments, deposited during the transgressive phase of a relative sea level rise.
Based on biostratigraphic results, Clavel *et al.* (1993) demonstrated that within the Jurassic and Subalpine domains, the *Orbitolina* beds are not of the same age. They were progressively deposited during the upper Barremian to lower Aptian.

In the study area the (lower) *Orbitolina* beds are interpreted as packages of third order transgressive systems tracts. In the Platé and Aravis region they have an upper Barremian age (Ba4), in the northeastern Bornes Massif ("Rocher de Cluses") they are of lower Bedoulian age (Bd1). The *Orbitolina* beds (synonym *Orbitolina* marly limestones) are described in detail in microfacies type 17A (see chapter 8 MICROFACIES AND FACIES TYPES).

Chapter 4: BIOSTRATIGRAPHY

General remarks
Orbitolinids, ammonites and echinids are the most commonly used biostratigraphical tools for Lower Cretaceous carbonate sediments. Dasycladacean algae, anthozoans, stromatoporoids and chaetetids provide further biostratigraphic support.

4.1 Orbitolinids

Orbitolinids are the most useful fossils for determining the age of shallow-water Urgonian platform carbonates. It is necessary to recognize, that orbitolinid biozonations are only local valid. Orbitolinid distributions were controlled by environmental, biological and paleogeographical factors (Moullade *et al.* 1985), which limited their spatial and vertical distributions. Many orbitolinid species are restricted to particular biofacies (Arnaud-Vanneau 1980, Moullade *et al.* 1985). However, Clavel (pers. comm. 1994) supposed, that orbitolinids have not been restricted to shallow marine environments and they these large benthonic foraminifers inhabited also hemipelagic sites.
The most recent orbitolinid-biozonations for the Lower Cretaceous Subalpine and Jura mountains were proposed by Arnaud-Vanneau (1990) and by Clavel *et al.* (1992, 1993, 1994). These two proposed biozonations differ in the interpretation of the age of orbitolinid *Valserina broennimanni.* For Arnaud-Vanneau *et al.* (1990) *Valserina broennimanni* is of Late Barremian to Early Aptian age. According to Schroeder (1993) and Schroeder *et al.* (1989, 1994) *Valserina broennimanni* is a member of the continuous phylogenetic line *Valserina/Palorbitolina* and is of Late Hauterivian to Early Barremian age.
In this study the orbitolinid-biozonation proposed by Schroeder and coworkers (in Clavel *et al.* 1993, 1994) was used. A preliminary biozonation of orbitolinid distribution was established by Schroeder *et al.* (1968) for the Haute-Savoie and Ain (France). The authors subdivided the "Urgonian" into five biozones, each one characterized by one or more orbitolinid species. One of these selected outcrops was "Rocher de Cluses", which was also studied here.
Orbitolinid biozonation is essential for sequence stratigraphic interpretations. On the platform, where they are the only indicator fossils, third-order depositional sequences have been correlated by the means of Orbitolinid-biostratigraphy (Clavel *et al.* 1994). Fig. 4.1 shows the orbitolinid-repartition between Upper Hauterivian to Lower Aptian time (Clavel *et al.* 1993). Orbitolinids have been correlated to the ammonite-zonation established by Busnardo (1984).

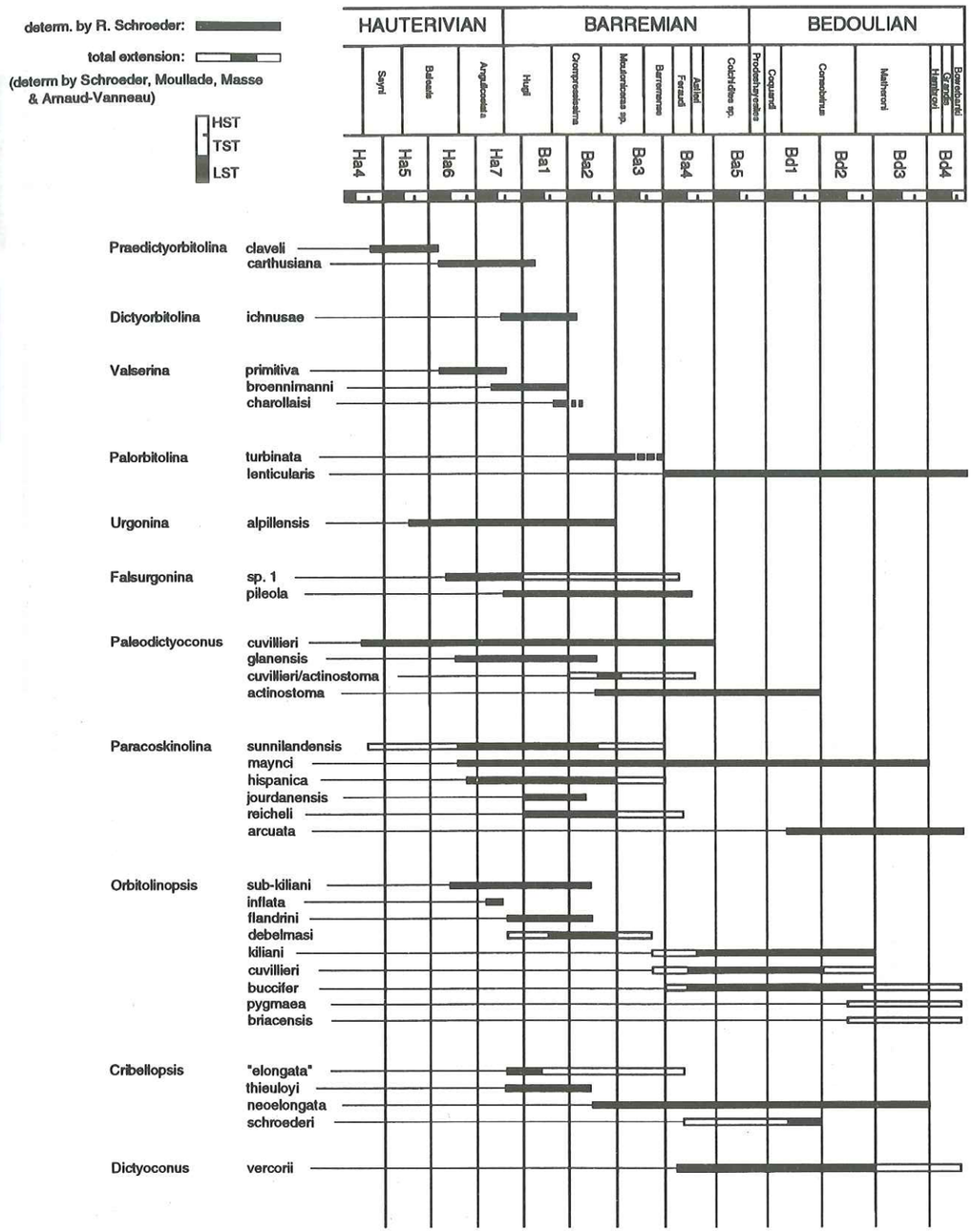


Fig. 4.1. Orbitolinid-distributions in upper Hauterivian - Bedoulian time interval (after Clavel *et al.* 1993) .

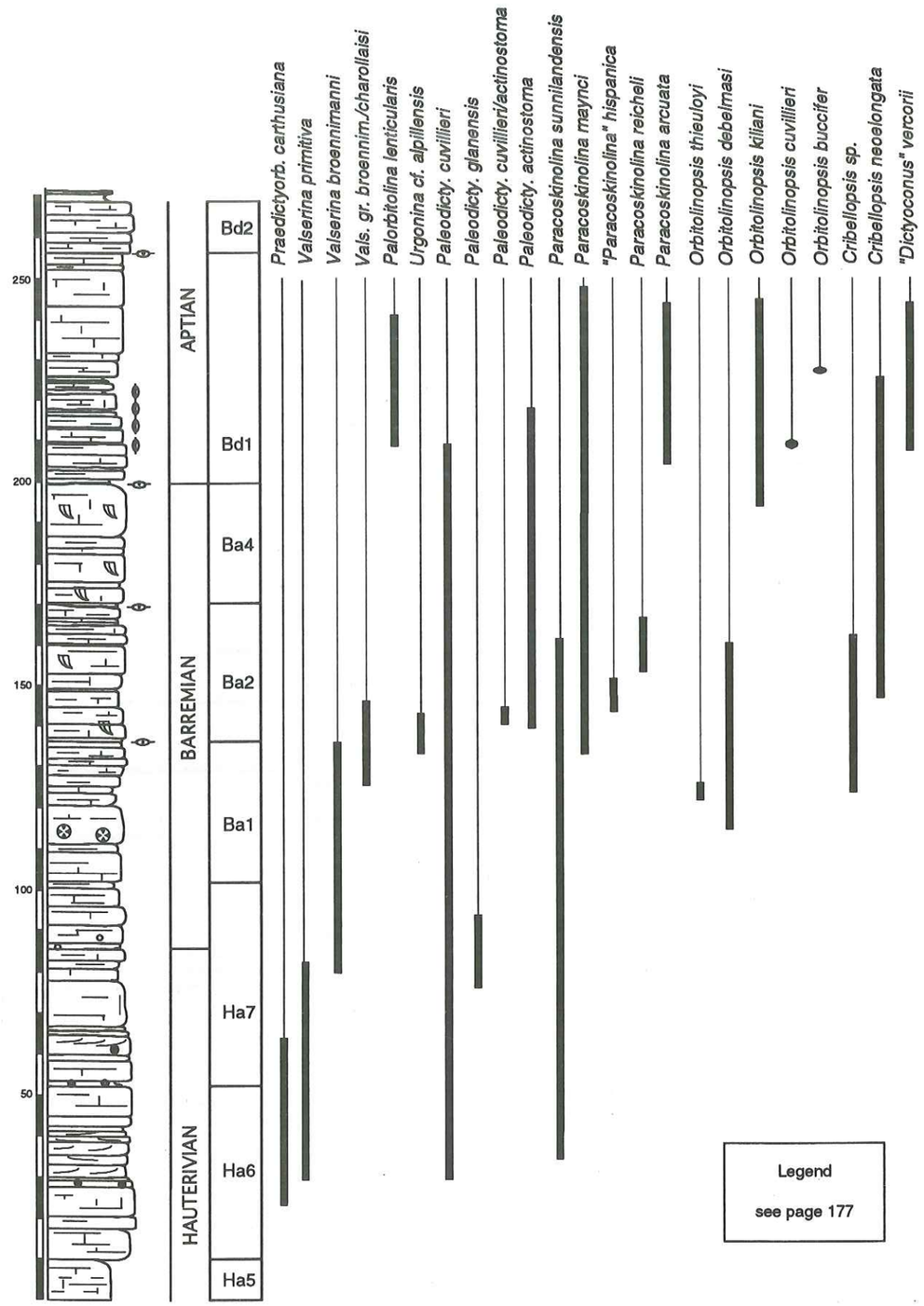


Fig. 4.2. Orbitolinid-distributions in the **"Rocher de Cluses"** section.

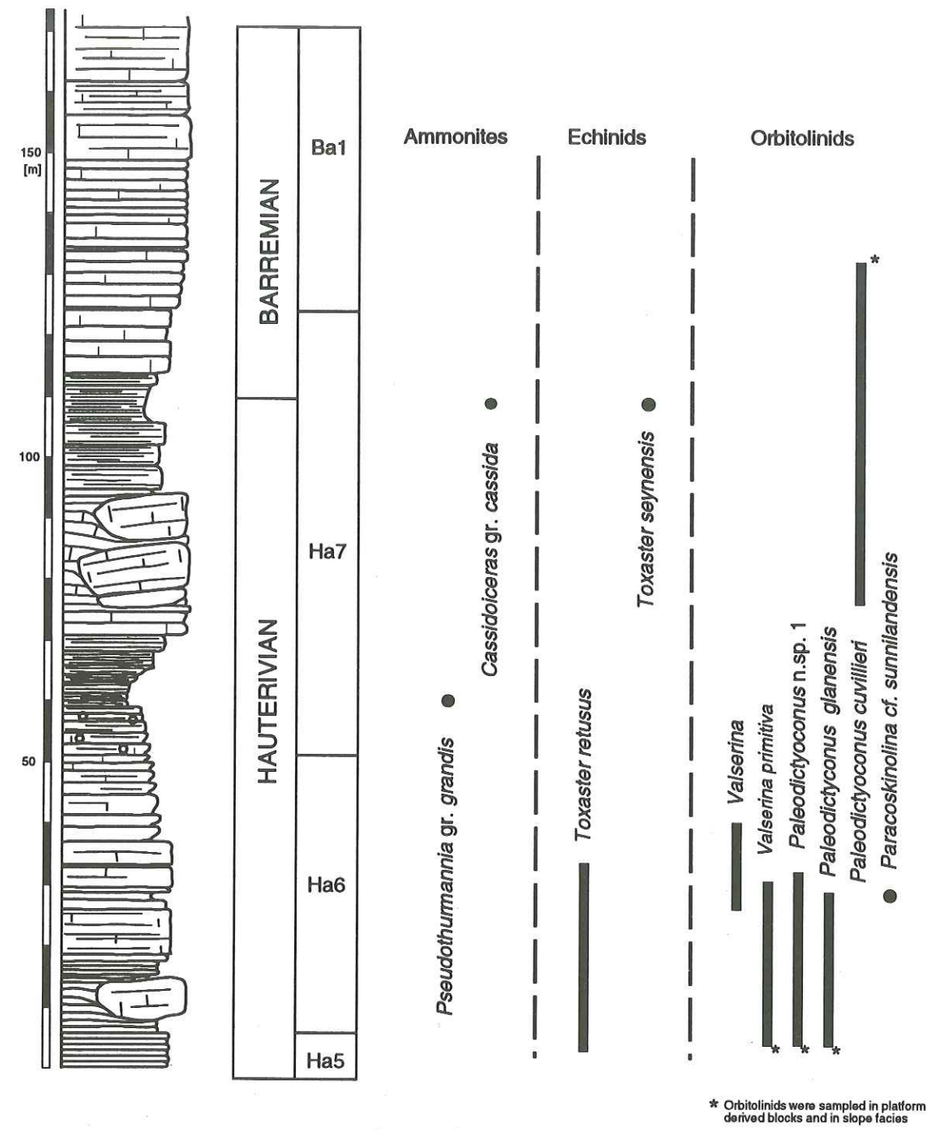


Fig. 4.3. Ammonite-, Echinid- and Orbitolinid-distributions in the **"Bella Cha"** section (Aravis Chains).

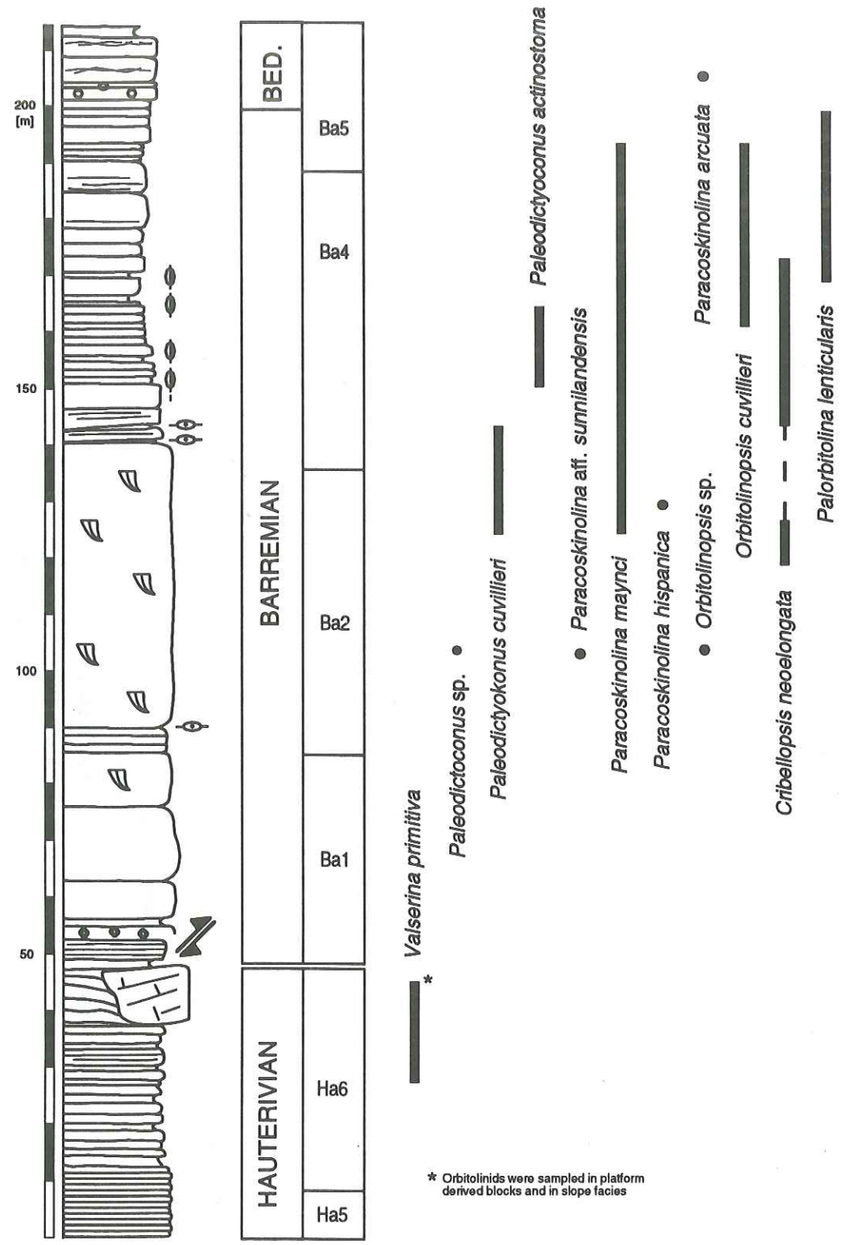


Fig. 4.4. Orbitolinid-distributions in the "Grande Forclaz" section (Aravis Chains).

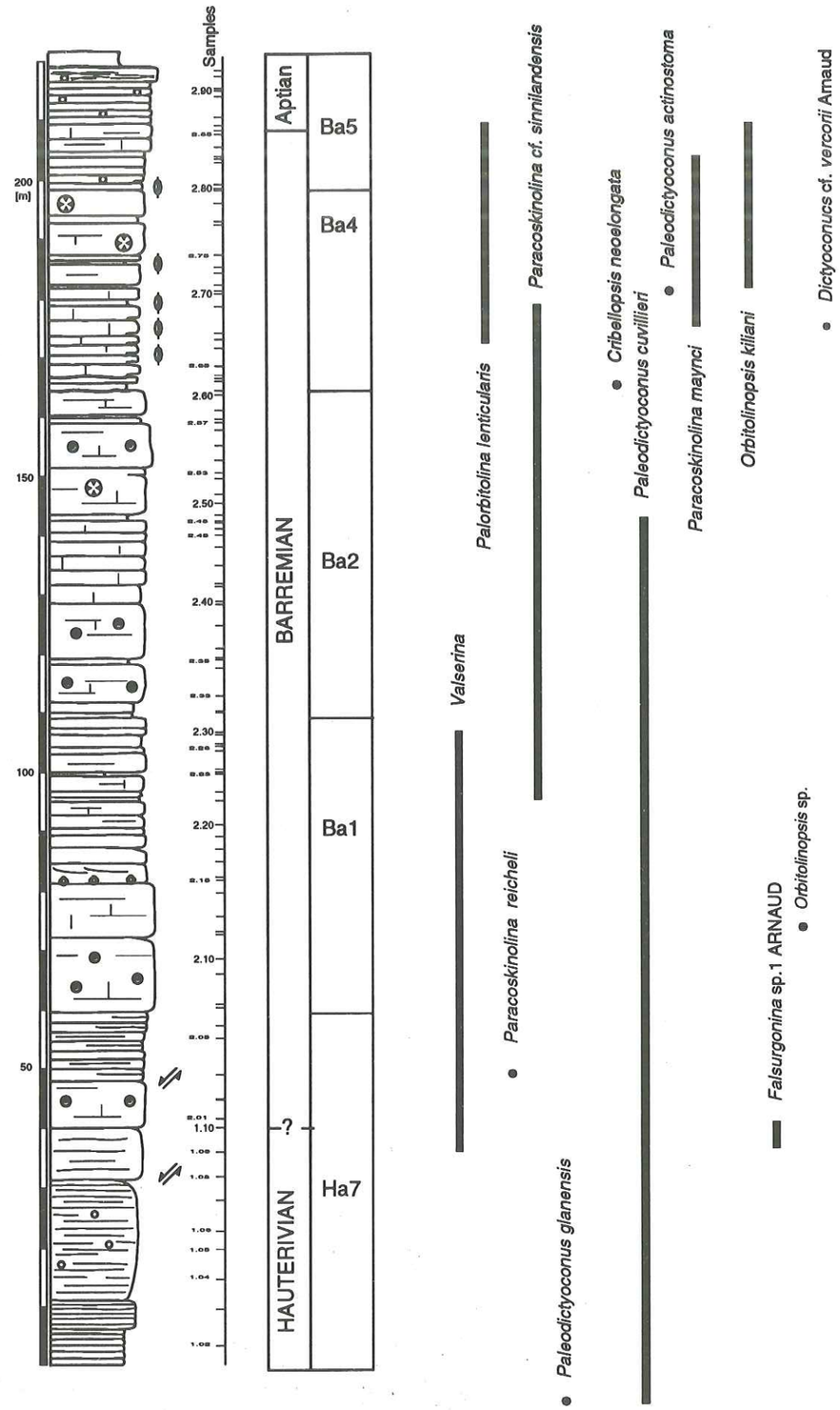


Fig. 4.5. Orbitolinid-distributions in the "Flaine" section (Platé Massif).

4.2 Ammonites

Biozonations based on ammonites are widespread and well accepted. In this study, the ammonite-biozonation established by Busnardo (1984) was used.
Ammonites of Late Hauterivian to Early Barremian age (*Angulicostata* to *Hugii*-zone) were recovered from hemipelagic slope deposits (Fig. 4.3). Ammonites, orbitolinids and echinids were correlated with sequence stratigraphic interpretations.
Recovered ammonites: *Crioceratites* sp. grande taille
Pseudothurmannia gr. *grandis*
Cassidoiceras gr. *cassida.*

4.3 Echinids

Echinids are the third important indicator fossil group which were here used for biostratigraphic investigations.
Toxater retusus and *Toxaster seynensis* are two echinid species which have been found in hemipelagic sediments (Fig. 4.3).
Toxater retusus lived during the Late Valanginian to Late Hauterivian, and *Toxaster seynensis* appeared in the Late Hauterivian.
After Clavel *et al.* 1993 these two species belong to two different phylogenetic lines. The replacement of *Toxaster retusus* by *Toxaster seynensis* occurred in a very short period in the Upper Hauterivian and their coexistence is limited to the Late Hauterivian *Angulicostata* ammonite-zone (Clavel *et al.* 1987 and 1993). For this reason, the coexistence of these two echinid species is a very important time marker. The short interval corresponds to the highstand system tract of the third order depositional sequence Ha6 (Clavel *et al.* 1992).

Chapter 5: SEDIMENTOLOGY AND DESCRIPTION OF THE STUDIED SECTIONS

5.1 "Rocher de Cluses" (Fig. 5.1.a-c, plate 1 and 2)

Previous works
Charollais (1962), Schroeder *et al.* (1968), Guibert (1966).
Location
The section "Rocher de Cluses" lies about 45 km east of Geneva, in the Arve valley at the south-western end of Cluses, Haute-Savoie. The outcrop is well exposed on the road between Cluses and the village Nancy-sur-Cluses.
Coordinates: 928.00/2126.50 (mean value)
Altitude: 480 (mean value)
Thickness: 255 m
Age: Upper Hauterivian to lower Aptian (Bedoulian)

Unit 1 underlies the Urgonian limestones. The unit is composed of marly limestones with abundant echinids *Toxaster retusus.* As a result of weathering the marly limestones are more eroded than the following Urgonian limestones. The unit is built up by 0.8 to 1.2 m thick carbonate bodies, where the lower parts of these bodies seem to be more resistant to weathering than the upper parts. Characteristic for these marly limestones are abundant detrital quartz and glauconite pellets, ooids and bryozoan fragments embedded into a micritc matrix.
Unit 2 (samples 01 to 34) is about 20 m in thickness and built up by four carbonate banks. A thin internal laminated bedding of 15 to 20 cm thickness is visible. The whole succession of unit 2 is well bioturbated (which could be responsible for the wavy laminated bedding). At the base (sample 2) there are several 3 to 6 cm thick black colored silicificated bands. They are stratiform, arranged among the limestone beds. The assemblage of unit 2 consists of a calcarenite, mainly composed of peloids, small benthonic foraminifers, echinoderm fragments and pelecypod shells. Detrital quartz and accessory glauconite are present. Unit 2 is terminated by a 1 m thick dolomite bank (samples 28 to 31). Thin section analysis indicates the same original sediment than the facies below (microfacies type 2) before dolomitization took place.
Unit 3 (samples 35 to 70) is 22 m thick and is subdivided into two parts. The lower part (samples 35 to 56) presents packages of five regular 2.5 m thick carbonate bodies. These bodies are built up by 5 to 15 cm thick low-angle bidirectional cross-bedding sets. These crossbedded sets show frequent alternations in grain-sizes and sediment composition. The sets are interpreted as tidal current deposits.
The upper part of unit 3 (samples 57 to 70) outcrops as a 10 m thick massive limestone ledge. In comparison to the lower part this section is composed of coarser-sized skeletal calcarenites. Numerous stromatoporoid and chaetetid heads, large benthonic foraminifers (*Lituolidae*: *Rheophax giganteus sp.*, *Everticyclammina sp.*, *Lituola cf.* and *Orbitolinids*), intraclasts and skeletal components build up the facies. As sediment structures are low-angle, up to 30 cm thick sand sheets are recognizable. The top of the unit is knifed by a sharp sedimentological contact.
Unit 4 starts with a 0.5 m thick marly to micrite limestone bed (samples 71 to 75). This bed contains mainly micrite intraclasts, small benthonic

foraminifers and peloids. The limestone is partly dolomitized. In the following there are two massive limestone bodies separated by a 0.7 m thick fine-grained echinid calcarenite. The lower limestone body (samples 76 to 87) is built up by several "fining upward" trends. Each one of them is about 0.5 to 0.8 m thick. These "fining upward" trends are composed at their bases by calcirudites rich in stromatoporoids, chaetetids, corals and oyster shells. Towards the top of the sequences grain sizes diminish and the macrofossils are no longer present.
The upper 6 m thick bank of the unit (samples 93 to 101) outcrops as an oolitic limestone with some oyster shells and stromatoporoids. In the uppermost part cross-bedding structures are visible. A well-pronounced discontinuous horizon with a thin 3 to 5 cm thick coal-layer terminates the oolite.
Unit 5 (samples 103 to 125) is a 14 m thick massive oncoid-rudist limestone. The first meter of the unit is composed of partly dolomitized ooid-micrite, overlaying an oyster patch-reef, followed by packages rich in large *Bacinella*-oncoids/lumps (up to 2 cm in size). The upper third of the unit (samples 118 to 125) is built up by rudist patch-reefs. Within this unit rudist shells become larger whereas oncoids and algal lumps become smaller from the base to the top.
Unit 6 (sample 126 to 136) is built up by three limestone beds which show a "thickening upward" trend. The first and the second beds are composed of very fine-grained calcarenites (smaller than 0.15 mm). The third bed consists of a coarse-grained (up to 3 mm) skeletal limestone which passes into an ooid-grainstone. Important indicator fossils within this unit are the orbitolinids *Valserina primitiva* and *Valserina broennimanni*. They appear together only in this unit.
Unit 7 (samples 137 to 149). This 10 m thick unit is readily identified in the field by its dark gray color and fine-grained composition. The whole unit shows an intensive bioturbation. Thin section and geochemical analysis indicate a high amount of detrital quartz (up to 20%) and carbonate insoluble residues.
Unit 8 (samples 150 to 159) is about 6 m in thickness and characterized by frequent alterations of fine-grained limestone layers (< 0.5 mm) and coarser-grained layers (1-3 mm). The limits between these layers are always sharp. The thickness of the fine-grained layers varies from 20 and 120 cm and the coarser-grained layers between 5 and 40 cm. The ratio between the fine grained and the following coarse-grained layers is always approximately 4:1.
Unit 9 (samples 160 to 178) is built up by two massive limestone bodies and is approximately 16 m thick. The unit is characterized by the presence of a high quantity of reef-building organisms (stromatoporoids, chaetetids and corals). The lower 8 m thick carbonate bank (samples 160 to 169) is built up by 30 cm thick "fining upward" cycles. From the base to the top of a cycle the particles become smaller (from 1-3 mm to less than 0.5 mm). These cycles are frequently intercalated by 0.5 to 0.8 m thick rudstone-layers rich in the reef-building organisms (stromatoporoids and chaetetids).
The upper part of the unit (commencing with sample 172) is a 5 m thick coral-stromatoporoid patch-reef with globular to hemispheric massive corals. The remaining uppermost part of the unit consists of reef debris from the underlying patch-reef.
Unit 10 (samples 179 to 183) is 6 m thick and built up by three massive very fine-grained (about 0.1 mm) calcarenite beds. Thin section analysis shows a wackestone-texture with a composition of pellets, very fine echinoderm-fragments and rare thin ostracod shells.
The section from the base of this **unit 11** to the top of the **unit 15** (sample 270) represents the so-called: "rudist limestones", "Urgonian limestones s.s", "Lower member of the Urgonian limestones" (see also chapter 3 LITHOSTRATIGRAPHY). In the outcrop "Rocher de Cluses" the "rudist

limestones" are built up by alternations of rudist patch-reefs and beds composed of oncoids/algal lumps, small benthonic foraminifers, dasycladacean algae and debris of rudist shells.
Unit 11 (samples 184 to 205) is about 13 m in thickness and outcrops as a package of five massive carbonate bodies. The basinal body shows packages of layers which differ by their compositions and grain-sizes. These layers are composed of 1 - 3 mm sized bioclast-grainstones or by fine-grained (smaller than 0.5 mm) calcarenites consisting of peloids and echinoderm fragments.
The following packages (samples 185 to 193/=202) are built up by rudist patch-reefs whereas the uppermost bed (sample 194 corresponds to samples 203 to 205) shows minor rudists but more algal lumps/oncoids, small benthonic foraminifers, gastropods, ostracods and reworked sediments. Thin section analysis indicates fenestral structures of the upper five meters and a dolomitization of the uppermost part.
Unit 12 (samples 206 to 217) is approximately 12 m thick and built up by three regular thick carbonate packages. Each one of these beds consists of a different composition. The basinal bank is built up by a dense colonized rudist patch-reef, the second one shows loosely packed rudist shells embedded in an oncoid/lump rich facies and the third bank is composed of a limestone of mm-sized components containing dasycladacean algae, small benthonic foraminifers, abundant Orbitolinid-foraminifers, echinoderm fragments and peloids and debris of rudist shells. The three limestone banks of unit 12 show the development of a "fining-upward" sequence.
Unit 13 (samples 218 to 223) is about 6 m thick and shows at its base rudist shells and stromatoporoids. In the upper part the facies changes into a rudist patch-reef facies. In the lower part of the unit fine parallel lamination is recognizable.
Unit 14 (samples 224 to 243; 12 m thick) is built up by nine irregular thick carbonate bed sets. A subordinate thinner bedding (0.3 to 1 m bed thickness) is developed. The lower part of this unit (samples 224 to 233) is composed of a fine-grained carbonate with a wackestone texture, whereas the upper part exhibits a rudist patch-reefs facies.
One, probable two discontinuous surfaces are outcropped by samples 234 and 238. This unconformity surface is overlain by a 0.4 m thick micrite limestone bank. Thin section analysis indicates brackish to lacustrine sediments containing the gastropods *Planorbis*, thin ostracods and some Miliolids. Fenestral structures suggest subaerial exposure of the depositional environment.
Unit 15 (samples 244 to 270). This section of the outcrop has been intensively tectonically influenced and implies a wrong stratification.
The unit is approximately 30 m in thickness and exposes the typical "rudist limestones". The succession is characterized by the alternation of rudist biostromes and beds containing oncoids/algal lumps, dasycladacean algae and partly benthonic foraminifers. Unit 15 is truncated at its top by a pronounced discontinuous surface that terminates abruptly with the "rudist limestones".
Unit 16 (samples 271 to 285) is approximately 10 m thick and overlies the well pronounced discontinuous surface. The unit is characterized by a succession of discontinuous bed sets. For example, bed thicknesses within the same limestone beds diminish from 1.5 m to 0.8 m over a lateral distance of 10 meters. This kind of discontinuous bedding is visible within each one of eight recognizable beds. The lower part of the unit (samples 271 to 277) consists of very fine-grained, partly micrite dominated limestones. Microfossils like the gastropods *Planorbis* indicate a brackish to lacustrine paleomilieu. Other fossils include miliolids and ostracods. Abundant successive erosive surfaces and fenestral structures suggest temporal subaerial exposures of the paleoenvironment. The limestones in the

uppermost part (samples 278 to 284) contain coarse-grained material. Rudist shells, oncoids/algal lumps, dasycladacean algae and small benthonic foraminifers are the predominant components.

Unit 17 (samples 285 to 322) is described in the literature as the: "Lower Orbitolina limestones". In the outcrop they represent a 20 m thick succession of five sequences. Each sequence is characterized by stacking patterns of massive carbonate beds which are terminated by the 0.20 to 0.50 m thick marly limestone layers (see also in chapter 9 DEPOSITIONAL ENVIRONMENTS: transgressive facies). The 0.3 to 0.5 m thick *Orbitolina marly limestones* are less resistant to weathering and therefore form erosion grooves. These marly layers are composed of large benthonic foraminifers, dasycladacean algae, detrital quartz, clay minerals, somewhat glauconite and organic material (coal pieces). These marly limestones are intensively bioturbated.

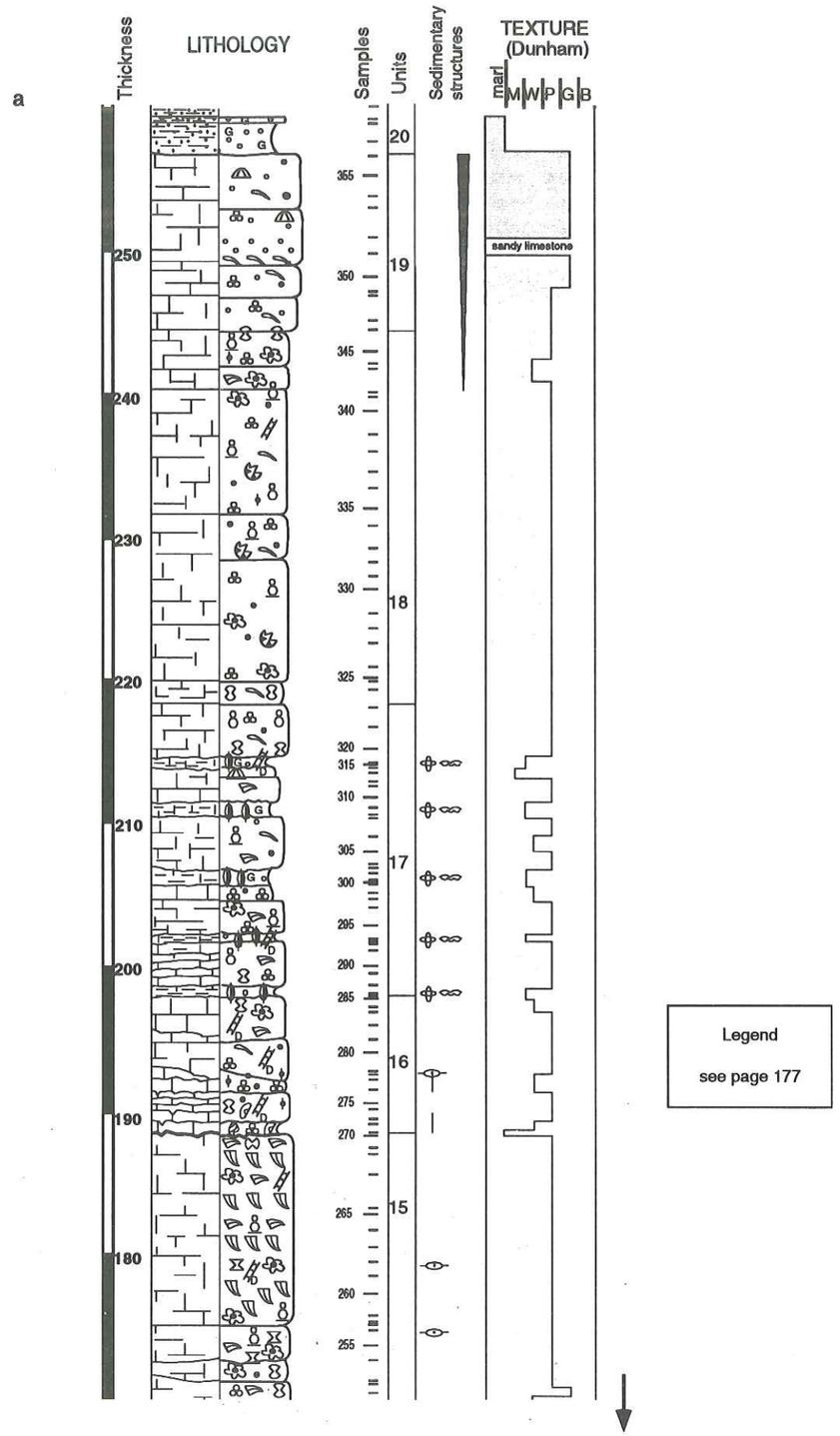
The massive limestone beds are composed of a rudist patch-reef and oncoid facies.

Unit 18 (samples 323 to 345) is about 30 m thick and built by four massive carbonate ledges. The basinal part is composed of a bioclastic to intraclastic grainstone whereas the composition of the following packages is homogenous composed of peloids, small benthonic foraminifers, small-sized aggregate grains and oncoids. Macrofossils like rudists, oysters and corals occur in beds (up to 1 m thick), which are well separated from the fine-grained peloidal grainstones.

Unit 19 (samples 346 to 356) is built up by four carbonate beds which represent the uppermost 15 m of the outcrop. The four beds show a thickening-upward trend. The unit is characterized by the high quantity of detrital quartz (up to 50%, between samples 351 and 352). The carbonate component consists of a fine-grained (less than 1 mm) calcarenite. The dominant particles are peloids, small benthonic foraminifers, echinoderm fragments and thin pelecypod shells.

Unit 20 presents the "Helvetic Greensandstones" (Delamette 1994). This glauconite-rich sandy and marly limestone overlies the Urgonian limestones, separated from them by a sharp, distinct contact.

Fig. 5.1. a-c. Synthetic log of the "Rocher de Cluses" section



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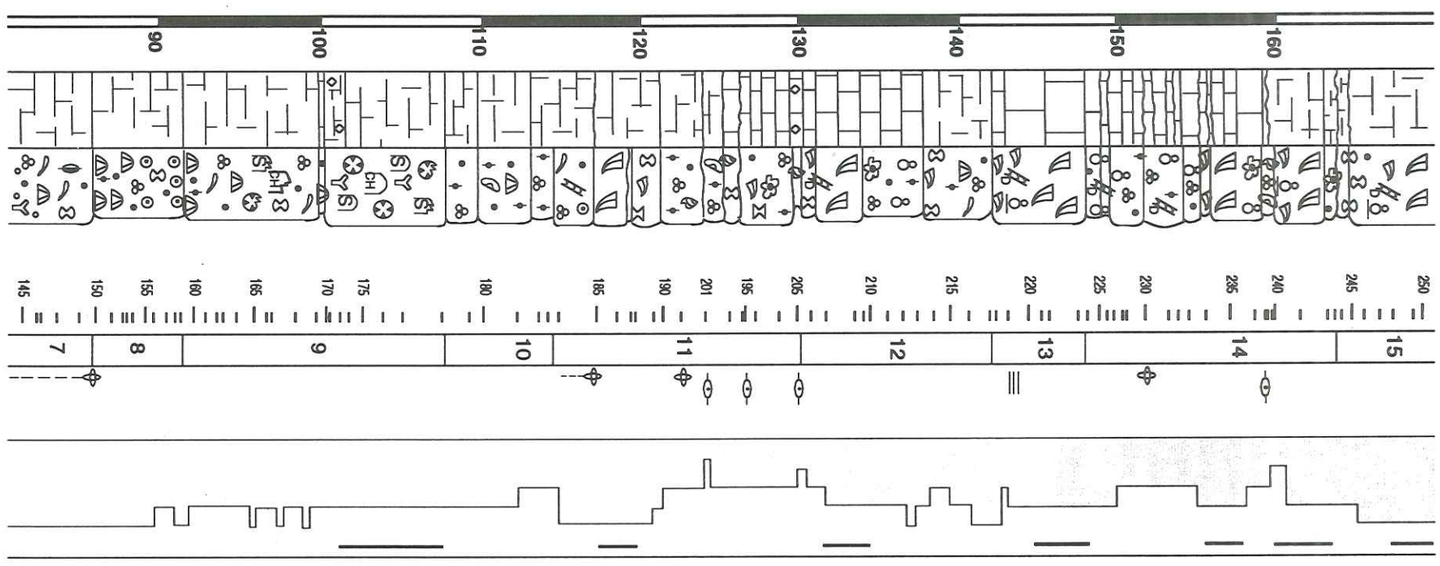
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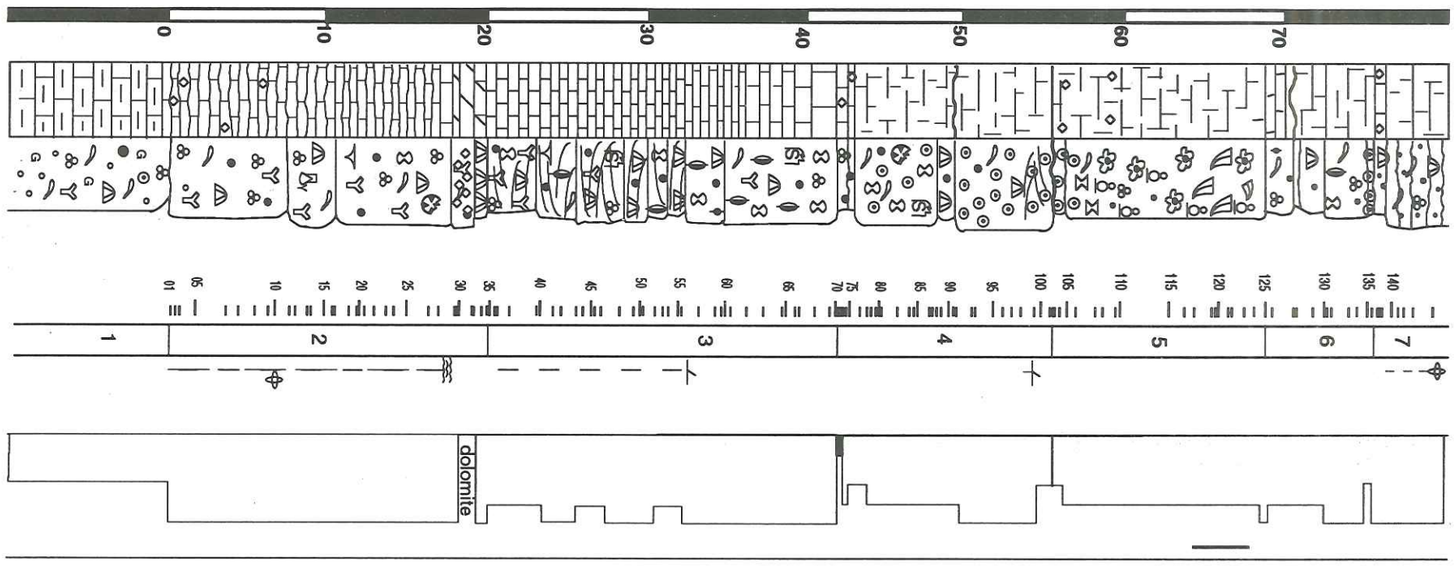
c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10
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40
50
60
70
1
2
3
4
5
6
7
dolomite

5.2 Aravis Chains

Section-no.	Location	Coordinates
01 - 07	Adroit des Aravis	920.50/2105.62
08 - 12	Combe de Bella Cha	922.62/2108.75
13 - 15	Combe du Grand Crêt	923.23/2109.10
16	Combe de Pacally	923.65/2110.30
17	Combe de Tardevant	924.27/2110.45
18	Combe de la Forclaz	924.60/2112.00
19	Combe de la Balme	922.28/2107.40
20	Combe des Verts	927.10/2113.40
21	Combe du Mont Charvet	925.29/2111.75
23 - 24	Combe de Bella Cha	922.62/2108.75
GF	Combe de la Grande Forclaz	924.60/2112.00
To	Combe de Torchère	921.70/2107.00

In the Aravis Chains, 25 sections were sampled. Two representative sections ("Bella Cha" and "Grande Forclaz") are described in detail. The **"Bella Cha"** section is representative for outcrops where two mass flow deposits are developed. These are Balme, Bella Cha, Grand Crêt (from SW to NE) (Fig. 5.2). The **"Grande Forclaz"** section represents the sections where only one horizon of mass flow deposits are outcropped. These are Pacally, Tardevant, Grande Forclaz, Mont Charvet (from SW to NE) (Fig 5.2).

Previous works:
Charollais *et al.* (1967), Froidevaux (1976), Muller (1985), Détraz *et al.* (1986).

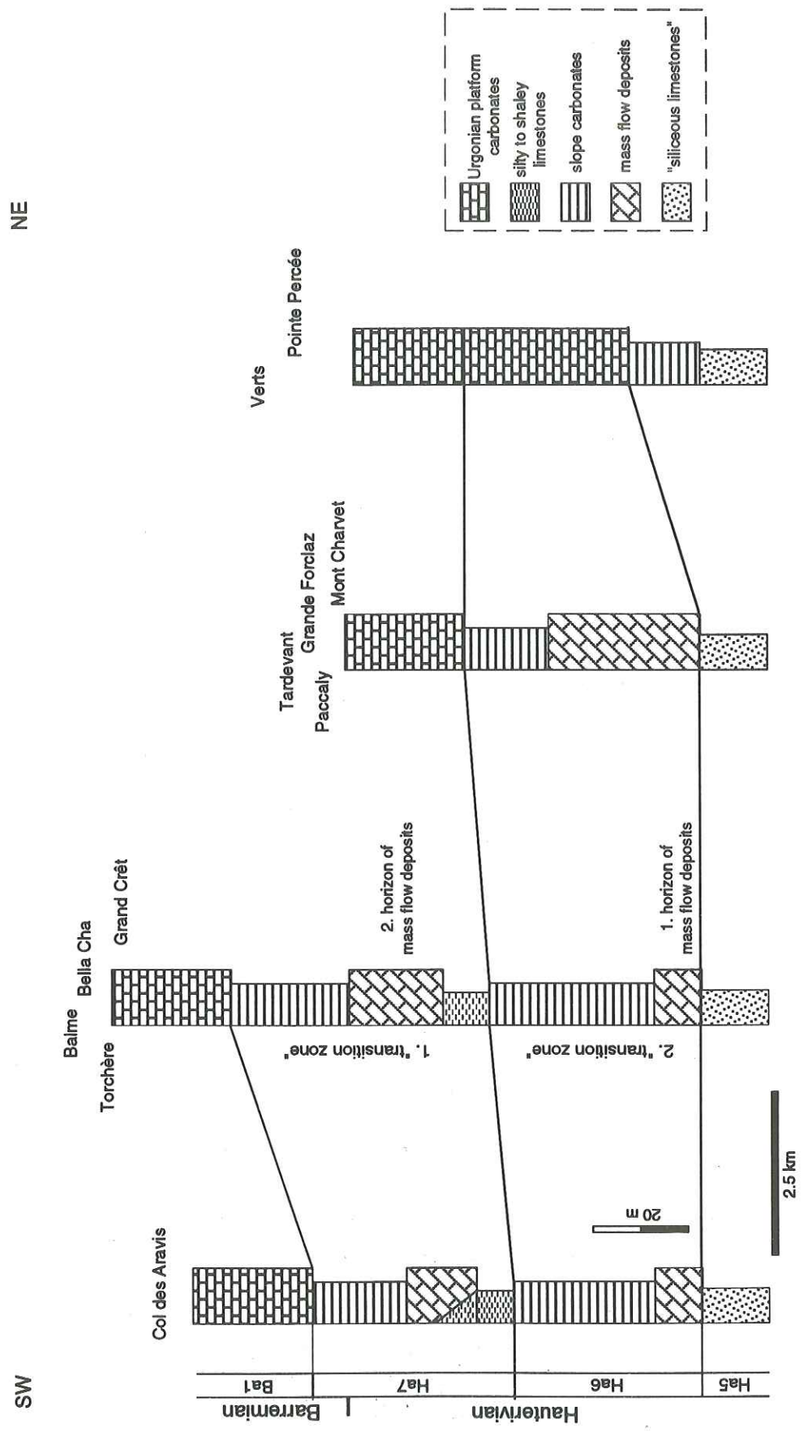


Fig. 5.2. Schematic profile of the Aravis chains.

5.2.1 "Bella Cha" (Fig. 5.3.a-b, plate 3)

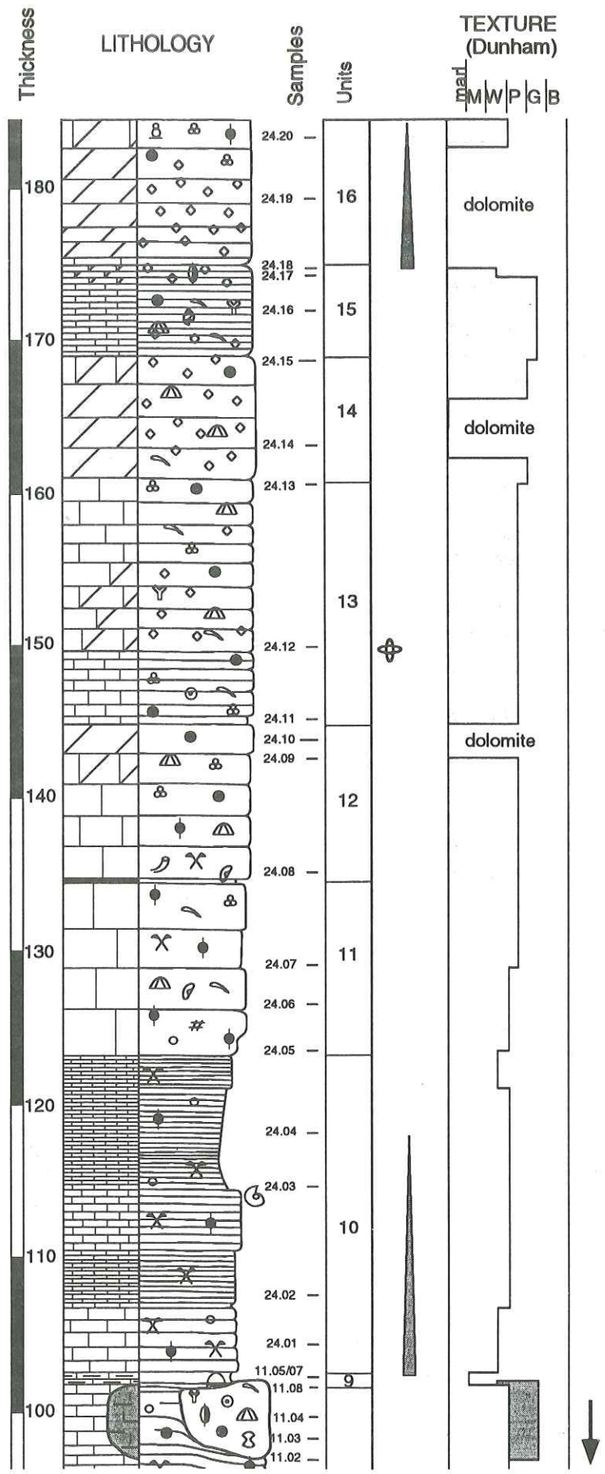
Location: The sections 8-12, 23 and 24 were sampled on the southwest flank of the "Combe de "Bella Cha"". The valley trends southeast to northwest and inclines toward the northwest (southeastern flank of the Thônes-syncline).
Coordinates: 922.62/2108.75 (mean value)
Altitude: 2400 m (mean value)
Thickness: 185 m
Age: Upper Hauterivian to lower Barremian

Unit 1 represents the uppermost, glauconite rich part (microfacies type 18) of the siliceous limestones. The limestones show a 0.30 to 0.80 m thick regular bedding
Unit 2 comprises the first horizon of mass flow deposits. In the "Bella Cha" section this unit is approximately 10 to 12 m thick.
Unit 2a (samples 8.01 to 8.08) contains samples of the circalittoral outer platform to slope deposits. Stratal patterns are characterized by medium-scaled slump and slide blocks with intercalated beds of the autochthonous background sediments. Microfacies analysis indicates a similar composition of these non-lithified background sediments and most slide and slump blocks.
Unit 2b (samples 8.A to 8.H) is characterized by a platform derived megablock, built up by a medium to coarse-grained grainstone (microfacies type 2 and 3). Megablocks with a platform origin are distinguished by their brighter rock color from the circalittoral limestones juxtaposed to them.
Unit 3 (samples 8.10 to 8.12, 23.01) is about 12 m in thickness and built up by a very regular cm to dm bedding. The stratal patterns indicate a slightly thinning-upward trend. The limestones consist of a dark-colored fine-grained sediment. Sediment composition and outcrop appearance are similar to the thick series of the underlying siliceous limestones.
Unit 4 (sample 23.02) is characterized by a 2.5 to 3 m thick recessive bedding. The stratal patterns exhibit dark, nearly black colored shaley limestones. The unit is rich in echinids (*Toxaster retusus*) and brachiopods.
Unit 5 (samples 23.03 to 23.07). The roughly 8 m thick unit is built up by 2 thick carbonate ledges, separated by a 1 m thick shaley limestone layer. Each ledge shows a regular bedding (0.5 m). Ooids and dasycladacean algae can be recognized among a fine grained dark-colored matrix.
Unit 6 (samples 8.13 and 8.14, 23.08 to 23.12). This 18 m thick unit is built up by 1.5 m to 0.4 m thick stacking beds with a thinning-upward tendency. Stratal packages show an alteration of pure limestone beds and somewhat more micrite to marly layers. In general, the marly to micrite layers occur in somewhat thinner patterns. Ooids are recognizable, but microfacies analysis indicates the dominance of circalittoral fine-grained material with abundant sponge spicules.
Unit 7 (sample 23.13, 10.06) is approximately 12 to 15 m thick and exhibit a thinning-upward trend. The basal part of the unit has a sandy limestone composition. Towards the top, it adopts an increasingly black colored, shaley character. Within this unit well preserved ammonites are found (*Crioceratites* sp. grande taille and *Pseudothurmannia* gr. *grandis*). In the top-part of the unit a submarine hardground is developed. The hardground is characterized by cm-sized sponge and coral fragments, *Bacinella* lumps, phosphorite nodules and pyrite.
Unit 8 (samples 9.01 to 9.03, 10.01 to 10.05, 11.01 to 11.08, 12.01 to 12.06) represents the second horizon of mass flow deposits. Composition is similar to the first horizon, but the thickness of this unit 8 is greater (up to 25 m). Huge slide and slump blocks >50 m in length are observed.
(Remark: The mass flow deposits are discussed in detail in chapter 10 SUBMARIBE MASS FLOW DEPOSITS).

Unit 9 (samples 11.05 and 11.07). This 2 to 3 m thick stratigraphic unit is composed of by black colored shaley limestones. Large, several cm-thick reworked sponge organisms abundant brachiopods and pelecypods and intensive bioturbation characterize this unit. In the "Tardevant" and "Pacally" sections conglomerates are present.
Unit 10 (samples 24.01 to 24.04) is the final marly to shaley limestone facies below the massive Urgonian platform carbonates. It is approximately 20 m thick. The unit shows a medium to thin bedding (0.3 to 0.2 m) with a thinning-upward tendency in the middle part and a slightly thickening-upward trend in the upper part. Thinnest beds exhibit a shaley constitution. Within these shaley packages the ammonite *Cassidoiceras* gr. *cassida* was found. Microfacies analysis indicates a very homogenous fine-grained pelletal packstone facies (facies type 22).
Unit 11 (samples 24.05 to 24.07) is composed of by four massive carbonate beds. The sediment consists of a fine to medium-sized peloid-bioclastic packstone rich in platform derived material. The unit terminates by a thin (0.5 m) micrite to marly horizon.
Unit 12 (samples 24.08 to 24.10) (10 m thick). The unit contains five, regular thick, massive packages. Microfacies analysis indicates medium-sized peloid-bioclastic pack- to grainstone facies (microfacies type 1A). These facies are typical for the initiation of platform sedimentation. The upper two carbonate ledges are entirely dolomitized.
Unit 13 (samples 24.11 to 24.13) is approximately 14 m thick and can be divided into two parts. The lower part (3 m) is characterized by numerous stylolites and a wavy bedding, which is interpreted as bioturbation marks. The upper part is composed of a series of regular thick, mostly dolomitized patterns. The unit is composed of fine to medium-sized particles (microfacies type 1A and 1B).
Unit 14 (sample 24.15) is about 8 m thick and consists of four regular thick, massive carbonate ledges. The whole unit is entirely dolomitized. Remaining carbonate grains indicate a medium-sized bioclastic limestone composition of the microfacies types 2 and 3.
Unit 15 (samples 24.16 and 24.17). The 5 m thick unit is characterized by a thin (0.2 to 0.3 m) bedding. Microfacies analysis indicates a bioclastic grainstone composition at the base. The top of this unit, however, consists of a wackestone texture, which is typical of the lagoonal environment.
Unit 16 (samples 24.18 to 24.20). This uppermost 10 m thick unit, which contains a thickening-upward trend is mainly dolomitized. Remaining carbonate particles show a wackestone texture indicating a low energy lagoonal environment.

Fig. 5.3.a-b Synthetic log of the **Bella Cha** section.

a



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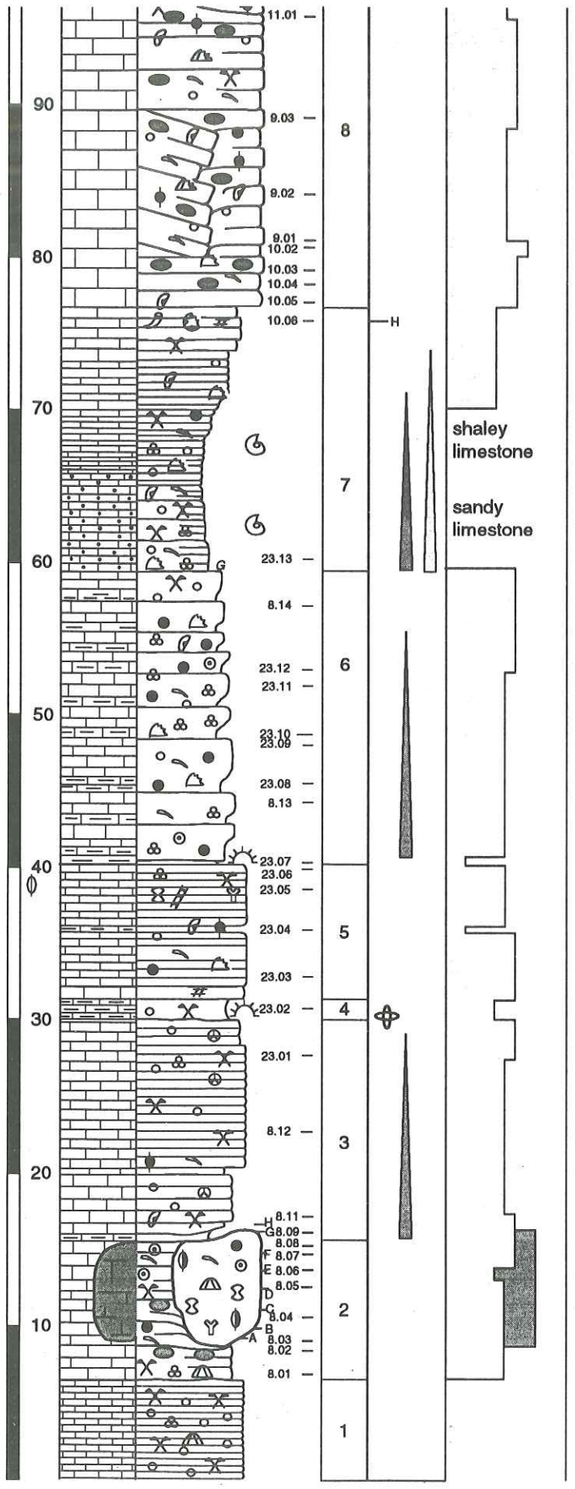


5.2.2 "Grande Forclaz" (Fig. 5.4.a-b, plate 4 and 5)

Location:
The outcrop is located in the "Combe de la Grande Forclaz". The valley trends southeast to northwest and inclines toward the northwest (southeastern flank of the "Thônes-syncline").
A reverse fault, which trends SW-NE in the Aravis mountains truncates the section within the "couches de transition". This fault has displaced the stratigraphic record by approximately 100 meters (Villard 1986) (plate 4).
Coordinates: 924.60/2112.00 (mean value)
Altitude: 1900 m (mean value)
Thickness: 185 m
Age: Upper Hauterivian to lower Aptian (Bedoulian)

Unit 1 (samples 18.01 to 18.03) represents the upper-most part of the "siliceous limestones". The sediment composition is mainly characterized by glauconite pellets and platform derived material (summarized in microfacies type 18).
Unit 2 (samples 18.04 to 18.09 and 18a.01 to 18a.07). This unit comprises the first mass flow deposits horizon. The stratal packages are tectonically truncated and expose a chaotic arrangement (plate 4). The thickness of unit 2 is approximately 30 m.
Unit 3 (sample 18.10). This unit is similar in composition to unit 9 in the "Bella Cha" section. The 2 to 4 m thick unit exposes black colored marly to shaley limestones, which are rich in reworked clasts at their base.
Unit 4 (samples 18.11, 18a.10). This unit represents the uppermost part of the "couches de transition". The unit is built up by regular, medium thick (0.5 m) bed sets. Limestone composition indicates a fine-grained circalittoral sedimentation.

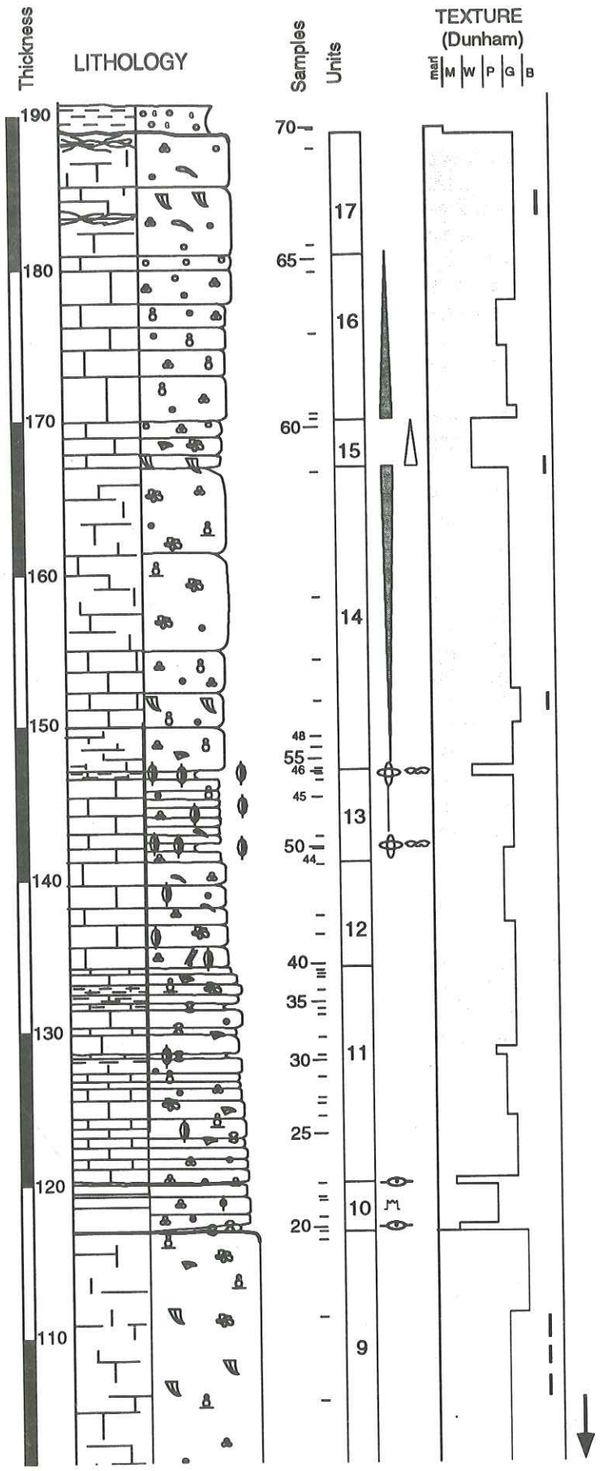
The following younger units are separated from the underlying record by a SW-NE trending reverse fault. Older strata on the southern side of the fault plane represents the upthrow block. Subsequent younger strata northwards of the fault plane exposes the downthrow block.

Unit 5 (sample 01) is approximately 2 m thick and exhibits the first undisturbed limestone bed on the northwest side of the fault plane. The bed is composed of fine-grained pellets and echinoderm fragments.
Unit 6 (sample 02). The unit is about 2 m thick and characterized by an erosion groove. The dark-colored micrite to marly limestones are mostly dolomitized. The thin bed sets show a wavy bedding.
Unit 7 (samples 03 to 09) is about 17 m thick and composed of two massive carbonate ledges. The lower ledge shows a wavy bedding, which is typical for bioturbation. The sediment consists of a fine-grained muddy composition. The upper ledge also consists of a small-sized sediment, but the particles have a grain-supported texture. In the top of the first ledge rudist patch-reef occurs.
Unit 8 (samples 10 to 12). The 12 m thick succession is characterized by abundant rudist-patch reefs. Their thickness ranges between some cm to several dm. Oncoids are frequent.
Unit 9 (samples 13 to 18). This approximately 50 m thick section represents the "rudist limestones" in the Aravis mountains. The whole unit is built up by the alternation of rudist biostromes and oncoid beds. It can be seen that rudist assemblages are more concentrated in the lower part of this unit. In the middle part the oncoid facies dominates and rudists rarely occur. In the top-part the rudist patch-reefs appear again. The thick unit is composed of a massive carbonate wall without any internal bedding.

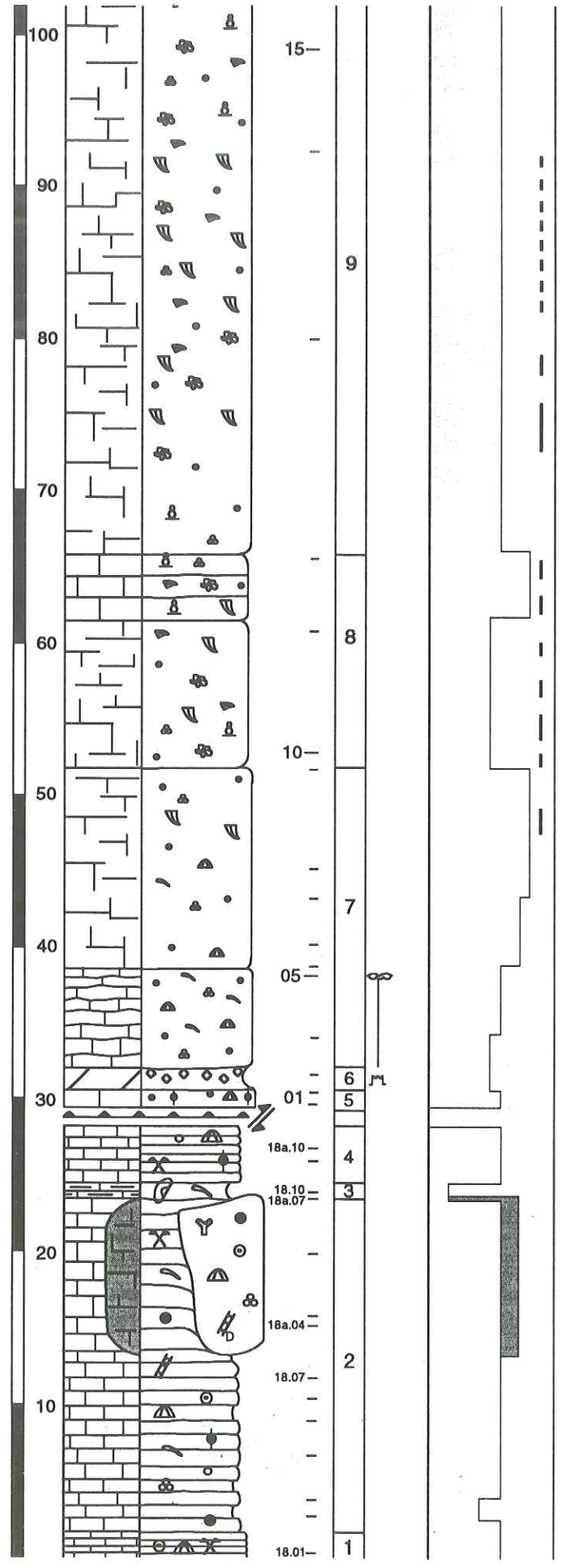
The unit terminates with an unconformity surface, which forms a characteristic mark in the outcrop.
Unit 10 (samples 19 to 24). The stratal patterns of this 3 m thick unit are bounded at the base and at the top by discontinuous surfaces. These surfaces are accompanied by thin, several cm thick, marly layers. The base of the unit contains abundant reworked clasts and fossil debris. The overlying packages consist of micrite limestones with pellets and small fossils (small benthonic foraminifers).
Unit 11 (samples 25 to 39) is approximately 14 m thick and built up by massive carbonate beds which alternate with marly limestone beds. The marly beds are less resistant to weathering and form groove marks. The marly limestone beds are rich in large orbitolinid-foraminifers. The massive carbonate beds contain an oncoid and algal lump facies.
Unit 12 (samples 40 to 44) is approximately 8 m thick and consists of five regular thick massive carbonate beds. Orbitolinids, oncoids and dasycladacean algae are present.
Unit 13 (samples 45 to 46, 50 to 54). This 6 meter thick marly unit is characterized by two intercalated "Orbitolina marly limestone layers". The two *groove marks* exhibit the typically developed "Orbitolina marly limestones", extremely rich in *Palorbitolina lenticularis*. Each one of these marly horizons is about 0.5 to 1 m thick.
Unit 14 (samples 47 to 48, 55 to 59). The unit is distinguished in the field by its bright rock color, which contrasts to the somewhat "dirty" brownish rock color of the underlying units 10 to 12.
The stratal packages of this 20 m thick unit shows a thickening-upward trend of massive carbonate beds. Some rudist patch-reefs determine the facies in the lower two ledges. The majority of this unit, however, is characterized by a medium-sized oncoid and algal lump facies.
Unit 15 (sample 60) The unit is approximately 3 m thick and shows three, regular thick stacked packages. This unit terminates the brightly colored carbonate rocks in the outcrop. The following stratal patterns, which built up the top-part of the Urgonian limestones form a drastically regressed yellowish, brownish wall.
The composition of unit 14 implies a protected, lagoonal environment. This roughly 3 m thick unit shows a fining-upward trend. The lower bed consists of rudist patch-reefs, the middle bed is composed by oncoids, large *Bacinella* nodules and rudist debris. The upper-bed exhibits a small-sized sediment composed of peloids, pellets and small benthonic foraminifers with abundant detrital quartz.
Unit 16 (samples 61 to 65). As already mentioned above, this unit and the following represent the upper part of the outcrop. The stratal record of these two units clearly distinguish them from the underlying carbonates.
This unit is approximately 10 m thick and exposes a thinning-upward trend. Carbonate particles consist of small aggregate grains, small benthonic foraminifers and peloids. Detrital quartz is present in the lower part, but increases to become the main component in the upper part of the unit.

Fig. 5.4. a-b Synthetic log of the "Grande Forclaz" section.

a



b



5.3 "Flaine" (Fig. 5.5.a-b, plate 7)

Previous works
Ayrton (1972), Breton (1972), Collet (1943), Pairis (1975)
Location
The section is situated approximately 3 km southwards of the ski station "Flaine"(France). The section occurs in a valley which trends W-E between the peaks "Col de Monithieu" in the north and "Tête des Lindars" and "Tête de Monthieu" in the south.
The section is part of a very slightly southward dipping flank of an anticline. A small-scaled thrust made it necessary to sample three different sections (Fl A-D; Fl 1.01-1.10); Fl 2.01-2.93), however, the sections are locally separated over small distances of only 50 to 150 meters.
Sections Fl. 1.A-D and Fl. 1._ :
Coordinates: 937,46/2118,75; altitude 2100 m (mean value)
Section Fl. 2._:
Coordinates: 938.56/2117.75; altitude: 2250 (mean value)
Thickness: 230 m
Age: Upper Hauterivian to Lower Aptian (Bedoulian)

Unit 1 (samples 1.A to 1.D, 1.01) represents the uppermost section of the "transition zone" (Conrad 1968, Pairis 1975). This "transition zone" forms 1 to 1.5 m thick massive carbonate banks in alternation with 0.2 to 0.5 m thick schisty stratified marly limestone layers. The limestones consist of fine-grained calcarenites which are composed of small peloids, small benthonic foraminifers, echinoderm, pelecypod and bryozoan fragments and ooids, with abundant detrital quartz and some glauconite.
Unit 2 (samples 1.02 to 1.05) forms the basinal section of the Urgonian limestones. The approximately 20 m thick unit is built up by a regular 0.20 to 0.40 m thick bedding. The limestone composition shows homogenous calcarenites with peloids, echinoderm, pelecypod and bryozoan fragments and detrital quartz (5%).
Unit 3 (samples 1.06 to 1.10) is 18 m thick and differs from the underlying unit by its brighter rock color. The calcarenites are of similar composition to unit 2, however, the particles are coarse-grained with ooids. There is no more quartz present. The unit is well bedded with bed sets up to 0.1 to 0.3 m thick.
Unit 4 (samples 2.01 to 2.03). With this unit begins the second section. The unit is composed of a 8 m thick massive ooid body with a grainstone texture.
Unit 5 (samples 2.04 to 2.07) is approximately 12 thick and built up by seven 1.2 m to 1.6 m thick light gray colored carbonate banks. The limestone composition varies between beds containing bioclastic calcarenites and beds that are dominated by intraclastic grainstones.
Unit 6 (samples 2.08 to 2.11) occurs as a 12 m thick massive ooid-arenite. The basinal part of the unit consists mainly of peloids with an upward increase of ooids (coarsing-upward trend).
Unit 7 (samples 2.12 to 2.15) is 9 m thick and separated from the underlying unit by a distinct contact. The unit is characterized by parallel bedding with 10 to 25 cm thick layers. These layers differ in composition and grain-size. The composition changes from fine-grained, peloid-bioclastic calcarenites to coarse-grained calcirudites with large oyster, rudist, coral, and stromatoporoid fragments.
Unit 8 (samples 2.16 to 2.23). The unit is roughly 18 m in thickness composed of three massive carbonate beds. The first bed, of which the base is dolomitized, consists of ruditic coral, stromatoporoid and rudist fossils, the middle part is composed of bioclastic peloidal calcarenites, and the third bed again exhibits a coarse-grained limestone rich in stromatoporoid, coral and rudist fossils. The unit shows a fining-upward trend from the base to the top

of the second bank (samples 2.16 to 2.21). The whole unit contains bed sets with bed thicknesses of 0.2 to 0.5 m. At the base, low-angle (12 to 16 degrees) planar crossbedding is visible. These cross-stratified layers are composed of calcirudites rich of reef organisms.
Unit 9 (samples 2.24 to 2.31) is about 10 m thick and begins with a 40 cm thick marly limestone layer. This marly horizon forms in the outcrop an erosion groove. The layer is rich in Orbitolinids and other large benthonic foraminifers.
The subsequent stratal patterns expose four massive limestone beds containing stromatoporoids and coral fossils. Unit 9 is terminated by a 0.7 m thick micrite limestone layer with intensive bioturbation.
Unit 10 (samples 2.32 to 2.39) is separated from the underlying unit by a sharp contact. The basinal package consists of a 2 m thick calcarenite with rudist, coral and stromatoporoid debris. The following part of the unit represents an approximately 14 m thick ooid bank. The whole oolite exposes stacking bed sets with thicknesses of 0.5 to 0.9 m in the lower part and 0.2 m thick packages in the upper part (thinning-upward). The ooid-arenite is dark-colored and differs from surrounding carbonate rocks.
Unit 11 (samples 2.40 to 2.47) is 14 m thick and built up by six massive carbonate beds. This unit is characterized by abundant corals, stromatoporoids, chaetetids and rudists. With exception of the basal part, which is intercalated by numerous stylolites, the rest of the unit is of a recognizable bright gray color. The stratal record shows a thinning upward trend, the components, however, indicate a coarsing-upward trend.
Unit 12 (samples 2.48 to 2.60) is approximately 23 m thick and separated from the underlying carbonates by a well-pronounced surface. This unit commences with a basinal 0.8 m thick micrite to marly limestone bed with abundant orbitolinid-foraminifers. The upper part is indicated by a thickening-up trend. The first bed is composed of small sizes (only some mm to cm) corals and stromatoporoids. In the top-part these fossils are of large sizes (up to 30 cm in diameter). The second bank consists of a bioclastic to ooid limestone with minor reef organisms. The third bed is built up by a rudist patch-reef accompanied with aggregate grains and some coral debris. The upper part of the unit is composed of a calcarenite with intensive bioturbation. In the uppermost part of this package original fossil shells are replaced by coarse calcite cements. Thin section analysis indicates dissolution cavities of mineralogical unstable components and their replacement by stable calcite cements. The surface that terminates this unit is intensive bioturbated.
Unit 13 (samples 2.63 to 2.74) is roughly 20 thick and corresponds to the "Lower Orbitolina beds" (Arnaud-Vanneau *et al.* 1990) This unit is composed of a package of nine carbonate beds with thicknesses between 1.5 to 2.5 m. In general the stratal patterns show a thickening-up. This unit exhibits a repetitive build-up. The massive carbonate ledges are regularly truncated by 0.3 to 0.7 m thick marly limestone beds, which are less resistant to weathering and form erosion grooves. From the base to the top the marly limestone layers show a change in their composition. They are composed of oncoids/algal lumps, *Bacinella*-aggregates, reworked sediments and orbitolinid-foraminifers in the lower part. In the upper part (above 2.70), these marly limestone beds are extremely rich in orbitolinid-foraminifers. The massive carbonate packages contain abundant coral and stromatoporoid fossils. The corals are represented by dendroid finger and massive branching forms. Unit 13 is the richest part of the section, containing corals and stromatoporoids.
Unit 14 (samples 2.75 to 2.78) is 12 m in thickness and distinguished from unit 13 by the development of thick massive carbonate ledges and a bright-gray rock color. Unit 14 is characterized by three coral biostromes. The

corals exhibit hemispherical growth forms, up to 0.5 m in diameter. These three biostromes are 0.3 to 0.6 m thick and of large lateral extensions.

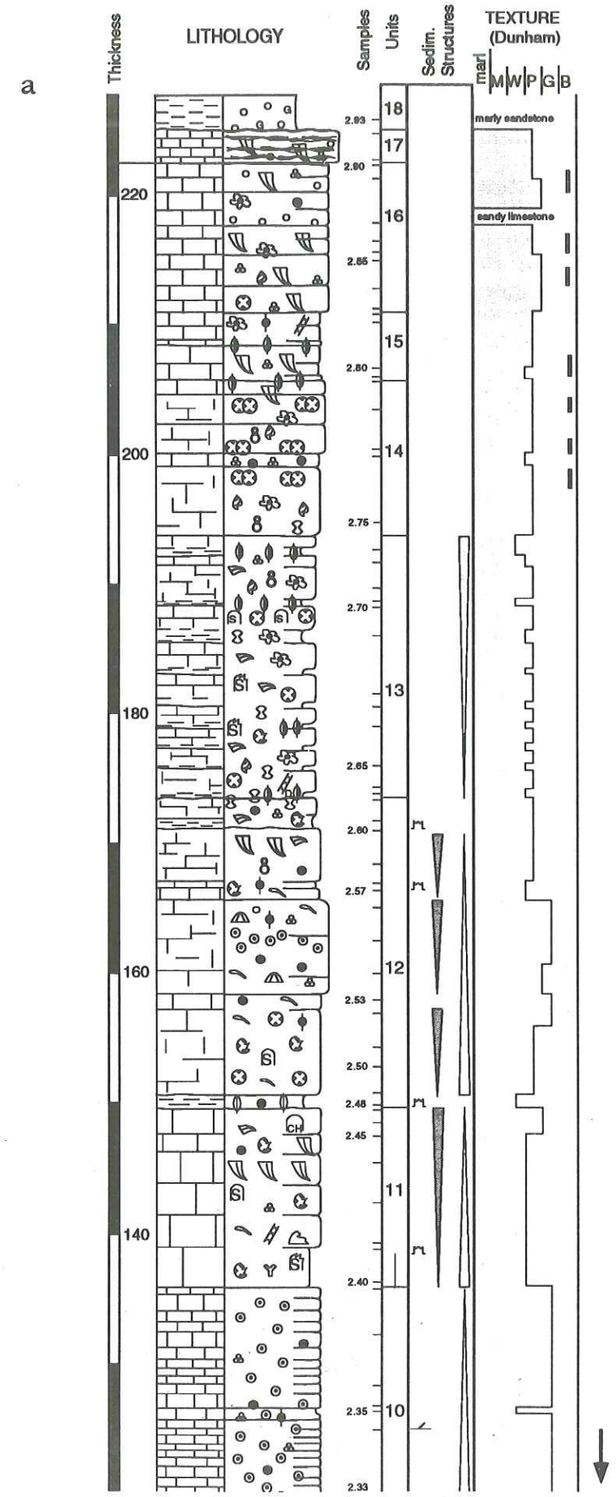
Unit 15 (samples 2.79 to 2.83) is 5.5 m thick and consists of two carbonate beds. This unit shows a similar development as unit 13 ("lower Orbitolina beds"). The basinal parts of the two beds consist of 0.2 to 0.3 m thick horizons extremely rich in orbitolina-foraminifers and detrital quartz. In contrast to the orbitolinid-rich marly limestone layers in unit 13 these layers do not expose erosion grooves. In contrast, as a result their high amount of quartz these layers are more resistant to weathering than the surrounding carbonate beds. Overlying limestone beds contain small rudist patch-reefs with a oncoids, dasycladacean algae and peloids.

Unit 16 (samples 2.83 to 2.90) corresponds to the "rudist limestones". This unit is approximately 11 m thick and built up by five limestone packages. These five carbonate packages show 0.8 to 1.2 m thick loosely packed rudist patch-reefs. *Nerinea* gastropods with shell-sizes up to 20 cm are frequent. Corals are also rarely present. Thin section analysis indicates a limestone composition of composite grains, oncoids, algal lumps and small benthonic foraminifers. The uppermost part contains a high percentage of detrital quartz.

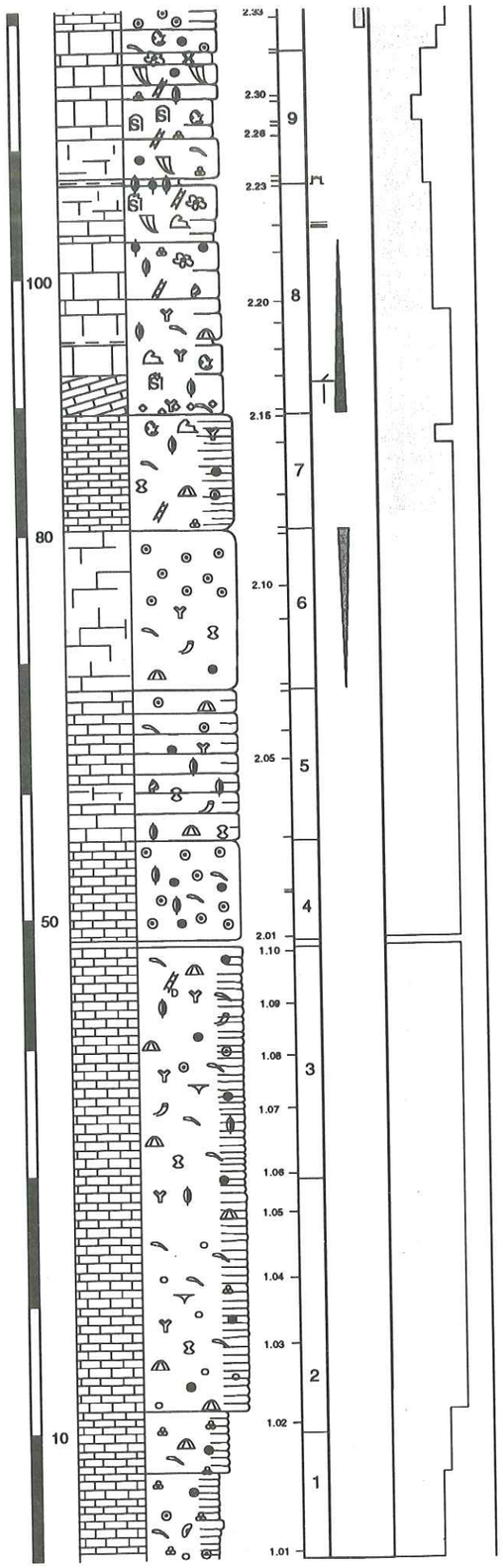
Unit 17 (samples 2.91 to 2.92) is 2.5 m thick and the uppermost unit of the section. This bank is characterized by numerous parallel to bedding striking quartz-veins. These quartz-veins are more resistant to weathering than the surrounding carbonates. Rudists are the dominant macrofossils and the limestone matrix is composed of a calcarenite with peloids, benthonic foraminifers, echinoderm and pelecypod fragments.

Unit 18 (sample 2.93) cuts the limestones with a distinct sharp contact. This unit consists of the "Helvetic Greensandstones" (Delamette 1994).

Fig. 5.5.a-b. Synthetic log of the "**Flaine**" section.



b



Chapter 6: Clay mineralogy

6.1 Introduction

The clay mineral assemblages of limestones and marly limestones have been studied in the following sections: i) "Flaine" (34 samples), ii) "Rocher de Cluses" (4 samples), iii) "Bella Cha" (2 samples) and iv) "Grande Forclaz" (3 samples). The main purposes were to study the variation of clay mineral assemblages within the established sequence stratigraphic framework and to investigate the thermal maturity of the Urgonian limestones (additional purpose of R. Schegg, Geneva).

6.2 Methods

Each sample is decarbonated using hydrochloric acid. The excess acid is removed by successive washing with deionized water. The clay fraction is separated by sedimentation and centrifugation, and oriented pastes are made on glass slides. X-ray diffraction analysis was carried out at the "Laboratoire de Dynamique sédimentaire et structurale" (Lille, France) by Jean-François Deconinck using a Philips diffractometer (PW 1730) with CuK-alpha radiation. XRD patterns of the samples were obtained in (1) natural conditions (air-dry) and (2) after saturation with ethylene glycol and (3) heated up to 490° C for 2 hours. Semi-quantitative evaluations are based on the peak heights and areas summed to 100%, the relative error being about 5%.

The method of sample preparation is described in detail in Holzapffel (1985).

6.3 Results

The clay mineral assemblages in the four studied section (Fig. 6.1, Tab. 1) are dominated by illite (30-100%, average 74%), with lesser amounts of random illite/smectite (0-60%, average 16%) and chlorite (0-40%, average 6%). Two samples (Fl 2.57 and Fl 2.59) from the "Flaine" section are characterized by the presence of corrensite (40 respectively 55%).

Despite the rather small thickness (<200 m) of the profile in "Flaine", the clay mineral assemblages of the Urgonian is highly variably, even when dominated by the illite component (Fig. 6.1). However, the co-existence of mixed-layer assemblages (corrensite, illite/smectite) which are characteristic for an early to medium stage in the diagenetic evolution with illite-chlorite assemblages which are characteristic for a late diagenetic environment indicate a strong lithological control on the clay mineral composition. No significant depth related mineral changes could be observed.

6.4 Discussion and interpretation

According to Chamley (1989), the clay mineral composition of slightly to moderately buried sediments display a wide diversity and variability, which reflects the various paleoenvironmental controls typically acting under conditions of the earth's surface. At depths of burial usually exceeding two kilometers, clay assemblages tend to become simpler, and to be more or less progressively enriched in illitic and chloritic minerals. Smectite tends to disappear downwards, irregular mixed-layers tend to be less expandable and to include subregular to regular types.

The results of comparative studies (Gorin & Monteil 1990, Moss 1992b, Schegg 1992, 1993) of thermal maturity of organic matter (vitrinite reflectance, Rock-Eval pyrolysis, fluorescence) and thermal modeling suggest that the Haut-Giffre, Platé, Aravis and parts of the eastern Bornes and Bauges massifs have experienced up to 5 km greater depth of burial than the Chartreuse and Vercors massifs and the western parts of the Bauges and Bornes massifs. It has been considered by these authors that the main cause of the increased burial of the northeast part of the chain was the emplacement of the Prealpine thrust sheets on this part of the orogenic belt in the upper Oligocene.
According to Moss (1992b), Cretaceous to middle Jurassic rocks of the NE part of the Subalpine Chains have experienced temperatures of around 175-225 °C. Vitrinite reflectance values of up to 0.8% Rr in Eocene and Oligocene units in the Bornes massif suggested that maximum temperatures of up to 135 °C were reached. In the "Rocher de Cluses" section the thermal maturity of a coaly horizon could be determined. The measured vitrinite reflectance is 0.72% Rr. Using the model of Barker & Pawlewicz (1994) a maximum paleotemperature of 109 °C can be calculated.
The results from organic maturation studies confirm conclusions which are based on clay mineral assemblages in different Cretaceous and Tertiary formations of the French Subalpine Chains (Deconinck & Debrabant 1985, Deconinck & Charollais 1986, Chaplet 1992, Moss 1992a, Schegg 1992, 1993). Moss (1992a) showed, for example, that the Hauterivian clay assemblages of the south-west part of the Subalpine Chains (Chartreuse, Vercors) are dominated by smectite, with lesser amounts of illite and highly expandable illite/smectite. Further to the north-east Hauterivian clay mineral assemblages are dramatically different, with illite and chlorite dominating the assemblages and only small percentage of smectite in illite/smectite. The clay mineral diagenesis of Mesozoic rocks of the Subalpine Chains is marked by the transformation of smectite into illite (marls) and of smectite into chlorite (limestones) through mixed-layer steps (Deconinck & Debrabant 1985, Deconinck & Charollais 1986).

The deduced high overburden (several km, see above) in the northeastern part of the Subalpine Chains should normally have resulted in stable clay mineral assemblages (illite, chlorite and small amounts of illite/smectite) in rocks of the Urgonian formation. Such assemblages have been observed in many of the studied samples. They represent detrital assemblages (illite, chlorite? and smectite as a precursor of the mixed-layer clay minerals) which have been diagenetically overprinted (->formation of illite, chlorite, corrensite, mixed-layer minerals). However, the occurrence of corrensite-rich assemblages (Fl 2.57 and Fl 2.59), expandable illite/smectite-rich assemblages (Fl 1.04, Fl 1.05, Fl 2.04 and Fl 2.07) and pure illite assemblages within the same profile (e.g. section "Flaine", length < 200m) indicates that there is a strong lithological control on the clay mineral assemblages of certain samples. Similar observations (e.g. persisting smectites in deeply buried sediments) have been made in the Swiss Molasse Basin. There, despite the disappearance of smectite towards the base of the Tertiary Molasse sequence (Monnier 1982), important amounts of highly expandable clay minerals have been found in the various Mesozoic carbonate formations (Persoz 1982).
Primary factors controlling the smectite to illite reaction are temperature and potassium availability, which seems to be derived usually from detrital K-feldspar or mica (Hower *et al.* 1976, Boles & Franks 1979, Pytte & Reynolds 1989, Weaver 1989). Secondary factors include time, rock/water ratio, fluid and rock composition, starting composition of illite/smectite and pressure (Pytte & Rynolds 1989, Weaver 1989).

The preservation of clay mineral assemblages characteristic for an early to medium diagenetic environment in deeply buried sediments is compatible with some experiments. Strong inhibiting effects on the illitisation of smectite due to the release of Ca and Mg have been demonstrated experimentally by Blank & Seifert (1976) and Roberson & Lahann (1981). Yau *et al.* (1987) show that Wyoming betonite is not affected by hydrothermal treatment at 200 to 460°C for 71 to 574 days, probably because calcite has stabilized the initial expandable clays. This could explain why deeply buried smectite or highly expandable illite/smectite remains preferentially in carbonate rocks. Another problem for the transformation of the expandable clays in carbonate rocks of the Urgonian formation could be the availability of K.

Given the advanced stage of diagenesis in the studied samples and the heterogeneous transformation of the clay mineral assemblages from one horizon to another, a detailed interpretation in terms of paleoenvironments seems to be excluded.
According to Chamley (1989), Cretaceous sediments of the Atlantic and Tethyan domains are often characterized by the abundance of Al-Fe smectites in the clay fraction of both exposed and submarine series. He suggested that the smectites basically derived from the erosion of Cretaceous soils massively developed under hydrolyzing and warm climate. The specific abundance of smectite relative to kaolinite indicates that the Cretaceous climate was probably dominated by noticeable contrasts in seasonal humidity, with well defined and rather long dry seasons (->subarid conditions). Our results indicate indeed an initial clay mineral assemblage which is probably dominated by smectite and illite, and which lacks kaolinite.

Sample	Chlorite %	Illite %	I/S %	Corrensite %	Quartz %	Carbonate %
Fl. D	15	85	0	0	*	
Fl 1.01	15	85	0	0	*	55.77
Fl 1.04	0	55	45	0	*	93.77
Fl 1.06	0	40	60	0	*	93.77
Fl 2.05	0	45	55	0	*	96.73
Fl 2.07	0	55	45	0		96.24
Fl 2.10	0	90	10	0		96.24
Fl 2.12	0	85	15	0		96.73
Fl 2.15	0	30	70	0		95.75
Fl 2.16	2	93	5	0		95.75
Fl 2.22	0	70	30	0		97.23
Fl 2.24	10	80	10	0	*	90.23
Fl 2.26	0	95	5	0		97.70
Fl 2.28	10	80	10	0	*	95.71
Fl 2.31	5	95	0	0		96.21
Fl 2.32	5	85	10	0		97.70
Fl 2.35	10	80	10	0		96.21
Fl 2.40	15	75	10	0		96.21
Fl 2.41	15	80	5	0		94.71
Fl 2.47	0	70	30	0	*	97.70
Fl 2.48	10	80	10	0	*	85.74
Fl 2.50	0	85	15	0		95.71
Fl 2.53	0	100	0	0		96.71
Fl 2.57	5	30	10	55		96.71
Fl 2.58	10	85	5	0		97.21
Fl 2.59	0	60	0	40		97.50
Fl 2.61	0	100	0	0		98.20
Fl 2.69	40	50	10	0		96.21
Fl 2.71	10	75	15	0	*	86.24
Fl 2.78	0	70	30	0	*	94.22
Fl 2.79	0	100	0	0	*	94.22
Fl 2.80	0	100	0	0	*	96.71
Fl 2.92	0	100	0	0	*	84.74
Fl 2.93	10	80	10	0	*	29
Cl 1.143	0	70	30	0	*	88.68
Cl 1.300	0	30	10	60		85.17
Cl 1.H08	15	75	10	0	*	76.15
Cl 1.357	5	75	20	0	*	26.05
BC 23.07	10	65	25	0	*	66.79
BC 23.13	20	55	25	0	*	63.84
GF 1.07	20	65	15	0	*	97.32
GF 1.57	5	60	30	0	*	84.67
GF1.64	0	95	5	0	*	85.67

Tab. 1. Analyzed clay minerals and carbonate contents of selected samples of the "Flaine" (Fl), "Rocher de Cluses" (Cl), "Bella Cha" (BC) and "Grande Forclaz" (GF) sections.

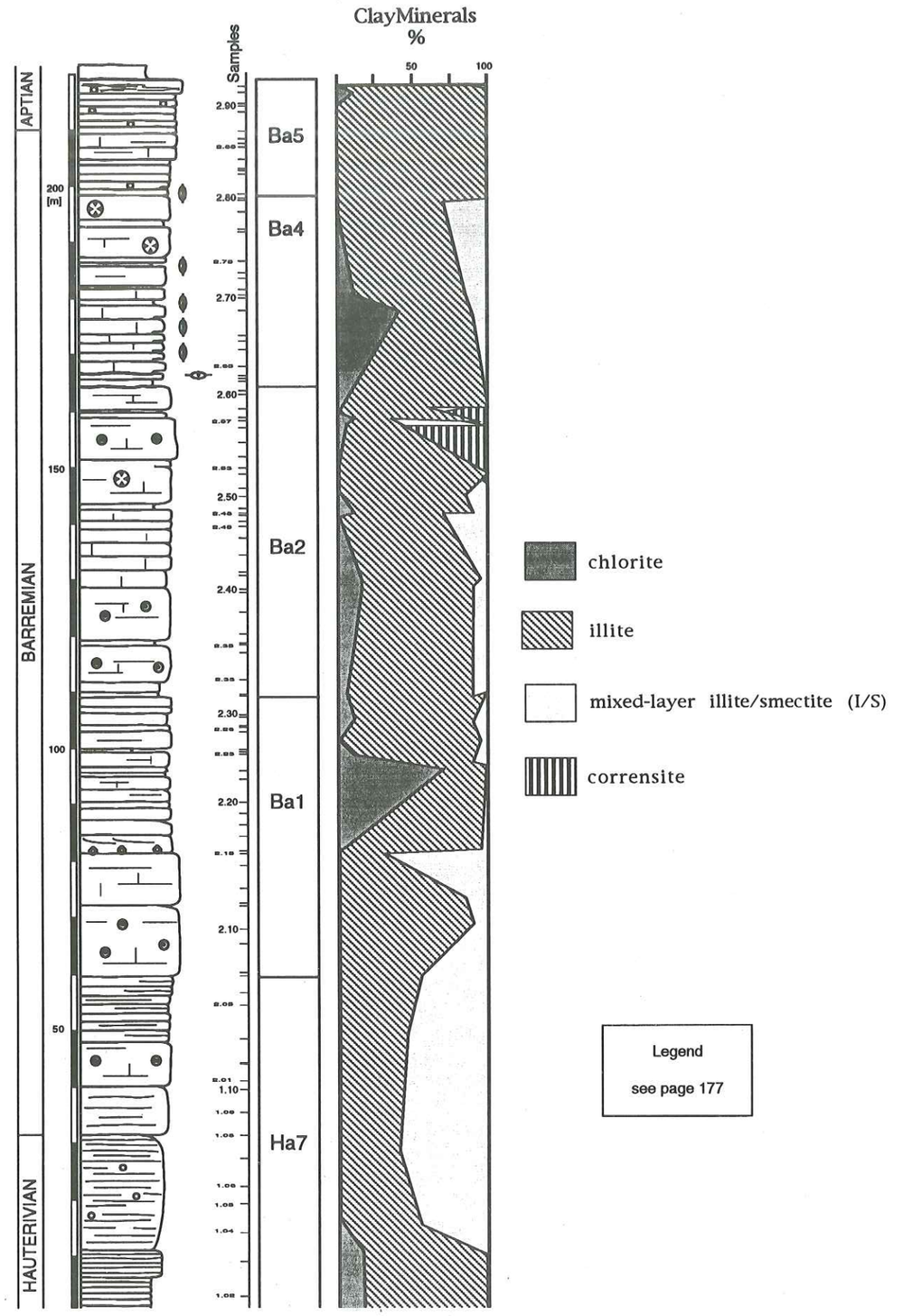


Fig. 6.1 Clay mineralogy of the "Flaine" section.

Chapter 7: PALEONTOLOGY

7.1 Foraminifers

Benthonic foraminifers, are the most abundant microfossils in the Urgonian limestones. They are powerful tools in the study of the paleoecology. Arnaud-Vanneau & Darsac (1984) showed that the main paleogeographic zones: 1. outer shelf, 2. shelf edge, 3. shelf lagoon and 4. sheltered environments of abnormal salinity, on the Lower Cretaceous carbonate shelf contain distinctive benthonic foraminifera populations .
Orbitolinid-foraminifers are the most important indicator fossils for biostratigraphy on the shallow-water Urgonian platform.
Determinations of the orbitolinids were made by Prof. R. Schroeder, other foraminifers were determined by Dr. M. Septfonataine, Dr. R. Wernli and by comparison with studies made by Arnaud-Vanneau (1980).

7.1.1 *Orbitolinidae* Martin 1980

Orbitolinids are the most important fossils for biostratigraphy in the shallow-water Urgonian limestones. The paleogeographical/paleoecological distribution of orbitolinids (and other benthonic foraminifers) was studied in detail by Arnaud-Vanneau (1980). Moullade *et al.* (1985) argued that many orbitolinids are restricted to particular biotopes.
Arnaud-Vanneau (1980) pointed out three major habitats for the orbitolinids. These are the shallow-water carbonate sands on the platform border with a somewhat elevated water energy. After Arnaud-Vanneau these are the preferred areas for *Paracoscinolina sunnilandensis, Urgonina alpillensis, Orbitolinopsis debelmasi, Paleodictyoconus cuvillieri, Valserina primitiva, Valserina broennimanni,* and *Palorbitolina lenticularis.* Other zones for orbitolinid habitat are channel-systems and depressions cutting the inner-platform (Arnaud-Vanneau 1980). Inside these channels the orbitolinids and other agglutinated foraminifers were supplied with detrital material (mostly quartz grains) by prevailing currents. These channel-systems are the preferred habitats for the orbitolinids: *Paracoscinolina maynci, Paracoscinolina arcuata, Orbitolinopsis kiliani, Cribellopsis neoelongata, Palorbitolina lenticularis lenticularis* and *Palorbitolina lenticularis praecursor.* The "Orbitolina limestones", which are composed of marly limestones rich in detrital quartz, clay mineral, other terrestrial materials, and abundant Orbitolinids, are after Arnaud-Vanneau (1980) and Arnaud-Vanneau & Arnaud (1990) examples of widespread channel-system deposits.
After Arnaud-Vanneau (1980) a third habitat for orbitolinid foraminifers are the external parts of the lagoons. In these ecological environments the foraminifers are associated with chaetetids, rudists and dasycladacean algae. In comparison with the two environments mentioned before, these lagoonal facies are dominated by low energy regimes. These zones were inhabited by the orbitolinids: *Paracoscinolina reicheli, Paracoscinolina maynci, Paracoscinolina arcuata, Paleodictyoconus cuvillieri, Paleodictyoconus actinostoma, Cribellopsis neoelongata, Valserina broennimanni* and *Palorbitolina lenticularis praecursor.*

In this study orbitolinid fossils were recovered in nearly every depositional facies zone. They were recognized in the hemipelagic limestones until the protected inner-lagoonal carbonates.

7.1.1.2 Orbitolinids in the "Rocher de Cluses" section

The first major orbitolinid concentration appears in the high-energy platform marginal lithoclastic and bioclastic carbonate sands (microfacies type MFT-3). Within these high-energy amalgamated deposits it is not possible to say if the orbitolinids inhabited these platform-marginal shoals or if they were transported in.
Another section with abundant orbitolinids is exposed in somewhat finer grained carbonates (samples 113 to 150). This part shows units of the "transitional zone" (Masse & Philip 1981, see also chapter 9 DEPOSITIONAL ENVIRONMENTS) representing open-lagoonal to outer-platform sediments with slightly higher water-energy conditions. This part of the section contains the orbitolinids: *Valserina primitiva, Valserina broennimanni* and *Paleodictyoconus glanensis.* The fossils are well preserved and show only minor abrasion. It is assumed that these carbonate beds represent the orbitolinid's living and depositional environment.
The third section showing elevated Orbitolinid quantities is a lagoonal facies with rudist and oncoid banks (microfacies type 15B and 14) in alternation with lagoonal bioclastic shoal deposits (microfacies types 2 and 3). The Orbitolinids are very well preserved without any abrasion features. It is therefore assumed that this lagoonal facies represents a living space for orbitolinid foraminifers.
The fourth and in the literature most frequently described orbitolinid deposits are the thin bedded *Orbitolina marly limestones.* These marly beds contain abundant *Palorbitolina lenticularis, Paracoskinolina maynci, Orbitolinopsis kiliani.* In all of the examined sections, it was easy to recognize the *Orbitolina marly limestones* in the field, as a result of their less resistant nature to weathering. The absence of any sedimentary geometries and sedimentary structures made it impossible to interpret them as channel deposits as it is described by Arnaud-Vanneau (1980) and Arnaud-Vanneau & Arnaud (1990).

In the following the orbitolinids, which are determined in "Rocher de Cluses" are listed. For their stratigraphic distributions see figure Fig. 4.2

Cribellopsis cf. neoelongata
? *Dictyorbitolina ichnusae* ?
Eopalorbitolina ?
Orbitolina X
Orbitolinopsis buccifer
Orbitolinopsis cf. *debelmasi*
Orbitolinopsis debelmasi
Orbitolinopsis kiliani
Orbitolinopsis sp.
Paleodictyoconus actinostoma
Paleodictyoconus cuvillieri
Paleodictyoconus cuvillieri/Paleodictyoconus actinostoma
Paleodictyoconus glanensis
Palorbitolina sp.
Palorbitolina lenticularis
Paracoskinolina maynci
Paracoskinolina sp.
Praedictyorbitolina carthusiana
Urgonina
Urgonina cf. *alpillensis*
Valserina sp.
Valserina broennimanni
Valserina primitiva

Valserina primitiva/Valserina broennimanni

7.1.1.3 Orbitolinids in the Aravis sections

Additionally to the already described depositional milieus for orbitolinids in the section "Rocher de Cluses" there are the particular megablocks which moved into the hemipelagic environment (see chapter 10 SUBMARINE MASS FLOW DEPOSITS). Orbitolinids were found in some of these megablocks, as well as in the *in situ* sediments. Microfacies analysis indicates that some of these blocks are built up by shallow-water carbonates of the high-energy platform-marginal shoals (microfacies type 2 and 3). With these platform derived megablocks embedded in pelagic to hemipelagic carbonates there is the possibility to correlate platform biostratigraphic indicator fossils with hemipelagic biostratigraphic indicator fossils.
The orbitolinids are listed in alphabetic order. For their stratigraphic distribution see figure 4.3 and 4.4.

First "mass flow" horizon:
Dictyorbitolina ?
Paleodictyoconus cuvillieri
Paleodictyoconus glanensis
"*Paleodictyoconus* n. sp. 1" ARNAUD
Paleodictyoconus sp.
Valserina broennimanni (primitive forms)
Valserina primitiva
Valserina sp.

"Couches de Transition":
Paleodictyoconus sp.
"*Paleodictyoconus* n. sp. 1" ARNAUD
Paleodictyoconus cuvillieri
Paleodictyoconus glanensis
Paracoskinolina aff. *sunnilandensis*
Paracoskinolina cf. *sunnilandensis*
Valserina broennimanni (primitive forms)
Valserina primitiva
Valserina sp.

Second mass flow horizon: (recovered autochthonous and allochthonous facies)
Paleodictyoconus cuvillieri
Paleodictyoconus glanensis
Valserina primitiva
Valserina sp.

Platform carbonates:
Orbitolinopsis
Orbitolinopsis cuvillieri
Orbitolinopsis cf. *cuvillieri*
Paleodictyoconus actinostoma
Paleodictyoconus cuvillieri
Paleodictyoconus cuvillieri/Paleodictyoconus actinostoma
Paleodictyoconus sp.
Palorbitolina
Palorbitolina lenticularis
Paracoskinolina aff. *sunnilandensis*
Paracoscinolina cf.

Paracoskinolina cf. *arcuata*
Paracoskinolina hispanica
Paracoskinolina maynci
Paracoskinolina sp.
Urgonina

7.1.1.4 Orbitolinids in the "Flaine" section

In the section "Flaine" orbitolinids were found in shallow-water, high energy carbonates and in the *Orbitolina marly limestones* occuring between the more resistant carbonate banks.
The orbitolinids which were found in the section "Flaine" are listed in alphabetic order. For their stratigraphic distribution see Fig. 4.5.

Cribellopsis neoelongata
"*Dictyoconus* ? cf. *vercorii*" ARNAUD
"*Falsurgonina* ? sp.1" ARNAUD
? Orbitolinopsis debelmasi ?
Orbitolinopsis cuvillieri (A + B) 2.72
Orbitolinopsis cf. *kiliani*
Orbitolinopsis kiliani
Orbitolinopsis kiliani (A + B) 2.74/1
Orbitolinopsis sp.
Paleodictyoconus actinostoma
Paleodictyoconus cuvillieri
"Paleodictyoconus" glanensis
Paleodictyoconus sp.
Palorbitolina lenticularis
Paracoskinolina maynci
Paracoskinolina reicheli (without horizontal septuls)
Paracoskinolina cf. *sunnilandensis*
Valserina

7.1.2 *Ammodiscidae* Reuss 1862

Glomospira sp. is a species of low energy, inner-platform environments, however in this study it was also found in outer-platform deposits.

7.1.3 *Astrorhizidae* Brady 1881

Hyperamminoididae Loeblich and Tappan 1984 (Loeblich & Tappan 1988)
Giraliarella ? prismatica (n. sp. Arnaud-Vanneau, 1981) was found in circalittoral platform-margin to slope deposits. In the Aravis outcrops *Giraliarella ? prismatica* is presented within the mass flow deposits and also in the following transgressive beds. In the "Flaine" outcrop this species is associated with lagoonal deposits, which are amalgamated with transgressive open-marine components.

7.1.4 *Ataxophragmiidae* Schwager 1877

Pfenderinidae, Siphovalvulina, Pseudolituonella Marie 1955, Dobrogelina Neagu 1979,

7.1.5 Charentiidae Loeblich and Tappan 1985

The genus *Melathrokerion* Brönnimann and Conrad, 1967 was found in micrite rich inner-platform sediments. This agglutinated foraminifer is rarely represented in the studied sections.

7.1.6 ***Cuneolinidae*** Saidova 1981
This family is represented by the genus *Vercorsella* (Arnaud-Vanneau 1980), *Cuneolina hensoni, Novalesia, Sabaudia.* and *Sabaudia sp. Vercorsella* was described for the first time by Arnaud-Vanneau, 1980. The author noted the similarity to the genera *Novalesia* and *Cunelina.* Arnaud-Vanneau (1980) found this agglutinated genus abundant in deposits containing quartz and other terrestrial debris. In the studied outcrops "Rocher de Cluses", "Aravis" and "Flaine", *Vercorsella* is also abundant in quartz-rich marly limestones (e.g. Orbitolina limestones).

7.1.7 **Cyclamminidae** Marie 1941 (after Loeblich & Tappan 1985)
The planspiral, agglutinating foraminifers *Choffatella decipiens* are typical of quartz-rich, marly carbonate layers indicating transgressive periods of sea-level change. They are associated with other agglutinating foraminifers such as *Palorbitolina lenticularis, Vercorella, Nautiloculina* and *Dobrogelina* in the "Orbitolina marly limestones". Arnaud-Vanneau (1980) described them as fossils in inner-platform channels rich in quartz and terrestrial material.
Another genus is *Everticyclammina.* This was found together with *Pfenderinidae* in fine grained lagoonal carbonates. Arnaud-Vanneau (1980) and Septfontaine (pers. com. 1993) regard *Everticyclammina* as an indicator fossil for shallow platform, lagoonal environments. However, these foraminifers were often also found in high-energy carbonate sand shoal deposits where they were transported in.

7.1.8 **Involutinidae** Bütschli 1880
The genus *Trocholina* with its conical perforated, primarily aragonitic test is a frequent foraminifer fossil in open marine sediments. *Trocholina* is located in shallow platform to hemipelagic slope limestones. It was never found in protected lagoonal sediments.

7.1.9 **Lituolidae** de Blainville 1825
These agglutinated foraminifers with their large diversity of different developed tests are widespread distributed over the shelf. Less frequently they are found in protected, micrite limestones. The genus *Nautiloculina cretacea* with its lenticular, planspiral form of a characteristic foraminifer in quartz-rich, terrestrial material-bearing carbonate packages. In these facies they are associated with other agglutinated foraminifers including *Palorbitolina lenticularis* and *Choffatella decipiens.*

7.1.10 **Miliolidae** Ehrenberg 1839
The miliolids are the most abundant foraminifers in the studied sections. They are present in the pelagic/hemipelagic, outer platform to inner platform, protected inner-lagoonal to brackish/lacustrine series. Their preferred paleoecological environment was the protected lagoonal shelf where they are the most of all the fossils (microfacies types MFT-6 to MFT-8). *Quinqueloculina* and *Triloculina* are the most frequently occurring miliolids. *Nummoloculina* and *Derventina* are present sometimes. The miliolids are distributed over the whole platform but their quantity and test size are good indicators for paleoecological interpretation (Arnaud-Vanneau 1980, Arnaud-Vanneau & Darsac 1984). In relation to their test size the largest forms could be found in open to slightly protected lagoonal environments whereas in direction to the platform-border and to deeper circalittoral zones and in the continental direction to more protected to restricted areas the miliolid sizes diminished drastically. The same results are well illustrated by Arnaud-Vanneau & Darsac (1984) who analyzed the distribution of miliolids and other benthonic foraminifers over the shelf. *Pseudotriloculina* are also distributed all over the different facies zones, but they are good indicator

fossils in very restricted lacustrine and brackish environments, where apart from the small gastropods *Planorbis* they are the only fossils.

7.2 Algae

The calcareous algae are frequent components in the Urgonian limestones. As a result of their distribution on the shelf depended on the prevailing facies, calcareous algae are a useful tool in reconstructing the paleoenvironments (Conrad 1969, 1970, 1977, Flügel 1982, Wray 1979).
The most abundant calcareous algae are dasycladacean algae which are distributed over the whole of the shallow shelf.

7.2.1 Dasycladacean algae

Dasycladacean algae are the most abundant calcareous algae which were found in the studied Urgonian limestones. Their occurrence and abundance are closely related to the depositional environment (Conrad 1970). However, it seems to be clear, that much of their "debris" were transported into regimes, which were unfavorable for living environments, e.g. hemipelagic and high-energy platform margin deposits.
As dasycladacean algae have potential value in biostratigraphy and paleoenvironmental investigations (Conrad 1977), they were examined with particular attention by M. Conrad and B. Granier.

Environmental distribution:
Recent dasycladacean algae inhabit mainly shallow, tropical to subtropical marine waters. They prefer normal marine salinities, some species (*Acetabularieae*) tolerate brackish to hypersaline waters. Water depths where dasycladacean algae occur range from below the low tide mark to about 30 m. The maximum abundance of recent dasycladaceans lies in a depth range down to 5 m (Konishi & Epis 1962).
Most dasycladacean algae colonize sand and mud bottoms, in low-energy zones either in protected areas or below intense wave agitation (Wray 1977). Elliott (1968) concluded that the ecological requirements of fossil dasycladacean algae were essentially the same as those of recent species.
Stratigraphic zonation and depositional environments of the dasycladacean algae in the lower Cretaceous are well documented by Conrad (1969, 1970, 1977), Conrad & Peybernès (1976, 1979) and Peybernès (1979).
The occurrence and abundance of dasycladacean algae are best developed in the section, "Rocher de Cluses". This section represents about 160 m of thick inner-platform carbonates rich in dasycladacean fossils. Their stratigraphic distribution in the "Rocher de Cluses" section is illustrated in **Fig.** 7.1
The following list describes all of the Dasycladaceae/ Acetabulariaceae observed in the studied sections. They were determined by M. Conrad, Geneva and B. Granier, Paris

? Actionoporella fragilis
Actinoporella nigra
Actinoporella gr. podolica
Actinoporella silvaeregis
? Angioporella sp.
Carpathoporella sp.
Clypeina
Cylindroporella sp. 1
Cylindroporella sp. 2

Cylindroporella sp. aff. sp. 2
Cylindroporella sugdeni
Gakhumella huberi
Heteroporella ? paucicalcarea
Heteroporella ? paucicalcarea géante
Neomeris sp.
"Praturlonella"
"Praturlonella ? danilovae"
Pseudoclypeina sp.
Salpingoporella sp. (cf. melitae)
Salpingoporella genevensis
Salpingoporella melitae
Salpingoporella muehlbergii
? Suppiluliumaella sp.
Vermiporella tenuipora
Pseudoactionporella fragilis
Clypeina nigra
Deloffrella querifoliipora
Dissocladella hauteriviana
Heteroporella sp.
Heteroporella paucicalcarea
Terquemella sp.

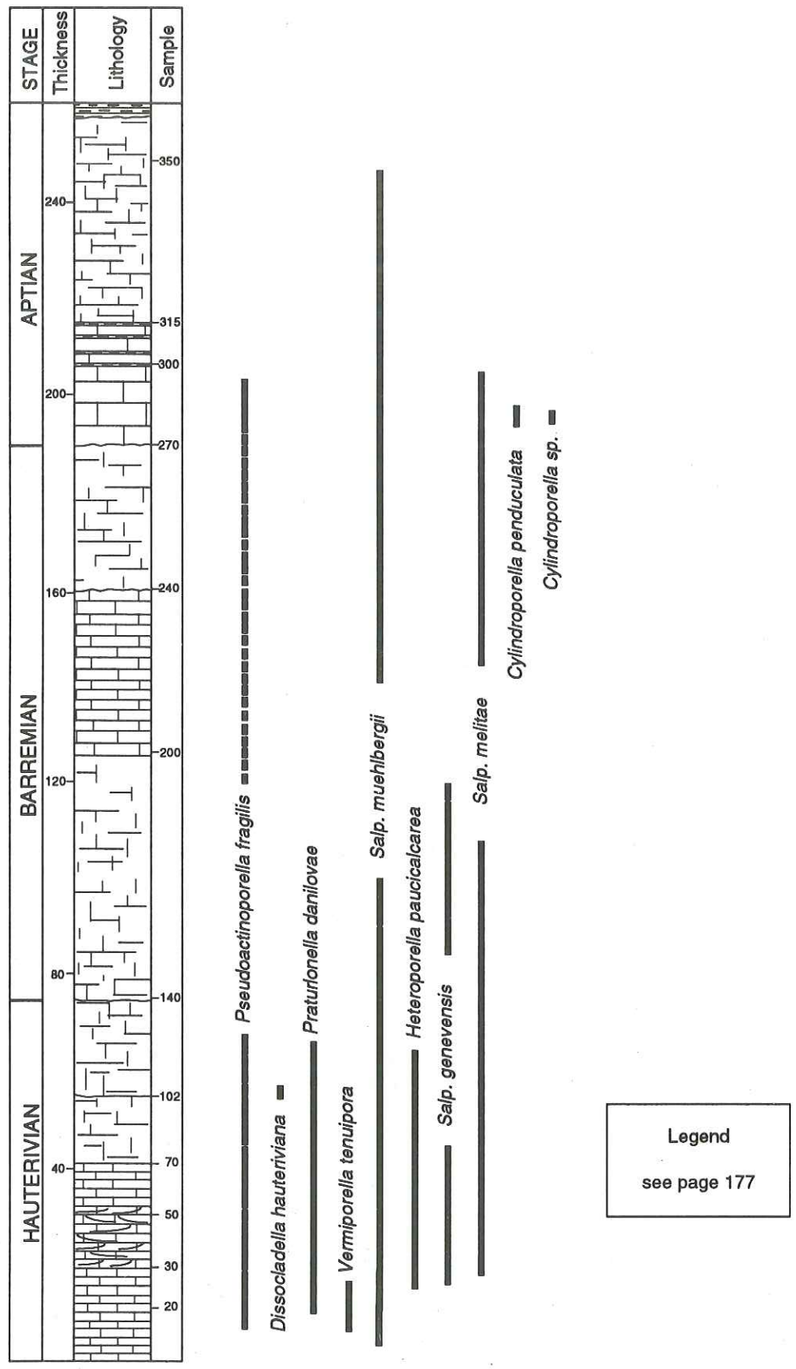


Fig. 7.1. Dasycladacean algae distributions in the **"Rocher de Cluses"** section.

7.2.2 Oncoids

According to Monty (1972) ancient marine oncoids are better compared with recent freshwater oncoids in regard to morphology, structure and microstructure.

Three different oncoid types were identified.
Oncoid type 1: **Foraminiferal-algal-oncoids**: coatings of encrusting foraminifers (*Nubecularia*), intergrown with encrusting algae. The oncoids are irregularly shaped and range between 2 to 7 mm in size (plate 13/2).
Oncoid type 2: ***Bacinella* oncoids**: These represent the largest oncoids (up to 15 mm), which could be distinguished and are very similar to *Bacinella* lumps but differ in that they encrust only one nucleus (plate 13/3).
Oncoid type 3: ***Girvanella* oncoids**: ellipsoid to irregularly shaped, coated grains containing micrite layers and recognizable algal structures. These fine algal filaments are determined as the cyanophyceae algae *Girvanella* (Wray, 1977). The oncoids are 1 mm to 3 mm in diameter.

Large *Bacinella*-lumps are found within a matrix of angular intraclasts and rudist shells which form a poorly-sorted rudstone texture (sample 106 to 110). This oncoid/algal lump facies probably represents channel lag deposits within an open lagoon.
A quieter water environment is indicated by the association of foraminiferal-algal-oncoids, encrusting foraminiferal-algal-lumps, smaller *Bacinella*-lumps and *Bacinella* oncoids which encrusted rudist shells and other carbonate particles.
The vicinity to the rudist beds (MFT-15B) and their debris facies (fossil rudstone/floatstone, MFT-16) assumes also a proximity of this facies in the paleoenvironment. Their settings are interpreted as open to slightly protected lagoons.

7.2.3 Codiaceae
This family is represented by only some fossil debris of the genus *Halimeda* with the two species *Boueina* and *Arabicodium*. These fossils are found in high-energy carbonate sand deposits, and in reworked transgressive quartz- and marl-bearing carbonates.

7.2.4 Soleonoporaceae
From this family some fossils of the genera *Solenopora sp.* and *Marinella lugeoni* were identified. Wray (1977) and Flügel (1979) noted for the *Solenoporaceae* a wide range of open-marine environments from back-reef to fore-reef areas. Beckmann & Beckmann (1966) interpreted for *Marinella lugeoni* a back-reef shoal to fore-reef/ open-reef shoal environment. Conrad (1977) illustrated *Marinella* in external infralittoral areas.
In the section "Rocher de Cluses" the two genera were found in open-marine high-energy shoal deposits but *Marinella lugeoni* was also present in protected micritc limestones. In the Aravis Chains and in the "Flaine" sections *Marinella lugeoni* is a fossil in hemipelagic carbonate series.

7.2.5 Cyanophyceae
Cyanophyceae algae are represented by the genus *Girvanella* . They can be identified by their very fine (10-20 μm) tubular filaments. Often they encrust other objects or have a massive, nodular, oncoidal habitus. In these cases they are classified as *Girvanella*-oncoids. Sometimes *Girvanella* algae built up their nodules or encrusting masses together with encrusting foraminifers (foraminiferal-algal oncoids).

Girvanella organisms are present in the most protected inner-platform carbonates. In these paleoenvironments the fossil diversification was very reduced and only small Miliolids, peloids, small aggregate grains and *Girvanella*-oncoids were observed in these facies (microfacies type 9). Therefore, *Girvanella*-oncoids are only in a somewhat higher quantity in the upper part of "Rocher de Cluses", because this succession represents the most protected inner-lagoonal carbonates of all studied sections.

7.3 Chaetetids

Chaetetida was distinguished as an independent group of cnidaria by Turnsek & Masse (1973), while Rigby & Scrutton (1985) attributed them to sponges (class Demospongea).
Chaetetids belong with corals and stromatoporoids in the reefbuilding biota. Together with corals and stromatoporoids these organisms were extensive inhabitants of the *transitional zone* environment. However, chaetetids preferred somewhat more protected sites than corals or stromatoporoids. Sometimes they appear in association with rudists biostromes. Similar results are described by Turnsek & Masse (1973) and Turnsek *et al.* (1981) who observed chaetetids patch-reefs in the Lower Cretaceous from Provence (southeast France) from central reef to back-reef areas.
The species *Chaetetopsis krimholzi* Yaworski (Jurassic - Lower Cretaceous) was determined by D. Turnsek (Ljubljana) from the section "Rocher de Cluses".

7.4 Stromatoporoids

No generally accepted classification exists for stromatoporoids. They have been attributed to Hydrozoa (Turnsek & Masse 1973, Turnsek *et al.* 1981) and also to Porifera (Jansa *et al.* 1983, Rigby & Scrutton 1985, Wood 1985). Stromatoporoids of the investigated limestones were determined by D. Turnsek (Ljubljana).
Stromatoporoids are good paleoecological indicators. They are most common in shallow-water environments and in slightly deeper lagoonal zones or upper slopes (Flügel 1982). Turnsek *et al.* (1981) found Mesozoic stromatoporoids in reef and lagoonal facies. A general "energy zonation" in reliance on growth forms is proposed by Bourque *et al.* (1988).

Stromatoporoid organisms are mainly found in limestone facies indicating moderate to elevated water energy environments (*transition zone*). In these sites the largest forms (up to 15 cm in diameter) built up patch-reefs with corals and chaetetids. *Disparistromaria urgonica* Turnsek could be identified as a reefbuilder in the *transitional zone* ("Rocher de Cluses" section, samples 160 to 170).
The species: *Cladocoropsis* sp., *Spongiomorpha* sp. and *Steineria tabulata* are abundant in beds built up by high energy marginal shoal-water carbonates. Turnsek & Masse (1973) described these species in back-reef to lagoonal environments in the Lower Cretaceous of southern France.
Stromatoporoids were also found in low energy lagoonal deposits beside rudist, oncoid and *Bacinella* nodules.

7.5 Corals

Corals appear in different growth forms: hemispherical, dendroid finger, stick like, massive branching, globular columnar and tabular. Coral sizes

range from some mm to massive forms with more than 30 cm in diameter. The corals are mostly associated with stromatoporoids and chaetetids (microfacies type 15A). The majority of the platform carbonates in the "Flaine" section are interpreted to have been deposited in high to moderate energy depositional environments containing abundant coral fossils.
The thickest reef-constructions are 0.3 m to 0.6 m thick biostromes ("Flaine" section) or they may occur as bioherms up to approximately 3 m ("Rocher de Cluses" section).
However, patch-reefs built up by corals are only poorly developed in the studied sections. Bioconstructions are mainly represented by rudist patch reefs. This predominance of rudists and the lack of coral organisms in Lower Cretaceous carbonates is also mentioned by Masse & Philip (1981).
Corals were determined by D. Turnsek (Ljubljana) and R. Baron-Szabo (Berlin).
Polyphylloseris cf. punctata ERRENST 1991
Columnocoenia sp.
Dermosmilia sp.
Fungiastrea sp.
Meandraraea meandriformis Morycowa
Microsolena guttata Koby

7.6 Sponges

Sponge spicules are one of the main components in the hemipelagic deposits. In shallow-water carbonates mm to cm large fragments were found in the high energy shoal deposits (microfacies type 3). Well preserved sponge organisms appear extremely rarely. Their poor preservation is a result of friability and a rapid destruction after death.
Nevertheless in the Aravis Chains they are abundant and encrust the top-surfaces of the megablocks in the mass flow deposits. It is noted that they colonized only platform-derived blocks (for explication see chapter 12 SEQUENCE STRATIGRAPHY AND PALEOGEOGRAPHY).
Sponge organisms have not been determined in this study. However Charollais *et al.* (1967) have already discovered and described these sponge occurrences. Their results are listed below:
Scytalia curta Moret
Porospongia sp. A
Porospongia sp. B
Jerea sp. (very common)
Rhizopoterion tubiforme SCHRAMMEN
Rhizopoterion sp.
Periphragella sp.
Periphragella cf. *elongata* Moret
Cytoracea cf. *impressa* (ROEMER)
? Perodinella sp.
Elasmostosa sabaudiana DE LORIOL
Eurete sp.

7.7 Ammonites

Ammonites were found only in the hemipelagic carbonate packages of the "Couches de transition" in the Aravis Chains (Fig. 4.3). They are the most important biostratigraphical indicators. R. Busnardo, Lyon, determined the Ammonites:
Crioceratites sp. grande taille ("Bella Cha")
Cassidoiceras gr. *cassida* ("Bella Cha")

Pseudothurmannia gr. *pseudo-melbosi* ("Bella Cha", collection Clavel 168.1)
Torcarella gr. *fabei* ("Bella Cha")
Torcapella sp.(Mont Charvet)
Pseudothurmannia gr. *grandis* ("Bella Cha")
Emericiceras gr. *emerici* ("Bella Cha")

7.8 Nautilus

In the hemipelagic carbonate series in the sections "Verts" (20.03) and "Bella Cha" (BC 8.14), two well-preserved Nautilus specimens belonging to the same species were found. One of them was determined by H. Tintant, Dijon who attributed it to the genus *Eucymatoceras gr. plicatum* (Fitt.) form aff. *stschurowskii* (Milos.) (Late Hauterivian - Aptian).

7.9 Gastropods

The gastropods *Planorbis* (plate 14/3) and *Nerinea* are good paleoecological indicators.
The small *Planorbis* were typical inhabitants of lacustrine to brackish environments. They are present in the microfacies representing the most restricted paleoenvironment (microfacies type MFT 12) where they are associated with fine shelled ostracods and small benthonic foraminifers.
The spired gastropods *Nerinea* (Jurassic-Cretaceous) were inhabitants of protected lagoonal environments (Salomon 1987). In the studied sections they are frequent macrofossils only in the "Flaine" outcrop, where they are associated with rudists and oncoids (microfacies type 15.B), but also with corals and chaetetids fossils, which indicate a more open, higher energy regime.
The shells are often well-preserved showing their high spired shells with heights of up to 20 cm.

7.10 Echinoderms

Most of the echinids lived in shallow sea conditions, similar to today. They usually prefer sandy or calcarenite sediments or they live attached to rocks. In contrast to the echinids living in the shallow sea, Clavel (1989) identified for the genus *Toxaster* a circalittoral, pelagic to hemipelagic paleoenvironment.
Fragments of Echinoderms are very abundant in the studied sections. Their fragments are represent in pelagic/hemipelagic to inner-platform limestones. The debris is normally composed of plates or spines between 0,2 mm to a few mm in size. As a result of high porosity of up to 50% (Bathurst 1971) and the resulting very low specific weight of only 1.5 g/cm^3 their debris could be easily transported onbank or offbank by prevailing paleocurrents. Therefore it is possible to find small echinid fragments in pelagic to hemipelagic deposits as well as in protected low energy deposits in inner-platform areas. In the studied sections the most abundant fragments of echinoderms occur in deposits adjacent to the platform margin deposits, either in front or behind them (microfacies type 1), as well as in the very high-energy sand shoals (microfacies types 2 and 3). Echinoderm fragments are generally overgrown by a syntaxial low-Mg calcite cement in an optical continuum with the single fossil crystals.
In inner-platform deposits small echinoderm fragments (about 0.2 mm) are associated with peloids and pellets representing very quiet energy sediments.

In the Urgonian limestones echinids have a major biostratigraphic significance (see chapter 4 BIOSTRATIGRAPHY).
Well preserved echinoids were collected in the hemipelagic slope series underlying the platform carbonates. They were determined by B. Clavel who identified the genus *Toxaster* with the two species *Toxaster retusus* LAMARCK and *Toxaster seynensis* LAMBERT. According to Clavel *et al.* (1993) the genus *Toxaster* is characteristic of a circalittoral depositional site. It has never been found on the shallow platform.

7.11 Bryozoans

Fragments of bryozoans are always present in open marine carbonates of the examined limestones. They were never found in protected, inner-lagoonal, micrite rich sediments.
Bryozoans are components of platform margin carbonate sand deposits where their 1 to 3 mm large debris are associated with echinoderms, pelecypods, foraminifers and lithoclasts (microfacies types 1 to 3). They are also components in coral-stromatoporoid-chaetetid patch reefs (microfacies type 15A) where their colonies encrusted the reef-building organisms.
Small sizes and the reworked character of their fragments made it impossible to determine their original morphology, which could indicate their paleoecological environment as mentioned by Cuffey (1972) and Flügel (1982). Fragments of bryozoans are always indicators of the open-marine, mostly shallow carbonate facies, but they have (with the exception of reef dwellers) no value for paleoecological investigations.

7.12 Rudists

The rudist bivalves are the most typical and most abundant macrofossils occurring in the Urgonian limestones. As a result of their abundance these Lower Cretaceous platform deposits are described as "rudist limestones" (see chapter LITHOSTRATIGRAPHY). Their biological and ecological evolution is well documented by, Kauffman & Johnson (1988), Masse (1976, 1979, 1981), Masse & Philip (1981), Scott (1988) and Skleton (1976).
In the Jurassic to the Early Cretaceous primitive rudist bivalves with their predominantly aberrant, doubly coiled shell morphologies (*Requieniidae* and early *Monopleuridae*) were best adapted to protected shelf and lagoonal environments. In these biofacies they lived as dispersed individuals, in a loosely packed sociable order. They had not yet attained the capacity to construct reefs. Beginning in Barremian time important evolutionary innovations made it possible for the rudist bivalves to construct wave resistant frameworks, which enabled them to inhabit high-energy reef environments where they displaced more and more coral-algal communities. These evolutionary innovations of rudist bivalves are the developments of erect, uncoiled to nearly straight growth forms, which lead to tabular, conical forms. With the evolution of more ornamented shells the rudists increased their wall strength, which enabled them to fix their valves in the surrounding sediment, and therefore the ability to interlock and co-cement among species. These new adapted valves enhanced the rudists to live in gregarious growth behavior and pseudocolonial aggregations. They could resist wave and current activity and enabled them to colonize high-energy environments (Kauffman & Johnson 1988). Furthermore Kauffman & Johnson (1988) suggest that environmental factors such as chemical and/or thermal changes could have triggered the replacement of coral-algal communities by rudists. Masse & Philips (1986) describe that main innovations in rudist shell evolution were just before geodynamic crises.

Paleogeographic changes triggered by tectono-eustatism and climate fluctuations are considered by these authors as important factors for rudist evolution.

The two families Monopleuridae and Requieniidae were recognized in this study. They occur in three different populations: 1.) as scattered, loosely packed individuals, 2.) as medium well organized colonies, and 3.) as closely packed communities. Rudist bioconstructions are summarized in the microfacies type 15.B. Rudist settlements occurred mostly in slightly protected environments. They rarely constructed small patch-reefs also in protected to semi-restricted sites. Only some isolated rudist individuals were found in elevated water energy environments ("Flaine" section).

7.12.1 Rudists in the "Rocher de Cluses" section

The first 120 meters of the section are composed of high-energy platform margin and "transition-zone" sediments. These units do not represent the rudist living environments. The first rudist colonies occur as a medium intense colonization, about 2 m in thickness. Together with cm-large *Bacinella*-aggregates and oncoids they build up a 15 m thick carbonate bank (samples 105 to 125) within the "transitional-zone" units (Masse & Philip, 1981). For the second time rudists appear in the "rudist limestones" (Arnaud-Vanneau & Arnaud, 1990). This part of the section is about 60 m thick (samples 185 to 270). The "rudist limestones" are interpreted as slightly protected lagoonal deposits.
The rudists occur in 0.5 to 2 m thick "rudist-banks" where the majority of the shells are not sedimented in life-position. Rudist patch-reefs, their debris and algal products (oncoids, algae-aggregates) build up sequences consisting of two units (Fig. 9.2) The basal unit is composed of rudist debris, oncoids, *Bacinella* algae and algal encrustions. The second unit contains closely packed rudist-reefs which are followed again by the basal unit. The limits between these units are often clear and well pronounced. These sequences are about 1 to 3 m in thickness. The upper part of the section (samples 319 to 356) separated from the lower one by the "Orbitolina marly limestones" is of Aptian age. It consists mainly of low diversified protected lagoonal sediments with sporadic rudists. The absence of the rudists in protected lagoonal sediments agrees with the observations of Kauffman & Johnson (1988) and Masse & Philip (1981) who describe that rudist bivalves were evolutionarily adapted to life in high-energy reef environments, beginning in Barremian to Cenomanian time.

7.12.2 Rudists in the Aravis mountains

The Aravis Chains display the thickest series of "rudist limestones" in the studied area. They are associated with alternating oncoids, *Bacinella*-lumps and algal encrustions(Fig. A.3.a-b). These sequences are deposited in a somewhat more open lagoonal environment than the "rudist limestones" in the "Rocher de Cluses" section. Furthermore, the "rudist limestones" of these two outcrops are not of the same age.

7.12.3 Rudists in the "Flaine" section

As already described in chapter 4 DESCRIPTION OF THE OUTCROPS, the "Flaine" section is mainly built up by high energy bioclastic sands, oolites, coral and coral-stromatoporoid-chaetetid patch-reef and their coarse grained debris

facies. Rudist beds occur only in the uppermost 20 m of the section (Fig. A.4a-c). Rudists are associated with large *Nerinea* gastropods, corals and oncoids. In the lower parts of the outcrop rudists appear only sporadically. In the "Flaine" region rudist bivalves colonized the most open lagoonal environments in comparison with the other studied sections in Barremian to Lower Aptian time.

Chapter 8: MICROFACIES AND INTERPRETATION OF THE DEPOSITIONAL ENVIRONMENT

General remarks

Previous work
Previous studies of microfacies and facies analysis of the Urgonian limestones are Arnaud (1981) (southern Vercors, western Diois and Dévoluy, SE-France), Arnaud-Vanneau (1980) (northern Vercors, Chartreuse, SE-France), Bollinger (1988) (Helvetic Shelf, E-Switzerland), Conrad (1969) (region of Geneva, W-Switzerland and SE-France), Masse (1976) (Provence, S-France), Orsat & Strohmenger (1993) (Chartreuse, SE-France) and Vieban (1983) (Ain, Savoie and Haute-Savoie).

Methods
The descriptions of the microfacies types were based on the standard microfacies type SMF-classifications by Flügel (1972) and Wilson (1975). The carbonate classification follows Folk (1959, 1962,) with additional information from Strohmenger & Wirsing (1992), Dunham (1962) and Embry & Klovan (1972). The carbonate contents of selected samples were determined by using the "carbonate-bomb" method (Müller & Gastner, 1971).

8.1 Platform facies

8.1.1 Microfacies type 1 (MFT-1)

Microfacies type 1 is characterized by fine grained (0.1-0.5 mm) calcarenites with packstone- to grainstone textures. The dominant components are peloids, small benthonic foraminifers, echinoderms fragments, pelecypods, bryozoans and rare ooids.
According to the different particle arrangements, two subtypes (MFT- 1A, 1B) were recognized.
Field observations:
This microfacies forms the basal part of shallow water platform carbonates in all of the studied sections. Carbonate sediments are medium to thickly bedded and frequently dolomitized in part. Parallel to wavy bedding (bioturbation features) are common sedimentary structures.

8.1.1.1 Microfacies type 1A (MFT-1A) (plate 12/1)
Biopelsparite
Fossil-peloid packstone/ grainstone

Thin section analysis:
Fine-grained calcarenites with a high diversity of skeletal grains: small benthonic foraminifers (textulariids, miliolids), echinoderm fragments, pelecypods, bryozoans, brachiopods, gastropods, rare serpulids and ostracods.

Non-skeletal components consist of abundant peloids, small intraclasts and some ooids. Additional minerals are detrital quartz and accessory glauconite.
Depositional environment: platform margin, transition zone.

8.1.1.2 Microfacies type 1B (MFT-1B):
Echinoderm-pelsparite
Fossil-peloid grainstone

Thin section analysis:
This facies subtype is dominated by peloids and echinoderm debris. The average grain size is less than 0.2 mm. The peloids are identified as original fecal pellets and small micritized carbonate particles. Other clasts include pelecypods, miliolids and textulariids as well as angular detrital quartz grains. The primary porosity of the well-sorted grainstones is completely plugged by echinodermal syntaxial cements.
Depositional environment: low energy depositional sites, muddy shelf and also lagoonal environments.

8.1.2 Microfacies type 2 (MFT-2)
Biopelsparite
Fossil-peloid packstone/grainstone

Thin section analysis:
This microfacies is composed of a medium-sorted, outer-platform to platform margin skeletal grains: Pelecypods, echinoderms, bryozoans, brachiopods, coral fragments, small and large benthonic foraminifers and some fragments of red algae. Nonskeletal components are composed of peloids, subrounded intraclasts and rare ooids. The grain sizes range between 0.4 mm and 2 mm and rarely up to several centimeters.
The high intergranular pore space (up to 60%) of the sediment is completely filled by early diagenetic even rim cements and later diagenetic blocky, coarsely crystalline, equigranular cements. The carbonates show grainstone and rare packstone textures.
Field observations:
Limestone rocks composed of this microfacies type (and also by MFT-3) form the lower parts of the studied sections. The light-gray carbonates form massive carbonate bodies. Planar-bedding sets of 10 to 25 cm thickness and bidicrectional cross-bedding sets (5 to 20 cm thick) occur and sedimentary structures are absent. The crossbedding sets show frequent alternations of coarse and fine sand.
Depositional environment: platform margin, transition zone.

8.1.3 Microfacies type 3 (MFT-3) (plate 12/2)
Intra-biopelsparite
Intra-fossil-peloid packstone/ grainstone

Thin section analysis:
The presence of coarse sand sized subrounded intraclasts, fragments of well-rounded anthozoans, stromatoporoid and chaetetid, and large agglutinated benthonic foraminifers (Lituolidae: *Rheophax giganteus* sp., *Everticyclammina* sp., *Lituola* cf., Arnaud-Vanneau 1980) characterize these medium-sorted microfacies. The grain size ranges from 0.2 mm to 3 mm, with occasional fossils of up to several cm. The non-skeletal allochems consist of mainly micrite agglutinated grains ("aggregate grains" (Illing 1954)) which were originally derived from the inner-platform. Skeletal components

include pelecypods, bryozoans, echinoderms, gastropods, brachiopods, small and large benthonic foraminifers and algal fragments (stromatoporoids, chaetetids, red algae and undifferentiated algal clasts). This microfacies consists mainly of a grainstone/rudstone texture. The interparticle pore space is always completely closed by early diagenetic fine-granular cements and later diagenetic blocky, fine to medium crystalline cements.
Field observations:
Like the microfacies type 2, the limestones of this microfacies form massive, light-gray carbonate bodies with medium (0.3 m) to thick bedding (1.2 m). Often the two microfacies types MFT-2 and MFT-3 appear together in alternate sets. Sedimentary structures range from planar-bedding to cross-bedding and graded-bedding.
Interpretation:
The sediment composition with a grain-supported, sometimes ruditic rock texture, well-rounded intraclasts and the lack of fine-grained allochems like pellets (fecal pellets) and peloids (particles without recognizable internal structures, McKee & Gutschick 1969) suggests sedimentation in high-energy, shallow subtidal environments. The mixing of open marine components and inner-platform to outer inner-platform components (*transition zone*) and lagoonal components (aggregate grains, peloids, benthonic foraminifers, dasycladacean algae) indicate a well functioning drainage system between the inner and outer-platform. These sediments are considered as barrier shoal complex deposits (Inden & Moore 1983). The high amount of intraclasts, which were mechanically abraded indicate reworking processes.
Depositional environment: platform margin, transition zone.

8.1.4 Microfacies type 4 (MFT-4) (plate 12/3)
Oosparite
Ooid-grainstone

Thin section analysis:
The percentage of ooids and superficial ooids range from 20 to 90%. The ooids occur with radial and random microfabrics. They are about 0.4 mm in diameter. The remaining particles consist of peloids, abraded intraclasts and skeletal debris. Peloids, skeletal debris and small ooids are common as ooid nuclei.
The grain-supported textures are always completely plugged by calcite cements of different diagenetic generations. The first cement generations are grown as early diagenetic even-rim cements with bladed to granular habitus. Later generations are precipitated as coarse equigranular blocky calcite cements. Neomorphism (Folk 1965) of the early diagenetic cements is common. In some horizons of the oolite sets meniscus- and gravity cements occur ("Rocher de Cluses", samples 99 to 101). These early diagenetic cements indicate the influence of meteoric waters (Longman 1980). However, leaching of allochems is not visible.
Field observations:
Oolitic limestones occur as 5 m to roughly 20 m thick carbonate ledges. These ooid-bodies always separate the underlying high-energy, outer-platform to foreshoal facies from the following more moderate-energy "transition-zone"-facies. The section "Flaine", which is for the most part built up by high-energy, open-platform carbonates, contains three oolitic-limestone banks (unit 4, 6, and 10). In the "Rocher de Cluses" section one ooid bank (unit 4), which separates underlying outer-platform carbonates from the following "transition zone" limestones, is developed. A somewhat spectacular thin coal-layer, which truncated the grain-supported oolite bed in the "Rocher de Cluses" section occurs. The directly overlying bed consists of micrite ooid-limestones with a wackestone texture.

Interpretation:
Modern ooid precipitation occurs in shoals and beaches in the Bahamas (Ball 1967, Halley *et al.* 1983, Harris 1979, Hine *et al.* 1981 and Illing 1954), Shark Bay (Hagan & Logan 1974a and the Persian Gulf (Loreau & Purser 1973) in water depths < 5 m.
Early diagenetic meteoric meniscus- and gravity-cements suggesting a periodic emersion of the ooid deposits.
The same depositional environment for the ooid grainstones are considered corresponding to their modern analogues within tidally-influenced, high-energy shoal complexes and tidal deltas.
Depositional environment: platform margin, high energy shoals in the transition zone and open lagoon.

8.1.5 Microfacies type 5 (MFT-5) (plate 14/2)
Oomicrite
Ooid-wackestone

Thin section analysis:
In contrast to the ooid-grainstones of microfacies type MFT-4, the ooids of this microfacies type are embedded in a micrite matrix. The ooids display the same radial to radial-concentric, and superficial microstructures as in the ooid-grainstones. Rare cerebroidal ooids (Carozzi 1962) are present. The diversity of clasts is reduced; there are few peloids, fragments of pelecypods, gastropods, and small foraminifers, which sometimes provided the nuclei for ooid growth.
Field observations:
Carbonate rocks composed of mud-supported oolitic limestones play only a minor role in the studied outcrops and appear only in the section "Rocher de Cluses" (unit 5 and the uppermost top of unit 6) where they overlie the ooid-grainstones. There, they build up 1.5 to 0.5 m thick massive banks.
Interpretation:
Present-day ooids with radial microfabrics have been formed in low-energy environments as described from the Trucial Cost of the Arabian Gulf by Loreau & Purser (1973). The same low-energy environment is also considered for random ooids (Fabricius 1977) and cerebroidal ooids (Kahle 1974, Sandberg 1975).
The examined ooid-wackestones contain ooids with the above mentioned microfabrics. These ooids, formed in relatively low-energy sites, were transported by storms into very low-energy environments, where the carbonate ooze was prevented from being washed and/or winnowed away. These conditions exist in deeper-water troughs between ooid bars, on the leesides of ooid belts, dunes or islands (Halley, Harris & Hine 1983).
Depositional environment: low energy environment on the shelf lagoon.

8.1.6 Microfacies type 6 (MFT-6)
Poorly washed intra- biopelsparite to intra- biopelsparite
Intra-fossil-peloid packstone/ grainstone

Thin section analysis:
This microfacies type contains a high component diversity including peloids (> 30%), intraclasts, aggregate grains, ooids, small and large benthonic foraminifers, pelecypods, and echinoderms, dasycladacean algae, encrusting algae and gastropods. *Bacinella*-lumps and oncoids occur occasionally. The sediment is moderately sorted, closely packed and grain size varies from 0.15 mm to 1 mm. In contrast to the biopelsparite facies of MFT-1A and MFT-2, bryozoans, brachiopods and echinoderms are less abundant. Corals,

stromatoporoids and chaetetids are frequent in the "Flaine" section . Most of the non-skeletal and skeletal debris are micritized or coated by micrite envelopes (Bathurst 1966). Shell fragments with micrite envelopes still show primary internal structures or are replaced by sparry calcite cements.
Field observations:
In the "Rocher de Cluses" and "Flaine" sections this microfacies type build up 1 to 2 m thick beds. Rare parallel-stratifications and storm deposit-sequences are visible. In the "Rocher de Cluses" section, sets consisting of this microfacies are characteristically embedded between rudist-oncoid limestones. In the "Flaine" section the same microfacies build up bodies between stromatoporoid-coral reefs. Carbonate sets forming the microfacies type 6 play rather a minor role in the build-ups of these two sections. In contrast, within the "Grande Forclaz" section, the middle part of the outcrop (samples 31 to 43) is mainly composed of 6 m thick carbonate beds possessing this microfacies type.
Interpretation:
Comprising almost all carbonate grains existing on the shallow carbonate platform, with a predominance of inner-platform particles, sediments of this microfacies are considered as lagoonal deposits. Grain supported textures indicate a depositional environment within the zone of currents and wave actions. According to prevailing sediment composition, the microfacies is interpreted as shallow water carbonate sand deposits, transitional from open lagoonal to slightly protected lagoonal environments.
Depositional environment: transition zone, open lagoon.

8.1.7 Microfacies type 7 (MFT-7) (plate 13/1)
Biopelsparite
Foraminifer- peloid packstone

Thin section analysis:
This facies type is characterized by a low component diversity and the predominant appearance of small benthonic foraminifers. Most of the foraminifers are miliolids: *Quinqueloculina*, *Triloculina* and *Pseudotriloculina*, but *Glomospira*-foraminifers are also abundant. Skeletal grains comprise up to 70% to 80% of the sediment. Additional particles are peloids, pellets, small pelecypod shells and dasycladacean algae debris. The sediment is well-sorted and shows a homogenous grain size of 0.15 mm to 0.3 mm. An obvious relationship exists between this microfacies and the peloid packstones/grainstones of MFT-8, where most of the particles are micritized small benthonic foraminifers.
Field observations:
This facies type is mostly developed in the "Rocher de Cluses" section, where it forms some dm to 1.5 m thick and massive carbonate beds.
Interpretation:
The low component diversity is a typical feature for restricted environments. *Quinqueloculina*, *Triloculina*, and *Pseudoloculina* are considered by Arnaud-Vanneau (1980) as indicator fossils for slightly elevated water-salinity. These small benthonic foraminifers dominate this microfacies and are considered as tidal channel- or tidal bar deposits on protected, low-energy sites of the inner-platform (Flügel 1982, Tucker & Wright 1990). Wilson (1975) described this microfacies type as typical for restricted carbonate environments (standard microfacies SMF-16).
Depositional environment: protected to semi-restricted lagoon.

8.1.8 Microfacies type 8 (MFT-8)
Pelsparite
Peloid packstone/grainstone

Thin section analysis:
This microfacies type is composed of well-sorted sediments possessing a homogenous grain size and composition. It consists of about 60% to 80% of peloids (*sensu* Illing 1954), which are about 0.2 mm in diameter. In the early stages of micritization skeletal grains are readily identifiable and the origin of small benthonic foraminifers (predominantly miliolids) and fine pelecypod debris are visible. The remaining 10% to 20% of the sediment is composed of small foraminifers, pelecypod shells, echinoderm fragments and some ooids and small grapestones.
Interpretation:
The peloid packstones/grainstones of MFT-8 were most likely deposited where water energy was high enough to winnow out the micrite but to weak to remove it from peloids and skeletal grains. Such settings are widely developed in lagoons somewhat protected conditions. Wilson (1975) describe the peloid packstones/grainstones as typical of restricted carbonate environments.
Depositional environment: protected to semi-restricted shelf lagoon.

8.1.9 Microfacies type 9 (MFT-9)
Aggregate-biopelsparite
Aggregate-fossil- peloid packstone/grainstone

Thin section analysis:
This microfacies is a medium grain-sized sediment, which commonly shows packstone textures. A characteristic feature of this facies type is a very low component diversity. The predominant grains are peloids (micritized foraminifers and micritized intraclasts), small foraminifers (predominantly miliolids: *Quinqueloculina*, *Triloculina*, *Pseudotriloculina*) and 0.5 to 1 mm large irregularly shaped aggregate grains. These aggregate grains (*grapestones*, Illing 1954) are agglutinated by micrite, sometimes sparitic cements. Components of these aggregates are peloids, small foraminifers and algal encrusted grains. Further characteristic components of this microfacies are the *Girvanella*-oncoids and algal encrusted grains.
Field observations:
This microfacies is mainly developed in the "Rocher de Cluses" section, and to a lesser extent in the "Grande Forclaz" section but is absent in the "Flaine" section. In the middle part of the "Rocher de Cluses" section, the microfacies is completed sometimes with the oncoid/rudist patch-reef sequences. In the terminal part of the "Rocher de Cluses" and "Grande Forclaz" sections (above the *Orbitolina beds*) the microfacies forms massive to thick-bedded ledges. There they are stratigraphically associated with fine-grained biopelsparites of microfacies 7 and 8 (Fig. A. 1a-c).
Interpretation:
Based on their sediment composition, sparse component diversity and stratigraphic position within the overall facies framework, the aggregate-pelsparite microfacies is inferred to reflect a protected lagoonal environment. Packstone textures suggests sufficient currents and wave action preventing much deposition of lime mud occurred. As pointed out by Bathurst (1967, 1975), Illing (1954), Purdy (1963) and Wolf (1964) for the Great Bahama Bank, aggregate grain belts cover wide sites behind high-energy oolite- and sand shoals. For Enos (1983), grapestones are typical of shallow water settings with slow sedimentation rates. After Tucker & Wright (1990) grapestone lithofacies form in areas where currents and waves

remove lime mud but the lime sands are only affected during major storms. In modern grapestone settings on the Bahamas, the carbonate sands are stabilized by subtidal surficial algal mats (dominated by the blue-green alga *Schizothrix* (Bathurst 1967)), *Thalassia* grass and codiacean algae, prevent sands from eroding currents (Neumann *et al.* 1970, Scoffin 1970).
Depositional environment: protected to semi-restricted lagoon.

8.1.10 Microfacies type 10 (MFT-10)
Pelmicrite to biopelmicrite
Peloid wackestone to fossil-peloid wackestone

Thin section analysis:
This microfacies is composed of lime mud wherein fecal pellets, peloids, miliolids, textulariids, dasycladacean algae, thin undifferentiated pelecypod shells and gastropods are embedded. Aggregate grains, oncoids, *Bacinella*-lumps and ostracods also occur. The content of allochems varies between 20% and 80%. The facies is often characterized by the predominance of monospecific organisms. Therefore it is possible to distinguish different types of fossil-peloid wackestones: Foraminiferal-pelmicrite, Dasycladacean-pelmicrite and Echinoderm-pelmicrite.
Field observations:
This microfacies appears in minor frequency within the "Rocher de Cluses" and "Grande Forclaz" sections. In the "Flaine" section the microfacies is absent. The pelmicrite/pelsparite facies occurs as thin to medium-bedded beds. The dark colored muddy limestones are characterized by their fine sized textures without any macrofossils. The microfacies is typically found either below or above pronounced lithological boundaries, which are interpreted as limits of depositional sequences. There they occur together with the intertidal fenestral microfacies of type 11 (e.g. "Rocher de Cluses" section).
Interpretation:
For these bioclastic mudstones two depositional sites are considered.
1. The muddy texture with a relatively high diversity of fossils suggesting deposition in a quiet water, lagoonal environment protected from wave and current influence (Flügel 1982).
Depositional environment: protected to semi-restricted lagoon
2. The micrite limestones with a sparse diversity of fossils (small miliolids, gastropods, dasycladacean algae and ostracods) and their position within the stratigraphic framework reflect deposition in protected lagoons or bays with restricted conditions.
Depositional environment: restricted environment (peritidal settings).

8.1.11 Microfacies type 11 (MFT-11)
Fenestral intra- biopelmicrite to -sparite
Fenestral intra-fossil-peloid wackestone to -packstone

Thin section analysis:
This microfacies is characterized by fenestral fabrics (Tebbutt *et al.* 1965), irregular arranged cracks, forming brecciated clasts, leached mollusk shells, and meteoric phreatic gravity cements.
The fenestral fabrics are of subhorizontal stromatactis types (Wolf 1965). Open spaces are filled by blocky calcite cements and micrite to silty carbonate, forming geopetal fabrics. The vertical to subvertical cracks lined with brecciated carbonate clasts are also filled by fine micritc to silty matrix and blocky calcite cements. This microfacies occurs also with irregular several millimeter wide vugs and voids, with a truncate primary sedimentary texture. They are also filled by carbonate mud and coarse, drusy mosaic

calcite cements. Leached mollusk shells are replaced by coarse-sized calcite cements. Peloids and intraclasts are the most common allochems. The most abundant microfossils are small benthonic foraminifers *Quinqueloculina, Triloculina, Pseudotriloculina, Pseudolituonella, Pfenderina, Siphovalvulina.* Dasycladacean algae, coral-, stromatoporoid- and red algal fragments, echinoderm debris, pelecypod shells and large benthonic foraminifers are also present. In contrast to the fenestral biopelmicrite of the microfacies type MFT-12, there is a greater diversity of fossils.
Field observations:
This microfacies is rarely exposed in the field. They occur typically as thin beds within the uppermost part of carbonate beds containing normal marine lagoonal deposits (rudist-oncoid limestones for example) and truncated by clearly developed contacts which are overlain by the same lagoonal deposits. This microfacies is directly overlain by beds of microfacies type MFT-12 (fenestral biopelmicrite). Plugs of clear, blocky calcite cements replaced mollusk shells and vugs are characteristically features of this microfacies.
Interpretation:
The overall facies composition suggests a lagoonal depositional environment with normal-marine conditions. Fenestral fabrics, shrinkage cracks and occasionally euhedral dolomite rhombs in the micritc matrix, indicate a peritidal environment (Folk 1973), from very shallow subtidal to supratidal zones. The early diagenetic leaching of mineralogical unstable/metastable carbonate components (aragonite and high Mg-calcite), associated neomorphic recrystallization (Folk 1965), precipitation of meteoric phreatic gravity-cements (Longman 1980) are linked to subaerial exposure. It is considered, that the deposits of this microfacies were periodically subject to subaerial exposure caused by minor eustatic sea-level fluctuations.
Depositional environment: restricted intertidal environment.

8.1.12 Microfacies type 12 (MFT-12) (plate 14/3)
Fenestral biopelmicrite
Fossil mudstone to fossil-peloid wackestone

Thin section analysis:
This microfacies is characterized by a muddy texture, containing fenestral fabrics and vertical to subvertical cracks. The several mm-sized fenestral fabrics are filled by micrograined carbonate and blocky calcite cements, forming geopetal fabrics. The cracks are funnel-shaped, truncating the host sediment. They are also filled by a fine micro-sized matrix and coarse blocky calcite cements. The low diversity of allochems consists of peloids and some fossils. The term peloids (McKee & Gutschick 1969) implies fecal pellets, organic pelleting of mud and micriticized allochems. Fossils include small benthonic foraminifers: *Quinqueloculina, Triloculina, Pseudotriloculina, Nummoloculina, Dobrogelina, Pfenderina,* abundant ostracods, thin-shelled gastropods *Planorbis,* and further undifferentiated thin-shelled mollusks. Intraclasts are common. The primary sediment texture was been partly destroyed by burrows and bioturbation.
Field observations:
The muddy limestones of this microfacies are developed only in the "Rocher de Cluses" section (unit 14 and 16). In unit 14 the microfacies forms only about 30 cm irregular thick sets, separated by sharp boundaries from under- and overlying beds. The mudstone rock is dark-gray in color. Several-cm wide funnel-shaped fractures, running vertically to bedding, are also filled by a fine-grained limestone. Within the 10 m thick unit 16, the microfacies overlies a pronounced unconformity surface and forms carbonates of microfacies types MFT-10, MFT-11 and MFT-13.

Interpretation:
Based on their muddy textures with fenestral and crack fabrics, dark-gray to black in color, sparse fauna with intense bioturbation, the *fenestral biopelmicrite facies* is inferred to reflect peritidal deposition (Folk 1973) under restricted water circulation. The gastropods *Planorbis,* which are limited to lacustrine to brackish environments support this assumption. For this depositional environment cut-off lagoons, tidal bays to coastal ponds with restricted marine water circulation are proposed.
Depositional environment: restricted environments (ponds).

8.1.13 Microfacies type 13 (MFT-13)
Intra-biopelsparrudite
Intra-fossil-peloid rudstone

Thin section analysis:
This microfacies is characterized by reworked sediments, several mm to cm in size. The intraclast morphologies range from well rounded to subangular. The composition of this microfacies depends on the position on the shelf where sediments were reworked. This is why this microfacies shows a widespread composition from marginal shoal- to restricted inner-lagoonal deposits.
The intra-biopelsparrudite is composed of reworked sediments of the microfacies types MFT-2 to 4 from the shelf margin in high energy zones and are composed of ooid intraclasts, coral and stromatoporoid fragments, oyster valves, lithoclasts, peloids, etc. This microfacies indicate that deposition occurred in channels on the outer-platform to outer inner-shelf ("transition zone"). However, samples contain reworked, low energy, inner-shelf sediments. In these cases, the well lithified carbonates were probably exposed to high current activity which enabled reworking of the limestones.
Field observations:
Beds, which are composed of this microfacies are characteristically in the vicinity of well recognizable bounding surfaces. They represent frequently the lower-most and/or the upper-most part of massive carbonate ledges.
Interpretation:
Sediments of this coarse grained microfacies type were either derived from reworking processes (including the infiltration of meteoric waters) or deposited as lag sediments. They are good indicators for channel deposits. They can be correlated with sequence boundaries or maximum flooding surfaces.
Depositional environment: no specific depositional environment.

8.1.14 Microfacies type 14 (MFT-14) (plate 13/2)
Oncoid-biopelsparite to poorly washed oncoid-biopelsparite
Oncoid-fossil-peloid wackestone/ floatstone to packstone/ rudstone

Thin section analysis:
This microfacies is characterized by the presence of oncoids and algal lumps, algal encrustings and *Bacinella*-aggregates. Oncoids occuring in the examined outcrops are grouped into three oncoid types: (1) *Foraminiferal-algal-oncoids,* (2) *Bacinella oncoids* and (3) *Girvanella oncoids.* They appear as irregularly, rounded to elliptical formed nodules. Their sizes range from some mm to more than 1 cm. Oncoids appear always together with other algal products (algal lumps, algal nodules, etc.) and it is not always possible to distinguish between them. Further components of this microfacies are abundant small benthonic foraminifers (mostly miliolids), dasycladacean

algae, gastropods and peloids. *Girvanella oncoids* (type 3) are mostly found within aggregate grains microfacies (microfacies type 9), which is characterized by a low component diversity. The rock textures range from poorly washed packstones to packstones. They also occur rarely as muddy limestones with wackestone textures.
Field observations:
Transferring microscopic results to stratigraphic outcrop developments show, that sections containing oncoids are mostly related with the appearance of rudist bivalves. Oncoids occur in the same stratigraphic units as the rudists. "Oncoid beds" overlie frequently rudist patch-reefs and are overlain themselves by an adjacent rudist patch-reef. These alternations of rudist populations and "oncoid-beds" characterize thick sections of the studied outcrops (*rudist-limestones*), especially in the "Rocher de Cluses" and "Grande-Forclaz" sections. In the "Flaine" section, oncoid beds (as well as the rudist populations) occur only in the upper part of the section.
Interpretation:
Depositional environments of oncoids and algal lumps are broadly discussed. by Bathurst (1967), Gebelein (1969), Monty (1967, 1972), Peryt (1977, 1981), Riding (1977) and Wolf (1964).
In the studied outcrops foraminiferal-algal-oncoids, *Bacinella* oncoids and admixed marine fauna suggest deposition in shallow, normal marine waters. The vicinity of oncoid beds to rudist patch-reefs in stratigraphic successions as well as the presence of oncoids and *Bacinella* lumps within rudist facies support the assumption of deposits in a slightly protected lagoonal environment. Oncoid beds 0.3 to 1 m thick, are frequently found juxtaposed to the rudist beds. In general the same depositional environment is considered for the two facies, however the absence of abundant rudist bivalves in the oncoid layers indicates a slightly change of the prevailing depositional environment. This could be caused by a change in paleo-water depths and/or paleo-salinities (see also chapter 9 DEPOSITIONAL ENVIRONMENTS). Conrad (1977) described for the Lower Cretaceous surrounding Geneva, encrusting algae paleoenvironmental distributions in *middle* to *external infralittoral* sites.
Furthermore, oncoids and their related algal lumps are also characteristic components of limestones, which are interpreted as protected to semi-restricted lagoonal deposits. There they occur with facies types characterized by low component diversity (MFT-7, 8, and 9). Rudists, dasycladacean algae, large benthonic foraminifers, which accompanied oncoids in open lagoonal settings are absent.
Depositional environment: slightly protected to protected shelf lagoon.

8.1.15 Microfacies type 15 (MFT-15)
Bioconstructions

Microfacies type MFT-15 represents organic build-ups. Two subfacies were determined in response to their organism communities. These are: 15A: coral-stromatoporoid-chaetetid biolithites and 15B: rudist biolithites

8.1.15.1 Sub-microfacies type 15A (MFT-15A)
Coral-stromatoporoid-chaetetid biolithite
Coral-stromatoporoid-chaetetid boundstone

Organic build-ups composed of corals, stromatoporoids and chaetetids characterize this microfacies. The reef build-ups vary in their community composition and population density. Two types of patch-reefs occur in this sub-microfacies. In one case the build-ups are dominated by stromatoporoids

and chaetetids, otherwise they are built up by only corals and/or stromatoporoids. Corals appear in different growth forms: hemispherical, dendroid finger, stick like, massive branching, globular columnar and tabular are prevailing growth forms. Organism sizes range from some mm to massive forms more than 30 cm in diameter. Stromatoporoids and chaetetids appear in hemispherical, bulbous forms.
Some of these organisms could be determined by Turnsek (see chapter 7 PALEONTOLOGY) Reef debris, bryozoans, echinoderms are further components of this facies.
Depositional environment:
The patch-reef is regarded as an organic build-up of the "transition zone" (Masse & Philip 1981) in the outermost inner-shelf to platform margin where water circulation conditions are favorable. Smaller organisms are also represented in lagoonal deposits.

8.1.15.2 Sub-microfacies type 15B (MFT-15B)
Rudist biolithite
Rudist bafflestone

(for description see also chapter 7 PALEONTOLOGY)
The 0.50 m to 2 m thick rudist patch-reefs containing a high density of rudist valves (Requieniidae and Monopleuridae). Many rudist tests are not in growth position, however it is considered, that they are deposited near their original living place. The rudists form biopeloidal limestones showing packstone and sometimes wackestone textures. Encrusting algal lumps, foraminiferal-algal oncoids, large *Bacinella* oncoids and *Bacinella* lumps also form part of this rudist facies.
Depositional environment:
Most of these rudist populations probably colonized quiet water environments from the inner-platform. However some rudist clusters appear in the higher energy "transition zone" (Masse & Philip 1981).

8.1.16 Microfacies type 16 (MFT-16)
Biomicrudite to biosparrudite
Fossil floatstone to fossil rudstone

Thin section analysis:
This microfacies is characterized by coarse to gravel sized sediments and reworked, abraded skeletal material. The marine fauna is typically composed of reef-building organisms like corals, chaetetids, stromatoporoids, rudist- and oyster shells. Rudist shells are mostly encrusted by algae and/or sessile foraminifers. Further skeletal grains are bryozoans, echinoderms and large foraminifers. Nonskeletal grains are micritized particles. Rock types are predominantly grain-supported, though mud-supported textures are also observed.
Field observations:
Rocks consisting of this skeletal debris facies are typically in vicinity to beds composed of coral-, stromatoporoid-, chaetetid-, and rudist bioconstructions (MFT-15A and 15B). Both lower and upper contacts of this facies are generally gradational, however sharp planar bedding plane breaks also occur. Sedimentary structures observed in this facies are rare, but the most well-preserved, low-angle planar crossbeddings within the studied outcrops are built up by this facies ("Flaine" section, basal ledge of unit 8).

Interpretation:
The stratigraphic vicinity to reefal bioconstructions of these debris facies suggest deposits in proximity to their corresponding autochthonous reef facies.
Depositional environment: This microfacies appear always together with reef-constructions.

8.1.17 Microfacies type 17 (MFT-17)
Poorly washed marly intra-biopelsparite
Marly intra-fossil wackestone/packstone

Thin section analysis:
Limestones with a carbonate content of 80 to 90%. The insoluble residue is made up of detrital quartz (up to 15%), clay minerals, organic rich material (coal-tinsels) and accessory glauconite and pyrite. The composition diversity is high and contains circalittoral over lagoonal to terrestrial elements ("textural inversion", Folk 1962). The dominant fossils are: small benthonic foraminifers (miliolids, textulariids), large benthonic agglutinating foraminifers (especially Orbitolinids, *Choffatella decipiens, Everticyclammina hedbergi*), dasycladacean algae, echinoderm fragments, gastropods, brachiopods, ostracods and rudist valves. Some preserved echinids (unfortunately it is not possible to determine them) are good indicator fossils of the circalittoral influx. Coral and stromatoporoid fragments are also present. Further allochems consist of intraclasts, peloids and oncoids/algal lumps.

8.1.17.1 Sub-microfacies type 17A (plate 14/1)
Orbitolina marly limestones (Lory 1846)

The *Orbitolina marly limestones* (Lory 1846) are included in this reworked marly limestone facies. The facies is distinguished by the abundance of: *Palorbitolina lenticularis, Orbitolinopsis kiliani, Paracoskinolina maynci, Paleodictyoconus cuvillieri* and *Paleodictyoconus actinostoma, Cribellopsis neoelongata and Paracoskinolina sunnilandensis..*
Field observations:
In the field the marly to muddy limestones of this facies are easy to identify, because these 0,30 to 1 m thick beds are less resistant to weathering and therefore form erosional grooves striking between the more resistant carbonate banks. The layers of this facies often shows nodular bedding caused by intensive bioturbation, emphasized by a series of stylolites. In the "Rocher de Cluses" section this marly facies occur above the well-pronounced unconformity surface (sample 271), where it represents the unit of the "Orbitolina limestones".
Interpretation (see also chapter 9 DEPOSITIONAL ENVIRONMENTS)
Based on their composition, containing circalittoral to lagoonal fauna and also continental particles, this facies is interpreted as transgressive deposits when sea-level was flooded over the shallow-water to partly emerged carbonate platform. Deposits of this marly limestone facies could occur all over the platform without a specified depositional environment. Evidence of terrestrial influx is indicated by the occurrence of clay minerals and organic material suggesting proximity to the continent. Arnaud (1981) and Arnaud-Vanneau *et al.* (1990) interpreted for the Vercors mountains, SE-France, the *Orbitolina beds* as tidal (?) channel deposits.
Sediments with the marly limestones facies are considered as transgressive deposits, when the platform was flooded during the interval of relative sea-level rise. Reworked sediments, textural inversion and terrestrial material

like detrital quartz and clay minerals indicate the flooding of the shelf. The thin layers of these marly limestones, sometimes concentrated with skeletal and nonskeletal allochems, quartz grains and the presence of glauconite and pyrite could indicate sediment condensation.
Depositional environment: "transgressive facies".

8.1.18 Index "q":

The index "q" is used to indicate the presence of more than 10% detrital quartz grains. In this study a high amount of quartz detritus was observed in the microfacies types 1, 6 and 7:
1q: Quartz-rich fossil-peloid packstone/grainstone (MFT-1A).
6q: Quartz-rich intraclast-fossil-peloid packstone/grainstone (MFT-6).
7q: Quartz-rich fossil (foraminifer)-peloid packstone/grainstone (MFT-7).

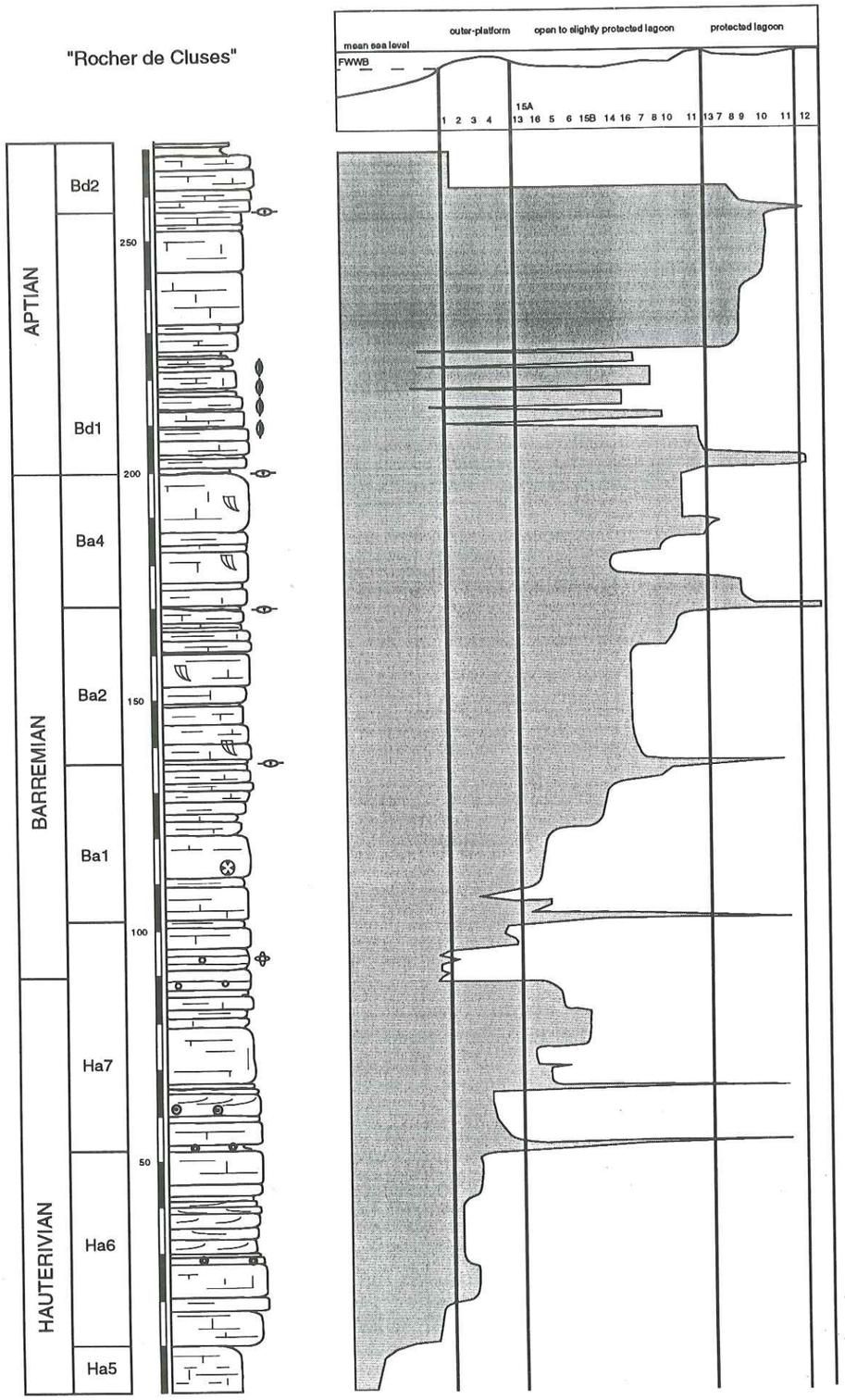


Fig. 8.1. Microfacies development during the late Hauterivian to early Aptian in the "Rocher de Cluses" section.

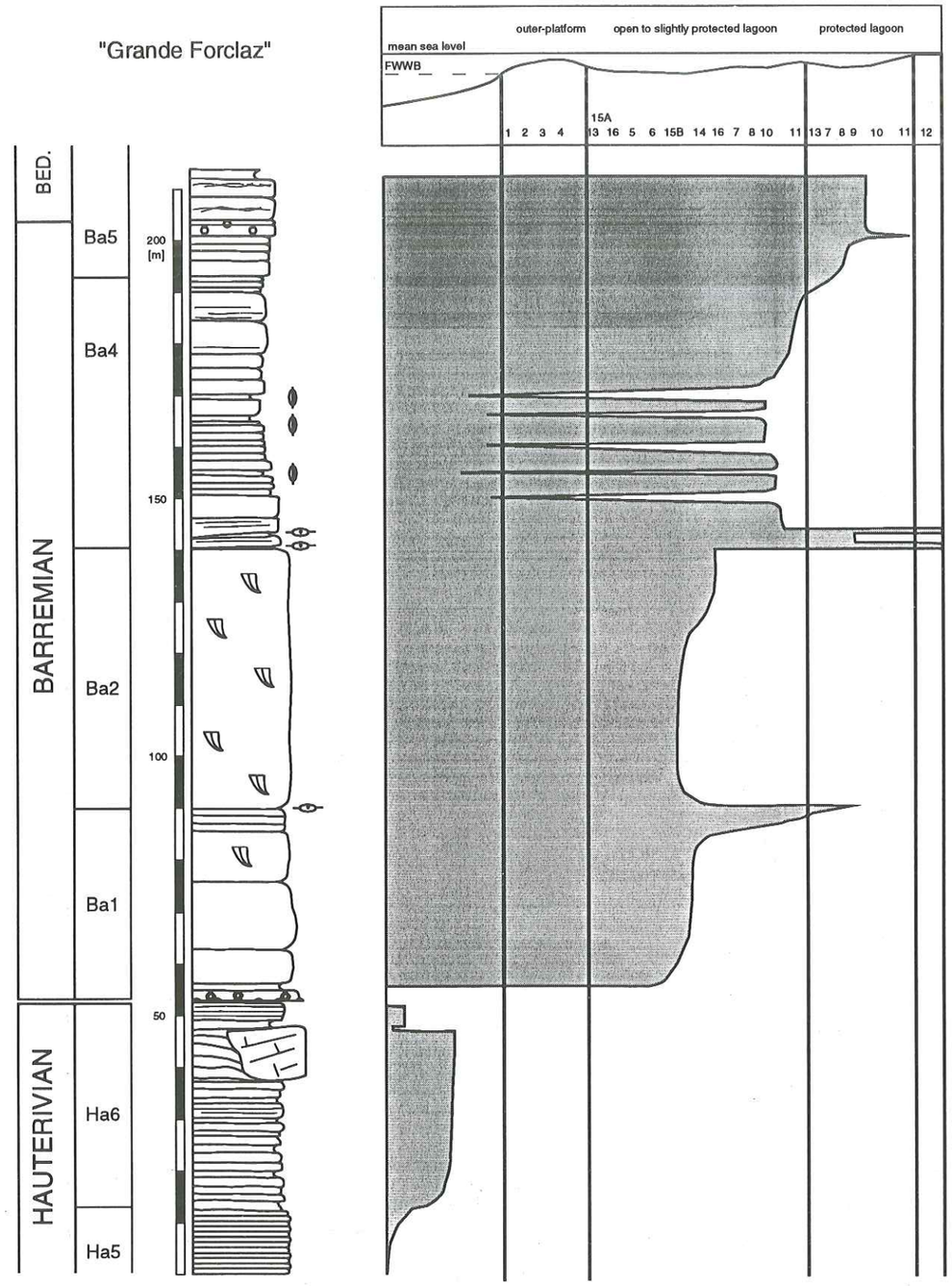


Fig. 8.2. Microfacies development during the late Hauterivian to earliest Aptian in the "Grande Forclaz" section.

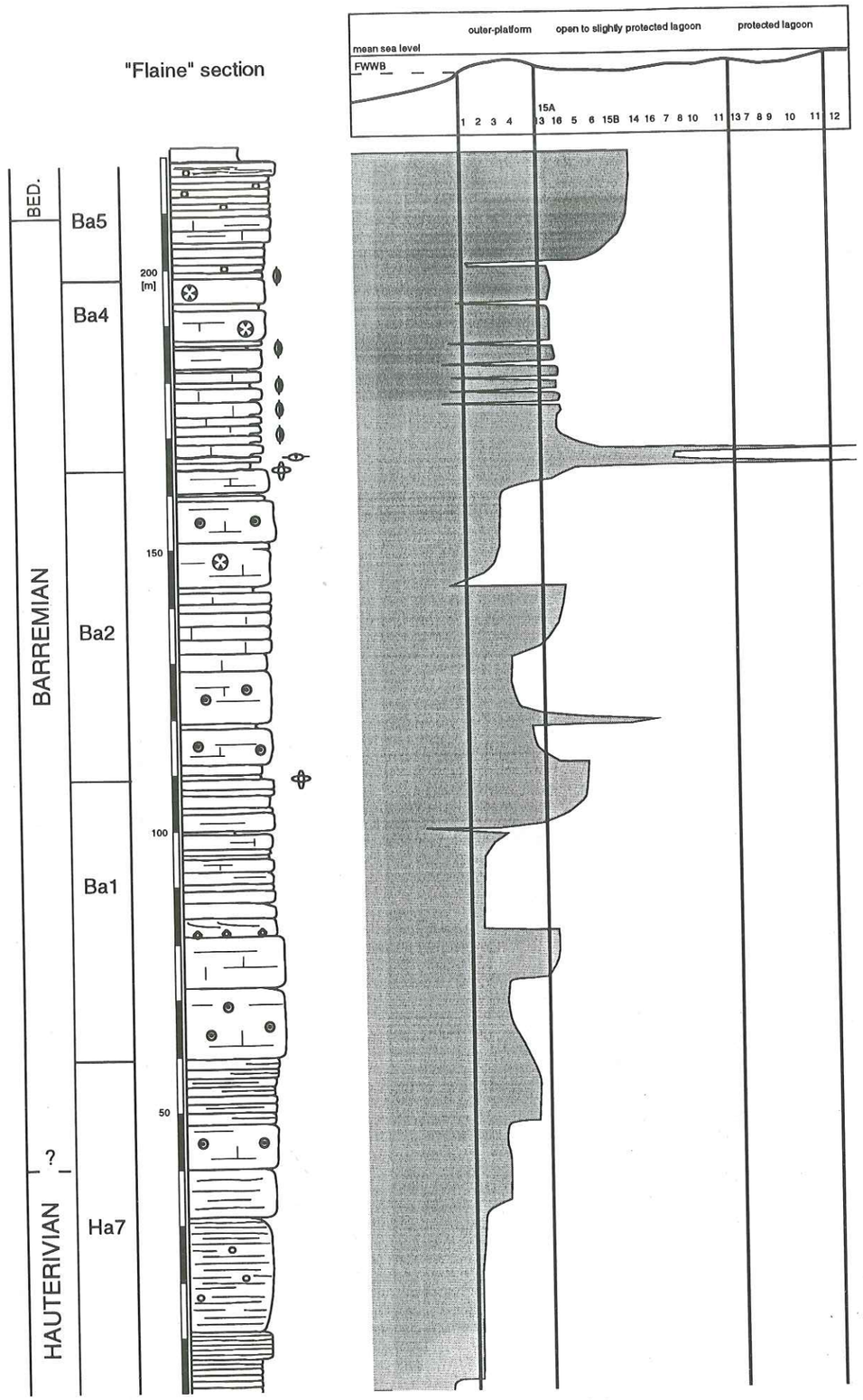


Fig. 8.3. Microfacies development from the late Hauterivian to earliest Aptian in the "Flaine"section.

8.2 Slope facies

The following, slope facies type deposits are described. For these sediments the term **facies** (*sensu* Walker 1992) was used. This different usage comparable to chapter 8.1, where **microfacies types** were described makes sense as the hemipelagic limestone series are more characterized by exposed bed sets and macroscopic features, rather than in a frequent change of microfacies composition.
(used terminology for bedding thickness: very thin bedding: < 10 cm; thin bedding: 10-30 cm; medium bedding: 30-60/80 cm; thick bedding: > 80 cm)

8.2.1 Facies type 18
Medium bedded glauconite-rich marly limestone facies

Thin section analysis:
The facies consists of medium- to coarse-sand, mixed skeletal peloidal and oolitic wackestones. A mixing of shallow-water- and deep-water shelf particles and abundant peloidal glauconite grains characterize this facies. Offbank transported allochems from the shallow-water shelf margin are ooids, large peloids, bryozoan- and dasycladacean algae debris. Components indicating the open, deeper shelf environment are sponge spicules, *Toxaster retusus* echinids, red algae fragments, *Trocholina* foraminifers and the *Paleodictyoconus carthusiana* orbitolinids. Further skeletal debris without specific environment are miliolids, brachiopods, serpulids and large echinoderm fragments. Minerals: typically for this facies are abundant (up to 5%) glauconite peloids which are up to 0.4 mm in size. Opaque minerals like pyrite, iron-oxides and phosphate minerals. Subangular Quartz detritus is also frequent. The carbonate content is about 75%.
Field observations:
The glauconite rich marly limestone facies forms the upper 2 to 15 m thick part of the hemipelagic 400 to 650 m thick "calcaires greseux à miches" (Charollais *et al.* 1988).
In the "Rocher de Cluses" section the glauconite-rich marly facies form approximately 15 m thick limestones, which are less resistant to weathering and therefore form recessive beddings. The facies directly underlies the shallow-water Urgonian platform carbonates from which it is separated by a sharp contact.
In the northeastern part of the Aravis mountains (Pointe Percée) (Muller 1985) the facies has a thickness of about 8 m and underlies exactly like in the "Rocher de Cluses" section the massive urgonian limestones.
In the central part of the Aravis mountains (where submarine mass flows occurred) the thickness of the glauconite-rich marly facies is reduced to 2 to 6 m and is overlain by the first horizon of mass flow deposits. The contact between the glauconite facies and the mass flow deposits is knife sharp with sometimes recognizable erosive character. The glauconite-rich marly facies is thin- to medium-bedded (0.2 to 0.5 m).
In the "Flaine" section this glauconite-rich marly limestone facies was not found.
Interpretation:
The micrite texture, the abundance of whole hemipelagic fossils (*Toxaster retusus*) and the lack of storm-reworked features suggest deposition on the muddy shelf/deep ramp /ramp slope below the storm-wave base (assuming a 40 m storm-wave base, Elrick & Read 1991). The proportion of shallow water carbonate allochems indicate the relative vicinity of the platform. It is assumed, that the carbonate debris was transported by storms or off-platform water currents into the deep ramp environment. The presence of glauconite-

pellets, phosphates, and Fe-oxides could indicate condensed sedimentation (Loutit *et al.* 1988). Glauconite-rich depositions are widespread on present-day continental shelves and slopes at water depths between 50 to 500 m (Odin *et al.* 1988).
Depositional environment: proximal to middle slope.

8.2.2 Facies type 19 (plate 11)
Mass flow deposits:

The heterogeneous composition of the mass flow deposits is discussed in chapter 10 SUBMARINE MASS FLOW DEPOSITS.

8.2.3 Facies type 20
Medium bedded quartz-bearing fossil-pelsparite to poorly washed fossil-pelmicrite

Thin section analysis:
The facies is characterized by needle like sponge spicules, small benthonic foraminifers, thin echinodermal debris and peloids. The needle like (longitudinal sections) and circular (cross-sections) sponge spicules are of bright-colored neomorph recrystallized calcite cements. Circular calcispheres and thin bivalve shells are more rare, but typical particles of this microfacies. The quartz content varies from 2% to 10%. The micrite matrix is minor but may form up to 20%. Argillaceous and organic material, Pyrite and Fe-oxides are accessory present but can arise up to 5%. The microfacies shows a packstone- to wackestone-texture, is well-sorted and grain sizes are approximately 0.15 mm in average. Where micrite/argillaceous matrix is enriched, dolomite rhombs occur.
Field observations:
Rocks of this microfacies were observed only in the Aravis mountains where they represent the unit of the *Couches de transition* (Détraz *et al.* 1986). Rocks are dark gray to nearly black in color. Carbonate ledges of this microfacies are built up by 20 cm to 30 cm thick beds and are about 8 m to 10 m in thickness. Ledges with black colored rocks form remarkable erosional grooves. These horizons are extremely rich in macrofossils, especially *Toxaster retusus* echinids.
Interpretation:
Their fossil composition: sponge spicules, calcispheres, benthonic foraminifers, and *Toxaster retusus* echinids, dark color, and parallel bedding indicate a deep-water, hemipelagic deposition (Clavel *et al.* 1987). The stratigraphic position within the overall framework indicate for these microfacies deposits a hemipelagic lower shelf slope environment. The presence of organic material, pyrite and Fe-oxides could indicate deposition under somewhat marine reducing conditions.
Depositional environment: distal to middle slope.

8.2.4 Facies type 21 (plate 10/2 and 10/3)
Medium to thick-bedded poorly washed intra-biopelsparite/ micrite

Thin section analysis:
This facies is characterized by a mixture of shallow subtidal and deep subtidal allochems. Allochems indicating a deep-subtidal environment are sponge spicules, circalittoral benthonic foraminifers (hyaline forms (*Lenticulina*), *Trocholina*, *Earlandia*, *Tritaxia pyramidata*, etc.) and thin-valved bivalves. In

the field the macrofossils *Toxaster retusus* and a Nautiloid were found. Allochems of shallow subtidal environments include ooids, bryozoans, dasycladacean algae and rare oncoids. Other particles indicating no specified depositional environment are serpulids, echinoderm fragments, red algae, peloids and pellets. The matrix content (including limestone mud and argillaceous material) varies from 5% to 25 %. Detrital quartz content varies from accessory to 15%. Pyrite and Fe-oxides are also present. The average grain-sizes are approximately 0,2 mm but some components have sizes > 1 mm.
Field observations:
This microfacies type is the dominant microfacies of the *Couches de transition*. On the one hand this microfacies is the typical "matrix" of the debris flow deposits, whereas limestones of the facies form medium- to thick-bedded ledges also within the *Couches de transition*.
Interpretation:
The fossils: Nautilus, sponge spicules, certain foraminifer species and the muddy texture are considered as autochthonous to "para-autochthonous" components and reflect a deposit of a deep subtidal, hemipelagic environment. Marine, shallow subtidal allochems such as ooids, dasycladacean algae, oncoids, etc., are interpreted as allochthonous storm deposits. The lack of wave- and storm-reworked features suggest deposition in a open-marine, deep-subtidal environments below fair weather wave base (FWWB), probably also below storm-wave base.
The depositional environment for this facies most likely belongs to the middle to upper shelf slope. The presence of pyrite and Fe-oxides and sometimes an enrichment of organic material could indicate reducing conditions.
Depositional environment: proximal slope.

8.2.5 Facies type 22
Medium- to very thin-bedded sandy to shaley limestone facies

Thin section analysis:
The sandy limestone facies consists of a well-sorted fine-sand-size (< 0.1 mm) composition. The carbonate content of the rocks forming this facies is approximately 65%. The thin skeletal debris include sponge spicules, echinoderms, hyaline foraminifers, pelecypod- and ostracod valves. Macrofossils include well preserved echinids (Toxaster) and ammonites. Small peloids and pellets are frequent. The matrix content, comprising micrite and argillaceous material forms approximately 20%. The quantity of silty to fine-sand-size sediments ranges up to 15%. The proportion of pyrite and other opaque minerals is about 5% and glauconite is accessory present. The sandy limestone facies shows intensive bioturbation.
Field observations:
The sandy to argillaceous limestone facies occur as intervals (10 to 15 m) of sandy limestones to argillaceous limestones, with thinning-upward trends of bedding thicknesses, and fining-upward trends of grain-sizes. Rocks composed of the sandy composition show dark-gray to tan colors with thick to medium-bedding. The upper part of this facies interval occurs as dark, fine laminated argillaceous limestones. Some of the *Toxaster* echinids are replaced by iron-nodules while maintaining the original habitus. The sandy to argillaceous limestone sequence forms recessive slopes, due to resistance in less weathering.
Interpretation:
The very fine grained sandy to shaley composition without any platform particles indicate either a far distance to the platform or that the platform was out of pace and could not provide this environment with material

because of decreased carbonate production or by trapping of the material on the platform.
Depositional environment: distal slope.

8.2.6 Facies type 23
Medium- to thin-bedded muddy pelletal limestone facies

Thin section analysis:
This facies is characterized by a fine-sand-size calcarenite with a homogenous, well-sorted wackestone to poorly washed packstone texture. The facies is dominated by dark-colored pellets (< 0.08 mm), which make up 80% of the total composition. Skeletal debris comprises of sponge spicules, small echinoderm fragments, and thin-valved bivalves (pelecypods, brachiopods and ostracods) and some hyaline small foraminifers. Subangular detrital quartz content forms up to 5%. Disseminated pyrite and other opaque minerals are rare (2%). Dolomite rhombs are scattered.
In certain stratigraphic levels abundant *Choffatella* foraminifers occur.
Field observations:
Rocks composed of this facies occur as dark-gray to black in color. The muddy to shaley limestones form beds of 15 to 25 cm thicknesses. These limestones are less resistant to weathering than under- and overlying ones and form more pronounced erosional grooves in the outcrops. The basal contact of this facies is sharp where it rests on top of the underlying mass flow deposits. Upper contacts grade into overlying thicker-bedded to massive slightly coarser grain-size fossil-peloid-facies. Macrofossils are echinids (*Toxaster*) and ammonites.
Interpretation:
The dark color, muddy to shaley textures, very fine grain-size pellets and peloids as well as occuring fossils like ammonites, the *Toxaster* echinids, sponge spicules, and present foraminifers are inferred to reflect deep-water deposition in the hemipelagic to pelagic zone. The black colors, shaley textures abundant pyrite and iron-oxides could indicate sedimentation under marine reducing conditions.
Depositional environment: middle slope.

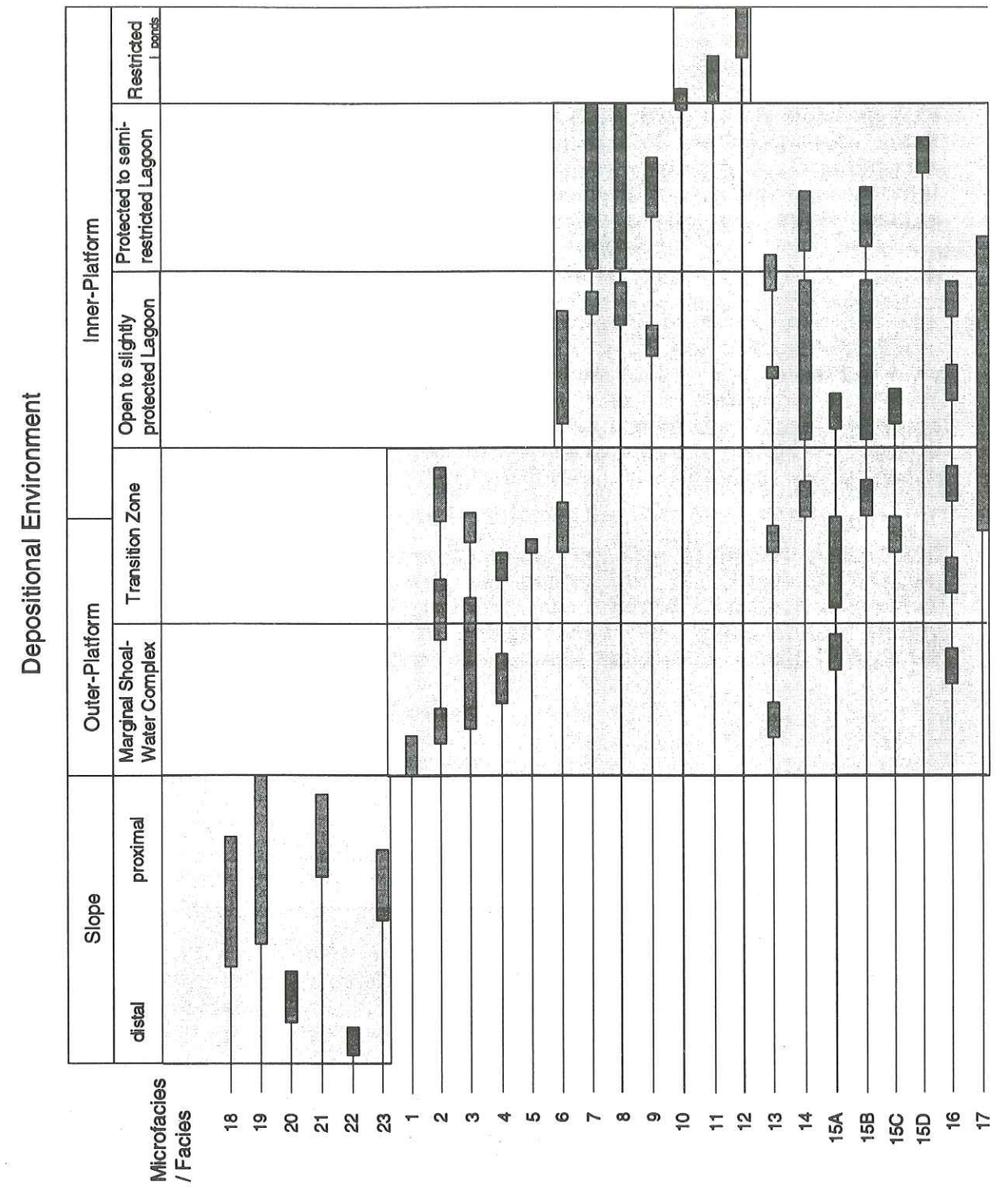


Fig. 8.4. Microfacies/Facies distribution on the slope and platform.

Chapter 9: DEPOSITIONAL ENVIRONMENTS

General remarks

Petrographic investigations of the stratigraphic record made it possible to distinguish between different depositional environments, which characterized the paleogeography from the late Hauterivian to early Aptian. These paleogeographic sites comprise the I. **muddy shelf**, II. **outer-platform** and III. **inner-platform**. These three units itself are characterized by seven different depositional settings: (1) **slope**, (2) **marginal shoal-complex**, (3) **open lagoon**, which can be subdivided into a (3a) **transitional zone** and a (3b) **slightly protected lagoon**, (4) **protected to semi-restricted lagoon**, (5) **intertidal**, (6) **lacustrine/brackish**, and (7) **transgressive** (Fig. 9.1).

9.1 Muddy Shelf

General aspects:
The muddy shelf encompasses the site of environments passing seaward from the shallow water platform margin to the deep water shelf.
The sediments have several origins: hemipelagic, shallow ramp, and continental influx. Sediment proportions vary spatially and temporally according to 1) proximity and productivity of the shallow water "carbonate factory", 2) prevailing wind direction and wave currents, 3) shelf topography, 4) proximity to continental hinterland, 5) tectonic activity, 6) biologic evolution.

9.1.1 Shelf Slope

In the late Hauterivian (Ha 6; *Balearis* ammonite-zone) to earliest Barremian (Ha7, basinal *Angulicostata* ammonite zone) in the subalpine realm transitional from the northern Jura platform to the southern pelagic Dauphinois basin hemipelagic to shallow-water sediments came to deposition over pelagic to hemipelagic deposits of the continental shelf ("siliceous limestones"). The featureless southwards sloping seafloor appears to have been of homoclinal ramp type.
The carbonate slope is outcropped only in the central Aravis Chains over a distance of several hundred meter. There, slope deposits build up 50 to 100 m thick "transitional" sequences between the pelagic to hemipelagic siliceous limestones and the overlying platform carbonates. These series are described as the "couches de transition" (Détraz *et al.* 1986) and contain the mass flows deposits (see chapter 10 MASS FLOW DEPOSITS). Equivalent transitional series are less thick (some 10 to 20 m) and mass flow deposits are absent in the northeastern part of the Aravis Chains (Pointe Percée), in the parallel Borne Massif range to NW and in the eastwards situated Platé Massif. Sediment composition in these sites indicates deposition in shallower water-depths. They are described as "zone de transition inférieure" (Conrad 1969) or "couches de transition" (Pairis 1975). According to Conrad (1969) and Pairis (1975) these series belong already to the Urgonian platform carbonates.

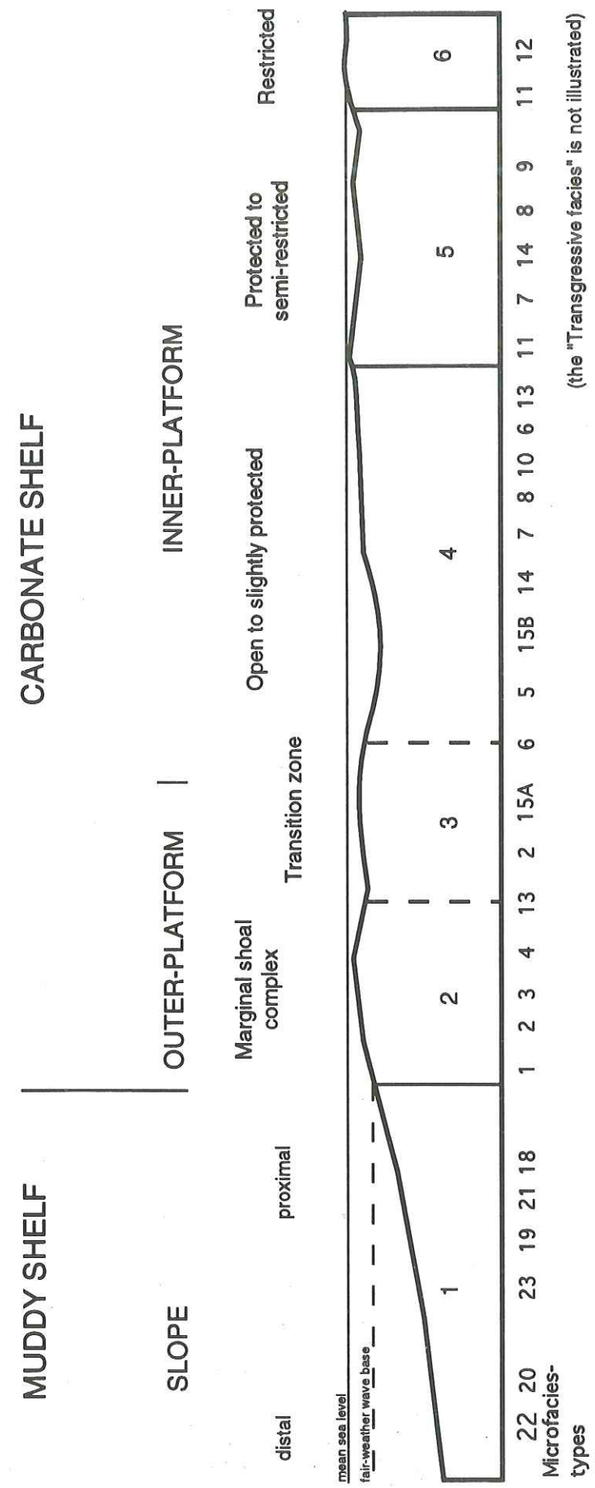


Fig. 9.1. Schematic cross-section of the carbonate shelf. Numbers indicate depositional environments and microfacies types as defined in the text.

9.2 OUTER-PLATFORM

9.2.1 Marginal shoal-complex

General aspects:
The shelf margin is the primary zone of energy absorption where ocean waves, storm events, and possibly tidal currents, impinge on the seafloor. These margins are very important to the overall development of the inner shelf. According to Schlager (1981) the growth potential of a carbonate platform is determined by the growth potential of its edge.
Carbonate shelves can be distinguished between rimmed and open shelves (e.g. Ginsburg & James 1974, Read 1985).
Rimmed shelf margins (and their slopes) may be divided into: (1) depositional or accretionary, (2) bypass and (3) erosional shelf margins (McIlreath & James 1984, Read 1985). Rimmed shelves typically exhibit a wide range of continuos to semi-continuos barrier reefs and/or carbonate sand shoals .
As there is a wide range of exposures to waves, tides and oceanic currents, Hine *et al.* (1981) distinguished rimmed shelves by physical processes: (1) windward margins (open or protected), (2) leeward margins (open or protected), and (3) tide dominated.
Ball (1967) classified sand accumulations from the Bahamas and South Florida into: Tidal-bar belts, marine sand belts, aeolian ridges, and platform interior blankets.
On an open shelf, wave energy is not as intense as on a rimmed shelf margin because storm waves and ocean swells are not abruptly confronted with the gradually shoaling ramp surface (Tucker *et al.* 1990). Therefore, along open shelves/ramps with a gently seaward dipping profile, a well developed margin is absent at the shelf edge. Wave action in the shoreface zone, however, can also form barrier/beach carbonate sand and ooid shoal complexes (Read 1985) separating the homoclinal or distally steepened slope from the inner shelf.

Discussion:
The basal part of the Urgonian limestones (s.l.) are built up by shoal-complex deposits. In the northern part of the studied realm ("Rocher de Cluses") they form a 55 m thick sequence (1/5 of the whole section), in the Aravis they represent a 45 m thick unit (the thickness of the whole section is about 150 m). In the southeastern part of the studied area, in the Platé Massif (Flaine), the shoal-complex carbonates are approximately 70 m in thickness (total thickness of the Urgonian limestones is 210 m). In general a thickening of these marginal shoal-complex deposits from the north to the south is observed.
The marginal shoal-complex consists of medium- to high-energy external-platform deposits, which separates the circalittoral shelf slope from the inner-platform. The carbonate sands from this environment were deposited in the shallow subtidal zone from below the FWWB (fair-weather wave base) and up to the sea level. The various grainstone facies consist of the microfacies types: 1A, 2, 3 13 4, (bioclastic to intraclastic grainstones and rudstones, and ooid grainstones).
Microfacies 1A (fine-grained packstones to grainstone facies), represents proximal, marginal shoal-complex deposits. With this facies platform progradation started over the underlying shelf slope.
The highest water energy sites of the marginal shoal-complex are built up by sediments of microfacies types 2, 3, and 13 (bioclastic/intraclastic grainstones and rudstones) and ooid-grainstones (microfacies type 4). They are interpreted as having been deposited in shallow shoreface, shoal, and

intershoal (tidal inlets) zones. The high percentage of interparticle porosity (partly up to 60%) which is filled by fine and coarse-grained cements (A- and B-cements) implies very rapid cementation before sediment compaction occurred. Meniscus- and gravity cements occurring in some ooid-grainstone beds suggest deposition in the intertidal zone.
The few recognizable sediment structures show bidirectional cross-bedding (tidal currents), gentle seaward-dipping(5 to 15°) tabular planar cross-beds, and horizontal bedding. Some thick (up to about 1 m) tabular planar cross-bed sets have basal lags of coarse skeletal debris (stromatoporoid- and coral debris).
The shoal-water complex represents an important source for the on- and off-bank transport of carbonate grains. Towards the inner-platform the marginal shelf complex provided the transition zone during storm events or by a landward migration in response to sea level rises. Off-bank transport occurs during seaward storm events; progradation of the shelf wedge during periods of relative sea level stillstand or sea level fall (e.g. Eberli *et al.* 1989, Kendall *et al.* 1981, Schlager *et al.* 1994). Proximal shelf slope deposits are mainly composed by platform margin derived components.
The vertical succession of the marginal shoal-complex implies a shallowing upward sequence, generally indicating the progradation of the shelf margin wedge (see also chapter 12 SEQUENCE STRATIGRAPHY AND PALEOGEOGRAPHICAL EVOLUTION). All of the examined outcrops show the same vertical facies development beginning with fine-grained bioclastic grainstone/packstone facies (MFT-1A) through to coarse-grained bioclastic/intraclastic grainstone facies (MFT-2,-3, and -13. The uppermost parts of this sequence are commonly built up by the ooid grainstone facies (MFT-4).

9.3 INNER-PLATFORM

General remark

The inner-platform comprises the sites behind the high energy shoal-complex. These sites are mainly protected from ocean swell and storms. Depositional environments of the inner-platform encompass the *transition zone*, open to slightly protected lagoon, protected to semi-restricted lagoon with reduced water drainage and restricted environments with strongly reduced water communication.

9.3.1 Transition Zone

General aspects:
The *transition zone* is composed of the area between the high energy marginal shoal-complex and the moderate to low energy shelf-lagoon. Open marine wave action is mostly kept back by the marginal shoal-complex and moderate energy depositional environments could be established. The *transition zone* is characterized by an assemblage of shelf margin to inner-shelf facies indicating the different hydrodynamic conditions.
Important factors that influence sedimentation are on-bank transport of shelf margin sediments. Washover deposits can form notable portions of these transitional zone deposits (Reinson 1992). Tidal channel systems that connect the inner-shelf with the ocean significantly characterize this depositional environment. Channels provide the back-margin sites with fresh water and nutrients and enable the colonization of reef-building

organisms. If the water regime is strong enough high energy carbonate shoals or tidal bar belts (Ball 1967, Halley *et al.* 1983) may be formed.
Masse & Philip (1981) described a *transition zone* between the high energy platform margin and the inner-platform lagoon containing coral-, stromatoporoid-, and chaetetid assemblages for the Urgonian limestones in the Provence region, of southern France.

Discussion:
The *transitional zone* represents a very important depositional environment on the inner-platform. The "Flaine" section, which is considered as the most distal part of the platform, is built up of more than 50% of these *transitional zone* carbonates.
The most characteristic deposits within the *transition zone* are coral-stromatoporoid-chaetetid patch-reefs (facies type 15) and their reef debris deposits (microfacies type 16). The largest patch reefs, composed of corals, stromatoporoids and chaetetids occur within the *transitional zone.* It is thought, that these reef-builders were colonized near tidal channels with good drainage. These moderate to high energy water sites were provided by fresh water and sufficient nutrient. Where these patch-reefs were exposed to high energy regimes, the growth of massive corals was favored whilst stromatoporoid and chaetetid communities were less frequent. Patch-reefs consisting of dendroid and branching corals and stromatoporoids and chaetetids imply more moderate water energy conditions. Oyster and rudist bivalves appear in the transition zone as scattered individuals and loosely packed clusters. Highly dense rudist patch-reefs, which are typical for slightly protected, lagoonal environments, are absent.
Thin planar carbonate beds, 10 to 20 cm in thickness, which cut underlying facies are frequently developed. These thin sheet-like layers composed of high energy shelf edge allochems and ooids are considered as washover deposits (Reinson 1992).
In contrast, up to several meters of thick carbonate beds, composed also of high to moderate energy carbonate sands and oolites are interpreted as autochthonous deposits (Ball 1967). Necessary hydrodynamic conditions could of been induced in major tidal channels, where high energy shoals and belts or moderate water energy sand-flats may have developed. Coarse grained intraclastic/bioclastic rudstones (microfacies 13), which mark sometimes the base of these shoal deposits could be interpreted as channel lag deposits.
The intermediate geographic position of the *transition zone* made this depositional system very sensitive to sea-level changes. Small variations in sea level could have immediately caused a facies shift either to more external- or to inner-platform conditions. Regarding the sequence stratigraphic interpretation of the deposits, it is noticeable, that they commonly form part of the 3rd order transgressive system tracts, where they produce facies secessions of "catch up" and "keep-up" coral-, stromatoporoid and chaetetid patch-reefs and high energy carbonate sand deposits with open marine, circalittoral biota. Where this depositional environment occurs rarely as highstand system tracts, the facies successions consist of rudist patch-reefs together with stromatoporoid- and chaetetid organisms and oncoid- dasycladacean-algae limestone beds.
The *transition zone* carbonates from the "Flaine" section are approximately 90 m, in the "Rocher de Cluses" section about 50 m and in the Aravis mountains about 45 m in thickness.

9.3.2 Open to slightly protected lagoon

General aspects:
Lagoons occur as relatively quiet-water environments protected from ocean swell and storms by more or less developed barrier systems. Tidal currents enter the lagoons via inlets between the barriers and hence high current velocities may occur. The main physical factors within the shelf-lagoon are currents generated by winds and tides (Purdy 1963a). Efficient tidal exchange may keep lagoons close to oceanic salinity. Climate is playing a major role in controlling the biota, salinity and mineral precipitation. Lagoons are the sites of accumulation of fine-grained sediments of either lime-sand or lime-mud.
Today open lagoons occur along parts of the Trucial Coast, Persian Gulf (Purser 1973) and Yucatan Shelf (Logan *et al.* 1969, Ginsburg & James 1974). Examples of protected lagoons occurring behind barriers are the Florida Bay (Monty 1967, 1972, 1976, Multer 1977, Enos & Purkins 1979) and in part the Shark Bay of Western Australia (Logan *et al.* 1970, Logan *et al.* 1974). Smaller lagoons occur on the Great Bahama Bank (Bathurst 1967, Multer 1977).

Discussion:
Limestones composed of lagoonal sediments are best developed in the "Rocher de Cluses" and Aravis area.
The shelf-lagoon with all its different facies zones form the largest areas on the inner-platform. The Urgonian limestone *s.s.* (*rudist limestones* in the sense of d'Orby) are built up by lagoonal carbonates.
The influence of open marine wave action was mostly reduced, allowing the colonization of organisms preferring moderate to quiet-water conditions. The shelf lagoon contains a large spectrum of different facies- and microfacies types. Limestones with packstone and even grainstone textures inferred high current conditions which were able to winnow the micrite ooze. Carbonates with wackestone to fossil-mudstone textures indicate low energy sites where limestone mud accumulated.
The lagoonal environment of the Urgonian limestones are mostly characterized by the extensive colonization of **rudist** bivalves. These rudist buildups make up some dm to 2 m thick rudist beds (MFT-15). Masse & Philip (1981) and Kauffmann & Johnson (1988) interpret rudist settlements mostly as inner-platform populations within low to moderate energy and sometimes restricted environments during the Late Jurassic and Early Cretaceous.
One of the most characteristic features of the outcropped lagoonal limestones is the vertical alteration of beds with rudist debris facies (MFT-16) combined with oncoid/algal lump facies (MFT-14) followed by rudist clusters/patch-reefs (MFT-15) (Fig. 9.2). The numerous shell debris are an ideal source for oncoid nuclei and algal encrustings.
Further characteristic constituents of the inner-shelf lagoon are the **dasycladacean *algae.*** According to Conrad (1969, 1970, 1977) and Conrad & Peybernès (1976) most of the Hauterivian - Albian dasycladacean algae of the Urgonian limestones lived in external to middle infralittoral environments where they occupied somewhat protected sites. According to these authors dasycladaceans lived preferentially in water depths of less than 10 meters.
Dasycladacean algae occur within the micrite limestones rich in rudist debris, *Bacinella* and oncoids.
The most abundant micro-organisms of the lagoonal limestones are small **benthonic foraminifers**, mostly miliolids. They are more or less present in nearly every facies type. Sometimes they occur in high concentrations together with dasycladacean algae, and peloids (MFT-7) embedded in a micrite matrix. These assemblages form some dm to 1.5 m thick limestone beds. Sedimentary structures suggesting more detailed information about depositional processes are absent. Within the overall environmental

framework, these deposits are regarded as tidal channel- (Flügel 1982) or tidal flat deposits (Hardie & Shinn 1986, Tucker 1992, Wilson 1975).
Orbitolinid-foraminifers are abundant in open-lagoonal deposits where they appear in most of the different facies types. They are distinctly higher in concentration in the fine-grained miliolid-peloid wackestones facies (MFT-7), which are considered as tidal channel deposits. Arnaud-Vanneau (1980) already described vast Orbitolinid colonizations in channels cutting lagoonal sites. Arnaud-Vanneau (1980) suggested that orbitolinids colonized channels because there they found enough material in suspension required for agglutination.
Gastropods are represented by *Acteonella* and *Nerinea*. In a larger number they occur only in the uppermost part of the Flaine section, where they are associated with loosely packed rudist clusters and less frequently with branching corals and stromatoporoids.
Corals, chaetetids and **stromatoporoids** are rare organisms within the open lagoonal environment. They colonized the moderate to high energy *transitional zone*. Their debris are found within oncoid and/or rudist facies, however, they do not play an important role as a lagoonal environment facies indicator.
Characteristic features of the lagoonal limestones are repeated shallowing-upward units, < 0.5 m to > 2 m in thickness. These units always show approximately the same facies succession: starting up with coarse-grained rudist debris facies, followed by the intensely packed rudist banks and terminated by loosely packed rudist clusters and oncoid/algal lump facies. This repetition of facies succession is considered as small-scaled cyclicity. Such cycles can be interpreted as the products of autocyclic (Ginsburg 1971) and/or allocyclic processes (e.g. Strasser 1991). Figure 9.2 shows the vertical succession of a "rudist-oncoid-cycle".

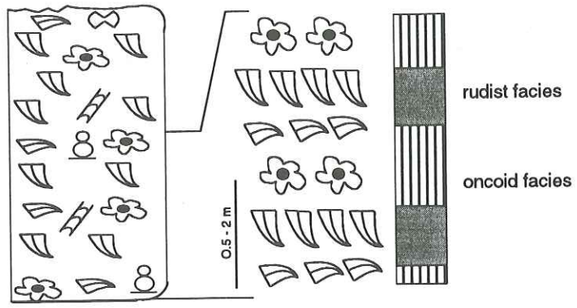


Fig. 9.2. "rudist-oncoid cycle". A cycle starts up with a basal layer of rudist debris, oncoids and algal lumps (1), followed by rudist patch-reefs (2). Oncoid-rich limestones terminate abruptly the rudist biostromes and build up the upper parts of these cycles.

9.3.3 Protected to semi-restricted lagoon

General aspects :
A protected shelf-lagoon may be defined as any setting on the shelf with slow water circulation with possible abnormal salinity, depleted nutrients, temperature extremes, or depauperate biota. Restriction that reduces wave or current energy may be due to physiographic barriers. However, protected settings may also occur without significant elevated topographies. Broad expanses of shallow water can damp out tidal and wave energy (Enos 1983). The biota is typically impoverished and species diversity is low, but the few

species that are may occur in large quantities (Enos 1983, Tucker 1992, Wilson 1975).
Modern examples of protected lagoons are:
(1) Shark Bay, Western Australia with salinities reaching up to 70 % (Logan *et al.* 1970). The sediments of the bay are composed of low diverse sand-to-silt-sized foraminifers, mollusks, peloids and quartz (Davies 1970). Water depth ranges from 2 m to intertidal.
(2) Trucial Coast, Persian Gulf (Kor al Bazm Lagoon) (Loreau & Purser 1973). Salinities reach up to 60 % and sediments are mainly composed of foraminifers, cerithid gastropods, pelletal sands and aggregates.
(3) In the Florida Bay, a lagoon with restricted conditions is developed behind the Florida Keys. Salinity varies seasonally between 15 and 70 %. Water-depth is, for the most part, less than 2 m. Sediments of the bay are dominated by lime mud and accumulate in seagrass-stabilized banks (Enos & Perkins 1979). The lime mud is mostly formed by the disintegration of green algae, especially *Penicillus* and *Halimeda*. The fauna is dominated by molluscs.
The Bimini Lagoon on the Great Bahama Bank is an example of a mud-free, very low energy, protected lagoon with sandy sediments which are composed of skeletal grains, peloids, fecal pellets, small grapestones and thin oolitic coatings (!) (Bathurst 1967, Multer 1977, Winland 1974).

Discussion:
Limestones, which are interpreted as protected to semi-restricted lagoonal deposits, may represent proximal sites of the Urgonian platform. In contrast to open-lagoonal deposits the fauna diversity is drastically reduced. Sediments which characterize these protected-lagoonal environments are summarized in the microfacies types 7, 8, 9 and 14. Predominant carbonate particles are sand-sized peloids (mostly micritized skeletal debris), small benthonic foraminifers (*Pseudotriloculina*, *Quinqueloculina*, and *Glomospira*), pellets (fecal pellets?) and small aggregate grains (*grapestones*, Illing 1954). Oncoids, and algal lumps (MFT-14) are abundant and characteristic components of this depositional environment. *Girvanella* filaments within some oncoids are characteristic features of this environment.
Deposits characterized by these sediment compositions are extensively described as deposits occupying numerous protected lagoonal sub-environments. In modern environments they occur as shallow subtidal peloidal-sands (Bathurst 1975, Beales 1958, Illing 1954, Wilson 1975), tidal flats (Hardie & Shinn 1986, Ginsburg *et al.* 1977, Shinn 1983a), tidal channel sediments (Hardie & Shinn 1986, Shinn *et al.* 1969) and as tidal channel bars (Shinn et al. 1969, Shinn 1986).
Stratiform massive biostromes consisting of the arenaceaous foraminifer *Bdelloidina* Carter (Coscinophragmatidae) which were recently described by Schulte *et al.* (1993) are characteristic features of the quartz-rich parts of the restricted lagoonal carbonates. According to these authors, the stratiform massive morphologies of these foraminifer-reefs are formed under low water energy and reduced sedimentation rates. The massive presence of these agglutinating foraminifers-bioconstructions is related to the appearance of quartz grains, which used for agglutinating material. The same bioconstructions can be observed in the "Flaine" section, where these patch-reefs were grew with a quartz grain support in a lagoonal environment, although in a somewhat higher energy regime.
The protected-lagoonal carbonates were mostly sedimented in shallow subtidal areas. However, early diagenetic solution of metastable carbonates (aragonite and high-magnesium calcite (Folk 1965), and fenestral fabrics accompanied with meteoric phreatic carbonate cements, indicate an intertidal environment (MFT-11).

Several fining-up/shallowing-up sequences are developed similarly to the small-scaled cycles of more open lagoonal sites. They consist of 0.3 m to 1 m thick basal beds, which are rich in large oncoids, algal lumps, dasycladacean algae, and contain also rudists, oysters and solitary corals. Sometimes, these basal beds are underlain by small layers composed of mm to cm-sized reworked clasts. Towards the top of these sequences, particle size and diversity decreases and the small-sized foraminiferal-peloidal lithofacies dominate. Thicknesses of these fining-up/shallowing-up units are less than 1m to about 4 m. These fining-up/shallowing-up cycles can be interpreted as the results of migrating (tidal) channels, especially where basal intraclast beds can be regarded as basal channel lags derived from eroded cutbank materials (Cloyd *et al.* 1989, Shinn *et al.* (1969).

9.3.4 Restricted Environments (Peritidal environments)

Deposits of restricted peritidal environments are built up by limestones, which are summarized in the microfacies types MFT-7, 11, and 12. The limestone beds in the stratigraphic record are characteristically of small thicknesses, of an average of 20 to 30 cm. They are either formed with one to a few layers or are built up of vertical successions up to several meters thick (for example "Rocher de Cluses" unit 16). Individual carbonate beds are abundantly limited by stylolites. The most characteristic feature of these deposits is the low faunal diversity, which diminishes as the depositional environment is more restricted.
The restricted limestone deposits, according to their composition, can be subdivided into 1) shallow subtidal to intertidal- and 2) brackish to lacustrine pond-subenvironments.
The juxtaposition of these restricted limestones to emersive horizons in the stratigraphic records is a remarkable feature. In the Aravis mountains ("Grande Forclaz" section) and in the "Rocher de Cluses" section the series of these carbonate facies directly overly the well-pronounced discontinuous surface. Mojon (1986, 1988) already described several well developed lacustrine limestones rich in charophytes, which are associated with emersive horizons for the Urgonian limestones in the northern Subalpine Chains. One of his described emersive horizons can be correlated with a major discontinuous surface in the "Rocher de Cluses" section which marks the limit between Barremian and Aptian times.

9.3.4.1 Subtidal to Intertidal Zones

Shallow subtidal wackestone carbonates show a somewhat higher biota diversity with benthic foraminifers (*Pseudotriloculina*, *Triloculina*, *Quinqueloculina*, and *Glomospira*), encrusting algal products and algal lumps and dasycladacean algae. Fenestral structures, keystone vugs and gravitational cements in some of these deposits indicate that these carbonates were deposited in very shallow water sites with periodically subaerial exposures.
Irregular thick (from 0.5 to 2 m) lens-like limestone units consist of a lagoonal composition containing rudists, oysters, large oncoids, small coral heads and orbitolinid-foraminifers. These sequences are considered as tidal channel deposits. The lentil-like bed forms in the stratigraphic record can be interpreted as cross-sections of channel deposits. Layers more rich in reworked clasts and fossil debris are interpreted as basal channel lag deposits. Frequently these tidal channels deposits terminate with an intertidal facies (microfacies types 11). Hardie & Shinn (1986) describe tidal channels as the most important subtidal zone within tidal flats. According to these authors, tidal channels are important because they are the main supply for offshore sediments, entering the peritidal system. Tidal channels are responsible for the daily exchange of marine water and the drainage of freshwater from the tidal flats.

9.3.4.2 Ponds

Ponds containing brackish to lacustrine carbonates (microfacies type 12) are the most restricted environments of the investigated Urgonian limestones. They contain a very restricted biota composed of some foraminifers, ostracods, small bivalves and *Planorbis* gastropods as an indicator fossil for restricted environments (Septfontaine 1993, pers. comm). Normally these gastropods are associated with charophytes, however, only some uncertain fragments were recognized in thin sections.
Fenestral structures, plugged by meteoric cements, and root marks (?) are abundant features and indicate an intertidal environment with periodic subaerial exposure.
Bright dolomite rhombs are distributed within the dark-brownish micrite matrix. The amount of dolomite in this facies, however, is very low and dolomite crystals occur only dispersedly.
Micrite intraclasts are present. They could be produced by tidal or flow currents in very small and shallow channels or creeks or by reworking due to storm effects.
The amount of quartz detritus and clay minerals is generally low. The average carbonate content of these restricted limestones ranges between 96 to 98% $CaCO_3$.

9.3.5 Transgressive Facies

General aspects and discussion:
The *transgressive facies* does not represent a well specified depositional environment as with the above mentioned depositional environments. The *transgressive facies* is rather considered as an event, which drastically cut already existing depositional settings. Such events are thought to be marine transgressions when the platform was abruptly flooded. The resulting deposits are characteristically made up of a mixture of open marine, lagoonal, and continental material (clay minerals, quartz grains, organic material) ("textural inversion", Folk 1962). This transgressive facies appear in the outcrops as single, thin (0.3 to 1 m) marly limestone beds, intercalated between the massive carbonate banks, or they are developed as successions of several repeated layers in alteration with massive carbonate beds (plate 2, 5 and 6). A well-known example of such a succession are the *Orbitolina limestone beds* (e.g. chapter 5 DESCRIPTION OF THE SECTIONS, Fig. 5.1 unit 17 "Rocher de Cluses").
In the Bornes Massif and in the Aravis Chains these transgressive *Orbitolina*-rich marly limestone intervals drowned lagoonal rudist-oncoid- and dasycladacean-oncoid environments. In the area around Flaine, more open lagoonal sites with coral-chaetetid-stromatoporoid patch-reefs were surpassed by *Orbitolina* marly limestone layers.
Well-preserved organisms, like rudists, *Bacinella*-nodules, coral-, chaetetid- and stromatoporoid-organisms, which are indicator fossils of the underlying massive carbonate facies, suggest that patch-reefs still existed during these transgressive periods. When transgressions decreased in intensity, previously existing depositional environments and sedimentation reinstalled again, until they were again interrupted by new transgressive periods. In

this way, characteristic alternating sequences of vertical stacking deposits, composed of lagoonal- and transgressive facies, could have been developed.

The *Orbitolina marly limestones* are interpreted as tidal channel deposits by Arnaud-Vanneau *et al.* (1990). According to Arnaud-Vanneau (1980), (tidal ?) channels and their borders were preferred living environments for *Palorbitolina lenticularis* and other agglutinated orbitolina-foraminifers, where they could find enough suspension material for nutrition and agglutination.
Concave/convex depressions and shields of the developed *Orbitolina marly limestones* can be interpreted as channel structures in the "Rocher de Cluses" section. In the "Flaine" section, however, stratiform *Orbitolina marly limestones* cover underlying patch-reefs.

9.4 Conclusions

Studied limestone series are composed of packages reflecting sedimentation within different depositional environments. Microfacies investigations and the comparison with well described recent and ancient examples allow to classify these depositional environments. En gros three paleogeographical domains were determined. These are: (1) the **hemipelagic slope** with its muddy to grainy fine-sized sediments, and two horizons of mass flow deposits. (2) The **external-platform** with high energy shoal sediments, and (3) the **inner-platform** with open, slightly protected through restricted sites. The recognition of these depositional environments and their overall succession in the stratigraphic record makes it possible to reconstruct the paleogeographic history of the Urgonian carbonate platform. Figures A.1 to A.4 summarize the vertical development of defined depositional environments in the studied sections. By comparison of the studied sections it can be recognized that nearly the whole **"Flaine" section** is built up by platform margin to open lagoonal ("transition zone") sediments. Only the upper part exposes a slightly protected to protected lagoonal environment. The "Flaine" domain represents to the most external part of the Urgonian platform in the studied realm. The **Aravis Chains ("Grande Forclaz" section)** is the only domain where slope outcrops a lateral extension. A featureless sea floor without remarkable break imply (partly ?) a slope of a homoclinal ramp type (Read 1982, 1985). Platform carbonates expose a intermediary paleogeographic position. The mainly part of the section exhibit "rudist limestones" indicating a slightly protected depositional environment. Only the upper part of the section implies protected to semi-restricted paleoconditions.
The domain in the northwestern **Bornes Massif ("Rocher de Cluses" section)** represents the most internal paleogeographic sites upon the Urgonian platform, indicated by semi-restricted and lacustrine to brackish deposits. However, the most part of the outcrop implies also good water circulation conditions, which allows the installation of high energy sand shoal, coral-stromatoporoid-chaetetid patch-reefs and rudist biostromes.

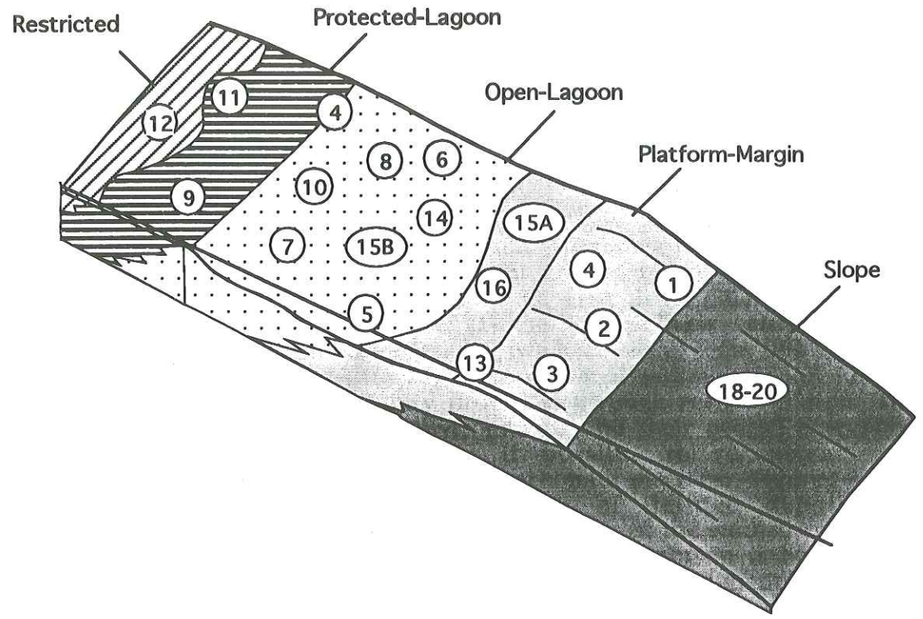


Fig. 9.3. Depositional model for the carbonate shelf in the study area. Numbers indicate the distributions of the determined microfacies types (see also Fig. 9.1. and chapter 8).

Chapter 10: SUBMARINE MASS FLOW DEPOSITS

10.1 General remarks

In a series of combe exposures cross-cutting the SW-NE trending Aravis Chains distinct horizons of allochthonous deposits are traceable for about 15 km (Fig. 10.1.a and b). The nature of these deposits suggests that they result from submarine gravity mass movements, derived from catastrophic slope and platform margin collapses. Mass-transport processes include slumping, sliding, and debris flows (Fig. 10.2). Five facies types forming these deposits have been determined.
These studied mass flow deposits belong to the "couches de transition" (see chapter 3 LITHOSTRATIGRAPHY), which are interpreted as slope deposits.

10.1.1 Previous works

Charollais *et al.* (1967) described for the first time a horizon of "lentils" built up by shallow-water platform carbonates.
Favre (1984) described in the SW of the Aravis mountains (Tournette area) allochthonous, platform-derived deposits in the "couches de transition".
Détraz *et al.* (1986) provided a detailed geological map from the Aravis domain, wherein Muller (1985) described in detail the localities and microfacies of these "lentils".
Giddy & Pairis (1993) interpreted these deposits as tilted blocks generated during synsedimentary stretching processes (listric faults).

10.1.2 Location

Fig. 10.1.a and b illustrate the geographic extension of mass flow deposits.
In the most northeastern part of the Aravis (Pointe Percée), no mass flow deposits are developed. In this area, the deep-marine circalittoral facies is directly overlain by shallow-water platform carbonates.
Between the "Combe de Mont Charvet" and the "Combe de Pacally" one horizon of mass flow deposits occurs (corresponds to the "first" (lower) horizon).
In the southwestern part of the Aravis, between the "Combe de Grand Crêt" and "Col des Aravis" two horizons of mass flow deposits are traceable, which correspond to the "first" (lower) and "second" (upper) horizon.

10.1.3 Age

Biostratigraphic data (ammonites, echinids and orbitolinids, Fig. 4.3 to 4.4) combined with sequence stratigraphic interpretations determine these horizons as late Hauterivian in age.
The first (lower) horizon, deposited from the "Mont Charvet" to the "Col des Aravis" is interpreted to represent lowstand deposits of the sequence Ha6 within the *Balearis* ammonite-zone. The second (upper) horizon, extending from the "Grand Crêt" to the "Col des Aravis", is considered to define the lowstand deposits of the sequence Ha7, in the *Angulicostata* ammonite-zone.

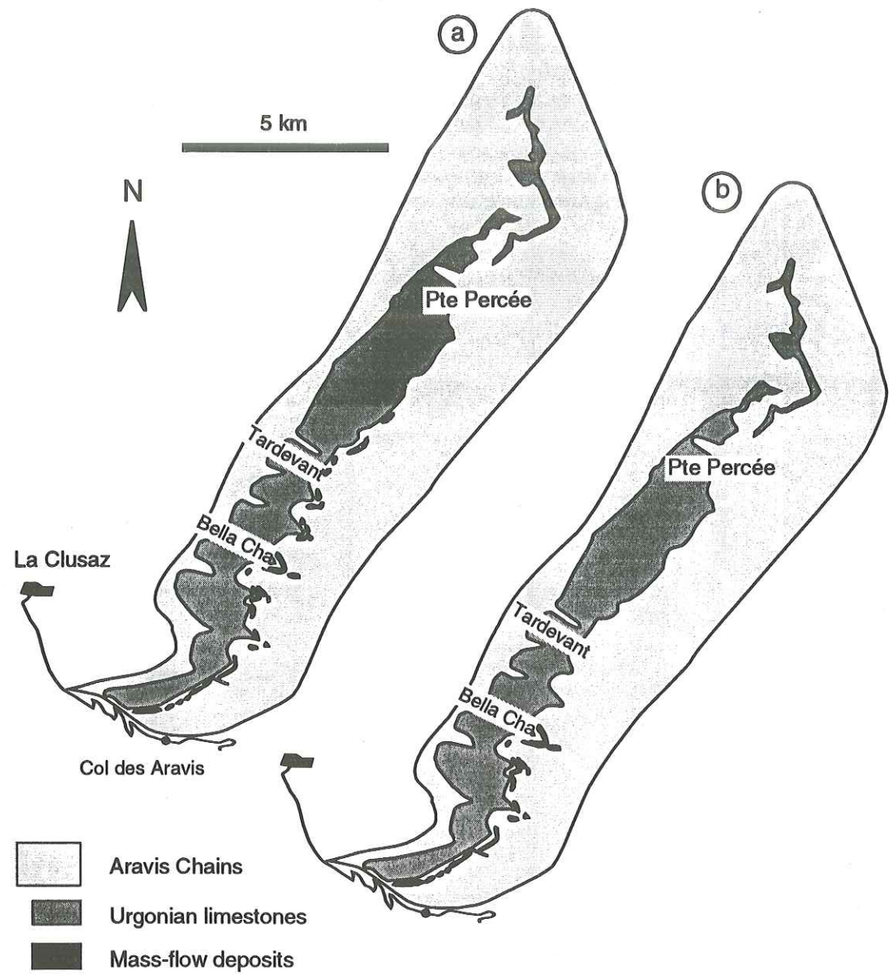


Fig. 10.1. (a) indicates the localities of one horizon of mass flow deposits, (b) indicates the localities of two horizons of mass flows.

10.1.4 Geological setting

The domain of the Aravis realm broadly coincides with the transition from the prograding carbonate platform from the NW and the subsident Dauphinois Basin to the SE. Making allowance for the present day tectonic dip, the planar bedded stratal geometries exposed in the combes suggest deposition on an apparently slightly dipping featureless sea floor. After Spence (Spence *et al.* 1992, pers. comm. 1992), this transition between platform and basin corresponds to a homoclinal ramp type.

10.2 Composition of the mass flow deposits

The mass flow deposits possess a heterogeneous composition, characterized by different-sized slide and slump blocks and debrites (Fig. 10.2). The term debrites or debris flow deposits is used to describe deposits consisting of a medium to fine-grained matrix with a varying proportion of matrix-supported clasts (Einsele 1991).
In this study, it was possible to determine five facies types, which represent the sedimented gravity submarine mass flows .

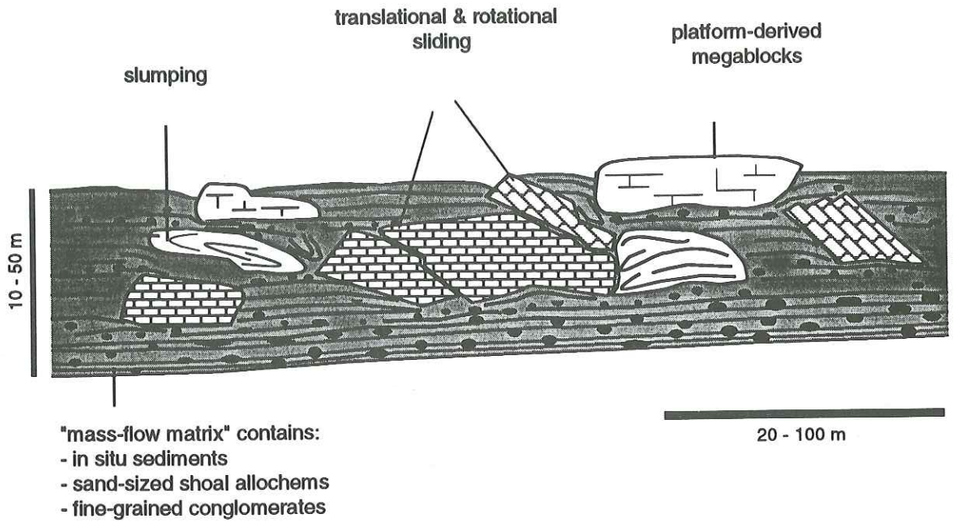


Fig. 10.2. Schematic illustration of the mass flow composition.

10.2.1 Facies descriptions

Five facies types were determined to describe mass flow deposits occuring in the Aravis mountains. Where possible they were compared with facies terms described by Mullins & Cook (1986).

10.2.1.1 Facies type 1: *in-situ* facies (plate 11/2 and 11/3)

This facies is composed of a fine-grained mixture of hemipelagic material and platform-derived, shallow-water components. The facies type exhibits a mixture of the facies types 20, 21 and 1A.
It can form well bedded packages, but deposits that lack obvious evidence of bedding are also frequently developed. In the field, this facies frequently seems to intercalate slump and slide blocks.
Interpretation:
The in-situ facies reflect prevailing autochthonous slope sedimentation. Dependent on the paleoslope position (proximal or distal) sedimentation was more or less influenced by platform influx. The in-situ facies indicates from the NE to the S.W in the Aravis realm a deepening (finning) tendency.
Facies type 1 corresponds to Facies G in the nomenclature after Mullins & Cook (1986).

10.2.1.2 Facies type 2: Mud-supported conglomerate facies (plate 9)

This facies is composed of lime mud and fine-grained circalittoral particles. Most clasts are less than 10 cm in diameter and rarely consist of head-sized, well rounded clasts. Microfacies analysis indicates that clasts and the embedding matrix are of the same depositional setting (plate 9/3). The facies indicate a downslope fining, however, all material that form this conglomerate facies has a slope origin (monogenetic conglomerates). The mud-supported conglomerate facies is dispersedly distributed within the mass flow deposits but it can be well recognized, that they are much more concentrated at the base and at the top of these units.
Interpretation:
Mud-supported conglomerates are interpreted to have been transported and deposited mainly by debris flow (Cook *et al.* 1972, Einsele 1992, Mullins & Cook 1986). This conglomerate facies is considered to be the result of an increase in mass disaggregation from the transformation of slumps and slides into debris flows (Fig. 10.3).
Facies type 2 corresponds to Facies F of the nomenclature after Mullins & Cook (1986).

10.2.1.3 Facies type 3: Clast-supported conglomerate facies

This facies is composed of a very close-packed conglomeratic texture and is characterized by its "fractured" appearance. Individual clasts are less than 10 cm across. The conglomerate composition implies a hemipelagic origin.
Deposits of the clast-supported conglomerate facies was only recognized as the basinal unit of the mass flow deposits, where they may form several meter thick beds. However, this facies consists of very irregularly thick deposits, and is frequently absent.
Interpretation:
Crevello & Schlager (1980) have interpreted the occurrence of clear, graded sand and rubble deposited by turbidity currents, massive, poorly sorted sand and rubble transported and deposited by grain flow or high density turbidity currents. The developed deposits indicate no grading. They are well sorted and exhibit more or less the same diameter. The fact, that they occur always directly below the mass flow deposits, suggests that they form the basal part of these mass flow deposits.
Facies type 3 corresponds to Facies A of the nomenclature after Mullins & Cook (1986).

10.2.1.4 Facies type 4: Slump and Slide facies (plate 7)

Slump blocks can be recognized by their internal disturbance and folding. Internal deformation varies from simple, large-scale and overturned (inverse folding) folds . Internal bedding is partly well recognizable or may be lost through homogenization. Slumps are interpreted to have been semi-consolidated when moved basinward (Coniglio & Dix 1992, Einsele 1991, Mullins & Cook 1986). Microfacies analysis indicates a circalittoral slope origin for the slump blocks, possessing a predominant poorly washed packstone texture.
Slide blocks show no or only minor internal deformation. They occur as rotational and translational masses. The size of slides range from single small-sized sheets (plate 7/2 and 7/3) up to hectometric blocks (several hundred of meters x 40 m, plate 3 and 4). Slide blocks expose well developed stratification as well as massive ledges. Well bedded slide masses without

internal deformation and a deposition parallel to the overall stratigraphic record are sometimes very difficult to distinguish as displaced blocks. The composition implies an upper slope to deeper outer platform origin with fine to medium-sized packstone to grainstone textures.
Interpretation:
Slide and slump blocks are interpreted to have been derived from the slope to outer platform collapse. The coherent stratal rafts suggest that the slides were already consolidated. Slumps, however, which show significant internal sediment deformation are interpreted to have been semi-consolidated when slope collapse occurred. Slumps and slides developed into debris flows (conglomerate facies) due to the break-up of the beds and continued downslope.
This facies type 4 corresponds to Facies F of the nomenclature after Mullins & Cook.

10.2.1.5 Facies type 5: Platform-derived megablocks (plate 7/2)

Megablocks of this facies type are composed of medium to coarse-grained bioclastic/intraclastic grainstones, which are typical of the shallow, high energy platform marginal environment (plate 11/1). Similar sediment composition is summarized in microfacies types 2 and 3.
In the stratigraphic record these blocks are distinguished from surrounding rocks by their bright gray color. They are always deposited in the upper parts of the mass flow deposits. A characteristic feature of these units are encrustings of sponges on the top-surfaces.
These slide masses are described as "lentils" (Charollais *et al.* 1967).
Calculating the whole quantities of the mass flow deposits, these platform-derived blocks represent only a minor quantity.
Interpretation:
The megablocks are interpreted to have been produced by catastrophic platform margin collapse. Microfacies analysis indicates that the blocks obtained entire lithification before margin failure occurred.

10.3 Initiating mechanisms of mass flow movements

10.3.1 Theoretical considerations of mass movements

Submarine mass movements take place, if the shear stress exceeds the shear resistance of the sediment at some depth below the sedimentary surface. Shear stress increases with slope angle and depth below the sea floor. Deep below the surface of a gentle slope the shear stress can be as high as on a steep slope at shallow depth. For this reason, there is a trend for thick mass deplacements to occur on slightly dipping slopes, whereas thin mass movements are typical for steep slopes (Carter 1975, Einsele 1992, Shepard & Dill 1966). It has been recorded that gravity submarine mass flows travel over gentle slopes of less than 1° and over distances of several hundred kilometers (e.g. Embley 1976, Cook *et al.* 1972, Fortuin *et al.* 1992).

A summary of triggering mechanisms for platform-margin and slope collapse are listed.
- earthquake shocks
- faulting along fault scarps
- gravitational instabilities caused by compaction, submarine cementation and increases in sediment loading (oversteepening)
- storm-wave activity
- increase in pore water pressure due to increased sedimentation rates

- sudden loading by approaching slides/slumps generating secondary failure plains
- development of biogenic gas and release of gas reducing shear strength
- major relative sea level falls

For detailed discussions see Carter (1975), Cook *et al.* (1972), Cook & Mullins (1983), Einsele (1991 and 1992), García-Mondéjar *et al.* (1993), Jaquin *et al.* (1991), Kenter (1990), Morgenstern (1967), Mullins *et al.* (1986), Pedley *et al.* (1992), Schlager & Chermak (1979), Schlager & Camber (1986), Schlager *et al.* (1994).

10.3.2 Triggering mechanisms for mass flow movements in the Aravis

The over-all character of most megablocks and conglomerates suggests that they formed by the break-up of entirely to partly lithified slope material and parts of the platform margin at the time mass movement was initiated.
Field evidence indicates a low angle of the depositional slope. Therefore, the collapse of high angle build-ups or margins (Kenter 1990, Mullins & Cook 1986, Schlager & Ginsburg 1981) are not considered have triggered these mass flows.
From the data available we cannot determine the initial fracture mechanisms. Theoretically, nearly all above mentioned processes can be regarded as triggering mechanisms provoking mass flow movements in the Aravis. However, the same mechanisms, which seem to have possible induced catastrophic slope and platform margin collapse are discussed somewhat in detail:
- Synsedimentary tectonism due to movements along basement faults seems to be a very possible triggering mechanism. During the Lower Cretaceous, the Aravis realm was a tectonically sensitive region. The high subsident Dauphinois Basin, to which the Aravis belongs, was influenced by the onset of seafloor spreading of the Ligurian ocean (Lemoine *et al.* 1986). Wildi *et al.* (1989) reconstructed the Mesozoic subsidence history and calculated for the Aravis area strongly increased subsidence rates with up to 100 m/my during the Lower Cretaceous (for comparison, in the same time a subsidence rate of 10 m/my was calculated for the western Jura and in the realm of the Aare massif). After Bourrouilh (1987) and Eberli (1987) rapid subsidence and active faulting during rifting and early drifting can provoke extensive mass movements.
- A major relative sea level fall can affect several processes, which decrease slope stability:
  - overloading of the slope, due to increased sediment input.
  - emersion of the shelf margin with subsequent margin destruction.
  - due to decreasing sea level, extended areas of the slope and the margin are confronted to tidal- and storm generated wave action.
  - finally, a relative sea level can totally turn the depositional setting, for example, a former carbonate setting can be overridden by siliciclastic sedimentation. The abrupt change in sediment composition can lead to depositional instabilities.

The overall stratigraphic history allows to correlate these two horizons with the lowstand/shelf margin systems tract of the late Hauterivian sequences Ha6 and Ha7.
(For detailed discussion see chapter 12 "Sequence stratigraphy and paleogeography of the Urgonian limestones").
- High relict pore water pressure could have decreased shear strength of the basinal part of the carbonate slope deposits. A high amount of relict pore water accumulated above the (impermeable) micrite to marly limestones

(glauconite rich marly limestones, microfacies 18) could have decreased shear strength due to a high pore water pressure. This layer could have represented a potential decollemont horizon.

10.4 Paleogeographic reconstruction of the Aravis domain during time when mass flow movements occurred

10.4.1 Discussion

As already mentioned, the mass flow deposits are traceable trough the Aravis mountains range from the "Combe de Mont Charvet" in the NE as far SW as the "Col des Aravis". Deposits exhibit remarkable differences in thicknesses and compositions.
From the NE to SW the following important features can be observed:
• Decrease in deposit thickness, from > 40 m ("Combe de Tardevant") to approximately 10 m ("Col des Aravis").
• Spectacular decrease of individual block-sizes. In the "Combe de Tardevant", tilted blocks and rotational slides occur up to 40 m thick and several hundred meters long. In the "Combe de Bella Cha" blocks expose thicknesses of maximal 10 m, and in the "Col des Aravis" slides are reduced to meter thick sheets.
• Increase of slumps. While in the northeastern area, mass flow deposits are characterized by internal undisturbed tilted blocks, rotational and translational slides. In a southwestern direction proportion of internal deformed blocks (slumps) increase.
• Increase of debrites. The northeastern realm is predominated by thick slides and slumps, while in the southwestern direction the amount of debrites increase.
• Deepening of the depositional environment. In situ facies as well as resedimented deposits indicate a northeastern to southwestern deepening trend.
Fig. 10.3. shows a conceptual model of downslope transformation of tilted blocks and slides into smaller-sized slides and slumps, and debris flows.

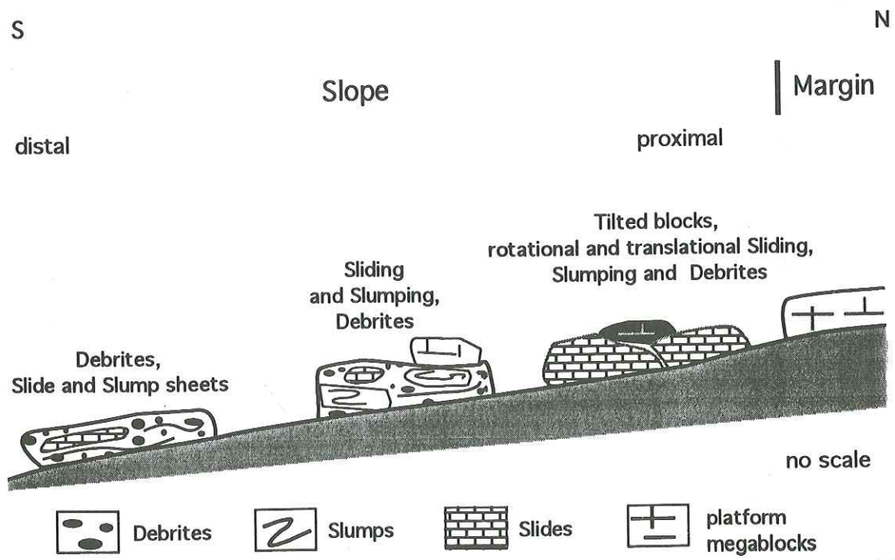


Fig. 10.3. Downslope transformation of gravity mass flow deposits.

Very similar development can be recognized in the second ("upper") horizon of the mass flow deposits. However, the extension of this horizon is limited between the "Combe de Grand Crêt" (central Aravis realm) and "Col des Aravis" (SW).

10.4.2 Interpretation

10.4.2.1 Sedimentary aspects

Facies development indicates, that the northeastern mass flow deposits (for example "Combe de Tardevant") represent the most proximal part of the collapsed slope and segments of the platform-margin. Immense tilted blocks and chaotic slides produced by synsedimentary stretching (Gidon & Pairis 1993) imply only minor displacements.
Mass flow deposits, which were situated on the middle part of the slope are interpreted to have occurred in the "Combe de Bella Cha". These deposits are characterized by a mixture of medium to large-sized slides, slumps, and a high proportion of debrites.
Mass flow deposits in the SW area of the "Col des Aravis", which are dominated by the mud-supported conglomerate facies and small-sized slide and slump sheets, and by fine-grained autochthonous sediments, represent the most distal part of the outcropping mass flow deposits.
(It is noticeable, that exposed sections indicate a NE-SW deepening, however, in every combe, mass flows (especially the large slide and slump blocks) indicate a movement form a northern to northwestern direction).

10.4.2.2 Tectonic aspects

Tectonic maps by Détraz *et al.* (1986) and Villars (1986) indicate a series of faults cutting the Aravis mountains range. Most of them are of tertiary age, however, Villars (1986) described also fractures of pre-tertiary age. In his tectonic map, a series of SE-NW oriented faults seem to be particular interest. They exhibit exactly the same SE-NW orientation as the "combes". In this study the combes are interpreted to reflect fault systems, along which nearly vertical displacements occurred (dip-slip movements).
The movements are considered to had been responsible for creating a downthrown area, in which the mass flows avalanched. Moreover, these tectonic movements may have provided slope and platform margin detachment.
Such a faulting between major dip-faults could explain the sharp boundaries between areas, where mass movements occurred, and adjacent undisturbed depositional settings. The existence of faults with dip-slip movements are observed in the combes. They mostly expose deplacements of approximately 10 meters.

10.5 Conclusions

Deposited allochthonous deposits traceable in the Aravis mountains range are interpreted to reflect catastrophic slope and platform margin collapses during the late Hauterivian.
This region represented a homoclinal ramp slope transitional from the prograding carbonate platform to the NW and the Dauphinois Basin to the SE.
Considering that this paleoslope was a tectonically unstable area, faulting movements could have provoked slope and platform margin failure. Present-

day, the SE-NW trending combes are interpreted to indicate these zones along which tectonic deplacement have taken place Vertical faulting movements could explain the sharp boundaries between the downthrown area upon which sediment packages glided downslope, and the adjacent, undisturbed sites upon which "normal" sedimentation occurred (Fig. 10.4).
A relative sea level fall could have decreased slope and platform stability, additionally to tectonic/seismic activities. The lower (first) horizon of mass flow deposits is interpreted as lowstand deposits of the sequence Ha6. The upper (second) horizon is considered as the lowstand deposits of sequence Ha7. For detailed discussion see chapter 12 SEQUENCE STRATIGRAPHY OF THE URGONIAN LIMESTONES.

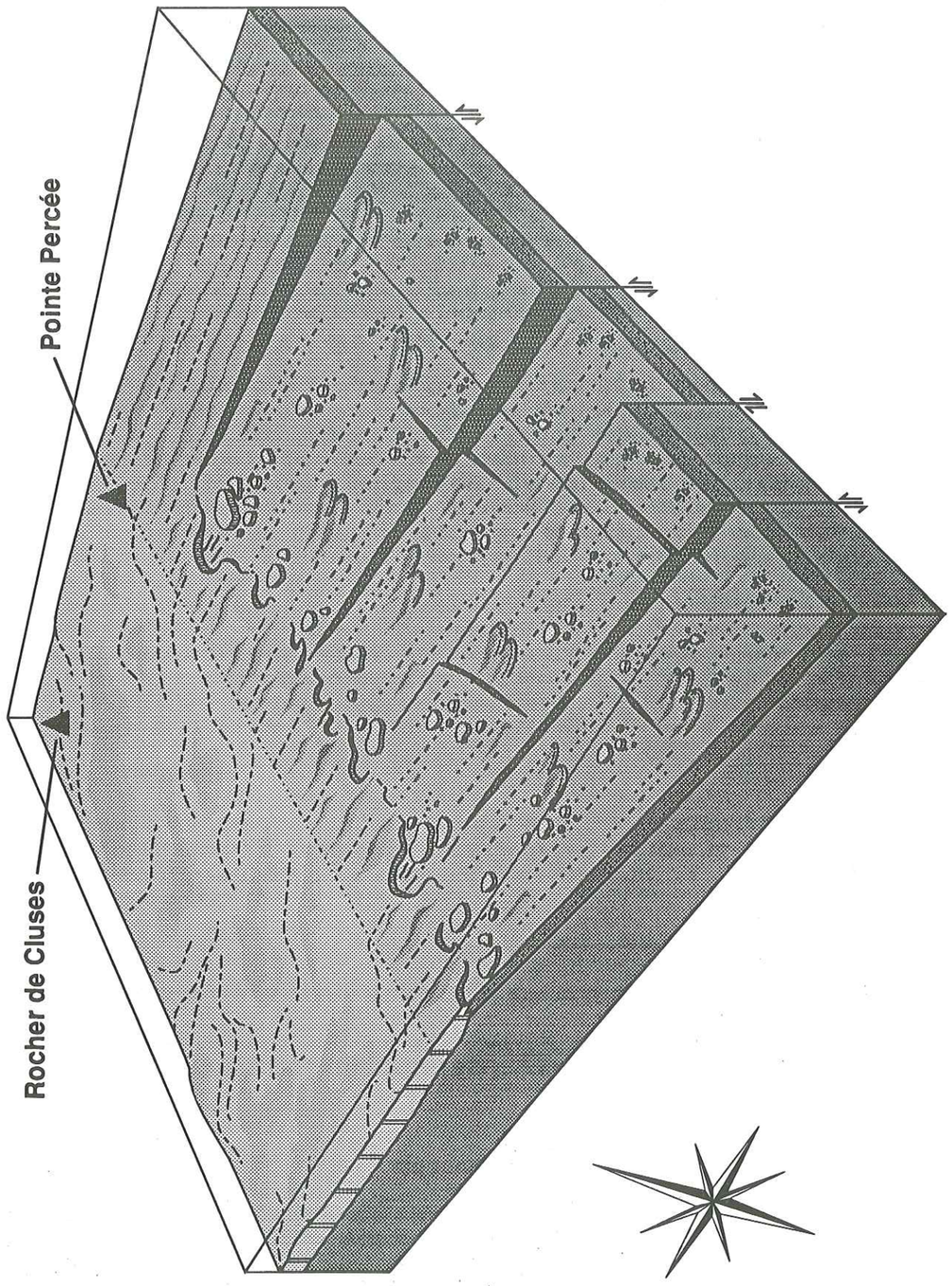


Fig. 10.4 : PALAEOGEOGRAPHIC RECONSTRUCTION OF THE ARAVIS REALM DURING THE LATE HAUTERIVIAN (Ha 6)

Chapter 11: Sequence Stratigraphy, Definitions

11.1 Introduction

In the concept of sequence stratigraphy variations in stratal pattern and lithofacies distribution are controlled by (1) tectonic subsidence, (2) eustasy, (3) sediment supply, and (4) climate. The interaction of subsidence and eustasy produces a relative change of sea level, which creates the available space for accommodation of the sediments. Tectonic and climate control the amount and types of sediments deposited. The thickness of sediments is primarily controlled by tectonic subsidence. The depositional stratal patterns and distribution of lithofacies are controlled by the rate of relative change of sea level (Van Wagoner *et al.* 1988, Sarg 1988).

Sequence stratigraphy originates from the concept of seismic stratigraphy, developed mainly by Vail and coworkers at the Exxon Production Research in seventies. On seismic sections they recognized depositional sequences (see definition below), bounded by unconformities and their correlative conformities, as **chronostratigraphically** significant units. On the basis of stratal geometries and patterns of erosional truncation, onlap, downlap and basinward shifts of coastal onlap, and biostratigraphic data, Vail *et al.* (1977) were able to generate charts of global cycles of relative changes in sea level from the Phanerozoic.
Sequence stratigraphy is an outgrowth of seismic stratigraphy and a more multidisciplinary approach to stratigraphic analysis. Sequence stratigraphy is based on well-log, core and outcrop data, in addition to seismic data. The conceptual background to sequence stratigraphy, together with a new and more detailed Mesozoic and Cenozoic sea level cycle chart was published by Wilgus *et al.* (1988) and Van Wagoner *et al.* (1990).

11.1.1 Definition

Sequence stratigraphy is the study of rock relationship within a chronostratigraphic framework of repetitive, genetically related strata bounded by surfaces of erosion or nondeposition, or their correlative conformities (Van Wagoner *et al.* 1988).

11.2 Sequence stratigraphic terminology and definitions

Fundamental sequence stratigraphic concepts and terminology used in this work can be found in Vail *et al.* (1977), Wilgus *et al.* (1988), and Vail *et al.* 1991.

11.2.1 Sequence (depositional sequence)

The basic unit of sequence stratigraphy is the sequence (depositional sequence *sensu* Mitchum) which is defined as a *stratigraphic unit composed of a relatively conformable succession of genetically related strata and bounded at its top and base by unconformities or their correlative conformities* (Mitchum *et al.* 1977).

11.2.2 Systems tract

A systems tract is a linkage of contemporaneous depositional systems (Brown 1969, Brown & Fisher 1977).
A sequence can be subdivided into systems tracts which are defined by their position within the sequence and by the stacking patterns of parasequence sets and parasequences bounded by marine-flooding surfaces (Van Wagoner *et al.* 1988).
Four systems tracts can be recognized (Van Wagoner *et al.* 1988, Vail *et al.* 1991):
(1) Lowstand systems tract (bounded at its base by a Type 1 sequence boundary). Vail *et al.* (1991)
(2) Shelf margin systems tract (bounded by a Type 2 sequence boundary)
(3) Transgressive systems tract
(4) Highstand systems tract

The term "deposits" (Baum & Vail 1987) may also be used, referring to stacking patterns of systems tracts.
Lowstand systems tract (LST) is referred to as *lowstand deposits* (*LSD*).
Transgressive systems tract (TST) is referred to as *transgressive deposits* (*TD*).
Highstand systems tract (HST) is referred to as *highstand deposits* (*HSD*).

11.2.3 Lowstand systems tract and shelf margin systems tract

In this study, is was never possible to distinguish between a type 1 and type 2 sequence boundary, therefore, the lowstand systems tract (LST) and the shelf margin systems tract (SMST) are summarized as **lowstand/shelf margin systems tracts (LST/SMST).**
On shallow platforms, lowstand/shelf margin deposits are only partly developed on the external platform margin. Bioclastic grain- to packstone rock units (microfacies type 1) and the oolite packages (microfacies type 4) are the most characteristic stratal patterns of these systems tracts.
Two spectacular horizons of mass flow deposits, exposed in the central Aravis mountains, are interpreted as lowstand deposits (plate 3 and 7). For detailed description see chapter 10 MASS FLOW DEPOSITS.

Description
These *lowstand deposits* have a heterogeneous composition: fine-grained slope sediments (in situ facies), conglomerates, and rotational and translational slide and slump blocks. Most of this reworked material implies a hemipelagic/circalittoral slope origin. Some of the megablocks ("lentils") are composed of coarse-grained bioclastic grainstones (microfacies types 2 and 3) derived from the platform margin.
The top of the allochthonous lowstand deposits indicates sediment starvation and hardgrounds were locally developed. The top-surfaces of platform-derived megablocks are intensively bored, with corrosion and abrasion features, and extensively encrusted by sponge organisms.

Interpretation: (for detailed discussion see chapter 10 MASS FLOW DEPOSITS).
The allochthonous lowstand deposits are interpreted to be derived from the collapse of the slope and the platform margin, caused by tectonic activities and by the relative fall of sea level at the beginning of the lowstand phase.
After Jaquin *et al.* (1991) and Vail *et al.* (1991), deposits of slump and slide blocks are characteristically associated with the end of the lowstand prograding complex and early phases of the transgressive systems tract.

Controversially, for Droxler & Schlager (1985), allochthonous carbonate deposits on the slope or in the basin are most likely to be transported during the highstand systems tract, when carbonate production is at its maximum (*highstand shedding*). Reijmer (1991) distinguishes between allochthonous highstand and lowstand deposits by means of their compositions. After Reijmer (1991), the dominance of platform-derived allochems indicates highstand shedding, whereas the prevailing of slope material indicates a deposition during the lowstand systems tract. Reijmer's simple method supports the assumption of lowstand deposits for the mass flows in the Aravis realm .

11.2.4 Parasequence sets, parasequences

A parasequence set is a succession of genetically related parasequences which form a distinctive stacking pattern that is bounded, in many cases, by major marine-flooding surfaces and their correlative surfaces (Van Wagoner 1985).

According to Posamentier & James (1993) the parasequence is a descriptive term devoid of issues regarding origin, nature and significance of their bounding surfaces and spatial and temporal relationships. The authors affirm, that parasequences should not be considered as small-scale sequences. Nonetheless, recently, Van Wagoner *et al.* (1990), Mitchum & Van Wagoner (1991) and Posamentier & James (1993) describe that parasequence sets or parasequences may be associated with high-frequency eustatic cycles. Vail *et al.* (1991) use the term *parasequences* or *simple sequences* to define stratigraphic units deposited within high-frequency eustatic cycles (fourth- and fifth-order cycles).

In this study, only the original descriptive definition of the term *parasequence* will be used.

11.2.5 Sequence boundaries (SB)

11.2.5.1 Type 1 sequence boundary (SB1)

A type 1 sequence boundary (SB1) is characterized by subaerial exposure and erosion leading to valley incision on the shelf. The sequence boundary is associated with a basinward shift of facies, a downward shift in coastal onlap, and onlap of overlying strata. A type 1 sequence boundary is formed when the rate of eustatic sea level fall exceeds the rate of basin subsidence at the *offlap break* (Vail *et al.* 1991) producing a relative fall in sea level at that location. The development of basin-floor fans, slope fans, and lowstand prograding complexes occurs in the basin (Van Wagoner *et al.* 1988, Vail *et al.* 1991).

11.2.5.2 Type 2 sequence boundary (SB2)

A type 2 sequence boundary (SB2) is characterized by localized subaerial exposure on the shelf. However, significant erosion and basinward shift of facies is lacking. A type 2 sequence boundary is formed on the shelf when the rate of eustatic sea level is less than the rate of basin subsidence at the offlap break. A shelf-margin prograding complex is developed, pinching out landwards of the *offlap break* of the underlying highstand deposits (Van Wagoner *et al.* 1988, Vail *et al.* 1991).

11.2.5.3 Sequence boundaries on (homoclinal) ramps

For siliciclastic and carbonate shelf sediments, a type 1 and a type 2 sequence have been distinguished according to the underlying sequence boundary. The latter reflects the magnitude of the relative sea level fall and the position of sea level relative to the offlap break (see definition above). This

distinction between two types of sequence boundaries is possible for settings exhibiting a major physiographic shelf break. However, on shelves characterized by a homoclinal slope (homoclinal ramp-type), this distinction may be not easy. For both settings a basinward shift of deeper-ramp and shallow inner-ramp facies may occur with subsequent subaerial exposure of inner-ramp sites. Tucker (1993) discusses this problem and mentions some criteria for boundary identification and for distinguishing between type 1 or 2 boundaries.

11.2.6 Maximum flooding surface (mfs)

The maximum flooding surface (mfs) is the top of the transgressive deposits. It coincides with the most rapid increase in water depth. This surface marks the change from a landward-onlapping and upbuilding sedimentary unit to a basinward-prograding downlapping wedge (*downlap surface*). The maximum flooding surface frequently occurs at the base or within the top of a condensed section caused by very low sedimentation rates (Loutit *et al.* 1988).

11.2.7 Condensed section (CS)

Condensed sections are thin marine stratigraphic intervals consisting of pelagic to hemipelagic sediments characterized by very slow depositional rates (Loutit *et al.* 1988). They commonly occur within the transgressive and distal highstand system tracts. Condensed sections are usually associated with marine hiatus (omission surfaces or marine hardground) and may be characterized by abundant and diverse fossil assemblages, and authigenic minerals (glauconite, phosphorite and siderite).

11.3 Sea-level changes

Six orders of cyclic sea-level changes have been defined with durations ranging from hundreds of millions to tens of thousands of years (Vail *et al.* 1991).

First-order eustatic cycles (*megacycles*) or *continental flooding cycles* with durations of more than 50 m.y.. They are interpreted to be associated to the expansion and subsequent break-up of supercontinents.

Second-order eustatic cycles (*supercycles*) are considered to reflect changes in the volume of mid-ocean ridges, related to "long-term" changes in seafloor spreading rate (tectono-eustatic) (Pitman 1978) and additionally by "short-term" glaciation effects (glacio-eustatic) (Vail *et al.* 1977). These second order relative change in sea level lead to major transgressive - regressive cycles with large eustatic falls of more than 50 m at their boundaries. Second order cycles have durations of 3 to 50 m.y..

Third-order eustatic cycles (*sequence cycles*) have periodicities averaging 0.5 to 3 m.y.. They are built up by depositional sequences (see preceding definition) and are related to waxing and waning of continental ice masses (Vail *et al.* 1977, 1991). After Haq *et al.* 1988 these third-order sequences can be correlated globally. Whether tectonic events influence third-order cycles globally or whether their influence is only from local extension is still a matter of debate (e.g. Cloetingh 1988, Kauffmann 1984, Miall 1991 and 1992, Vail *et al.* 1991).

High-frequency cycles (*fourth-, fifth-, and sixth-order cycles*; *parasequences* or *simple sequences sensu* Mitchum *et al.* 1991 and Vail *et al.* 1991, respectively). They develop on time scales of 10.000 to 500.000 years. These small-scale sequences are related to climatic cycles (Fischer 1986),

which may be the result in orbital forcing due to Milankovitch rhythms. These Milankovitch cycles consist of (1) the *precession cycle* of the equinoxes (21.000 years), (2) the *obliquity cycle* (41.000 years), and (3) the two *eccentricity cycles* (100.000 and 400.000 years) (Berger 1980, Berger *et al.* 1984).

11.4 Controls on carbonate sedimentation

Carbonates are "living systems", largely produced *in situ* within the depositional environment, whereas siliciclastics are introduced from external sources. Carbonate depositional systems are very sensitive to environmental changes, such as temperature, salinity, light, nutrient supply, water energy, clastic contamination, and currents driven by winds and/or tides (see reviews in Reading 1986, Schlager 1991, Tucker & Wright 1990). Carbonate detritus is mostly produced by organisms and photosynthetic processes (Schlager 1981). The maximum potential of carbonate production is within 10 m of sea level and drops off drastically below this depth.

11.5 Sequence stratigraphy of carbonate systems

Sequence stratigraphic concepts were first applied to siliciclastic depositional systems (Jervey 1988, Posamentier *et al.* 1988, Van Wagoner *et al.* 1988, Vail *et al.* 1984, Haq *et al.* 1987). In 1988 Sarg presented a detailed discussion on the application of sequence stratigraphic concepts to carbonates. Carbonate depositional systems appear to respond to relative sea-level changes in a similar way as siliciclastic depositional systems. Consequently the same systems tracts can be recognized (Vail *et al.* 1991). After Vail *et al.* (1991), lowstand and shelf-margin systems tracts are well-developed in carbonate depositional basins. They are often the major prograding units that build the platform outward and prograde into the basin. Sliding and slumping processes are common in the mudstone facies. Basin-floor fan complexes, composed of massive carbonate debris, derived from the collapse of the platform margin caused by the relative sea level fall are common features at the beginning of the LST. Carbonate slope fan complexes consisting of levee channels and attached lobes (Jaquin *et al.* 1991) are also deposits associated with the lowstand systems tract. According to Vail *et al.* (1991) in the basin highstand systems tracts are starved, in the lower part and accumulate as thicker beds upwards.
On the contrary to the concepts of Vail *et al.* (1991), Droxler & Schlager (1985), Mullins (1983) and Schlager (1991) have proposed the "highstand shedding model".
The highstand tends to be the period of maximum carbonate production and platforms tend to shet most sediment. Massive deposits on the shelf slope can be recognized as slope aprons or toe-of-slope aprons with respect to slope architecture (Mullins 1986). In modern sediments in the Bahamas, Droxler (1984) and Droxler & Schlager (1985) Schlager *et al.* (1994) recognized, that platform shed most sediments during highstands of sea level. Wilber *et al.* (1990) and Glaser & Droxler (1991) interpreted sediment bodies on the Bahamas and Caribbean platform flank of the Late Quaternary also as highstand wedges. During periods of sea level lowstands, carbonate production on the shelf decreases and sediment supply into the basin is negligible (Droxler & Schlager 1985, Schlager 1991).

Chapter 12: Sequence stratigraphy and paleogeographic evolution of the Urgonian Platform

12.1. Introduction

12.1.1 General remarks

In 1985 P. Vail and coworkers determined third-order sequence boundaries based on biostratigraphic data for the Lower Cretaceous in the south-east of France. For the Hauterivian parastratotype (Vergons) they recognized seven third-order sequences (**Ha1-Ha7**); in the Barremian stratotype (Angles) they determined five third-order sequences (**Ba1-Ba5**); and for the Bedoulian stratotype (La Bédoule) four sequences (**Bd1-Bd4**) were determined. These sequence boundaries and corresponding depositional sequences (LST/SMWST, TST, and HST) have been carried out in subsequent studies along profiles from the Vocontian Basin to the shallow shelf.
In 1992 Clavel *et al.* proposed a cycle chart for the Lower Cretaceous which correlates obtained biostratigraphic data with sequence stratigraphic interpretation in a chronostratigraphic framework.
Biostratigraphy is mainly based upon ammonites (Busnardo 1984), echinids (Clavel 1989) and benthic orbitolinid foraminifers (Clavel *et al.* 1993) (Fig. 4.1).
This study was focused "only" on a small window of the large carbonate shelf upon which Urgonian limestones were deposited It is therefore clear that sequence stratigraphic interpretations were at first only of "local" value. As a result the, sequence stratigraphic results have been integrated into the concepts of Clavel *et al.* (1987, 1992, 1994), which were established by studies from the Jura platform in the North to the Vocontian Basin in the South.

12.1.2 Biostratigraphy

The age of sequences has been established by the means of orbitolinids, echinids and ammonites. Echinids and rare ammonites were collected together with orbitolinids in hemipelagic deposits. In shallow-marine platform carbonates, however, only orbitolinids are presented.
Only the detailed biostratigraphic results, especially the repartition of orbitolinids in platform carbonates, made it possible to determine third-order sequences and their systems tracts (Fig. 4.1-4.5).

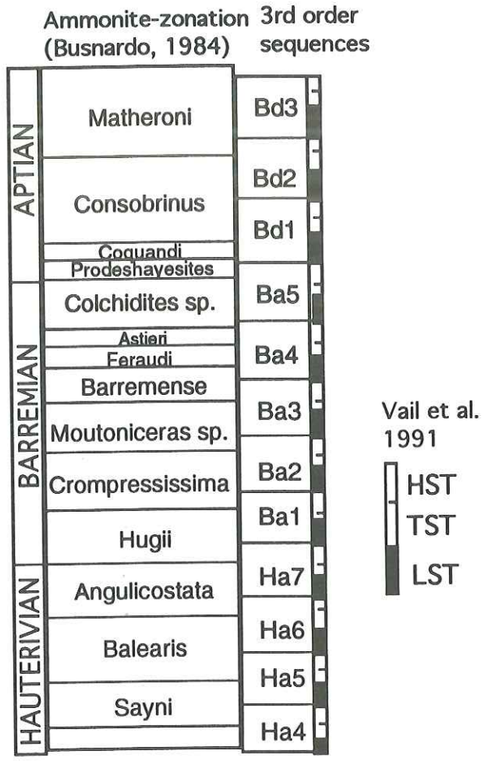


Fig. 12.1. Correlation of the ammonite biozonation and 3rd order depositional sequences from the late Hauterivian to early Aptian (modified after Clavel *et al.* 1994).

12.2 Third-order depositional sequences and paleogeographic evolution

12.2.1 Sequence Ha6

General remarks
With the sequence Ha6 the installation of the carbonate shelf started in the area of study. An autochthonous lowstand/shelf margin complex was deposited in the northern part of the area ("Rocher de Cluses") and in the northeastern Aravis (Pointe Percée). In the same time, in the central Aravis zone slope and platform margin failure occurred. Resulting depositional sequences (Ha6 and Ha7) are built up by hemipelagic limestone series with spectacular mass flow deposits at the base.
The sequence boundary is evident in the stratigraphic records, which separate the glauconite rich marly limestone facies from the following mass flow deposits as well as platform carbonates in depositional stable sites.
(From the Flaine site there is no data).

12.2.1.1 "Rocher de Cluses"

Lowstand/shelf margin systems tract
The 18 m thick lowstand/shelf margin systems tract is characterized by a coarsening-upward/shallowing-upward trend. This tendency corresponds to a progradation of high-energy shoal sediments (microfacies type 2) over extensively bioturbated, moderate-energy foreshoal deposits (microfacies type 1A). The carbonates have a grainstone texture.
The lowstand/shelf margin deposits are terminated by a 1.5 m thick dolomite bank. Euhedral to subhedral dolomite rhombs replaced mostly primary calcite carbonates, composed of the same microfacies (microfacies type 2) as the upper lowstand/shelf margin deposits below.
Dolomite substitution is considered as an early diagenetic process when relative sea level arrived at its lowest point and shoal sedimentation occurred near or at water surface. Dolomitization is related to fluid circulation near the coastal mixing zone, interpreted by the *mixed water-unconfined coastal aquifer model* (Morrow 1990, Tucker & Wright 1990, Zenger *et al.* 1980).

Transgressive systems tract
This systems tract is built up by cross-stratified carbonate beds, at first with a thickening-upward trend and in its upper part with a thinning-upward tendency. Microfacies analysis indicates an upward increase of open marine components in the transgressive stacking patterns. The limestones are composed of high energy shoal sediments of the microfacies types 2 and 3 (medium to coarse grained bioclastic grainstones).
The period of the most rapid relative sea level rise is represented by a thin limestone bed at the top of the TST and composed of small-sized echinoderm fragments and peloids/pellets. The *mfs* indicated by a thin layer rich in reworked clasts above the fine-grained limestone bed which is considered to represent the maximum flooding surface.

Highstand systems tract
Microfacies analysis of the interpreted highstand deposits implies sediment progradation over the underlying transgressive stacking pattern. The sediment composition indicates a moderate energy environment with the presence of stromatoporoid and chaetetid organisms. Limestone beds show a thickening-upward trend.

12.2.1.2 Aravis (Combe de "Bella Cha")

Lowstand Systems tract
The mass flow deposits are interpreted as lowstand deposits.
The stratal patterns of the lowstand, downlap against the underlying sequence boundary Ha6 (plate 8/1). The allochthonous lowstand deposits are composed of a fine grained muddy to silty conglomerate facies. The most spectacular elements of the mass flow deposits are up to 30 m thick and several 100 m large rotational and translational slide blocks. Microfacies analysis of this allochthonous deposits implies deep marine slope to shallow marine platform margin origins (for detailed description see chapter 10 MASS FLOW DEPOSITS).
The allochthonous lowstand deposits are believed to be derived from the collapse of the slope and platform margin caused by tectonic activities during the relative fall of sea level.
As a result the composition of the mass flow deposits they are interpreted as lowstand deposits. The major part of the slide and slump blocks indicate a hemipelagic/circalittoral origin. Only the minor proportion of the blocks was transported from the adjacent platform margin. According to Reijmer

(1991) allochthonous lowstand deposits, are mainly composed of slope material.
The high amount of unlithified shallow-water platform sediment indicates, that carbonate production was not completely decreased on the platform. On the contrary, exposed oolite beds (see Flaine section) are mostly interpreted as prograding lowstand/shelf margin deposits.
According to Vail *et al.* (1991) massive slide and slumps and megablocks are very common within the mudstone facies, and moreover, during contemporaneous seismic/tectonic activities.
The lowstand systems tract was terminated by sediment starvation, indicated by a hardground, borings and encrusting by sessile sponges on the top-surfaces of some megablocks.

Transgressive systems tract
The allochthonous lowstand deposits were "drowned" by the onlapping transgressive systems tract when sea level began to rise (onlapping features on sponge organisms indicate their colonization after sliding). Rapid sea level rise is marked by the deposition of a condensed section. This condensed section is a dark shaley limestone, very rich in fossil debris (mainly brachiopods) and reworked sponges. The shaley micrite contains burrowed beds and hardgrounds. The thickness of the condensed section is approximately 0.5 to 1 m.
The succeeding transgressive deposits indicate a deepening of the sedimentary environment. The regular medium-bedded (0.2 to 0.3 m thick) limestones show nearly the same composition (microfacies type 19) as the underlying pelagic siliceous limestones. The fine grained sediments are characterized by sponge spicules, pellets, quartz-grains, thin bivalve shells and calcispheres.

Condensed section
The maximal transgression and a period of starved sedimentation are indicated by a roughly 3 m thick condensed section. The dark colored shaley limestones are extremely rich in well conserved echinid fossils (*Toxaster retusus*). Microfacies analysis records a wackestone texture with abundant quartz and clay minerals.
A second condensed section separating the early highstand from the late highstand is considered as a duplication of the major condensed section. Such doubling is frequent in the stratigraphic records and is the result of the superposition of sequences of different orders (Pasquier 1995, Tucker 1992).

Highstand systems tract
The following highstand systems tract is about 25 m thick and built up by two parts. The lower part is interpreted as an early highstand systems tract. It is built up by medium-bedded limestones, and is similar to the transgressive systems tract. Sediment composition, however, shows a high proportion of platform derived (unlithified) particles (microfacies type 20). The platform derived particles are interpreted by the input of the approaching platform margin, when carbonate production is at its maximum on the platform (Droxler & Schlager 1985, Jaquin *et al.* 1991, Mullins 1983, Schlager 1991). The early highstand systems tract is interpreted to be deposited during the last phase of relative sea level rise. The thin to medium-bedded stratal patterns could indicate a more rapid increase of accommodation space than the rate of sedimentation.
The late highstand systems tract shows in its lower part approximately the same sediment composition as the early highstand, but in the upper part there is a distinct increase in quartz and clay minerals (both 25%).
This high proportion of quartz and clay minerals indicate beside the "carbonate factory" a further sediment source. During the period of the late

highstand it is supposed that relative sea level was falling. In function of this sea level fall the platform with its different depositional environments prograded basinward. In this way siliciclastic sediments from the hinterland were able to bypass the shallow shelf and were deposited on the deeper slope.
Stacking patterns of parasequences (*sensu* Van Wagoner 1985) are well developed in the highstand systems tract (plate 3, Fig. 13.2). They are bounded by 0.3 to 1 m thick shaley limestones rich in echinid fossils and rare frequent ammonites. These parasequences as well as subordered limestone beds imply a thinning-upwards trend. This feature is interpreted to reflect the decreasing amount of accommodation space at the end of the highstand systems tract.

Summary

With the depositional sequence Ha6 shelf carbonate sedimentation started upon the slope of the Dauphinois Basin in the examined area. Platform progradation occurred from the Jura platform in the northwest to the Dauphinois Basin in the southeast.
Sedimentation in the central Aravis region was strongly influenced by an enhanced subsidence. The sequence Ha6 started with an allochthonous lowstand complex fed by the collapse of the slope and platform margin. TST and HST are built up by hemipelagic to circalittoral parasequence sets with a broadly shallowing-upward tendency.
In the area around the "Rocher de Cluses" section, the shelf sedimentation was not affected by a forced subsidence. After a considerable relative sea level fall platform carbonates prograded over the underlying hemipelagic slope. The whole sequence is composed by moderate to high energy shoal sediments. Differences in sediment composition, grain size and stratal beds made it possible to distinguish the systems tracts.

12.2.2 Sequence Ha7

General remarks
The period of the Ha7 sequence is characterized by a further splitting up of the depositional area in the Aravis. During the interval of the sequence Ha6 sedimentation was controlled by an enhanced subsidence, which induced slope and platform margin collapse and a hemipelagic sedimentation in the forced subsided region in the central Aravis (from the Col des Aravis (SW) to the Combe de Mont Charvet (NE), Fig. 10.1a). During the time of sequence Ha7 forced subsidence continued in a more reduced region, comprising the area from the Col des Aravis to the Combe de Grand Crêt (Fig. 10.1b). The deposited stacking patterns of the systems tracts are similar to the sequence Ha6. In the other parts of the Aravis autochthonous Urgonian platform carbonates were deposited.
In the Flaine realm the sedimentation of platform carbonates started as well by the progradation of the shoal margin complex over circalittoral deposits.
In the "Rocher de Cluses" section the sequence is built up by sediments of the shoal margin complex and the transition zone.
The limit between Hauterivian and Barremian (limit between *Angulicostata* and *Hugii* ammonite-zone) is located somewhat above the maximum flooding surface.

12.2.2.1 "Rocher de Cluses"

Sequence boundary
The SB is identified by a thin marly horizon (0.1 to 0.3 m) rich in detrital quartz and feldspath minerals. An overlying 1 m thick limestone bed, which is partly dolomitized is composed of reworked carbonate material, the micrite matrix suggests vicinity to the unconformity surface.

Lowstand/Shelf margin systems tract
The lowstand/shelf margin systems tract is built up by stacking patterns, which imply a progradation of the complex. The lower part, which suggests a relative sea level fall is composed of a coarse grained intraclastic, bioclastic, and oolitic limestones, terminated by a thin coal horizon. The early phase of sea level rise enabled the first settlements of *Bacinella*-oncoid clusters and rudist patch-reefs. The thickness of the lowstand/shelf margin complex is approximately 25 m.

Transgressive systems tract
The transgressive systems tract is relatively thin and occurs a thickness of approximately 8 m. The TST is associated with a retrogradation of the shelf margin. Shoal sands and fine-grained open-marine sediments indicate a backstepping of the depositional environment.

Maximum flooding surface/Condensed section
The *mfs* is indicated by a submarine omission surface, overlain by a thin partly dolomitized limestone bed. In the outcrop this physical surface is marked by a knife cut line. Development of the mfs is associated with an overlying approximately 10 m thick condensed section. The composition of this cs indicates an increase in water depth above the *mfs*, associated with the influx of quartz and clay minerals. Accessory glauconite grains, Fe-oxides, and intensive bioturbation support the assumption of a starved sedimentation. Loutit *et al.* (1988) explained this elaboration by the rate of sediment yield. According to the authors, small sediment yield moves the point of maximum water depth to later in time than the point of maximum rate of eustatic rise.

Highstand systems tract
Limestone series interpreted as highstand deposits show a shallowing-upward trend. The lower part contains abundant but small-sized stromatoporoid, chaetetid and coral heads combined with a fine grained bioclastic limestone facies. The amount of detrital quartz is still high, but significantly reduced compared with the underlying condensed section. The upper part contains less reef-building organisms. The sediment is composed of a rhythmic bedding of fine-grained and coarse-grained bioclastic limestones. The HST terminates with an oolite bed containing abundant detrital quartz.

12.2.2.2 Aravis mountains (Combe de "Bella Cha")

Between the HST of sequence Ha6 and the thick mass flow deposits of sequence Ha7 there is a 10 m thick succession of sandy to shaley limestones, which indicates a sudden remarkable deepening of the depositional site. The top of this unit is marked by a condensed section rich of pyrite, limonite-nodules, pyrite, quartz and sponge-heads (several cm in diameter). This condensed section is directly overlain by the conglomeratic facies of the mass flow deposits which are interpreted to be the LST/SMST of the sequence Ha7.

Interpretation
Biostratigraphic data show that this sandy to shaley limestone succession is not a (third-order) depositional sequence. Ammonites found in these shaley limestones and in the following stratigraphic record indicate uppermost Hauterivian to lower Barremian. It is not excluded, however, that this succession is basically built up by higher frequency depositional systems tracts.
These deposits could reflect a tectonically enhanced subsidence phase which was assumed for this region. Continuous tectonic/seismic activities could finally have also triggered the subsequent mass flow deposition.
Another possibility could be a starvation of carbonate production on the carbonate shelf and a subsequent basinward lack of particle carbonates (Droxler & Schlager 1985). Continental material such as quartz and clay minerals could have been bypassed the shelf and been deposited as basin floor fans in the distal slope/basin during the early phase of the lowstand (Jaquin *et al.* 1991, Vail *et al.* 1992).

Lowstand systems tract
This systems tract exhibits exactly the same mass flow composition than its equivalent in sequence Ha6. Slide and slump blocks from the circalittoral shelf slope and the platform margin, conglomerates and a circalittoral background-sediments built up this allochthonous systems tract.

Transgressive systems tract
The transgressive surface shows an onlapping with the underlying top-surface of the lowstand deposits together with a subsequent marly layer of reworked clasts. The transgressive systems tract is indicated by a thinning-upward and fining-upward trend. Limestone composition indicates a deepening of the depositional environment.

Condensed section
The condensed section implies the same very fine grained pelletal limestones than the underlying transgressive systems tract. The black rock color, which imply an increase in clay minerals and organic material and a very thin bedding indicate the condensed section.

Highstand systems tract
This systems tract is divided into two (1) an early and (2) late highstand systems tract. The early highstand shows nearly the same sediment composition as the underlying stratal patterns. Rare platform derived particles and a thickening of the stratal patterns indicate a slow down or even stop of the backstepping phase.
The upper HST is characterized by thick carbonate ledges composed of circalittoral to outer platform limestones. Stacking packages indicate a rapid basinward shift of the depositional sites, which is explained by a decrease in relative sea level.
The highstand deposits are bounded at their top by a thin micrite limestone layer, which is mostly dolomitized.

12.2.2.3 Flaine

Platform sedimentation started with the sequence Ha7. Stacking patterns imply approximately the same limestone composition as occurred in the "first" depositional sequences in other outcrops of the study area.
Abundant failure systems, which caused small-scaled truncations, however, made it impossible to determine a correct development of the systems tracts.

Undisturbed examinations were possible some meters below the sequence Ba1.

Summary

In the "Rocher de Cluses" section, the lowstand/shelf margin complex implies progradation during the period of sea level fall and the early phase of increase in water depth. During the lowest point of water depth, the depositional environment was subaerial exposed in the northeastern Borne area. This produced a discontinuous surface and the development of a coal layer. With the marine transgression, fine- to medium grained outer platform sediments (microfacies type 1A) were deposited and indicate a backstepping of the depositional sites. The high amount of siliciclastic detritus is very characteristic of this marine transgression, which drowned underlying lagoonal facies. Between the TST and the HST a 10 m thick condensed section contained a small sediment yield and indicated that maximum water depth occurred later in time than the rate of relative sea level rise (mfs) sensu Loutit *et al.* (1988).
Well stratified rhythmic limestone beds in the HST imply a shoal sedimentation influenced by storm reworking and storm transporting processes (see chapter 9 DEPOSITIONAL ENVIRONMENTS). It is seen, that the developed HST is not very thick (roughly 10 m). The same feature is also observed for the HST in the Aravis realm. Stacking packages above the TST are more characterized by thick stratal patterns interpreted as condensed sections (and the early HST in the Aravis realm), than by bed sets of the overlying highstand deposits.
In the Aravis site, platform carbonates prograded over slope deposits in the northeastern part, between Combe Mont Charvet and Combe de Pacally. They built up stratal packages of sediments of the high energy outer platform depositional environment.
The central part of the Aravis mountains is characterized by the deposition of a second mass flow horizon and overlying fine-grained slope sediments. Stratal patterns overlying the second horizon of mass flow deposits are mostly composed of fine-grained transgressive and condensed deposits. The "real" highstand systems tract exhibit the uppermost thick massive ledges of this depositional sequence.

12.2.3 Sequence Ba1

Generals remarks
With the deposition of this sequence, platform installation also finally occurred in the central Aravis. In the other study areas platform progradation continued. The top of the sequence is terminated with intertidal deposits. In the "Rocher de Cluses" section, there is no development of the lowstand/shelf margin wedge. The TST directly overlies the unconformity surface, which comprises the sequence boundary Ba1 and the transgressive surface.

12.2.3.1 "Rocher de Cluses"

Sequence boundary/Transgressive surface
Microfacies analysis is the best indictor of the change of the sequences. The underlying quartz-rich ooid-bed of the HST is abruptly capped by a fine-grained open marine bioclastic limestone ledge (microfacies type 1B). It indicates a landward shift of marine transgression.

Transgressive systems tract
The TST starts up with a fine-grained outer platform sediment composition directly overlying the SB/TS. This small-sized bioclastic facies changed upward into a coral, stromatoporoid patch-reef facies. Small grown reef organisms at the beginning of the TST exhibit the catch-up phase during relative sea level rise. Exentsive patch-reefs growth, which follows in the stratigraphic record are interpreted as the *keep-up* phase. A drastic decrease in reef-organisms density and subsequent fine grained open marine sedimentation disrupted any reef growth settlement (*give-up* phase). The top-surface of this open marine package is considered to be the maximum flooding surface. It contains abundant ostracods and resedimented ooids.

Highstand systems tract
The vertical development of the HST exhibits progradational stacking packages with a shallowing-upward tendency related to the relative sea level fall.
The HST occurs as three depositional units. The lower unit is built up by reworked high energy coarse-grained bioclastic grainstones (microfacies type 3), overlain by the middle unit composed of rudist, stromatoporoid, coral patch reefs and finally terminated with the third unit of intertidal bioclastic mudstones. The uppermost part is broadly dolomitized, which is related to early diagenetic processes within the intertidal to supratidal zone.

12.2.3.2 Aravis

Lowstand/Shelf margin systems tract
The complex is typically built up by fine grained bioclastic limestones (microfacies 1A) with a decreasing amount of detrital quartz. Carbonate beds show regular thickness at the beginning and a thinning-upward trend in the uppermost part. Vertical microfacies development indicate progradational stacking patterns. The uppermost beds of the complex contain abundant ooids.
Transgressive systems tract
Stacking patterns exhibit a thickening-upward trend with well developed limestone beds, whereas limestone composition shows a fining-upward trend. Microfacies analysis indicates an outer platform deposition in moderate energy sites of the shoal margin complex. The maximum flooding surface is interpreted to be associated with an approximately 2 m thick dolomite bank, which covers the TST. This dolomitized bed is rich in orbitolina-foraminifers, which are frequently good indicators for maximum flooding surfaces.

Highstand systems tract
High energy shoal carbonates (microfacies 2) directly overly the dolomitized condensed section. This brusque change in sediments suggests a sudden decrease in water depth, combined with a basinward shift of the depositional environments. Continuos progradation of the HST is marked by the deposition of low energy lagoonal limestones. The uppermost bed comprises fenestral structures, which indicate a intertidal to supratidal environment.

12.2.3.3 Flaine

Lowstand/Shelf margin systems tract
The LST/SMST is very distinctive, above the sequence boundary Ba1, where it forms a significant surface in the outcrop. The 20 m thick LST/SMST is

composed of two units. The lower unit indicates a shallowing-upward tendency from a bioclastic limestone to a pure oolite complex. The upper unit is built up by thin stacked carbonate beds composed of lagoon/transition zone derived bioclastic limestones.
Stacking packages suggest basinward progradation of the LST/SMST complex. The deposition of the ooids could indicate the lowest point of relative sea level. The second unit may be deposited during a period of relative stable sea level or during the first slight phase of relative sea level rise.

Transgressive systems tract
The TST is built up by coarse grained bioclastic grainstones and abundant reef-building organisms as stromatoporoids and corals indicating a platform shift of the depositional environment. The base of the systems tract is broadly dolomitized. Stacking patterns of the TST occur as well developed regular thick limestone beds. Microfacies analysis indicates a deepening-upward trend with an increase of platform margin to circalittoral components.

Maximum flooding surface
The mfs is considered to be represented by a thin 02. to 0.4 m thick marly limestone layer (microfacies 17) overlying the TST. The thin marly layer contains abundant circalittoral fossils. The most characteristic fossils are well preserved orbitolinid-foraminifers. Nodular bedding indicates intensive bioturbation. In the outcrops this horizon is easy to identify, because the thin bed is less resistant to weathering and therefore forms an erosion groove.

Highstand systems tract
The HST is composed of transition zone to open lagoonal sediments, which indicate a basinward progradation of the depositional environment. Corals and stromatoporoids are abundant in the lower part, but rudist clusters dominate in the upper part.
Stacking patterns show a thinning upward trend, which could be related to the decrease of available accommodation space.

Summary

With the sequence Ba1 the last remaining area of the circalittoral shelf slope was covered by the platform progradation in the central Aravis realm (from Adroit des Aravis to Combe du Gand Crêt). Limestone successions of the sequences exhibit a high energy shoal to lagoonal deposition (*transition zone*).
In the northeastern Bornes Massif ("Rocher de Cluses") the sequence started with the transgressive systems tract above the summarized sequence boundary and transgressive surface. The LST/SMST which is thought to have been pinched out near the shelf margin is not developed. Transgressive and highstand systems tracts imply the build-up by *transition zone* limestones.
In the Platé region the sequence is classically built up by a progradational oolite- LST/SMST, retrogradational to aggradational TST and an aggradational HST.

12.2.4 Sequence Ba2

General remarks
With the sequence Ba2 the colonization of vast rudist biostromes (Urgonian limestones s.s.) began to dominate lagoonal settings, which is outcropped in

the stratigraphic records of "Rocher de Cluses" and Aravis ("Grande Forclaz"). Platform progradational stacking patterns passed into aggradational sets. Lowstand/shelf margin systems tracts are no longer developed in these study realms. The sequence boundaries and transgressive surfaces are combined to represent the basinal unconformity surfaces.
In the Flaine section the sequence Ba2 is still composed of the three systems tracts and indicates progradational and aggradational stacking packages. Oolite limestones and coral-stromatoporoid patch-reefs indicating high to moderate energy environments characterize the systems tracts.
The sequence Ba2 terminates all over the study realm with an emersion, caused by a major relative sea level fall.

12.2.4.1 "Rocher de Cluses"

Sequence boundary/Transgressive surface
The sequence boundary/transgressive surface is marked in the outcrop by a remarkable hardground surface, indicating a period of nondeposition, which overlies the intertidal to supratidal sediments of the uppermost part of the preceding highstand deposits.

Transgressive systems tract
The systems tract is built up by thick limestone beds with a thickening-upward trend. The lowermost part is composed of intertidal tidal flats, partly developed as tidal channel deposits. The lack of basinal intraclastic deposits could indicate a slight relative sea level rise without any major reworking processes. Subsequent beds show upward deepening, which led to the deposition of oncoid limestones and finally the growth of rudist reefs.

Maximum flooding surface
The mfs is indicated by a 0.2 m thick micrite to marly horizon rich in aggregate grains and dasycladacean algae. This level also marks a significant change in sediment composition. The preceding transgressive deposits have packstone to grainstone textures, with the exception of the basinal intertidal limestones. Highstand deposits above the mfs are characterized by a micrite rich texture.

Highstand systems tract
The stratal packages of the HST occur as lagoonal deposits, composed of algal lumps, oncoids and small rudist clusters. The highstand terminates with a thin, approximately 0.5 m thick bioclastic mudstone, which is interpreted as having been deposited within a brackish to lacustrine environment. This thin mudstone bed indicates an extremely basinward progradation or a major decrease in water depth.

12.2.4.2 Aravis ("Grande Forclaz" section)

Sequence boundary
The boundary is marked by a distinguished surface in the outcrop. Carbonate deposits of the underlying HST, which are closed to the sequence boundary contain open-space structures and solution breccia. These sedimentary features are related to the sedimentation near or at the sea level surface, which indicate the lowest point of relative sea level.

Transgressive systems tract and Highstand systems tract
The two systems tracts are summarized because the entire succession has the same composition, which makes it impossible to distinguish between them.
The sequence is mostly characterized by the alternation of 0.3 to 2 m thick rudist patch-reefs and oncoid beds. In the lower part of the unit there is a dominance of the rudist clusters. They are more concentrated in the lower part of the unit, while oncoid and algal lumps dominate in the upper part. This arrangement could be regarded as a criteria to differentiate between the transgressive - and the highstand deposits (?).
The highstand systems tract terminates with a well-exposed discontinuous surface (plate 8/2), which indicates a subaerial exposure of the depositional environment.

12.2.4.3 Flaine

Sequence boundary
A hardground surface indicating a period of non or reduced sedimentation is interpreted to represent the sequence boundary. Sediment history below and above this discontinuous surface also suggests the point of most rapid relative sea level fall.

Lowstand/Shelf margin systems tract
The approximate 20 m thick complex is built up by two units, each one shows a thin regular bedding. Microfacies analysis indicates an increase in ooid proportion from the base to the top, which suggests a shallowing-upward trend caused by a relative sea level fall.

Transgressive systems tract
A brusque change in sediment composition above the top lowstand surface (*tls*) indicates a rapid increase in water depth. The stratal packages of the transgressive systems tract are composed of particles, which are typical for the moderate energy transition zone. Stromatoporoids and corals are the most characteristic organisms in the lower part. After this systems tract rudist bivalves replace the corals, which implies a reduction in water energy.

Maximum flooding surface
The mfs is represented by a 0.5 m thick condensed section. This thin marly bed already indicates features typical for the "Orbitolina marls". Orbitolina-foraminifers (*Paracoskinolina* cf. *sunnilandensis* and *Paleodictyoconus cuvillieri*) are the dominant fossils. Quartz and pyrite are also present. Nodular bedding of the mfs is caused by extensive bioturbation.

Highstand systems tract
The highstand systems tract can be subdivided into three units. Vertical sediment composition of the systems tract indicates a shallowing-upward tendency. The first unit is dominated by small patch-reefs built up by coral and stromatoporoid organisms. The middle part is indicated by a mixture of reef-building organisms, their debris and medium-sized shoal components. This second part terminates with an oolite limestone bed. The third unit is interpreted as a late HST deposited during the phase of relative sea level fall. The uppermost part of the HST shows solution breccia as a result of freshwater penetration. Dissolved particles, especially with a primary aragonite and high Mg-calcite mineralogy and gravitate cements indicate the influence of meteoric waters.
The late highstand systems tracts of sequence Ba2 terminates with a very important unconformity surface.

Summary

The three systems tracts are only developed in the Flaine section, which imply progradational and aggradational stacking patterns.
In the Aravis and "Rocher de Cluses" realm platform progradation passed into an aggradation systems tract with only slight shiftings in the depositional environments. Therefore, transgressive and highstand systems tracts show nearly the same sediment composition, which is mainly dominated by the presence of rudist patch-reefs.
The uppermost parts of the highstand systems tracts in all of the study sections indicate a deposition within an intertidal to brackish lacustrine environment. The top-surface of the sequence represents an important emersion, which imply a major relative sea level fall (see also discussion of sequence Ba3 below).

12.2.5 Sequence Ba3

General remarks
This depositional sequence is not seen in the study area. This lack, however, is at odds with the biostratigraphic results. Arguments are based on the results of Clavel *et al.* (1994).
During the period of the sequences Ba3 to Ba4 (*Barremense* - base *Colchidites* sp.-ammonite zone, Busnardo 1984) the second order cycle reached its maximum regression (Clavel *et al.* 1992). According Clavel *et al.* (1994) the sequence Ba3 was only deposited in the southern Vercors, which represents the most external platform site in the Subalpine realm during the lower Barremian. Only in this realm platform sedimentation occurred, the northeastern to northwestern platform sites were emerged.

Discussion:
Sequence Ba2 terminates with a well outcropped discontinuous surface. In all of the studied sections a second sequence boundary, also associated with an discontinuous surface is developed some cm to meters above what in the stratigraphic record. Between these two discontinuous surfaces intertidal to brackish/lacustrine limestones were deposited. They are interpreted to be packages of the late highstand systems tract (see description above). The duplication of the sequence boundary can be explained by the superposition of different order sequences (Pasquier 1995, Strasser *et al.* 1994).
However, it can also be considered, that the deposits between these two sequence boundaries represent a failed sequence Ba3. In this case the bounding surface below would correspond to the sequence boundary Ba3 and the bounding surface above corresponds to the sequence boundary Ba4 (plate 9/2).

12.2.6 Sequence Ba4

General remarks
During the transgressive phase of the sequence Ba4 the *(lower) Orbitolina beds* (Arnaud-Vanneau & Arnaud 1990) were deposited in the Platé and Aravis region. The subsequent highstand systems tract indicates a basinward shift by the deposition of platform progradational sets.
In the northeastern Bornes Massif platform aggradation continued with the deposition of the rudist limestones.

12.2.6.1 "Rocher de Cluses"

Sequence boundary/transgressive surface
The sequence boundary is considered to overly deposits.
The sequence boundary/transgressive surface is indicated by a notable change in sediment composition. The microfacies below the boundary is composed by the brackish/lacustrine limestones of the uppermost Ba2 highstand. Microfacies above indicates the deposition and reworking of lagoonal deposits.
In the outcrop the discontinuous surface marks a thin but significant limit.

Transgressive systems tract and highstand systems tract
The systems tract is built up by thick massive beds of rudist limestones.
The whole succession is built up by aggradational rudist limestones, which makes it difficult to distinguish between the two systems tracts.
In the lower part stacking rudist beds are less frequent. Beds composed of coarse-grained intraclasts and algal coatings regularly intercalate the patch-reefs. Maybe these appearances could be considered to estimate the transgressive systems tract? The upper part of the unit is built up by regular alterations of rudist patch-reefs and oncoid/rudist debris beds. The upper part of the unit can be considered as the highstand systems tract. However, as already mentioned the build-up of the sequence Ba4 is very regular and characterized by aggradational stacking patterns of rudist patch-reefs and their associated facies.
The sequence Ba4 is abruptly capped by a well developed discontinuous surface.

12.2.6.2 Aravis ("Grande Forclaz" section)

Sequence boundary/Transgressive surface
As already discussed the sequence boundary in the Aravis area is twice developed and related to two well developed discontinuous surfaces (plate 8/2).

Transgressive systems tract
The thick transgressive systems tract is built up by medium to thick carbonate beds intercalated by thin micrite to marly limestone layers. The massive beds exhibit lagoonal sediments, while the marly layers are composed of transgressive facies rich in orbitolina-foraminifers and reworked clasts. These successions can be interpreted as parasequence sets (*sensu* Van Wagoner 1985). Every thin transgressive layer corresponds to a marine-flooding surface. In the upper part of the systems tract, beds show a thinning-up tendency and the repetition of the orbitolina rich marly horizons becomes more frequent. This unit represents the *Orbitolina beds.* The uppermost bed, which overlies this transgressive succession is comprised of the thickest marly marine-flooding deposits. The top of this layer is considered as the maximum flooding surface.

Maximum flooding surface
As already described, the transgressive systems tract contains a series of marine-flooding surfaces. The point of maximum rate of relative sea level rise is interpreted to be within the uppermost outcropped marly limestone bed.

Highstand systems tract
This systems tract is built up by thick massive carbonate ledges with at first a thickening-up and in the upper part a thinning-upward trend. Sediment

composition indicates a progradation of protected lagoonal facies from deeper lagoonal deposits to shallow lagoonal oncoid beds. Rudists are very rare. The top of the highstand consists of a wackestone facies indicating a restricted, intertidal environment.

12.2.6.3 Flaine

Sequence boundary/transgressive surface

The boundary surface is twice developed in a vertical distance of 3 meters. The surfaces indicate periodically emersion of the diagenetic influence by meteoric waters.

Transgressive systems tract
The transgressive systems tract corresponds to the *Orbitolina beds.* The deposits are built up by stacking patterns of parasequences. The massive carbonate beds are dominated by oncoids and large gastropods at the base and pass into coral, chaetetid and stromatoporoid patch-reefs to the top. The beds have a thickening-up tendency. Vertical facies development suggests a deepening-upward trend. The carbonate beds are regular capped by thin marly limestone horizons (*Orbitolina marls*), which indicate also a thickening-up. The TST terminates by the truncation of an approximate 0.7 m thick *Orbitolina marly layer.* Its top-surface is interpreted as the **maximum flooding surface.**

Highstand systems tract
This systems tract is composed of thick, massive beds with a thinning-upward trend. The HST contains the largest individual coral heads, which were found in the study area. The patch-reefs are only 0.3 to 0.8 m thick but they can be recognized over a large stratiphorm extension. Within the HST three of these biostromes are developed. Horizontal outbuilding is related to a relative sea level fall where coral organisms tried to follow optimal conditions by basinward progradation. Apparently the decrease in sea level was rapid, because coral growth terminated abruptly. The last outcropped patch-reef is overlain by a thin limestone bed indicating an intertidal depositional environment.

Summary

The sequence boundary Ba4 represents one of the best outcropped discontinuous surfaces in the study realm and it is interpreted as having been repeated for a second time some cm ("Rocher de Cluses") to several meters (Aravis, Platé) in the subsequent stratal record.
With the sequence Ba4 a recognizable platform retrogradation occurred in the Flaine and Aravis realm. The deposition of inner-platform aggradational stratal packages, however, is exhibited in the "Rocher de Cluses" section.
The *(lower) Orbitolina beds* are built up by stacking parasequences of the transgressive systems tract in the Platé and Aravis region. Each layer of the Orbitolina *marl* corresponds to bounding marine-flooding surfaces of these parasequences.
The top-surface of the sequence indicates intertidal depositional environments in the Platé and Aravis and an emersion in the northeastern Bornes Massif ("Rocher de Cluses").

12.2.7 Sequence Ba5

General remarks
Significant biostratigraphic results by the means of orbitolinids (Fig. 4.2) indicate the lack of the sequence Ba5 in the northwestern Bornes Massif ("Rocher de Cluses" section).
In the Platé and Aravis realm, the study sections terminate with deposits of this sequence. Sediment composition exhibits a high quartz amount, especially in the lower part. Limestone composition implies the deposition in a slightly (Platé) to protected (Aravis) shelf lagoon. The quartz distribution in the carbonate sediments shows in the Platé and in the Aravis exactly the same development.

12.2.7.1 "Rocher de Cluses"

The sequence Ba5 is not developed in this outcrop. Arguments for this assumption are provided by means of orbitolinid-biostratigraphic results (Fig. 4.2). An explication for this is that the well-developed discontinuous surface truncating the top of sequence Ba4 indicates subaerial exposure. Overlying deposits contain the orbitolina foraminifers *Paracoscinolina arcuata*. This species appears in the Early Aptian (Bd1) (Fig. 4.1).

12.2.7.2 Aravis ("Grande Forclaz")

Sequence boundary/transgressive surface
The sequence boundary is marked in the outcrop by a well developed surface and a change in bed thicknesses.

Transgressive systems tract
The systems tract is built up by thinning-upward bed sets. Microfacies analysis indicates an increase in water depth, however, without a notable shift of the depositional environment. Total sedimentation occurred within the protected lagoon. The lowermost bed of the TST contains approximately 10% quartz detritus, but disappears somewhat above. The quartz appears again at the top of the TST an increase up to 40%.

Maximum flooding surface
The *mfs* is interpreted to be next to the sandy limestone bed containing the highest amount of quartz detritus.

Highstand systems tract
The HST is represented by two massive limestone beds containing the same lagoonal deposits as in the TST below. Only the quartz proportion rests relatively high (approximate 5 to 10%).
The HST terminates by a discontinuous surface and is knife cut by the overlying "Helvetic Greensandstones" (Delamette 1994).

12.2.7.3 Flaine

Sequence boundary/transgressive surface
The SB/TS occurs as a thin marly horizon rich in reworked sediments, orbitolina-foraminifers and a high quartz proportion.

Transgressive systems tract
The systems tract is built up by regular thick stratal packages of lagoonal sediments. The basinal transgressive bed contains abundant quartz and reworked clasts from underlying already lithified deposits. The following packages are built up by the *rudist-limestones*, associated with corals and large *Nerinea*-gastropods. Rudist settlements appear in extended patch-reefs for the first time in the Platé realm. However, compared with the other study areas, these rudist colonies are very reduced in thickness.

Maximum flooding surface/condensed section
A thin bed where the quartz amount rises suddenly up to 30% is considered to represent the point of maximum rate in sea level rise. Small benthonic foraminifers and echinoderm debris indicate an open marine influx.

Highstand systems tract
In the outcrop there are no recognizable differences between the stacking packages of the TST and HST. The succession of regular, thick carbonate beds continue up to the end of the Urgonian limestones. Rudist clusters still dominate the facies. Corals are replaced by oncoids and algal lumps. The presence of quartz is the most characteristic feature for the HST. Microfacies analysis indicates a reduction in fossil diversity compared with the TST.
The replacement of corals by oncoids and algal lumps and the forced reduction of component diversity could be caused by a reduction of free water circulation and/or the influx of quartz.
The HST (and also the carbonate platform) ends with a discontinuous surface and is overlain by the "Helvetic Greensandstones" (Delamette 1994).

Summary

With the sequence Ba5 (uppermost Barremian - lowermost Aptian) the Urgonian limestones terminate in the Platé Massif and Aravis Chains. The platform carbonates are capped by a knife cut discontinuous surface.
Stratal patterns of the transgressive- and highstand systems tracts indicate the deposition of moderate to low energy lagoonal sediments which are interpreted by a basinward shift of the depositional environments. The very low fossil diversity also can be related to unfavorable living conditions indicated by the high amount of quartz detritus. The influx of siliciclastic detritus perhaps polluted the environment and drowned the depositional site (Schlager 1981). Funk *et al.* (1993) described the same features for the Helvetic realm as "phases of unhealthy platform growth".
Based on orbitolinid biostratigraphic data (Fig. 4.2) it is interpreted, that the sequence Ba5 is not developed in the northeastern Bornes Massif, which represents the most internal sites of the platform.

12.2.8 Sequence Bd1

General remarks
The sequence Bd1 (lower Aptian, Bedoulian) only occurs in the "Rocher de Cluses" section. Evidence of an Early Aptian age is provided by Orbitolinid biostratigraphic results.
Stacking parasequences of the transgressive systems tract build up the *(lower) Orbitolina beds*. Subsequent highstand deposits exhibit protected lagoonal limestones.

12.2.8.1 "Rocher de Cluses" section

Sequence Boundary/transgressive surface
The SB/TS is linked with the discontinuous surface of the sequence Ba3, which forms a significant discontinuous surface.

Transgressive systems tract
The lower part of the systems tract is built up by brackish/lacustrine and intertidal deposits, mixed with protected lagoonal sediments. This succession of very shallow water limestones contain series of superimposed discontinuous surfaces indicating frequent subaerial exposure of this depositional system. The position of this unit within the depositional systems is not clear and will discussed below.
The restricted facies is capped by a thin bed of marine flooding deposits, the first layer of the Orbitolina marls. The subsequent transgressive systems tract is built up by stacked parasequences which are regularly truncated by thin condensed sections (marine flooding surfaces). The massive carbonate units of the parasequences are built up by lagoonal limestones.

Maximum flooding surface
It is considered that the maximum flooding surface lies within the uppermost condensed section. The presence of glauconite grains, thin coal layers, pyrite and nodular bedding, confirm the condensed character.

Highstand systems tract
The highstand systems tract is built up by thick massive units with a thinning-upward tendency.
Limestone composition implies the succession of aggradational sets for the most part of the highstand. Only the upper part is built up by progradational bed sets. The whole HST is composed of protected oncoid and algal lump rich lagoonal limestones (microfacies type 14). The HST terminated with intertidal deposits, which show subaerial exposure features.

Summary

The succession of brackish/lacustrine to intertidal limestones are interpreted as the lowermost part of the transgressive systems tract. The unit is interpreted to be deposited during a slow increase in relative sea level after a period of emersion. The best argument for this interpretation is the well developed discontinuous surface which underlies this restricted facies.
Another interpretation is also possible and has already been discussed for sequence Ba3: The restricted unit could also represent the failed sequence Ba4. In this case the first marine-flooding surface (first *Orbitolina marl* layer) bounding these limestone series at the top, is the sequence boundary/transgressive surface of the subsequent sequence Bd1.
Stacking parasequence sets deposited during the transgressive phase of relative sea level rise built up the *Orbitolina beds*. Each *Orbitolina marl* layer represents a condensed section with a basinal marine-flooding surface.
The highstand systems tract is mostly built up by aggradational stratal units and passes into progradational sets in the uppermost part.
The sequence finished by the deposition of intertidal sediments, which indicate subaerial exposure.

12.2.9 Sequence Bd2

General remarks
The sequence Bd2 is the uppermost unit of the outcropped Urgonian limestones in the "Rocher de Cluses" section. Sedimentation is mostly characterized by the presence of high quartz proportions. Carbonate composition and the stratigraphic quartz distribution is identical to the deposits of the sequence Ba5 in the Platé Massif and Aravis mountains.

12.2.9.1 "Rocher de Cluses"

Sequence boundary/Transgressive surface
The SB/TS is marked in the outcrop by a change in the thickening tendency of developed beds. The underlying HST shows a thinning-upward trend and the TST above the bounding surface indicate a thickening-upward trend. The marine transgressive surface is indicated by a thin deposit of reworked clasts.

Transgressive systems tract
Limestone beds exhibit a thickening-upward trend. The most characteristic feature of the TST is an initial upward increase of detrital quartz. Maximum was recorded by the deposition of siliciclastic detritus (> 60%). Above this maximum, the quartz proportion decreases but remains high (> 20%). Carbonate particles are composed of fine-grained open marine sediments indicating a relative sea level rise and backstepping of the depositional settings.
The TST is terminated by a distinctive discontinuous surface and overlain by the "Helvetic Greensandstones" (Delamette 1994).

Summary

Urgonian limestones terminate with the transgressive systems tract of the sequence Bd2. As already mentioned in the discussion of sequence Ba5, maybe the quartz influx polluted the carbonate factory and thus drowned the carbonate platform.

12.3 Conclusions

The Urgonian limestones in the northern Subalpine Chains were deposited on a carbonate shelf which developed between the uppermost Hauterivian and the lower Aptian (Bedoulian) (Fig. 13.1 and Fig. 12.7).
A "general" trend of relative sea level fall enabled the progradation of platform carbonates over the slightly southwards dipping hemipelagic slope of the Dauphinois Basin. This relative fall in sea level is interpreted to be the major marine regressive phase of a second-order eustatic cycle, which has its maximal regression in the upper Barremian (Clavel *et al.* 1992).
Exposed stacking patterns allow sequences and systems tracts to be identified according to the criteria proposed by Posamentier & James (1993), Vail *et al.* (1991), Van Wagoner (1985), Van Wagoner *et al.* (1988). Field evidence, sedimentological data and biostratigraphic results, based mainly on orbitolinid distribution (and completed with ammonite and echinid data) led to the interpretation of third-order sequences ranging from the sequence Ha6 to sequence Bd2. However, investigations imply, that some of the sequences have missing. It is assumed, that sequence Ba3 was not deposited in

the studied area. Sequence Ba5 lacks in the "Rocher de Cluses" section, however it is presented in the Flaine and Aravis sections, where the sequence composed the top-part of the outcrops.

In the **"Rocher de Cluses"** section the installation of shallow-marine platform carbonates began with the sequence Ha6 and terminated in the lower Bedoulian sequence Bd2. The sequences Ba3 and Ba5 are missing. Lowstand/shelf margin deposits are only recognized within the depositional sequences Ha6 to Ha7.

Limestone ledges of the "Rocher de Cluses" section best expose the platform progradation of studied area. The lower part exhibits deposits of the marginal high energy shoal complex, the middle part is built up by open to slightly protected lagoonal limestones, exhibiting coral-stromatoporoid and rudist patch-reefs. The upper part exposes deposits of protected to semi-restricted lagoonal environments. Major relative sea level falls produced brackish to lacustrine environments or even platform exposure. The sequences Ba3 and Ba5 are missing. The influence of marine transgressions produced a sedimentation of fine-grained open marine bioclastic arenites with high amounts of terrestrial material.

The stratal patterns in the central **Aravis** occur as depositional sequences in the shelf slope and the shallow platform. Spectacular mass flow deposits derived from slope and platform margin collapses build up the lowstand deposits of late Hauterivian sequences (Ha6 and Ha7). Platform carbonates indicate a Ha6 (Pointe Percée), Ha7 (central Aravis realm), Ba1 (southwestern part) to Ba5 age.

The Aravis realm is interpreted to represent an intermediate location on the paleoshelf. The stratal patterns of the Aravis sections exhibit aggradational bed sets deposited in a slightly protected lagoonal environment. The thickest rudist limestones of all of the studied sections are seen in this region. Only the upper part of the outcrop is built up by progradational bed sets composed of protected lagoonal environments. Large-scaled relative sea level falls are indicated by the deposition of intertidal sediment. Deposits of brackish to lacustrine limestones have not been found. Well-developed discontinuous horizons and the lack of sequence Ba3 also indicate platform exposure over longer periods.

In the **Flaine** area platform sedimentation started with the sequence Ha7 and terminates in the sequence Ba5. Lowstand deposits on the platform have been recognized in sequences Ba1 and Ba2. Stacking packages of the section exhibit the dominance of aggradational to slightly progradational bed sets deposited in high to moderate energy platform margin to open lagoonal sites. Only the upper part of the section indicates the progradation of slightly protected to protected lagoonal sediments. A major sea level fall is indicated by well-developed emersion surfaces and the lack of the sequence Ba3.

The "death" of platform sedimentation could have been announced by the major influx of siliciclastic detritus in the uppermost parts of the outcrops. Funk *et al.* (1993) related these "unhealthy phases of platform growth" by the input of detritus and nutrients as a result of an increase in weathering rates on the adjacent European continent Föllmi (1989).

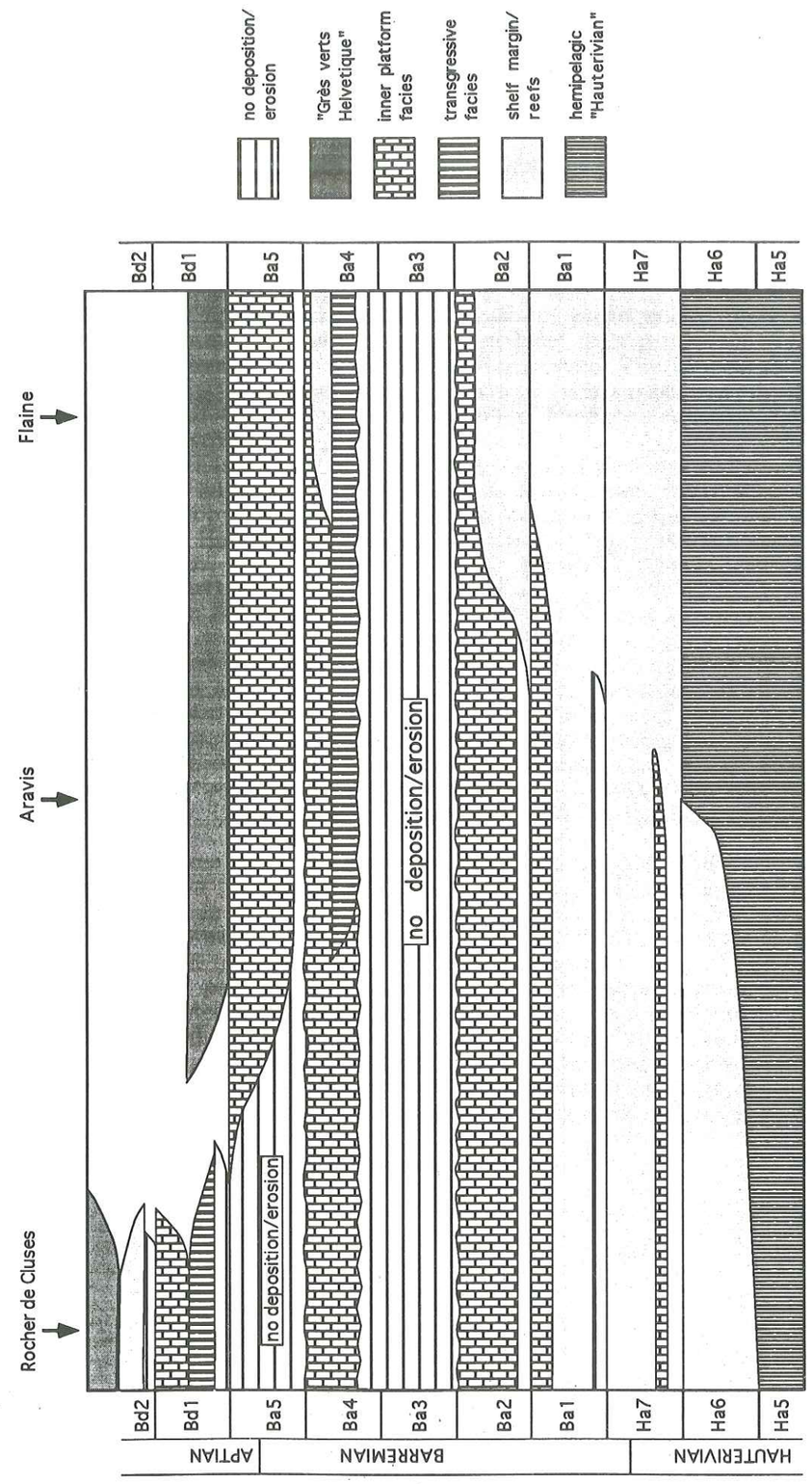


Fig. 12.2. Progradation of the Urgonian platform in the northern Subalpine Chains during the late Hauterivian to early Aptian.

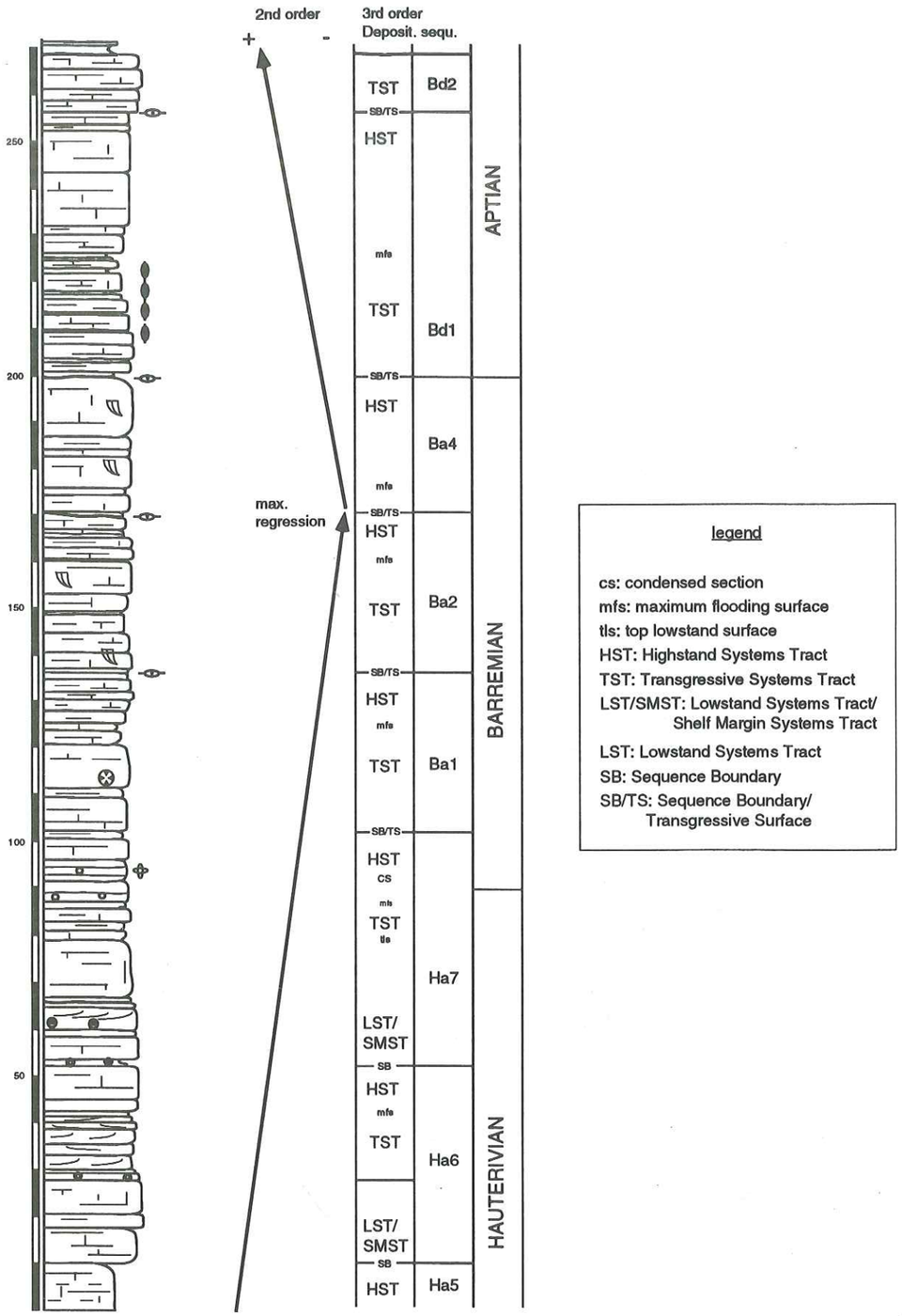


Fig. 12.3. Sequence stratigraphic interpretation of the "Rocher de Cluses" section.

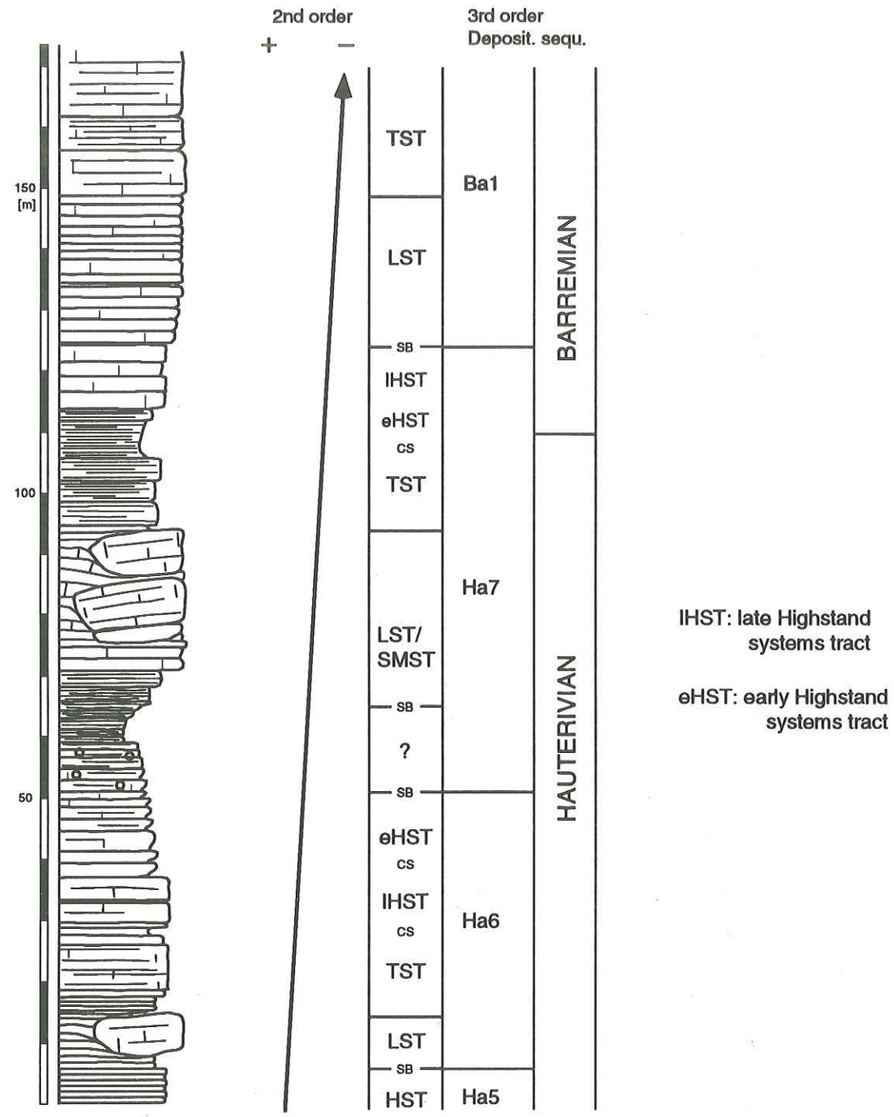


Fig.12.4. Sequence stratigrphic interpretation of the "Bella Cha" section.

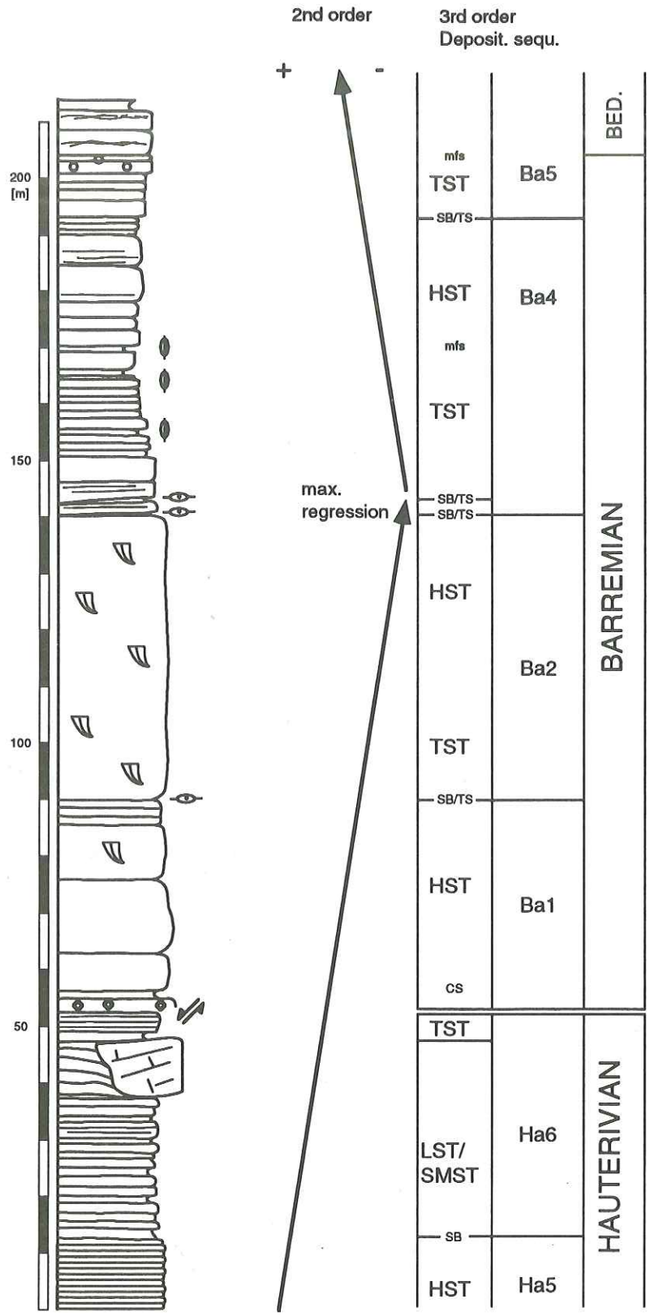


Fig. 12.5. Sequence stratigraphic interpretation of the "Grande Forclaz" section.

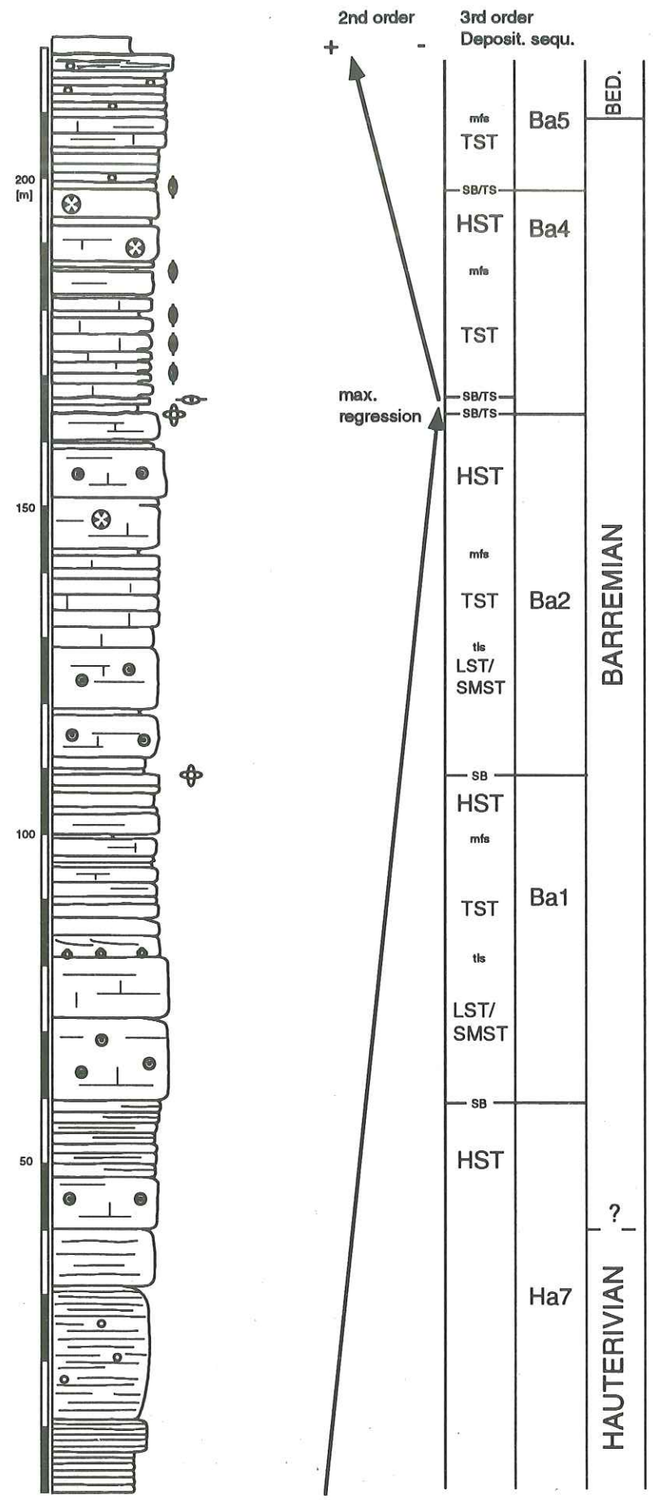


Fig. 12.6. Sequence stratigraphic interpretation of the "Flaine" section.

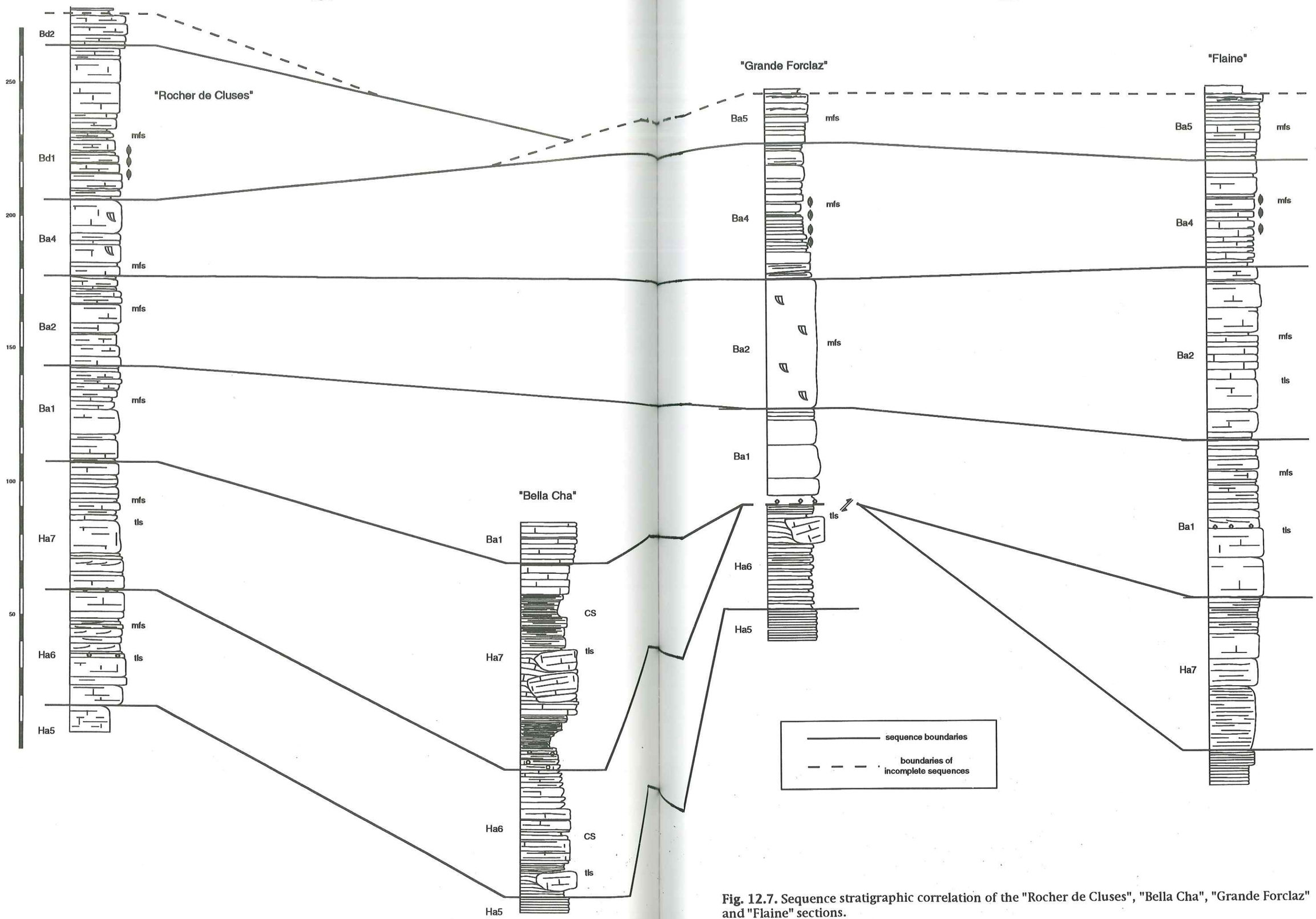


Fig. 12.7. Sequence stratigraphic correlation of the "Rocher de Cluses", "Bella Cha", "Grande Forclaz" and "Flaine" sections.

Chapter 13: Conclusions

In the northwestern **Subalpine Chains** detailed outcrops were studied in the northwestern **Bornes Massif, Platé Massif,** and **Aravis mountains** (Fig. 1.3) to interpret sedimentologic, paleogeographic and the biostratigraphic history of the Urgonian limestones and their distal hemipelagic equivalents. Four sections have been used as "reference" sections, (1) "Rocher de Cluses" (Bornes Massif), (2) "Bella Cha" and (3) "Grande Forclaz" (Aravis mountains), and "Flaine" (Platé Massif) (Figs. A.1-A.4). Ten other sections were further studied to complete these investigations.

By means of microfacies analysis **23 microfacies- and facies types** were established as basic units of depositional environmental interpretations. **seven** sites of **depositional environments** were recorded and used to reconstruct the paleogeographic history. These are: (1) muddy shelf/slope, (2) marginal shoal-complex, (3) "transition zone", (4) open to slightly protected lagoon, (3) protected to semi restricted lagoon, (6) restricted environments, and (7) "transgressive facies". The "transgressive facies" represents a less well-developed depositional environment to marine transgressive events, which "switched-down" prevailing paleoenvironments. The best described sequences of these transgressive pulses are the *Orbitolina beds.*

Biostratigraphic results are mainly based on the investigation of orbitolinid-foraminifers, which are the most useful fossils for determining the age of the shallow-water platform carbonates. In hemipelagic deposits, ammonites and echinids complete biostratigraphic investigations (Fig. 4.2-4.5). Biostratigraphy based on orbitolinid distributions were used for sequence stratigraphic interpretations (Clavel *et al.* 1993, 1994).

Sequence stratigraphic analysis focused on the interpretation of third-order sequences. Stratal patterns of the slope and platform, allowed to the identification of sequences and depositional systems tracts following the sequence-stratigraphic criteria proposed by Clavel *et al.* (1992, 1993, 1994), Posamentier & James (1993), Sarg (1988), Vail *et al.* (1991), Van Wagoner (1985), Van Wagoner *et al.* (1988).
Apart from sedimentological criteria, orbitolinid distributions were the most important means for sequence stratigraphic interpretations.
Biostratigraphic data and sequence stratigraphic interpretations imply a progressive installation of the platform from the NW Bornes domain to the Aravis and Plate area in the SW. This interpretation agrees with Clavel *et al.* (1987, 1994). These authors reported a major direction of the platform progradation from the Jura mountains to the NW and the Dauphinois Basin to the SE.
Examined platform carbonates are predominately built up by progradational and aggradational bed sets. Backstepping of depositional environments over long periods were never observed in the stratigraphic record.
Biostratigraphic data indicates the lack of depositional sequences on the platform, which coincide with outcropping emersive surfaces, subaerial diagenetic features, and restricted lagoonal to pond facies in the vicinity of these boundaries. It is considered, that sequence Ba3 is absent all over the studied realm and sequence Ba5 is absent in the "Rocher de Cluses" section.

Platform installation occurred in the "Rocher de Cluses" realm in the late Hauterivian *Balearis* ammonite-zone (sequence Ha6).
In the tectonic influenced Aravis realm, platform installation happened in three steps. In the northeastern part (Pointe Percée) platform sedimentation started in the *Balearis* ammonite-zone (sequence Ha6) as in the "Rocher de Cluses" area. In the central part of the Aravis, platform carbonates prograded over circalittoral deposits in the uppermost Hauterivian *Angulicostata* ammonite-zone (sequence Ha7). Finally, in the SW Aravis region, platform architecture was stabilized in the basinal Barremian *Hugii* ammonite-zone (sequence Ba1) (Fig. 12.7).
In the Platé Massif ("Flaine" section) the Urgonian platform prograded over circalittoral slope deposits in the uppermost Hauterivian *Angulicostata* ammonite-zone (sequence Ha7).
The Urgonian platform attained its maximum extent in the uppermost Barremian/earliest Aptian times (sequences Ba4 to lower Ba5). Platform architecture from this period is traceable along the entire western to northern Alps (Arnaud-Vanneau & Arnaud 1990, Bollinger 1986, Funk & Briegel 1979, Föllmi 1989).
The Urgonian platform terminates in the "Flaine" and "Grande Forclaz" section in the earliest Aptian *Prodeshayesites* ammonite-zone, in the upper sequence Ba5, and in the "Rocher de Cluses" section in the Early Aptian *Consobrinus* ammonite-zone (sequence Bd2) (Fig. 12.7).
In all of the studied sections Urgonian platform carbonates are sharply truncated by the overlying "Helvetic Greensandstones" (Delamette 1994) (plate 8/3).
The finale of platform sedimentation was perhaps already announced by the sudden appearance of siliciclastic detritus, several meters below the top-surface. Föllmi (1989) and Funk *et al.* (1993) described the same "platform unhealthy growth" from the Swiss Helvetic shelf. For the Late Aptian, Föllmi (1989) mentioned, that the influx of boreal water into the tethyan domain could have deflected tethyan current systems, and a regional deterioration in climate enhancing thus the availability and influx of siliciclastic material. Perhaps similar environmental conditions could have been affected sedimentary sites in more western parts on the Helvetic Shelf in the Lower Aptian where this study was carried out.

Gravity submarine mass flow deposits traceable in the Aravis mountains are interpreted to reflect catastrophic slope and platform margin collapses. Reasons for catastrophic slope and platform failure are well described in recent and fossil deposits (e.g. Cook *et al.* (1972), Cook & Mullins (1983), García-Mondéjar *et al.* (1993), Schlager & Camber (1986), Schlager *et al.* (1994).
For the mass flow movements in the Aravis, the interplay between tectonic/seismic activities and relative sea level falls are considered as possible trigger mechanisms for slope and platform collapses.
By means of sequence stratigraphic interpretations, the lower (first) mass flow horizon has been interpreted as lowstand deposits of the sequence Ha6. The upper (second) horizon has been interpreted as lowstand deposits of the sequence Ha7.

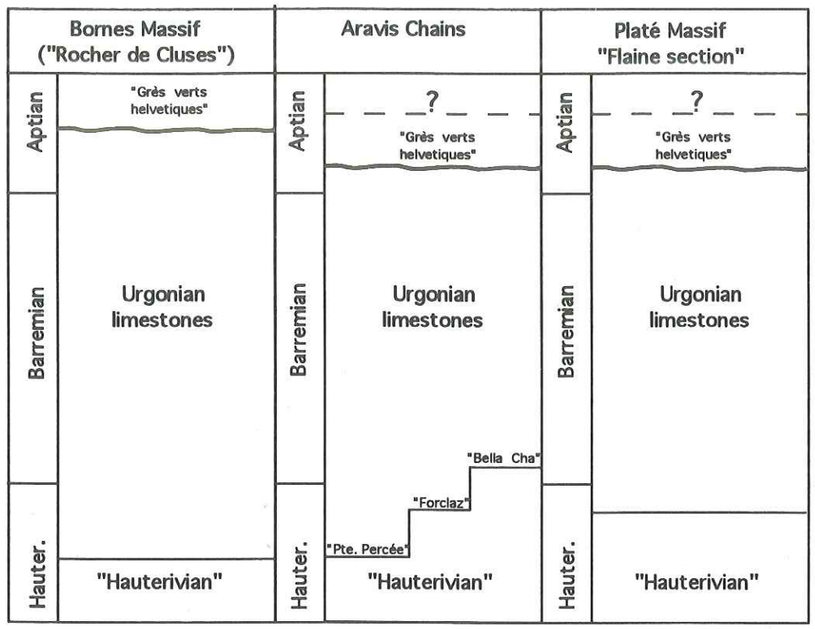


Fig. 13.1. Simplified lithostratigraphic relationships of the Urgonian limestones in the Bornes Massif, Aravis mountains, and Platé Massif.

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PLATES

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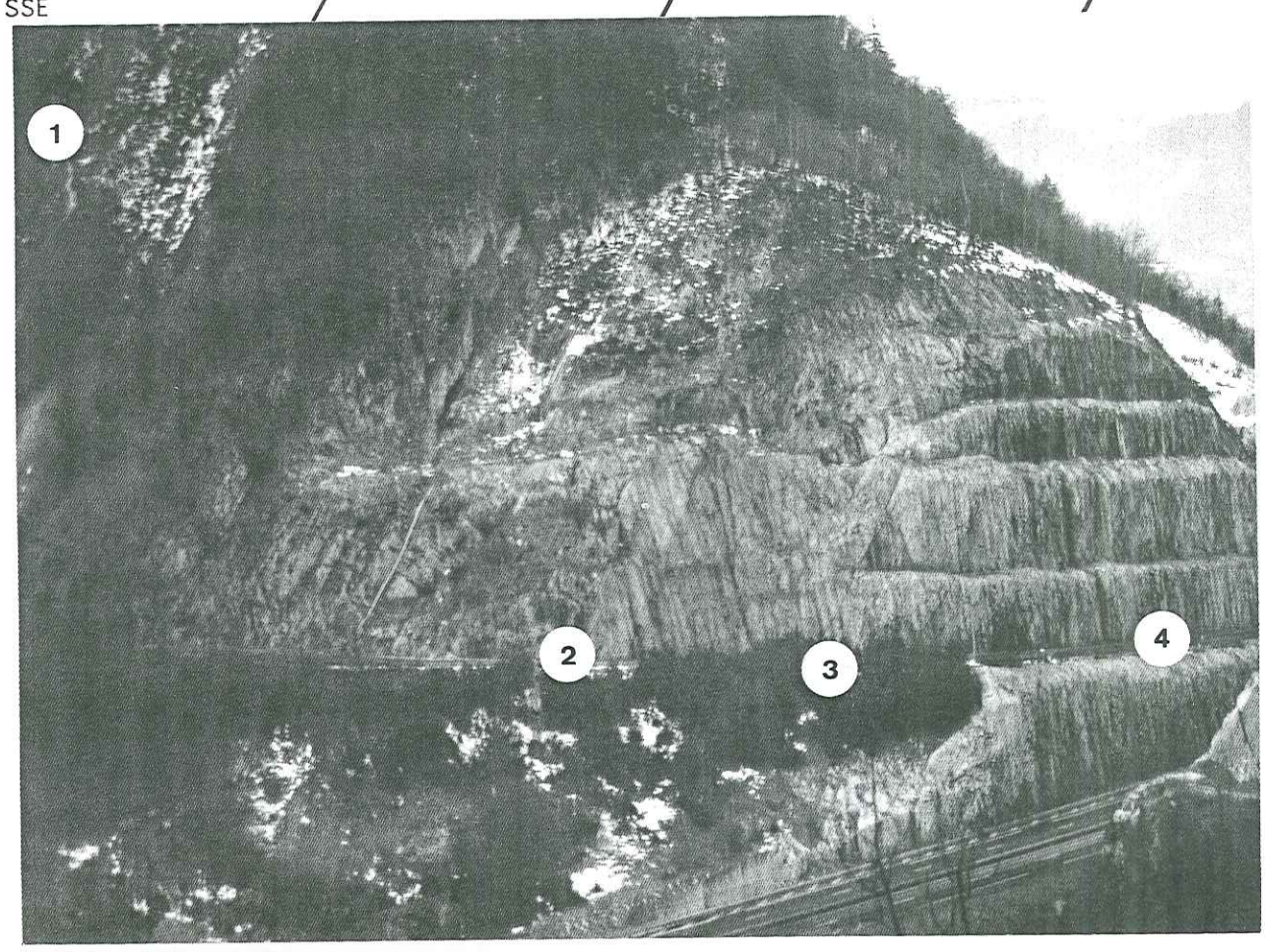
plate 1

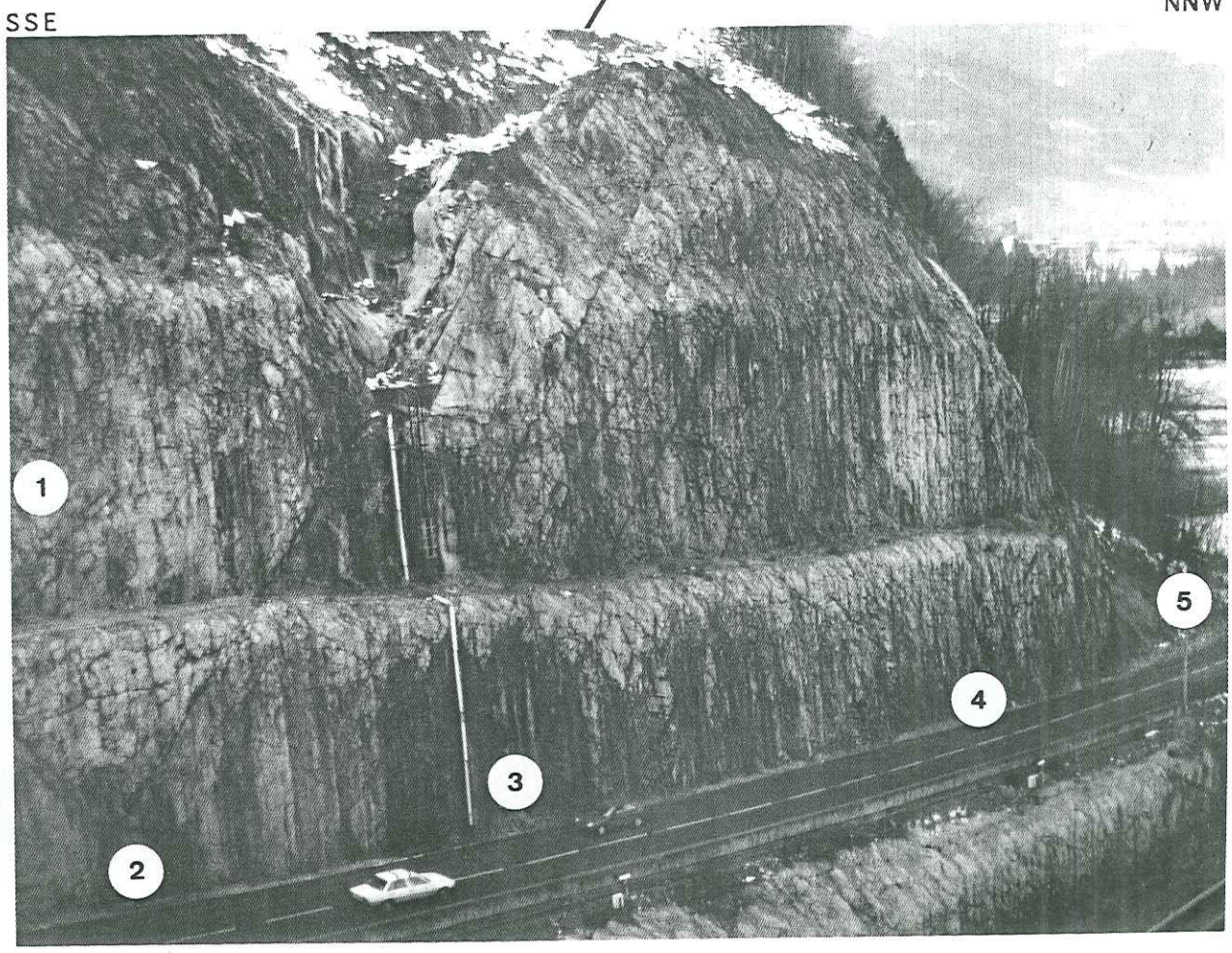
"Rocher de Cluses" section (part 1)



1. "Hauterivian"
2. oolite bank with adjacent coal layer (arrow, sample 1.102)
3. massif coral-chaetetid-stromatoporoid patch reef (sample 1.175)
4. quartz-rich unit (sample 1.142)
5. "rudist limestones"

plate 2

"Rocher de Cluses" section (part 2)



1. "rudist limestones"
2. lacustrine/brackish limestones
3. "Orbitolina beds"
4. quartz-rich unit (sample 1.352)
5. "Grès verts helvetiques"

Plate 3

"Bella Cha" section

plate 3

"Bella Cha" section

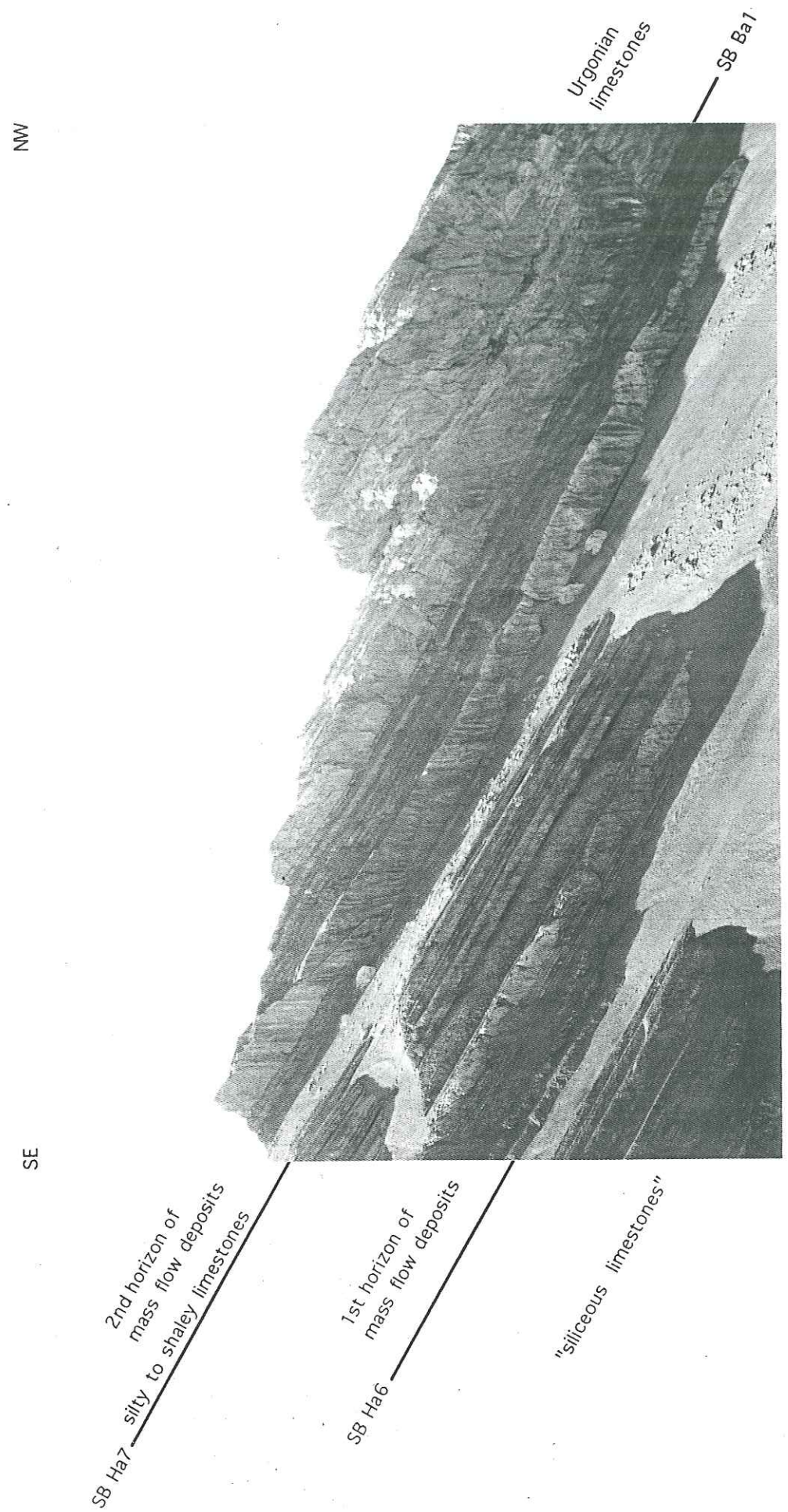
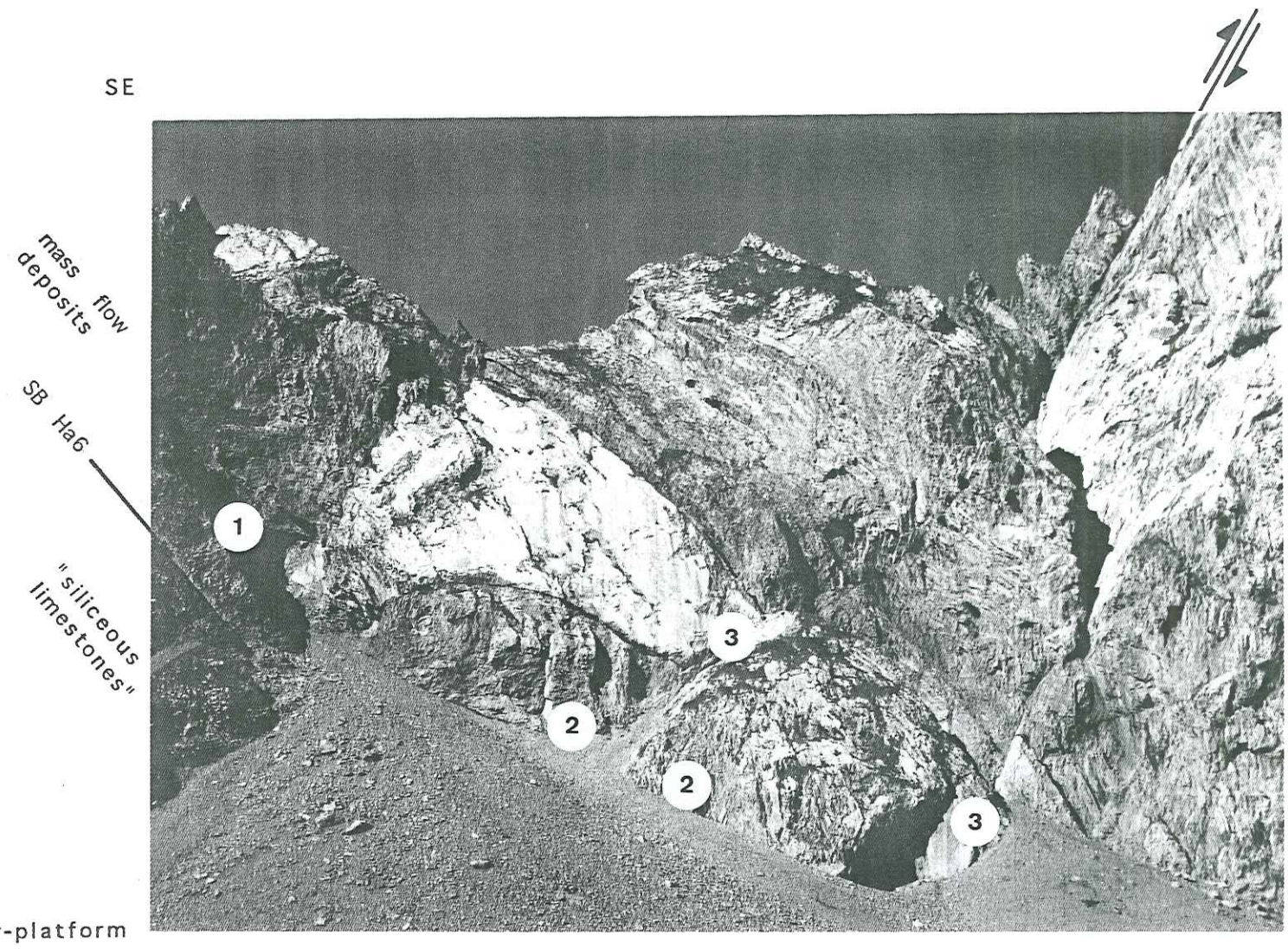


plate 4

"Grande Forclaz" section (part 1)



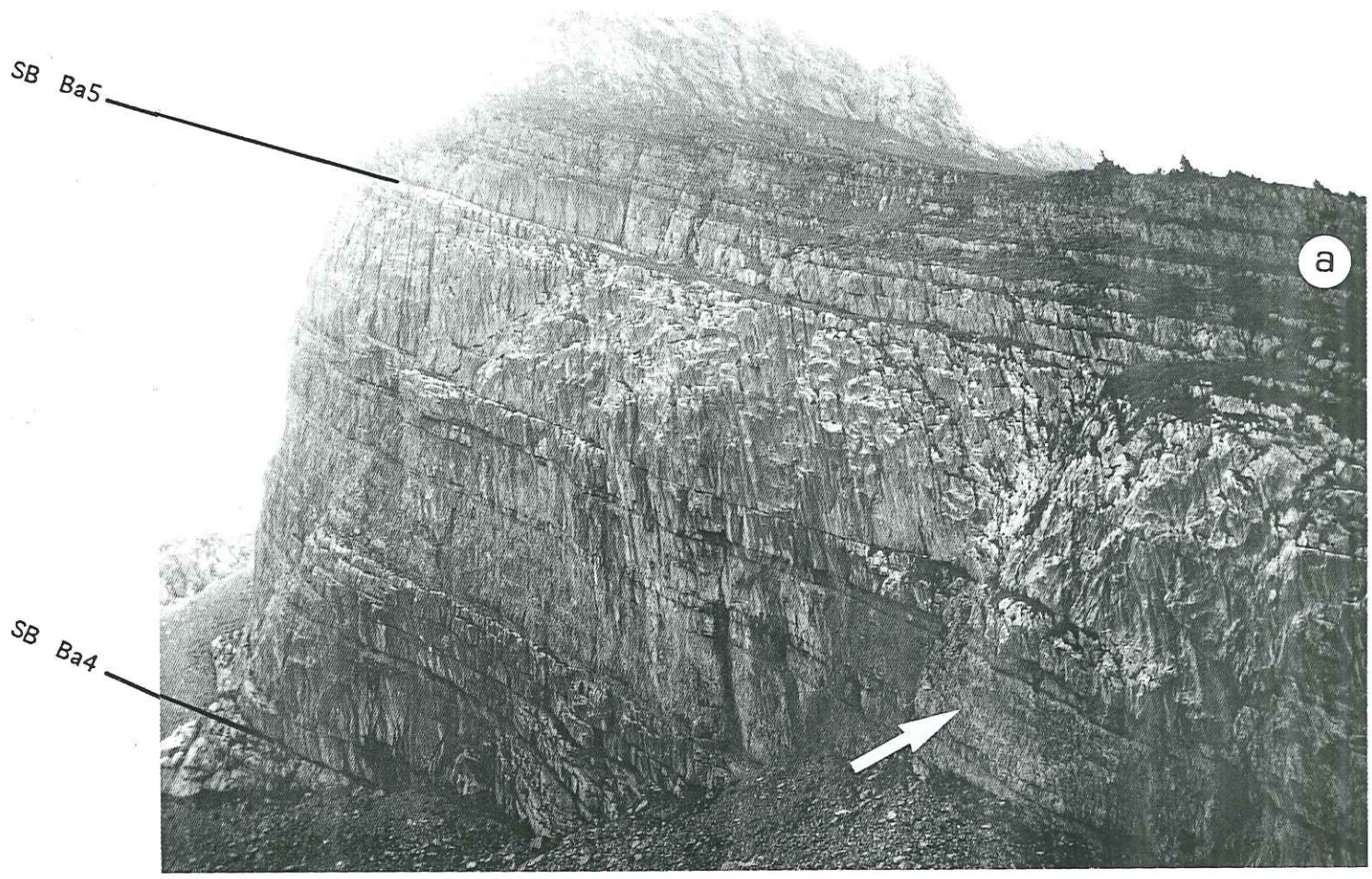
① hemipelagic slope limestones

② circalittoral/outer-platform limestones

③ platform-margin carbonates

plate 5

"Grande Forclaz" section (part 2)



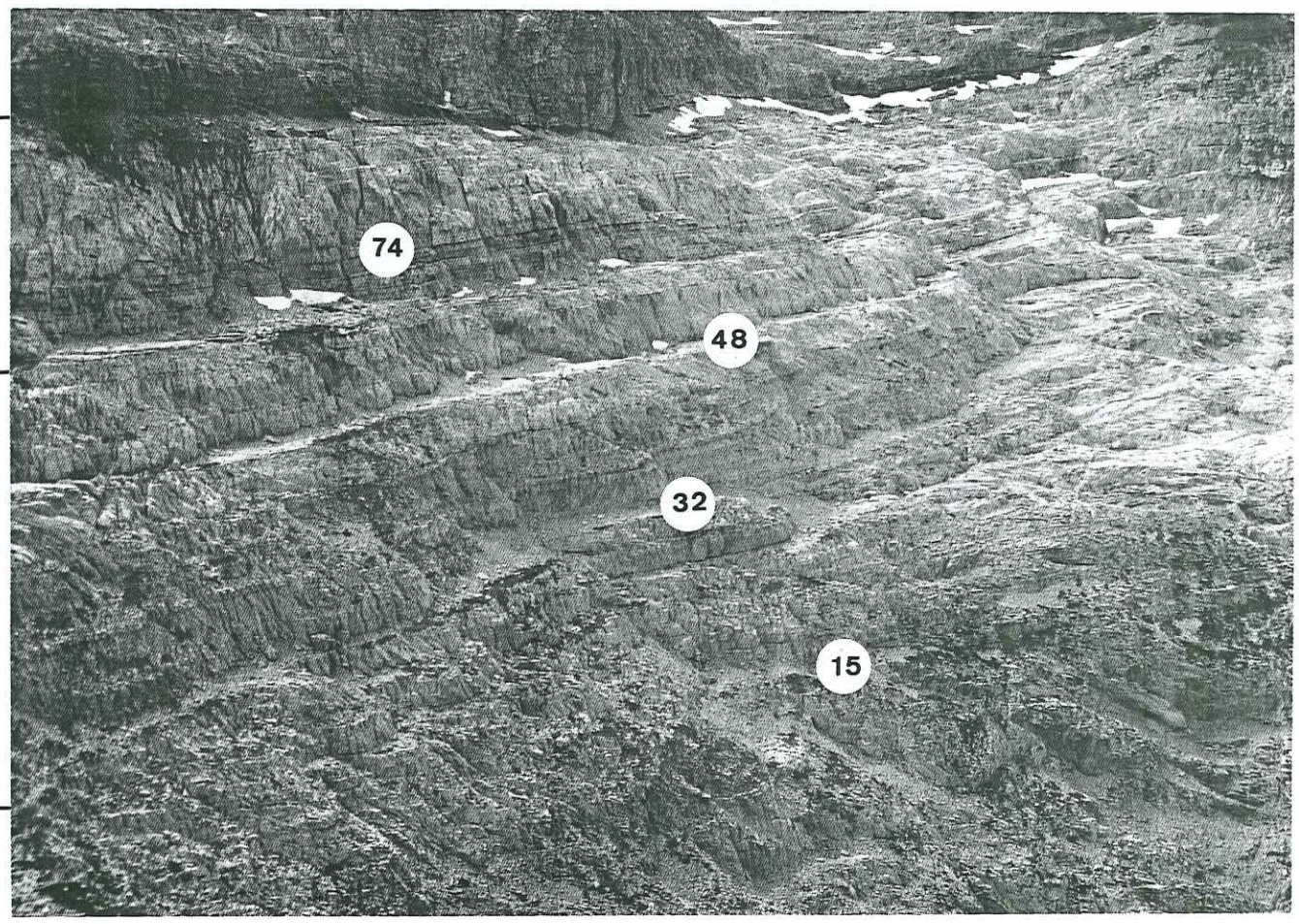
The photo shows the upper part of the section, which is mainly built up by bed sets of the sequence Ba4. At the base of the section, an unconformity surface is interpreted as the sequence boundary Ba4. The somewhat micritic to marly limestones represent the Orbitolina beds (white arrow). The uppermost part of the section, which is interpreted as the sequence Ba5 indicates a well recognizable thinning-upward trend, and contains partly abundant quartz detritus (a).

Plate 6

"Flaine" section

plate 6

"Flaine" section



"Flaine" section looking in a southwest direction. The section exhibits well-bedded limestones, which are regularly intercalated by thin micrite to marly layers. Most of these carbonates consist of medium- to coarse grained bioclastic to oolitic grainstones, indicating platform margin to open lagoonal depositional sites. The Urgonian limestones are sharply truncated by the overlying " Helvetic Greensandstones. Some samples are indicated for orientation purposes.

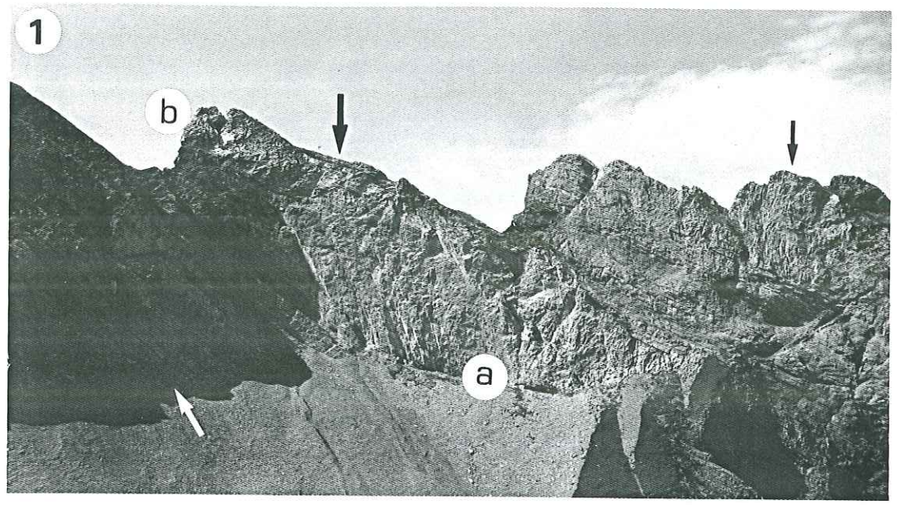
Plate 7

Downslope development of the (lowermost) mass flow deposits (Aravis Chains).

7.1 "Combe de Tardevant" looking in a southwest direction. Photo shows large rotational (a) and translational slide blocks (b). The white arrow indicates the "siliceous limestones". The Urgonian platform carbonates are marked below the small black arrow on the right. (For tectonic interpretations see Gidon & Pairis 1993, Fig. 2).
Scale: white arrow: approximately 15 m.

7.2 "Combe de Bella Cha". On the right hand side of this photo a megablock derived from the collapsed platform margin (large arrow) is illustrated. For the sediment composition of this block see plate 11/1. The medium-sized arrow marks a slide sheet, and the small arrow indicates the "insitu" facies (see photomicrograph plate 11/1 and 11/3).
Scale: the large megablock is roughly 8 m thick. For total outcrop view see also plate 3).

7.3 "Col des Aravis". The mass flow deposits are formed of relatively small-sized slump and slide blocks (large arrow), conglomerate facies(small arrow, see plate 9) and a fine-grained "insitu" facies (plate 11/2 and 11/3).
Scale: see person. The lower and upper limits of this horizon are indicated on the edges of the photo.



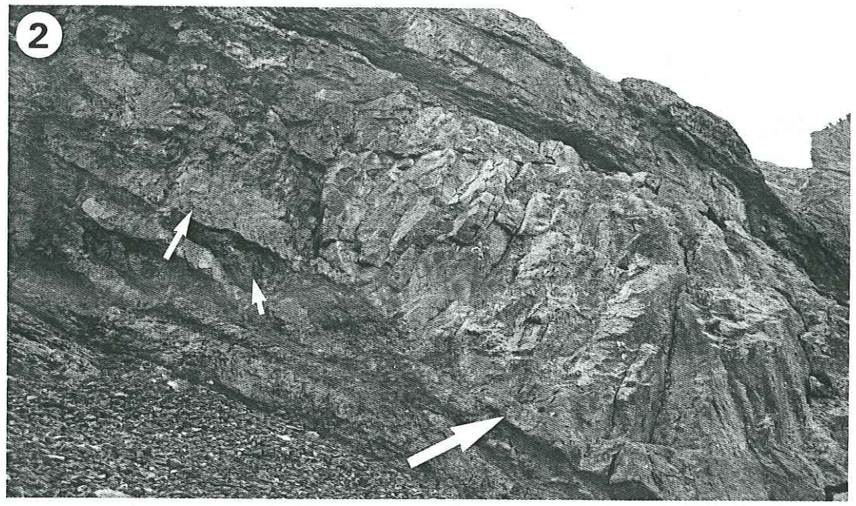


Plate 8

8.1 "Col des Aravis". The photo shows clinoform stacking packages of the interpreted lowstand/shelf margin systems tract of sequence Ha6. The basinward dipping bed sets downlap against the underlying sequence boundary Ha6 ((2) and (1) respectively).
The illustrated outcrop belongs to the same stratigraphic unit as the lower-most horizon of the mass flow deposits. The section indicates apart from slope failure and subsequent mass movements that the development of undisturbed prograding lowstand/shelf margin deposits on the slope also occurred.

8.2 "Grande Forclaz" section. This photo shows an unconformity surface (black arrow), which is interpreted to represent the sequence boundary Ba4. The upper-most unconformity surface, located two meters above, (white arrow) is interpreted to represent a duplication of the preceeding sequence boundary. The carbonate ledge between these two surfaces is composed of protected lagoonal shallow subtidal to intertidal limestones.

8.3 "Grande Foclaz" section. This photo shows the top-surface of the Urgonian limestones, which are sharply overlain by the "Helvetic Green sandstones" (Delamette 1994). These truncated boundaries are typical for all the studied sections.

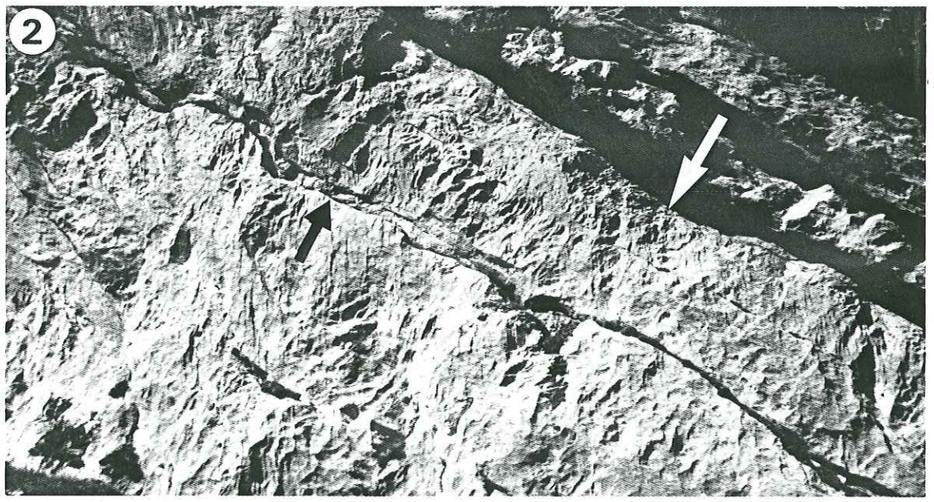


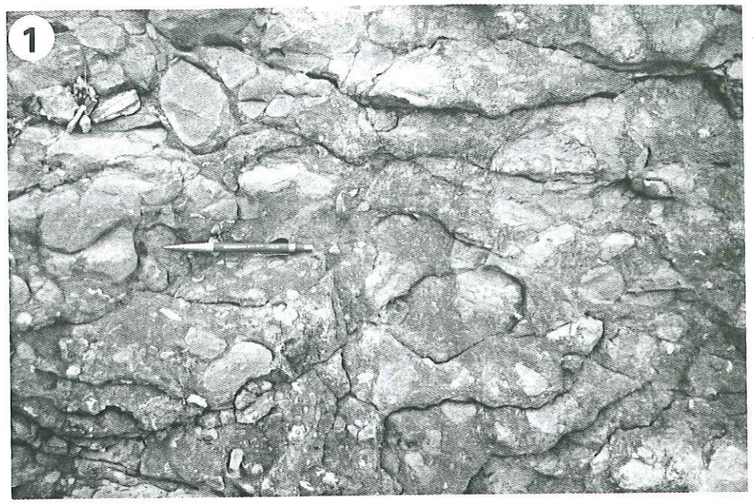
Plate 9

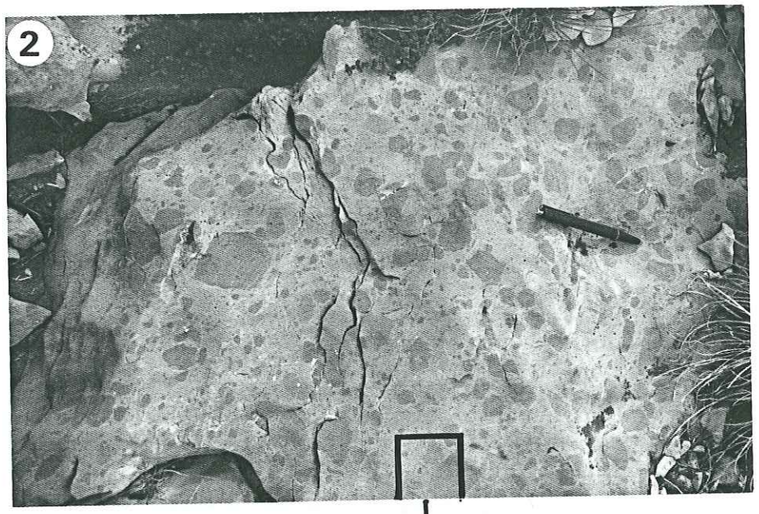
Conglomerate Facies

9.1 "Conglomerates facies" of the mass flow deposits. The fine-grained conglomerates are embedded in a muddy to marly matrix. This matrix contains abundant fossil debris and indicates intensive bioturbation. This kind of conglomerate facies is usually found in the upper parts of the mass flow deposits. ("Combe de Pacally")

9.2 "Conglomerate facies". These clasts tend to exhibit breccia forms. This type of conglomerate is very common in the mass flow deposits and represent a high proportion of the mass flow "matrix". ("Col des Aravis")

9.3 A photomicrograph of the "conglomerate facies" illustrated above. This photo indicates that the clasts and the matrix are not of the same composition. The left side of the photo shows the conglomerate matrix characterized by a micritc texture. The right side of the photo shows a conglomeratic clast with a poorly-washed packstone texture. Microfacies analysis indicates, however, that in general the sediment composition is similar. It is assumed, that the already lithified to semi-lithified clasts derived from upper slope sites and were deposited in deeper water, micrite dominated slope areas.





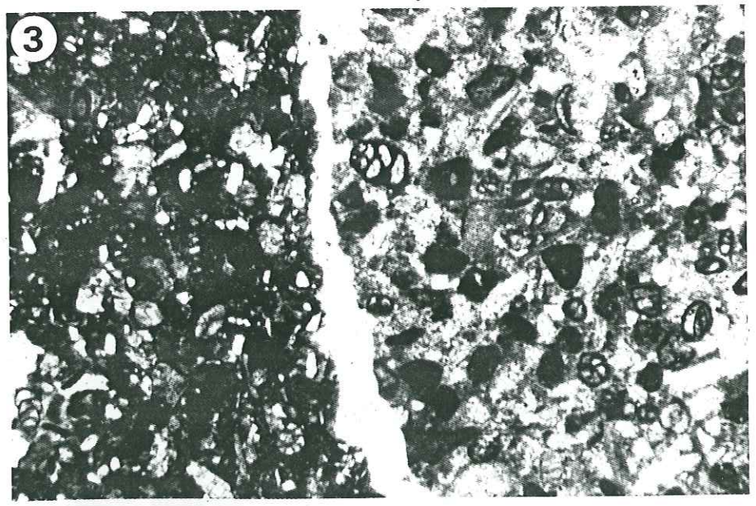


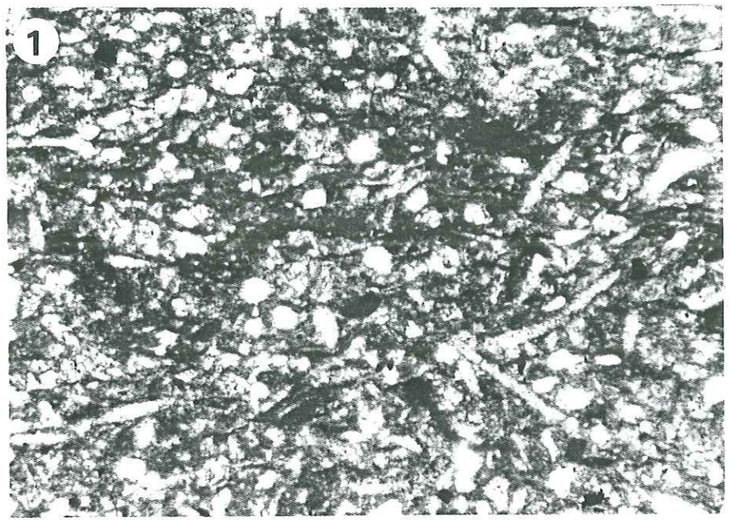
Plate 10

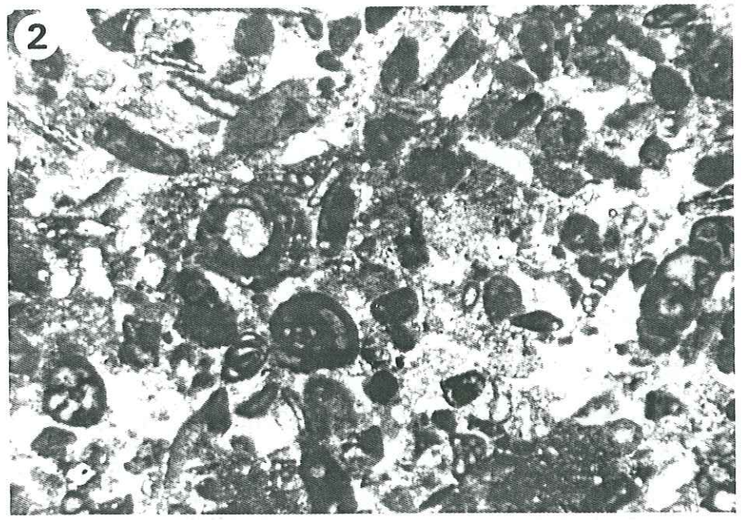
Slope Facies

10.1 "Siliceous limestones". The fine-grained silty limestone is mainly characterized by calcified sponge spicules. Other components are pellets, thin bivalve shells (pelecypods and ostracods) and abundant detrital quartz.
Scale: horizontal photo length: 3.6 mm, sample Mo 21.01

10.2 Fossil-peloid packstone (microfacies type 21). This slope deposit is partly composed of platform-derived particles, such as peloids, ooids and platform inhabiting foraminifers, etc..
Scale: horizontal photo length: 3.6 mm, sample BC 23.03

10.3 Intraclastic-fossil-peloid packstone (microfacies type 21). This sample was taken a few meters above sample BC 23.03. This facies consists of a distinctly higher proportion of platform-derived particles. Bryozoan fragments, extraclasts and ooids are characteristic components of these proximal slope deposits.
Scale: horizontal photo length: 4.32 mm, sample BC 23.05





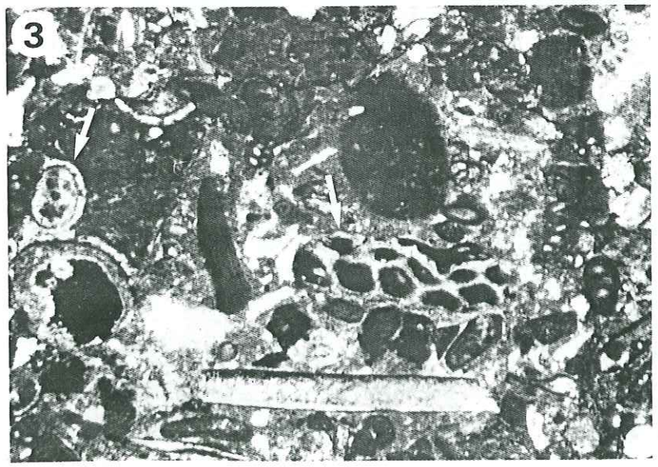


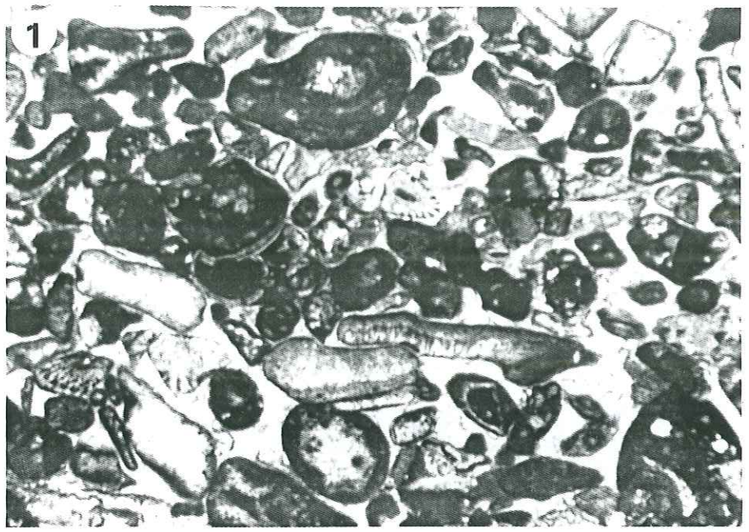
Plate 11

Mass flow facies

11.1 Medium- to coarsed grained intraclastic-fossil grainstone of microfacies types 2 and 3, which is typical of platform margin sites. However, the sample was recorded in a megablock within the mass flow deposits. The high primary interparticle porosity and cement petrography indicate lithification in the shallow-water platform environment, before deplacement occurred.
Scale: horizontal photo length: 4.32 mm, sample: BC 8E

11.2 Poorly washed Biopelsparite. "In situ " facies of the "lower" mass flow deposits. The medium-sized microfacies is largely composed of platform grains e.g. ooids (arrow), that were transported as unlithified material from the platform into circalittoral settings.
Scale: horizontal photo length: 2.8 mm, sample BC 8.03

11.3 Poorly washed ooid-bearing intra-biopelmicrite. "In situ" facies of the "lower" mass flow deposits. Notice the high proportion of platform influx. Ooids and even irregular formed oncoids/algal lumps (arrow) are frequent components in these allochthonous deposits.
Scale: horizontal photo length: 2.8 mm; sample BC 8.06



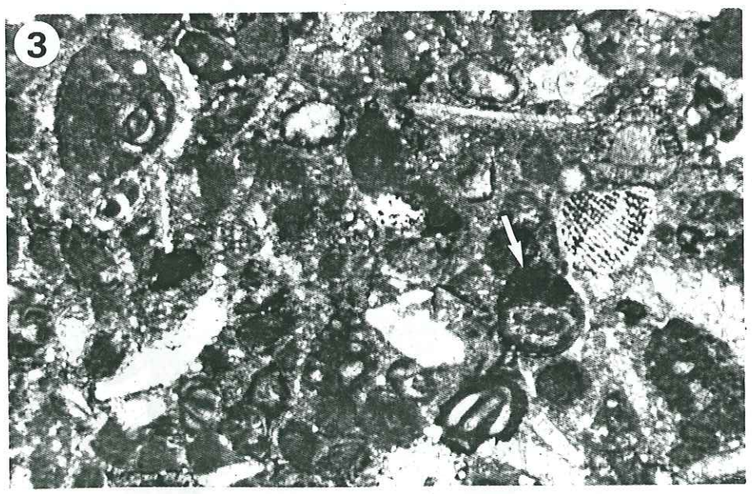


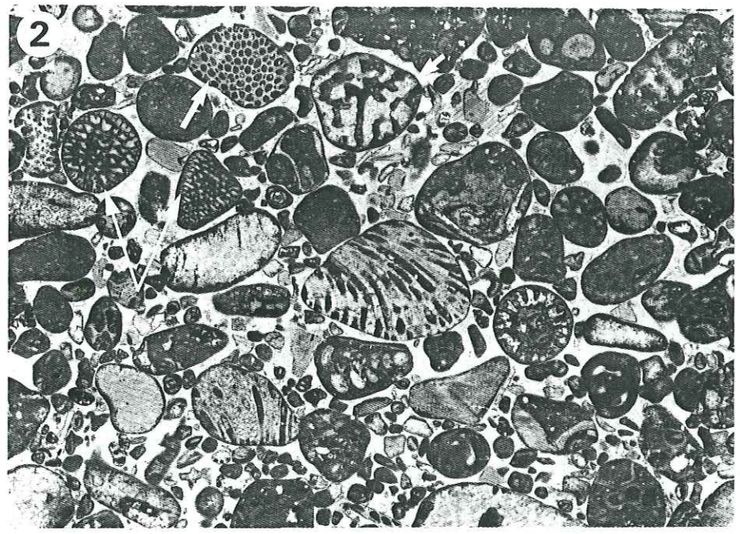
Plate 12

Outer-Platform Facies

12.1 Fossil-peloid grainstone (microfacies type 1A) with abundant small benthonic foraminifers, echinoderm and pelecypod fragments, peloids and some ooids. The basinal parts of studied platform carbonates are typically composed of this microfacies.
Scale: horizontal photo length = 7 mm; sample Cl 1.01

12.2 Intraclastic-fossil-peloid grainstone (microfacies type 3). Well rounded particles form this microfacies. The sediment is interpreted to have been deposited in high energy platform margin sites. Characteristic fossils are orbitolinid-foraminifers (thin arrows), bryozoans (arrow) and sponge or coral fragments (short arrow).
Scale: horizontal photo length: 1.2 cm, sample Cl 1.65

12.3 Ooid grainstone (microfacies type 4). The most characteristic feature of these high energy sediments is the high primary interparticle porosity. Ooids show mainly radial-concentric microstructures.
Scale: horizontal photo length: 4.3 mm, sample Cl 1.98



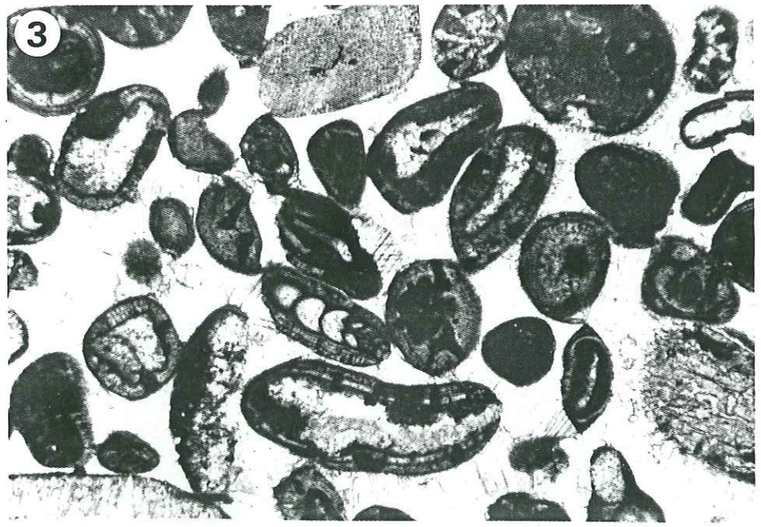


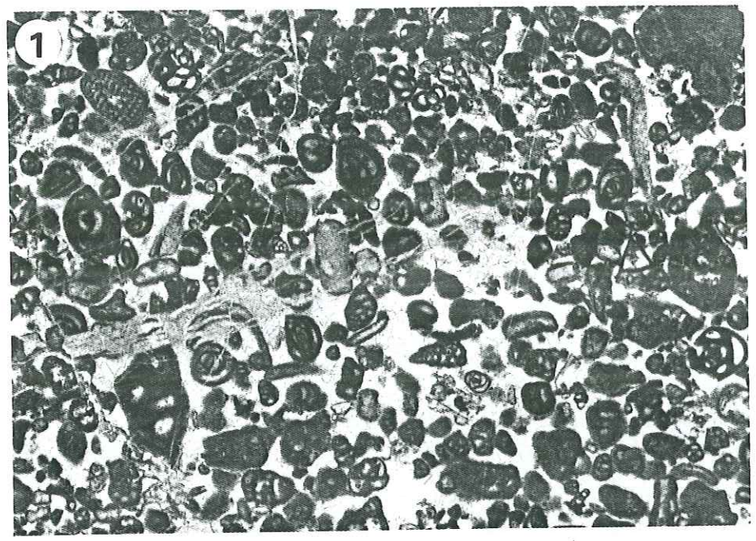
Plate 13

Inner- Platform Facies

13.1 Biopelsparite (Foraminifer- peloid packstone, MFT 7). This microfacies is mainly composed of small benthonic foraminifers (miliolids and textulariids), and peloids (chiefly micritized foraminifers). The most abundant miliolids are *Quinqueloculina* spp. and *Triloculina* spp.
Scale: horizontal photo length: 7 mm;

13.2 Oncoid-biopelsparite (MFT 14). Irregular-shaped foraminiferal-algal-oncoids dominate this microfacies. They appear as irregularly, elliptical formed nodules.
Scale: horizontal photo length: 4.3 mm, sample Cl 1.115

13.3 *Bacinella irregularis* which produces large oncoids/algal lumps in the oncoid facies (MFT 14). *Bacinella* lumps occur mainly in slightly protected sites, but they also occupied protected to semi-restricted environments.
Scale: horizontal photo length: 2.2 cm, sample Cl 1.108



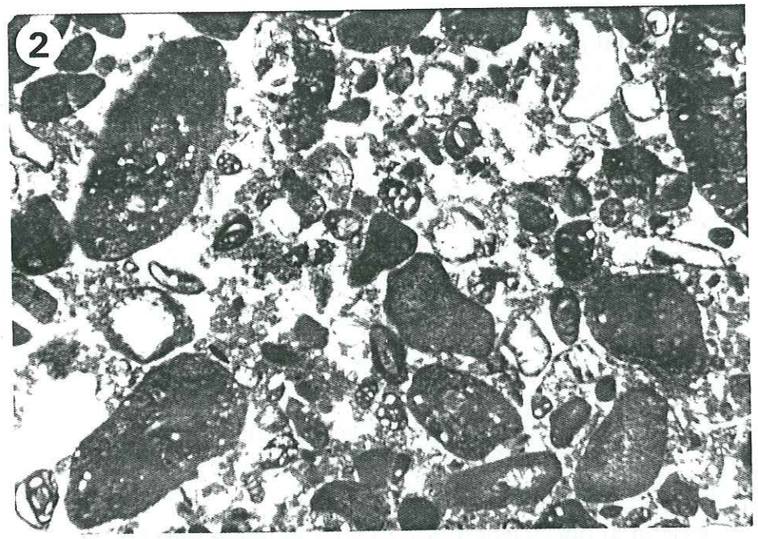


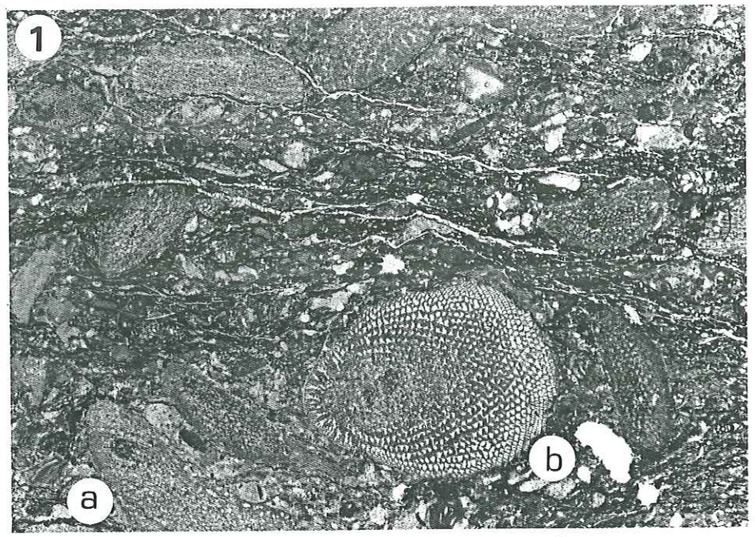
PLATE 14

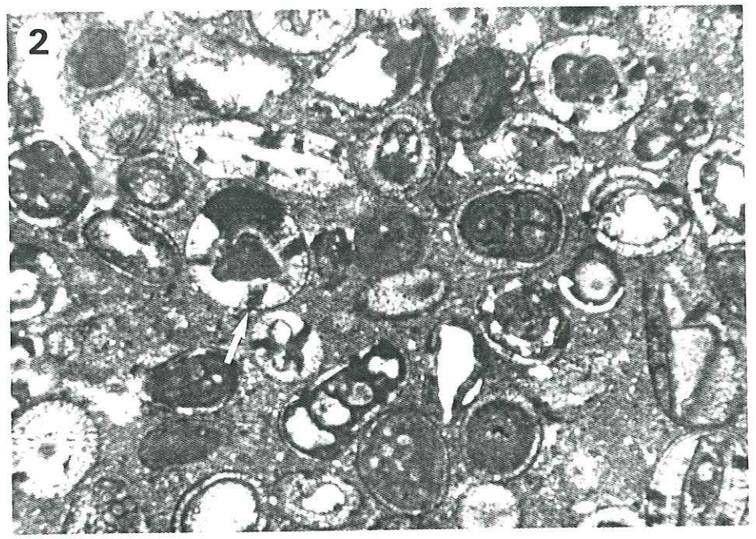
Inner-Platform Facies

14.1 *Orbitolina* marly limestone facies (MFT 17A). The orbitolinid foraminifer *Palorbitolina lenticularis* (a) and *Orbitolinopsis kiliani* (b) are embedded in a quartz-bearing marly limestone matrix. The microfacies is further composed of intraclasts and echinoderm fragments. Stylolites are the predominant diagenetic structures, emphasized by the accumulation of dark colored organic and argillaceous material.
Scale: horizontal photo length = 1.2 cm, sample Cl 1.300

14.2 Ooid wackestone (MFT 5). The radial and radial-concentric ooids are embedded in a micritc matrix. In this photo there are cerebroid ooids (arrow) visible.
Scale: horizontal photo length = 4 mm, sample Cl 1.101

14.3 Fenestral mudstone (MFT 12). Fenestral fabrics with a very low component diversity are the characteristic features of this microfacies. The gastropod *Planorbis* (arrow) indicates a brackish to lacustrine environment.
Scale: horizontal photo length = 7.2 mm, sample Cl 1.239





ANNEXES

Legend

Lithology

- Bedded limestones
- Irregular bedded limestones
- Massive limestones
- Dolomitc limestones
- Dolomite
- Marly limestones
- Silty, sandy to shaley limestones
- Marls

Lithofacies

- Matrix
- Sparite
- Lithoclasts, aggregate grains lumps, oncoids
- Ooids
- Peloids
- Bioclasts
- Dolomite
- Quartz
- Glauconite

Fossils

- Foraminifera, small benthonic
- Bivalves, undifferentiated
- Sponge spicules
- Calcispheres
- Brachiopods
- Echinoderms
- Echinids
- Ammonites
- Sponges
- Bryozoans
- Serpulids
- Foraminifera, large benthonic
- Algae, undifferentiated
- Dasycladacean algae
- Oncoids
- Algal lumps
- Stromatoporoids / fragments
- Chaetetids/fragments
- Corals/fragments
- Oysters
- Rudists, debris
- Gastropods
- Ostracods

Allochems

- Ooids
- Peloids
- Pellets
- Lithoclasts, angular
- Lithoclasts, rounded
- Aggregate grains
- Conglomerates

Minerals

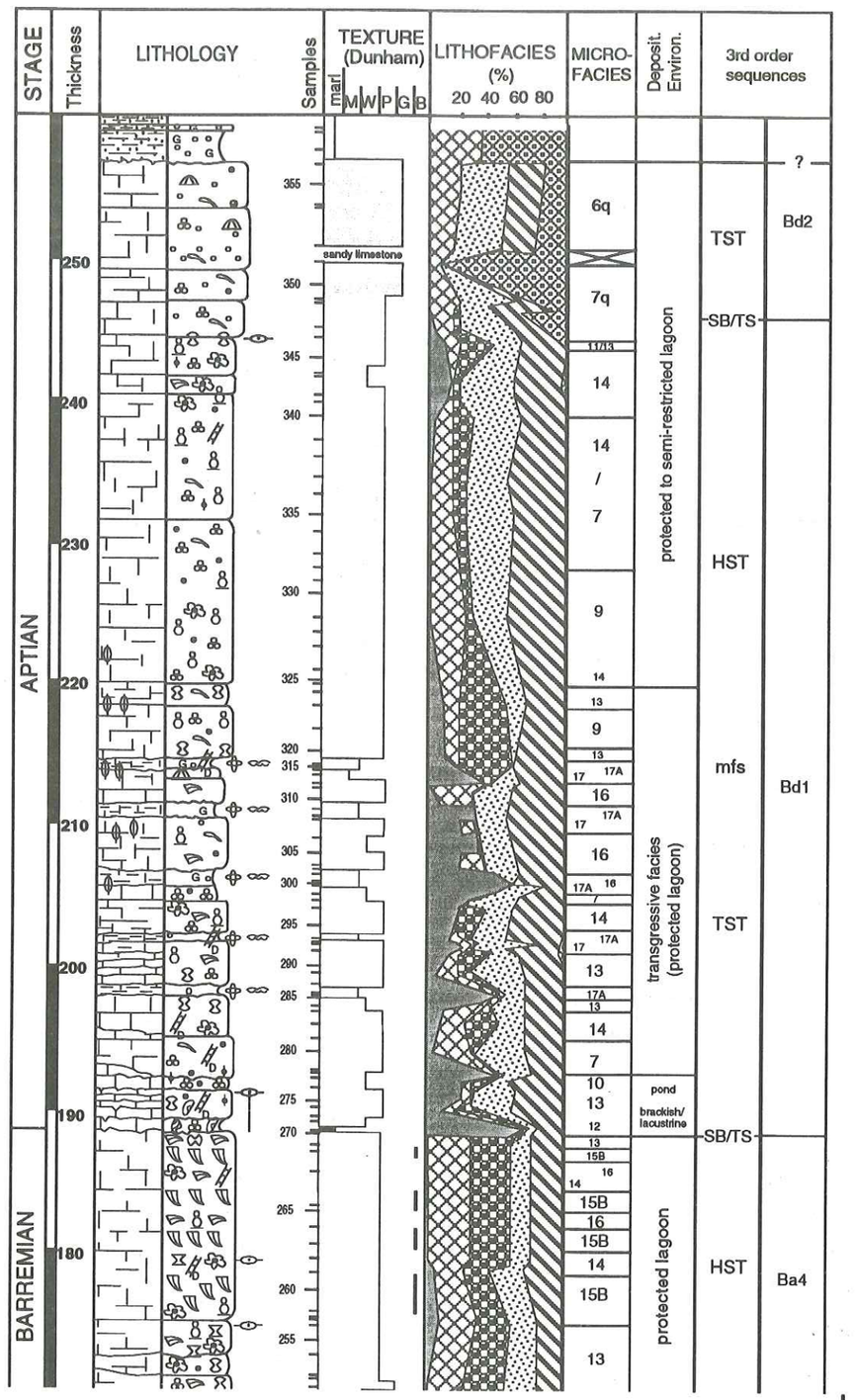
- Quartz, detrital
- Dolomite
- Glauconite
- Pyrite
- Phosphate

Sedimentary structures

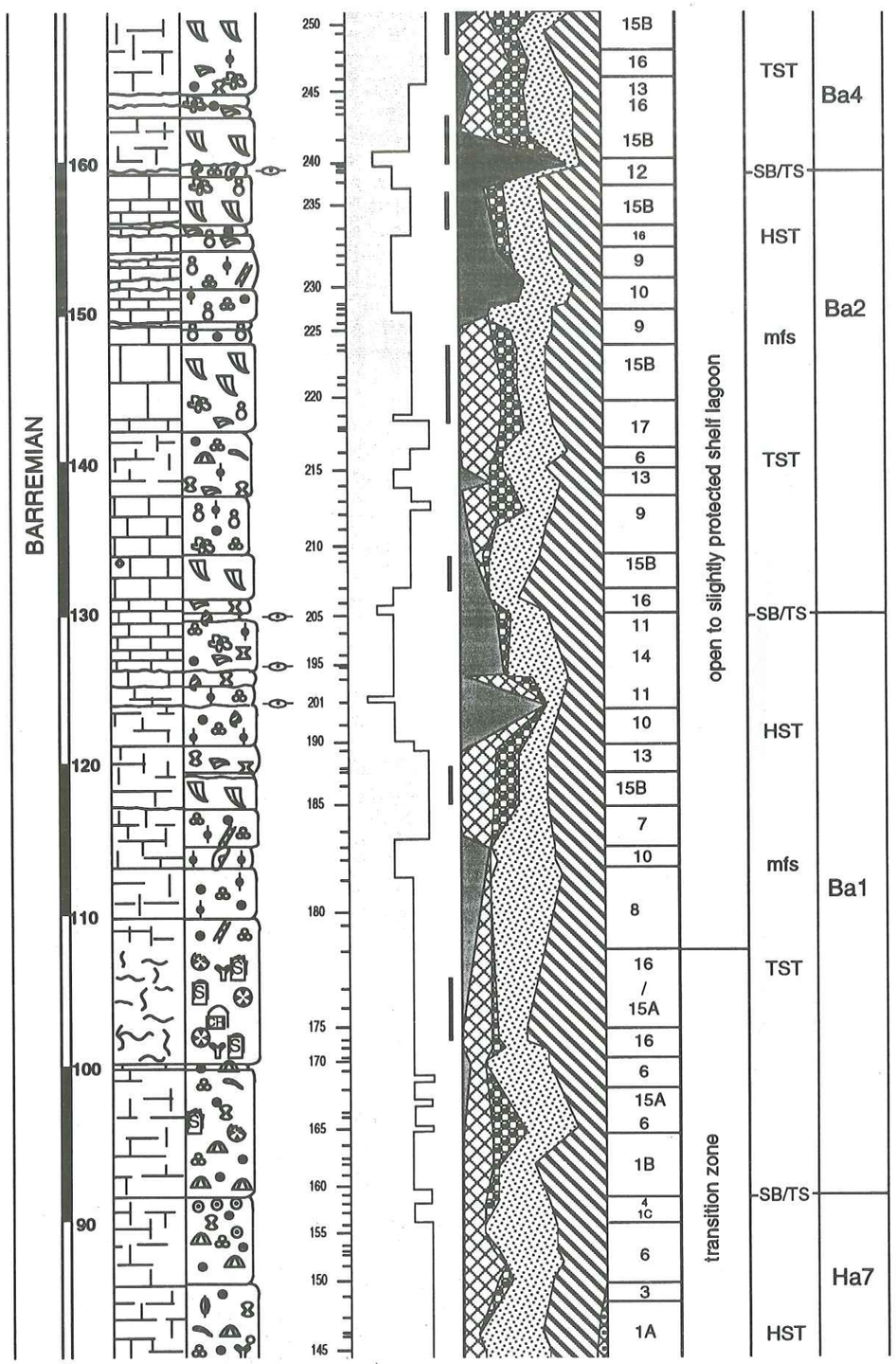
- Cross-bedding
- Nodular bedding
- Irregular bedding
- Bioturbation
- Fenestral fabrics
- Stylolites
- Thickening-up/Thinning-up
- coarsening-up/fining-up

Fig. A.1.a-c Synthetic log and summary of the "**Rocher de Cluses**" section.

a



b



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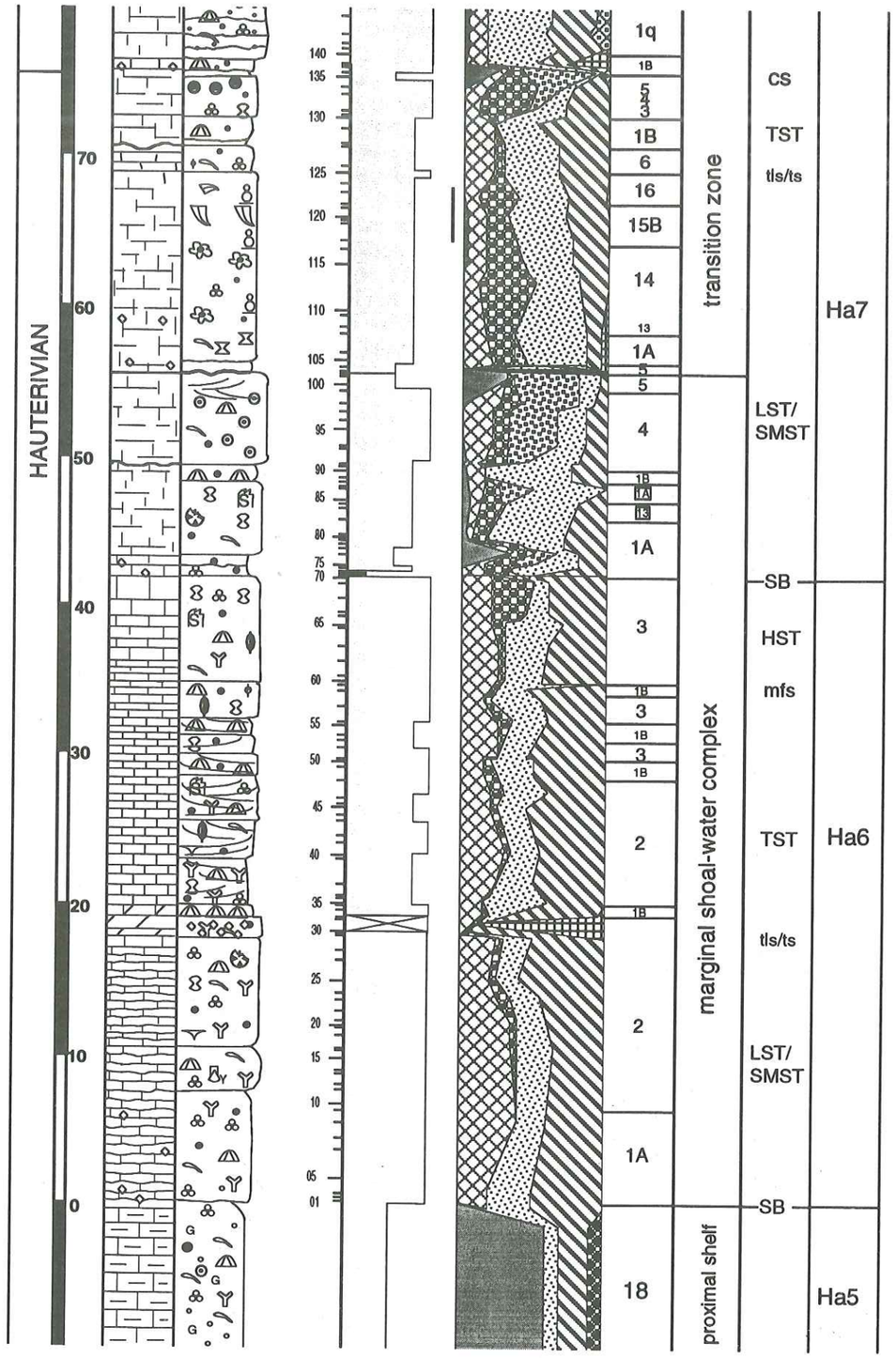


Fig. A.2.a-b Synthetic log and summary of the "Bella Cha" section.

a

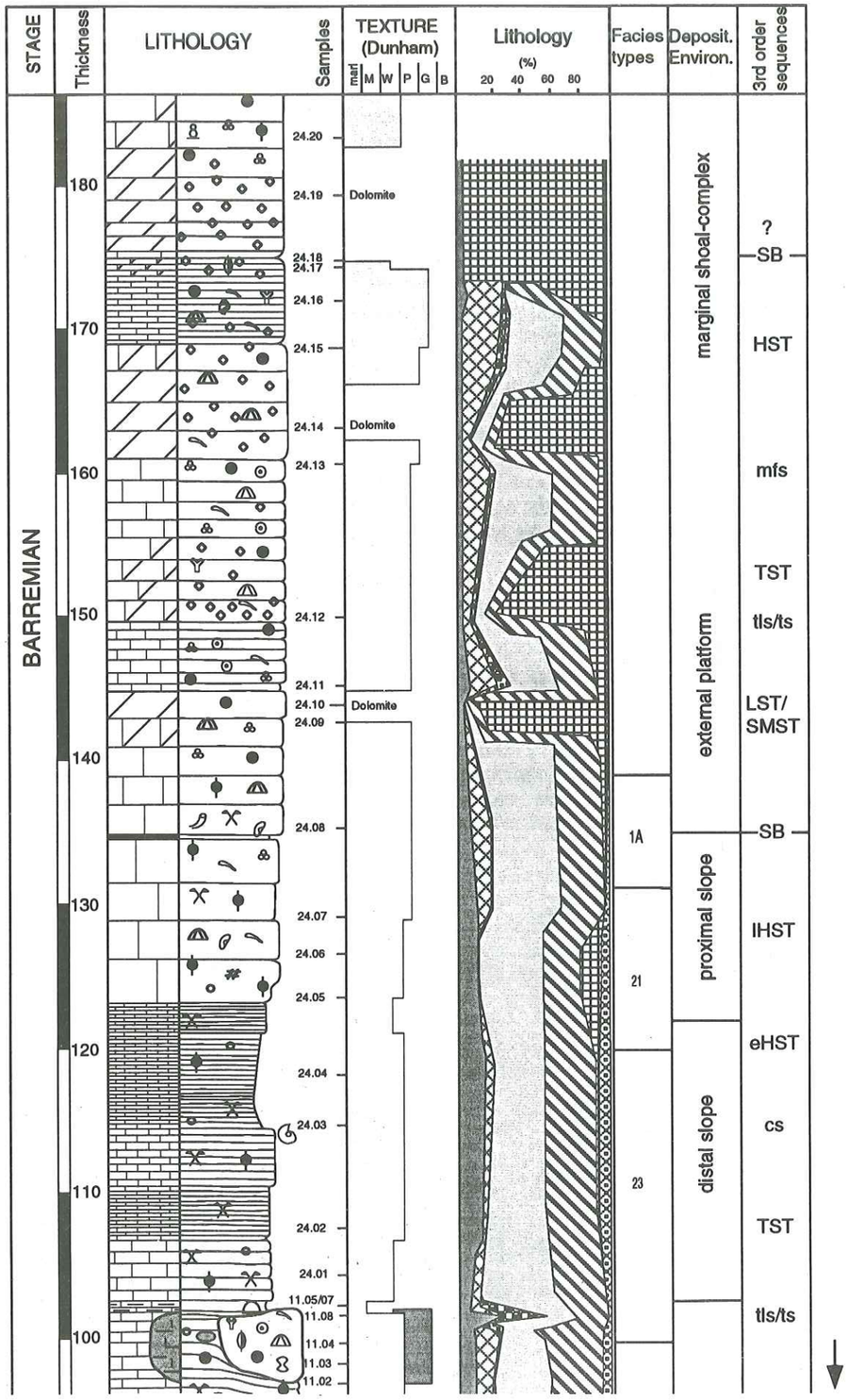
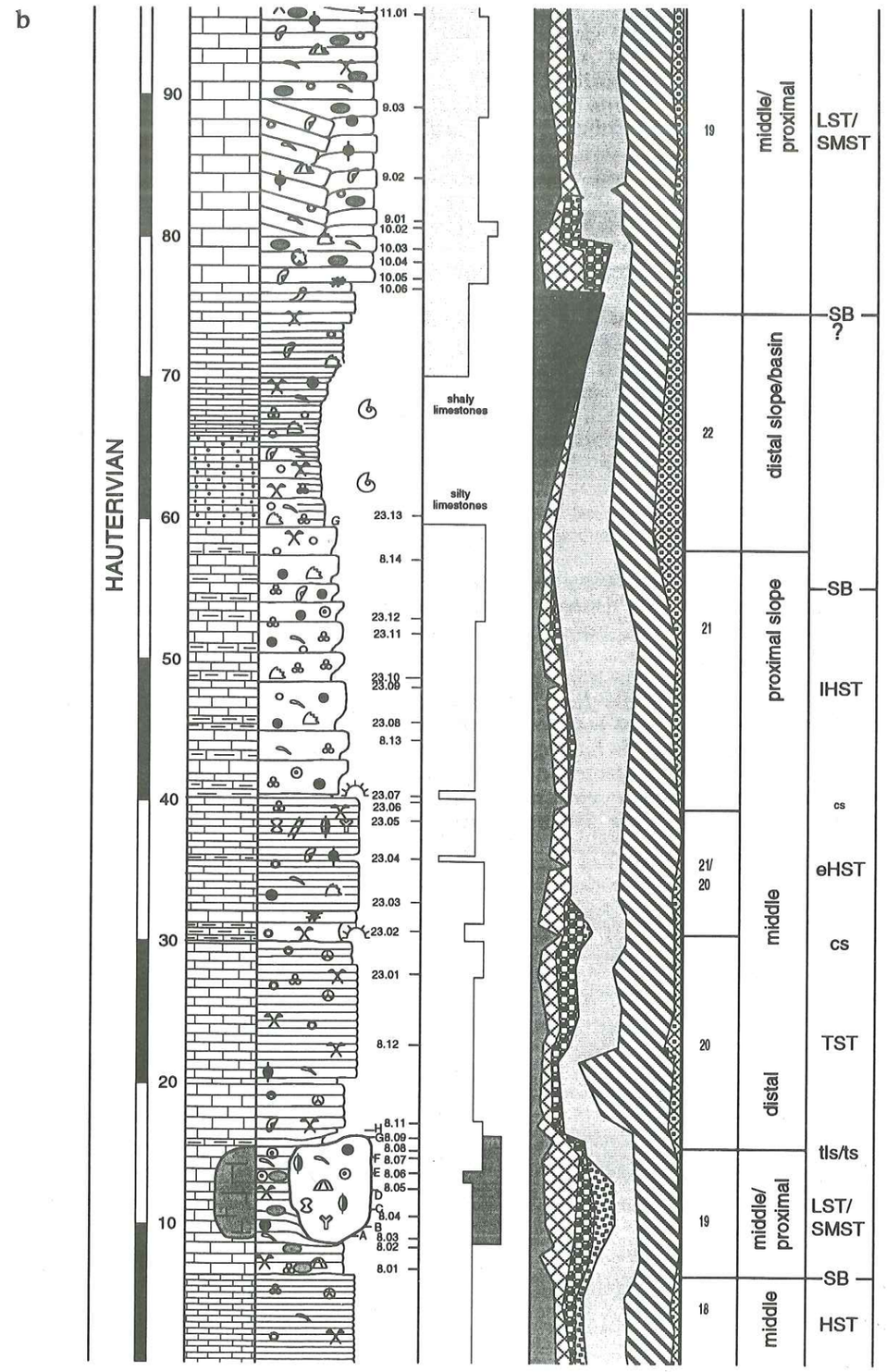


Fig. A.3.a-b Synthetic log and summary of the "**Grande Forclaz**" section.



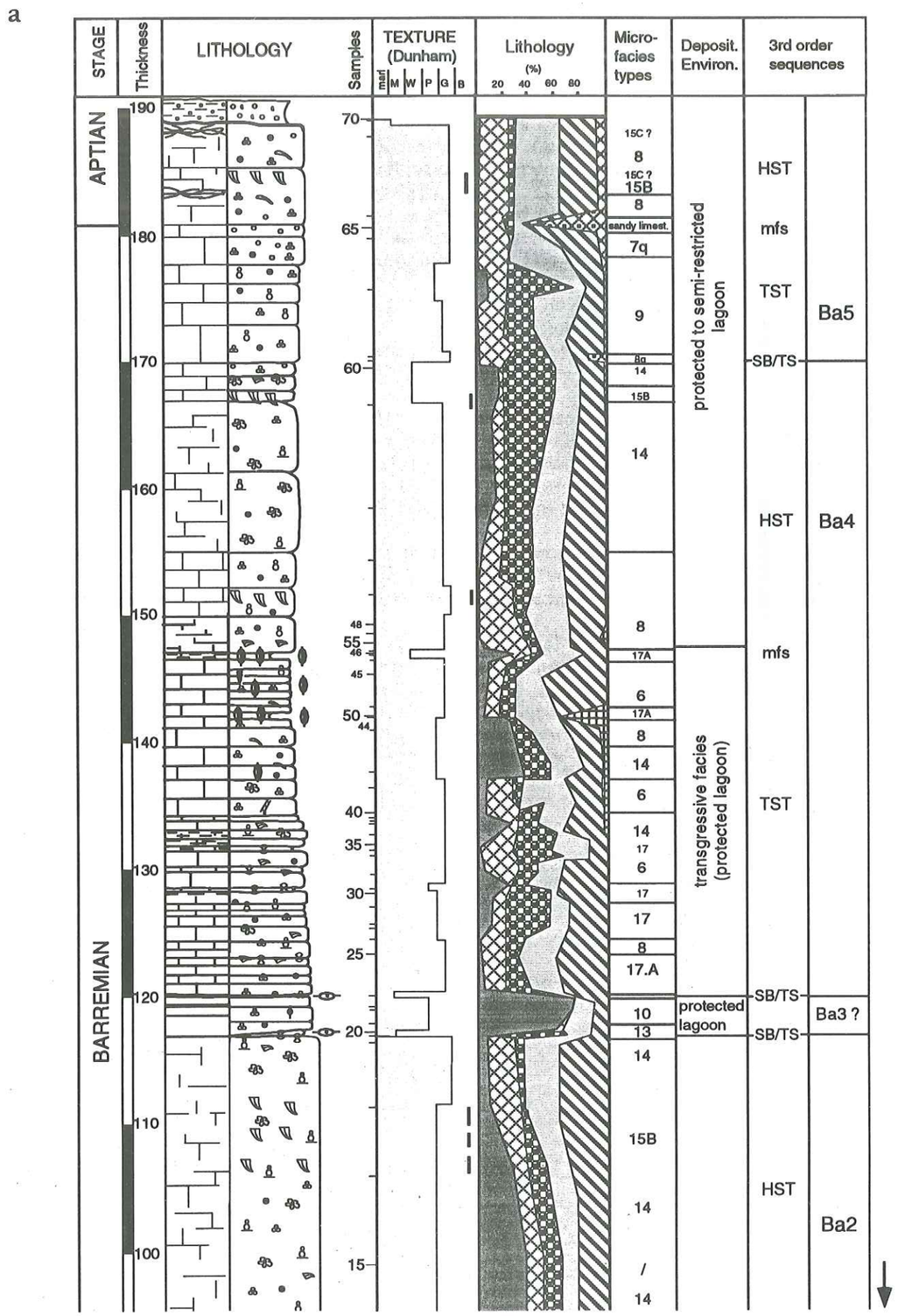
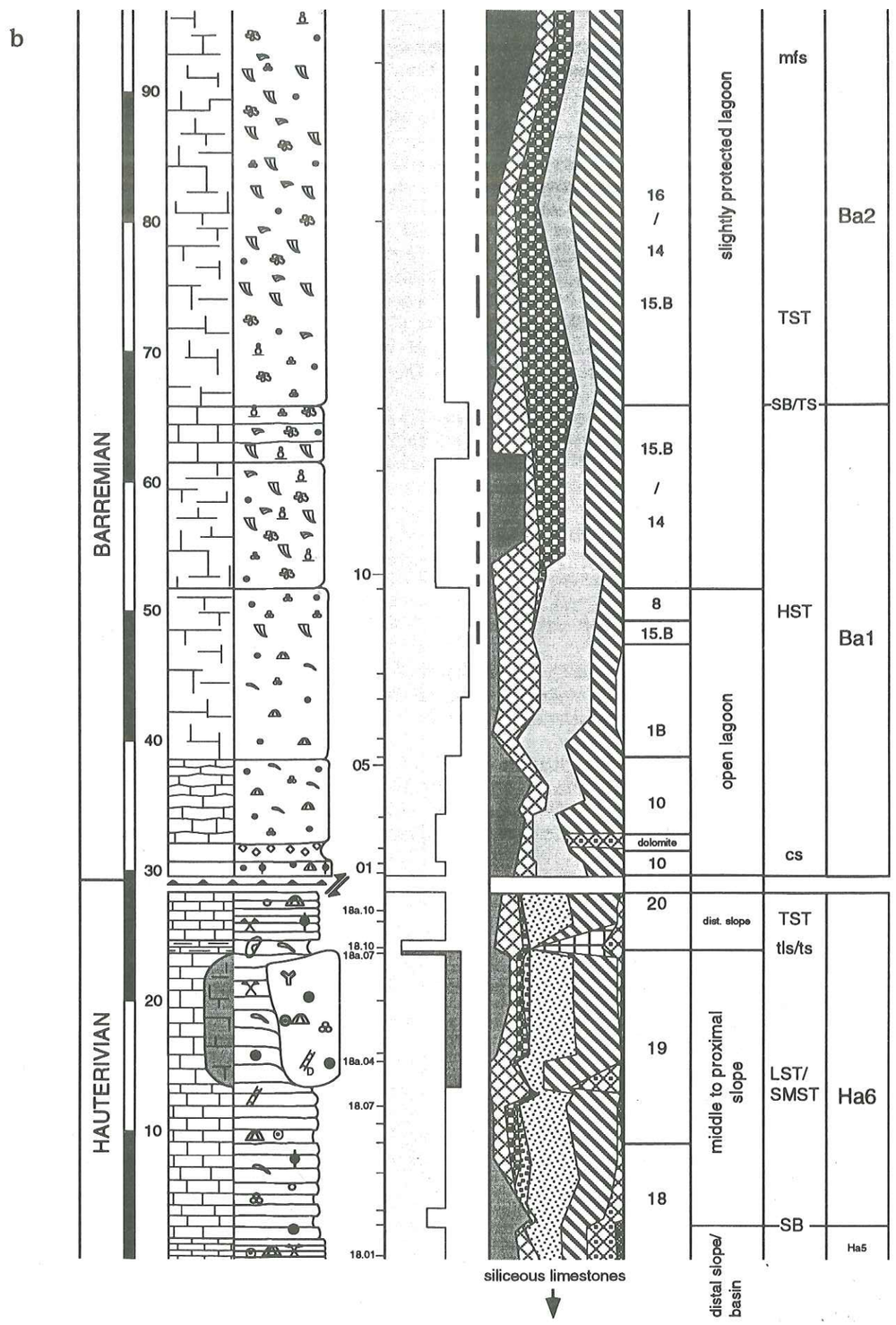
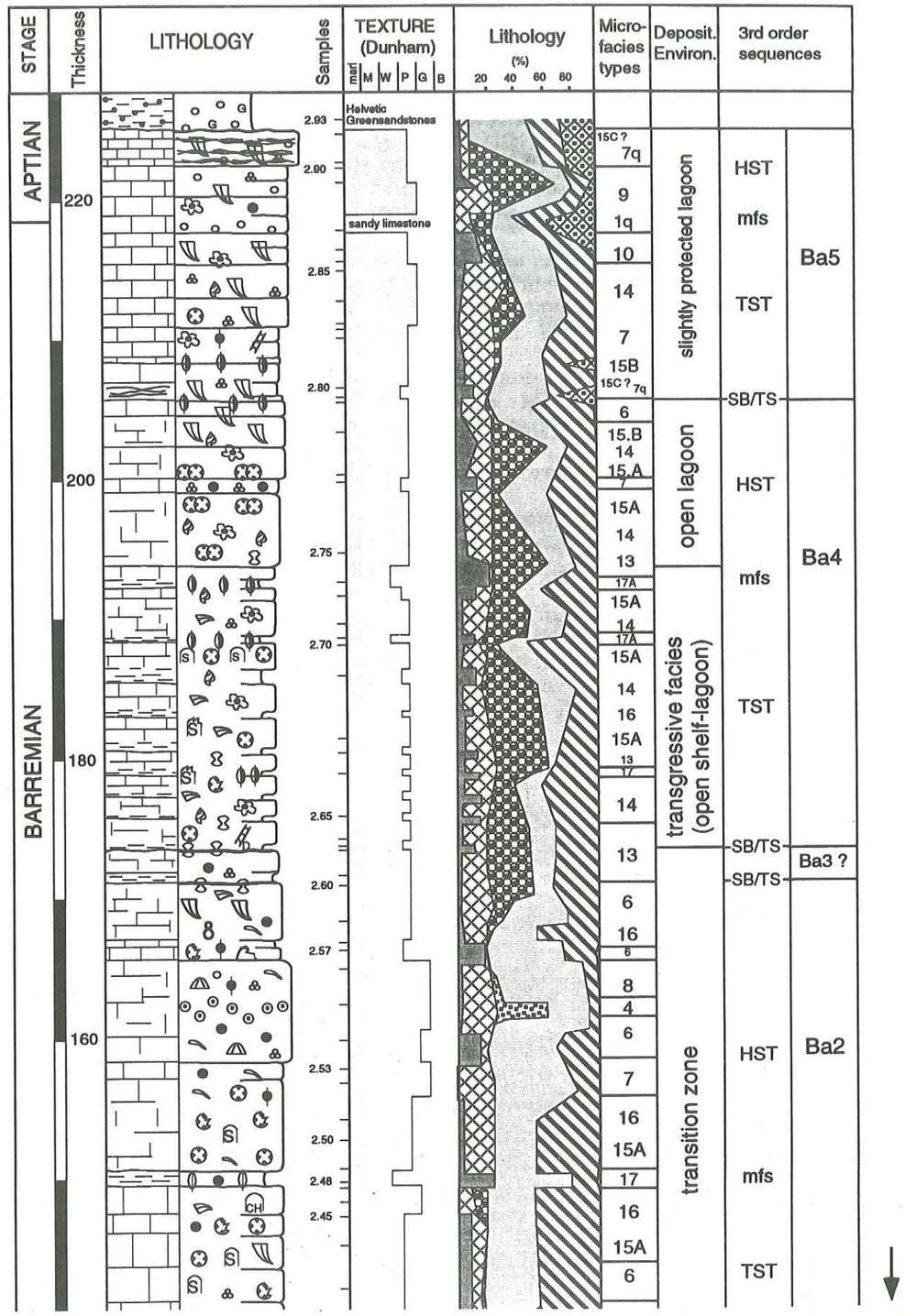


Fig. A.4.a-c Synthetic log and summary of the "Flaine" section.



a



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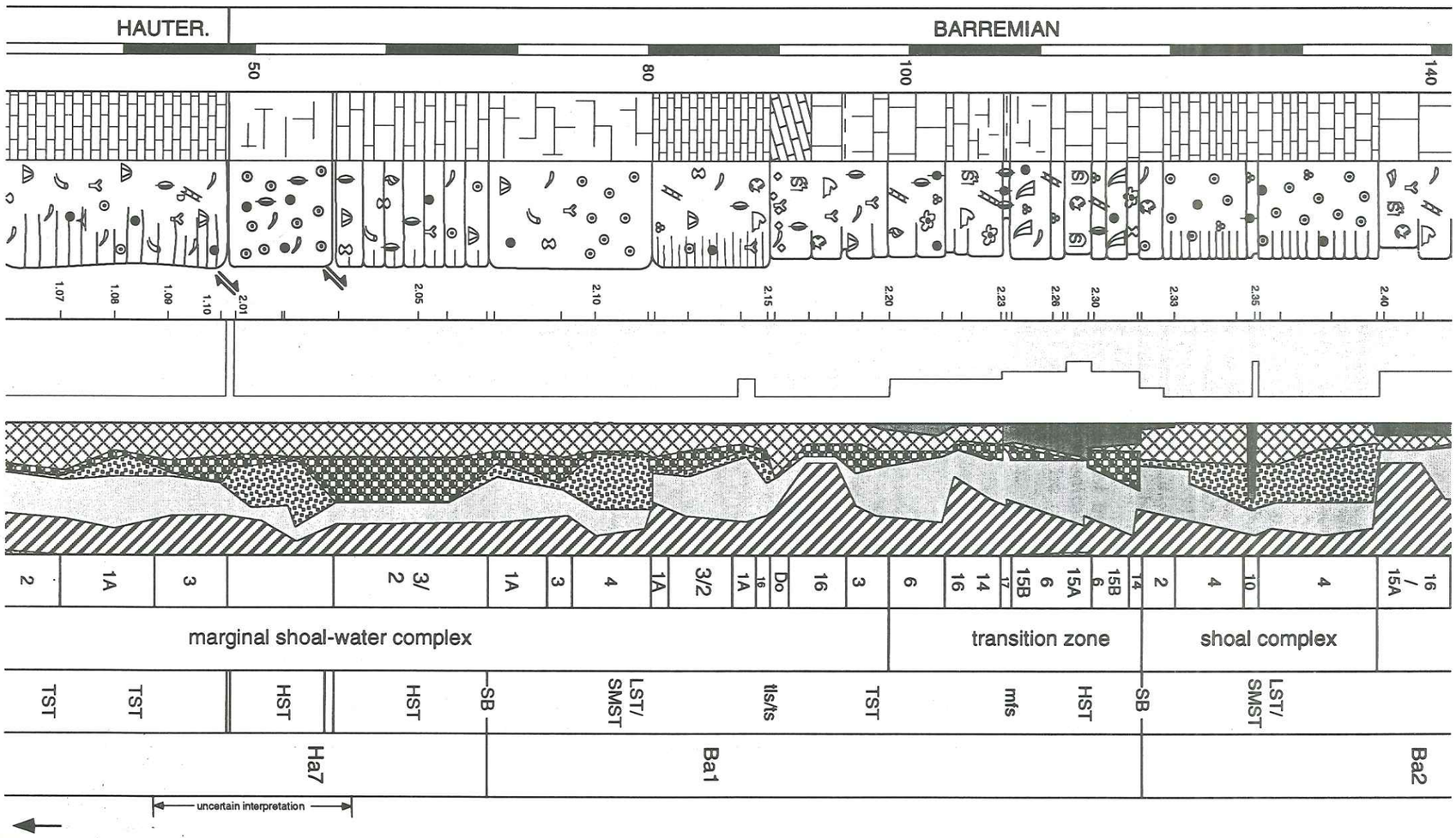
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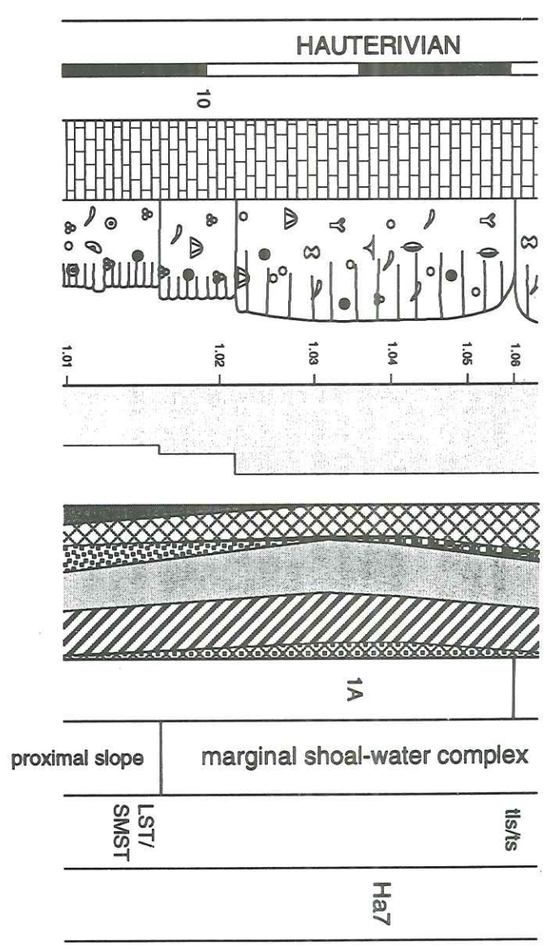
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Ha7