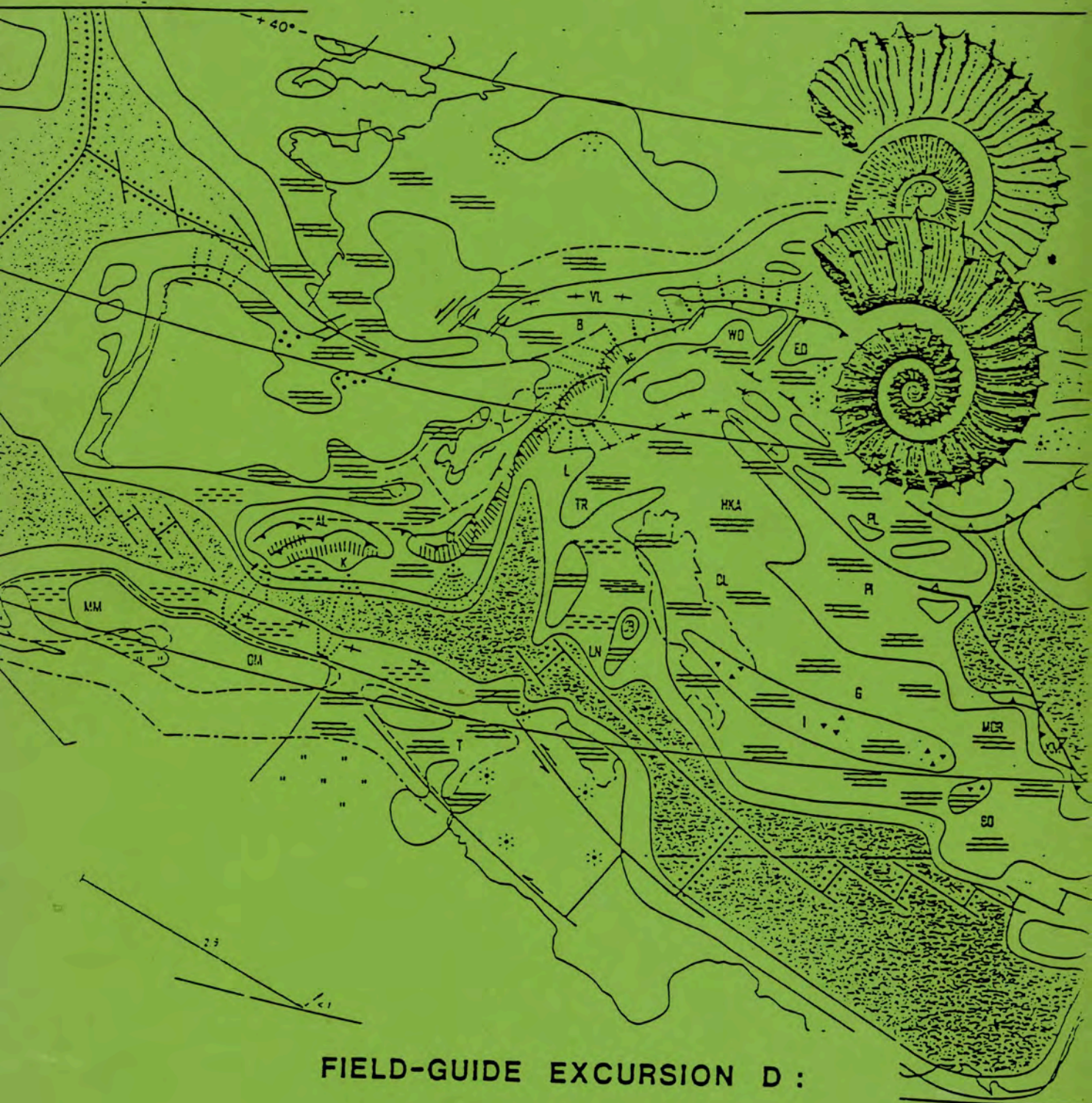


RD INTERNATIONAL CRETACEOUS SYMPOSIUM

Tübingen, 26.8. - 8.9.1987



FIELD-GUIDE EXCURSION D :

GRENOBLE, FRANCE

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FIELD-GUIDE EXCURSION D

GRENOBLE, France

THE LOWER CRETACEOUS FROM THE JURA PLATFORM
TO THE VOCONTIAN BASIN
(SWISS JURA, FRANCE)

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THE LOWER CRETACEOUS DEPOSITS IN THE JURA AND THE SUBALPINE CHAINS

A. PROGRAM

First day : Friday, September 4 th.

T. ADATTE and G. RUMLEY

From Tübingen (R.F.A.) to Annecy (France)

Theme : The Lower Cretaceous of the stratotypic area near Neuchâtel (Switzerland)

First stop and lunch : Marnière de Cressier (Lower Hauterivian) near Neuchâtel

Second stop : Juracime quarry (Valanginian), near Neuchâtel

Transit to Annecy (France)

Second day : Saturday, September 5 th.

A. ARNAUD-VANNEAU, H. ARNAUD and T. BOISSEAU

From Annecy to Grenoble

Theme : The Berriasian-Valanginian carbonate platform of the southern Jura and subalpine chains, the Pierre Jaune de Neuchâtel and the Urgonian platform

First stop : La Chambotte section (Upper Berriasian-Barremian) near Aix-les-Bains

Second stop : The Gorges du Guiers Mort section (Upper Berriasian-Lower Valanginian) near St. Laurent-du-Pont (Chartreuse, subalpine chains)

Transit to Grenoble (St. Pierre-de-Chartreuse, Col de Porte)

Third day : Sunday, September 6 th.

A. ARNAUD-VANNEAU and H. ARNAUD

From Grenoble to Die

Theme : The Urgonian platform and the Aptian transgression in the subalpine chains

First stop : The Gorges du Nant section (The Barremian-Lower Aptian Urgonian platform) near Cognin (Vercors, subalpine chains)

Second stop : Les Rimets area and the Marnes supérieures à Orbitolines (Lower Aptian) in the Rencurel syncline (Vercors)

Transit to Die (Vernaison valley, Col de Rousset)

Fourth day : Monday, September 7 th.

A. ARNAUD-VANNEAU, H. ARNAUD and J.-P. THIEULOUY

The Die area

Theme : The Pelagic sedimentation of the Vocontian basin

First stop : The Marignac-Serre de Jayon section (the Upper Berriasian reworking sedimentation)

Second stop : The Col de Romeyer section (the Valanginian-Lower Hauterivian pelagic sedimentation)

Third stop : The Chamaloc section (the Hauterivian-Lower Barremian pelagic sedimentation)

Return to Die

Fifth day : Tuesday, September 8 th

Return from Die to Tübingen.

(Die, Grenoble, Genève, Lausanne, Berne, Tübingen)

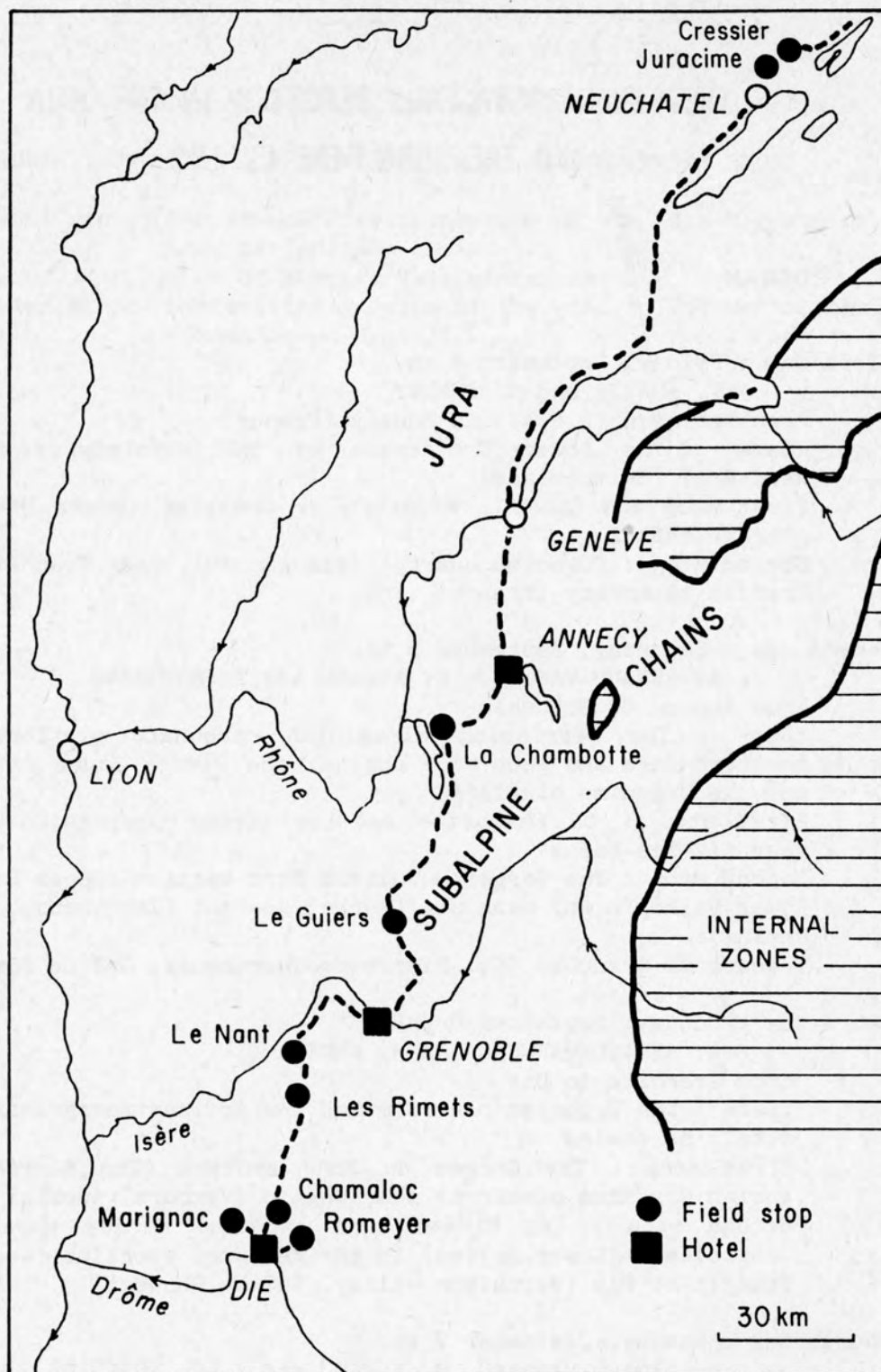


Fig. A1 : Schematic map showing the itinerary of the excursion from Neuchâtel (Switzerland) to Die (France) and the localization of the main stops.

B. THE WESTERN ALPS : A CONTINENTAL MARGIN OF THE MESOZOIC TETHYS (according to LEMOINE et al., 1986)

The Western Alps are a classical mountain chain built of thrust-sheets emplaced during the Alpine (i.e. Late Cretaceous and Tertiary) compressional phases. In recent years, the adoption of plate-tectonic concepts, the progress of marine geology and geophysics, and the development of Alpine sedimentological and tectonic research have allowed us to consider other aspects of the evolution of this mountain chain.

It is well known that the internal zones of the Alps contain ophiolitic thrust-sheets (a part of the so-called Penninic nappes) that now rest upon structural units derived from the European continental crust. The ophiolite bearing nappes are in turn tectonically overlain by other continental-crust-bearing sheets, the Austro-Alpine ones, which have Italian (Apulian-Adriatic) affinities. The Alps thus resulted from a collision between two continental domains which were originally separated by an oceanic area whose crust is now represented by the overthrust ophiolitic remnants. This palaeo-ocean was the Ligurian Tethys, a part of the Mesozoic Tethys. It lay between the European continent to the North or North-West and the Apulian-Adriatic continental block (also called Apulia or Adria) to the South or the South-East.

1. MESOZOIC EVOLUTION : FROM TRIASSIC PLATFORM CARBONATES TO LATE JURASSIC-CRETACEOUS PELAGIC DEPOSITS (Fig. A2)

Except for rare but nevertheless important exceptions (like the emergence of the Briançonnais domain from Middle Liassic up to early Bathonian time), all the palaeogeographic domains of the Western Alps were in marine environments. There are two main categories of Mesozoic sedimentary series, (1) those which were deposited upon a former continental margin (External, Subbriançonnais, Briançonnais and Piemont domains), and (2) those that were deposited upon an ophiolitic, i.e. palaeo-oceanic, basement (Ligurian domain). The oceanic series are Late Jurassic and Cretaceous in age. The continental-margin series were laid down upon a Variscan (and older) granitic-gneissic continental basement or Permo-Carboniferous continental deposits. All these series begin with the Triassic platform deposits, and grade upwards and discontinuously into hemipelagic (external platform) to pelagic (basinal) Late Jurassic and Cretaceous sediments.

Considering the main sedimentological features of these series, four main stages may be distinguished.

Triassic platform deposits (pre-rift)

Over the wide region that covered all the area which was to become the opposing continental margin of the Ligurian Ocean, mainly marine but shallow-water environments prevailed during the deposition of the Middle-Upper Triassic and (partly) Hettangian platform carbonates and evaporites. Differences in subsidence rates, detrital intercalations and local volcanic activity are evidence of the occurrence of a certain amount of extensional tectonics in the Triassic.

Liassic and Middle Jurassic rifting

The Early and Middle Jurassic is the time of birth and evolution both of (1) subsiding pelagic-hemipelagic basins, and of (2) submarine and even emergent shoals upon which condensed sedimentation took place. These basins and shoals correspond to synsedimentary grabens and horsts, in most cases to half-grabens and crustal tilted blocks.

Table 1 Structural and palaeogeographic domains of the Western Alps

Structural zones (Nappes or groups of Nappes or Fold belts)	Palaeogeographic domains	Tethyan affinity
External (or Dauphiné)	Dauphiné (Provence in the South)	European Continental margin
Valais ⁽¹⁾	Valais ⁽¹⁾	Slight Oceanic Influence
Subbriançonnais Briançonnais	Subbriançonnais Briançonnais	European Continental margin
Piemont	Piemont sensu stricto	
	Ligurian	Ocean (Ligurian Tethys)
Austro-Alpine ⁽²⁾ and South-Alpine	Austro-Alpine and South-Alpine	Apulian-Adriatic Continental margin

⁽¹⁾ Present in the Central Alps, disappears when going into the Western Alps (not present in the Grenoble and Briançon transects).

⁽²⁾ Not outcropping in the Western Alps, but for their transition to the Central Alps (Dent Blanche Nappe and Sesia Zone).

Table 2 Compared evolutions of the Western Alps (Ligurian Tethys and its European continental margin), and of the NE Atlantic

	Western Alps	NE Atlantic (Galicia, Biscay)
— Pre-rifting stage, with a certain amount of extensional tectonics	Triassic	Late Jurassic (and older)
— no doming		
— Rifting: synsedimentary horsts and grabens, and above all tilted blocks; structuration of the passive margin	Liassic + part of Mid. Jurassic (duration ± 40 m.y.)	Lower Cretaceous (duration ± 40 m.y.)
— Onset of oceanic spreading, subsidence of passive margin	Early Late Jurassic (± Bathon.-Callov. Oxford)	Early Late Cretaceous (± Aptian Cenom.)
— Spreading, tectonic activity low on the passive margin, high in the ocean	Late Jurassic Early Cretaceous	Late Cretaceous and so on
— Convergence of margins and continental collision	Late Cretaceous Tertiary	Not yet

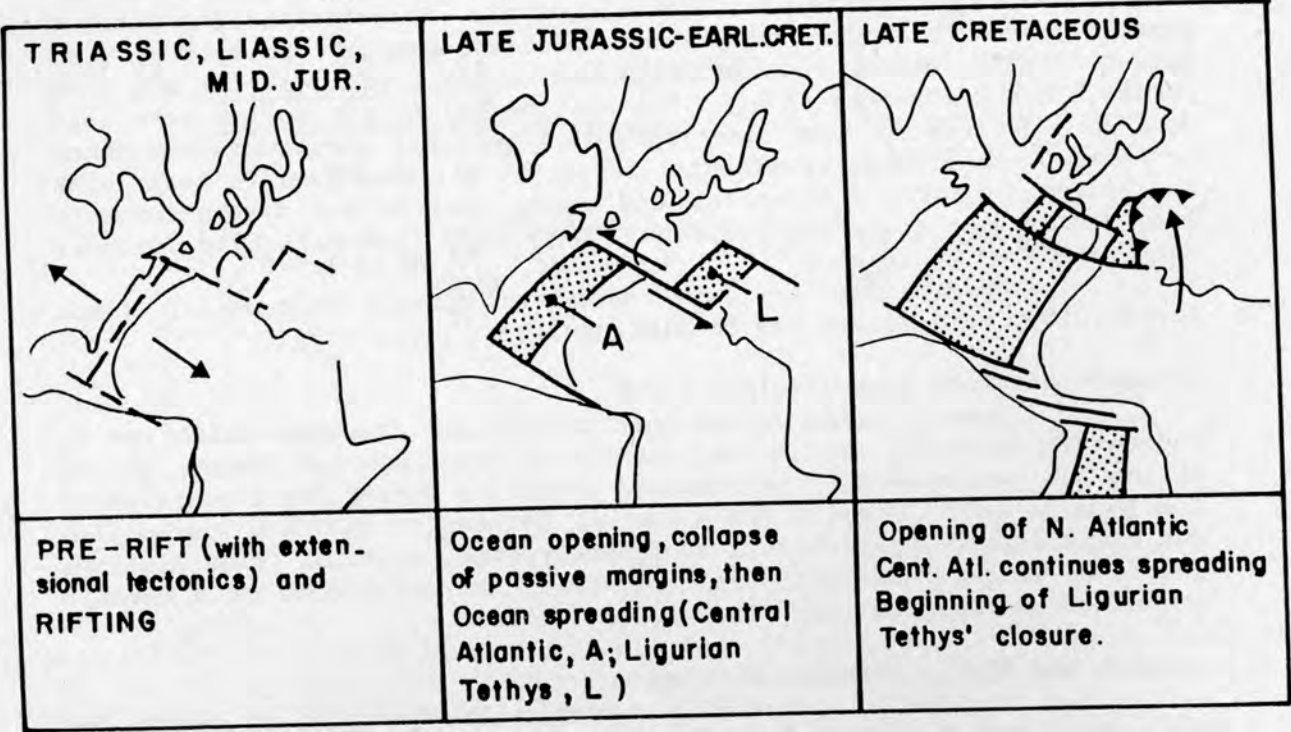


Fig. A2 : Three main stages in the development of the Ligurian Tethys and central Atlantic oceans. (after LEMOINE, et al., 1986)

However, there is no evidence of general uplift or doming at the onset of the rifting phase.

Late Jurassic-Early Cretaceous subsidence of the passive margin and onset of ocean spreading

In Late Middle Jurassic or Early Late Jurassic times, a major palaeogeographic change took place. The earliest oceanic sediments (radiolarian cherts) were deposited upon the newly-formed ophiolitic (oceanic) bottom of the Ligurian domain, indicating that the break-up of Pangea had begun. Carbonate platforms were located in the Jura, Massif Central and Provence areas. In the other areas, the sedimentary environment of this continental margin became hemipelagic or pelagic. This is evidence of a general subsidence of the whole passive margin, and possibly also of a strong attenuation of the basin-and-shoal pattern and of the corresponding fault-activity that prevailed during Liassic and Middle Jurassic times.

These events occurred more or less at the same time, and mark both the **end of continental rifting** and the **beginning of oceanic spreading** (this is the time of the so-called break-up unconformity). It should be noted that both these events are more or less coeval with the onset of spreading of the Central Atlantic Ocean : indeed, field data for the Western Alps fit well with the evolution predicted from global tectonic data.

The Late Jurassic-Early Cretaceous was also the time when detrital sedimentation (an indicator of tectonic activity) decreased at least in certain continental margin series but was widespread and important in the oceanic area. This suggests an oceanward migration of the main tectonic activity when continental break-up took place.

Late Cretaceous : renewal of detrital sedimentation on the continental margin

Pelagic sedimentation continued over some of the palaeogeographic domains (except for Jura, Vercors, Provence and the western part of the Vocontian basin), but two new facts must be emphasized. (1) A completely new palaeogeographical pattern appeared which does not inherit the previous rift-controlled palaeogeography. (2) Detrital sedimentation resumed over all palaeogeographical domains, more especially with the formation of the first flysch basins in the internal domains. All these data strongly suggest that tectonic suddenly increased on the continental margin. Whether or not this marks the beginning of closure of the oceanic area remains uncertain in the present state of knowledge.

Conclusion : tectonic evolution of the passive margin

The Mesozoic sedimentary evolution of the Western Alps thus demonstrates a tectonic evolution which strongly recalls that of the passive margins of present-day oceans, more especially of the starved margins of the Eastern border of the Northern Atlantic (Galicia margin, North Biscay-Celtic margin), where the continental break occurred 50 m.y. later (de GRACIANSKY *et al.*, 1979). Except for this time-shift, the evolution, whether sedimentological or palaeotectonic, was nearly identical.

2. MAIN FEATURES OF THE LIASSIC RIFTING IN THE EXTERNAL DOMAIN (DAUPHINE, ARDECHE)

The Jurassic and Cretaceous platforms were derived from the break up of the Triassic platform during the rifting of the European

continental margin. During the rifting period, in the Dauphiné domain, the rift structures are all normal faults, some of which may have a certain strike-slip component. These normal faults display large variations in size and offset, from numerous small faults with offsets of only a few tens of metres, up to the great faults that bound the major tilted blocks (for instance, the Ornon fault near Grenoble very probably had an offset of 1.5 to 2.5 km at the end of Jurassic times). All these faults bound a number of horsts and grabens of various size. The most striking structures are the major tilted blocks which are several kilometres to several tens of kilometres wide, and comparable in size to those recognized on seismic profiles of passive margin of present-day oceans. These blocks can be directly observed in the Cévennes-Ardèche area on the eastern Massif Central border (ELMI, 1983, 1984) and especially in the external crystalline massifs of the Dauphiné, near Grenoble (LEMOINE, 1984).

In these areas, several trends can be plotted, which can be divided into two main groups, namely the N-S to NE-SW faults, and the more or less NW-SE faults (E-W directions may also occur, but it is difficult at present to determine whether they were initiated during the rifting period, or later, during the post-rift subsidence of the margin). **The N-S to NE-SW directions of faults** correspond, in the Cévennes-Ardèche area and in the external zone of the Western Alps to the elongation of the major tilted blocks and their bounding normal faults. These trends are therefore candidate for those of the rift axis, i.e. of the Ligurian segment of the Mesozoic Tethys. Whether **the NW-SE faults**, which cut across these tilted blocks, represent transverse strike-slip (possibly transform?) ones, or not, cannot be clearly determined in the present state of our knowledge.

Syn-rift halokinesis. Everywhere, two conditions are required for the initiation of halokinesis. These conditions are : (1) presence of enough thick evaporite beds amidst the prerift or synrift sedimentary series, and (2) inhomogeneities either of the evaporitic beds or of their sedimentary cover (i.e. the presence of extensional faulting, and of the corresponding lateral facies changes in the synrift sediments). In the Western Alps, both conditions are present. Indirect evidence does exist (MASCLE et al., 1986) and moreover, in certain places, Jurassic diapirs are surprisingly well preserved (de GRACIANSKY et al., 1986). Finally, these first results of a study which is still in progress allow a model of the Jurassic-Cretaceous passive margin with already emplaced diapirs to be drawn.

C. SUBSIDENCE ON THE JURA AND SUBALPINE PLATFORM (ARNAUD, 1988)

During the Trias and, above all, the Lias, the interplay of two groups of fault allows the delineation of three large domains in southeastern France (fig. A3).

- The first (Jura, Bas Dauphiné, Ardèche), situated to the Northwest of the Cévennes faults and the Isère fault (VIALON, 1974) and the second (Haute Provence), located to the Southeast of the Durance fault, represent rather shallow marine domains on which consistently thin layers of deposits show few lateral variations. Among those which are known, the liassic palaeofaults have small throws.
- The third, located in the centre (Dauphinois or subalpine or Vocontian basin, Languedoc trench) represents a deeper marine domain characterized by basin type sedimentation which is both thick and laterally highly variable. Paleofaults are found wherever

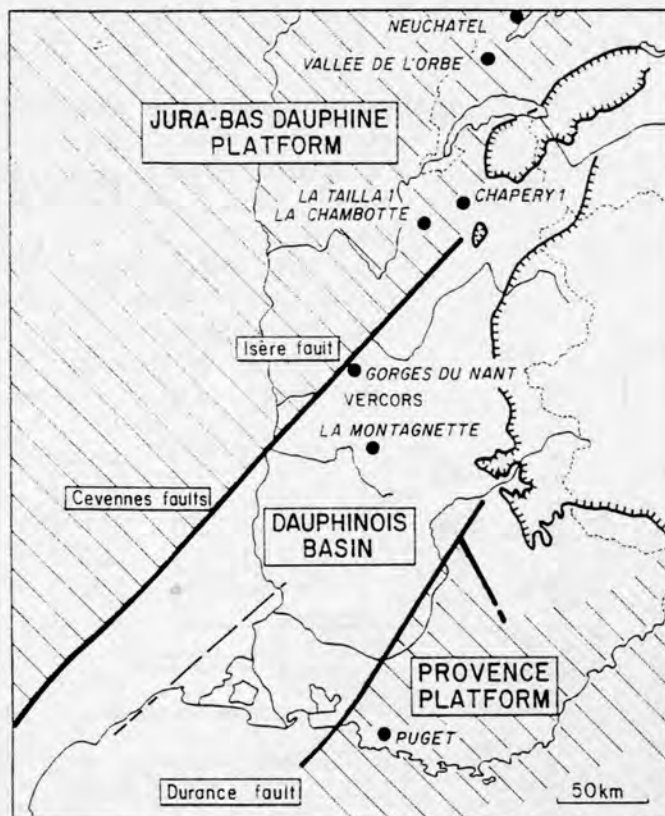
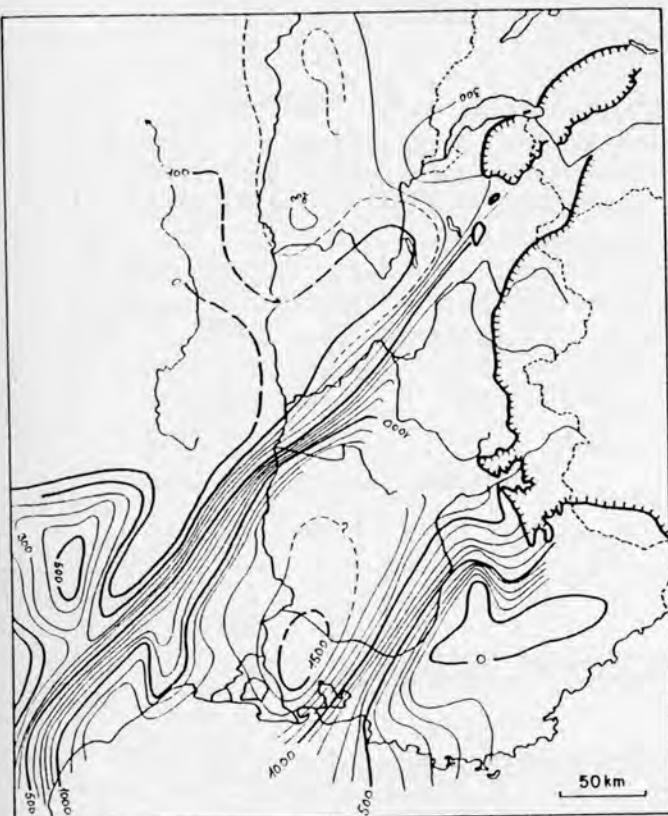


Fig. A3 : A, isopachs of the Liassic series ; B, location of the stable areas (Jura-Bas Dauphiné platform, Provence platform) and of the unstable domain (Dauphinois basin) in the Southeast of France.

Liassic series outcrop. They have throws which are often considerable and which delimit series of tilted blocks (LEMOINE, 1984).

From the Dogger to the Early Cretaceous, the Dauphinois basin (central domain) is highly subsident and globally unstable. It is the centre of a heavy accumulation of sediment and of a considerable deepening of the marine environment. This is contrary to the more stable domains of the Jura-Bas Dauphiné (Jura platform) and of Haute Provence which are characterized by clearly reduced subsidence, though still by rather shallow marine environments which, however, extend over large areas. On this continental edge, the sedimentation is mainly related to sea-level variations (fig. A4) :

- The relatively low sea-level periods were characterized by the development of inner platform carbonate facies and by their rapid progradation towards the tectonic fringes of the Dauphinois basin (northern subalpine massifs, Basse-Provence, Ardèche).
- The relatively high sea-level periods, on the other hand, were characterized by the development of outer platform facies and argillaceous and Cephalopoda facies, by the considerable retrogradation or the disappearance of inner platform facies and by the existence of a number of gaps or sedimentary anomalies (**drowned platforms**).

The Jura platform corresponds paleogeographically to the continuation of the southeastern part of the Paris Basin. During the Late Jurassic-Early Cretaceous opening and spreading stages, two

sedimentary entities can be distinguished (fig. A4).

- At the base (Upper Oxfordian-Middle Berriasian), a carbonate platform entity which rapidly prograded during this period to the Isère fault at the tectonic Northwest fringe of the Dauphinois basin.
- At the top (Upper Berriasian-Albian), a more varied entity, principally carbonate but characterized both at the Hauterivian and at the Albian by an abundance of detritic deposits. In the south-east of the Paris Basin, this entity is locally discordant on the Upper Jurassic limestone (PERNET, 1983).

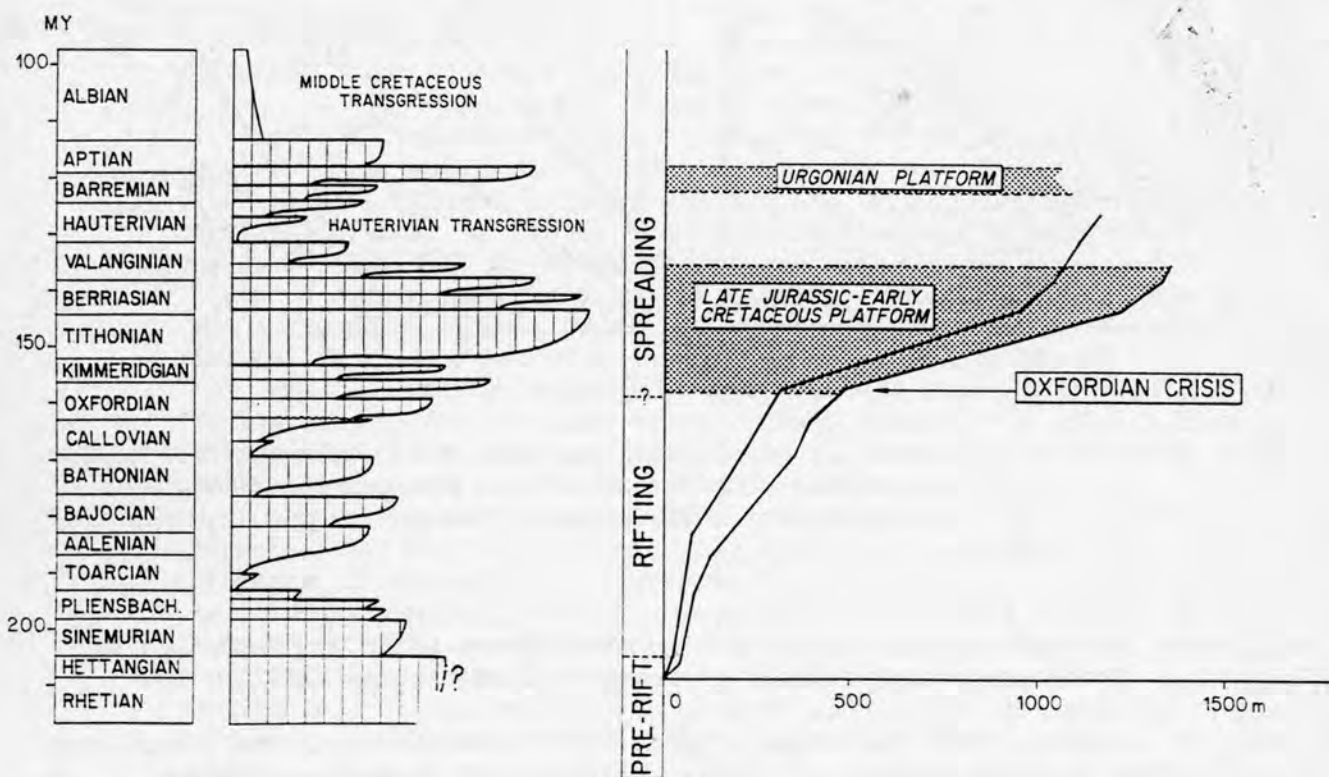


Fig. A4 : Schematic curve of facies evolution and curves of the sedimentation rates on the Jura platform during the rifting (Lias-Dogger), the opening and the spreading (Upper Jurassic-Lower Cretaceous) of the Ligurian Tethys.

In the Jura and the outer part of the northern subalpine massifs, the Lower Cretaceous may be subdivided into four lithological entities deposited during periods which were alternately regressive (low sea-level) and transgressive (high sea-level). The former were characterized by the deposition of carbonates in the very extensive inner domain of a shallow platform, and the latter by a more varied, sometimes argillaceous series deposited on a drowned platform.

The first entity (Upper Berriasian-Valanginian) consists of platform carbonates which follow those of the Late Jurassic. Four large negative sequences stand out during this interval (DARSAC, 1983). They fit together into a positive megasequence which highlights first of all an opening upwards of the environments, then a substantial deepening from the end of the Upper Valanginian (fig. A5, La Chambotte section). The latter represents the first stage of the Hauterivian transgression

NORTHERN VERCORS

GORGES DU NANT

LE FÂ

L'ECHAILLON

SOUTHERN JURA

LA CHAMBOTTE

LA TAILLA 1

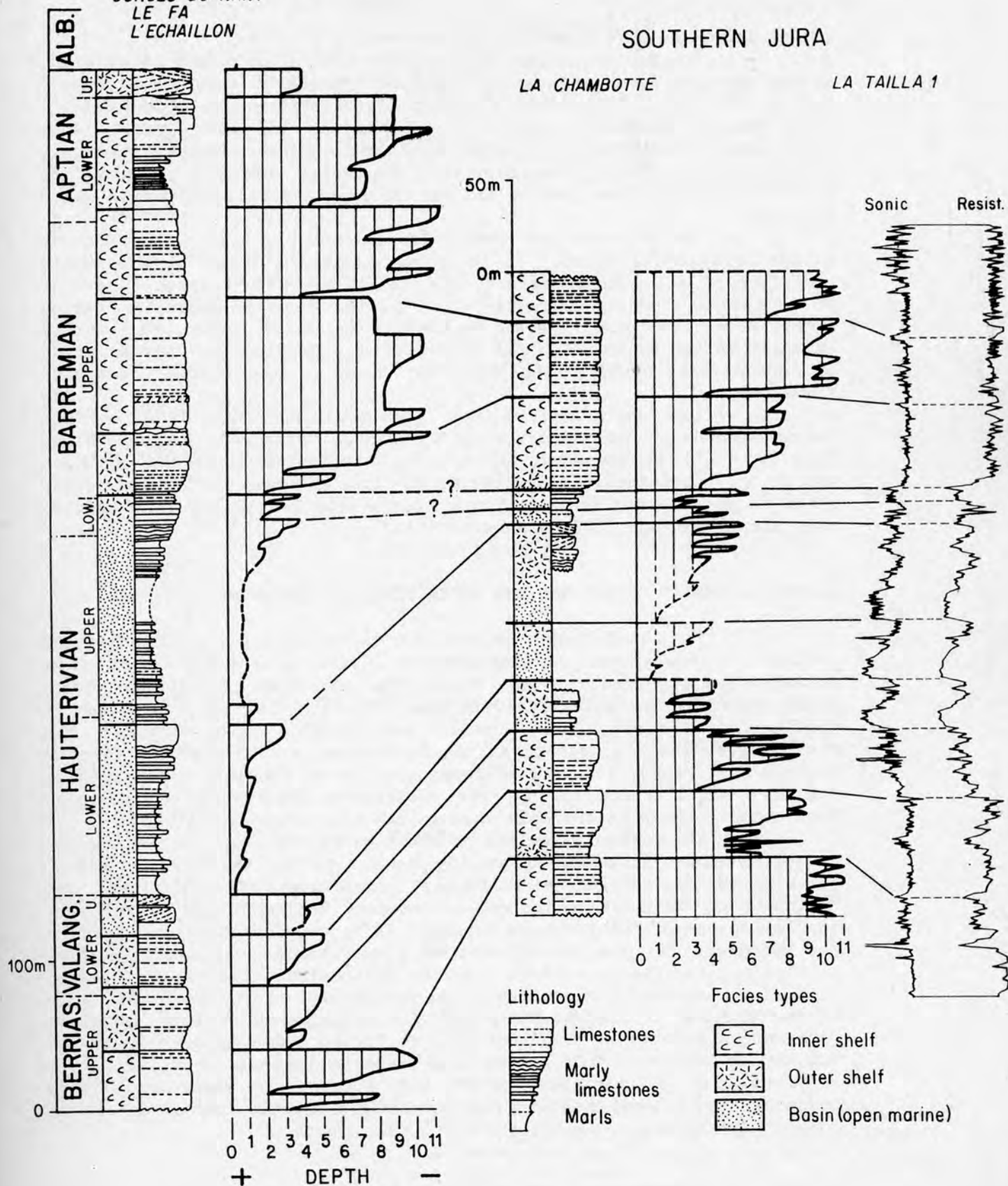


Fig. A5 : Facies evolution curves and stratigraphic correlations between the Northern Vercors, Northwestern border of the unstable Dauphinois basin (L'Echaillon, Le Fâ, Gorges du Nant section) and the stable platform of the Southern Jura (La Chambotte section, La Tailla 1 oil drilling). 0 to 11 : Microfacies F0 to F11.

during which the Jura platform was submerged.

The second entity (Hauterivian-Lower Barremian) is made up, at the base, of marls and marly limestone ("Marnes Bleues d'Hauterive") and, at the top, of bioclastic limestone ("Pierre Jaune de Neuchâtel") which grades laterally towards the SE, along the Isère fault, into argillaceous limestone and marls with Spatangidae. These formations, often rich in detritic minerals, were deposited during the maximum of the Hauterivian transgression and the sedimentary fill-up period which followed.

The third entity (Upper Barremian-Early Aptian) corresponds to the Urgonian limestone. It is made up, at the base, of bioclastic limestone of the outer platform type associated with oolitic limestone or with coral bearing limestone and, at the top, of Rudistid bearing limestone. Deposited during the regressive Barremian period, this entity is split in two by the "Couches inférieures à Orbitolines" member, rich in marl levels, highlighting the first stage of the middle Cretaceous transgression.

The fourth entity (Upper Aptian-Albian) consists of varied, fairly thin beds, deposited during the Middle Cretaceous transgression, that is : (1) at the base, 15 m thick bioclastic limestone of Upper Aptian age ("Lumachelle") and (2) at the top, several metres of sandstone or green sands or a polyzonal decimetric level rich in Ammonites from the Albian age ("Béton phosphaté").

1. THE OXFORDIAN CRISIS AND THE UPPER JURASSIC SUBSIDENCE (Fig. A4)

The Lias-Dogger period is characterized by consolidated sediment accumulations varying between 8 and 12,5 m/My, that is by overall slow subsidence rates. During the Oxfordian period, subsidence rates increased dramatically (Oxfordian crisis). They were subsequently stable until the end of the Jurassic period (from 35 to 47 m/My), and then progressively decreased at the Berriasian and Valanginian (from 6 to 15 m/My). Hence, in spite of compaction rates probably lower than in the more argillaceous series, the subsidence rates were, on average, four times greater in the Malm than in the Lias-Dogger (fig. A4).

The Oxfordian crisis no doubt marks the start of the oceanic spreading since it occurred at the same time as the first sediment deposits on the "liguro-piémontaises" ophiolites. It underlines the beginning of three major tectono-sedimentary modifications in the more stable sectors of the European margin : (1) a considerable subsidence of the basement, (2) the development of predominantly carbonate sedimentation in a regressive context, (3) the delineation, for the first time, of a vast inner and shallow domain on the Jura platform. The coincidence of the sinking of the basement and the development of very extensive carbonate platforms is found not only in Provence during the same period but can be observed also during the Barremian crisis (§ 2). It could indicate that a relatively great but sudden and momentary rising preceded the general settling of the margin at the beginning of the oceanic spreading.

2. THE EARLY CRETACEOUS SEDIMENTATION AND SUBSIDENCE : THE BARREMIAN CRISIS (Fig. A6)

In the Jura-Bas Dauphiné stable area (fig. A6), a correlation exists between consolidated deposit thicknesses and sedimentation rates.

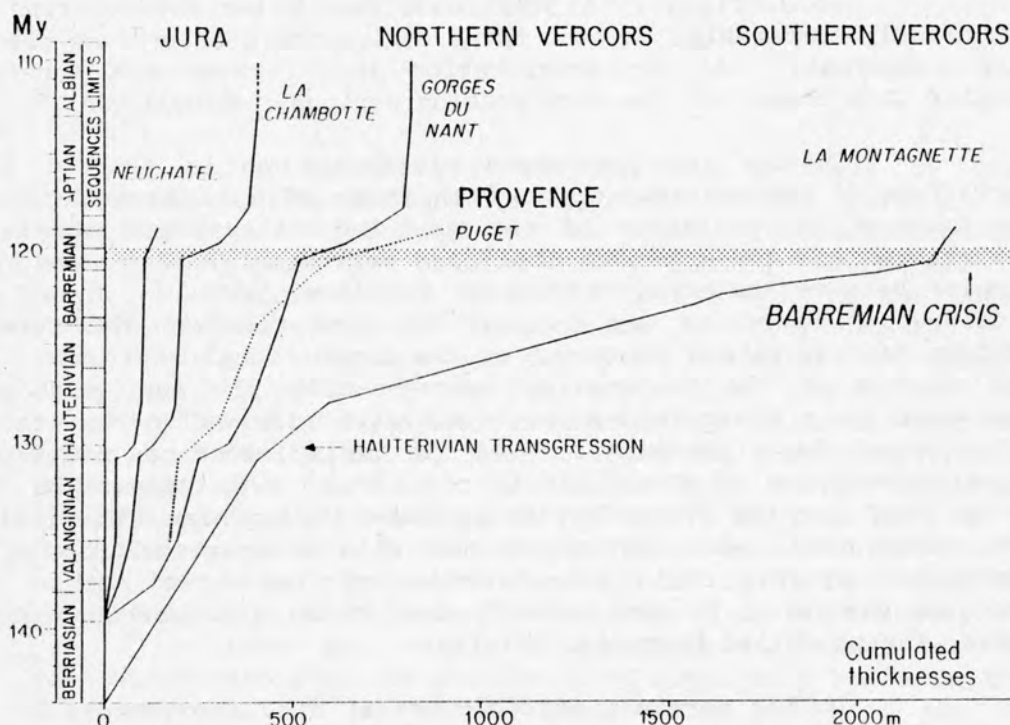
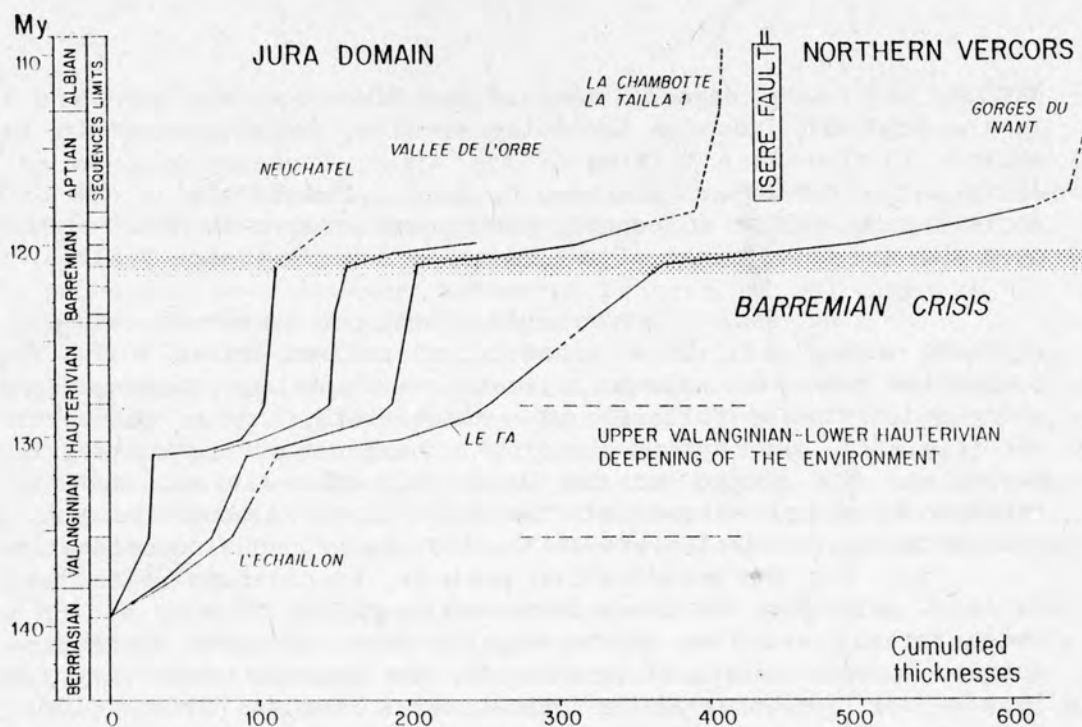


Fig. A6 : Curves of the minimal sedimentation rates during the Lower Cretaceous on the Jura platform (stable domain), the Vercors, to the NW of the vocontian basin (unstable domain) and the Provence platform (stable domain).

From a regional point of view, subsidence rates increase from the NW towards the SE between the Paris Basin and the Isère fault, the border between the Jurassien and Dauphinois domains. Indeed, they do not go beyond 0,8 m/My for the Upper Berriasian-Barremian in the SE of the Paris Basin (16 m of consolidated deposits in the Houpette section,

PERNET, 1983) but reach 10 m/My in the "Jura neuchâtelois" and 17 m/My in the Southern Jura (La Chambotte section, Chapéry 1 and La Tailla 1 wells). This shows a tilting of the whole, corresponding to an abrupt elevation in the NW, underscored by gaps and emersions in the SE of the Paris Basin, and to an equally abrupt break down in the Southern Jura near the tectonic fringe of the Dauphinois Basin (Isère fault).

The sedimentation rates are not constant, varying in a rhythmic manner (it is a question of minimal rates since the real compaction rates are unknown). Above the Upper Berriasian-Valanginian, whose sedimentation followed, at a slower rate, that of the Upper Jurassic (fig. A4), two rhythms stand out, the first at the Hauterivian-Lower Barremian, the second at the Upper Barremian-Albian. Each of these rhythms is characterized, at the base, by a strong increase in the sedimentation rate followed, at the top, by a gradual deceleration.

For the acceleration periods, the average rates range from 30 to 50 m/My for the Lower Hauterivian (50 to 90 m/My at the base of the interval) and from 40 to 90 m/My for the Upper Barremian- Early Aptian. For the deceleration periods, the average rates vary from 2 to 16 m/My for the Upper Hauterivian-Lower Barremian (2 to 4 m/My in the Jura, 16 m/My in the Northern Vercors) and from 2 to 4 m/My for the Middle-Upper Aptian in the whole of this region.

To conclude : (1) the rates during the acceleration phases are closely comparable, (2) the rates during the deceleration phases are also comparable, (3) the acceleration period rates are considerably greater than those of the deceleration periods.

On the Jura carbonate platform, one is tempted to link variations in sedimentation rates with those of subsidence rates, hence the idea of the existence of two subsidence steps, one at the Lower Hauterivian and the other at the Upper Barremian. Reality was probably simpler because the accelerations of the Lower Hauterivian and of the Middle-Upper Barremian are not in the same context. **The former** was contemporaneous with a deepening of the depositional environment during the maximum of the Hauterivian transgression. It may very well be explained by a moderate sea-level eustatic rise (40 m for the Upper Valanginian- Early Hauterivian) and by the maintenance throughout the Upper Valanginian of a subsidence rate of 16 m/My comparable to that established for the Upper Berriasian-Lower Valanginian. **The latter**, on the other hand, was contemporaneous with a decrease in the depth emphasized by the rapid establishment of the inner domain of the Urgonian platform. It was probably due to an increase in subsidence rates, the so-called **Barremian crisis**.

In the **margin's unstable areas, i.e. the Vercors** to the SW of the Isère fault, the northern part of the unstable Dauphinois basin corresponded, during the Lower Cretaceous, to the outer shelf of the Jura platform which prograded towards the south during this period. Determining the sedimentation and subsidence rates here is more difficult because of lack of knowledge of the compaction rates and deposition depths for most of the Cretaceous sediment. Despite the imprecision of this data, estimates allow the definition of three different periods characterized by (fig. A6, La Montagnette section):

- In the first (Berriasian-Lower Hauterivian), average subsidence rates estimated between 8 and 40 m/My,
- In the second (Upper Hauterivian-Lower Barremian), an abrupt acceleration of the subsidence rates (180 to 200 m/My).

- In the third (Upper Barremian-Lower Aptian) a deceleration of subsidence rates (average values from 40 to 60 m/My).

For each of these periods, the estimated subsidence rates are different from those calculated for the Jura platform, showing clearly the tectonic independence of these two domains. This independence does not, however, appear to be total at all times as two types of behaviour can be brought to light.

At the Berriasian-Lower Hauterivian and at the Upper Barremian-Early Aptian, the Jurassien domain and the Northern subalpine massifs were relatively interdependent. Indeed, the subsidence rates were barely higher in the latter domain (8 to 40 m/My), where their estimation is difficult, than in the former (14 to 23 m/My). This increase from NW to SE may then be interpreted as an accentuation of the phenomenon already established between the SE fringe of the Paris Basin and the Isère fault.

At the Upper Hauterivian-Lower Barremian, the independence of these two regions does however seem to be total. Indeed, the subsidence rate increased sharply in the Subalpine Vercors massif (180-200 m/My on the average) while it dropped considerably on the Jura platform (2 to 4 m/My). Here again, the Barremian crisis was responsible for these variations, as strong as they were momentary, of subsidence rates on either side of the Isère fault.

3. CONCLUSION

The Barremian crisis was the greatest of the tectono-sedimentary crises brought to light NW of the European continental margin between the Oxfordian and the Albian. It constituted the boundary between two stages of a complex process lasting several My.

Before the crisis, the first stage, at the Upper Hauterivian-Lower Barremian, was characterized by subsidence rates which were both highly variable from one sector of the margin to another and very different from those of the Berriasian-Lower Hauterivian. The reactivation of certain faults inherited from the liassic rifting (notably the Isère and Menée faults, H. ARNAUD, 1981) would therefore account for the juxtaposition of highly or, on the contrary, hardly subsident sectors, and explain the increased partitioning off of this part of the margin into blocks, perhaps tilted, whose raised parts could be at the origin of the Barremian regression noted in the Jurassien domain and of the appearance of a shoal in the Southeast part of the Vercors.

After the crisis, at the Upper Barremian, the second stage was characterized by the uniformity of subsidence rates in the whole of the region and by the strong acceleration noted in the less stable sectors. The generalized collapse of the margin was therefore contemporaneous with the development of the Urgonian platform.

In the evolution of the Ligurian ocean, no particular event can for the moment explain the Barremian crisis. Its origin must therefore be sought in more distant regions where it is more prominent. On the Galician margin, this was related to the tilting of blocks following the deeping of the margin which took place between the Valanginian-Lower Hauterivian and the Barremian (BOILLOT *et al.*, 1986). Because of this, the speeding up of subsidence rates noted at the Barremian on the alpine continental margin of the Ligurian ocean may be interpreted as one of the perhaps slightly later consequences of the rifting of the Galician margin and of the near Atlantic (Bay of Biscay).

D. THE STRATOTYPIC REGION NEAR NEUCHÂTEL (SWISS JURA)
(T. ADATTE & G. RUMLEY)

1. HISTORICAL EVOLUTION OF THE NOTION ABOUT THE STRATOTYPIC REGION NEAR NEUCHATEL (Jura mountains, Switzerland)

The Swiss Jura mountains, near the town of Neuchâtel, are the place where two historical stratotypes (Valanginian and Hauterivian) were defined. The figure A7 resumes the evolution of these historical concepts since the last century

The name Neocomian takes its origin from Neuchâtel (from latin, Neocomium, THURMANN, 1836) and was used to define the lowest Cretaceous marine layers. The Valanginian stage was defined by DESOR & GRESSLY (1853), in order to characterise the lower part of the Neocomian (fig. A8). The Hauterivian stage (from Hauterive, in France, village to the East of Neuchâtel) was proposed by RENEVIER (1874) in order to avoid a confusion between the Neocomian sensu lato and the Neocomian sensu stricto (upper part, fig. A7).

BAUMBERGER (1901) introduced the Berriasian (sensu COQUAND, 1871) for the Lower Valanginian, as defined by JACCARD (1869). This was based on chronostratigraphic considerations. Thus, the former Neocomian was divided into three independent stages, leaving aside the Barremian-Urgonian problem.

LOWER CRETACEOUS :

HISTORIC EVOLUTION OF THE STRATOTYPIC REGION

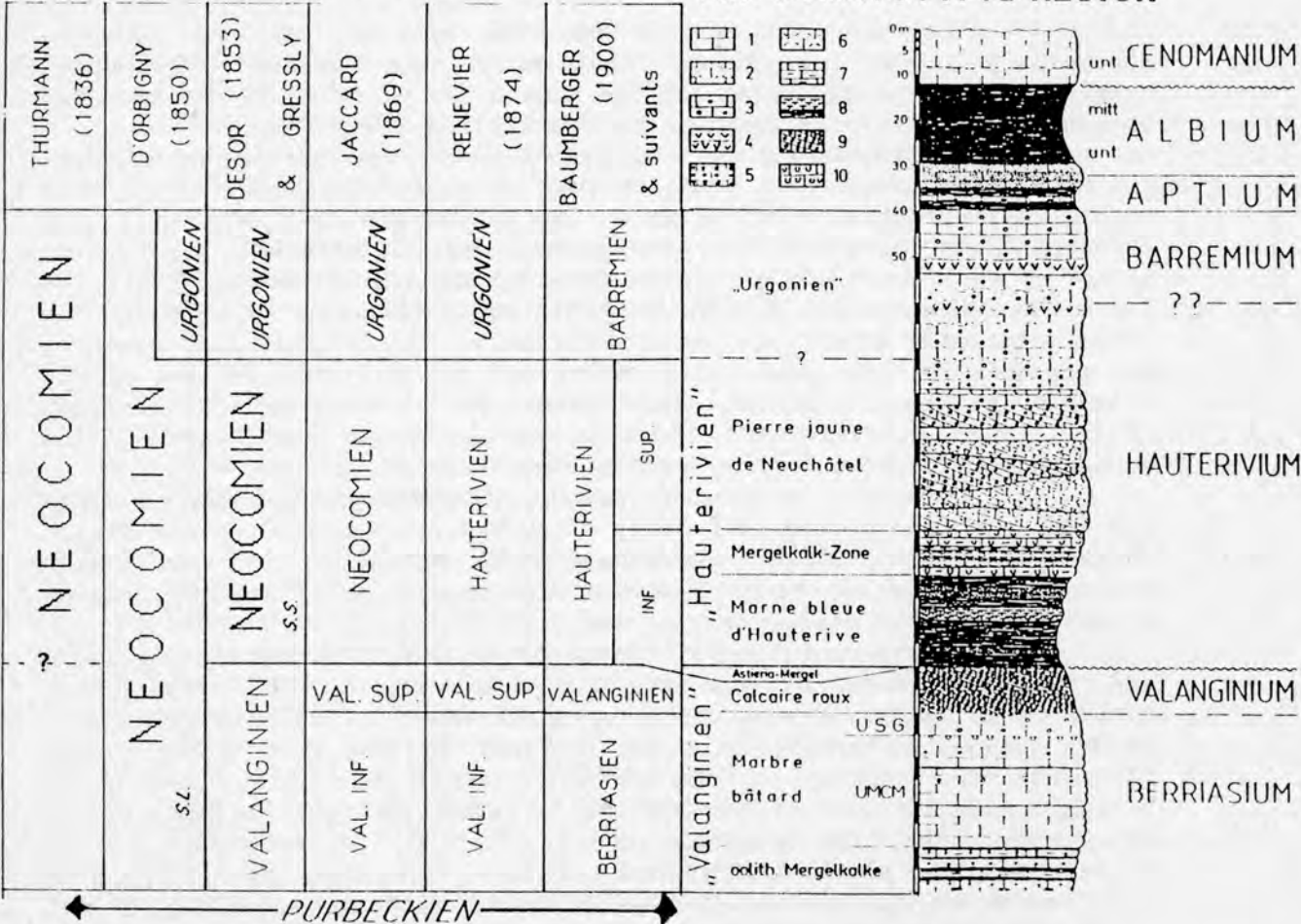


Fig. A7 : Historic evolution of the Lower Cretaceous concepts in the stratotypic region.

2. LITHOSTRATIGRAPHIC DESCRIPTION OF THE NEUCHÂTEL AREA LOWER CRETACEOUS

The stratigraphic succession of the Lower Cretaceous of the stratotypical region of Neuchâtel can be described as five main lithostratigraphic subdivisions, according to the historical definition (fig. A7). From the bottom to the top, above the purbeckian facies, we encounter the **Unité Inférieure Oolithique** (1) and the **Marbre Bâtard** (2), these two formations belonging to the Berriasian. Above, the **Calcaire Roux** (3) belongs to the Valanginian. Then, we have the **Marnes Bleues d'Hauterive** (4) and the **Pierre Jaune de Neuchâtel** (5), which are of Hauterivian age, and precede the urgonian facies.

(1) Following the lacustrine and marine facies of the "Purbeckian", the real marine facies of the Unité Inférieure Oolithique (U.I.O.) appear (marly black and grey limestone, with ooids, echinoderms and glauconite).

(2) The Marbre Bâtard is well stratified greywhite limestone (beds of 0,2 to 2 meters and more). Two parts can be distinguished : the lower part is massive micritic limestone called Unité Moyenne Calcaire massive and the upper part is limestone containing a rather great amount of quartz, the Unité Supérieure Gréseuse (U.S.G.). In this unit, we observe the association of *Keramosphera allobrogensis* and *Pseudo-textulariella courtoniensis* which is found throughout the Swiss Jura, and indicates a late Berriasian age. A stratigraphic gap exists between the U.S.G. and the next formation, the Calcaire Roux, which is of Valanginian age.

(3) The Calcaire Roux is a typical calcarenite with cross stratification, iron-ooids and echinoderm remains. The top of the Calcaire Roux is formed by a hard-ground, on which it is sometimes possible to find a very thin deposit of yellow marls (about 20 cm), the **Marnes à Astieria**. An ammonite, *Saynoceras verrucosum*, characteristic of

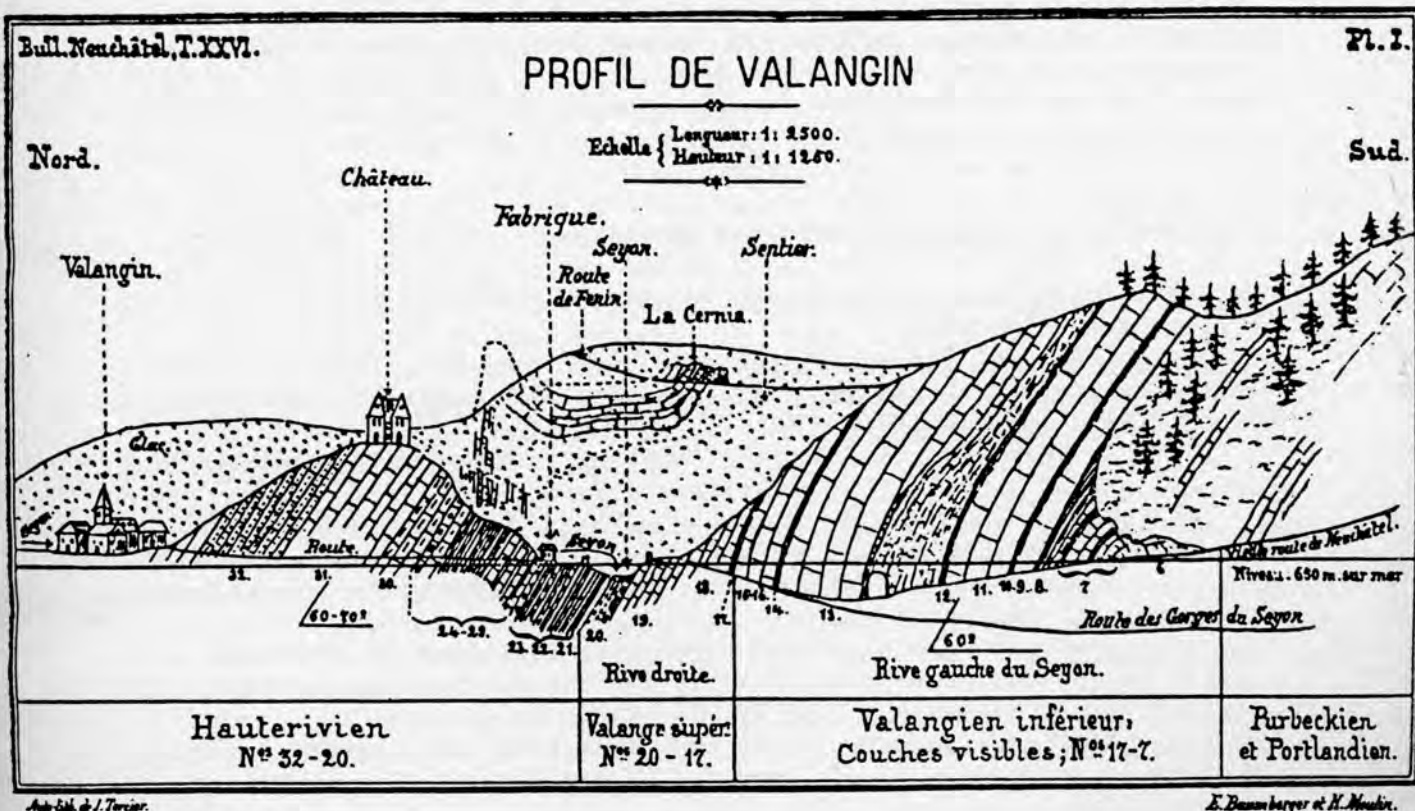


Fig. A8 : Geologic profile of Valangin, from BAUMBERGER & MOULIN (1899)

the basal Upper Valanginian, was found in these marls at Valangin. That is the reason why it is generally admitted that the whole Upper Valanginian is represented by these 20 cm of marls.

(4) The Marnes Bleues d'Hauterive follow in continuity. They are 20 meters of sediment containing a rather rich fauna : ammonites, brachiopods, echinoderms, etc... The common occurrence of Acanthodiscus radiatus in the first meters of the Marnes Bleues proves the Early Hauterivian age of this formation.

(5) The passage to the Pierre Jaune de Neuchâtel is gradual through a zone which is called **zone marno-calcaire**. This terminology tends to be abandoned because of variations in the thickness of this zone from place to place. The Pierre Jaune is again a limestone with cross stratification, ooids, echinoderm remains, bryozoans, but no typical fauna allowing us to give it a precise age. Therefore, the Hauterivian-Barremian boundary is till now not determined in the Swiss Jura.

E. SEDIMENTOLOGICAL AND MINERALOGICAL MAIN FEATURES OF THE LOWER CRETACEOUS CARBONATE PLATFORMS

1. MICROFACIES (A. ARNAUD-VANNEAU & H. ARNAUD)

In the South-East of France, carbonate platform facies are observed in three different types of sedimentational environments: standard platforms, drowned platforms and the reworking sediments in the basin.

1.1. Standard Platforms (Fig. A9)

On the standard platforms, well-developed during periods of relatively low sea level, 12 families of microfacies, classified from F0 to F11, may be distinguished in the Early Cretaceous. They constitute a natural continuation between an unconfined and oceanic environment characteristic of a deep marine domain, and a confined marine environment, shallow and sometimes emerged. These platforms are sufficiently recognizable to be able to establish vertical evolution curves of facies on the platforms and their margins.

F0: Biomicrite with Radiolaria and Ammonites

This is pelagic basin facies characterized:

Macroscopically by alternations of marls and bluish-grey ammonitic argillaceous limestone,

Microscopically by essentially pelagic organisms: Radiolaria associated, according to stratigraphic levels, with Calpionellids and pelagic foraminifera (Caucasella).

This facies comprise varying but sometimes substantial proportions of clay, silted quartz and glauconite.

F1: Biomicrite with Sponge Spicules

This hemipelagic facies deposited in mainly circalittoral environments, is characterized:

Macroscopically by marls or by bluish-grey argillaceous limestone with sparse macrofauna (some ammonites and Spatangidae) made up of 50 to 60% carbonates, 30 to 40% clay, 10 to 20% quartz and glauconite,

Microscopically by a large number of sponge spicules and by a fairly dispersed microfauna of small agglutinated foraminifera and Nodosariidae.

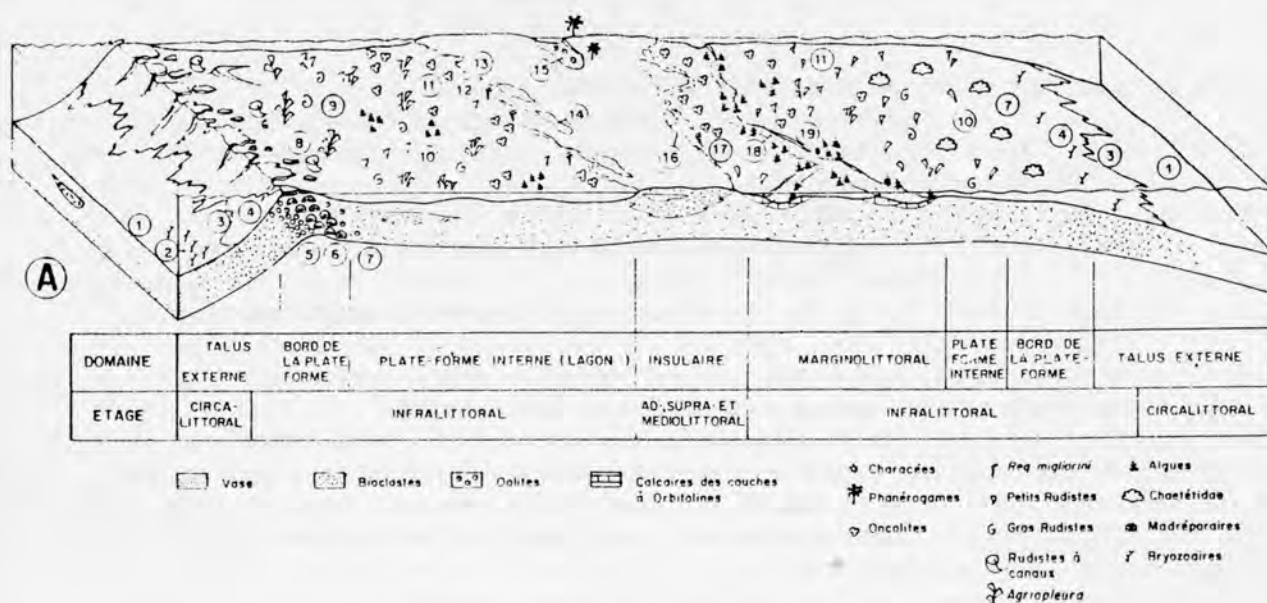


Fig. A9 : Schematic block-diagram of the Urgonian platform (after A. ARNAUD-VANNEAU, 1980 and H. ARNAUD, 1981). 1, sandy mud with *Spatangidae*. 2, coarse sands with *Bryozoans*. 3, fine-grained sands with *Echinoderms* and *Annelids*. 4, coarse sands with *Orbitolinidae* and *Dasycladaceae*. 5, oolitic sands. 6, coral reefs. 7, coarse coral sands. 8, mud with *Caprinidae* and *Caprotinidae*. 9, peloidal sands with *Agriopleura*, *Neotrocholina* and *Echinids*. 10, fine-grained sand with large *Rudists*. 11, fine-grained sand with small *Rudists* and *oncolites*. 12, fine-grained sand with *Requienia cf. migliorinii*. 13, sandy beach. 14, mud with *Pseudotriloculina*. 15, mud with *Chara* (and clays). 16, mud with *schizophytoids*. 17, mud with isolated *Rudists*. 18, mud and argillaceous mud with *Palorbitolina*. 19, mud with *Dasycladaceae*.

F2: Biopelmicrite with *Spatangidae*

This facies deposited in calm circalittoral environments is characterized:

Macroscopically by greyish-blue fairly argillaceous limestone (60-70% carbonates, 20-30% clay, 7-10% quartz) including a fair number of *spatangidae*,

Microscopically by sharp *spatangidae* debris associated with the peloids which characterize this facies.

The microfauna is made up of small agglutinated foraminifera (*Dorothia*, *Grudryina*, *Textularia*, *Glomospira*, *Valvulineria?*), some *Nodosariidae*, and some large complex test wall foraminifera (*Palorbitolina*, *Choffatella*).

F3: Biomicrite to biosparite with *Echinoderm* debris and small Foraminifera

Characteristic of circalittoral depositional environments, like the preceding F2 facies, these facies are slightly more calcareous (about 80% carbonates, 20 to 30% clay, less than 10% quartz). They are characterized:

Macroscopically by bluish to slightly reddish limestones, better embedded than the previous ones, which do not contain well-preserved macrofauna,

Microscopically by numerous small rounded *echinoderm* debris, numerous peloids and numerous small circalittoral foraminifers (specifically

similar to those cited in the F2 facies).

The erosion of the debris and the dredging of the sediment are, for the first time, signs of the existence of a weak but well-marked hydrodynamism.

F4: Biomicrite and biosparites with Bryozoans and Crinoids

These facies, deposited in circalittoral environments, are much coarser than the previous ones. They are characterized:

Macroscopically by reddish to yellowish-brown limestones appearing either as small meter-sized cross-bedded banks or else as small decimeter-sized banks intercalated in the marls,

Microscopically by populations very highly dominated or constituted exclusively by Bryozoans and Crinoids. Foraminifera are absent except for some large, robust and generally eroded forms (Lenticulina and Trocholina). These facies are comprised of 75-87% carbonates, 7-15% clay and 2-10% quartz.

F5: Biosparites with Large rounded debris

These highly carbonated facies (at least 90% carbonates) are characteristic of high energy infralittoral environments. They are characterized:

Macroscopically by decimeter-sized ochre banks with oblique or cross-stratified beds,

Microscopically by the abundance of rounded Metazoan and Algae debris, and, occasionally, by highly numerous large-sized benthic foraminifera.

The well-sorting, the presence of alternately fine or coarse centimeter-sized laminae, and the richness in dasycladacean algae and coral debris are evidence of the formation of these facies in infralittoral environments subject to a constant, moderate to strong, hydrodynamism. On the platform's outer slope, the coarse-grained sands may be transported laterally by storm currents to circalittoral environments.

F6: Oosparites and bio-oosparites

F7: Biosparites with Corals or Boundstones

These facies, deposited in infralittoral depositional environments subject to a weak to moderate, or even locally strong, hydrodynamism, contain 88 to 95% carbonates and, at the most, 1% quartz (quartz is furthermore most often absent).

Macroscopically, they appear either as decimeter-sized banks with oblique or cross-stratified beds (F6) or else in lenticular levels (F7). They are found either on the edge of the platform (their lateral extension is therefore generally reduced), or else in the inner platform, after a considerable submersion episode when the carbonate sedimentation returned to normal (in this case, these facies are observed in very vast regions). Aside from the Metazoan fauna which accompanies the Corals of facies F7, there is no autochthonous fauna except for one or two species of Foraminifera (Reophax? giganteus or Acruliammina neocomiana).

Microscopically, once again there are biosparites with rounded debris or oosparites, the elements of which are often well-sorted.

F8: Biosparites-biomicrites with Large Foraminifera sometimes accompanied by large-sized Rudists

These facies, which relate to sediments deposited in infralittoral environments, are considered to be "external lagoon" facies. They contain 86 to 95% carbonates and include at the most 1% quartz.

- c) They often contain a very rich and diversified fauna, often a mixture of infra- and circalittoral fauna.
- d) They sometimes display a mixture of two distinct facies, this mixture having been formed before the two sediments hardened.
- e) They often contain fairly high proportions of terrigenous detritic elements (quartz, clays,...).

1.3. Reworking sediments in the basin

Three types of gravity flow deposits (mud flow, sand flow, turbidites) are observed in the Vocontian basin (Early Cretaceous basin in the South-east of France) where they have truncated the pelagic and hemipelagic autochthonous substratum. These flows relate to the transport by gravity, all the way to the bottom of the basin, of sandy, sand-mud, or muddy sediments deposited on the margin or outer slope of the platform. However, the nature of the sediments deposited by gravity at the bottom of the basin is directly related to that of the sediments deposited at the same time on the platform margins: this results in the substantial variation in the nature of gravity deposits according to the relatively high or low sea level of the period.

a) During periods of relatively low sea level, (standard platforms), the margins and outer shelf slopes are characterized by bioclastic sands or coarse, well-sorted oolites. In the basin, the reworked sediments are deposited in banks sometimes decameter-thick made up of coarse-grained sand with a number of large Foraminiferida (Trocholina, Orbitolinidae, large agglutinated foraminifera) and dasycladadean algae. In the turbidites, vertically graded bedding is nevertheless poor or nil because of the originally well-sorted sediments deposited on the outer platform slope.

b) During periods of relatively high sea level (drowned platforms), the margins and outer platform slopes are characterized by generally fine-grained bioclastic sands and muddy sands, deposited in circalittoral environments. In this case, the reworked sediments in the basin are often deposited in small, reddish, decimeter-sized banks; they are well-sorted, from fine to very fine, with basal sedimentary structures. One finds mainly fine-grained biosparites with small circalittoral foraminifera or fine biosparites with large sponge spicules.

c) During periods of very high sea level (transgressions), the drowned platforms are the site of sedimentation in a deep environment (facies F1 or F2). The turbidites present in the basin are of two types:

- a massive remobilisation of sponge-spiculed mud
- the presence of small turbidites, millimeter- to centimeter-thick, reddish in colour, made up of very fine biomicrites or biosparites with small sponge spicules.

In conclusion, the granulometry, the nature of the bioclasts and the type of facies found in the bioclastic sedimentary bodies reworked in the basin are not directly related to the distance of the re-deposit areas from the source platform margins, but rather to the platform margin environments and thus to the variations in depth there observed. According to this interpretation, the vertical transition in the basin is not from proximal to distal turbidites, but rather from low sea level to high sea level turbidites. In this regard, the Col de Romeyer Valanginian basin facies section establishes this sort of evolution, conforming perfectly to that observed in the Chambotte section on the Jurassic platform.

2. MICROFACIES ARRANGEMENT (A. ARNAUD-VANNEAU and H. ARNAUD)

In the South-east of France, the general features of carbonate perivocontian platforms are similar from the Berriasian to the Aptian. There is no significant difference in this context between the Early Berriasian-Valanginian platforms and those of the Early Barremian-Aptian, historically referred to as Urgonian platforms ; on the latter, however, rudist facies show considerable development.

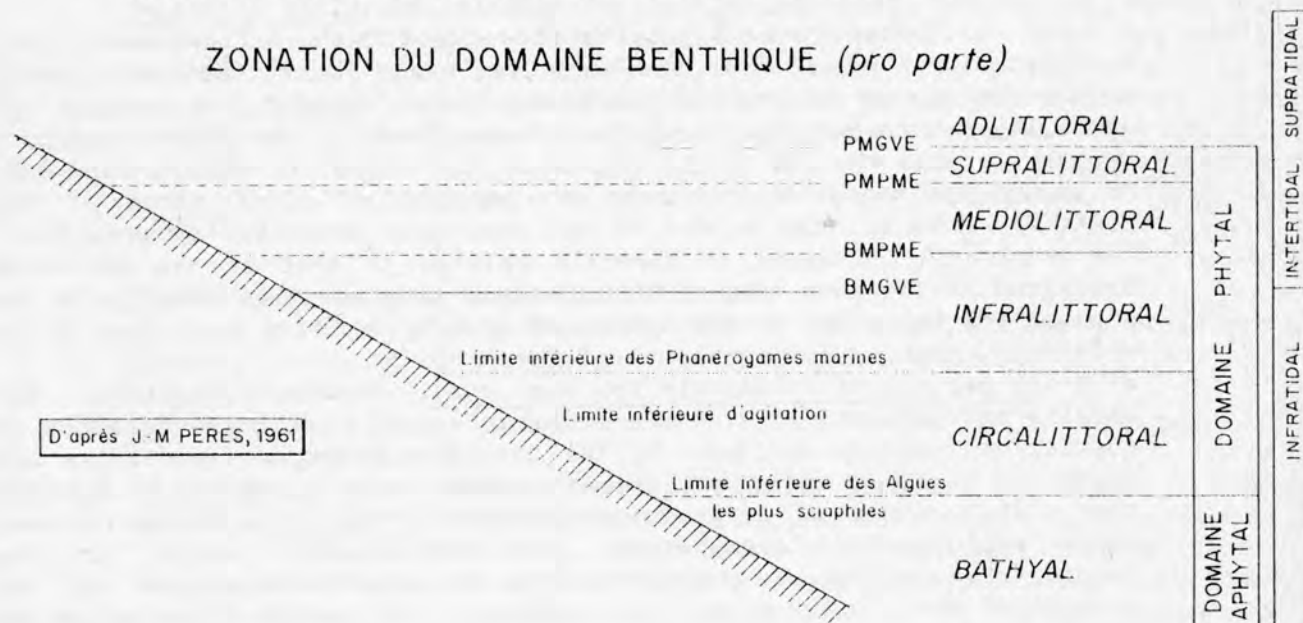


Fig. A. 11 : The vertical sea-floor zonation (H. ARNAUD, 1981)

1. Sea-floor zonation (fig. A11)

This zonation, defined by PERES and PICARD (1959), and then by PERES (1961), is based upon the vertical or horizontal staging of benthonic marine populations.

2.1.1 Vertical zonation

Seven bionomic stages have been defined; the first four are grouped together in the phytal domain (PERES, 1961; = photic system, PICARD, 1980), characterized by the penetration of light rays, while the last three - the bathyal, abyssal and hadal stages - make up the aphytal domain (PERES, 1961; = aphotic system, PICARD, 1980), which is always dark.

In the phytal domain, PERES (1961) distinguishes:

- the supralittoral stage "characterized by populations withstanding only exceptional immersions";
- the mediolittoral stage in which populations are "regularly subject to alternating emersions and immersions (tidal zone)";
- the infralittoral stage "beginning by exceptionally emerged levels and advancing to the lower life limit of marine phanerogams and dasycladacean algae (from 8 to 50 meters according to the turbidity of the water)";
- the circalittoral stage "found between the highest limit compatible with marine phanerogam or dasycladacean algae life and the deepest limit attained by the most sciaphilic algae (from about 80 to 200 m.)".

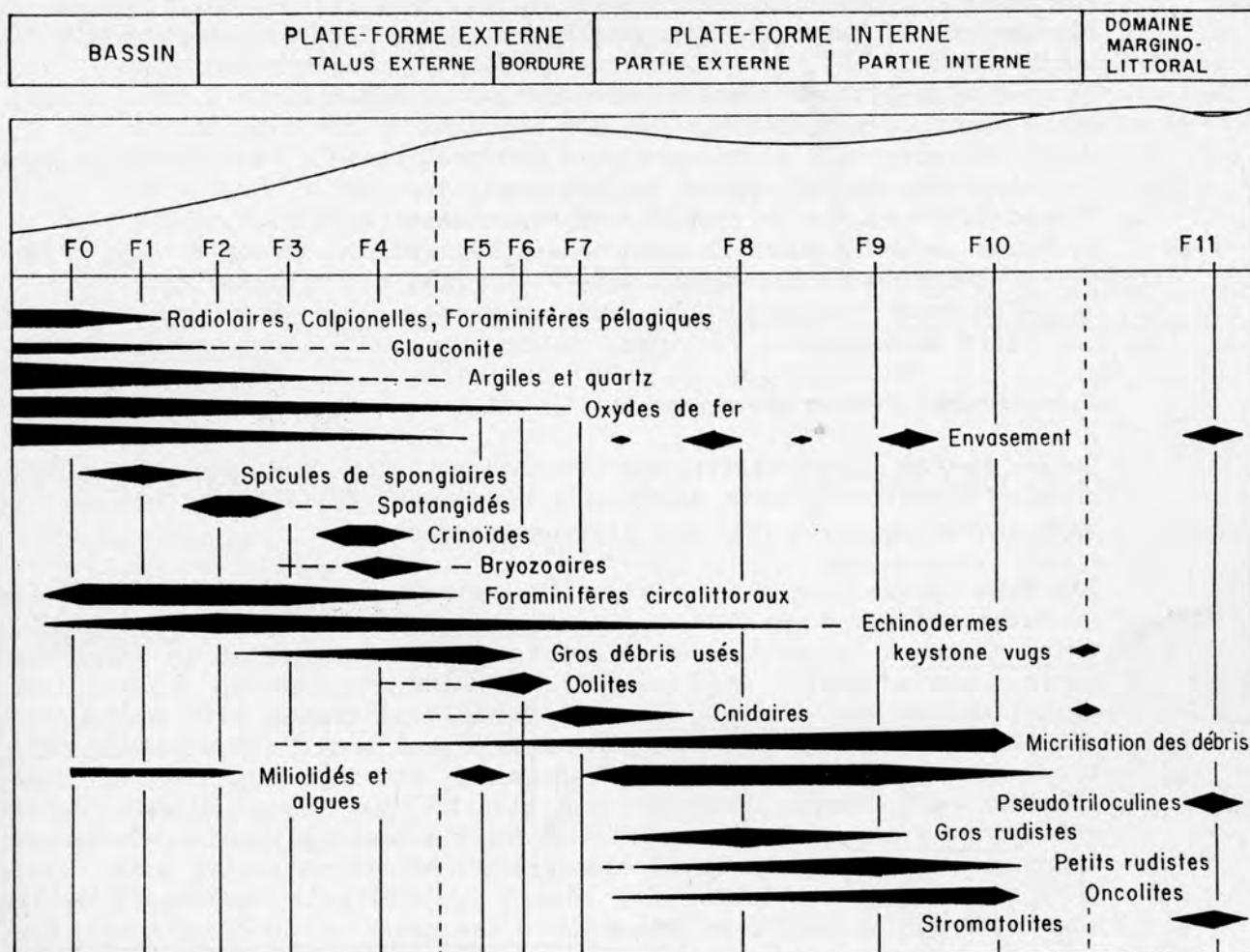


Fig. A 12 : The lateral facies arrangement.

- F 0 : Biomicrite with Radiolaria and Calpionellids.
 F 1 : Biomicrite with Sponge spicules.
 F 2 : Biomicrite with Spatangidae.
 F 3 : Biosparite with rounded Echinoderm debris and small Foraminifera.
 F 4 : Biomicrite and biosparite with Crinoids and Bryozoans.
 F 5 : Biosparite with large rounded debris.
 F 6 : Oosparite.
 F 7 : Biosparite with Corals ; Boundstone.
 F 8 : Biomicrite -biosparite with large Foraminifera, sometimes accompanied by large-sized Rudists.
 F 9 : Biomicrite -biosparite with Miliolidae and Rudists.
 F 10 : Biomicrite -biosparite with oncolites and Bacinella.
 F 11 : Micrite with Pseudotriloculina; Micrite with bird's eye ; Emersion facies.

2.1.2. Horizontal zoning

For the platforms of the Early Cretaceous, MASSE (1976) has proposed the distinction of three entities which are, going from offshore towards the continent:

- the prelittoral entity which merges with the circalittoral stage,
- the platform entity,
- the marginolittoral entity, corresponding to a temporarily emerged environment or one of variable salinity.

The platform entity is itself subdivided into:

- an outer shelf sub-unit characterized by an open environment dominated by hydrodynamism or by Corals bioconstructions;
- an inner shelf sub-unit whose environment is relatively less open and more calm.

2.2. **Lateral facies arrangement** (fig. A12)

Basin facies characterize the Vocontian basin and its hemipelagic margin. biomicrites with Radiolaria and ammonites (F0) and biomicrites with sponge spicules (F1) are distinguished here.

Platform facies permit the distinction between outer and inner platforms (= outer and inner shelf).

Outer platform facies include all the sediments deposited in unconfined marine environments and subject to weak to strong hydrodynamic agitation. On the outer slope, one finds biomicrites with spatangidae (F2), biomicrites with echinoderm debris and small foraminifera (F3), biomicrites and biosparites with Bryozoan and Crinoids (F4) and biosparites with large, rounded orlitolinidae and dasycladacean debris (F5). On the edge, where one often finds the most agitated environments, there are oosparites and bio-oosparites (F6), biosparites with corals (F7) and reefs. The latter are always only slightly developed on the edge of Urgonian platforms where there are never any true reef barriers.

Inner platform facies consist of sediments deposited in shallow environments, perfectly protected, often confined, and sometimes temporarily emerged. Several sedimentary groups stand out here, characterized by generally fine sediment which is particularly rich in micrite debris. Two distinct parts may be distinguished:

- the outer part is characterized by facies conveying the existence of little-confined or unconfined environments, with near to normal salinity and oxygen content, an abundant and varied fauna, the constant presence of echinoderms: biosparite-biomicrites with large foraminifera and large rudists (F8).

- the inner part and the marginolittoral domain are characterized by sediments deposited in far more confined environments with often hypo- or hyperhaline salinity, an impoverished fauna (fewer species, never more echinoderms): biosparite-biomicrites with Miliolidae and Rudists (F9), biosparite-biomicrites with oncolites and Bacinella (F10), medio- to supralittoral facies showing signs of emersion (F11).

2.3. **Vertical facies arrangement : sequences and discontinuity horizons**

3.1 Discontinuity horizons

A discontinuity horizon is an isochronous surface, from which one observes a change in sedimentation marked either by a lithological variation or by a rupture or inversion of the facies' evolution curve. On the platforms, these horizons correspond most often to an abrupt rise in sea level, a phenomenon which may be due either to

an eustatic movement or to a jerk of subsidence. This rise in sea level, always very rapid, may be considered as being instantaneous on the geological scale; it is conveyed by a modification of the physico-chemical parameters of the marine environment (temperature, currents, luminosity, depth,...), and thus by a more or less substantial modification of populations and, as a result, of sediment deposits.

These modifications may be accompanied at times by the erosion of a part of the deposits underlying the discontinuity horizon and/or by a more or less lengthy hiatus in sedimentation above it. In this case, there is a diachronism of the sediments situated immediately above or below the discontinuity horizon. This diachronism of fossilized sediments must not be likened to a diachronism of the discontinuity horizon: indeed, only the sediment is dated and not the geological event which is, itself, instantaneous on the geological scale.

PLATE-FORME SUBALPINE

BASSIN VOCONTIEN

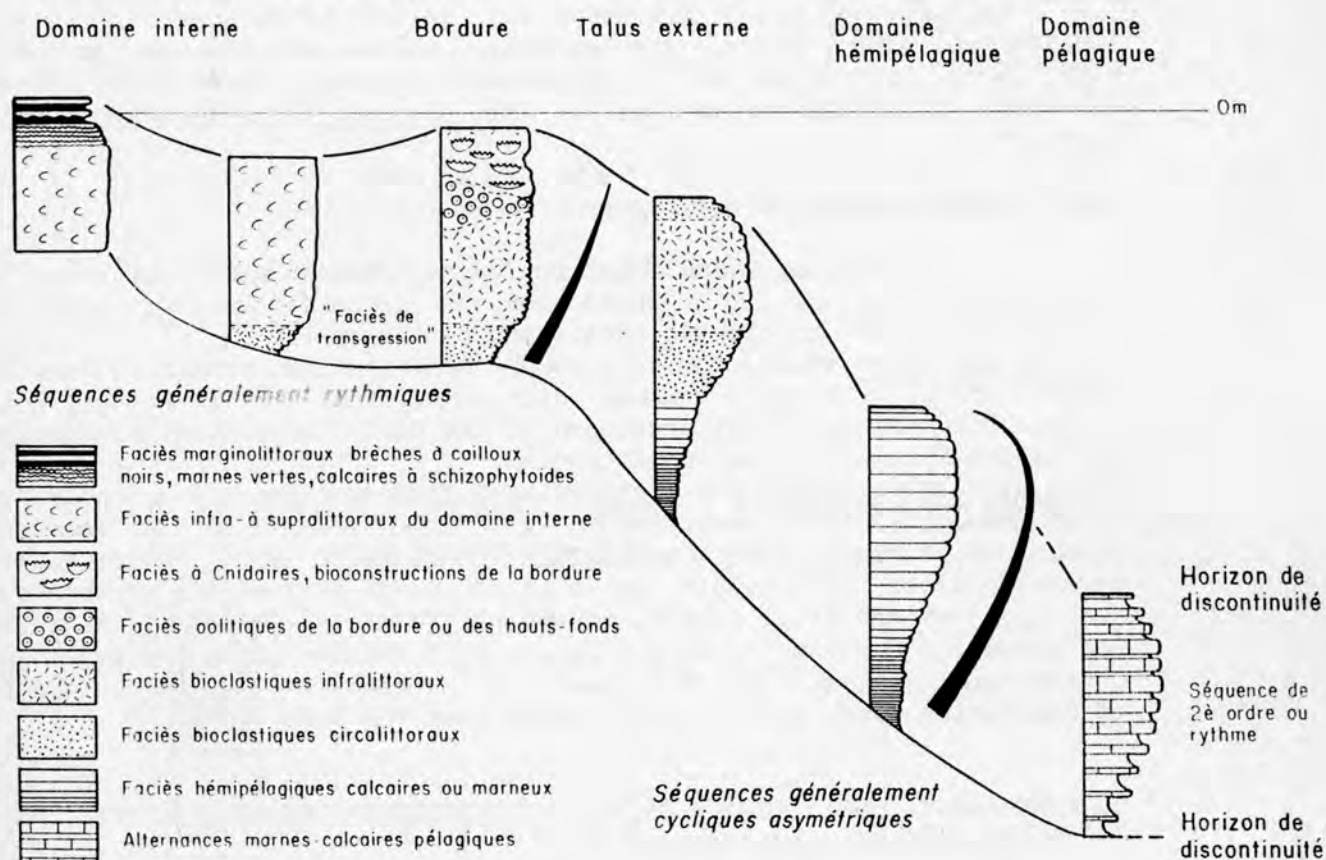


Fig. A13 : The lateral sequence arrangement (H. ARNAUD, 1961)

2.3.2 The Sequences

Under normal circumstances, sediment accumulation on the platform brings about a progressive filling up of the marine environment in such a way that on the same vertical section, one observes the continuous transition from a facies X to a facies Y characteristic of a more shallow depositional environment. On the metric scale, these small shallowing-upward sequences are most frequently observed on the platform (first order sequences). On the decametric scale, the primary sequences are grouped together in meso- and megasequences (second and third order sequences), far more complex in detail. While the first order sequences

are solely dependent upon local factors, the meso- and megasequences are bordered at the base and at the top by discontinuity horizons which highlight a more or less substantial regional deepening of the depositional environment.

2.3.3 Different Types of Meso- and Megasequences (fig. A13)

a) Rhythmic sequences, frequent particularly in the inner domain of the platform, are characterized by a continuous filling-up to the top and by a sudden rise of the facies which is generally substantial at the level of the top discontinuity horizon.

b) Cyclical sequences, almost always asymmetrical, are characterized at the base by a continuous filling-up of depositional environments and at the top by the progressive deepening which one begins to observe below the top discontinuity horizon.

Cyclical sequences are observed in mainly two cases:

- in the inner shelf, below the discontinuity horizons highlighting major transgression episodes;

- in the outer shelf and the basin. In the latter case, given the monotony of the facies, the cyclical nature of the sequence is highlighted by variations in carbonate content, with the lowest carbonate levels corresponding to the deepest environments on the platform.

2.4. Different types of morphology

In the southern Jura and septentrional subalpine massifs, the sediments of the Early Cretaceous are deposited on two types of paleotopographies: bioclastic shoals and platforms.

a) The platforms relate to very vast, very shallow submerged shoals, subhorizontal on a small scale, which are joined up to the basin by slopes. They are very well developed at the Early Berriasian-Valanginian and at the Upper Barremian-Basal Aptian.

b) The bioclastic shoals are distinguished from the Urgonian platform by a far reduced surface area and by the total absence of an internal domain and corresponding facies. They are found only at the Early Barremian along the N.E.-S.W. Menée fault (South-East of the Vercors).

There still exists, on the platforms and shoals of the Early Cretaceous, a dissymmetry in the facies distribution along the edges and on the outer slopes. This dissymmetry is probably due to the existence of dominating winds and currents coming from the East.

3. MINERALOGY AND CLAY FACIES (ROENTGENOFACIES) (T. ADATTE, A. ARNAUD-VANNEAU and G. RUMLEY)

The mineralogical study is done for all our samples of each profile. In this way, we try to show the relationship between the mineralogical association and the sedimentological environment. This method was first applied by VIEBAN (1983) and DARSAC (1983) under the direction of B. KUEBLER (Neuchâtel), A. ARNAUD-VANNEAU and H. ARNAUD (Grenoble).

In accordance with this method, we consider essentially the clay and the accessory minerals. Each sample is decarbonated, separated into two fractions (less than 2 and between 2 and 16 μ), and then analysed by X-ray diffraction.

The main minerals recognized are :

- quartz, iron oxydes (pyrite and goethite), titanium oxydes, and

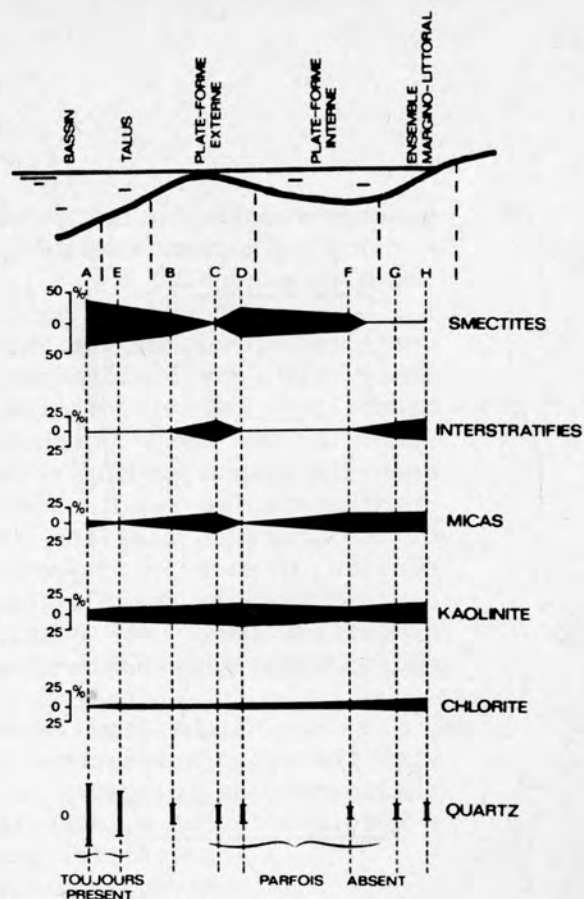
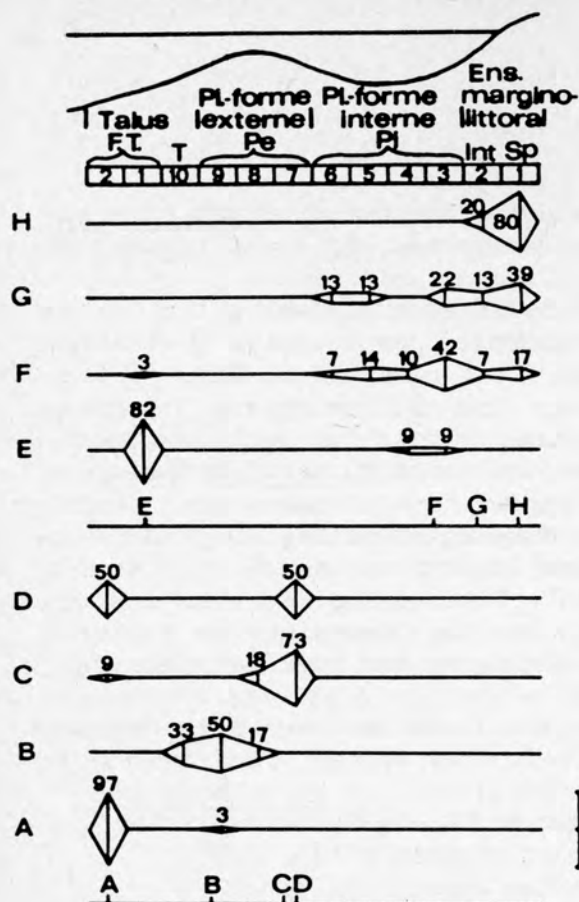
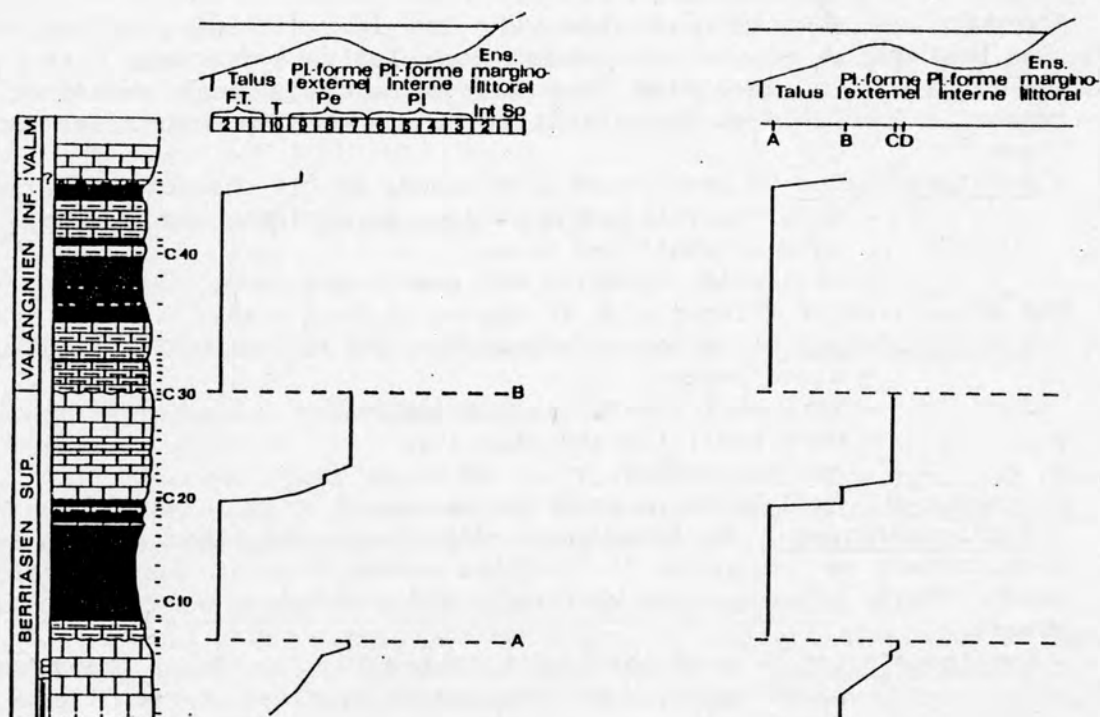


Fig. A14 : Roentgenofacies repartition on the platform (A to 10, the eight classes of roentgenofacies (after DARSAC, 1983))

Fig. A15 : Repartition of minerals on the platform



sometimes dolomite, plagioclase and feldspar for the accessory minerals;
- detritic micas, kaolinite, chlorite, smectites and mixed-layers, for the clay minerals.

We can observe the evolution of each mineral all along our profiles either through absolute intensities, or relative percentages (only for phyllosilicates). In order to draw a parallel between mineralogy and microfacies, we arrange the diffractograms in groups according to their morphological features. Then, for each sample, we seek the corresponding microfacies. We thus obtain the distribution of roentgenofacies (= classes of diffractograms) on a theoretical profile of a carbonate platform (Fig. A14). Knowing the mineralogical association of each roentgenofacies, we are able to determine the mineral distribution on the platform (Fig. A15). Finally, we can also draw the evolution curve of roentgenofacies, in the same way as that of microfacies. Figure A16 shows the similarity between the two curves.

Eight argillaceous facies are found and may be correlated with the microfacies previously described. They appear, from deepest to shallowest, as follows:

- Roentgenofacies A, associated with facies F1, is characterized by:
 - smectites, generally the major part,
 - micas,
 - kaolinite and chlorite, in moderate quantities,
 - thin quartz (highest content).

For this class, smectite and mica are often badly crystallized. The rapport between $< 2 \mu$ and $2-16 \mu$ fractions shows that thin clays and thin quartz are in a larger proportion in this class.

- Roentgenofacies B, associated with facies F2, is characterized by:
 - mixed layers,
 - micas, well crystallized,
 - kaolinite and chlorite in small quantities,
 - quartz, very rare.

The main characteristic is the very low intensities of all minerals. This induces an artefact in regard to relative percentage (fig. A15). The intensity of kaolinite does not reflect its real abundance. The rapport $< 2 \mu / 2-16 \mu$ shows that there are many big particles in this class.

- Roentgenofacies C, associated with facies F3, is characterized by:
 - well crystallized smectite, in variable quantities,
 - well crystallized micas,
 - kaolinite, chlorite and quartz are rare.

The proportion of thinner clay is higher in this class.

- Roentgenofacies C' is characterized by :
 - mixed layers,
 - very well crystallized micas,
 - more kaolinite and chlorite,
 - quartz is rare.

The ratio $< 2 \mu / 2-16 \mu$ is inversed in regard to C.

- Roentgenofacies D is associated with facies F4. This class has the same content as the group C', but the intensities of the minerals are lower. There is only more kaolinite and chlorite ; quartz is almost absent.

- Roentgenofacies E, associated with facies F5, F6, F7, is characterized by:
 - mixed layers but morphologically close to smectites,
 - micas,
 - a lot of kaolinite,
 - chlorite
 - some quartz.

In this class, the quantities of $< 2 \mu$ and $2-16 \mu$ are almost equal.

- Roentgenofacies F, associated with facies F8, is composed by :

- smectites in medium quantities,
- well crystallized micas,
- well-crystallized kaolinite, high content,
- chlorite,
- quartz is rare.

There is a thinner fraction in this class.

- Roentgenofacies G, associated with facies F9-F10, is composed by :

- mixed layers, high content,
- better crystallized micas,
- high content of kaolinite,
- chlorite,
- quartz is common again.

This is the class where kaolinite and mica are the best crystallized. There are more $2-16 \mu$ than $< 2 \mu$ particles in this class. Quartz is absent in the $< 2 \mu$ fraction and at its maximum in the $2-16 \mu$ fraction.

- Roentgenofacies H, associated with facies F11, is characterized by :

- a low percentage of smectite,
- a high percentage of illite,
- a significant percentage of kaolinite,
- the systematic presence of chlorite.

In conclusion, the roentgenofacies-microfacies association brings to light the following facts:

- In the micritic circalittoral facies, the roentgenofacies is dominated by smectite. This smectite is all the more abundant and well-crystallized as it is found in sediments deposited at a greater depth, or yet, at a period when the emerged zones were further from the depositional zone.

- In the inner lagoon infralittoral biomicrite-biosparite facies, smectite gives way to illite and, in particular, to kaolinite-chlorite.

- In the intermediate outer shelf-outer lagoon facies, one notes the mixture of varying proportions of smectite-illite-mixed layers associated at times with a small amount of kaolinite.

F. SEDIMENTARY AND BIOLOGICAL EVENTS

1. SUBMERSION EPISODES ON THE PLATFORMS (A. ARNAUD-VANNEAU)

1.1. Sedimentological recording (Fig. A17)

Three stages, named T1 to T3, have been distinguished for each submersion episode characterized by sedimentary, mineralogical and environmental modifications (ARNAUD-VANNEAU et al., 1986).

1.1.1 Stage T1: Opening of the depositional environments

This first stage, corresponding to a slight deepening of the depositional environment, is not accompanied by a radical modification of sedimentation on the platform. The latter remains purely or essentially carbonated. The only noticeable modification relates to the reduction in or disappearance of the most confined facies in favour of facies containing a much richer and diversified fauna consisting of species requiring normal salinity and oxygen content.

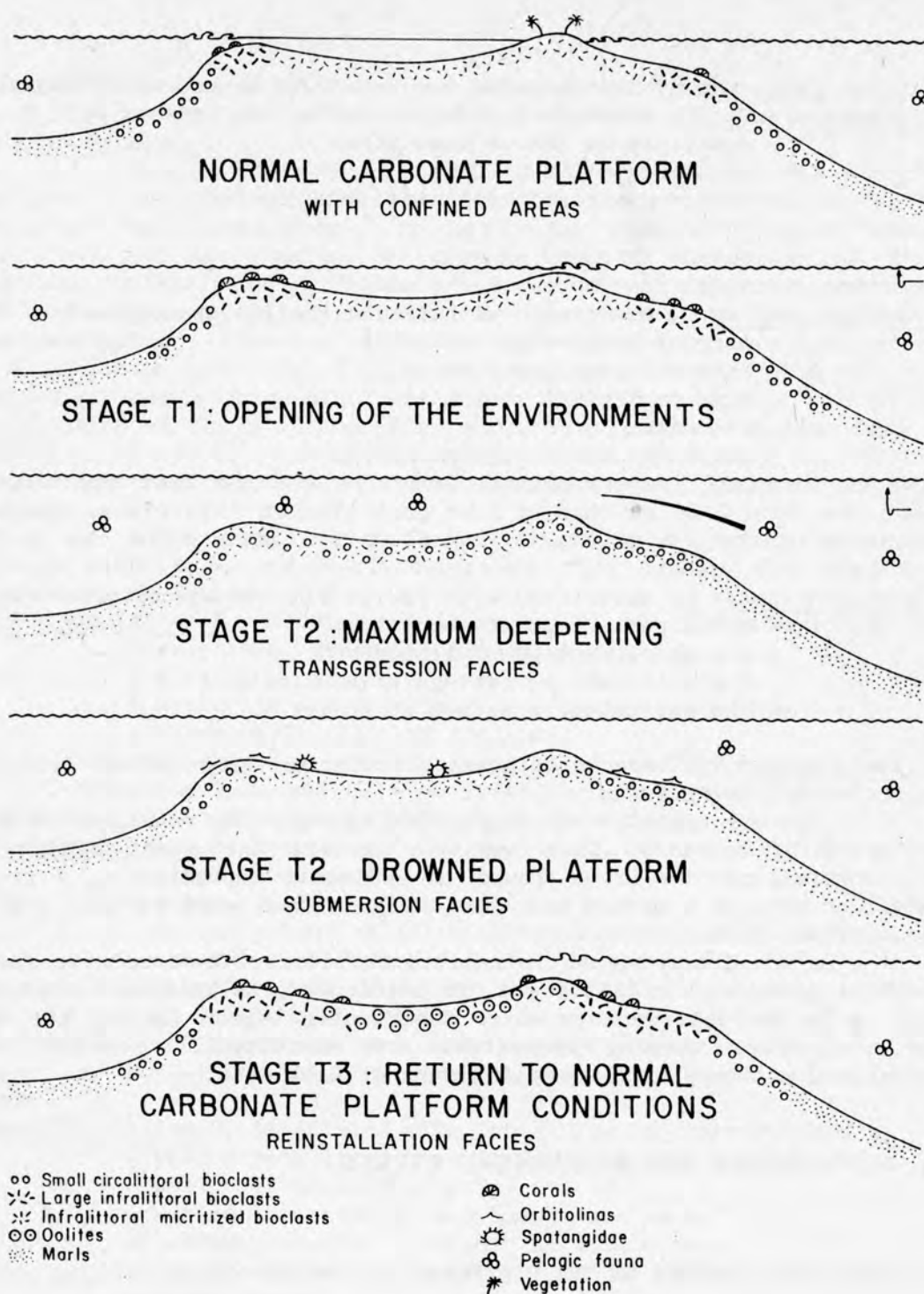


Fig. A17 : The submersion episodes on the platforms. Above, the standard (normal) platform, below the three stages of the submersion.

1.1.2 Stage T2: Maximum deepening of the depositional environments, period of platform submersion

The sedimentational environments are radically modified during this stage by major arrivals of detritic material (clays, quartz,...). Very often, the beginning of this stage corresponds to a sedimentary hiatus (discontinuity) sometimes highlighted by hardgrounds. Two episodes are often distinguished in this stage:

a) **The first**, at the base, corresponds to the maximum deepening period and is represented by very mixed sediments, reworked and oxydized ("transgression facies"). The latter also contain a very mixed fauna and

flora in which one finds supratidal organisms (Characae) joined by infralittoral foraminifera and, occasionally, by some pelagic organisms (Calpionellids, ammonites) who were finally able to enter the carbonate platform thanks to the generalized deepening of the environments.

b) **The second**, better represented in some cases than in others, corresponds to argillaceous carbonate sediments deposited below a still-substantial depth and in environments which are highly perturbed by the abundance of detritic material ("**submersion facies**"). They contain an abundant fauna and flora.

In the Jura and septentrional subalpine massifs, three types of submersion facies have been observed.

a) **Argillaceous limestones and marls with circalittoral muddy fauna.** In this facies, rich in quartz and glauconite (several "glauconite levels"), smectite largely dominates among the still relatively abundant clays. The fauna, often very rich, is made up of cephalopods (locally concentrated in horizons), irregular echinids (*Toxaster*,...), oysters (*Aetostreon*,...) and foraminifera represented either by hyalin test forms (*Nodosariidae*, especially *Lenticulina*) or by small-sized agglutinated species (*Dorothia*, *Gaudryina*, *Textularia*,...). In general, this type of deposit shows evidence of calm environments, probably devoid of major currents. One finds them on the submerged platforms as well as on continental shelves (for example, in the Parisian Basin).

b) **Bioclastic limestones with Bryozoans and Crinoids** ("Calcaires Roux" of the Upper Valanginian, "Lumachelle" of the Upper Aptian). These "calcaires roux", especially rich in iron oxydes, are characterized by very beautiful cross-bedded banks and by bioclasts showing evidence of little-diversified populations, very poor in microfauna and largely dominated by fixed forms (mainly bryozoans and crinoids). Very difficult to date for this reason, they correspond to sands deposited in circalittoral environments crossed over by steady currents which provided the steady feeding necessary for crinoid life. Their debris are spread over very vast areas. The appearance of this type of facies points to the disappearance over a more or less lengthy time period, sometimes definitive, of standard platform carbonated sedimentation.

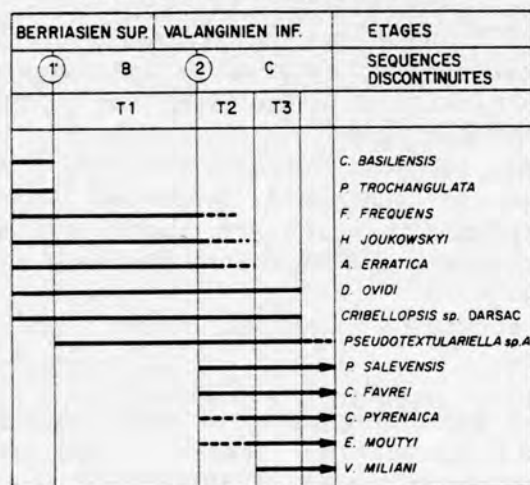
c) **The "béton phosphaté"** is typical of the Albian transgression in the septentrional subalpine massifs. It consists of condensed polyzonal deposits which are decimeter-thick and rich in ammonites, glauconite, phosphated debris and reworked elements. This facies correspond regionally to the ultimate stage in sedimentation on the ancient subalpine and jurassian platforms, deeply submerged, subject to ocean currents and dominated by very substantial detritic deposits.

1.1.3 Stage T3: Sedimentary filling-up and the return of carbonate platform facies

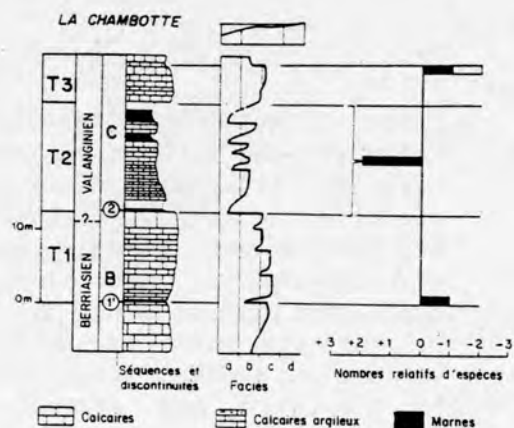
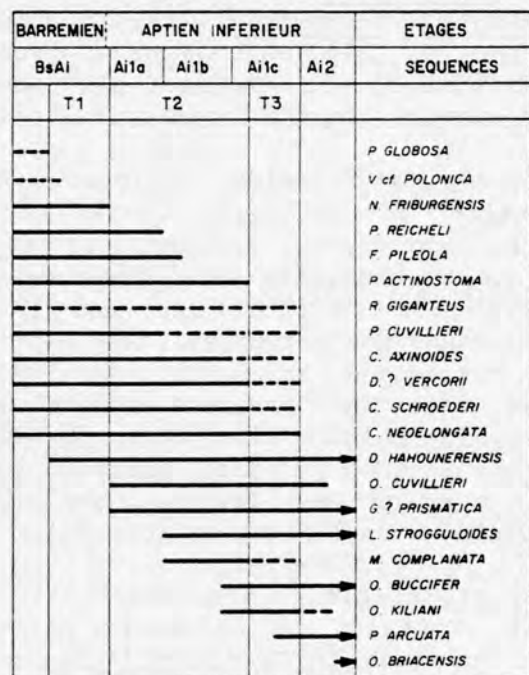
This period is marked by a progressive reduction in depth due to the sedimentary filling-up and, possibly, to a lowering of sea level (regression). Over very large areas, reinstallation facies appear, similar to certain outer shelf facies (for example, oolitic limestones or coarse bioclastic limestones), which vertically precede the facies typical of the inner platform domain. Morphologically, these facies, notably the oolitic facies, are never indicative of the margin or outer slope of the platform, but rather of a progressive filling-up on a submerged platform.

In cases where the Stage T2 deepening is minor, submersion and reinstallation facies are often absent. However, in the case of a

Species which appeared and disappeared during the deepening event of the platform at the Berriasian-Valanginian limit (southern Jura)

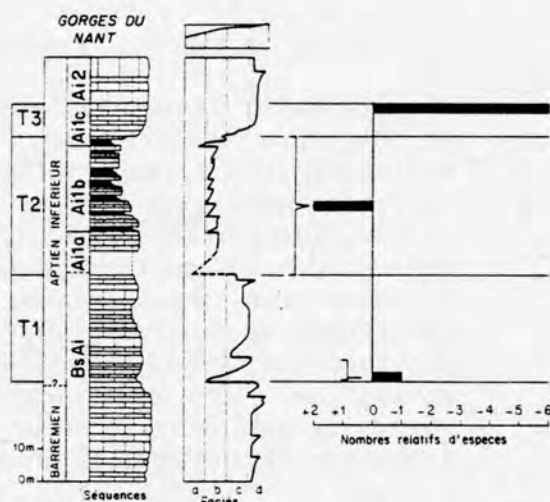


Species which appeared and disappeared during the deepening event of the platform at the Barremian-Aptian limit (northern Vercors)



Evolution curve of facies and relative numbers of appearing and disappearing species during the deepening event which occurred around the Berriasian-Valanginian limit. Type section: Chambotte (southern Jura). T1, T2, T3: the three stages of the deepening event. To the right, the black lines correspond to relative numbers of appearing and disappearing species, i.e., differences between appearing species (+) and disappearing species (-).

At the end of T3, the white line means that we do not know whether *Cribellopsis* sp. DARSAC really disappears.



Evolution curve of facies and relative numbers of appearing and disappearing species during the deepening event which occurred around the Barremian-Aptian limit. Type section: Gorges du Nant (northern Vercors)

Fig. A 18 : The renewal of the microfauna during the submersion episodes on the Lower Cretaceous platforms (A. ARNAUD-VANNEAU, 1986)

major or sustained deepening of Stage T2 (as in the case of the lower Aptian transgression), only submersion facies are represented. In any case, the submerged platforms no longer display as clear a lateral facies staging as standard platforms. Furthermore, inner shelf-type facies have generally disappeared or else are far less widespread.

1.2. Mineralogical recording

The submersion episodes are highlighted by sometimes major mineralogical modifications.

Clays: In general, roentgenofacies variations are comparable to those of microfacies. Clays are more abundant during Stage T2, and smectites are again observed, whereas they were practically absent from the deposits

on standard platforms.

Quartz often reappears, sometimes in substantial proportions, during Stage T2, and then disappears progressively during Stage T3.

Iron oxydes are highly abundant during Stage T2 and contribute to the individualisation of hard-grounds (most of the time, they highlight major discontinuities at the base of Stage T2). They are still present in the sediments deposited during Stage T3.

Bore content increases considerably as of the base of Stage T2 (where it becomes 2 to 3 times higher than the usual content in underlying platform facies). This increase, independent of the nature of the facies, is unrelated to any modification in salinity. No hypersalinity may be invoked since not only is the benthonic microfauna normal and diversified (at times, even more diversified than in the underlying beds), but this increase in bore content furthermore coincides with the period of maximum deepening and the arrival of pelagic fauna on the submerged platform.

1.3. Population recording (Fig. A18)

During submersion periods, populations are deeply modified due to the considerable modifications undergone by the marine environments. However, these periods are also accompanied by a very substantial specific renewal since identical submersion period facies display associations which are often very different. This renewal of the fauna corresponds to a complex process, several cases of which may be distinguished.

a) generally speaking:

- At the base of Stage T1, the species which disappear are slightly more numerous than those which appear.
- During the course of Stage T2, this tendency is clearly reversed: the species which appear are more numerous than those which disappear.
- Finally, at the end of Stage T3, there is another reversal: the species which disappear are much more numerous than those which appear.

b) certain species ("opportunistic" species) took advantage of the platform submersion to leave their native environments, sometimes situated on the outer shelf, to colonize new territories in the interior of the ex-inner domain. This is the case for Palorbitolina and Choffatella which are ubiquitous species found in both a relatively deep circalittoral argillocarbonate environment and in infralittoral environments which are sometimes even extremely shallow (REY, 1973). They are usually present in small numbers on the outer slope of the platform or in certain coastal mudflats (as in the case of Portugal). During submersion episodes, they took advantage of the temporary abundance of detritic matter to set themselves up in places where they were unknown and they colonized, rapidly and opportunely, the inner domain of carbonate platforms from which they had been excluded. They even managed to rapidly multiply at the expense of autochthonous microfauna. This pullulation is at the origin of what is referred to in many regions as Orbitolina and/or Choffatella layers.

c) Some migrant species make an appearance during the submersion periods thanks to the new communication channels which opened up at that time. However, unlike the ubiquitous forms, the migrant organisms remained in small numbers and never multiplied rapidly.

This is the case of the Rectodictyoconus giganteus which appears in each of the three submersion episodes situated between the Upper Barremian

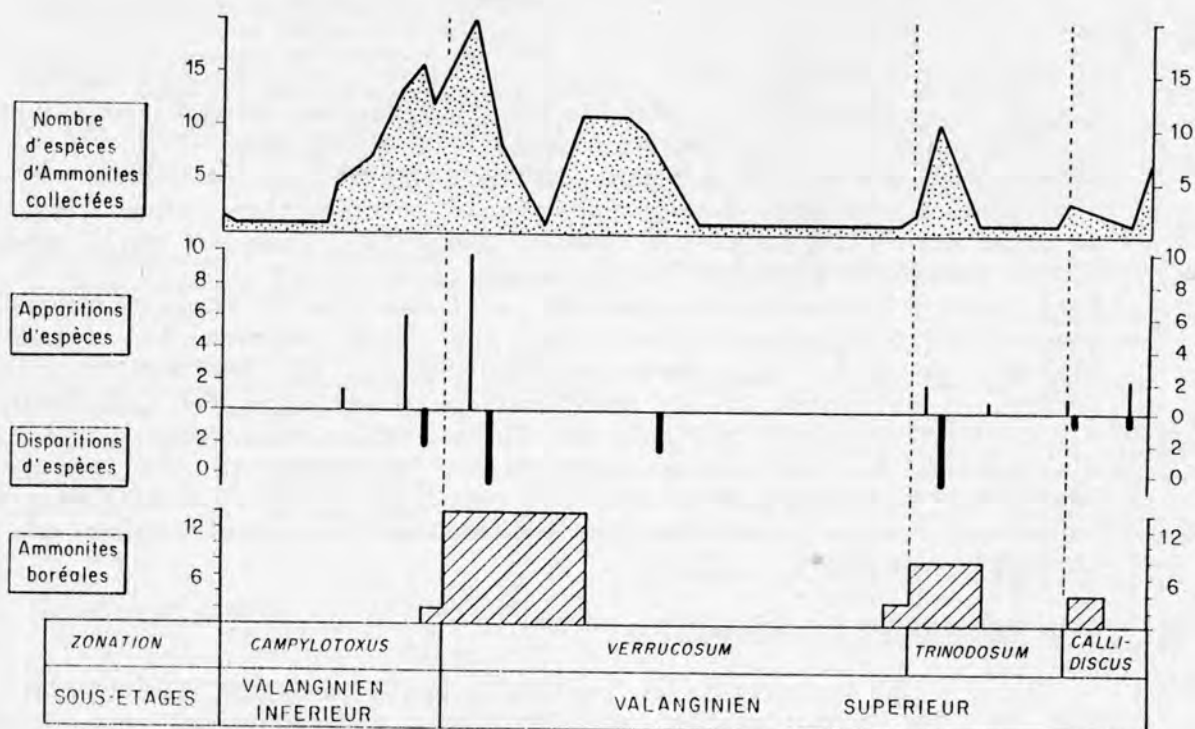


Fig. A 19 : Distribution of the ammonites in the Angles section (BOISSEAU *et al.*, 1982)

and the Lower Aptian: it disappears however each time the carbonate platform is no longer submerged.

These migrant species nevertheless present a problem in cases when their presence was not previously recognized and when they manage to set themselves up in a lasting manner in a new sector. In this case, a localized appearance may be confused with a true stratigraphic appearance.

2. SEDIMENTARY AND BIOLOGICAL CRISES IN THE BASIN SERIES (H. ARNAUD)

In the Vocontian basin, the pelagic Radiolaria and Cephalopod facies (facies F0) of the Lower Cretaceous are arranged in regular alternations of decimeter- and meter-sized banks of argillaceous limestones and marls. In spite of an apparently very monotonous sedimentation, two features may be underlined: (1) the fauna is not uniformly distributed in all of the banks, (2) the regularity of marl-limestone alternations is not perfect since the proportion of limestone beds compared to marly beds varies constantly.

2.1. Periods of ammonite renewal (Fig. A 19)

Ammonites are not evenly distributed in the series even though all or nearly all of the beds do contain them: certain beds contain very few and they are those belonging to species of little significance; other beds are however very rich in individual ammonites as well as in species. These concentrations in certain specific levels correspond to **renewal periods**, the so-called **biological events**, thanks to which most of the zones of the Angles hypostratotype section have been marked out. When examined in detail, these periods of ammonite fauna renewal display the same features as the periods of benthic foraminifera renewal on recent platforms. Two succeeding phases may be distinguished: the first is characterized by the massive appearance of new species, the second by the disappearance of numerous species,

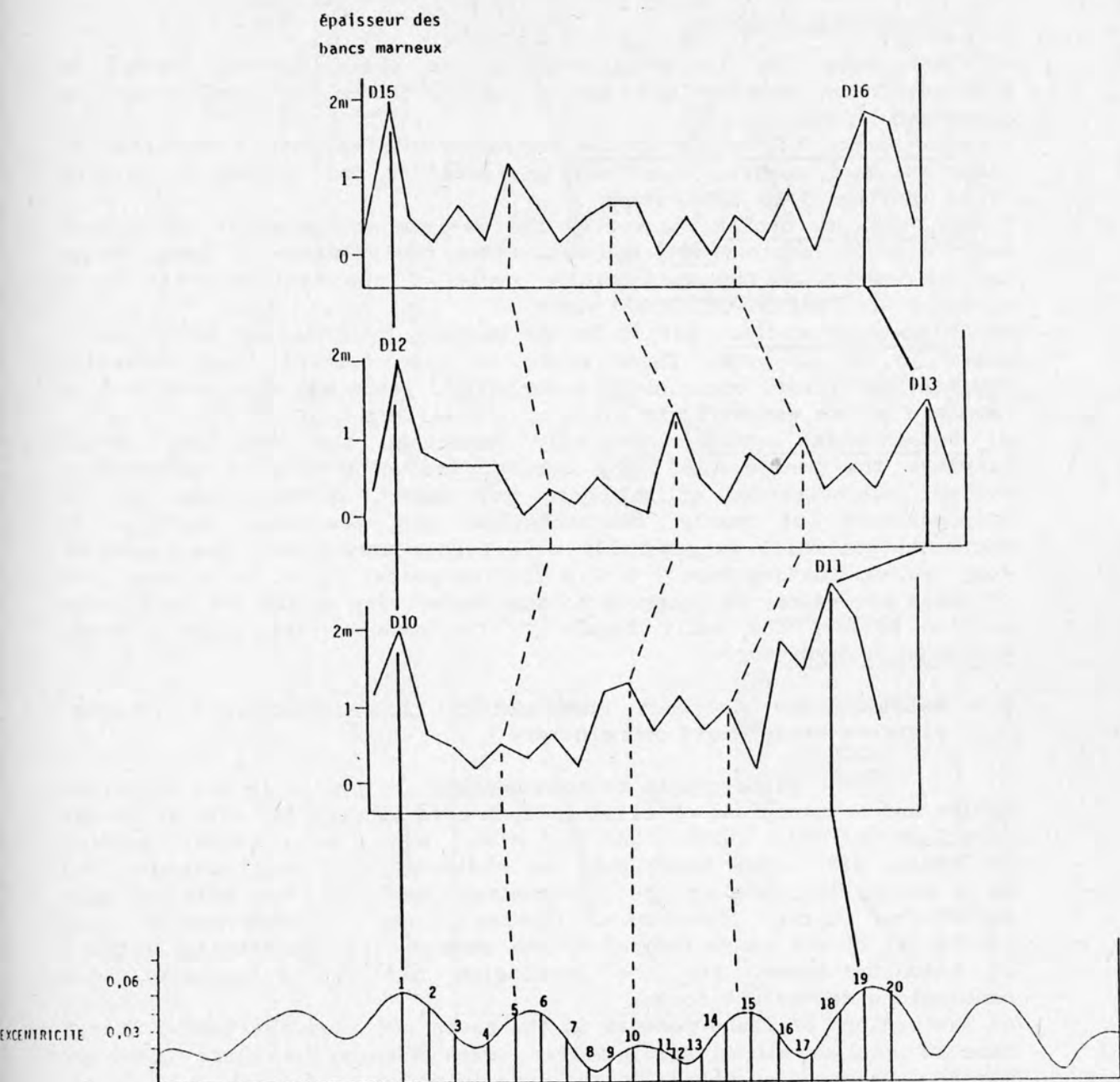


Fig. A 20 : Comparison between the thickness curves of the marly banks during three intervals of the Angles section (above) and the MILANKOVITCH's precession (1 to 20) and excentricity cycles (below). D10, bank 311, verrucosum zone ; D11, bank 323, verrucosum zone ; D12, bank 338, verrucosum zone ; D13, bank 348, verrucosum zone ; D15, bank 362, trinodosum zone ; D16, bank 373, trinodosum zone. The valanginian crises are in coincidence with the 400,000 year harmonics of the excentricity cycle (BOISSEAU, 1987).

notably among those which had previously appeared. It is during some of these renewal periods that boreal migrants appear in the Vocontian basin (BOISSEAU et al., 1982).

2.2. The cyclical nature of marl-limestone alternations (Fig. A20)

In the Valanginian of the Angles section, variations in the relative proportion of limestone and marls in each alternation or couple

of beds point to sedimentational cycles which may be linked to Milankovitch's astronomical cycles. Four orders of cycles may be discerned.

a) First-order elementary cycles corresponding to each alternation or limestone-marl couple, which may be linked to the equinox precession cycle lasting 19 to 23000 years.

b) Second-order cycles, marked by the maximum thickness of marly beds every 4 or 5 limestone-marl couples. Often poorly visible, these cycles may correspond to the excentricity cycle of the Earth's orbit which occurs over a period of 100000 years.

c) Third-order cycles, marked by the maximum thickness of marly levels every 16 to 22 beds. These peaks in clay content, the so-called **sedimentary crisis**, occur about every 400000 years and may correspond to harmonic of the excentricity cycle of the Earth's orbit.

d) Fourth-order cycles. Generally speaking, the Vocontian series displays the presence of long cycles, including 5 to 7 third-order cycles, characterized at the base and summit of the cycle by the preponderance of marly sedimentation and, in the middle, by sedimentation which is generally more highly carbonated. The cause of long cycles, lasting from 2 to 2,8 million years, is still unknown. One of these cycles may be observed in the Hauterivian of the Col de Rousset section between the marly levels at the base of the stage and the Subsajnella sayni marls.

2.3. Relationships between Sedimentary and Biological crises. Platform-basin event correlations

The relationship between sedimentary cycles in the Vocontian series and astronomical or climatic cycles is already familiar knowledge (COTILLON & RIO, 1984). On the other hand, more recent studies (BOISSEAU, 1987) have shown that the sedimentary crises, characterized by a strong increase in the thickness of marls at the base of each 400000-year cycle (third-order cycles), are contemporaneous with biological crises characterized by the more or less substantial renewal of Ammonite fauna. For the Berriasian and the Valanginian, two conclusions may be put forth.

a) The periods of fauna renewal in the basin are always situated at the base of well-developed marly levels, even though the phase when new species appear often begins in the underlying bed.

b) The large sedimentary discontinuities on the Berriasian-Valanginian platform, in particular the Di1 discontinuity of the picteti zone and the Di2 of the pertransiens zone, are characterized by a substantial renewal of benthic foraminifera populations and by the deposit of terrigenous detritic matter. These large discontinuities are contemporaneous with biological and sedimentary crises B10 and B15 which are apparent in the basin series. Two fundamental facts may thus be established concerning platform-basin correlations: (1) specific renewals of benthic populations on the platforms are contemporaneous with renewal periods of ammonites, (2) the deposit of terrigenous detritic matter on the platform is as significant as the marly deposits preponderant at the base of third-order cycles in the basin.

3. MAJOR DEEPENING PERIODS (=Transgressions) (A. and H. ARNAUD)

In the South-East of France, two major environment deepening periods are recognized, the first at the Hauterivian and the second at the Aptian-Albian. In the Parisian Basin, they correspond to marine transgressions on the continental shield. These two transgressions are

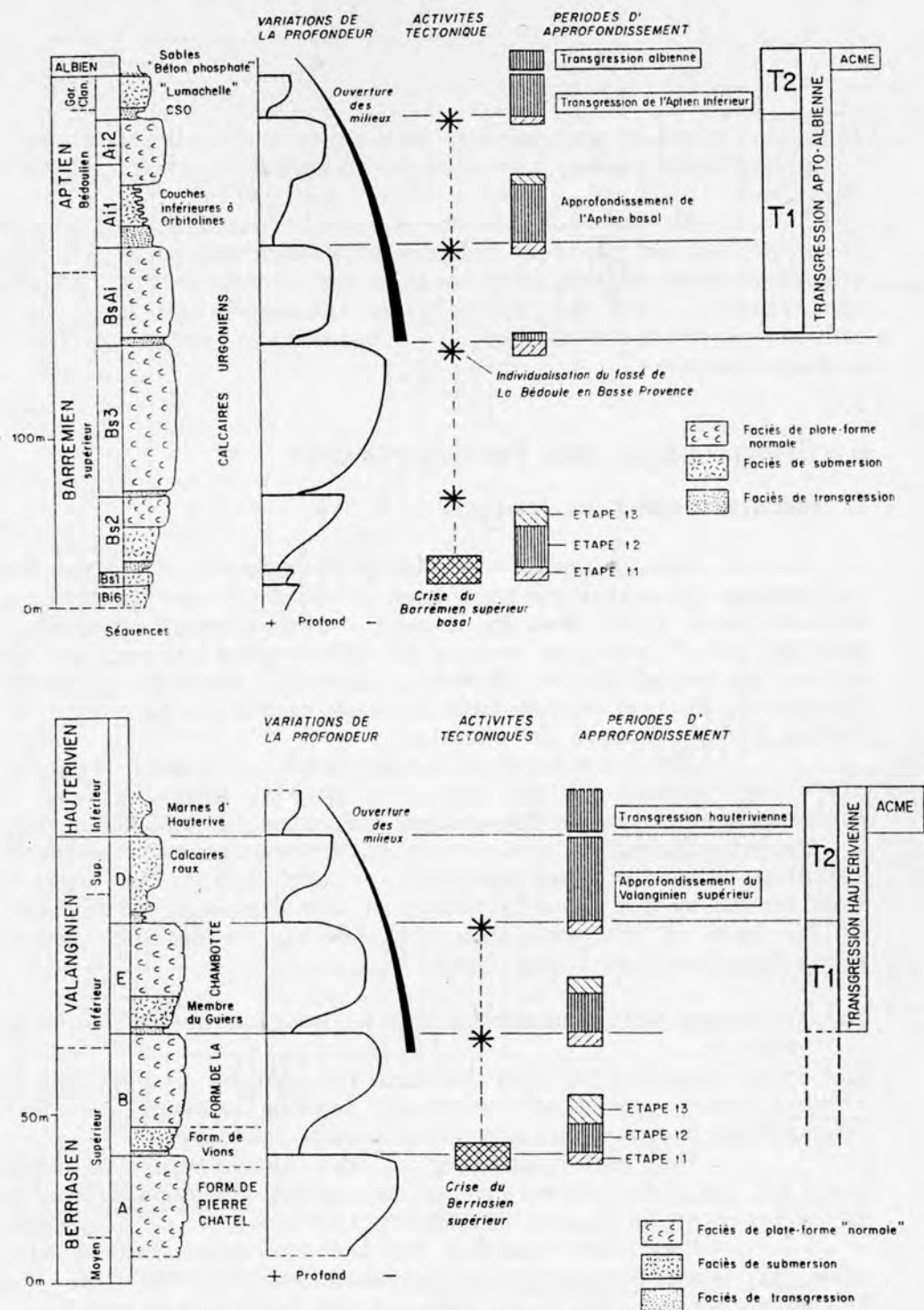


Fig. A 21 : The main features of the major deepening periods. Above, the Chambotte section ; below, the Northern Vercors section (A. ARNAUD-VANNEAU *et al.*, 1987)

responsible for the complete disappearance of carbonate platform sedimentation from the entire sector: this disappearance is momentary at the Lower Hauterivian and definitive at the Albian. Each transgression is followed by the deposit of a non-negligible quantity of terrigenous detritic minerals (Hauterivian marls, Orbitolina layers, Albian sands).

In each of these two cases, the transgressive phenomenon is not unique and catastrophic but corresponds rather to the sum of several succeeding phases of submersion which separate shallowing-upward sequences (fig. A 21). The maximum deepening, or "acmé" of the transgression, thus corresponds to the ultimate phase of a multi-phased process which determines the individualization of transgressive megasequences (positive) as shown by the Chambotte Berrasian-Valanginian

section. It would also appear that these transgressions are not only due to an eustatic cause, but also to hyperactivity all along the oceanic dorsals.

In the Jura and the subalpine massifs, the beginning of the jerky process of platform submersion always begins by a tectonic crisis: the Berriasian crisis, responsible for a substantial paleogeographical modification, for the Hauterivian transgression; the Upper Barremian crisis, with acceleration of subsidence, preceding the Apto-Albian transgression.

G. STRATIGRAPHY AND PALEOGEOGRAPHY

1. AMMONITES ZONES (H. ARNAUD)

All stages of the Early Cretaceous, from the Berriasian to the Aptian inclusively, have been created in the South-East of France and the Swiss Jura, that is to say in the same paleogeographical region. However, the historical choice of stratotypes in regions characterized either by basin facies (Berrias, Barrême, Apt) or by platform facies (Valangin, Hauterive) has made it very difficult to establish continuous zoning for the stages as a whole.

The zone definitions presently proposed (Fig. A 22) are of differing value and do not all comply with the two fundamental recommendations of the Copenhagen symposium (BIRKELUND *et al*, 1984):

- 1) The stratigraphic scale contiguity requirement can best be met by defining only the lower boundary of each unit. The upper boundary is then formed by the lower boundary of the next succeeding unit.
- 2) The base of the zone should preferably be defined according to the first appearance of a new taxon.

The following unit boundaries may be adopted according to BIRKELUND *et al* (1984).

The lower boundary of the Valanginian can be set at the base of the otopeta zone. The final decision depends however on the outcome of discussions over the Jurassic-Cretaceous boundary.

The lower boundary of the Hauterivian is defined on the basis of the first appearance of the genus Acanthodiscus. This boundary is well-set at La Charce (THIEULOUY, 1977).

The lower boundary of the Barremian can be set 1) at the base of the Pseudothurmannia beds or 2) at the top of the Pseudothurmannia beds (i.e. base of the Holcodiscus beds).

Two lower boundaries of the Barremian at Angles have been successively proposed, the first by IMMEL (1978) at the base of the Pseudothurmannia beds (bed 42), the second by BUSNARDO & VERMEULEN (1986) at the top of the Pseudothurmannia beds (bed 65). This last boundary is debatable for at least two reasons:

- 1) the angulicostata zone of the Upper Hauterivian is defined at the base by the appearance of this taxon and at the top, by its disappearance.
- 2) the hugii zone of the Lower Barremian is defined at its base, not by the appearance of the index species (which appears only 4 m. above the lower boundary of the hugii zone *sensu* BUSNARDO), but rather by the disappearance of P.angulicostata, the index species of the underlying zone.

The lower boundary of the Aptian should continue to be set according to the first appearance of Prodeshayesites.

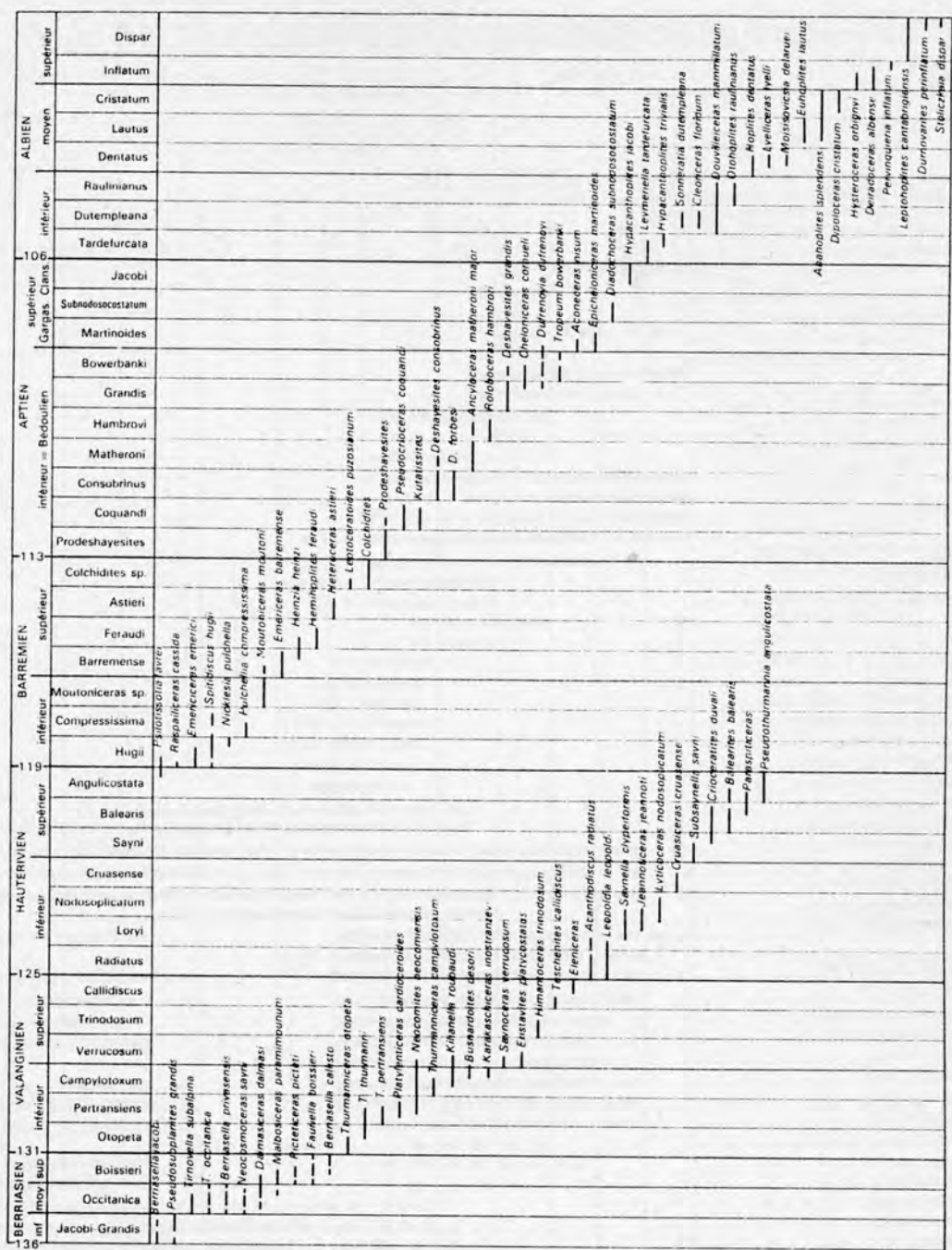


Fig. A 22 : Zonation and distribution of the ammonites (BUSNARDO, 1984)

Zone boundaries and zones themselves are not, on the whole, any better known than stage boundaries.

For the Berriasian, the zoning used is that of LE HEGARAT (1971) defined in several sections and notably in the Berrias stratotype. Zones and sub-zones are defined by species associations; their lower boundaries are not, however, based upon the appearance of index taxa.

For the Valanginian, the zoning used is that of BUSNARDO, THIEULOY & MOULLADE (1979), precisely defined in the Barret-le-Bas section and the Angles hypostratotype. Each of these zones is defined at its base by the appearance of the index species (zoning in accordance with the recommendations of the Copenhagen symposium, 1984).

For the Hauterivian and the Barremian, traditionally-used biozones in the South-east of France have never been as clearly defined as those of the Berriasian and the Valanginian. For the Hauterivian, the first zoning proposed since the Colloque sur le Crétacé inférieur (1963)

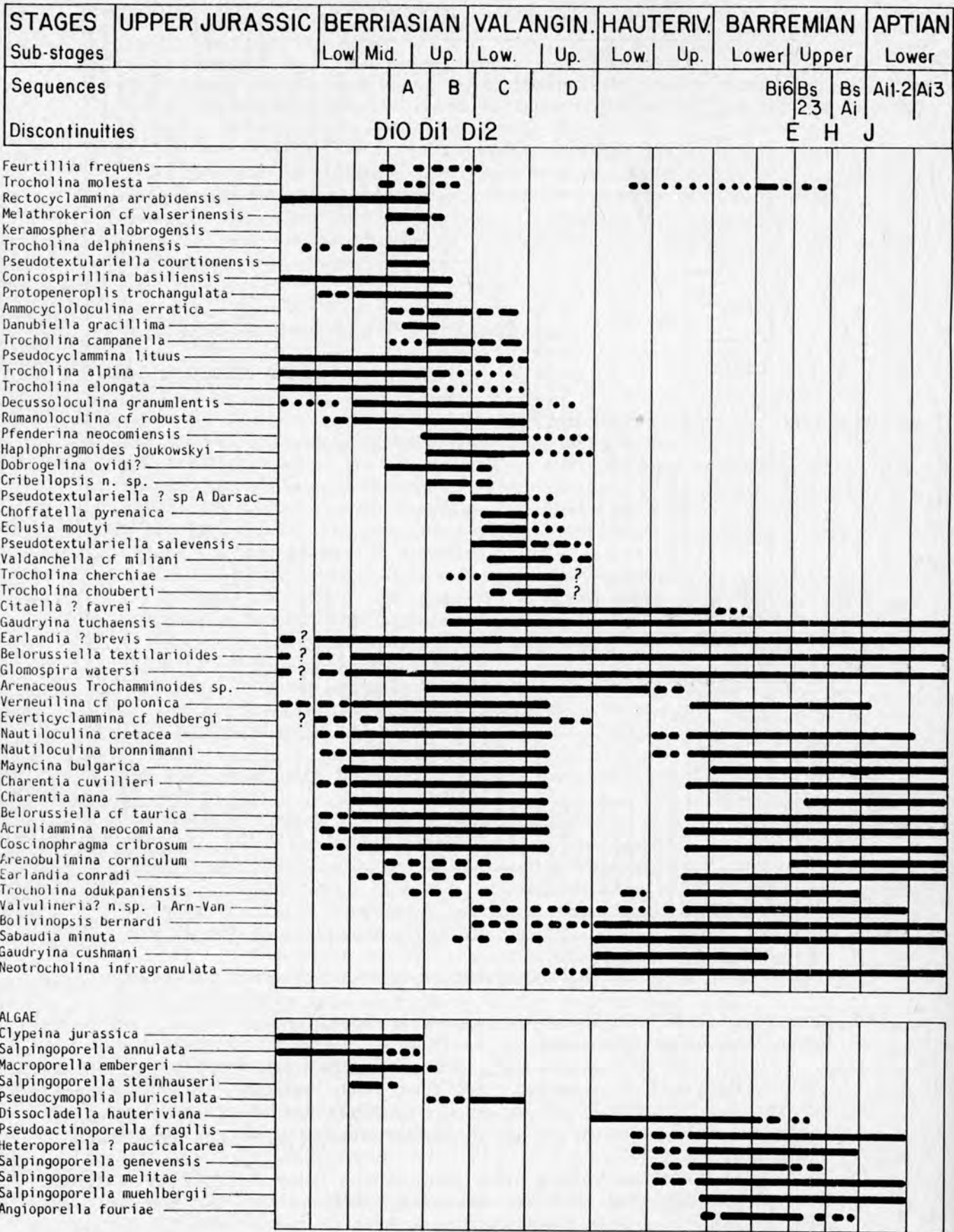


Fig. A 23 : Distribution of the major species of benthic foraminifera

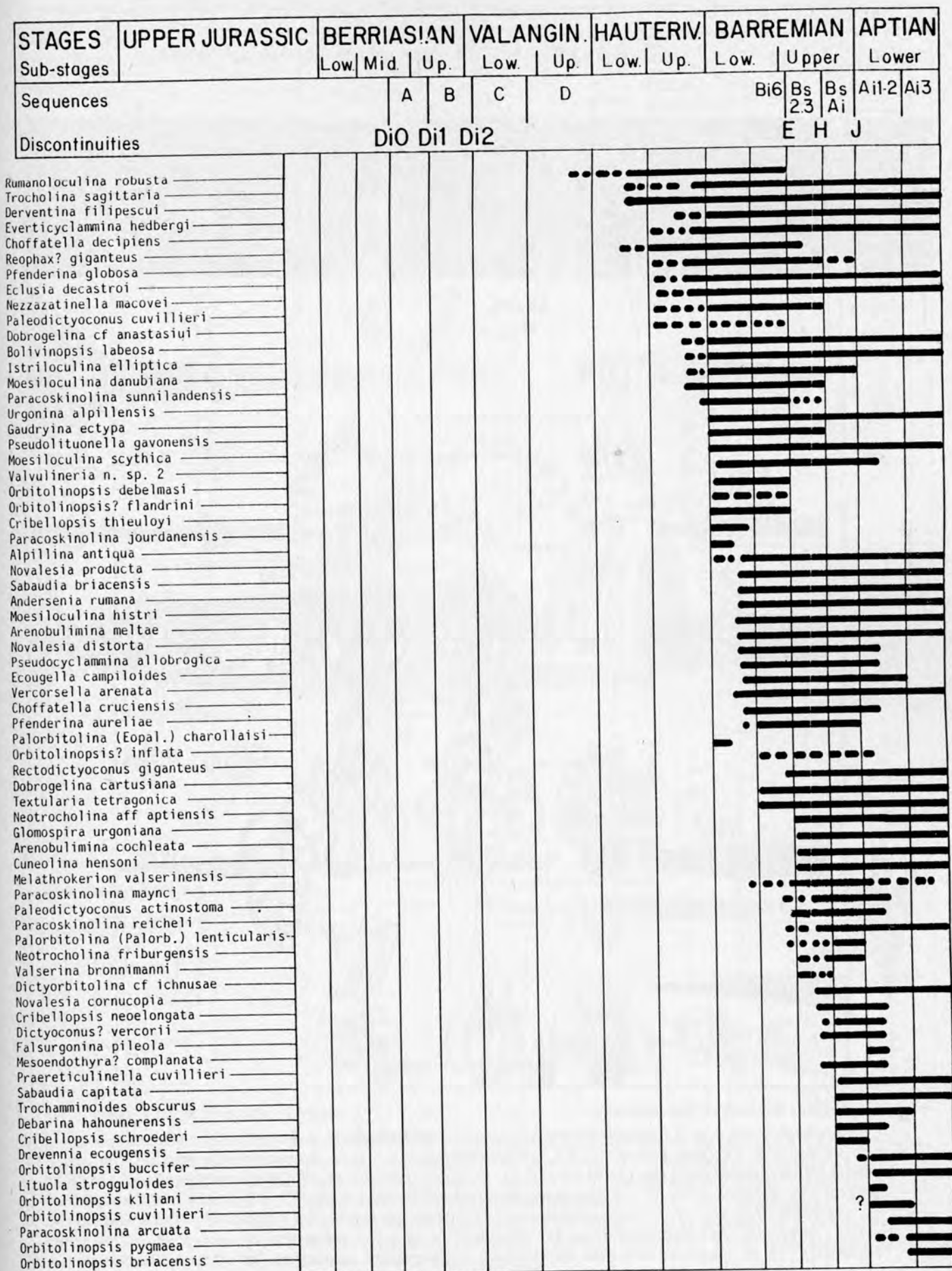
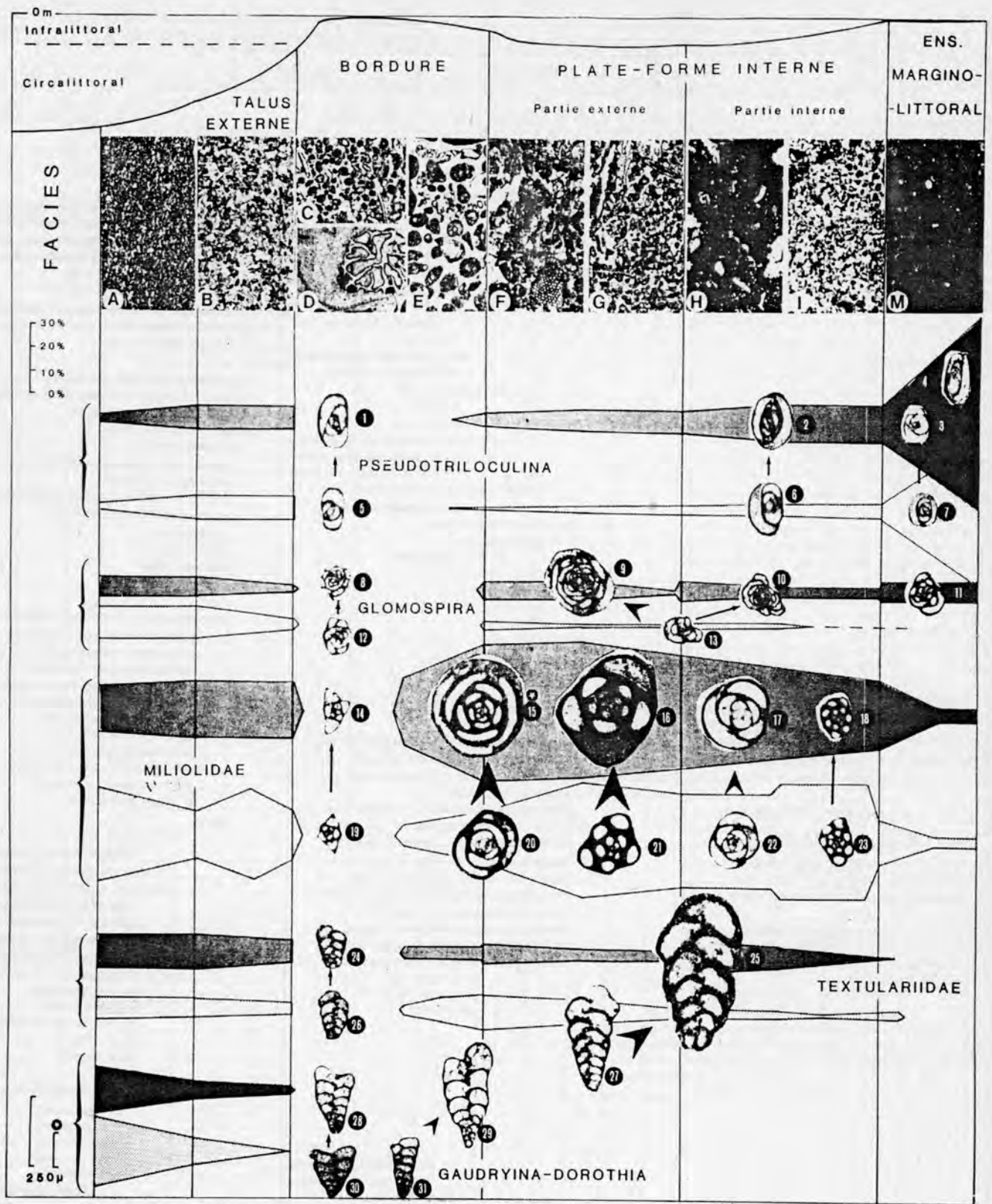


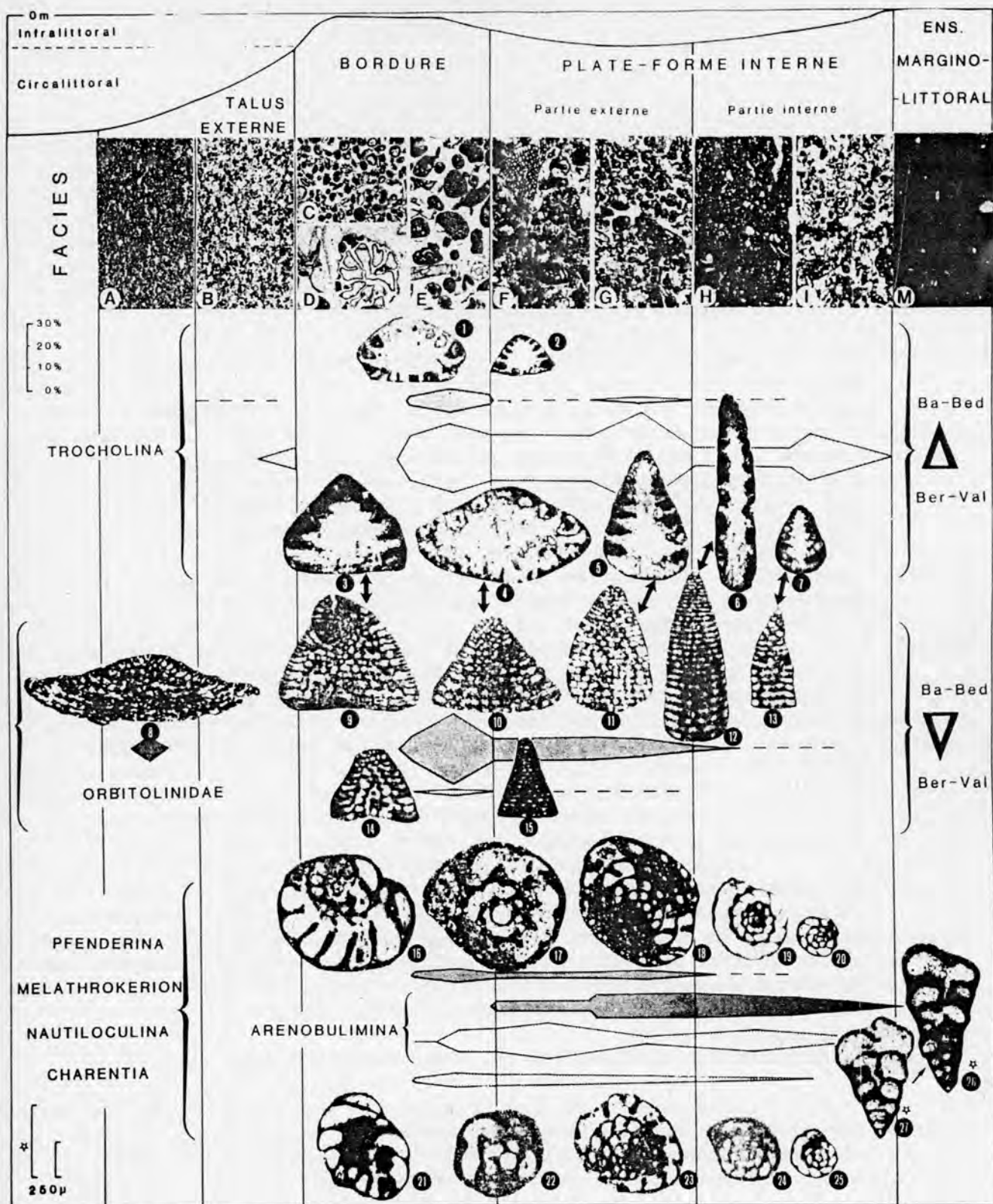
Fig. A 24 : Distribution of the major species of benthic foraminifera



. Légende des espèces. List of species.

1. *Pseudotriloculina* n. sp. 2 ARNAUD-VANNEAU ; 2. *Pseudotriloculina* n. sp. 1 ARNAUD-VANNEAU ; 3-4, *Pseudotriloculina* n. sp. ARNAUD-VANNEAU ; 5 à 7, *Pseudotriloculina* sp. ; 8, 12, *Glomospira glomerosa* EICHER ; 9, *Glomospira urgoniana*, ARNAUD-VANNEAU ; 10, 11, 13, *Glomospira* sp. ; 14, 19, *Quinqueloculina* aff. *danubiana* NEAGU ; 15, *Nummuloculina* sp. ; 16, *Quinqueloculina robusta* NEAGU ; 17, 22 *Triloculina* sp. ; 18, 23, *Sigmoillina* sp. ; 20, *Nummuloculina* ? ; 21, *Quinqueloculina* sp. ; 24, *Bolivinosia rhopaloides* ARNAUD-VANNEAU ; 15, *Textularia tetragonica* ARNAUD-VANNEAU ; 26, *Textularia* ? sp. ; 27, *Textularia* cf. *tetragonica* ARNAUD-VANNEAU ; 28, 30, *Gaudryina tuchaensis* ANTONOVA ; 29, *Dorothia* cf. *praeoxycona* MOULLADE ; 31, *Dorothia* cf. *hauteriviana* MOULLADE.

Fig. A 25 : Distribution of larger benthic foraminifera in the main biotopes of the Berriasian-Valanginian (light grey) and Barremian-Bedoulian (dark grey) shelves (ARNAUD-VANNEAU & DARSAC (1984). List of facies : see p. 44.



. Légende des espèces. List of species.

1, 2, *Trocholina* sp. ; 3, 4, *Trocholina* cf. *alpina* (LEUPOLD & BIGLER) ; 5, *Trocholina* sp. A3 DARSAC ; 6, *Trocholina elongata* (LEUPOLD & BIGLER) ; 7, *Trocholina* sp. 1 DARSAC ; 8, *Palorbitolina* sp. ; 9, *Paleodictyoconus cuvillieri* (FOURY) ; 10, *Alpillina antiqua* FOURY ; 11, *Paracoskinolina sunnilandensis* (MAYNC) ; 12, *Paracoskinolina maynci* (CHEVALIER) ; 13, *Paracoskinolina* cf. *hispanica* (PEYBERNÈS) ; 14, *Valdanchella* cf. *miliani* (SCHROEDER) ; 15, *Cribellopsis* sp. ; 16, *Pfenderina globosa* FOURY ; 17, *Melathrokerion valserinensis* BRÖNNIMANN & CONRAD ; 18, 23, *Nautiloculina cretacea* PEYBERNÈS ; 19, 24, *Charentia cuvillieri* NEUMANN ; 20-25, *Charentia nana* ARNAUD-VANNEAU ; 26-27, *Arenobulimina corniculum* ARNAUD-VANNEAU ; 21, *Pfenderina neocomiensis* (PFENDER).

Fig. A 26 : Distribution of large benthic foraminifera in the main biotopes of the Berriasian-Valanginian (light grey) and Barremian-Bedoulian (dark grey) shelves (ARNAUD-VANNEAU & DARSAC, 1984). List of facies : see p. 44.

Fig. A 25 et A 26 : list of facies. **Basin** : A, biomicrite with sponge spicules. **Outer shelf (slope and shelf edge)** : B, biosparite with small foraminifera ; C, oosparite ; D, Coral reefs ; E, biosparite with large rounded debris. **Inner shelf** : F, muddy facies ; G, biomicrite to biosparite with large foraminifera and Rudists ; H, muddy facies ; I, biomicrite to biosparite with small Rudists and oncolites. **Marginolittoral domain** : M, micrite with Pseudotriloculina.

was published by MOULLADE & THIEULOY (1967): the stage was then subdivided into 7 zones and 2 undifferentiated intervals. Two successive modifications were made to this plan. The first (BUSNARDO & THIEULOY, 1976) consisted of the disappearance of the two undifferentiated intervals and the distinction of a Cruasicerias cruasense horizon at the top of the nodosoplicatum zone (upper part of the Lower Hauterivian). The second set of modifications (BUSNARDO, 1984) was the most substantial, although the reasons for these modifications are unknown (Fig. A22): the disappearance of the jeannoti zone at the Lower Hauterivian, the creation of the cruasense zone at the top of the Lower Hauterivian, the replacement of the ligatus zone by a new balearis zone at the Upper Hauterivian.

For the Barremian, a very incomplete initial zonation of the Angles stratotype section was published by BUSNARDO (1965). It has just been replaced recently (BUSNARDO, 1984) by a new zonation based on the same section. It is just as imprecise as the previous one since the exact distribution of Cephalopods is still unknown. Only the base of the hugii zone, base of the Barremian stage, has been clearly defined (BUSNARDO & VERMEULEN, 1986), even though it still presents a problem since, as it was mentioned earlier, the index species only appears 4 m. above the base of the zone.

To summarize, the distribution of ammonites in the Berriasian-Valanginian is well-known in the South-east of France. On the other hand, Ammonite distribution in a part of the Hauterivian and especially in the Barremian has only been published in a very partial manner. At the present state of knowledge, the proposed zonation cannot be viewed as indisputable stratigraphic tools, but only as a framework subject to fairly large modifications (Fig. A22).

2. FORAMINIFERA DISTRIBUTION (A. ARNAUD-VANNEAU)

Because of their abundance and the diversity of the facies in which they are found, foraminifera are of particular interest not only from a stratigraphic point of view, but also in terms of the characterization of depositional environments.

The stratigraphic distribution of foraminifers is the result of complete inventories of microfauna and their localization in relation to the major discontinuity horizons dated by pelagic organisms (Calpionellids for the Berriasian-Early-Valanginian, ammonites for all levels). For the Berriasian-Hauterivian, scales have been established in the Jura and completed in the Chartreuse subalpine massif. For the Barremian and the Lower Aptian, they have been established in the Vercors where, particularly in the South, several Cephalopod intercalations exist at the Lower Barremian, the Upper Barremian (Matheronites limentinus level, Colchidites level) and the Bedoulian (Couches inférieures à Orbitolines, couche supérieure à Orbitolines). The distribution of the major species of stratigraphic value is presented in Figures A23 and A24.

The faciological distribution of benthic foraminifera has been described in detail by ARNAUD-VANNEAU (1980) and then by ARNAUD-VANNEAU and DARSAC (1984). On the Jurassic and subalpine platform, benthic foraminifera populations of the major carbonate platform biotopes remain relatively stable from the Berriasian to the Bedoulian (Fig. A25 and A26). Four paleographic domains can be characterized by these populations :

a) **circalittoral outer shelf populations** are represented by a fauna of small (from 150 to 200 μ) simple agglutinated test wall foraminifera (Gaudryina, Dorothia, Textularia...), small Miliolidae and Nodosariidae.

b) **infralittoral outer shelf (margin) populations** are made up of at least one-third large cone-shaped foraminifera (Berrasian-Valanginian Trocholina and Urgonian Orbitolinidae); the rest are large, complex, agglutinated foraminifera (Pseudocyclamina, Everticyclamina, etc....) or simple, agglutinated foraminifera (Charentia, Nautiloculina, etc...) and large-sized Miliolidae.

c) **inner shelf populations** consist of medium-sized foraminifera (250 to 500 μ) and dominant Miliolidae (50%) accompanied by Arenobulimina and Textulariidae ; the outer part of the inner shelf is distinguished from the inner part by the constant presence of large-sized margin microfauna;

d) **marginolittoral muddy environment populatons** are dominated by more than 60% thin test Miliolidae : Pseudotriloculina and Istricholoculina.

Throughout this period, the populations show no evolution in the marginolittoral unit and nearly none in the outer shelf circalittoral environments and in the innermost part of the inner shelf. On the other hand, in the infralittoral outer shelf environments and the outer part of the inner shelf, the appearance of these populations progressively changes, either in terms of an increase in the size of the species or by the replacement of some species by other new larger-sized ones (Miliolidae, Glomospira, Textulariidae); furthermore, at the Barremian-Bedoulian, the Orbitolinidae family almost entirely replaces the Berriasian-Valanginian Trocholina. It should be noted that in the latter case, the Urgonian Orbitolinidae species display approximately the same morphology and size as the Berriasian-Valangian Trocholina species previously inhabiting the same biotopes.

To conclude, benthic foraminifera populations remained relatively stable over a period of 20 million years. Three major factors do however characterize the evolution of these populations from the Berriasian to the Lower Aptian.

1) The most exposed and most agitated parts of the platforms (the margins) are the site of the most substantial specific renewals. Furthermore, this is where one finds short-lived species, that is to say those who are the most interesting from a stratigraphic point of view.

2) Flat Orbitolinas, and large, flat agglutinated foraminifera appear at the Barremian in the circalittoral environments of the outer slope. They later become preponderant in this domain thanks to exceptional events (drowned platform) and then develop to a very large extent at the Middle Cretaceous.

3) At the time of regularly occurring specific renewals, the newly-appearing species and families display a morphology which is entirely comparable to that of disappearing species.

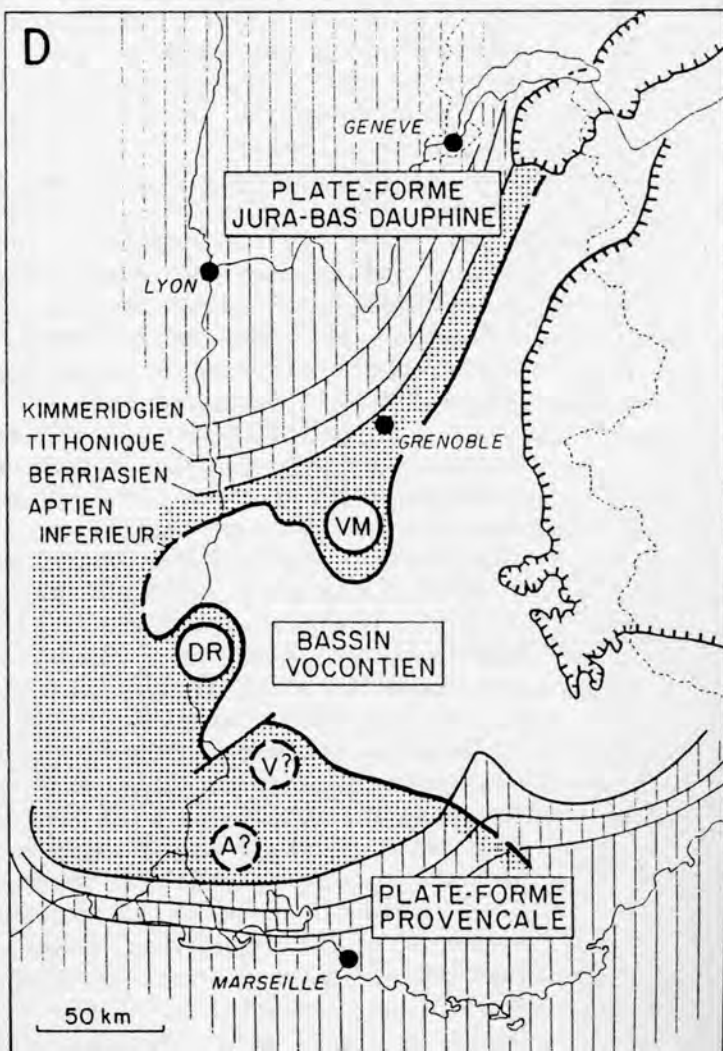
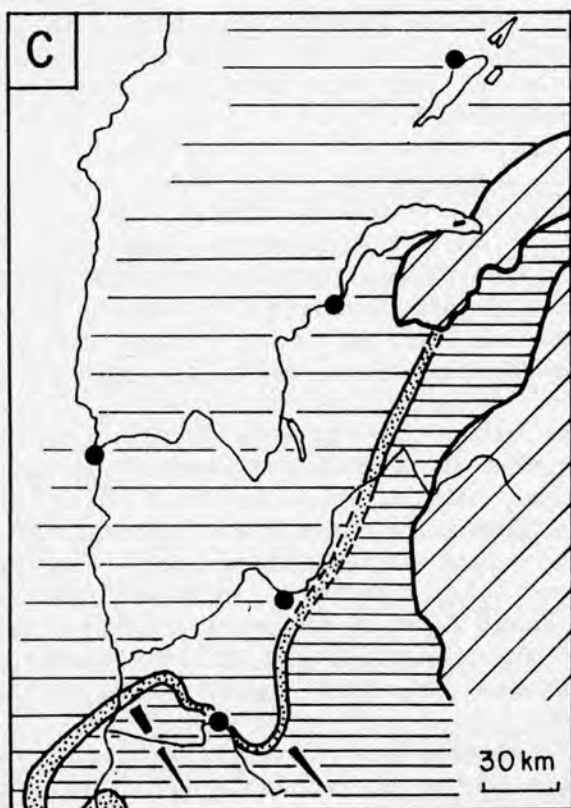
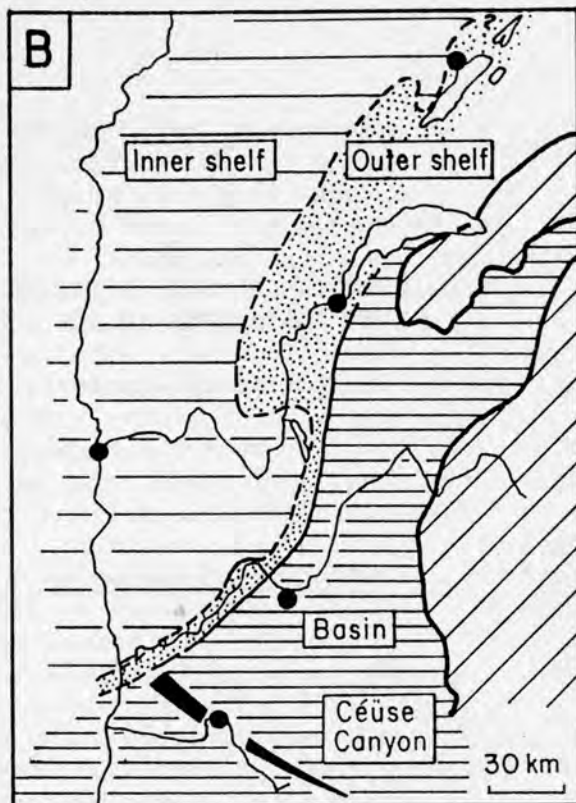
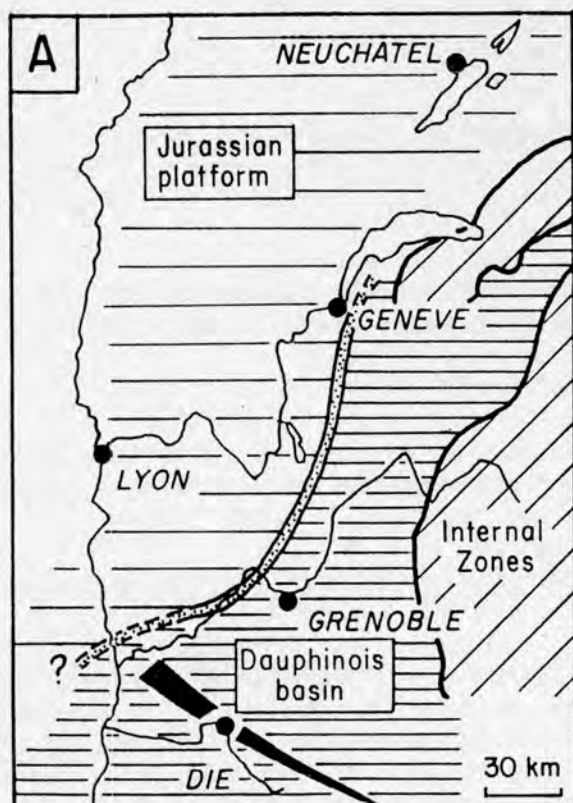


Fig. A 28 : Paleogeographic schemes. A, below the D11 discontinuity (base of the Upper Berriasian) ; B, between the D11 and D12 discontinuities (Berriasian- Valanginian boundary) ; C, at the Lower Aptian (top of the Urgonian platform) ; D, Paleo-

geographical modifications between the Kimmeridgian and the Lower Aptian in the Southeastern France: A. Alpilles mountains ; DR, Dent de Rez shoal ; V, Ventoux mountain ; VM : Southern Vercors Shoal.

3. DATATION OF THE CARBONATE SEDIMENTATION AND PALEOGEOGRAPHY OF THE LOWER CRETACEOUS IN THE JURA AND SUBALPINE CHAINS (A. & H. ARNAUD)

3.1. The Berriasian-Hauterivian Platform

Above the Purbeckian facies, 4 major discontinuities permit the distinction of 4 main sequences between the Middle Berriasian and the base of the Hauterivian.

3.1.1 Datation of the major upper Berriasian-Valanginian discontinuities

The Di1 discontinuity is located at the Upper Berriasian (picteti zone) by Calpionellids (DARSAC, 1983) and ammonite (CHAROLLAIS et al, 1986). The Di2 discontinuity is dated by ammonites of the Basal Valanginian, probably in the neighborhood of the boundary of the otopeta and pertransiens zones at Fontanil and Revard. The Di3 discontinuity can be correlated with the base of the Malleval Marls (northern Vercors) of the top of the Lower Valanginian (top of the campylotoxus zone). The Di4 discontinuity is complex and rarely visible. It is over-topped by ammonite marls of the Early Hauterivian (radiatus zone) but could also be situated in the top of the Valanginian.

3.1.2 Paleogeography of the Berriasian-Valanginian entity

The A sequence, between the "Purbeckian" and the Di1 discontinuity, corresponds to the Pierre Châtel Formation (STEINHAUSER & CHAROLLAIS, 1971). The inner platform domain covers all of the Jura and a part of the Bas Dauphiné all the way to the Isère fault. The very narrow outer slope of this platform is observed in the outer part of the septentrional subalpine massifs.

Above the Di1 discontinuity, the paleogeography of this domain is perceptibly modified. The B and C sequences, situated respectively between the Di1 and Di2, and the Di2 and Di3 discontinuities, correspond to the Chambotte formation (STEINHAUSER & CHAROLLAIS, 1971: the bioclastic facies which overtop the Di2 discontinuity make up these authors' Guiers member). In this locality, typical of the southern Jura, both B and C sequences still display inner platform facies at their summit. A dual vertical and lateral evolution may be observed as of this point, showing proof of a generalized tilting of the Jurassic domain.

a) Towards the North, the B and C sequences are arranged in a positive megasequence and the constituent facies become more and more external towards the North by the lateral transition to reddish calcareous bioclasts (**retrogression of the facies**). In the Neuchâtel region, the latter are often eroded up to the neighborhood of the Di1 discontinuity. This submarine erosion is probably due to violent currents during the submersion periods since Lower Valanginian ammonites, reworked from reddish limestones, are found at different points at the base of the Hauterivian marls.

b) Towards the South, the B and C sequences are arranged in a negative megasequence. The continuous progradation of the facies thus permitted the progressive filling-up of the northern margin of the Dauphinois basin.

3.1.3 Datation and Paleogeography of the Lower Hauterivian : the "Pierre Jaune de Neuchâtel" Formation

Above the Hauterivian marls which correspond to the Basal Hauterivian submersion period, the bioclastic and oolitic "Pierre Jaune de Neuchâtel" facies have been dated at the Lower Hauterivian thanks to the still unpublished results of the team headed by J. REMANE.

This limestone sequence is over-topped by a regional discontinuity which may be situated in the neighborhood of the Lower Hauterivian-Upper Hauterivian boundary. Above this discontinuity, the platform is again submerged and the facies are marly, at least in the southern Jura (facies F2). The age of this level is unknown: Upper Hauterivian or Lower Barremian according to different authors.

From a paleogeographical point of view, these bio-oolitic facies do not extend beyond the margin of the ancient Berriasian platform: they are therefore limited to the Jurassic domain.

3.2. The Southern Vercors Shoal

This shoal corresponds to bioclastic limestones particularly well-developed in the southern part of the Vercors along the N.E.-S.W. Menée fault ("Calcaires à débris de Glandasse" Formation).

3.2.1 Datation

This formation, several hundreds of meters thick, is intercalated with, or changes laterally into hemipelagic facies up to 2000 meters thick. It begins at the Pas de l'Essaure, several meters above the Hauterivian-Barremian boundary dated by a very rich and diversified ammonitofauna (H. ARNAUD *et al*, 1976). Most of these limestones are of Lower Barremian age. Its highest part (Bi6 member) is at least partly Upper Barremian since it is over-topped by the Matheronites limentinus marly level, very rich in ammonites, which, in spite of the imprecise zoning of Barremian ammonites, might be found in the middle part of the Upper Barremian (feraudi zone, *sensu* BUSNARDO). The Lower Barremian-Upper Barremian boundary, very poor in Cephalopods, has not been precisely localized, as in this case as well in the Angles section.

Benthic foraminifera, particularly orbitolinidae, are highly numerous. Two associations may be distinguished. The first, at the base of the Lower Barremian, includes : Paracoskinolina jourdanensis Foury & Moullade, Orbitolinopsis debelmasi Moullade & Thieuloy, O. ? flandrini Moullade, O. ? inflata Bassoulet & Moullade, Cribellopsis thieuloyi Arn.-Van., Alpillina antiqua Foury. The second, which appears in the Bi6 member (in which is the Lower Barremian-Upper Barremian boundary, includes Paracoskinolina reicheli (Guillaume), Paleodictyoconus actinostoma Arn.-Van. & Schroeder, Paracoskinolina maynci (Chevalier). Among these species, Paracoskinolina reicheli, a classic Upper Barremian species, also appears in this region in what is probably the Upper Barremian (upper part of the Bi6 member).

3.2.2 Paleogeography

These bioclastic limestones are particularly well-developed in the South-East of the Vercors where the lowest levels of the series are found. Towards the South-East, in the direction of the Vocontian basin, and towards the North-West, in the direction of the Jurassic platform, they change laterally into much thinner hemipelagic (F1), Spatangidae (F2) or fine bioclastic (F3) levels.

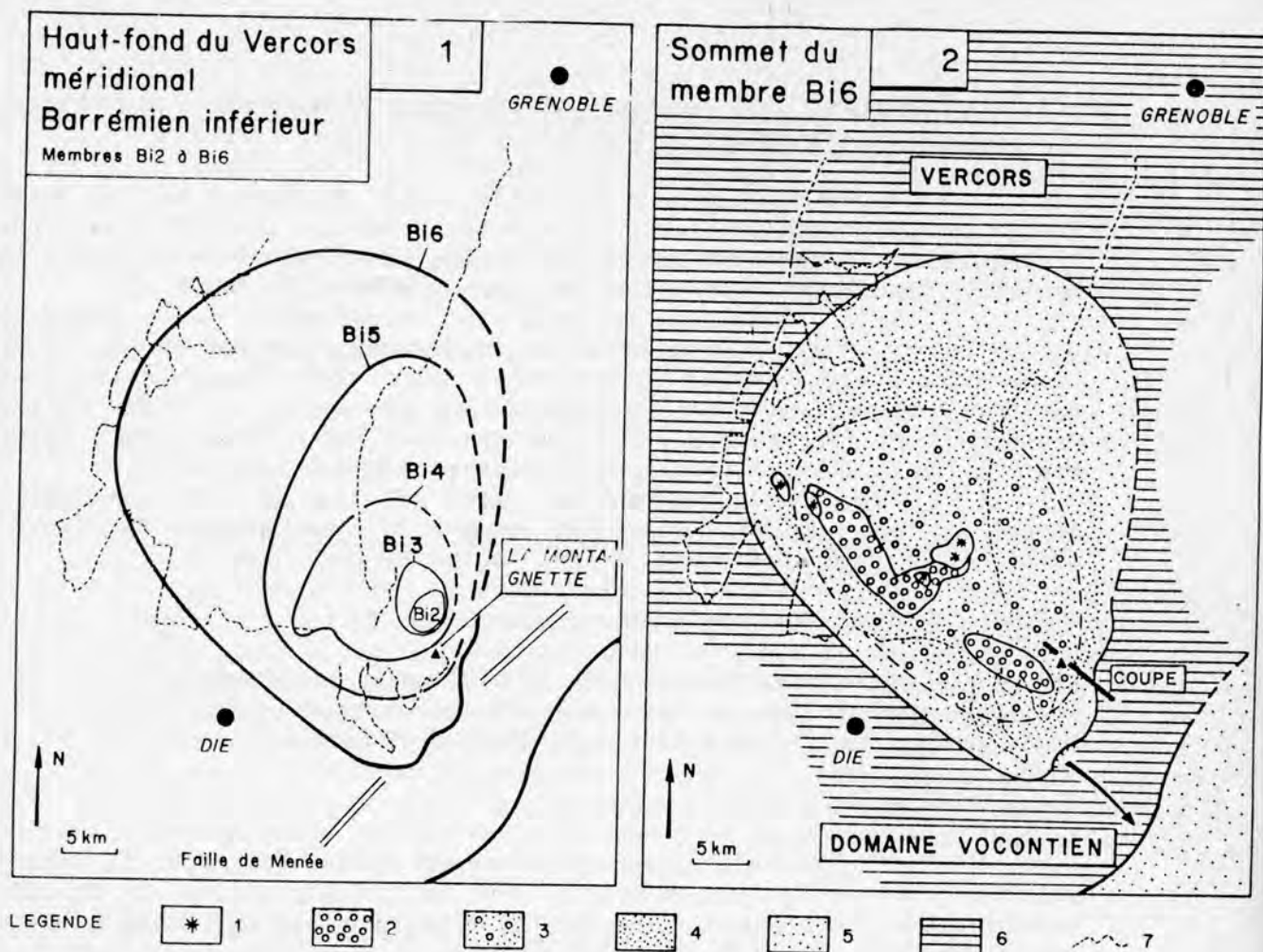


Fig. A 28 : The Southern Vercors Shoal. 1, the succeeding stages of the progradation (members Bi2 to Bi6); 2, paleogeographical map at the top of Bi6 member. List of facies : 1, coral reefs ; 2, oosparites ; 3 infralittoral biosparites with reworking oolites ; 4, infralittoral coarse biosparites ; 5, circalittoral biosparites ; 6 hemipelagic facies ; 7, cliff border of the Vercors.

CLAVEL *et al* (1987) have recently denied the existence of this shoal. This conclusion, which we refute entirely, is all the more surprising in that it is in complete contradiction with their arguments, which totally confirm our previous observations and interpretations (the ammonites cited are however rare, at times poorly localized in relation to previously published sections, and often specifically undetermined). Only an obsolete conception of sedimentology and the negation of field-observation evidences can account for such a contradiction. As a matter of fact, CLAVEL *et al* (1987) have confirmed the existence towards the North-West of lateral transitions between the coarse bioclastic facies (F5) of the southern Vercors and the F1 and F2 facies in the two sectors where we have already described them: on the one hand, in the Pas de la Balme area, and on the other, between Les Grands Goulets and Combe Laval.

The southern Vercors shoal appears all along the Menée fault. It develops in succeeding stages, but progradation of the facies is less substantial towards the South-East than towards the North-West. The top of the shoal is characterized by infralittoral bioclastic sands (F5), oolitic sands (F6) and some small, often dismantled Coral reefs. On the margins, a large dissymmetry is observed, probably due to the

presence of dominating winds and currents: coarse bioclastic facies (F5) in the South-East (windward margin ?), well-sorted and finer and finer bioclastic facies towards the North-West (F5 to F2, leeward margin ?).

3. 3. The Urgonian Platform

Well-developed in the Jura and subalpine massifs, the **Calcaires Urgoniens** (Urgonian Limestone) Formation is subdivided into two parts (lower part, upper part) by a major submersion episode which corresponds to the deposit of the **Couches inférieures à Orbitolines** (lower orbitolinid layers).

3.3.1 Datation

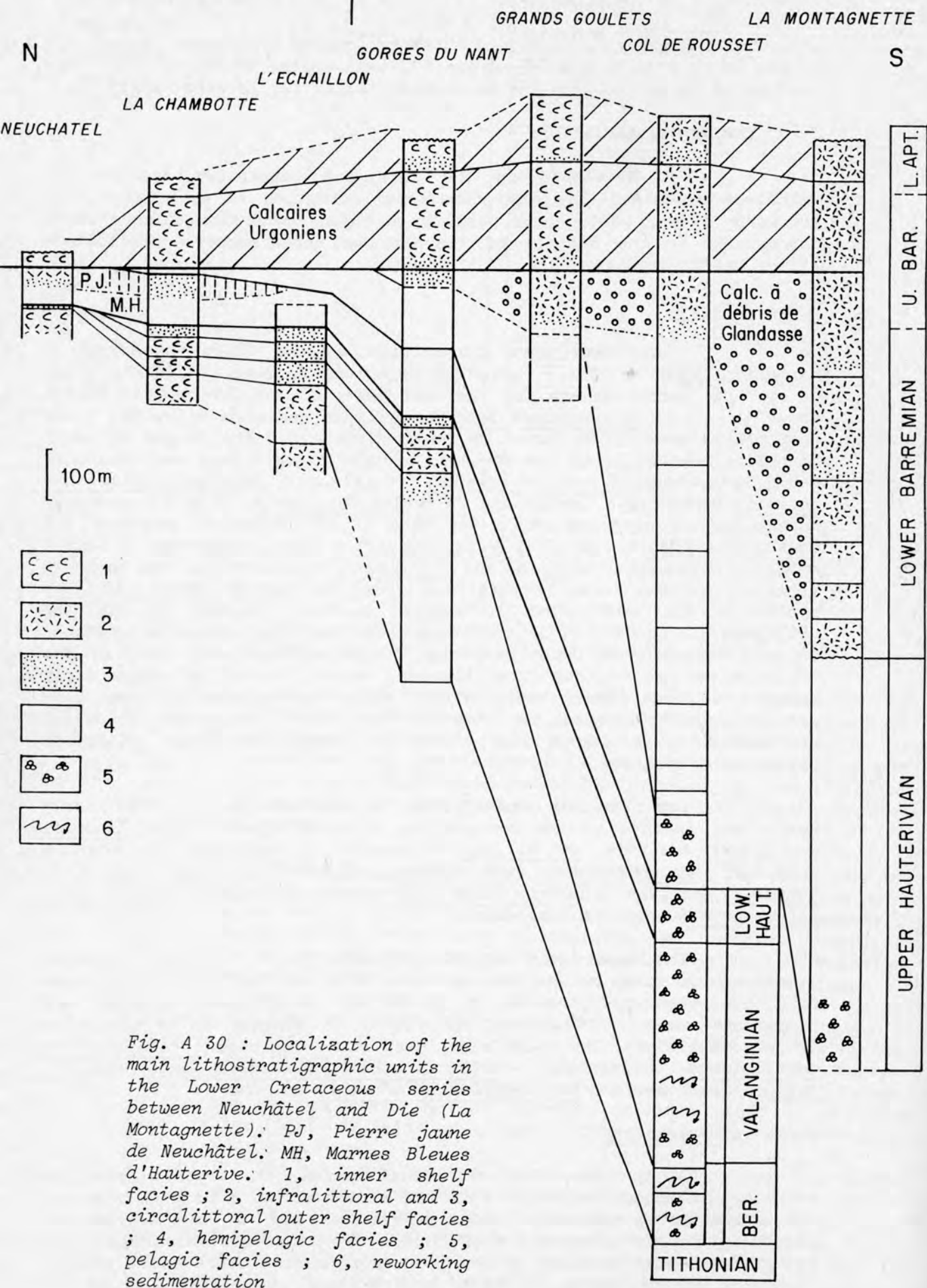
The lower part (lower mass of the Calcaires Urgoniens Formation, ARNAUD, 1981 = Calcaires Urgoniens du Jura, ZWEIDLER, 1985) is of Upper Barremian age for the most part. In the Vercors, it begins above the marly Matheronites limentinus layer and ends below the lower orbitoline-layer levels dated in the Chartreuse and the Bauges by Early Bedoulian Ammonites. In the Vercors, benthic foraminifers are numerous. Among them, Paracoskinolina reicheli (Guillaume), Eopalorbitolina charollaisi Schroeder & Conrad and Palorbitolina lenticularis (Blumenbach) appear or are presents as of the base of the formation wherever the facies are propitious (F8). Valserina bronnimanni Schroeder & Conrad appears in the upper part (at the Colchidites marl level of the Southern Vercors). In the Jura, foraminifera are rare, but do exist and they appear in the same order in several sections studied by ZWEIDLER (Eclepens, La Lance). It is therefore clear that the Calcaires Urgoniens du Jura Formation is Upper Barremian contemporaneous with that of the Southern Vercors. In the Jura, however, several meters of often marly undated sediment (Upper Hauterivian?, Upper Hauterivian to Lower Barremian?) exist between the top of the Pierre Jaune de Neuchâtel Formation (Lower Hauterivian) and the Upper Barremian Calcaires Urgoniens Formation.

Les couches inférieures à Orbitolines of the Early Bedoulian, enclose a rich association of foraminifera: Orbitolinopsis cuvillieri Moullade, O. kiliani Silvestri, O. buccifer Arn.-Van. & Thieuloy, Palorbitolina lenticularis (Blumenbach), Dictyoconus ? vercorii Arn.-Van., Cribellopsis schroederi, Arn.-Van., Cribellopsis neolongata (Cherchi & Schroeder).

The upper part of the Urgonian (upper mass of Urgonian limestone) is found between the previous level and the Couche Supérieure à Orbitolines layer, dated by Bedoulian ammonites (deshayesi and bowerbanki zones, THIEULOY & GIROD, 1965). It appears to be absent in the Neuchâtel Jura. The microfauna, very rich, includes : Palorbitolina lenticularis (Blumenbach), Orbitolinopsis briacensis Arn.-Van., O. pygmaea Arn.-Van. and Paracoskinolina arcuata (Arn.-Van.).

3.3.2 Paleogeography

At the Upper Barremian-Basal Aptian, the Urgonian platform extends over the whole of the Jura and septentrional subalpine massifs. The progradation towards the South-East was due to two concomitant phenomena: 1) the progressive filling-up from the Berriasian along the former North-West boundary of the Dauphinois basin (Isère fault scarp), 2) the existence of the southern Vercors shoal which developed in the



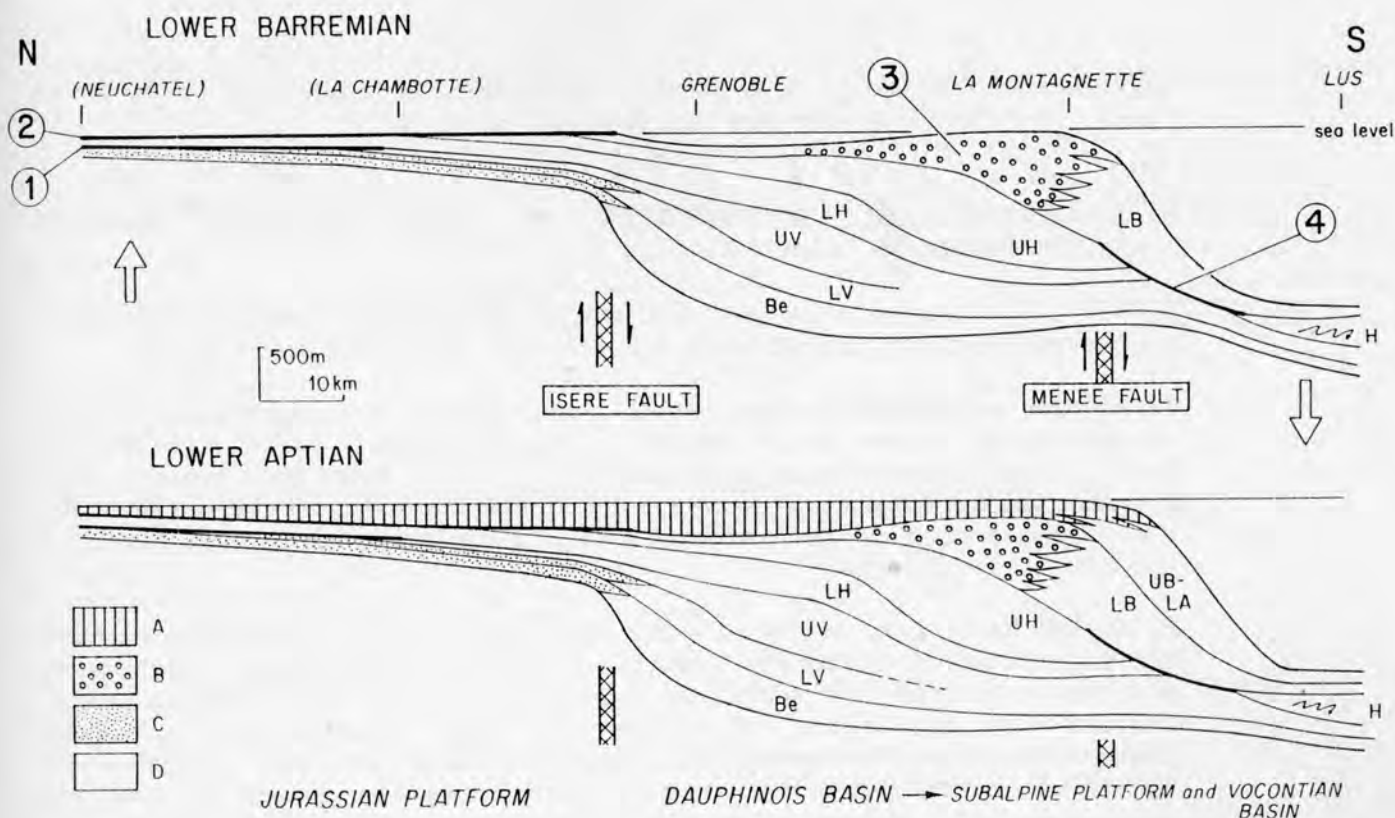


Fig. A 31 : Paleogeographic schematic section between Neuchâtel and Die (La Montagnette): 1, erosional surface of the Valanginian deposits in the Neuchâtel area ; 2, disappearance or great decrease of thickness of the Upper Hauterivian-Lower Barremian in the Jura mountains ; 3, Southern Vercors shoal (Lower Barremian) ; 4, submarine syndepositional ablation surface between Menée Fault and Col de la Croix-Haute. Be, Berriasian ; LV and UV : Lower and Upper Valanginian ; LH and UH, Lower and Upper Hauterivian ; LB, Lower Barremian ; UB-LA, Upper Barremian-Lower Aptian. The white arrows underline the general movement of this part of the European continental margin. A, Calcaires Urgoniens Formation ; B, Calcaires à débris de Glandasse Formation ; C, Berriasian-Valanginian platform series ; D, basinal hemipelagic to pelagic facies.

Dauphinois basin along the Menée fault.

To the North, as in the South in Provence, this substantial filling-up of the Dauphinois basin margin led to a reduction in the area of the basin and to the creation of a small residual basin in Diois and Ardèche: the **Vocontian basin**. East-West oriented, this small basin was largely open towards the East in the direction of a progressively deeper marine domain which, at that time, occupied the entire southeastern part of the European continental margin all the way to the Ligurian ocean.

On the Urgonian platform, inner platform facies are very well-developed, especially at the top of the Barremian. Outer shelf facies are arranged in a narrow strip, at the most 4-5 km. wide, which may be found especially in the North-East and South-West of the Vercors.

This platform was characterized furthermore by the existence of very large channels opening out to sea on the outer platform and deeply penetrating the interior of the inner domain. These channels drained the inner part of the platform and were traversed by violent currents (probably tidal currents). They are silted up by sometimes

argillaceous sediments and contain an extremely rich and diversified fauna, reworked from various neighboring biotopes.

4. ARRANGEMENT AND PARTICULARITIES OF LOWER CRETACEOUS PLATFORM SEDIMENTATION (A. ARNAUD-VANNEAU & H. ARNAUD)

Figures A 30 and A 31 highlight particularities of Lower Cretaceous platform deposits in the Jura and subalpine massifs.

- 1) **At the Valanginian**, depositional environments are distinctly deeper in the North (outer shelf facies in the Neuchâtel Jura) than in the South (inner shelf facies in Chambotte). In the Neuchâtel region, this accentuated submersion is conveyed by submarine erosion responsible for the disappearance of reddish bioclastic limestones up to the level of the Dil discontinuity.
- 2) **At the Barremian**, there is a distinct sedimentological hiatus between the infralittoral carbonate Urgonian platform facies (Upper Barremian) and the underlying circalittoral facies which are often argillaceous, undated but attributed to either the Upper Hauterivian or Upper Hauterivian-Lower Barremian. Two interpretations are thus possible. 1) the circalittoral Upper Hauterivian-Lower Barremian series is complete everywhere but becomes thinner and thinner towards the North. 2) The Upper Hauterivian-Lower Barremian series was partially eroded before the beginning of Urgonian limestone deposits. This erosion would therefore be contemporaneous with the sudden subsidence acceleration noted as of the beginning of Urgonian limestone deposits : this surface may then be due to the tectonic uplifting of this part of the margin, previous to its sinking at the Upper Barremian.
- 3) **At the Lower Barremian**, infralittoral bioclastic sediments appear, far away from the southeastern margin of the Jurassian domain on a shoal which appears along the N.E.-S.W. Menée fault. Because of this, the very rich Lower Barremian associations of benthic foraminifera are no longer found further to the North, neither in the Urgonian limestone where certain facies are compatible with their presence, nor in underlying levels, perhaps partly Barremian, where circalittoral facies could not be suitable for them. The paleogeographical role of this shoal is fundamental since it permitted the rapid filling up of a part of the Dauphinois basin and the later establishment of the Urgonian platform over very vast regions which, until then, had been a part of this basin. The average facies progradation speed is about 1 km/MA on the margin of the Jurassian platform from the Kimmeridgian to the Valanginian as well as on the margin of the Urgonian platform from the Upper Barremian to the Basal Aptian. On the other hand, because of the presence of this **precursory shoal**, the apparent progradation speed reaches nearly 20 km/MA at the Lower Barremian. This acceleration, or rather "**saut de progradation**" (Fig. A 32) is due to the existence of precursory shoals, other examples of which are found in the South-East of France (i.e. the Dent de Rez shoal, fig. A 28). Their appearance is probably linked to the replay of paleofaults inherited from the Liassic rift, such as the Menée fault for the southern Vercors shoal.
- 4) **At the Hauterivian-Barremian boundary**, the replay of the Menée fault is furthermore witnessed, between the Vercors and the Dévoluy, by the existence of a submarine synsedimentary ablation surface which cuts the series up to the Valanginian.

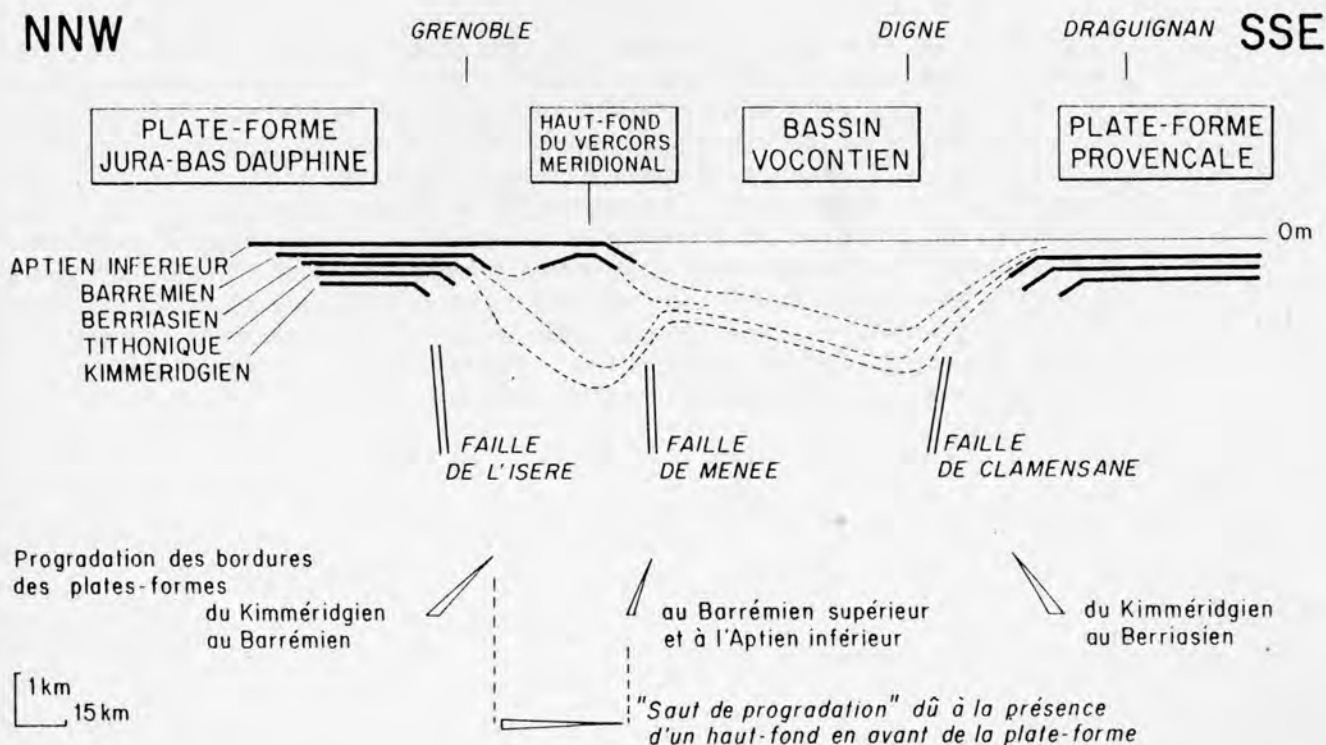


Fig. A 32 : Paleogeographical section through the Vocontian basin and the peri-vocontian platforms (Jura-Bas Dauphiné platform, Provence platform) showing the role of the precursory shoals (Southern Vercors Shoal = Haut-fond du Vercors méridional) in the progradation of the platform facies (the so-called "saut de progradation" between the Berriasian-Valanginian and the Barremian. Note that the appearance of the Southern Vercors Shoal is due to the tectonic instability of the "Barremian crisis" (H. ARNAUD *et al.*, 1986)

The localization and particularities of large carbonate sedimentary thrusts are well in accordance with two main elements: 1) the generalized tilting of the margin between the Jura and subalpine massifs (regular increase in subsidence rates between the Parisian and Dauphinois basins, par. C), 2) the replay of old faults inherited from the Liassic rift, i.e. the Isère fault and the Menée fault (rising of the N.W. compartment, break down of the S.E. compartment).

To conclude, the overall sedimentary characteristics permit the distinction between a stable Jurassian domain and an unstable Dauphinois domain.

The stable Jurassian domain is characterized by: 1) slight variations in thickness, 2) gradual vertical and horizontal facies variations (the series are highly similar from one region to another), 3) the preponderance of sea level variations (i.e. **eustatism**) over all the factors affecting sedimentation), 4) the role played by currents during periods of platform submersion (spread of "Calcaire Roux"-type Crinoid and Bryozoan sands, submarine erosion...)

The unstable subalpine domain corresponds to the N.W. margin of the Dauphinois basin on which the development of platform-type sedimentation was delayed. It is characterized by: 1) very rapid variations in thickness, often up to 100 m/km, 2) facies variations as rapid as they are unpredictable (at the Barremian, contrary to the general direction, there is progradation towards the N.W. in certain sectors of the

Vercors), 3) the preponderance of tectonic factors over the other factors affecting sedimentation (scarps with avalanche breccia at the Berriasian along the Isère fault, creation of precursory shoals along the paleofaults which continued to be active during the opening of the Ligurian tethys, an area of possibly ante-urgonian erosion in the Jura). This tectonic unstability, perceptible at the beginning of the Upper Berriasian (tilting of the Jurassic platform), is particularly substantial between the Hauterivian-Barremian boundary and the Upper Barremian. It may be seen as a faint echo of the events just described discordance of the Barremian over the Valanginian-Lower Hauterivian).on the Galician margin (creation of pre-Barremian tilted blocks, discordance of the Barremian over the Valanginian-Lower Hauterivian).

FIRST DAY : FRIDAY, SEPTEMBER 4 TH

THE LOWER CRETACEOUS OF THE STRATOTYPIC AREA NEAR NEUCÂTEL (SWITZERLAND)

T. ADATTE and G. RUMLEY

THEME

The first day is devoted to the visit of two outcrops in the stratotypic region of Valanginian and Hauterivian

FIRST STOP : QUARRY AND MARL PIT OF CRESSIER (Hauterivian)

Here, we will see the Marbre Bâtard and its contact with the Calcaires Roux and the Marnes Bleues d'Hauterive, from the Calcaire Roux to the Pierre Jaune de Neuchâtel. This is indeed the only place in the Jura where the whole of the Marnes Bleues can be seen at the surface, even if this outcrop shows a tectonic perturbation, probably caused by a collapse fold in the Pierre Jaune ; some trace of this fold can be seen outside the marl pit.

1. OUTCROP DESCRIPTION

This outcrop presents some inconveniences : tectonic complications, vegetation, frequent rockfalls and accumulation of the debris prevent us from having a good view of the series. These facts and the absence of a good stratification, in such a way that there are almost no clearly recognizable beds, make precise measurement and description very difficult. However it is the only place where we can see so much of the Marnes Bleues d'Hauterive and their contact with the lower and upper units.

The lithology given in the figure B3 was done by REMANE (1982). He measured the profile from the top of the Calcaire Roux and took samples at each meter. This involves of course imprecision for the total thickness, and for the position of the samples, especially when they are more distant from the reference point.

In the Northern part of the marl pit, we can see the contact between the Calcaire Roux and the Marnes Bleues d'Hauterive. There are no Marnes à Astieria here. The last bed of the Calcaire Roux is a grey calcarenite ending by a hard-ground ; a typical Marne bleue immediately follows. Between 3 and 4 meters higher is the main fossiliferous bed of the marl pit ; it is a marl with calcareous nodules. In the following meters, no beds can be clearly distinguished. Only between 24 and 25 meters, REMANE described a more calcareous bed with burrows, whose surface looks like a hard-ground. The upper part of the Marnes Bleues is hard calcareous marl showing no stratification. The transition to the Pierre Jaune de Neuchâtel is very quick ; the first calcareous beds are grainstones, surrounded by some marly levels. The typical Pierre Jaune with cross-bedded stratification appears a few meters higher. We can see it outside the marl pit.

2. PALEONTOLOGY AND STRATIGRAPHIE

As it was mentioned previously, the Marnes à Astieria does not exist in Cressier. This means that the Upper Valanginian is not represented here. Therefore, except for the Calcaire Roux, all of the marl pit serie belongs to the Lower Hauterivian.

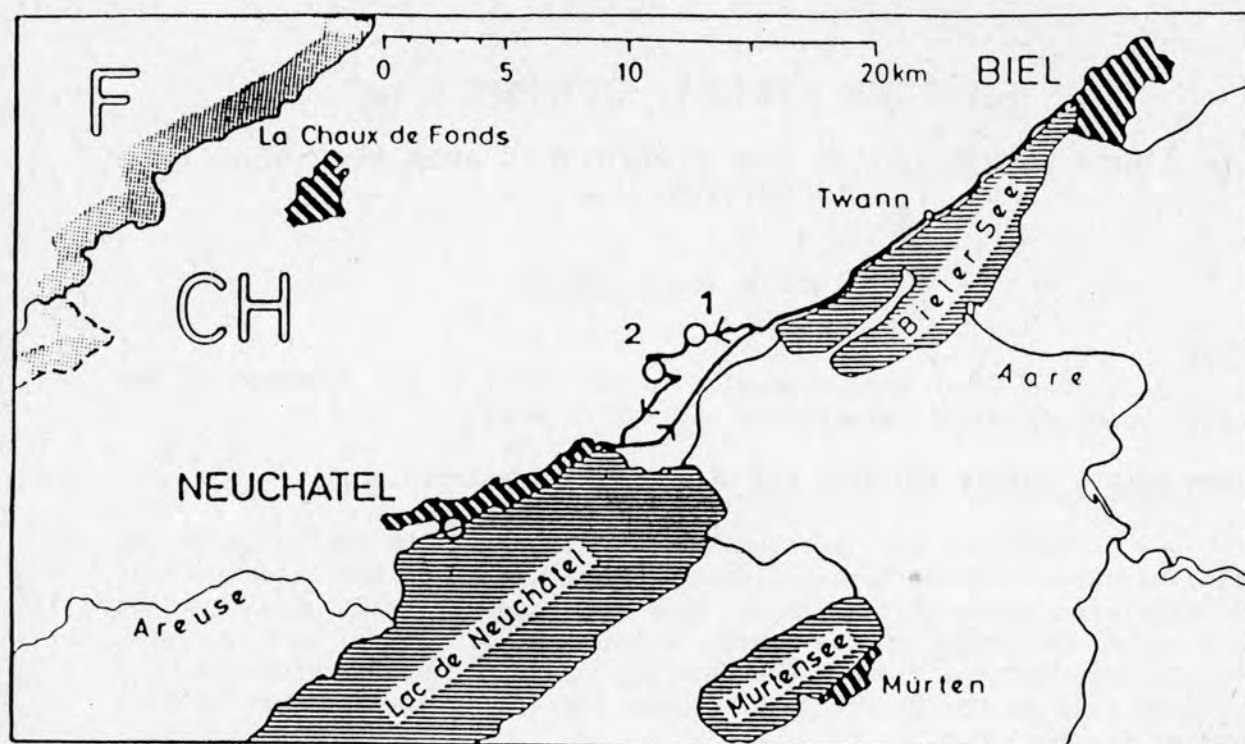


Fig. B 1 : General map of the region (with the localisation of the stops

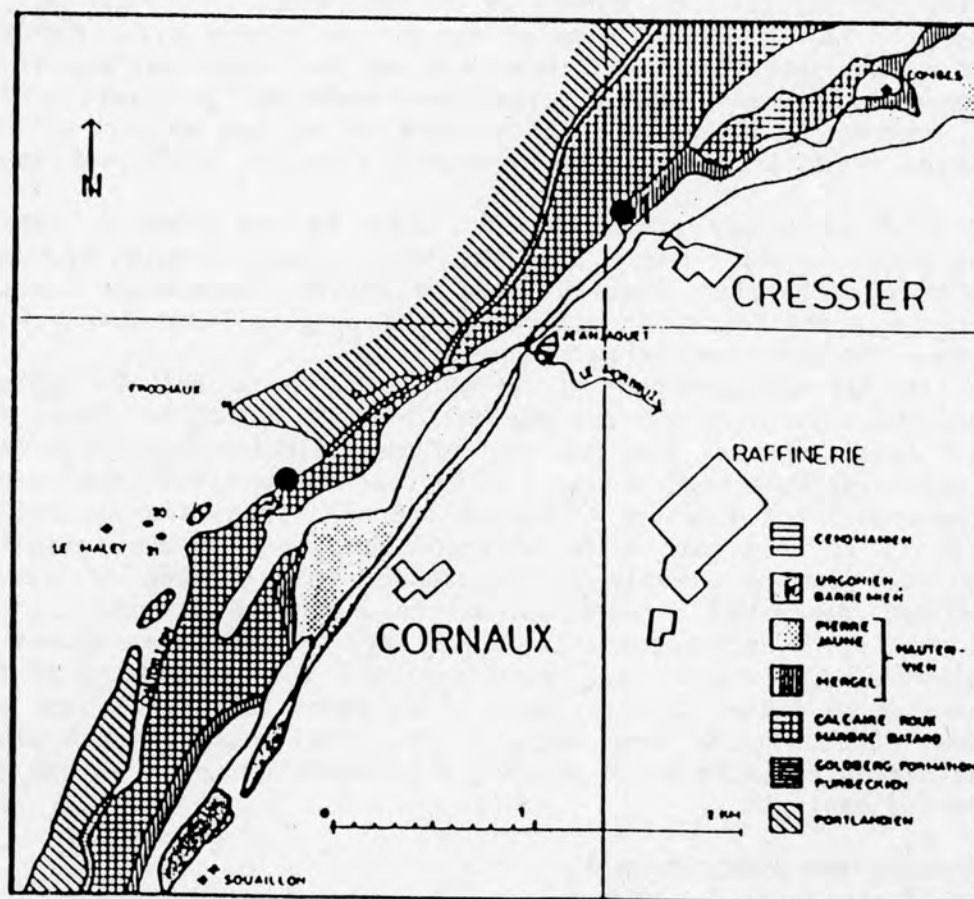


Fig. B 2 : Schematic geological map of the region of the outcrops (from Renz 1976)

Marnière de Cressier

Lower part

Upper part

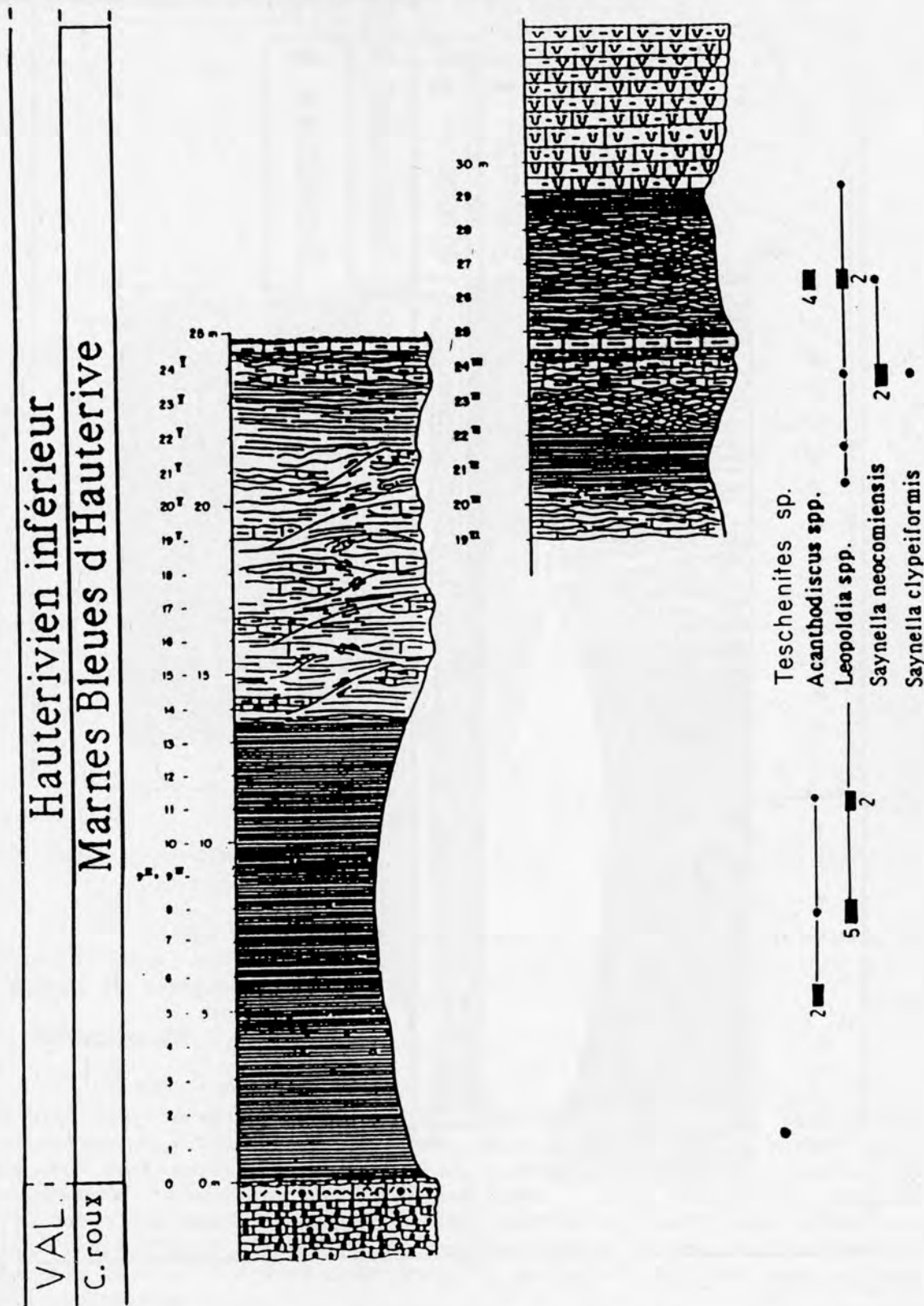


Fig. B 3 : Lithology and distribution of ammonites of the Marnière de Cressier (paleontologic data from BUSNARDO & THIEULOY)

The Marnes Bleues show a typical open-sea fauna, where we quite often find ammonites. Among them, the most frequent genus are Acanthodiscus and Leopoldia. Some Saynella and one Teschenites were also found by BUSNARDO & THIEULOY (fig. B3). All of these ammonites belong to the first zone of Hauterivian, the Acanthodiscus radiatus zone. This

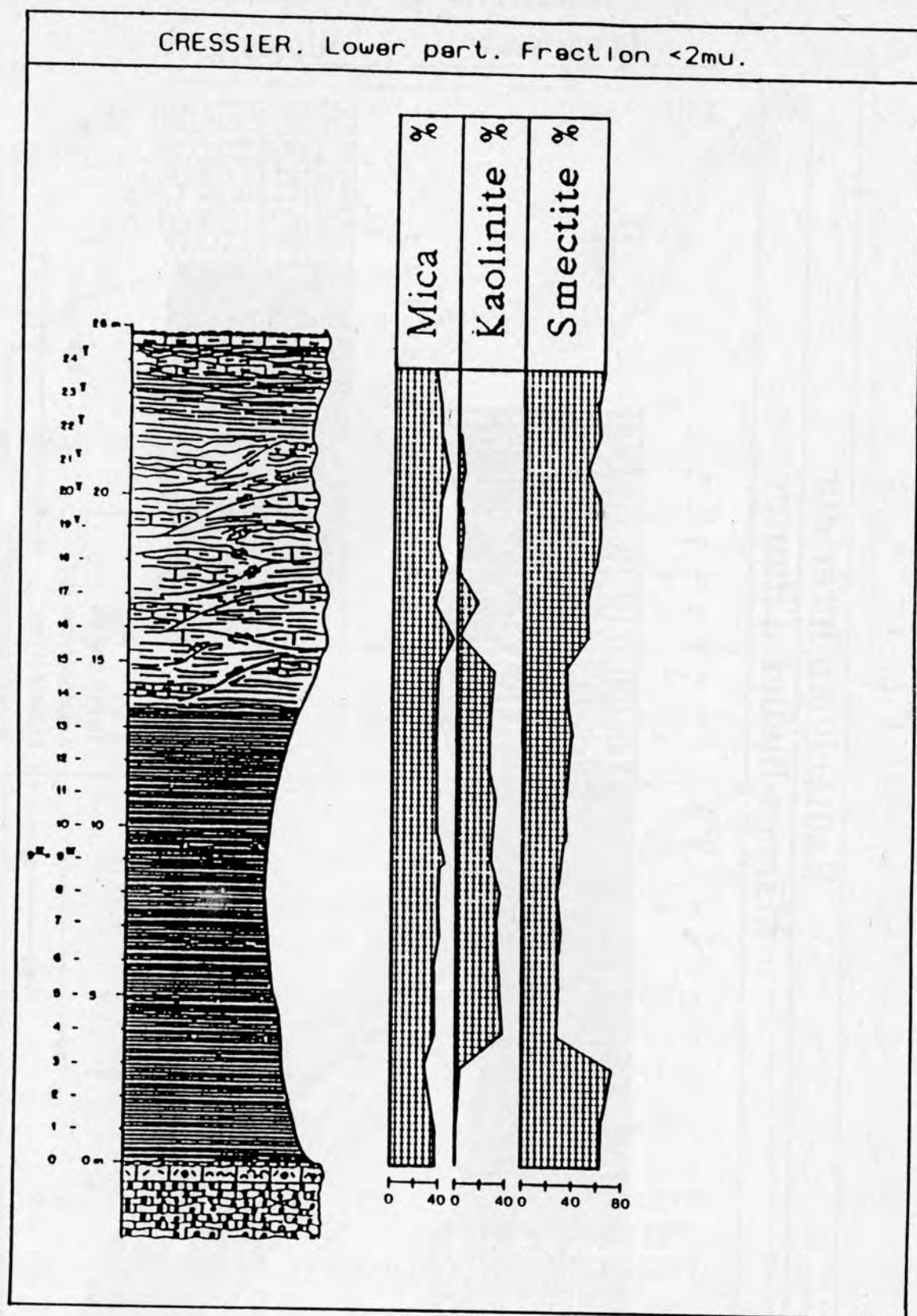


Fig. B 4 : Repartition of the clay minerals on Cressier profile (lower part)

means that there certainly exists no major lack of Marnes Bleues d'Hauterive. Otherwise, the fauna consists of many bivalvia, brachiopods, echinids (*Toxaster*) and some *Nautilus*.

The microfauna consists mainly of foraminifera. Among them the most frequent are *Lenticulina*, *Gaudryina* and some *Nodosariidae*.

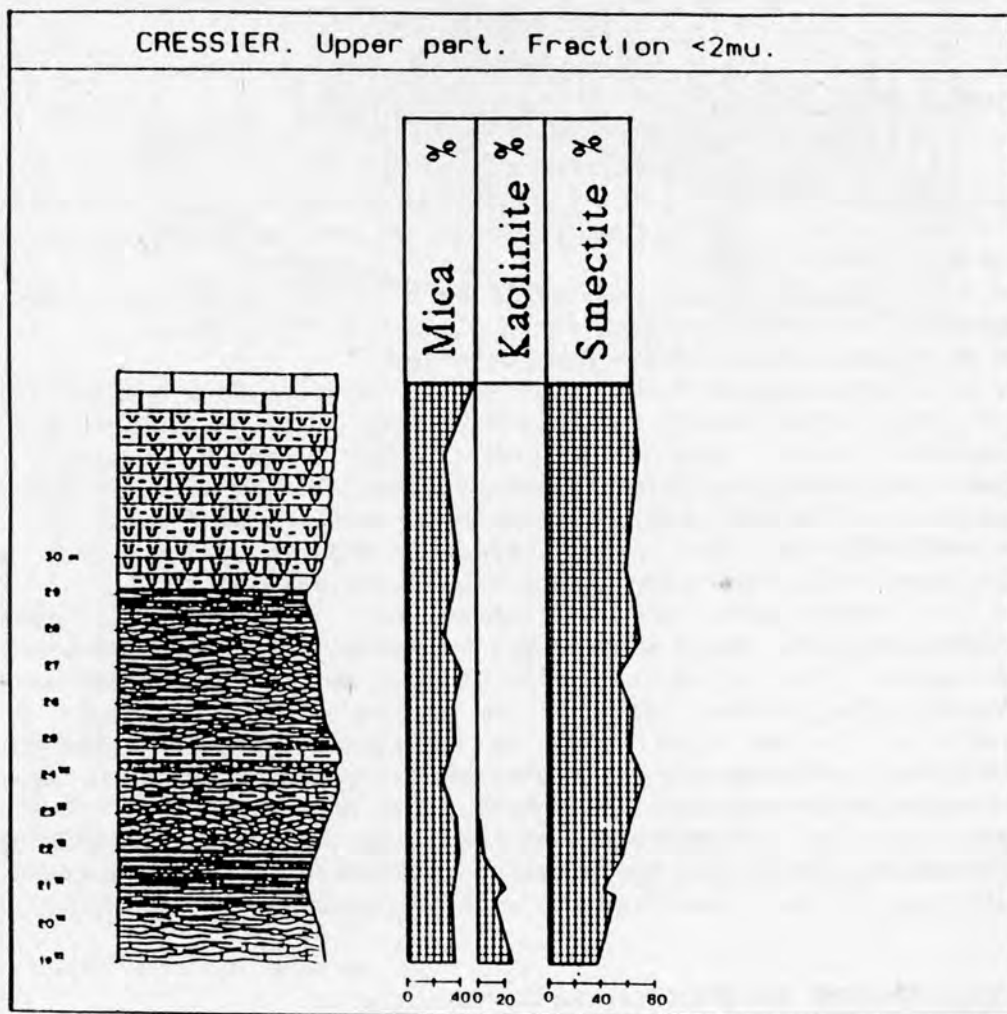


Fig. B 5 : Repartition of the clay minerals on the Cressier profile (upper part)

In the Pierre Jaune, the fauna is represented only by debris of brachiopods, bivalvia, echinoderms, bryozoans and crinoids. The most frequent foraminifera are Lenticulina and Gaudryina.

3. SEDIMENTOLOGY

After the hard-ground of the top of the Calcaire Roux, which is a biosparite with remains of echinoderms and bryozoans, begins the sedimentation of the Marnes Bleues, characteristic of a rather deep open-sea environment. These marls are biomicrites with many remains of echinoderms, some annelids and bryozoans. They frequently contain glauconite and quartz. Except for the hard-ground mentioned above, no significant change appears in the sedimentation of the Marnes Bleues, and this hard-ground certainly involves no major lack, as seen in the paleontologic part.

At the top of the Marls, the sedimentological environment changes gradually to an oolitic and/or bioclastic facies, the Pierre Jaune de Neuchâtel. It is a grainstone, either with ooids, or with debris of bioclasts, which are sometimes very large-sized. Glauconite and chlorite are frequent. On other profiles, a major discontinuity can be seen in the Pierre Jaune. This discontinuity is marked by a hard-ground with some pebbles. This discontinuity might be correlated with the discontinuity B defined by VIEBAN (1983) in the meridional Jura and the subalpine chains.

4. MINERALOGY

The mineralogy analyses for this profile concern only the insoluble residue. The figures B4 and B5 show the relative percentage of clay minerals for the fraction inferior to 2 microns. We can make the following remarks :

- The smectites constitute the major part of the mineralogy. They are present in a rather constant ratio all along the profile.
- The detritic micas show the same behaviour.
- The kaolinite appears 4 meters above the Calcaire Roux and is present, in a rather great amount (up to 40%), along about 10 meters, and then disappears almost completely (except for 2 or 3 samples). This behaviour is till now unexplained, because the presence of kaolinite in such a sedimentological environment is not a common fact.
- The chlorite is very rarely present and always in very small quantities. This behaviour is not significative.

These data are of course not sufficient to give an interpretation of the mineralogy. However, if we consider the mineralogical results of other profiles, we may announce a first conclusion. The presence of smectite as the major constituent of the clay minerals in the micritic facies is a general fact. Higher in the Pierre Jaune, in more energetic environments, the smectite is replaced by mixed-layers minerals. Therefore, the distribution of the clay minerals in the sedimentological environment certainly depends on hydrodynamism. Concerning the presence of kaolinite in the Marnes Bleues d'Hauterive, further investigation will be necessary.

STOP 2 : JURACIME QUARRY (Berriasian-Valanginian)

1. GEOGRAPHIC SITUATION

It is a big quarry, named Juracime, in which carbonates rocks are used to make cement. This is situated to the NW of the small village of Cornaux (fig. B1 and B2).

2. GENERAL DESCRIPTION

This quarry very clearly indicates the Lower Cretaceous from the Purbeckian facies (Berriasian) to the Calcaire Roux (Lower Valanginian).

From bottom to top, we can observe (fig. B6) :

- a) the end of Purbeckian facies
- b) the "Unité Inférieure Oolitique" (8 m, U.I.O.)
- c) the "Unité Moyenne Massive" (9 m, U.M.M.)
- d) the "Unité Supérieure Gréseuse" (10 m, U.S.G.)
- e) the "Calcaire Roux" (3m).

In order to simplify, we used the subdivisions of STEINHAUSER & CHAROLLAIS (1970), which apply rather well in this quarry. We have to observe however that at Cressier (stop 1), the U.S.G. does not show the same facies (very high content of quartz). All of this unit is here composed solely of carbonates.

2.1. Purbeckian

It is very difficult to observe the beds' succession because of a strong disharmonic tectonic. This succession is composed mainly of grey, black, sometimes green marls, limestones and breccia. These result

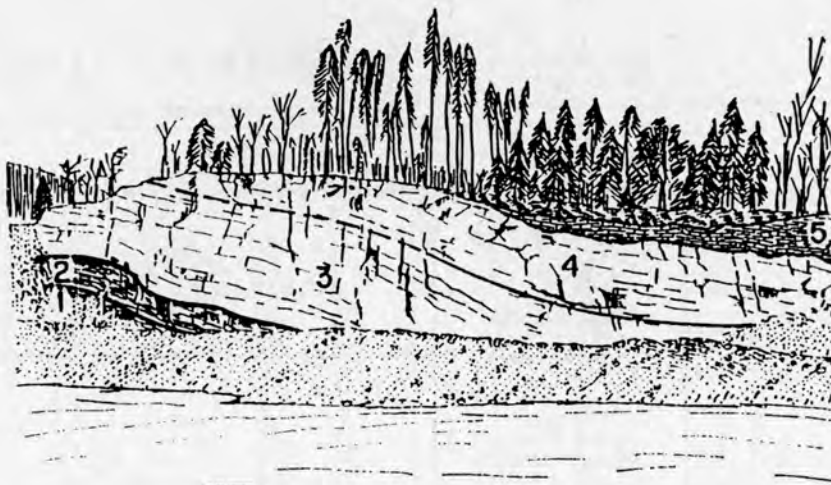


Fig. B 6 : General view of the Juracime quarry. 1, Purbeckian facies ; 2, Unité Inférieure Oolithique ; 3, Unité Calcaire Massive ; 4, Unité Supérieure Gréseuse ; 5, Calcaire Roux (from STEINHAUSER & CHAROLLAIS, 1970)

from a brackish to lacustrine environment. It is therefore common to find a lot of *Chara*, especially in green marls.

2.2. Unité Inférieure Oolithique

At the outcrop, it is difficult to separate this part from the Purbeckian. It is an alternance of blue-black marls and oolitic limestones. The presence of glauconite, echinoderms, bryozoans, remains of rudistes and some foraminifera (like *Feurtilla frequens*) are evidence of an open marine environment.

2.3. Unité Moyenne Massive

This unit is composed of thick beds of white limestones. These correspond mainly to a lagoonal environment with blue algae and many benthic foraminifera.

2.4. Unité Supérieure Gréseuse

It is a succession of red-brown limestones. Its very high content of detrital quartz is the main characteristic. This unit is terminated by a large erosion surface (fig. B7). These limestones indicate a more external environment. They contain the characteristic association *Keramosphaera allobrogensis* - *Pseudotextulariella courtoniensis* (fig. B9).

2.5. Calcaire Roux

It is a cross-bedding unit which lies above the U.S.G. with a major discordance. It cuts up to 2 meters into the underlying unit. It is composed of iron limestones with ferrous ooids. The contents of these limestones are mainly remains of echinoderms, bryozoans and bivalvia, in a sparitic cement.

3. LISTING OF THE OBSERVED MICROFACIES (fig. B8 and B9)

3.1. Slope and outer platform

Microfacies T1. Biosparite with very external intraclasts and large remains of echinoderms, pelecypods, brachiopods, bryozoans. The foraminifera are rare (*Miliolidae*, *Nodosariidae*). It is possible to observe a few ooids. Quartz is not common.
Texture : grainstone.

Microfacies Pel. Biosparite with small stretched remains of bioclasts

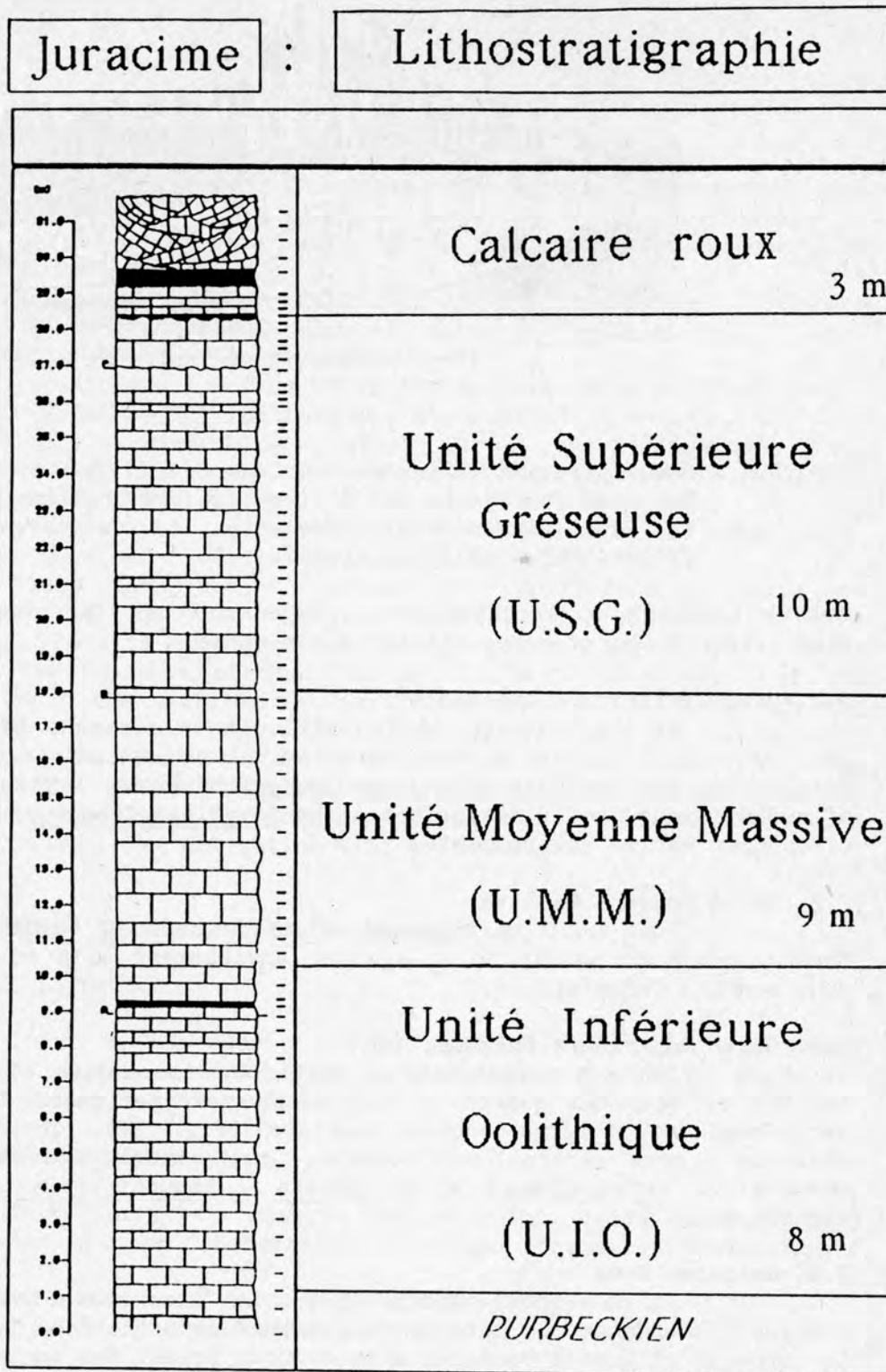


Fig. B 7 : Lithostratigraphy of the Juracime profile

and intraclasts. The ooids are present in large quantities ; they sometimes show a micritized border. Quartz and glauconite are present. Large remains of echinoderms. Foraminifera are more frequent : Nautiloculina, Nodosariidae, large agglutinated, Feurtilla, Miliolidae, Trocholina.
Texture : grainstone.

Microfacies Pe3. Biomicrite with stretched remains, rudistids, echinoderms and a few ooids. Quartz is sometimes present, glauconite as well. Foraminifera are more or less the same as in Pe3.
Texture : wackestone to packstone.

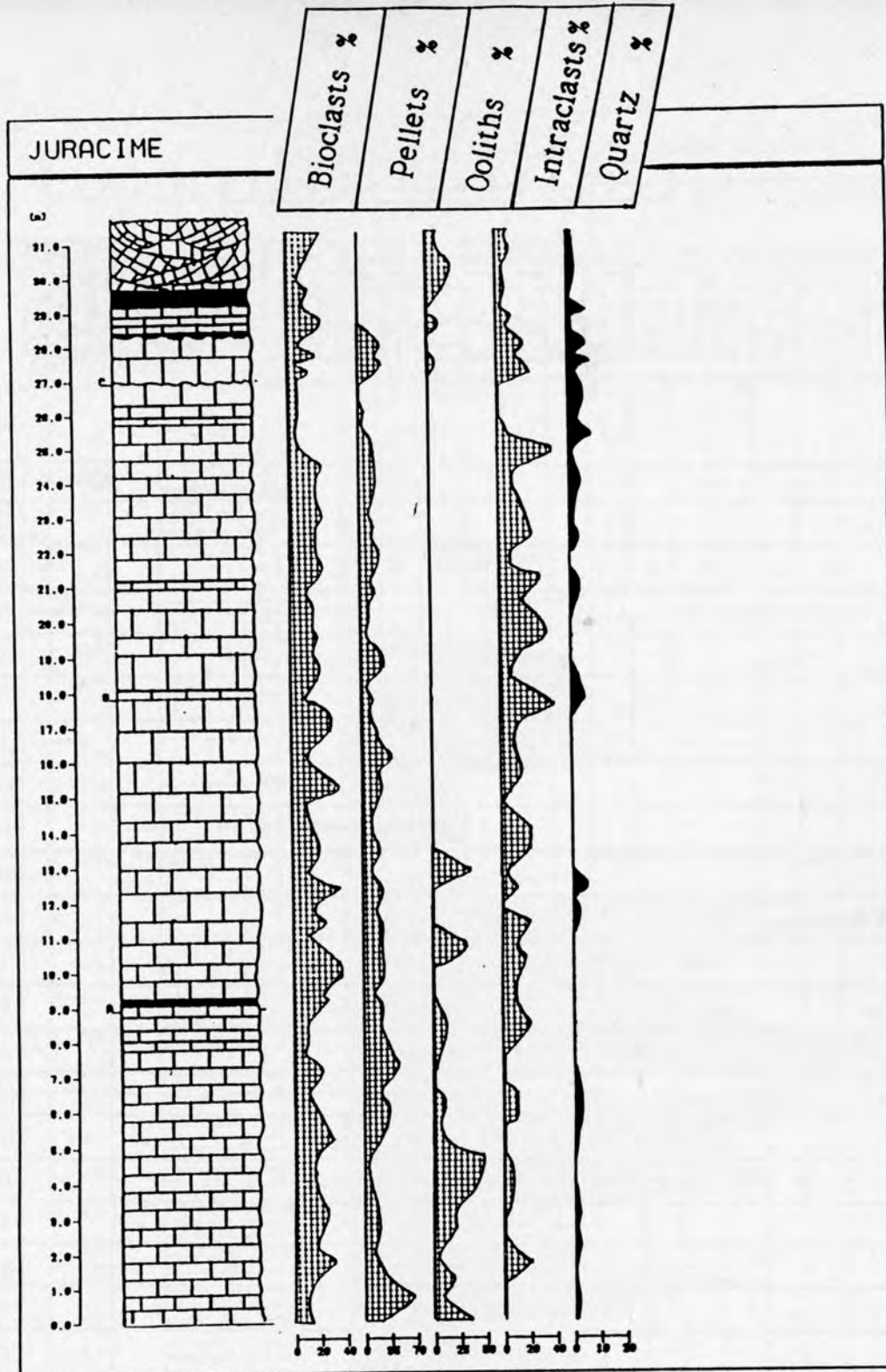
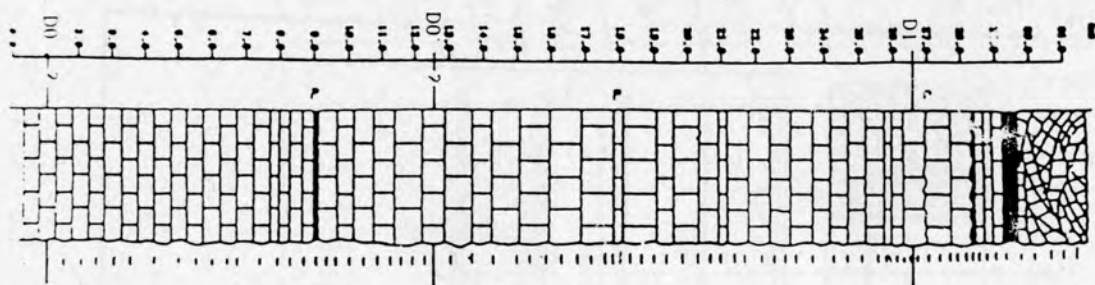


Fig. B 8 : Percentage of the principal elements observed in the micro-facies

Microfacies Pe4. Biosparite with remains of echinoderms, rudistids, corals. Quartz may be present in large quantities (especially in the U.S.G.). There are still a few glauconite. It is possible to find the same facies with micrite. Foraminifera are more diversified : Nodosariidae, Miliolidae, Nautiloculina, Polymorphinidae and numerous Trocholina.

Texture : grainstone or packstone.

Microfacies Pe5. Biosparite or biomicrite with remains of rudistids, echinoderms and corals. There are no more ooids in this facies. Quartz can be present with high content. Foraminifera are diversified :



-----	Bryozoaires
- - - - -	débris de Rudistes
-----	Madréporaires
-----	Echinodermes
-----	Gastéropodes
-----	Bivalves
-----	Brachiopodes
••	Keramosphera allobro.
••••••••••••••••••••	Pseudotextulariella co.
•	Pseudotextulariella spa.
••••••••••	Feurtillia frequens
••••••••••	Polymorphinidae
-----	Pseudocyclammina
-----	Quinqueloculina
-----	Nodosariidae Lenticulina
-----	Glomospira
-----	Miliolidae
-----	Pseudotriloculina
-----	Nautiloculina Bron.
-----	Verneuilina cf. po.
-----	Bielorusiella sp.
-----	Gros Aglutinants
-----	Pfenderina neocom.
•	Valdanchella
-----	Pyrgo
-----	Trocholines
-----	Haplophragmium cf. jou

-----	Characées
-----	Dasycladacées

Fig. B 9 : Distribution of the Foraminifera and bioclasts

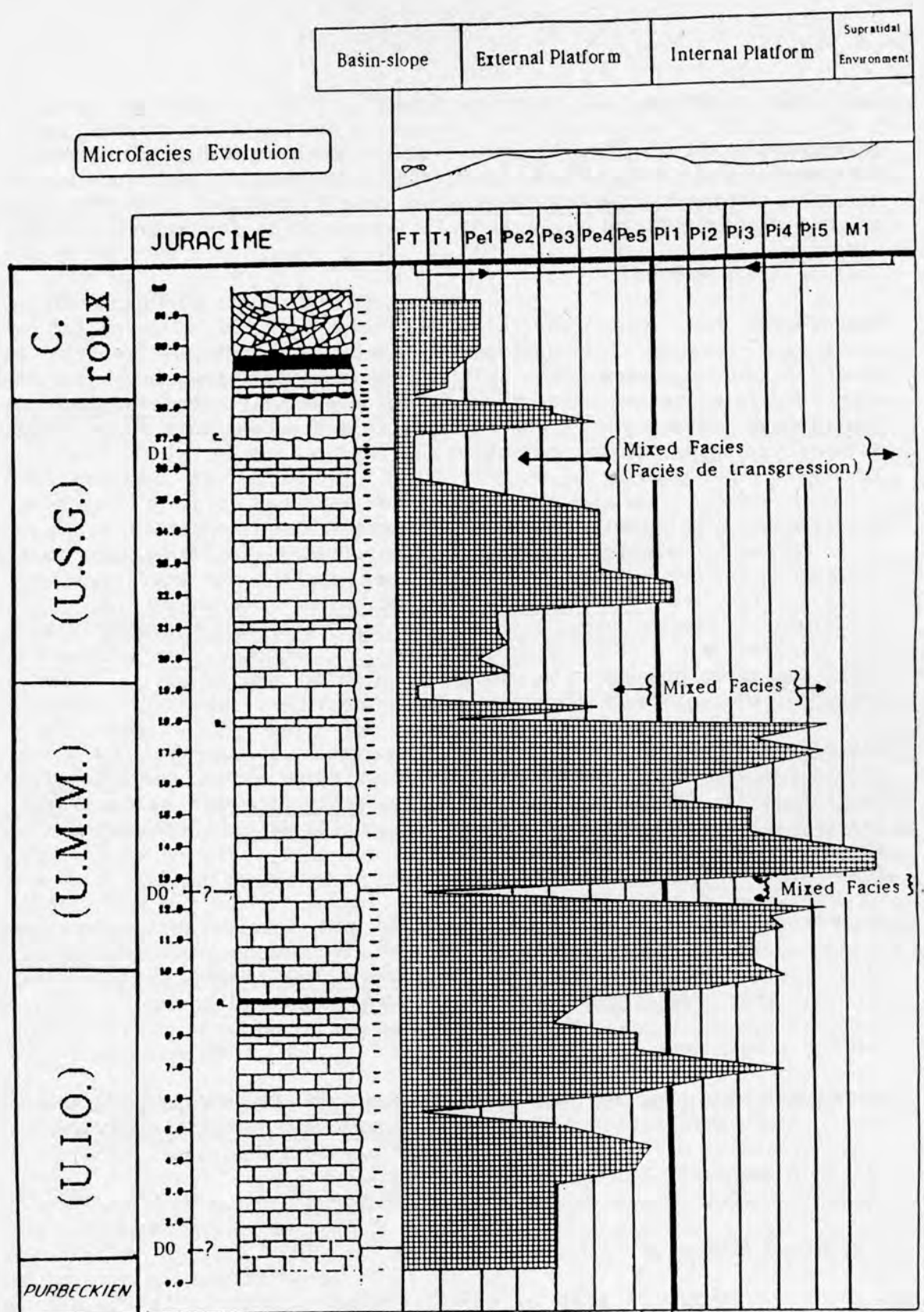


Fig. B 10 : Microfacies evolution curve

Miliolidae, Nodosariidae, Nautiloculina, Polymorphinidae, numerous Trocholina, Pseudocyclammina.
Texture : grainstone to packstone.

3.2. Inner platform

Microfacies Pi1. Biopelsparite with small micritized remains, echinoderms and foraminifera. Quartz is not common. Foraminifera are not common : frequent Pseudocyclammina, a few Trocholina, rare Pfenderina and Miliolidae, Lenticulina are still frequent. As for algae, sometimes Cayeuxia.

Texture : grainstone.

Microfacies Pi2. Biointramicrite, sometimes sparite with rolled and micritized remains. The echinoderms tend to decrease. Bivalvia and brachiopods are common. The Lenticulina are less frequent. The most abundant foraminifera are Trocholina, especially, Pseudocyclammina, Nautiloculina, rare Pfenderina and sometimes Pseudotextulariella. Algae, such as Cayeuxia, can be present.

Texture : packstone.

Microfacies Pi3. Biomicrite or biosparite with diversified fauna and with large foraminifera. The echinoderms tend to disappear. Algae (Dasycladals) are present as well. The remains are micritized. The foraminifera are Verneullina cf polonica, Nautiloculina, large Miliolidae, Pseudotriloculina, Glomospira, Pseudocyclammina, large agglutinated and a few Pseudotextulariella, Nodosariidae become more rare. Quartz is present with variable contents.

Texture : wackestone to packstone, grainstone.

Microfacies Pi4. Biomicrite with algae and numerous Trocholina. The Trocholina are the most abundant. The other foraminifera are Miliolidae, Nautiloculina, Pyrgo, Glomospira, Pseudotriloculina and seldom Pseudotextulariella. The algae are Dasycladals (Clypeina). Echinoderms are absent. Quartz is not common.

Texture : wackestone to packstone.

Microfacies Pi5. Biosparite or biomicrite with oncoids. Echinoderms are absent. The foraminifera are mainly Trocholina and Miliolidae, Glomospira, Pseudotriloculina, Belorussiella, Nautiloculina, rare Verneullina, Haplophragmium and Pseudotextulariella. Quartz is not common.

Texture : packstone to grainstone.

Microfacies M1. Micrite with Pseudotriloculina. The fauna is extremely poor. The foraminifera are Pseudotriloculina, Belorussiella, Pyrgo. The other bioclasts are only ostracods, rare bivalvia and algae. Bird's eyes are very common.

Texture : mudstone.

3.3. Mixed facies

These are what A. ARNAUD-VANNEAU (1980) calls "faciès de transgression" (mixed facies). They often correspond to discontinuities. There are a mixture of internal elements and external elements, and can also be a mixture of facies (for example M1 and slope facies). They always reveal very external conditions.

In our profile we have the following microfacies : Biopelmicrite with thin rolled remains. Echinoderms are very common. The more external foraminifera are small Polymorphinidae, mixed with more internal ones such as Belorussiella, Pseudotriloculina, Pyrgo, Miliolidae, Pseudotextulariella. Nodosariidae are very common. Algae are

present. As other elements, there are small pellets mixed with large ooids. Quartz is also characteristic of this type of facies. It is present in a higher proportion (up to 20%). Glauconite is often present.

It is evident that the position of one or two microfacies on the theoretic profile of a carbonate platform is a little bit arbitrary. However we are obliged to establish an order if we want to correctly use the results of mineralogy.

4. THE EVOLUTION CURVE OF MICROFACIES

The figure B10 shows the evolution of microfacies and principally three discontinuities. The discontinuity DiO (end of Purbeckian facies) corresponds to the installation of open marine conditions, causing a major change in fauna. The discontinuity DiO' suddenly breaks up the internal platform sedimentation that follows the more external facies of the U.I.O. It could correspond to the DiO' discontinuity which has been recognized in France by BOISSEAU (1987).

The discontinuity DiI corresponds to a major event which can be correlated from Neuchâtel to the subalpine chains in France.

All of these discontinuities are overlain by mixed facies.

5. MINERALOGY OF CLAY MINERALS

The figure B11 shows the content evolution of the main clay minerals which have been identified in our profile. These are smectite, mixed layers, mica, kaolinite, chlorite.

Smectite is not present in all of the samples. It seems to correspond mainly to micritic samples. When present, it makes up the biggest part of the clay assemblage (with mica). Mixed layers (mixture of smectite and mica) seem to show inverse behaviour. They occur mainly in sparitic samples. Mica are ubiquitous, but show large variations in quantity. Kaolinite and chlorite show the same behaviour. They appear together at the end of the U.I.O., when internal platform facies appear. Why these tendencies and these variations in quantity? The roentgenofacies method is a good way to answer these questions. All of these minerals have a detrital origin (important remark!).

As it was explained in the introduction (§ E 3, p. 26), the clay minerals have been arranged (like microfacies) in eight groups of roentgenofacies (A to G).

6. COMPARISON BETWEEN THE EVOLUTION CURVE OF MICROFACIES AND THE EVOLUTION CURVE OF ROENTGENOFACIES

These curves show the same trends (fig. B11 and B12). The discontinuities always correspond to a peculiar mineralogic assemblage. The roentgenofacies method is most certainly not as subtle as the microfacies method, but it reveals the link that exists between mineralogy and environment.

Smectites are especially present in external facies, where the hydrodynamism is low (micritic facies). They are present in internal facies too, but more rarely. If we have sparitic facies (outer and inner platform), the mixed layers take the place of the smectites. This fact could be caused by the size of the particles, for the study of the insoluble residue by COULTER (particles counter) shows that the roentgenofacies A is characterised by very thin particles and the roentgenofacies G or D by bigger particles. It seems that the outer platform is used as a barrier which catches the bigger particles. Thus,

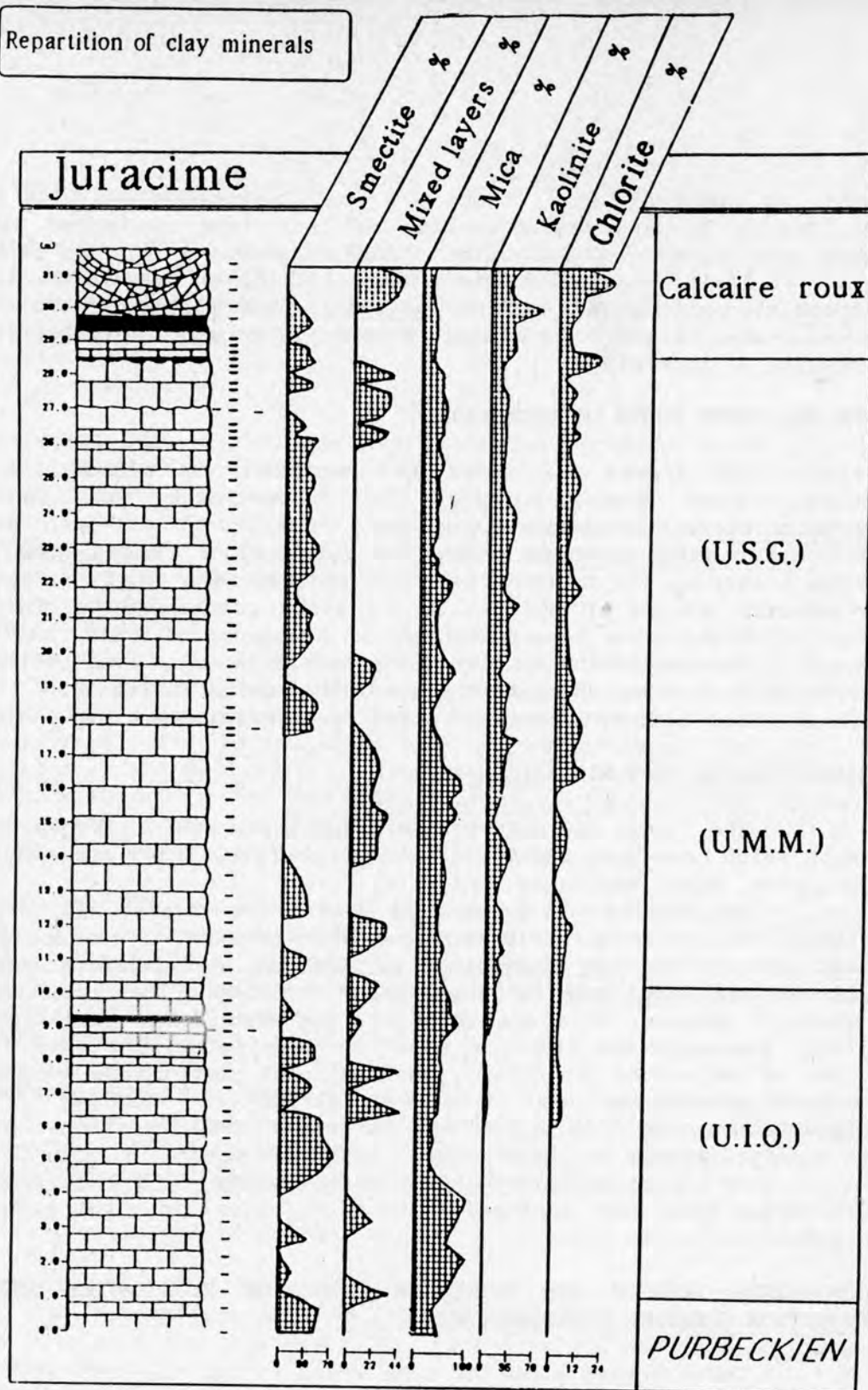


Fig. B 11 : Repartition of the clay minerals on the Juracime profile

for example, there is more and better crystallized mica and kaolinite in the internal platform, and less in more external facies. Kaolinite is not present in the U.I.O. (fig. B11). This could be caused by two things; Kaolinite is absent here because of the too external facies or because the sea is transgressing on the Purbeckian (there is no kaolinite in Purbeckian facies). In regards to the other profiles, the La Chambotte section (DARSAC, 1983), the first explication could be the best. Moreover, kaolinite appears in significant quantities, when the inner platform facies appear. The same remarks are valuable for chlorite. Finding kaolinite (sometimes a high content) in the mixed

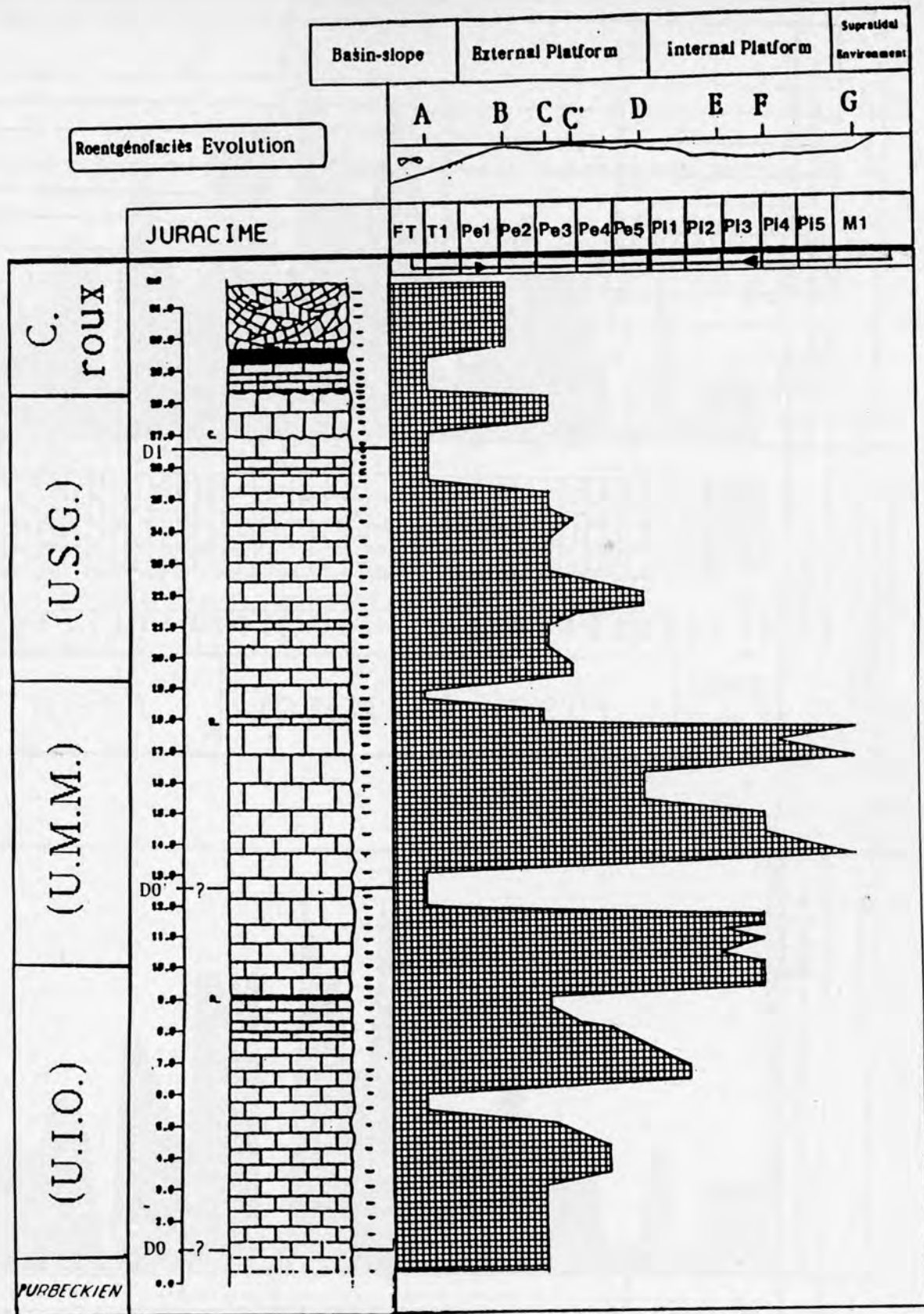


Fig. B 12 : The roentgenofacies evolution

facies is not too surprising, seeing that these facies show major reworkings. Micaceous minerals are relatively constant all along the profile, but they are better crystallized in internal than in external facies. They are less degraded.

All these facts prove that it is very dangerous to make correlations with mineralogy, especially with clays, because they are too closely linked with the environment (kaolinite, for example).

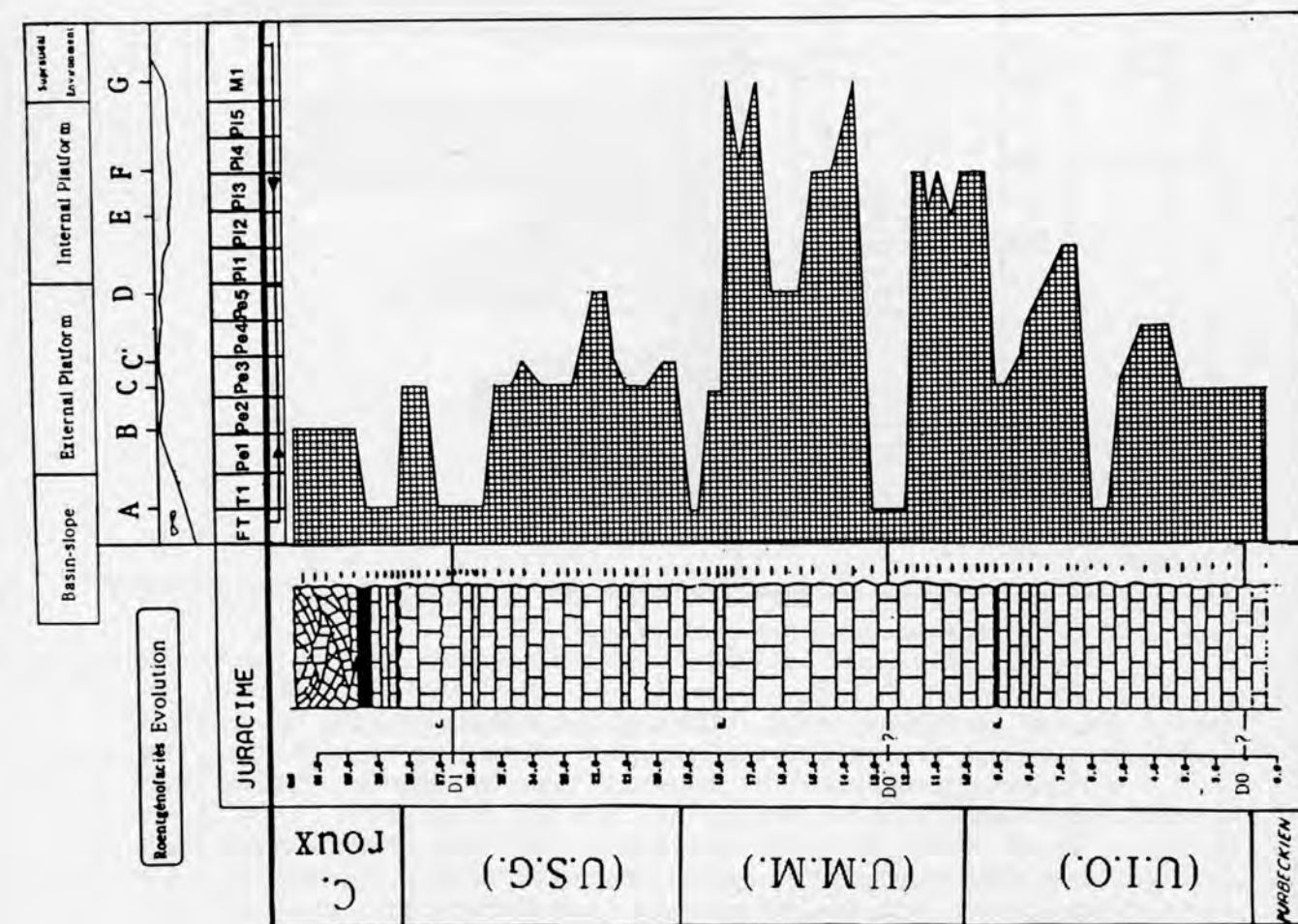
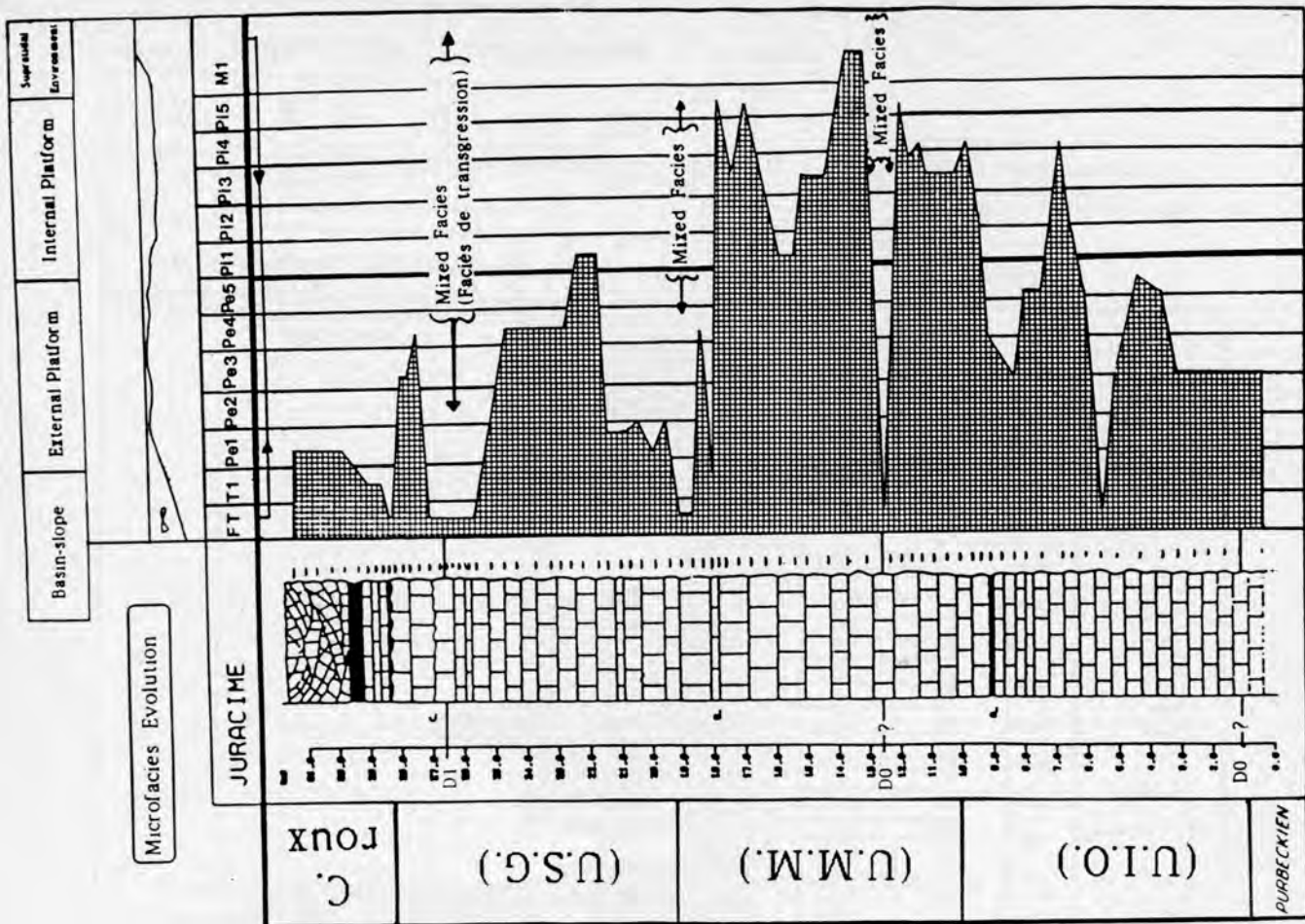


Fig. B 13 : Comparison between the roentgenofacies evolution curve and the microfacies evolution curve

7. COMPARISON OF THE CLAY MINERALS BETWEEN THE CHAMBOTTE SECTION AND THE JURACIME QUARRY

DARSAC (1983) and VIEBAN (1983) have used for the first time the methods of roentgenofacies at the La Chambotte profile. Their use is the same as that described in the introduction, with one difference : they only study the 2 microns fraction.

The repartition of the clay mineral on the platform for Juracime is slightly different from that for La Chambotte : there is more smectite at the Juracime in the inner platform. Kaolinite is sometimes present in outer platform facies, chlorite as well. The mixed layers are especially present in the sparitic facies of the outer platform.

The two first observations could be caused by the fact that the barrier is more efficient at the La Chambotte than at the Juracime. Moreover, the mixed facies observed at the Juracime are not as deep as at the La Chambotte profile; this is perhaps why kaolinite is found in the external facies. In spite of these differences, it remains clear that the environment is a major factor for clay minerals deposits for this type of carbonate platform.

AKNOWLEDGEMENTS

The authors thanks the **Fonds National Suisse de la Recherche Scientifique** for its assistance (Requête n° 2.575.0.84).

SECOND DAY : SATURDAY, SEPTEMBER 5TH

THE LOWER CRETACEOUS CARBONATE PLATFORMS ON THE JURA STABLE DOMAIN (FRANCE)

A. ARNAUD-VANNEAU and H. ARNAUD

With the collaboration of T. ADATTE for the roentgenofacies and
T. BOISSEAU for the Guiers Mort section

THEME

The second day is devoted to the examination of the evolution in time and space of two Lower Cretaceous Platforms ; viz, (i), the Berriasian-Valanginian Platform ; (ii), the Urgonian Platform. Only the first one will be examined in detail, the second one will be examined more precisely on the third day.

FIRST STOP : BERRIASIAN-BARREMIAN OF THE CHAMBOTTE SECTION

Location : Rumilly 5-6 (1/25000)

This section is located along road N 491b which runs from Chaudieu to St. Germain la Chambotte (Fig. C1). This road climbs up the western side of the Chambotte anticline, situated on the eastern side of Bourget Lake. This section was studied in 1983 by C. DARSAC for the Berriasian-Valanginian and by F. VIEBAN for the Hauterivian-Barremian.

1. BERRIASIAN-VALANGINIAN CARBONATE PLATFORM (Fig. C2, C3, C4)

This first platform, occurs above the Upper Jurassic Carbonate Platform and the marls and marly limestones of the Purbeckian which are covered by vegetation. The first outcrop of this first platform is Middle or Upper Berriasian ; the last, Lower Valanginian.

Lithology : the section displays three small calcareous cliffs with intercalated marls and marly limestones.

Vertical evolution : we consider that we have three main sequences, the top of each corresponding approximately to the top of each cliff.

Sequence A (about 30m) is constituted by small shalowing-upward sequences characterized by carbonated deposits of inner shelf environments. The sequences may show the following facies in ascending order : biomicrite-biosparite or packstone with larger Foraminifera, Trocholina and Miliolidae (F8), biomicrite or packstone-wackestone with oncolites (F10), micrite or mudstone with Pseudotriloculina (F11). They end with emersion levels such as beach rocks or micrite-mudstone with bird's-eyes (F10). The most spectacular one is a bank with root molds (B50).

Fauna and age : only benthic microfauna is significant, with the following association Pseudotextulariella courtionensis Brönnimann,

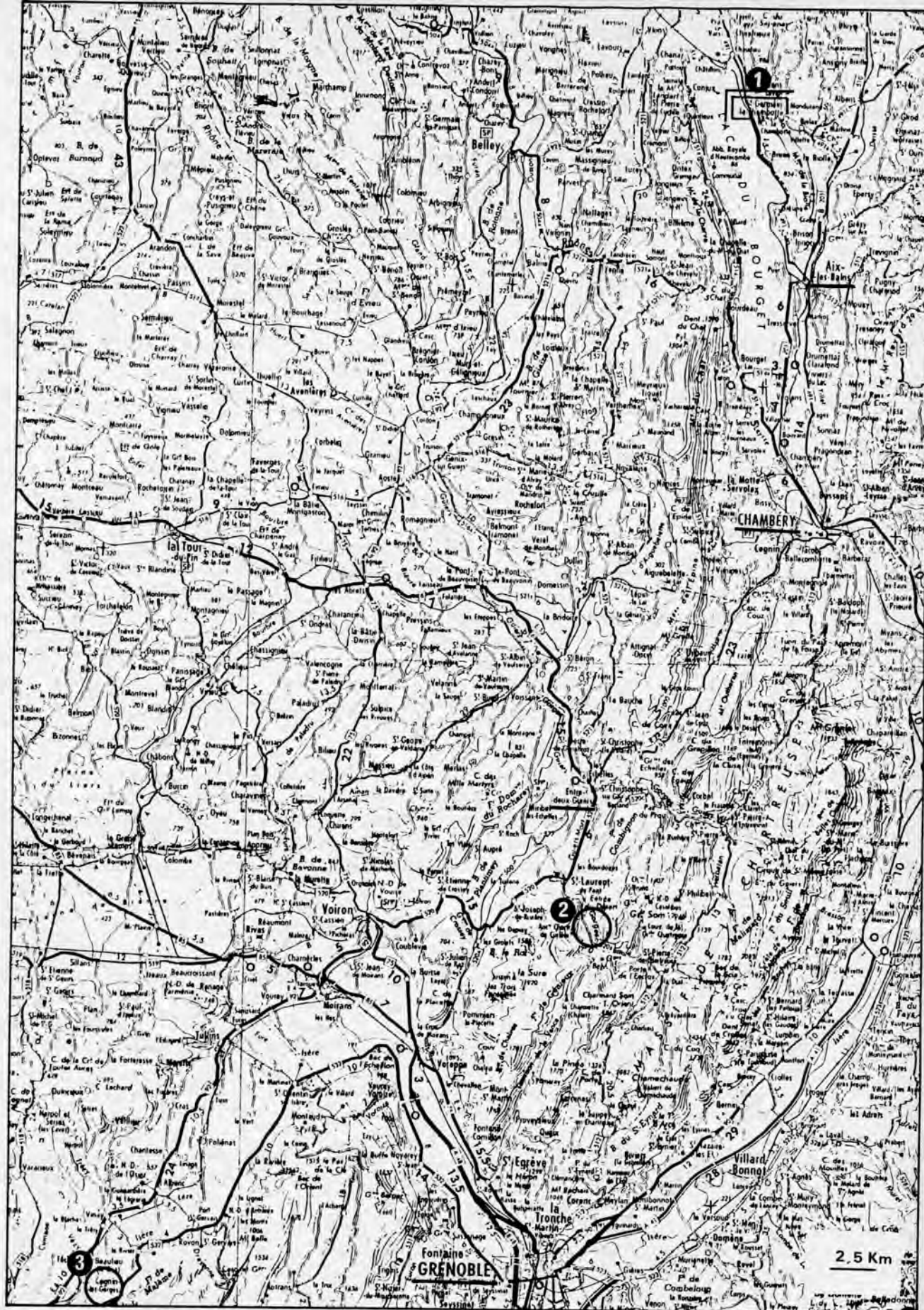


Fig. C 1 : Location map with the position of the second and third day field stops. 1, La Chambotte section ; 2, Le Guiers Mort section ; 3, Les Gorges du Nant section (third day stop).

Coupe de
la Chambotte

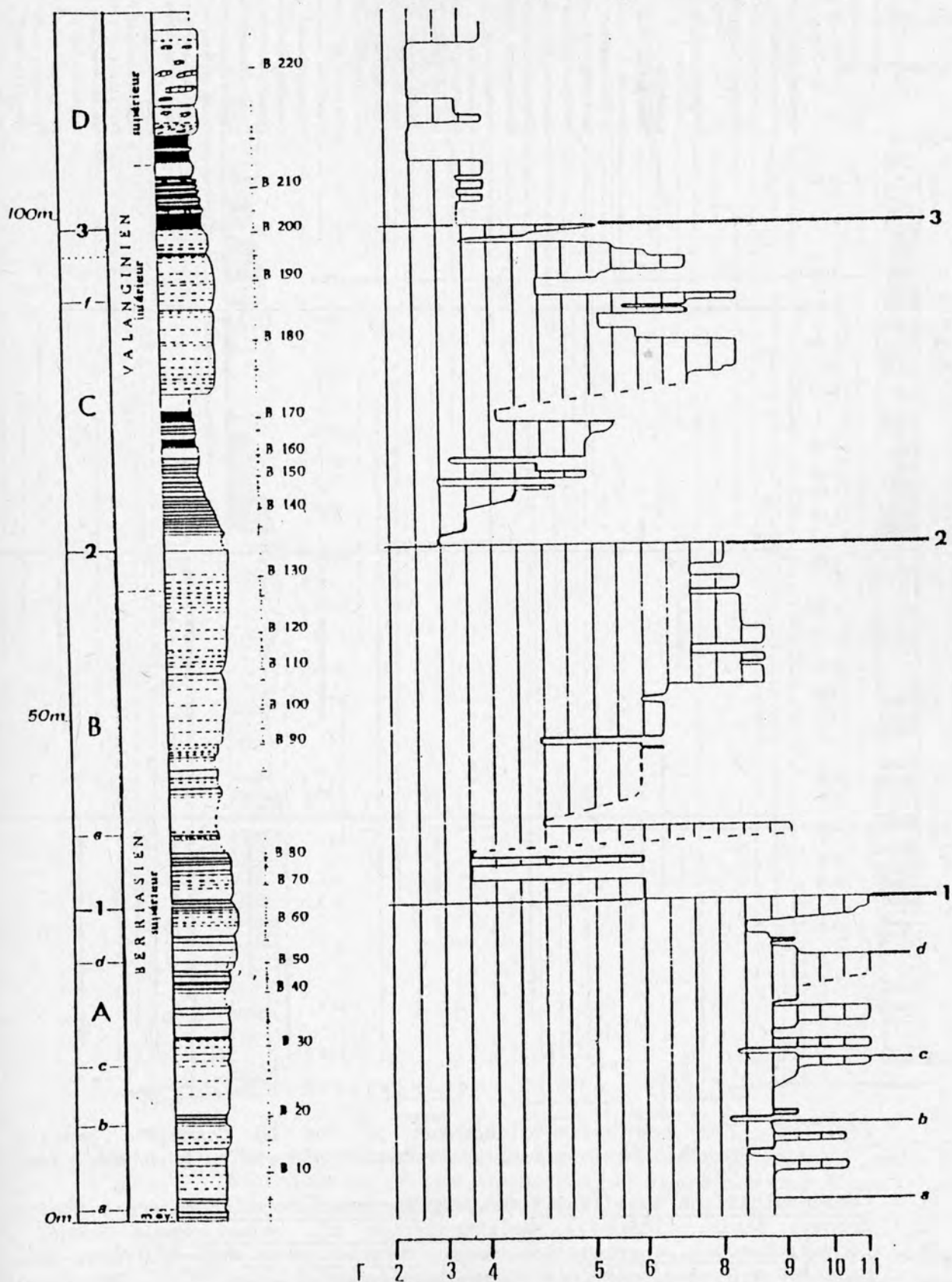


Fig. C 2 : The Berriasian-Valanginian of La Chambotte section.
Microfacies evolution curve (according to DARSAC, 1983)

Coupe de
la Chambotte

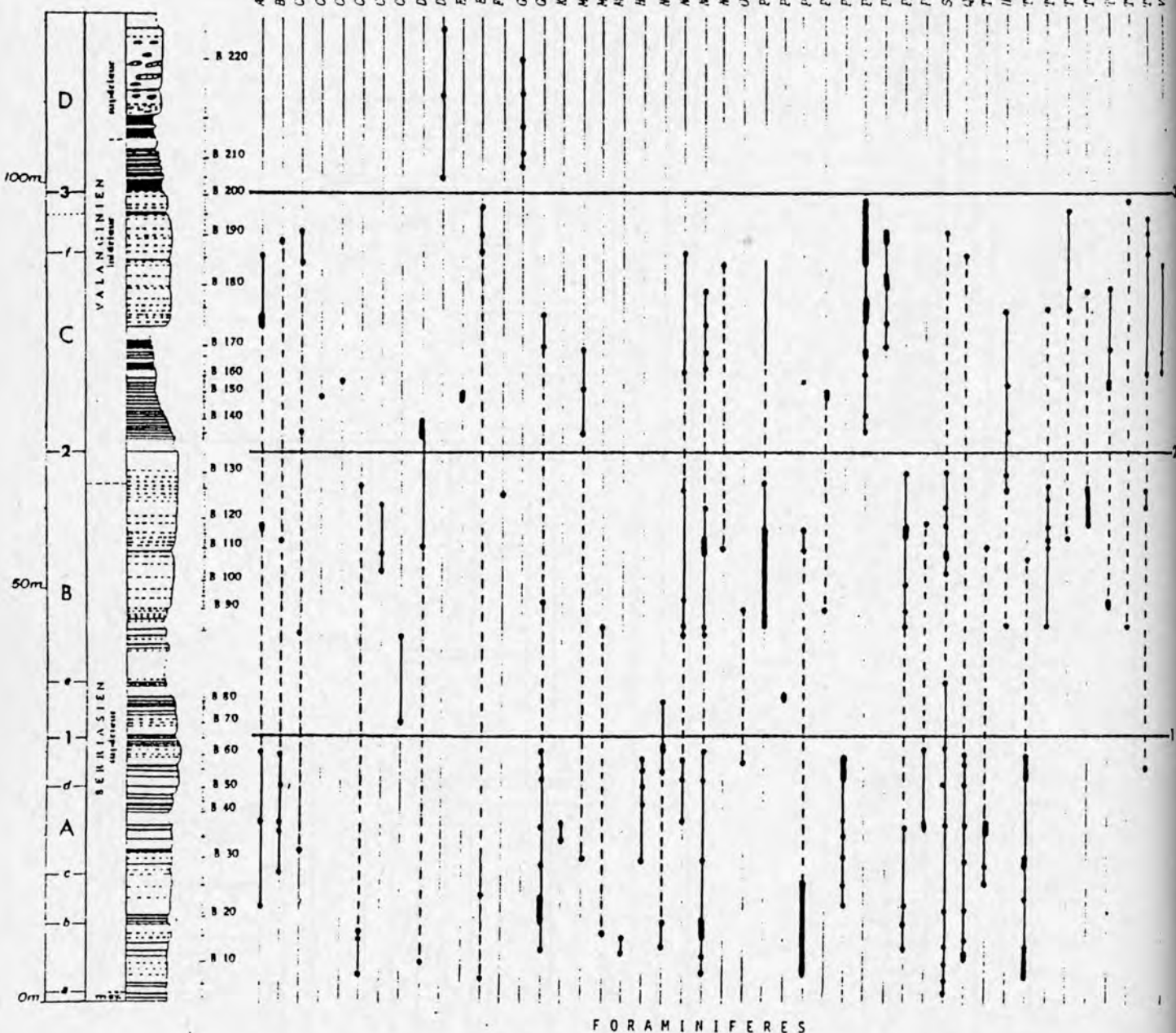


Fig. C 3 : The Berriasian-Valanginian of the La Chambotte section.
Benthic Foraminifera distribution (according to DARSAC, 1983)

Conicospirillina basiliensis Mohler, *Keramosphera allobroensis* Stein., Brönn., Zanin. (B35-B40), *Melathrokerion cf. valserinensis* Brönn. & Conrad, *Danubiella gracillima* Neagu, *Trocholina delphinensis* Arn.-Van., Boisseau & Darsac, and first *Trocholina campanella* Arn.-Van., Boisseau & Darsac ; all species of Middle to Upper Berriasian.

Discontinuity Dil, which corresponds to an important Upper Berriasian deepening, ends the first sequence. This badly-marked lithologic discon

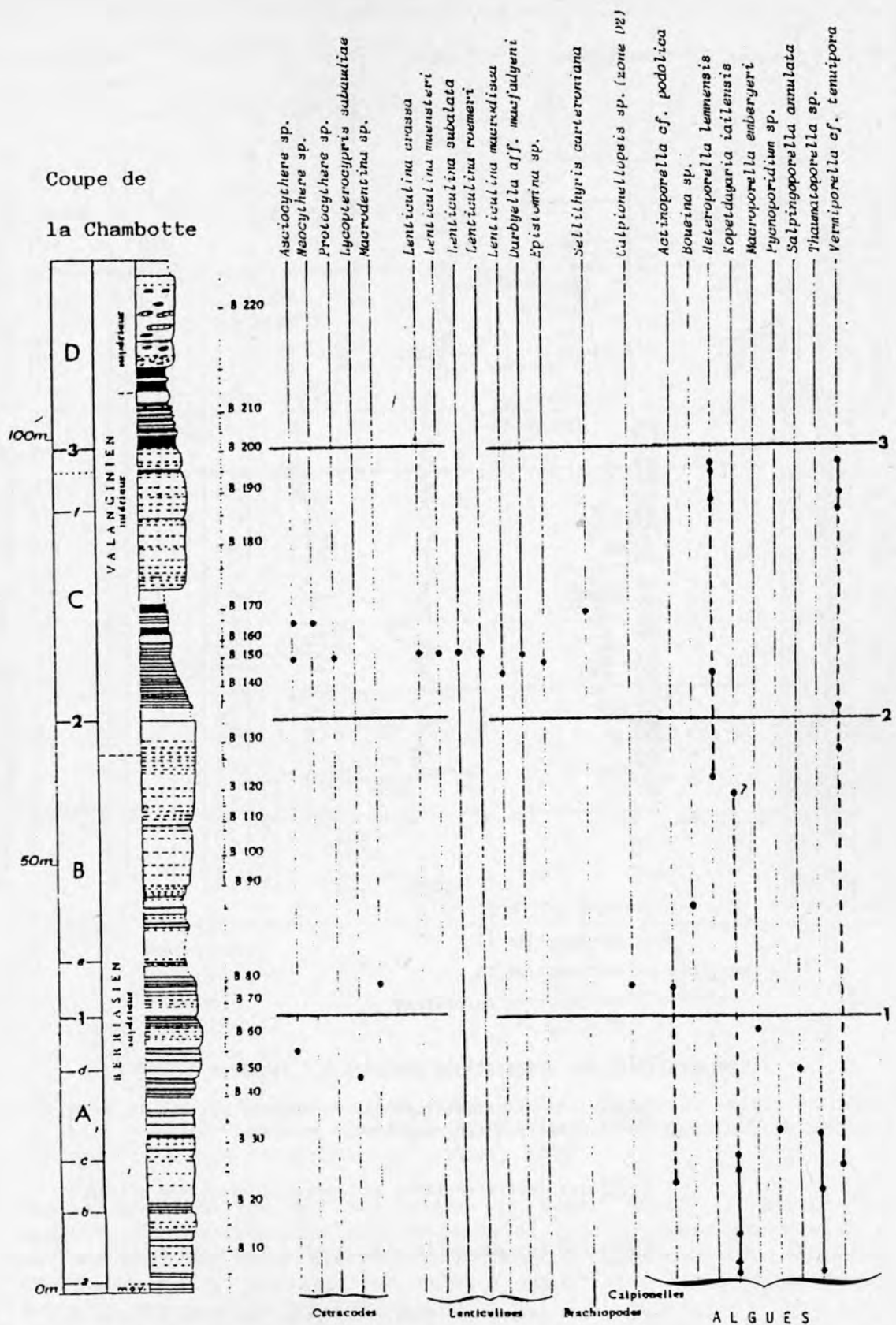
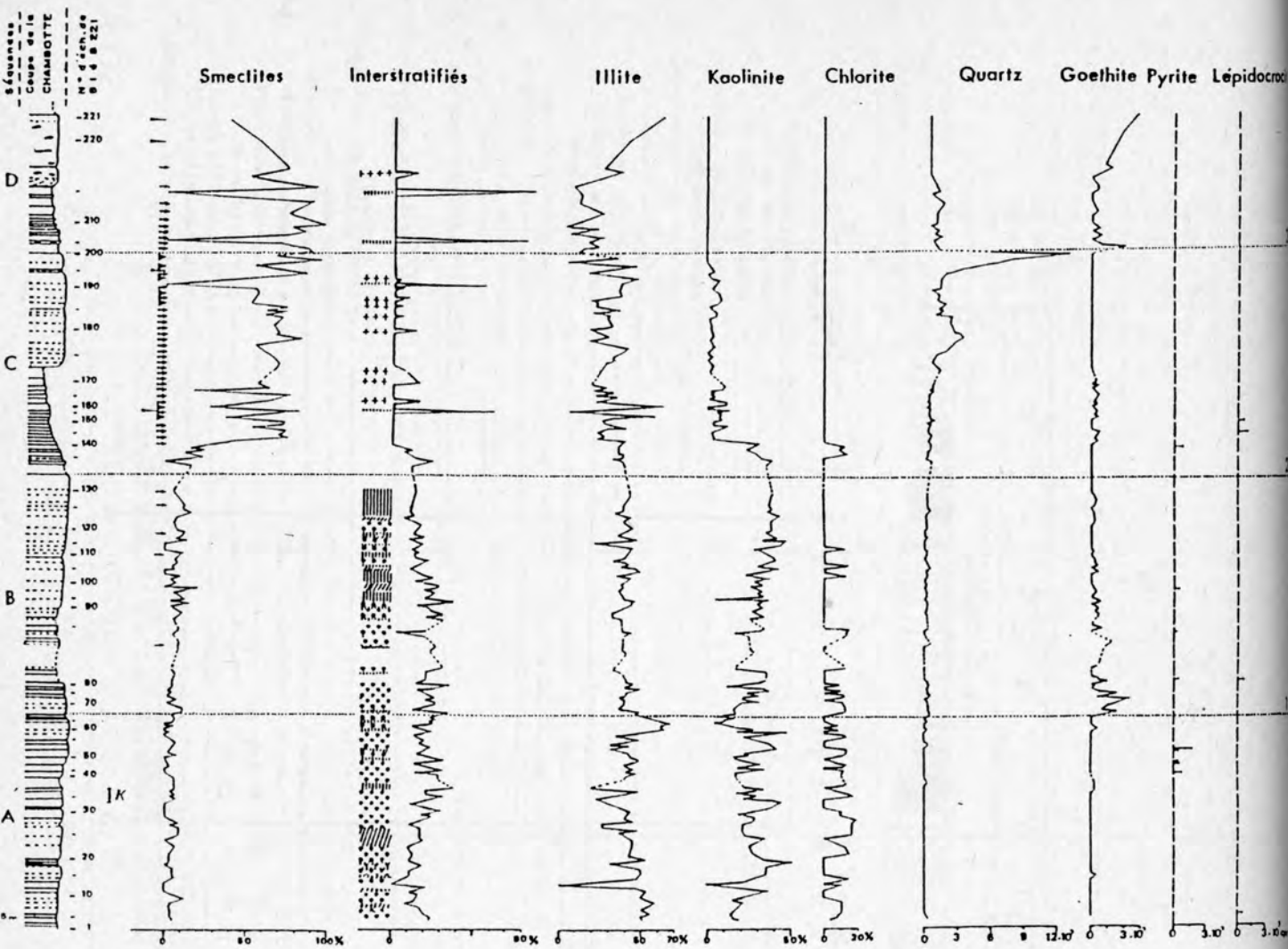


Fig. C 4 : The Berriasian-Valanginian of La Chambotte section.
Distribution of the Ostracodes, Calpionellids and Algae
(according to DARSAC, 1983)

tinuity lies between carbonated facies showing a slight deepening below, and "transgression argillaceous-carbonated facies" with irregular beds above. There are different kinds of transgressive facies : argillaceous limestone characterized by mixed sediments (mudstone mixed with packstone) and/or ferruginised grains, argillaceous limestone where marine fauna (Benthic Foraminifera and Calpionellids) are mixed with Charas, pebbles, etc...



LEGEND

- ▲ Smectite 12
 Smectites : → Smectite 14
 — Smectite en plateau

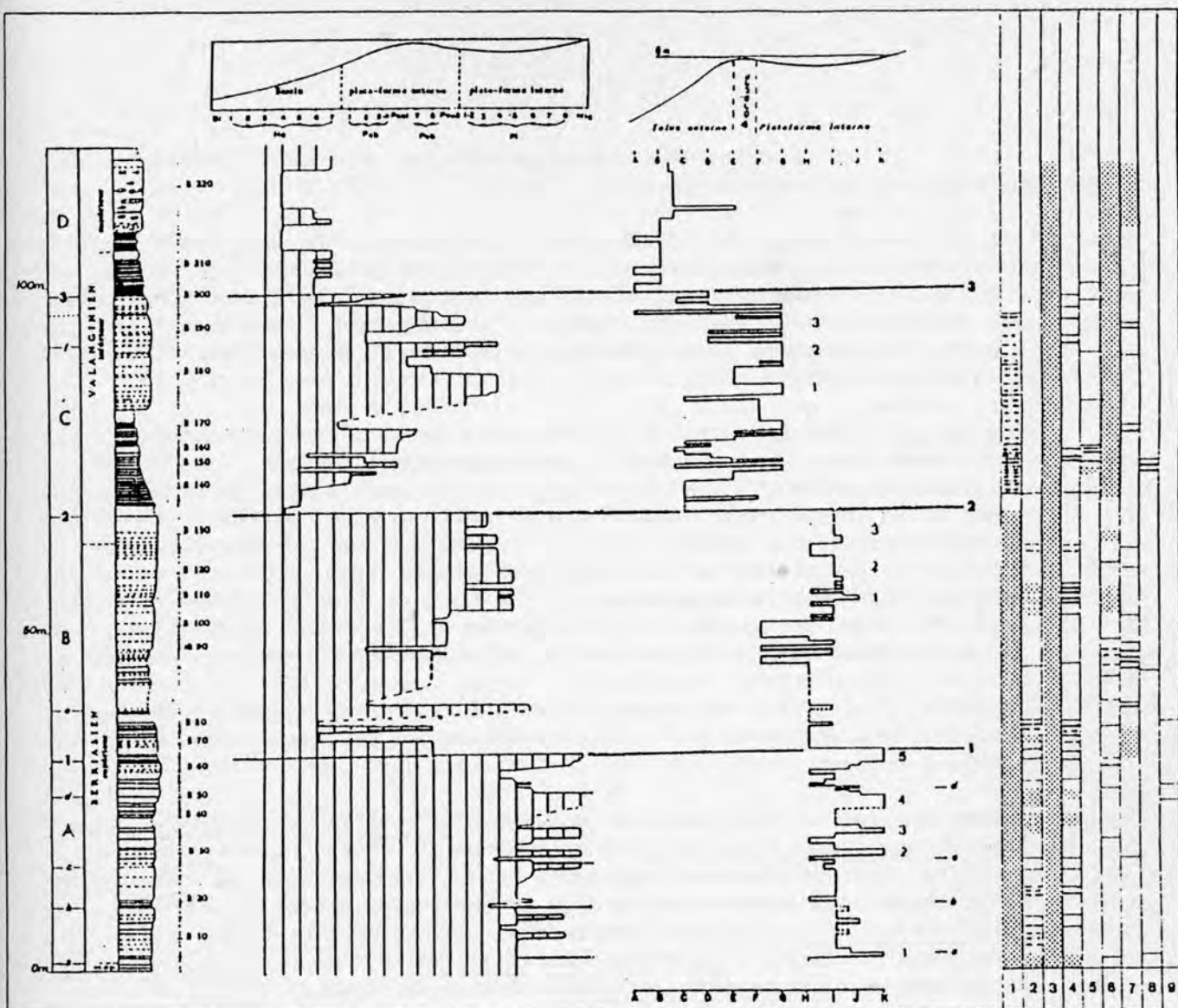
Interstratifiés sur préparations traitées à l'éthylène glycol :

- ▨ les interstratifiés qui ne donnent pas de pic individualisé (léger gonflement de 11 à 17 Å) ;
 ▤ les interstratifiés qui montrent un maximum à 14 Å ;
 ▧ les interstratifiés qui gonflent au delà de 14 Å ;
 ▩ les interstratifiés assez rares qui montrent une sur-structure à 27 Å.

κ] zone stratigraphique dans laquelle a été observé *Keramosphera allobrogensis*.

Fig. C 5 : The clay mineral distribution in the La Chambotte section (according to DARSAC, 1983)

Sequence B (45m) begins with the following "transgression facies", followed by high-energy outer shelf or bank margin limestones : biosparite-grainstone with rounded grains (F5) and oosparite (F6). These



- 1: kaolinite,
2: chlorite,
3: illite,
4: smectite 12,
5: smectite 14,

- 6: quartz,
7: goethite,
8: lépidocrocite,
9: pyrite.

Fig. C 6 : The Berriasian-Valanginian of La Chambotte section. Comparison between the microfacies and roentgenofacies evolution curves (according to DARSAC, 1983)

facies announce the reinstallation of inner shelf (inner platform) depositional environments and deposits of biomicrite packstone with some Rudists (F8). We have never observed emersion layers in this sequence. About 10m below the top, we note a small lithologic discontinuity, probably the same as the Guiers (Dil').

Fauna and age : true pelagic microfauna has been discovered in B72 : *Calpionellopsis* sp. (D2 zone in REMANE). The benthic microfauna is partially renewed : some species such as *Keramosphera allobroensis* Stein., Brönn., Zanin. disappeared previously ; and others such as *Pseudotextulariella courtionensis* Brönnimann, *Conicospirillina basiliensis* Mohler, *Melathrokerion cf valserinensis* Brönn. & Conrad, *Danubiella gracillima* Neagu and *Trocholina delphinensis* Arn-Van., Boisseau, Darsac disappear along the first meters. On the other hand, new species appear : *Pfenderina neocomiensis* (Pfender), *Cribellopsis* n. sp., while *Trocholina campanella* becomes abundant.

All species are characteristic of the Upper Berriasian and perhaps the Lower Valanginian.

Discontinuity Di2, very well-marked, corresponds to the sharp contact between the two sequences. This discontinuity corresponds to a new substantial deepening, most likely at the base of the Lower Valanginian. In the Revard (Subalpine chain), Valanginian Ammonites of the Otopeta-Pertransiens Zone have been discovered (Darsac 1983) 15m above this discontinuity.

Sequence C (30m) is a cyclic sequence and not a rhythmic sequence as are the first two. It begins with "**transgression facies**" consisting of yellowish-brown marls, followed by circalittoral outer shelf sediments such as fine-grained biosparite-grainstone with peloids and small Foraminifera (F3). Above, outer to middle shelf limestones such as biomicrite-biosparite or packstone-grainstone with Bryozoan and Coral debris (F4-5) are found associated with more or less thin beds of marls. As in the previous sequence, these facies announce the reinstallation of infralittoral-inner platform carbonate facies which are represented by biosparite-grainstone with only Rudist debris (F8). After these deposits, the cyclic sequence finishes with facies of more high-energy (biosparite) indicating a slight deepening in comparison with the previous facies.

Fauna and age : Some species such as Feurtillia cf frequens Maync, Haplophragmoides joukowskyi Char., Brönn., Zanin., Ammocycloloculina erratica Jouk. & Favre disappeared ; and another such as Dobrogelina ovidi Neagu disappears afterwards ; and new species appear such as Valdanchella cf miliani (Schroeder), Pseudotextulariella salevensis Char. Brönn. Zanin., Pseudotextulariella sp A Darsac, Eclusia moutyi Septfontaine, Choffatella pyrenaica Peybernès & Rey, Citaella? favrei Char. Brönn., Zanin.. All these species are indicative of the Valanginian.

Discontinuity Di3, marked by a decimeter thick marly layer, corresponds to a new deepening and indicates the end of infralittoral shelf deposits on the platform.

Sequence D (about 20m) begins by circalittoral facies : marly limestone with sponge spicules (F1), marls and marly limestone with Spatangidae debris (F2) and fine-grained biosparite-grainstone with peloids and small Foraminifera (F4). At the top of the sequence we observe a cross-bedded calcarenite, the so-called "Calcaire Roux". This limestone is a grainstone-packstone or biomicrite-biosparite with Bryozoans and Crinoids (F4) with stratiform cherts. This drowned platform facies indicates the submersion then the death of the platform.

Fauna and age : there are no significant macrofauna, and, except for some eroded Lenticulina, Foraminifera are absent from this kind of facies.

Discontinuity Di4 above the "Calcaire Roux", masked by vegetation, corresponds to a new deepening.

Conclusion

This section allows us to observe that the evolution of the Berriasian-Valanginian Carbonate Platform is not continuous, but rather interrupted on several occasions by four transgressive pulses, viz, (1)

Upper Berriasian, (2) between the Berriasian and the Valanginian, (3) Lower Valanginian, (4) upper part of the Lower Valanginian (this age is probable but the Calcaire Roux are still here undated). At the beginning, all sediments of the first sequence A correspond to inner shelf and tidal flat deposits ; however, after the first transgression pulse, tidal facies disappear entirely showing that the platform does not reach emersion levels. The Carbonate Platform then disappears by successive stages, each transgressive pulse submerging the platform more and more, and preventing the reinstallation of the innermost facies.

As a matter of fact, all these transgressive pulses enter into the main transgression of the Upper Valanginian-Hauterivian.

Berriasian-Valanginian sections of the Neuchatel area are highly indicative of the A sequence and D11 discontinuity, but after this discontinuity, the submersion is so great that the inner facies do not reappear and we observe only yellowish-brown cross-bedded calcarenite beds (F4) of the "Calcaire Roux". It is interesting to note that these "Calcaire Roux" are not of the same age as those of the Chambotte and there is a lateral transition to limestones of the B sequence of the Chambotte. The "Calcaire Roux" are only a sedimentary facies.

Roentgenofacies : Fig. C5 and C6 shows the evolution of roentgenofacies. It is clear that these facies show the same evolution as sedimentary facies and are characteristic of paleoenvironments (see § E3, p. 26).

Boron : In the two first sequences, the Boron rate is comprised between 200 and 320 ppm . This rate corresponds to normal marine salinity. In the third sequence, the rate is comprised between 100 and 200 ppm. This decrease is perhaps related either to the sea level rise and the entry of Boreal sea water into the Tethyan sea, or to a climatic change.

Just above the D11 discontinuity, we observe a sudden increase in the rate (about 500 ppm). This high rate has been found in transgressive facies, precisely when true pelagic microfauna (Calpionellids) has been observed. This rate does not correspond to an increase in salinity when Benthic Foraminifera are normal, and the presence of pelagic fauna shows that marine open sea currents exist on the platform. We believe that the abnormal rate denotes a Boron anomaly related to the transgression pulse and other mineralogical anomalies in sediments.

2. HAUTERIVIAN-BARREMIAN CARBONATE PLATFORM (Fig. C7 and C8)

The lower part of Lower Hauterivian is covered by vegetation. In fact, regional outcrops are very similar to those of the Neuchatel area with blue marls ("Marnes Bleues d'Hauterive" Formation) below and calcarenite (biosparite and oosparite) above ("Pierre Jaune de Neuchâtel" Formation). The first outcrop of the section begins by calcarenites.

Lithology : the base of the section which corresponds to marls and marly limestones is covered with vegetation except along the road. The upper part of the section, which corresponds to Urgonian limestone, constitutes the last highest cliff of the Chambotte mountain.

Vertical evolution :

There are two parts in this section, the first one consist of marls, marly limestones and calcarenite, the second one of Urgonian Platform

COUPE DE LA CHAMBOTTE

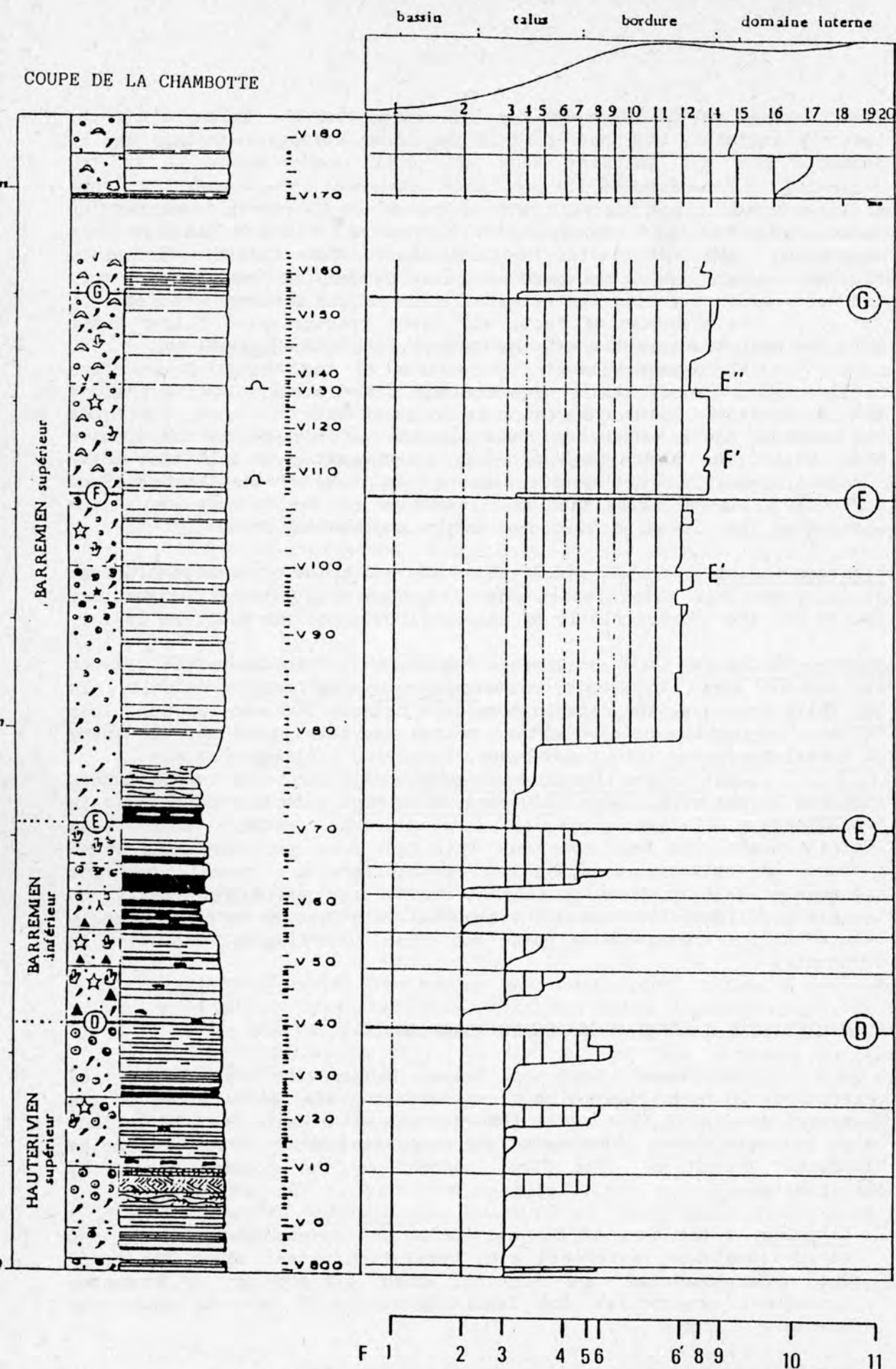


Fig. C7 : The Hauterivian-Barremian of La Chambotte section. The microfacies evolution curve (according to VIEBAN, 1983)

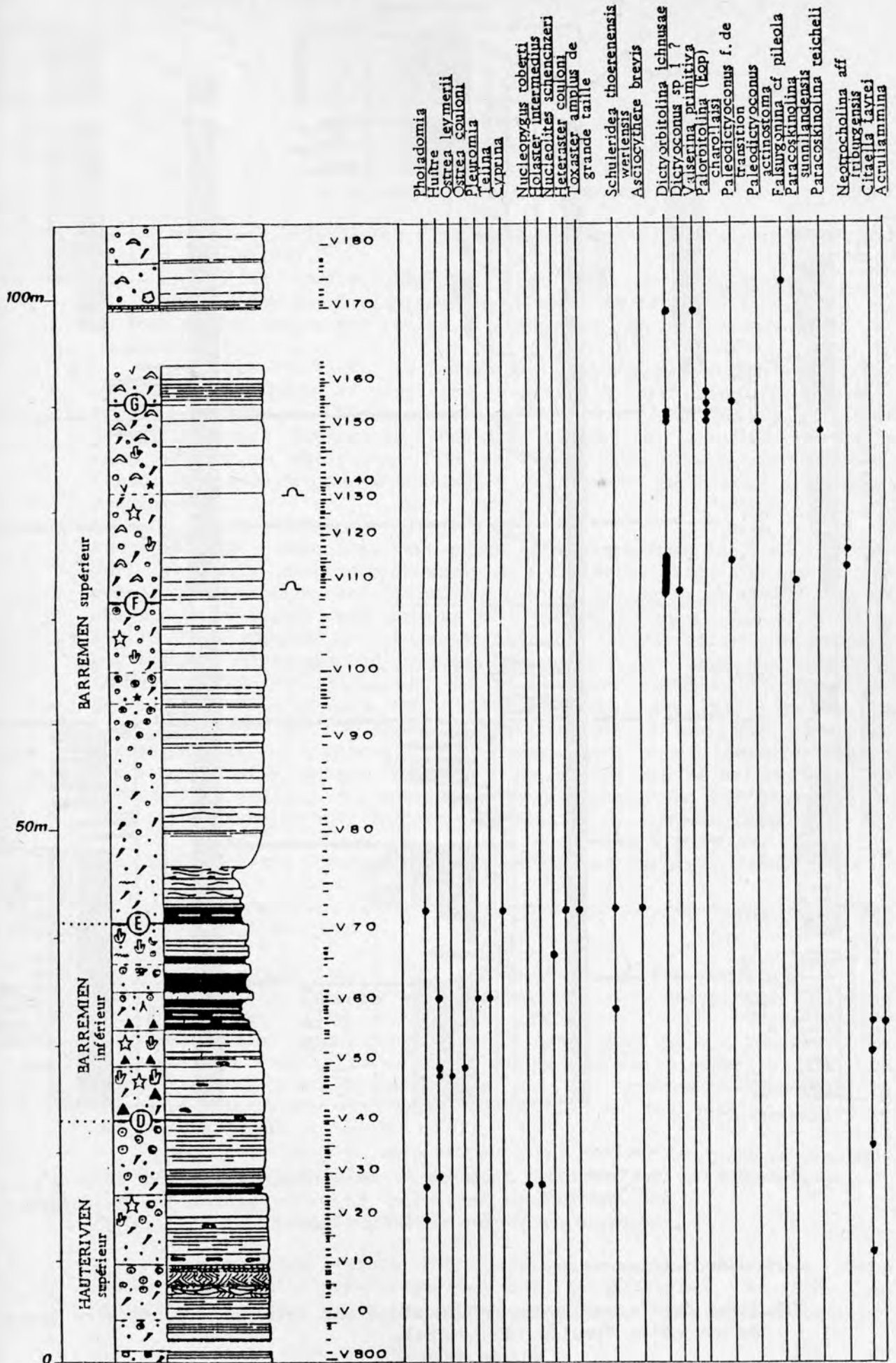


Fig. C 8 : The Hauterivian-Barremian of La Chambotte section: Distribution of the macrofauna, Ostracods and benthic Foraminifera (according to VIEBAN, 1983)

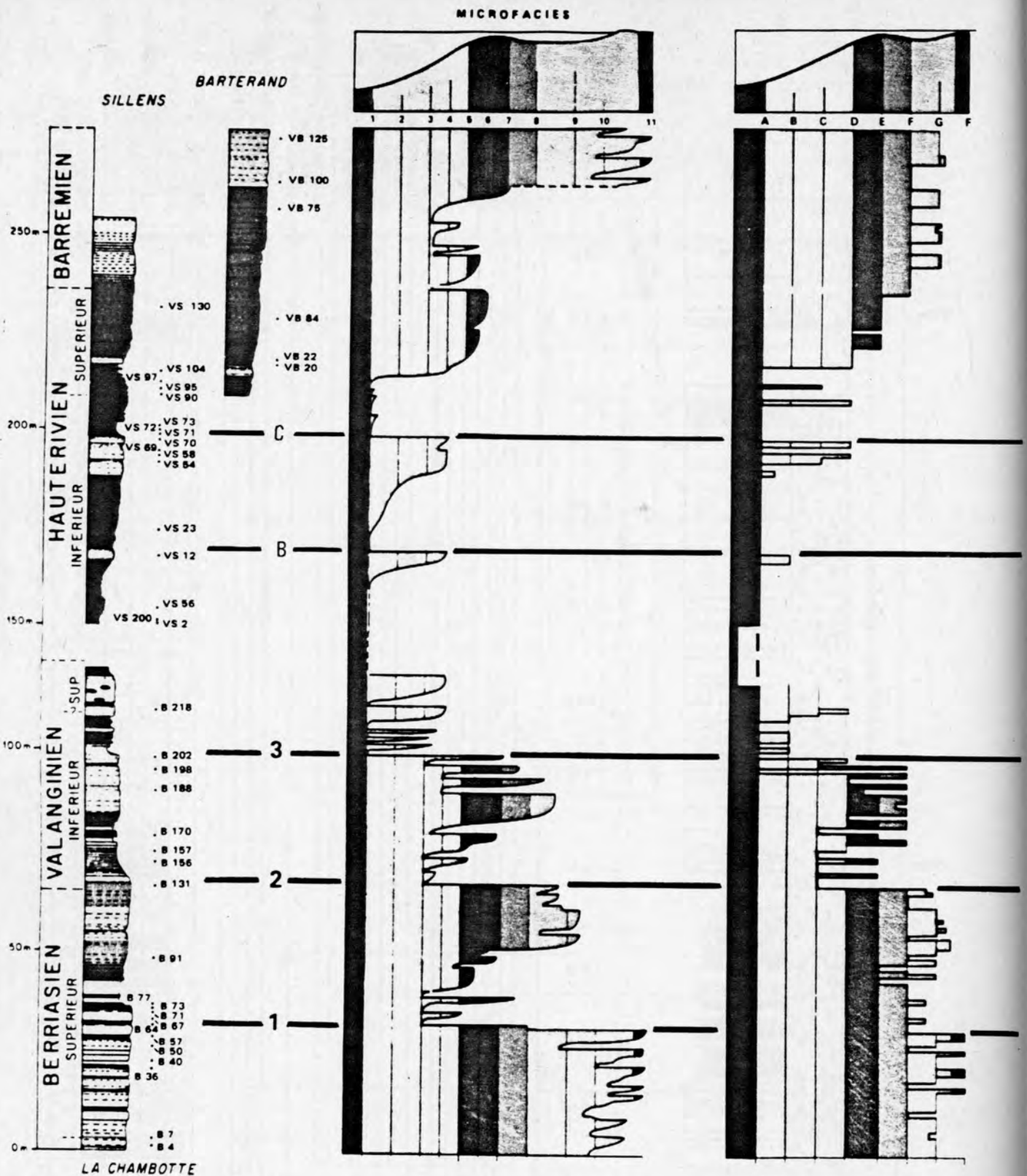


Fig. C 9 : La Chambotte, Sillens, Barterand, three sections showing all the Berriasian- Barremian jurassien series. The Microfacies and Roentgenofacies evolution curves.

carbonated sediments.

2.1. First part : marls, marly limestone and calcarenites, "Pierre jaune de Neuchâtel "facies (40 to 45m).

These facies are distributed in ten small shallowing-upwards sequences. For the first five (about 25m), each sequence displays the following arrangement in ascending order:

- (1) - a thin layer of yellowish-brown marl, sometimes associated with biomicrite-wackestone with Spatangidea (F2),
 - (2) - fine-grained biosparite-grainstone with peloids and rare small Foraminifera (F3),
 - (3) - biomicrite-biosparite, packstone-grainstone with Bryozoan and Crinoid debris (F4),
 - (4) - biosparite and/or oosparite (F5, F6) forming decimeter- or meter-thick banks with sometimes beautiful cross-bedding.
- In some cases, one or two facies of a sequence can be missing.

For the last five (about 20m), each sequence tends to begin with a thicker layer of marl, and ends with biomicrite-biosparite with Bryozoans, Crinoids, Bivalvia debris (F4) ; all the debris is often silicified. We have never observed biosparite or oosparite with cross-bedding in these last five sequences. For this reason , VIEBAN (1983) has placed the discontinuity D between the fifth and sixth sequences.

Fauna and age : Ammonites have never been discovered in this section. Marls and marly limestones contain some Echinoids (Fig. C8) and a very poor microfauna with rare Gaudyina-Dorothia, Cyclogyra sp, Spirillina sp and only one significant species : Citaella ? favrei Char., Brönn., Zanin.. These species are characteristic of circalittoral environments but are not stratigraphic species, except for the last one which is found from the Valanginian to the Hauterivian and probably the Lower Barremian. In her thesis VIEBAN (1983) thought that marly and marly limestone began in the Upper Hauterivian and finished in the Lower Barremian with the D discontinuity corresponding to the boundary between the stages. Today, we are not sure of this idea and we believe that it is possible that all the series may be attributed to the Hauterivian. The Lower Barremian will therefore be missing or extremely reduced.

2.2. Second part : Urgonian Platform carbonated sediments (about 60m)

Carbonated sediments are organized in two sequences ending by discontinuities F and G.

The first sequence (about 25m) begins above the discontinuity E with meter-thick marly limestone with Spatangidea (F2). Above, the following facies appear, in ascending order : (1), fine-grained biosparite-grainstone with peloids (F3) associated on the top with some bryozoans and colonial annelids ; (2), grainstone-biosparite (F5) and oosparite (F6) with cross-bedding ; (3), grainstone-packstone or biosparite-biomicrite with Coral debris (F7) at the base and Bryozoan and Crinoid debris at the top (F4).

Limestones of this sequence are similar to those of previous sequences, but their color is white or beige and not yellowish-brown.

Discontinuity F ends the sequence.

The second sequence (about 20m) displays infralittoral inner shelf facies with grainstone-biosparite with Orbitolinidae, Echinids and Rudists debris (F8). It is the first appearance of this kind of facies.

Discontinuity G interrupts this sequence.

A third sequence begins above, but it is interrupted by erosion.

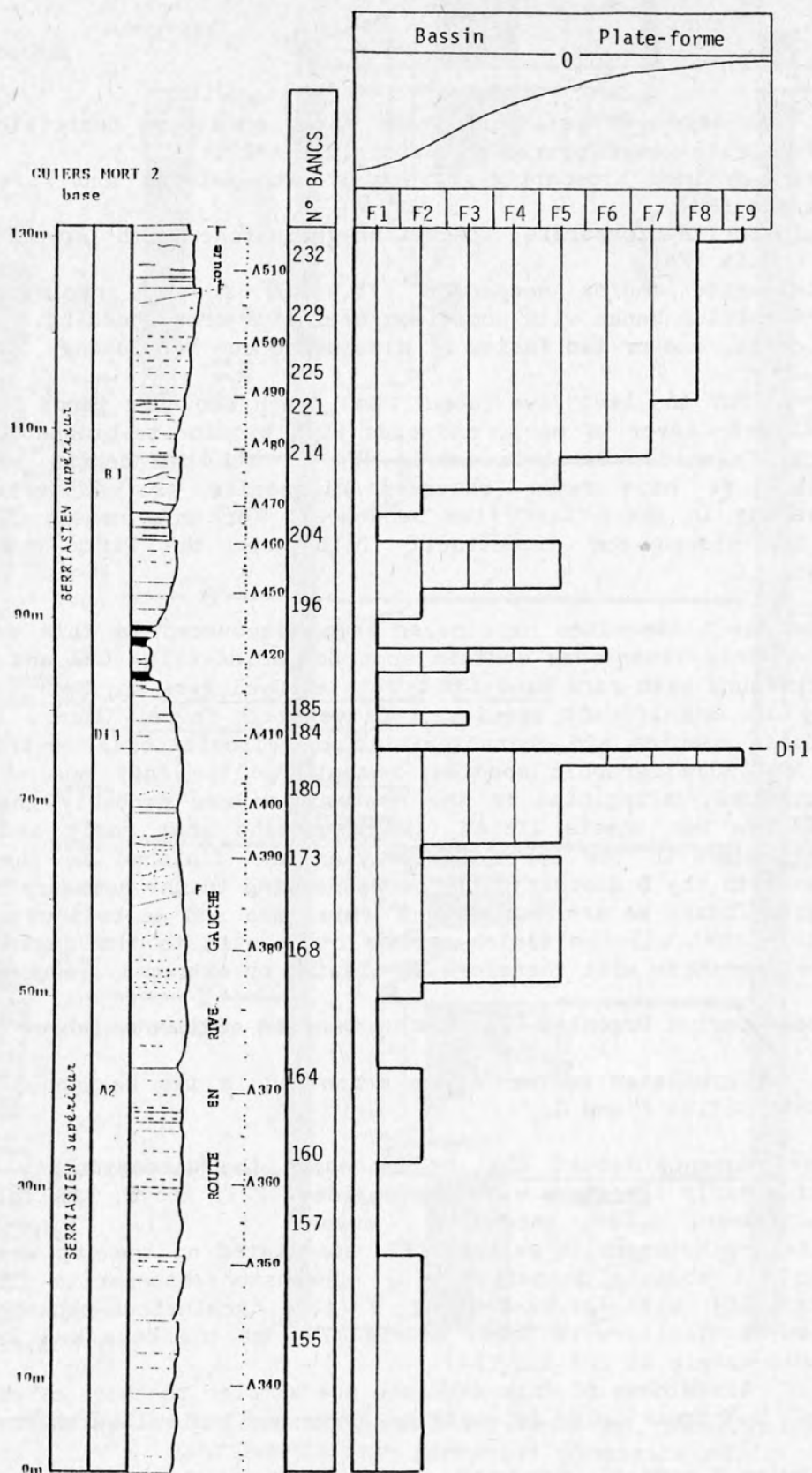


Fig. C 10 : The Upper Berriasian of the basal Guiers Mort 2 section.
The microfacies evolution (according to BOISSEAU, 1987)

Fauna and age : No significant microfauna are discovered in the first sequence. We have observed only some Trocholina (T. molesta Gorbatchick and T. odukpaniensis Dessauvage) and Arenobulimina (A. cochleata Arn.-Van.), all of which are characteristic of paleoenvironments of facies F5 and F6.

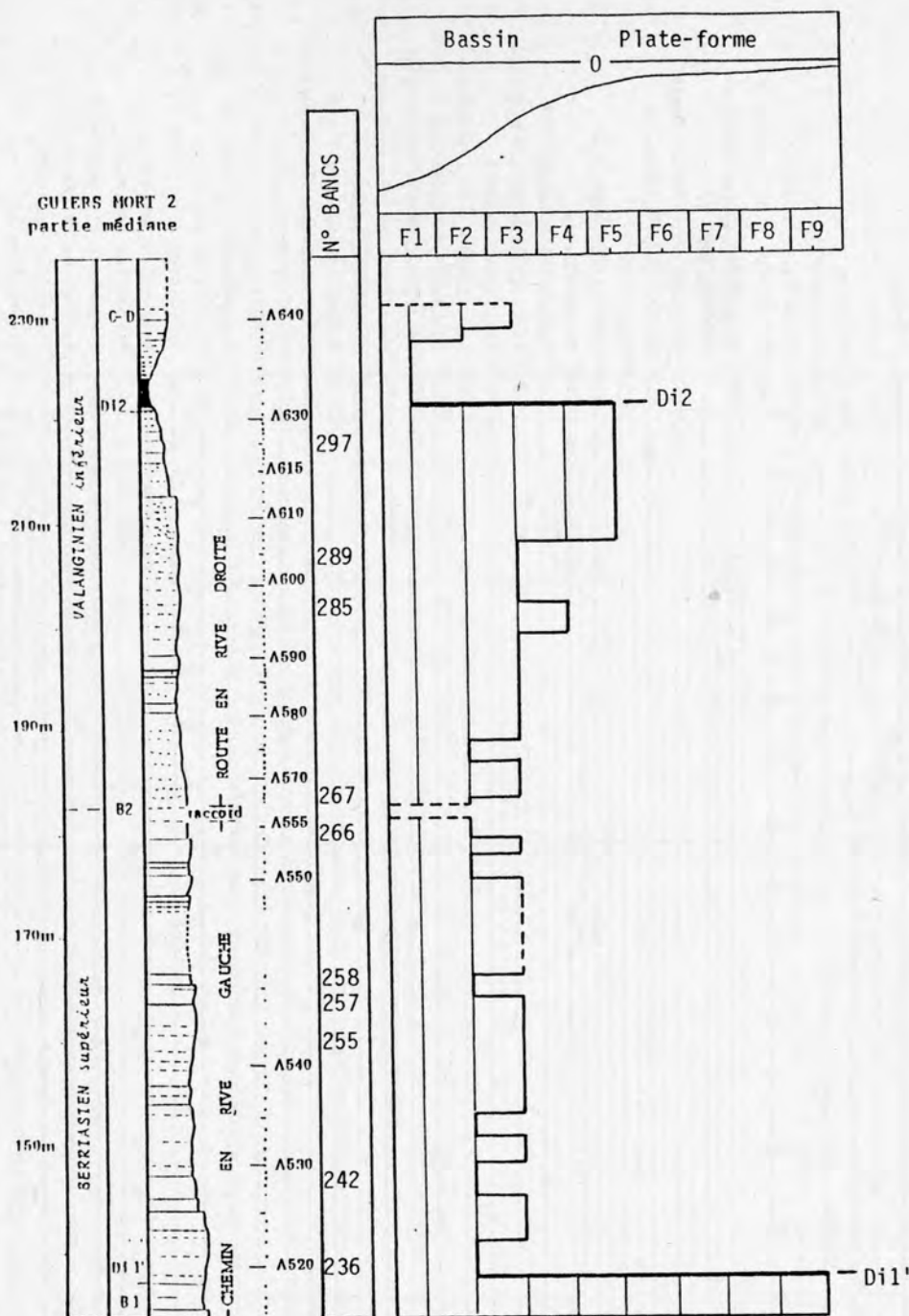


Fig. C 11 : The Upper Berriasian-Lower Valanginian of the middle Guiers Mort 2 section. The microfacies evolution curve (according to BOISSEAU, 1987)

In the second sequence, there are many species (Fig.C 8), and two significant species : Palorbitolina (Eopalorbitolina) charollaisi Schroeder & Conrad and Paracoskinolina reicheli (Guillaume) which is one of the index species of the Upper Barremian. In comparison with Vercors sections, we believe that both sequences are in the Upper Barremian and correspond to sequence Bs2, which is the installation sequence of the Urgonian platform.

Conclusion : the section allows us to observe the sudden appearance of a new carbonate platform, viz **Urgonian Platform**. All through the Hauterivian deposits, many small sequences end with high energy facies, such as grainstone-biosparite, or oosparite, but all the sequences are interrupted by a small deepening, and no inner or middle shelf

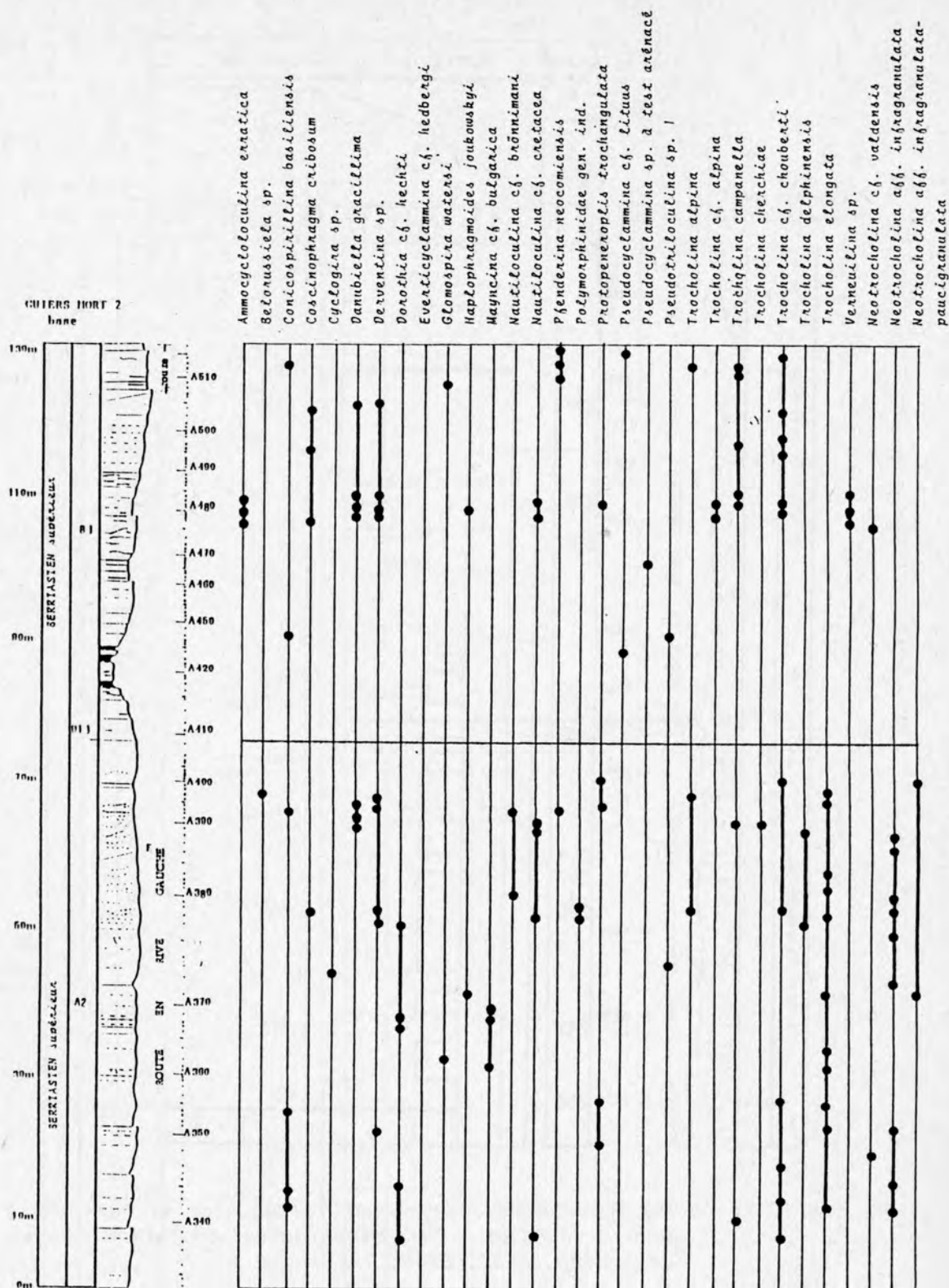


Fig. C 12 : The Upper Berriasian of the basal Guiers Mort 2 section.
Distribution of the benthic Foraminifera
(according to BOISSEAU, 1987)

carbonated deposits appear above. This platform appears only after the discontinuity E, and we think that this installation is synchronous from the Jura to the Vercors.

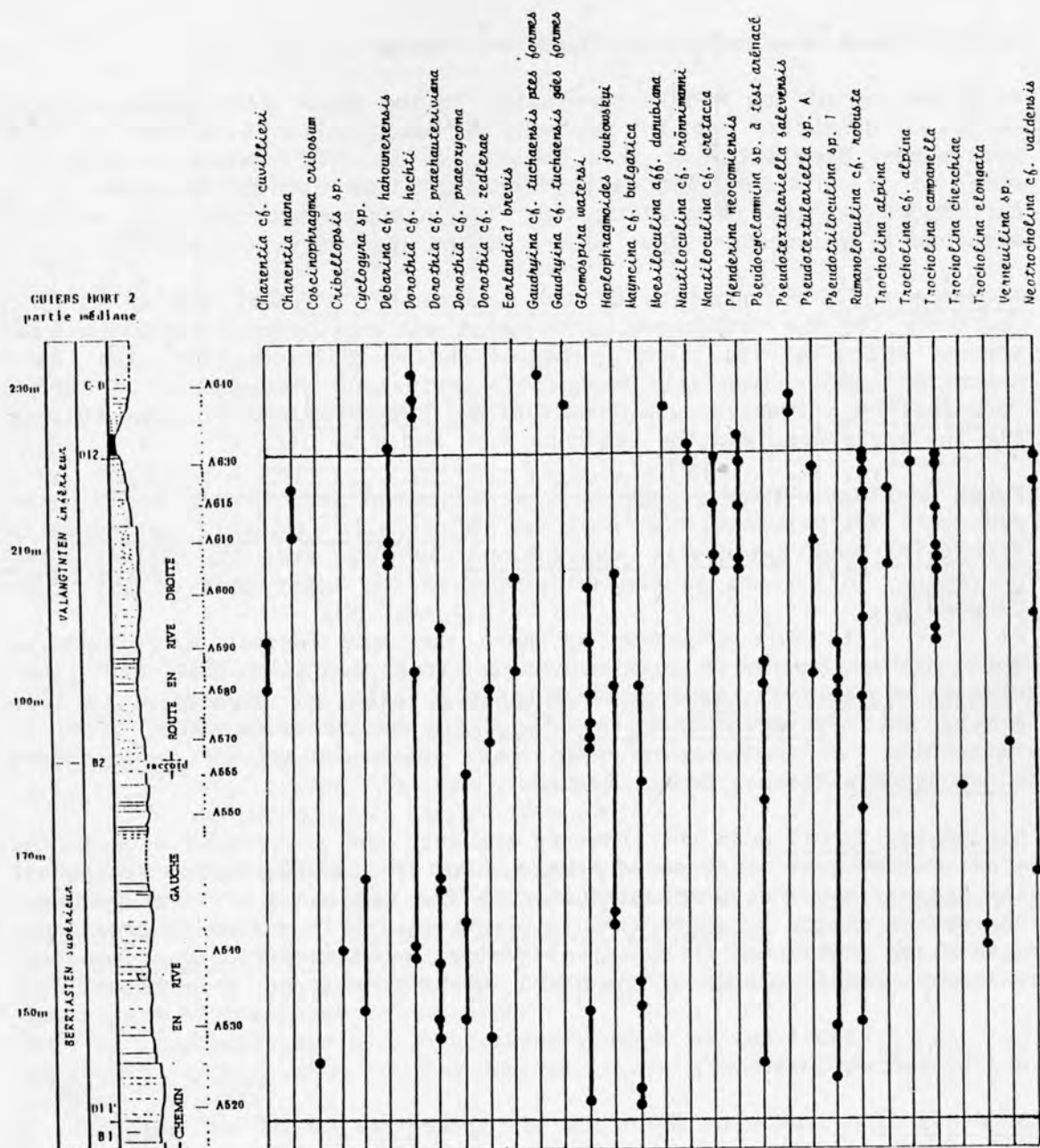


Fig. C13 : The Upper Berriasian-Lower Valanginian of the middle Guiers Mort 2 section. Distribution of the benthic Foraminifera (according to BOISSEAU, 1987)

SECOND STOP : THE BERRIASIAN-VALANGINIAN OF THE GUIERS MORT SECTION

Location : Grenoble 3-4 and Domène 1-2 (1/25000)

This section is located along road D 520b which runs from St. Laurent du Pont to St. Pierre de Chartreuse (Fig. C1). The road follows the Guiers Mort valley. This section is studied by T. BOISSEAU.

Vertical evolution (Fig. C10 to C13)

From the Late Jurassic (Tithonique) to the Middle Berriasian, sediments (170m for the Lower and Middle Berriasian) consist of marls and argillaceous limestones of pelagic facies with Ammonites and Calpionellids, associated with some allochthonous calcarenite beds (sand flow) coming from the next platform. Carbonate platforms do not

exist in this area before the Upper Berriasian.

From the top of the Middle Berriasian to the Upper Berriasian, pelagic sediments disappear and are replaced by calcarenites with more or less well-sorted bioclasts. At this moment, we believe that we are on the slope of the platform and we find normal slope carbonated sands which correspond to the progradation of the platform. At the end of the sequence A, we consider that we are on the edge of this platform.

Sequence A (240m) consists of two sequences A1 (140m) and A2 (100m), beginning, in the both cases, with marls and argillaceous limestone with sponge spicules (F1) and pelagic fauna (Calpionellids and rare Ammonites) and ending with biosparite-grainstone with debris of larger Foraminifera, Bivalvia and Corals (F4). Discontinuity Di0' is between the two sequences, and the sequence A is ended by Di1.

Fauna and age. The age of this sequence is well known due to the discovery of Calpionellids such as Calpionella alpina, Tintinopsella carpathica and Remaniella cadischiana and an Ammonite Malbosiceras pouyannei. This fauna is characteristic of the lower part of the Upper Berriasian.

In this sequence, we have the same benthic microfauna as that in the Chambotte section, except for the fact that the first Pfenderina neocomiensis (Pfender) appears below the discontinuity Di1, and we have Protopeneroplis trochangulata Septfontaine which lived in this kind of environment. We have never observed Keramosphera allobrogensis Stein., Brönn., Zanin..

Discontinuity Di1 ends the previous sequence and is located between the massive limestone of sequence A below, and the "transgression facies" of the base of sequence B above. There are the same kind of "transgression facies" as in the Chambotte : yellowish-brown marls and marly limestones with mixed sediments, ferruginised grains, pebbles. As in the Chambotte, there are Calpionellids of the D2-D3 REMANE Zone (Upper Berriasian).

Sequence B (130m) may be clearly subdivided into two sequences, B1 (50m) and B2 (about 80m).

Sequence B1 begins with about 10m of "transgression facies" capped by up to one meter thick oolitic limestone which is overlain by a thin layer of marl. The facies above consists of biomicrite-biosparite or grainstone-packstone with rounded grains (F5), followed by a Coral bioherm (F7) (A480-A490). The sequence ends with biomicrite-packstone with Rudists (F8). We believe that we are still on the margin of the platform.

Di1' discontinuity suddenly interrupts sequence A.

Sequence B2 consists of more embedded limestone intercalated with slightly argillaceous limestone. This formation contrasts with the following B1 which is a massive formation forming a cliff. The facies include biomicrite or wackestone-packstone with Echinoid debris (F2), fine-grained biosparite-grainstone (F3), biosparite-grainstone with rounded debris (F5). These sediments do not correspond to true platform facies, and we believe that they indicate the end of progradation of the platform and the beginning of its disappearance by submersion before the Di2 discontinuity.

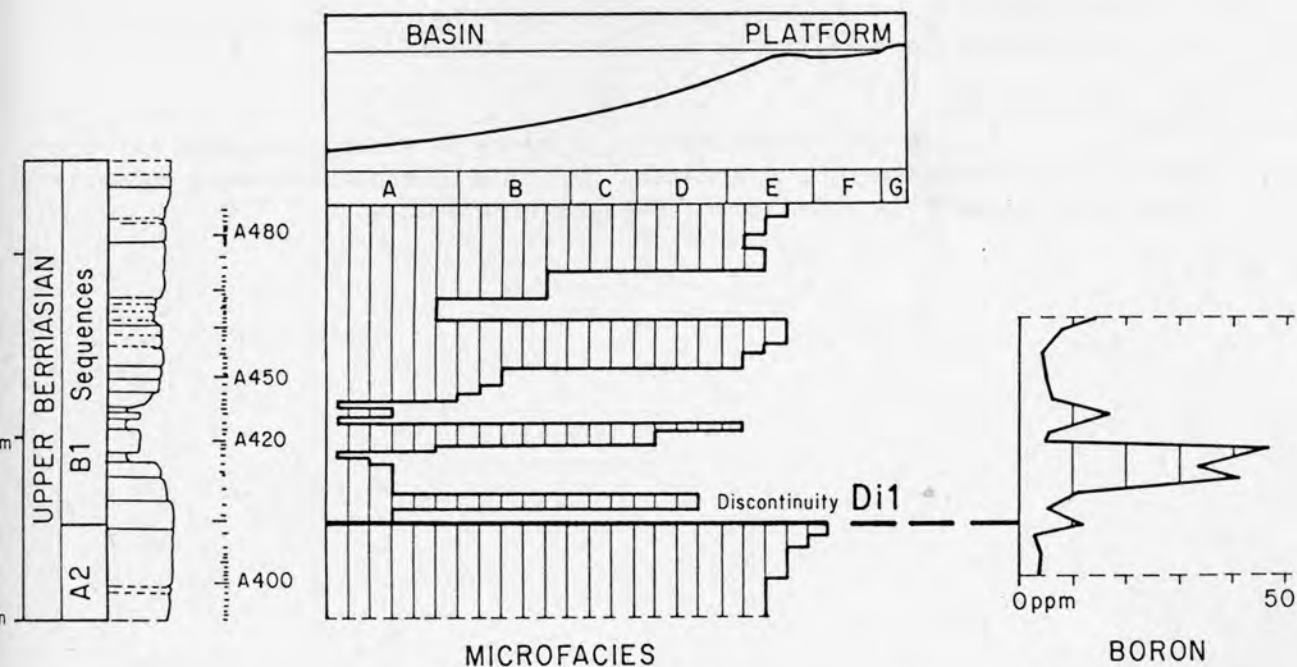


Fig. C 14 : Guiers Mort 2 section. Comparaison between the Microfacies evolution curve and the Boron content curve. We observe an increase in the Boron content just above the Di1 discontinuity. The Boron is analysed here using a new method. For this reason, the Boron content in ppm is different from that estimated with the standard method.

Fauna and age of Sequence B : the benthic microfauna is the same as in the Chambotte, but we may note the disappearance of Conicospirillina basiliensis Mohler, Protopeneroplis trochangulata Septfontaine and Danubiella gracillima Neagu just above the Di1' discontinuity. The age is the same as in the Chambotte : Upper Berriasian, and perhaps the lower part of the Lower Valanginian.

Discontinuity Di2 is as well-marked as in the Chambotte section and is overlain by marls.

Sequence C does not have inner platform facies as in the Chambotte, but shows deeper circalittoral facies such as marls and marly limestones (facies F1, F2), fine-grained biosparite grainstone (F3) and biosparite-grainstone with Bryozoans and Crinoids (F4) ("Calcaire Roux"). In this case, the "Calcaire Roux" are older than in the Chambotte, but younger than in the Neuchâtel area. These calcarenites correspond to reworked carbonated sand.

Fauna and age : we observe the same microfauna as in the Chambotte, associated with a circalittoral foraminifer which lived in the depositional environment of facies F1 or F2 : Gaudryina cf tuchaensis Antonova. We believe that it is of the same age : Lower Valanginian.

Conclusion :

This section shows evidence of :

- (1) sedimentation on the slope of the platform and on its margin when it was the most regionally extended,
- (2) a transition from inner platform facies (the Chambotte) to slope or margin facies,

- (3) the recording of deepenings of the same type on the inner platform (the Chambotte section) as well on its margin.

Boron (Fig. C14)

As in the Chambotte, we observe a sudden increase in the rate just above the Dil discontinuity. This phenomenon shows clearly that this anomaly is related to transgression pulse.

THIRD DAY : SUNDAY, SEPTEMBER 6TH

URGONIAN PLATFORM IN THE DAUPHINOIS BASIN INSTALLATION, EVOLUTION AND DISAPPEARANCE

A. ARNAUD-VANNEAU and H. ARNAUD

THEME

We have left the Jurassian Platforms to go to the Dauphinois Basin where pelagic sediments were deposited from the Lower Lias. This day is devoted to the examination of the installation, evolution and disappearance of the Urgonian platform in an area hitherto devoid of shelves.

FIRST STOP : SECTION OF CIRCALITTORAL SEDIMENTS BEFORE THE INSTALLATION OF THE URGONIAN PLATFORM. HAUTERIVIAN-BARREMIAN SECTION OF THE "GORGES DU NANT"

Location : Vif 1-2 (1/25000) (Fig. D1)

This section is located at the foot of the Urgonian cliff, at the bottom of the "Gorges du Nant".

Lithology : Marls and marly limestones at the bottom of the Gorges and argillaceous limestones forming the first small cliff just under the high Urgonian cliff.

Vertical evolution (Fig. D2, D3 and D4)

The section may be subdivided into two parts, (i) marls and marly limestones at the base, (ii) argillaceous limestones above.

1. FIRST PART : MARLS AND MARLY LIMESTONES (20m)

We have four small sequences (3 to 6m thick) associating a bed of marl and a wavy nodular bed of marly limestone ("calcaire à miches"). At the base of the section, the facies consist of biomicrite-wackestone with sponge spicules (F1) ; above, we have biomicrite-wackestone with Spatangidae (F2). These sediments correspond to circalittoral mud deposited in the Dauphinois basin where vasicol fauna lived. This fauna is constituted by many Spatangidae (*Toxaster amplus*) and some *Pinna*, *Pholadomya* and *Panopea* associated with small agglutinated Foraminifera (*Gaudryina tuchaensis* Antonova, *Belorussiella textilarioides* (Reuss), *Boliviniopsis bernardi* (Chevalier), *Glomospira glomerosa* Eicher, *Earlandia? brevis* Arn-Van., *Citaella? favrei* Char., Brönn. Zanin., *Choffatella cf tingitana* Hottinger, *Cyclogyra* sp., *Spirillina* sp.).

Age : Two Ammonites of the *ligatus* Zone have been discovered : *Crioceratites gr duvali* and *Plesiospitidiscus cf ligatus* ; the section thus begins in the last part of the Upper Hauterivian (*Pseudothurmannia angulicostata* has been discovered at the same level in the Balcon des Ecouges section, near the Gorges du Nant).

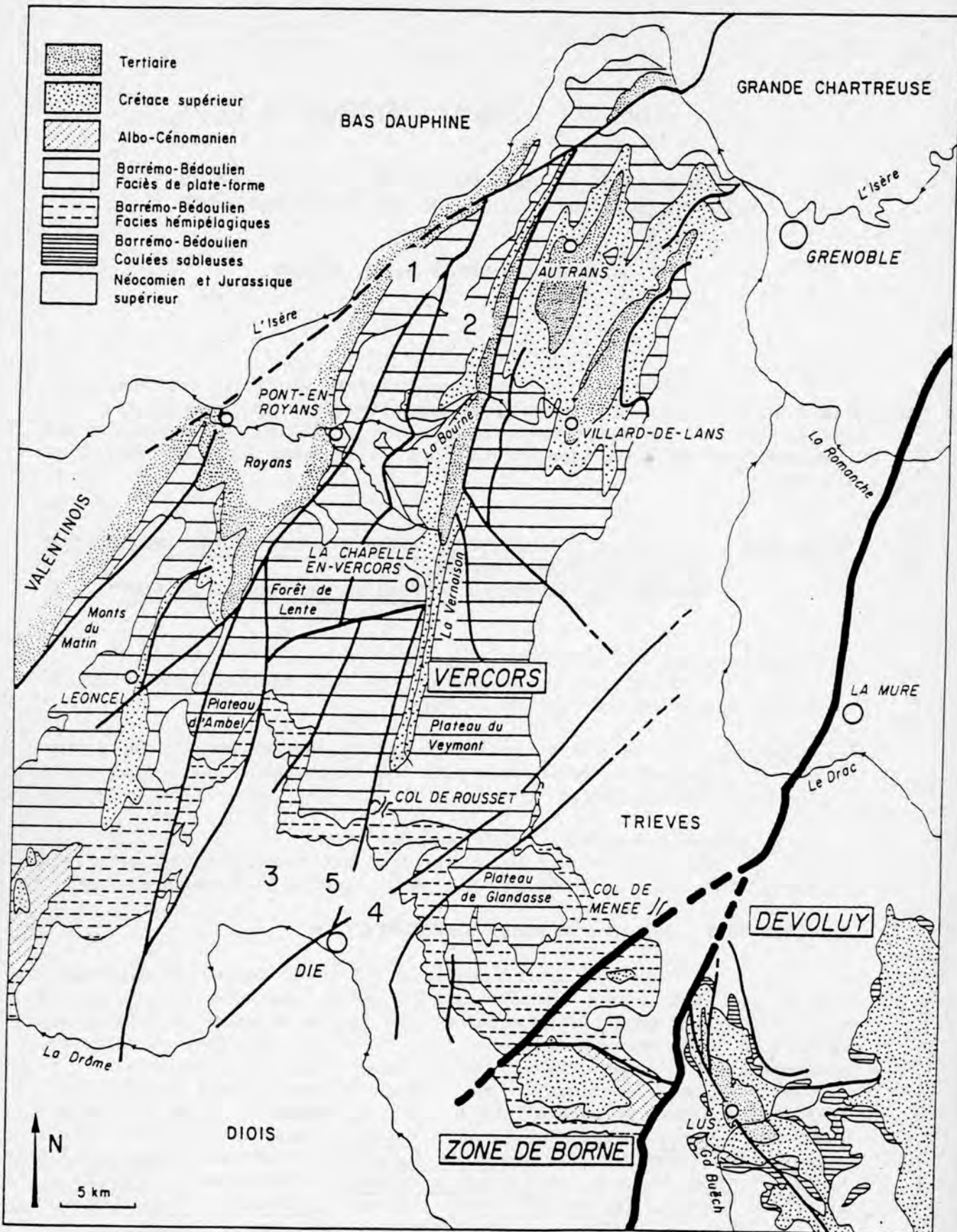


Fig. D 1 : Geological scheme of the Vercors with the location of the third and fourth day stops. 1, Gorges du Nant section ; 2, Les Rimets ; 3, Marignac-Serre de Jayon ; 4, Col de Romeyer section ; 5, Chamaloc section.

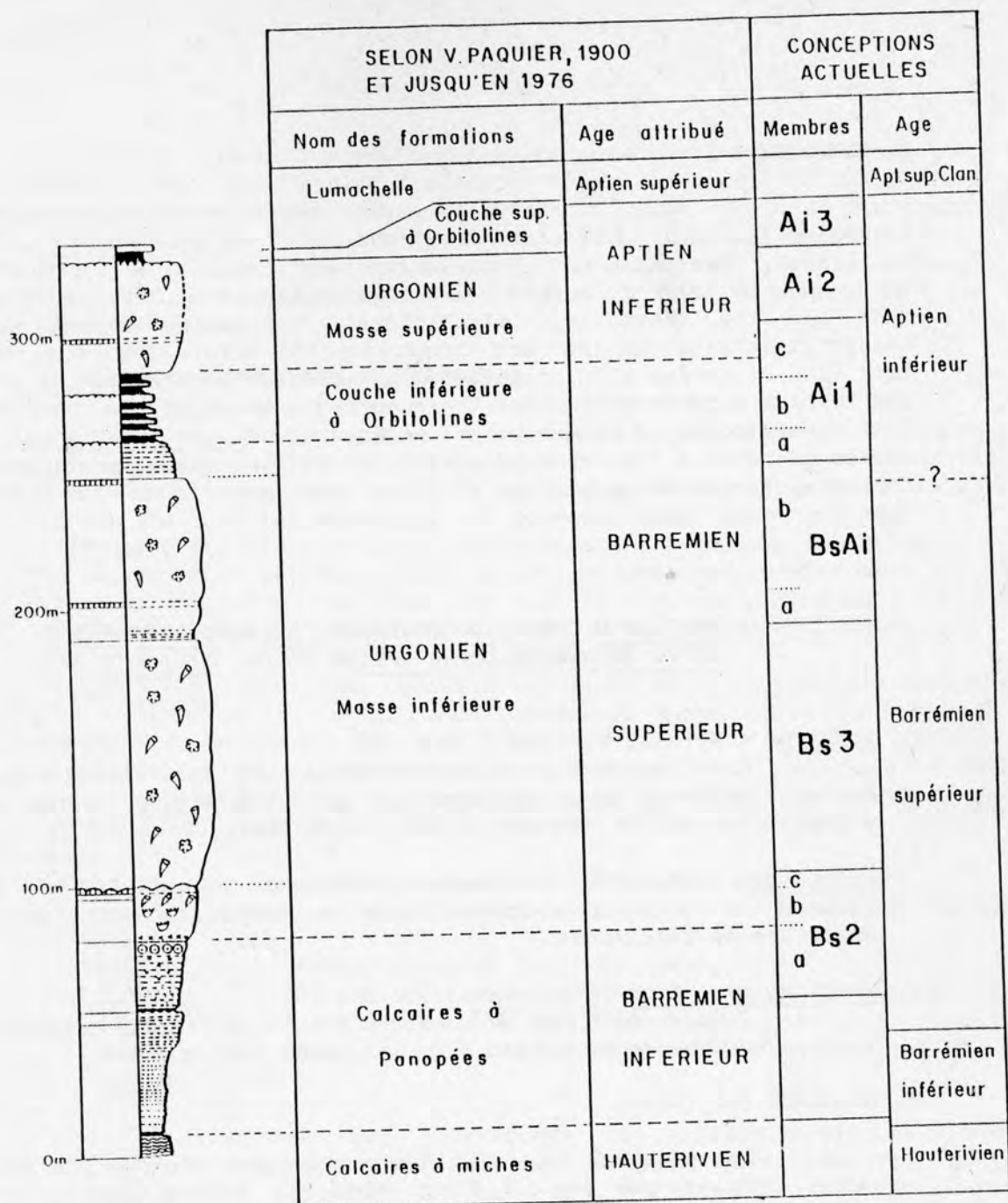


Fig. D 2 : The Urgonian synthetic section of the Northern Vercors
(A. ARNAUD-VANNEAU, 1980)

2. SECOND PART : ARGILLACEOUS LIMESTONES (about 35m)

We also have three sequences here, but these sequences begin with more argillaceous limestones and end with less argillaceous limestones. They begin with biomicrite-wackestone with Spatangidae (F2), followed by fine-grained biosparite-grainstone with peloids and small Foraminifera (F3) and end with biomicrite-wackestone with Bryozoans, Bivalvia and Annelids (F4).

The sediments correspond to circalittoral facies with vasicol fauna (except for a part of the fauna of F4), but we believe that depositional environments begin to be shallower than the previous ones.

Age : no significant fauna have been discovered, but, by correlations, we believe that these deposits are Upper Hauterivian to Lower Barremian.

3. CONCLUSION

In this locality, we may observe a Hauterivian-Lower Barremian section different from that of the Chambotte. In both localities, there are circalittoral sediments ; but in the Chambotte, the series is less thick and less argillaceous than in the Gorges du Nant. In the Chambotte, infralittoral high-energy facies such as biosparite-grainstone (F5) and oosparite (F6) exist. The appearance of this kind of facies with cross-bedding indicates the presence of currents and involves a bathymetry where these currents do exist. In the Gorges du Nant, we have not observed these facies : there are only circalittoral facies deposited in calm depositional environments protected from currents. For this reason, we believe that deposits of the Gorges du Nant are deeper than those of the Chambotte.

SECOND STOP : SECTION OF URGONIAN PLATFORM CARBONATED SEDIMENTS UPPER BARREMIAN-LOWER APTIAN OF THE GORGES DU NANT

Location : Vif 1-2 (1/25000) (Fig. D1)

This section is located along the road from Cognin to Mallevall where it cuts the Urgonian cliff. This road climbs up the western side of the "Gorges du Nant Anticline".

Lithology : Massive calcareous limestone making a high cliff, interrupted by three discontinuities underlined by marls or argillaceous limestones.

Vertical evolution (Fig. D2, D3 and D4)

This section may be subdivided into five parts corresponding to five megasequences called Bs2, Bs3, BsAi, Ai1 and Ai2.

1. SEQUENCE Bs2 (45m)

Sequence Bs2 begins with a marly layer found above the last sequence that we saw at the first stop. It begins above the same discontinuity E as in the Chambotte.

This megasequence may be subdivided into two sequences. The first sequence at the base shows, in ascending order, fine-grained biosparite-grainstone with peloids and small Foraminifera (F3) associated with some Bryozoans and colonial Annelids, biosparite-grainstone with rounded grains (F5) and oosparite (F6). A small lithologic discontinuity (F3) interrupts the sequence.

The second sequence shows the same facies in the same order at the base, but above, new facies appear : a bioherm with plate cup-like corals found on oosparite and above, there is a biosparite-grainstone corresponding to Coral sands with debris of various Corals, Bivalvia, Gastropods and spine of regular Echinoids (F7). The sequence ends with biomicrite-wackestone, partly dolomitized, Rudist and Coral debris (F8) which is crowned by emersion facies consisting of biosparite with keystone vugs.

Sequence Bs2 corresponds to an installation carbonate platform sequence. For the first time, infralittoral outer to middle shelf facies appear in an area where they were unknown.

Age and microfauna : significant macrofauna have not been discovered. We have benthic microfauna in facies F3 more like those of the first stop. Just two species are missing : Choffatella cf tingitana Hottinger and Citaella? favrei Char., Bronn., Zanin.. In other facies, we have only some Milolidae and micritized undetermined Orbitolinidae. By correlations with the southern Vercors, we believe that we are in the Upper Barremian.

2. DISCONTINUITY G AND SEQUENCE Bs3

Discontinuity G, ending the sequence Bs2, corresponds to a lithologic discontinuity underlined by a series of small paleokarst cavities filled with white sands and red clays. These karst cavities were developed during the Turonian emersion.

Just above the discontinuity, limestones are secondary dolomitized. We believe that the discontinuity horizon was used earlier as a drainage horizon, and this phenomenon may explain the early formation of karst cavities as well as the early secondary dolomitization of limestones.

Sequence Bs3 (about 90m) consists of inner shelf carbonated limestones. It is made up of small shoaling-upward sequences associated in a megacyclic sequence. The beginning and the end of Bs3 consist of biomicrite or wackestone-packstone with large Rudists, debris of Corals and Orbitolinidae (F8). Here and there, we have small sequences (3 to 7m thick) displaying, some or all of the following facies in ascending order:

- (1) biomicrite or wackestone-packstone with large Rudists (F8),
- (2) biomicrite-biosparite or packstone-grainstone with small Rudists and Oncoids (F9),
- (3) biomicrite or wackestone with Oncolites (F10),
- (4) micrite or mudstone with Pseudotriloculina (F11) associated with either algal mats (Stromatolites), or bird's-eyes, or dissolved shells, all these structures indicating the proximity of the emersion level.

Sequence Bs3 corresponds to infralittoral-supralittoral shallow water lagoon deposits. We may recognize many tidal flat facies, especially muds deposited in calm and protected areas with confined conditions. We have not observed fine or coarse beach sand. Limestones are often dolomitized, especially those of facies F10 and F11.

Age and microfauna : significant macrofauna are lacking, the most significant Foraminifer is represented by Valserina bronnimanni Schroeder & Conrad (Fig. D4) which, for us, indicates the Upper Barremian.

3. DISCONTINUITY H AND SEQUENCE BsAi

Discontinuity H, poorly marked, lies between massive limestone below and decimeter-thick limestone composed of fine-grained biosparite-grainstone (F3) with some eroded infralittoral Foraminifera above. This discontinuity corresponds to a slight deepening.

Sequence BsAi may be subdivided into two sequences, BsAi1 and BsAi2.

Sequence BsAi1, beginning with facies F3, is made up mainly of inner shelf carbonated sediments, but is less muddy than the facies of the previous sequence. We can observe biosparite-grainstone with large isolated or colonial Rudists (Agriopleura) and a rich microfauna

GORGES DU NANT

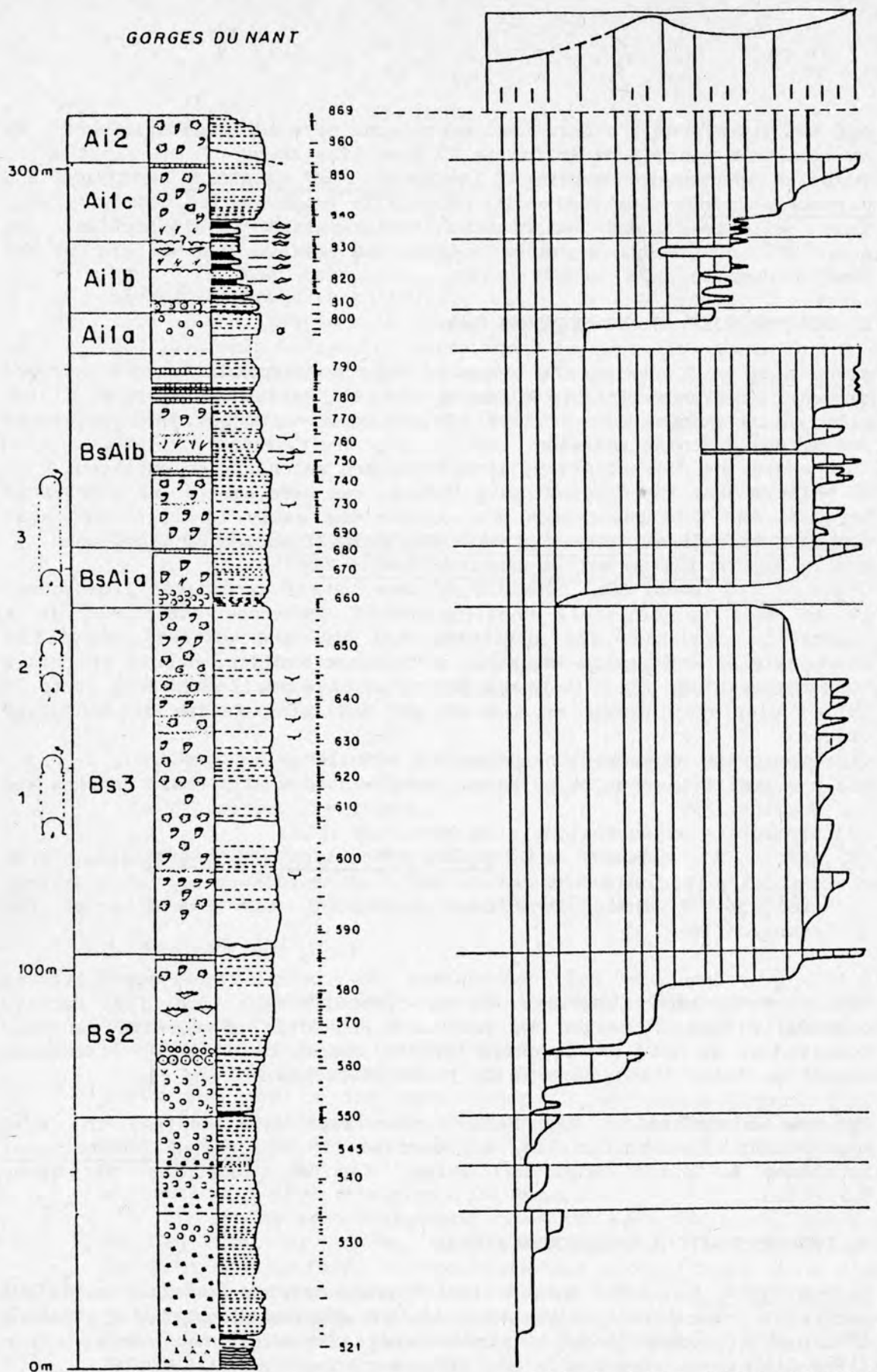
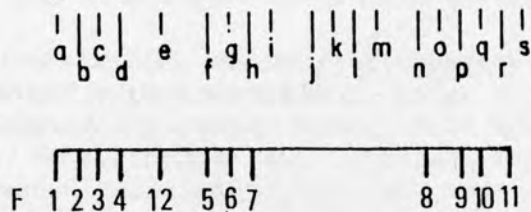


Fig. D 3 : The Upper Hauterivian-Lower Aptian section of the Gorges du Nant. The microfacies evolution curve (after A. ARNAUD-VANNEAU, 1980)



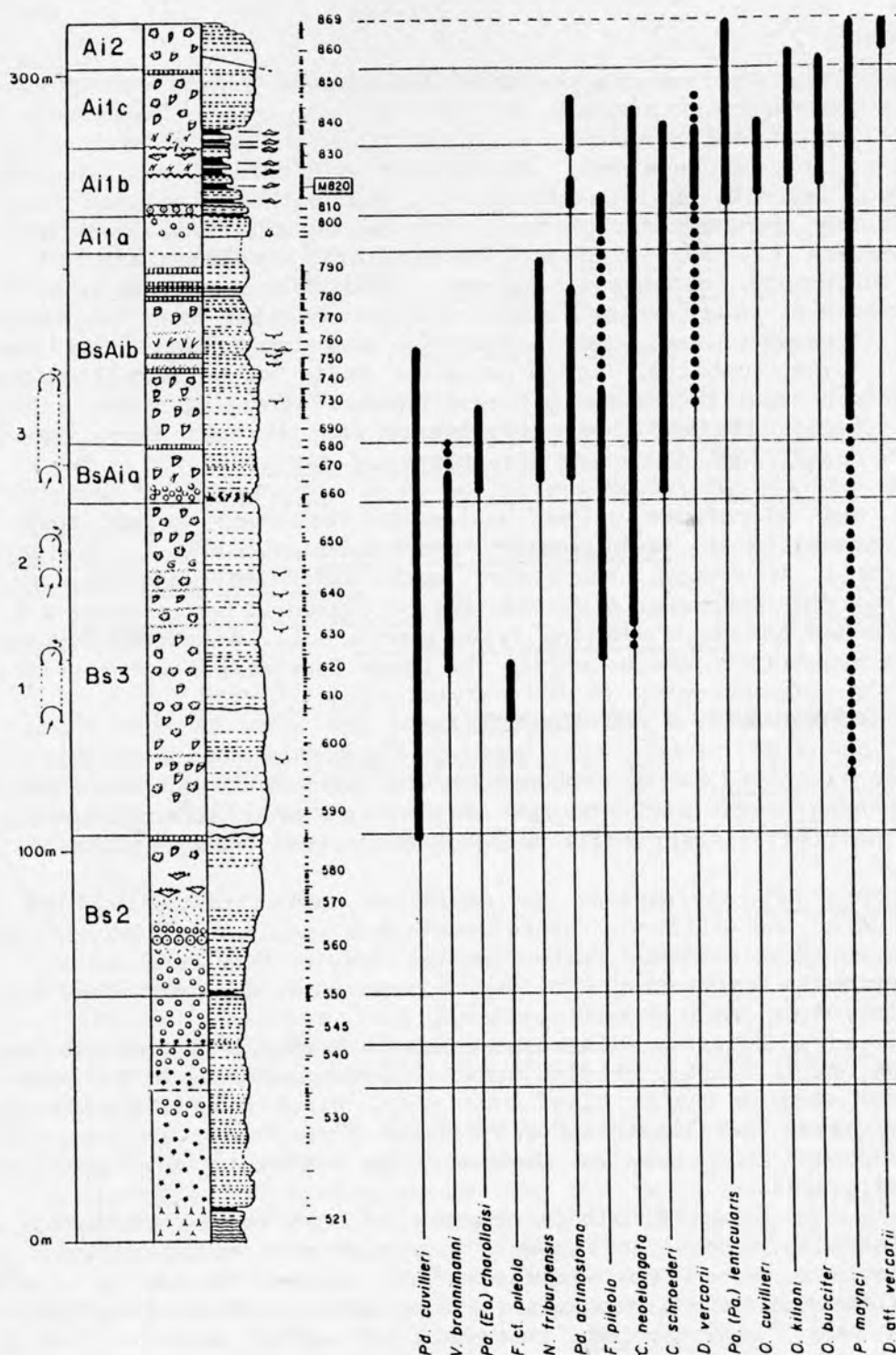


Fig. D 4 : The Upper Hauterivian-Lower Aptian of the Gorges du Nant section. Distribution of the main benthic foraminifera (according to A. ARNAUD-VANNEAU, 1980)

with abundant Orbitolinidae and Dasycladaceans (F8). The sequence ends with an emersion horizon corresponding to beach-rock.

Sequence BsAi2 displays mainly the same facies F8 as in sequence BsAi1, but with muddier facies. Here and there, we may observe the superposition of two peculiar facies : a decimeter-thick bank of coarse biosparite-grainstone with sometimes microstalactitic cement (**beach-rock**) below and a decimeter-thick bank of micrite-mudstone with *Pseudotriloculina* and bird's-eyes above. We believe that this

association corresponds to storm deposit. As BsAil, the sequence ends with beach-rock.

Sequence BsAi corresponds to infralittoral shallow water lagoon deposits as in sequence Bs3, but without confined environments and with open sea conditions. As a matter of fact, we note (i), the abundance of large Rudists, Foraminifera and Dasycladaceans, all of which require normal salinity and normal oxygen condition ; (ii), the decrease of muddy facies (biomicrite and micrite) and, to the contrary, the increase of sandy facies (more or less coarse biosparite) associated with storm deposits. During sequence BsAi, we believe that carbonate platform depositional environments present normal open sea salinity and are deeper (?) than those of sequence Bs3, so that the protected area with restricted conditions disappears.

Age and microfauna : we have only observed significant benthic microfauna with Cribellopsis schroederi Arn.-Van., Dictyoconus ? vercorii Arn.-Van., associated with Palorbitolina (Eopalorbitolina) charollaisi Schroeder & Conrad, Paleodictyoconus actinostoma Arn.-Van. & Schroeder and Neotrocholina friburgensis Guil. & Reichel. In our view, this association characterizes the Upper Barremian-Lower Aptian.

4. DISCONTINUITY J AND SEQUENCE Ail

Discontinuity J, very well-marked, corresponds to the most substantial deepening known in the course of the Urgonian platform evolution, : it is the first transgressive pulse of the Aptian transgression.

Sequence Ail corresponds to sediments deposited during the drowned period of the platform. The sediments are peculiar and consist of marls and marly limestones with Orbitolinas : they are called "marnes inférieures à Orbitolines". This sequence may be subdivided into three parts : Aila, Ailb and Ailc.

Sequence Aila corresponds to transgressive facies deposits : marls, marly limestones with mixed facies and fauna. In the same facies, we can observe Charas mixed with small circalittoral Foraminifera and limonitized infralittoral Foraminifera. These facies are capped by up to hard-ground where we may observe small Echinoids such as Nucleopygus roberti Gras.

Sequence Ailb corresponds to true "marnes à Orbitolines". It begins with a peculiar facies : oosparite with micro-oolites, normally unknown in normal carbonate platform. Above, "marnes à Orbitolines" consist of alternating nodular bedding marly limestones and marls, both with many Thalassinoides burrows. The marls contain a rich fauna (Echinoids, Bivalvia, Gastropods,...) and a rich microfauna with abundant Orbitolinas such as Palorbitolina (Palorbitolina) lenticularis (Blum.). The marly limestones contain nearly the same fauna, but Dasycladacean Algae are very abundant. We believe that the deposits correspond to tidal channel sediments, well-preserved through peculiar depositional conditions during this drowned period.

Sequence Ailc corresponds to a sequence announcing the reinstallation of normal carbonate platform environments. It begins with the last marl layer followed by carbonated facies with large Rudists (F8), small Rudists (F9) and ends with an emersion layer of biosparite with keystone vugs.

Sequence Ail displays submerged platform sediments deposited during drowned platform period and characterized by an abundance of

varied fauna, an abundance of clays (for a carbonate platform), the appearance of new facies and the disappearance of normal carbonate platform facies. After this first transgressive pulse, the platform starts again.

Age and fauna : two Ammonites have been discovered, the first in the Haute-Savoie by MORET & DELEAU, Deshayesites sp. ; the second in the Chartreuse by P. GIDON, Ancyloceras gr. matherianum. Both species are indicative of the Lower Aptian (Lower Bedoulian). Echinoids are frequent : Heteraster oblongus (Brongniart) is the most significant.

Microfauna are very rich (Fig. D4) and Orbitolinidae are very well represented by Palorbitolina (Palorbitolina) lenticularis (Blum.), Cribellopsis schroederi Arn.-Van. (M 820, type locality) and various Orbitolinopsis as O. cuvillieri Moul., O. kiliani (Sil.) and O. buccifer Arn.-Van. & Thieuloy.

This section is also the type locality of Vercorsella arenata Arn.-Van. (M 820).

5. SEQUENCE Ai2

Sequence Ai2, interrupted by ante-Senonian erosion, allows us to observe only the base. The facies correspond to normal inner platform facies with Rudists (F8-9), oncolites (F10) and micrite with bird's-eyes (F11). After the drowned period of Ail, the Urgonian platform starts again and we may observe depositional environment similar to those in sequences Bs3 or BsAi.

6. CONCLUSION

This section allows us to observe the installation and evolution of the Urgonian Platform in the Dauphinois Basin. Once again, as in the Chambotte, the platform installation is sudden above the discontinuity E. We may note that this installation begins above the circalittoral deposits which are likely deeper than those of the Chambotte.

The first sequence Bs2 announces the installation of the true Urgonian Platform environments, the second one Bs3 displays normal environments for this platform and the third one BsAi announces the subsequent deepening of sequence Ail with the disappearance of more confined facies corresponding perhaps to a slight deepening. Sequence Ail is the drowned platform period where normal platform carbonate sediments disappear and are replaced by marls and marly limestones characterizing facies of submerged platforms. This first drowned period corresponds to the beginning of the Aptian transgression. Before this transgressive pulse, depositional environments of the Urgonian Platform are reinstalled for a time (Ai2).

THIRD STOP : END OF THE URGONIAN PLATFORM

DRAINAGE CHANNEL OF LES RIMETS AND "MARNES A ORBITOLINES SUPERIEURES"

Location : Vif 1-2 (1/25000) (Fig. D1)

This outcrop is located on the western side of the Rencurel Syncline, near "Les Rimets" farm.

SW

NE



SW COLLET DE LA GRAND FONT

NE

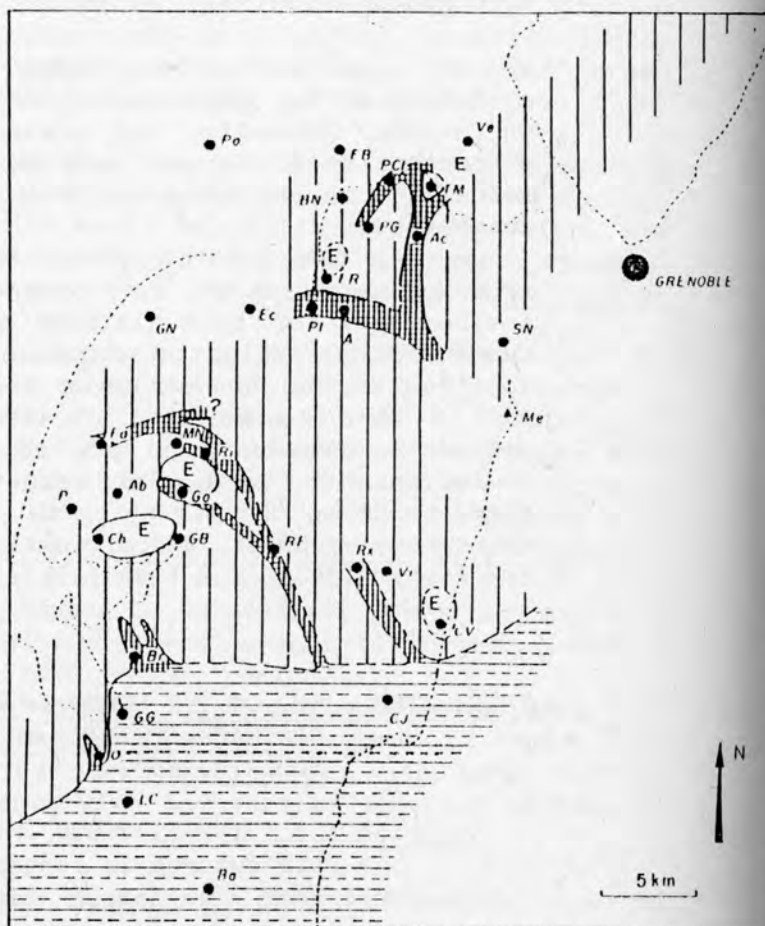
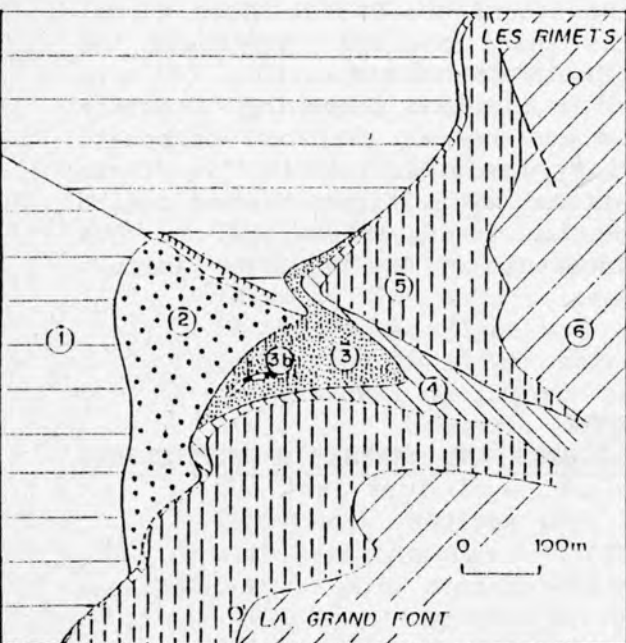
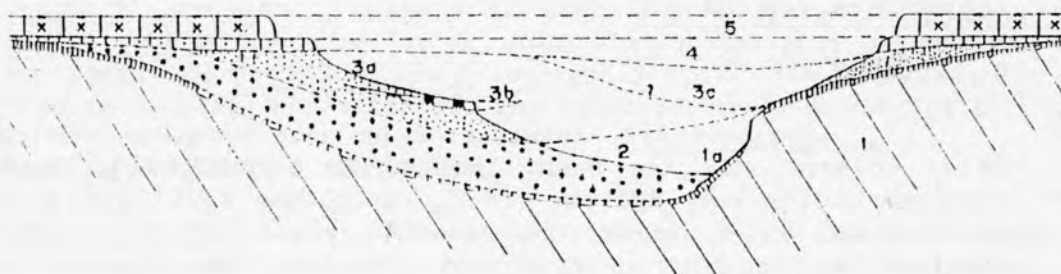


Fig. D 5 : The Ebb tidal channel of Les Rimets (p. 104).

A, General view of its NW-SE edge covered by the hard-ground.

B, NE-SW section of the channel : 1, Urganian Limestone ; 1a, hard-ground ; 2, 3, 3b, successive fillings with *Orbitolina* marls, so-called "Marnes à Orbitolines Supérieures" ; 4, biosparites to oosparites with *Orbitolinas* ; 5, "Lumachelle" yellowish cross-bedded biosparite with Crinoids and Bryozoans.

C, Map of the drainage channel of Les Rimets. Same legend as B. 6, Upper Cretaceous limestones.

D, General paleogeographic map showing the disposition of the Urganian platform last drainage channels with their *Orbitolina* marl fillings (Ri, Les Rimets)

Description (Fig. D5 and D6)

This outcrop will allow us to observe the end of the last Urganian deposits and a fossilized ebb tidal channel with its filling up of *Orbitolina* marls, so-called "Marnes à Orbitolines supérieures".

1. END OF THE PLATFORM (Fig. D6)

At the end of the Bedoulian, a major transgressive pulse drowned the Urganian platform and this platform gradually disappeared.

First stage : the last platform sediments (biomicrite or packstone-wackestone with large Rudists and Corals, F8) harden. On this hard surface, Corals can settle on the edge of the channel and a ferruginized hard-ground can expand.

Second stage : first marly limestone with *Orbitolinas*, then marls with *Orbitolinas* ("Marnes à Orbitolines supérieures") occur in the bottom of the channel (stage 2a, fig. D6), followed above (stage 2b, fig. D6) by biosparite to oosparite or grainstone with *Orbitolinas* (F5). On the highest places surrounding the channel, marls and bio-oosparite change laterally to orbitolinosparsite corresponding to a sand constituted by an accumulation of *Orbitolina* tests.

third stage : biosparite-grainstone with Bryozoans, Crinoids and Brachiopods (F4) so-called "Lumachelle" occur above. It corresponds to yellowish-brown cross-bedded calcarenite beds, very similar to the "Calcaires Roux" of the Swiss Jura and La Chambotte section. As in La Chambotte, this facies indicates the death of the platform.

Above, there are Albian sediments corresponding to phosphatic pelagic deposits with many Ammonites ("Béton Phosphaté").

2. AGE AND FAUNA

Les Rimets is a well known locality for fauna and microfauna. Several Ammonites of the *deshayesi* and *bowerbanki* zones have been discovered indicating the Upper Bedoulian : *Costidiscus recticostatus* (D'Orb.), *Macroscaphites striatisulcatus* (D'Orb.), *Valdedorsella cf. angladei* (Sayn), *Pseudohaploceras matheroni* (D'Orb.), *Zurcherella cf. zurcheri* (Jacob & Tobler), *Procheloniceras stobieskii* (D'Orb.), *Cheloniaceras cornuelianum* (D'Orb.), *Tropeum gr. hillsi* (Sow.).

Microfauna is abundant and "les Rimets" is the type locality

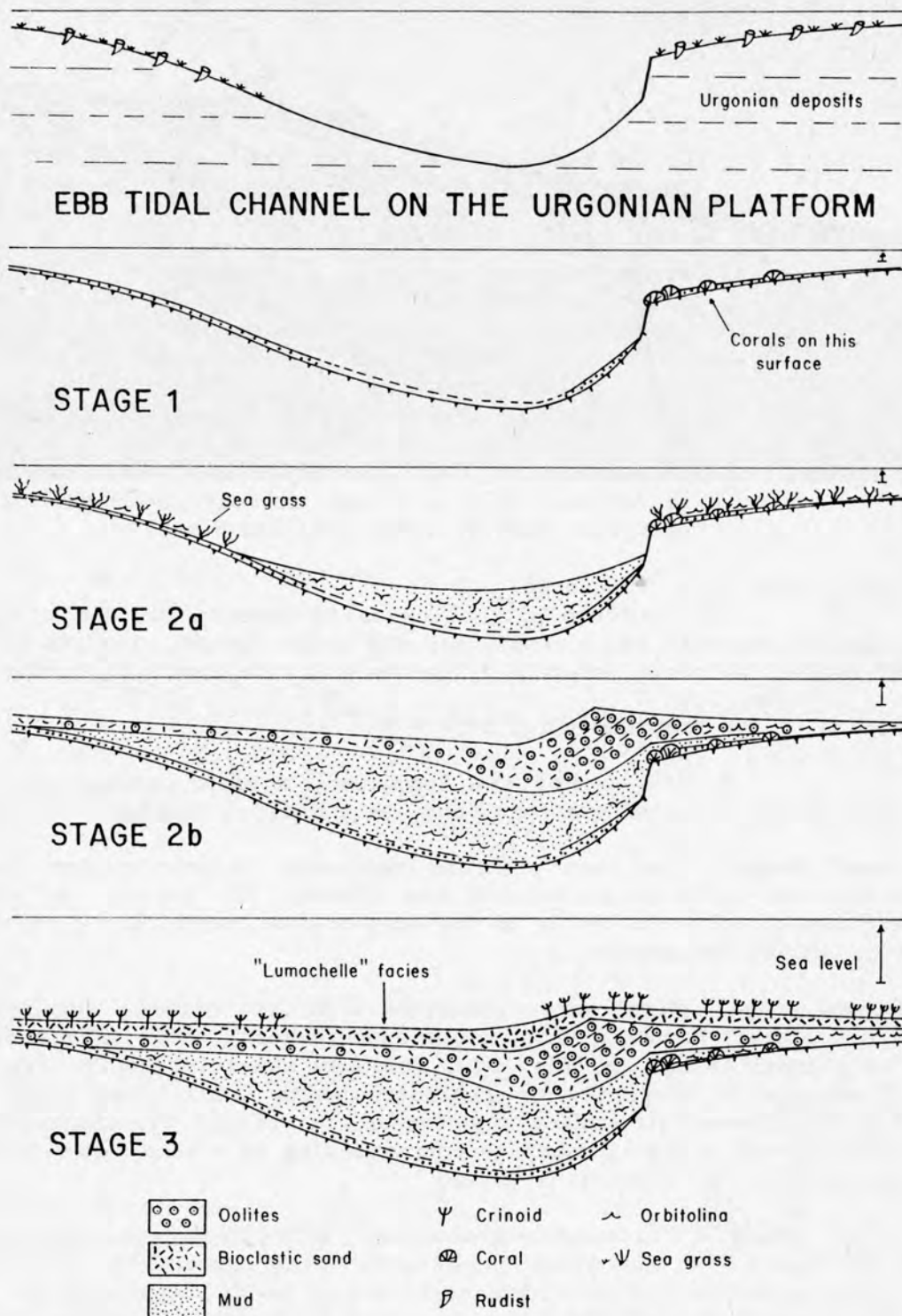


Fig. D 6 : The Ebb tidal channel of Les Rimets. The different stages of its evolution showing how this channel was fossilized (stages 1 to 3 : see text)

for Orbitolina conoidea and Orbitolina discoidea Gras 1852, junior synonym of Palorbitolina (Palorbitolina) lenticularis (Blum.). Orbitolina conoidea is of the A-form and Orbitolina discoidea is of the B-form of Palorbitolina (Palorbitolina) lenticularis.

3. CONCLUSION

The second transgressive Aptian pulse is responsible for the disappearance of the Urgonian Platform. As for the Berriasian-Valanginian carbonate platform, the Urgonian Platform disappears after successive transgressive pulses. The yellowish-brown cross-bedded

calcarenite of the "Lumachelle" facies, similar to the "Calcaire Roux" facies corresponding to a letal platform facies, is the last carbonated facies deposited. In fact, true Urganian platform carbonate facies disappeared before the marls and "Lumachelle" deposits.

As during the previous transgressive pulse (A11 level), the ebb tidal channel was fossilized with its filling up by Orbitolina marls. The outcrop of "les Rimets" shows clearly that these Orbitolina marls are only extended along depressions such as ebb tidal channels, and, laterally, are lacking entirely or change to Orbitolina limestones.

FOURTH DAY : MONDAY, DECEMBER 7TH

PELAGIC SEDIMENTATION OF THE VOCONTIAN BASIN

A. ARNAUD-VANNEAU, H. ARNAUD, J.-P. THIEULOY, M. ARGOT

with the collaboration of
H.J. OERTLI and J. REMANE for the determination of Ostracods and Calpionellids
T. BAS and C. LEREUS for the field work.

THEME

This day is devoted to the examination of: 1) the pelagic sedimentation of the Valanginian-Hauterivian series and the distribution of ammonites which were numerous in this domain, 2) the reworked sedimentation of the Late Berriasian (with inner platform bioclasts) and of the Valanginian (with only outer shelf sediments or hemipelagic bioclasts), 3) the marl-limestone alternations and cycles which were the most conspicuous features of the Vocontian basin sedimentation.

FIRST STOP : THE REWORKED SEDIMENTATION OF THE LATE BERRIASIAN NEAR MARIGNAC-EN-DIOIS (Fig. E1)

Location: Die 3-4 (1/25000)

This section is located along the road between Die and St. Julien-en-Quint, on the southern side of the small Serre du Jayon hill.

1. DESCRIPTION

This section, described by ALLIOT, FLANDRIN and MOULLADE (1964) and then by LE HEGARAT (1971), is made up of 6 superposed levels among which only Levels 1 to 3 may be observed. It has not been the subject of recent studies except for the microfauna which was reviewed by A. ARNAUD-VANNEAU.

1.1. Level 1

The level 1 corresponds to a mud-flow, several meters thick, made up of a mixture of a matrix of hemipelagic ooze with sponge spicules and two different types of allochem : 1) coarse bioclasts derived from the margin and inner domain of the Jurassic platform (numerous foraminifera, bivalvia, bryozoans, gastropods,...), 2) mud-pebbles ("phacoïds") composed of fine micrite with Calpionellids, Radiolaria, Stomiosphera (facies F0). These mud-pebbles, centimeter- to pluridecimeter-sized, are more or less well-shaped, conveying their transport in a compacted state within the mud-flow.

Among the reworked bioclastic sand foraminifera, one finds Trocholina alpina (Leupold), Trocholina delphinensis Arn-Van., Boisseau, Darsac, Trocholina elongata (Leupold), Trocholina molesta Gorbatchik, Pseudotextulariella courtoniensis Brönnimann, Nautiloculina brönnimanni Arn.-Van. & Peybernes. There are also two Calpionellid associations, the first in the phacoïds : Tintinopsella carpathica (Murg. & Fil.) and Calpionella alpina Lorenz of the C zone (Lower-Middle Berriasian), the second in a massive bank : Calpionellopsis simplex (Col.), Tintinopsella carpathica (Murg. & Fil.) and Calpionellopsis oblonga of the D1-D2 zone (Upper Berriasian).

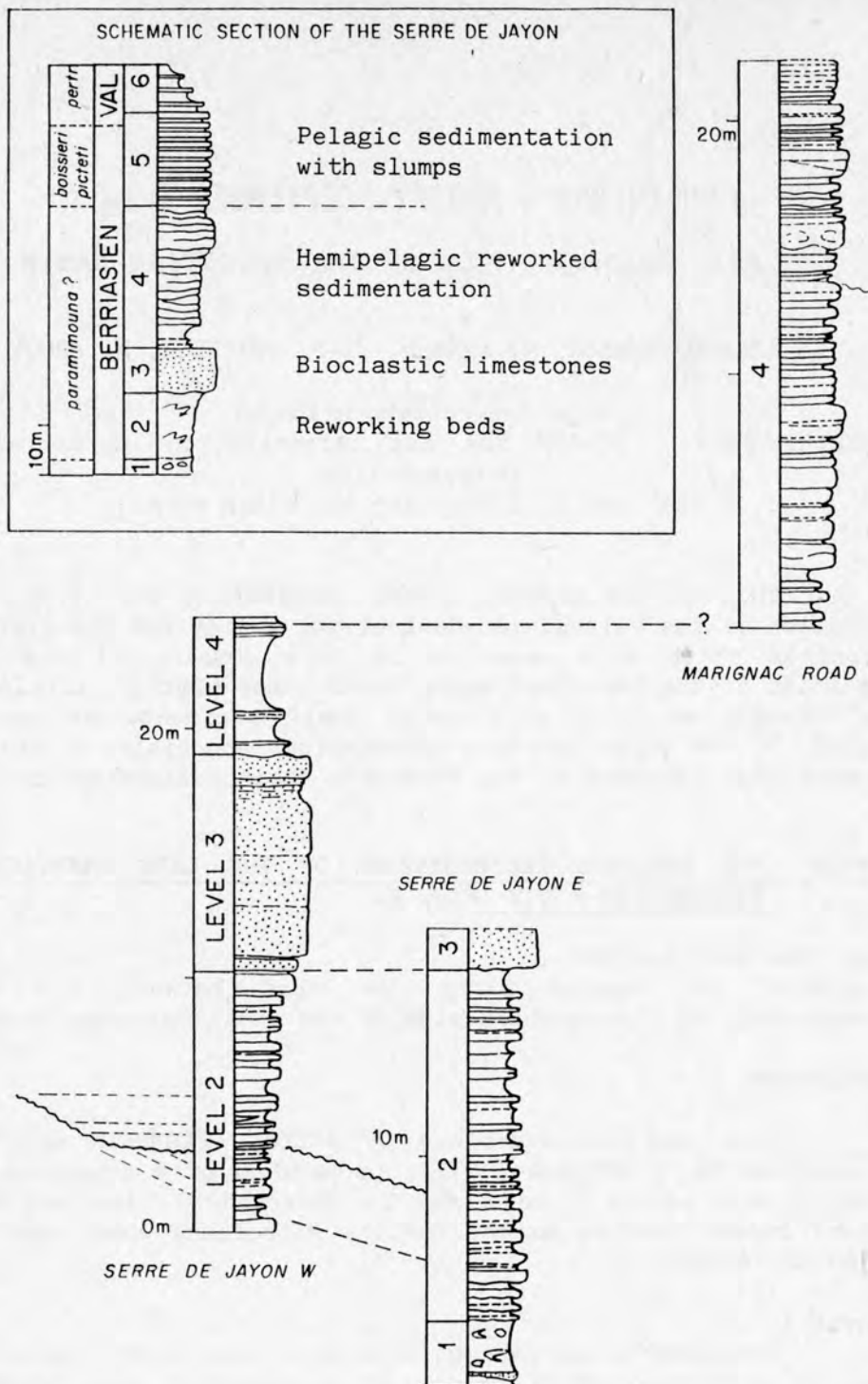


Fig. E 1 : The Serre de Jayon sections (near Marignac-en-Diois): 1 to 6 : level 1 to 6 according to LE HEGARAT, 1971).

At the bottom of the Vocontian basin, this outcrop displays the deposit of sediments which were subject to dual transport through the force of gravity: 1) the transport of infralittoral bioclastic sands from the inner domain of the Jurassic platform to the outer slope and the mixing with hemipelagic ooze, 2) the transport "en masse" of the previous mixture to which are added fragments of compacted ooze pulled away from the pelagic domain during the passage of the mud flow.

This level cannot be dated because of the manner in which it was deposited. In LE HEGARAT's view (1971), it may be assigned to the *privasensis* (?) sub-zone or to the *dalmasi* sub-zone (upper part of the Middle Berriasian). The two Calpionellids associations may indicate that all the sediments are reworked, without stratigraphical succession. However, the Calpionellids and the benthic foraminifera indicate for the younger deposits an early Upper Berriasian age, probably just below the

Dil discontinuity.

1.2. Level 2 (variable thickness, 15 to 20 m.)

This level is made up of a pile of hemipelagic marly limestone slumped beds with sponge spicules, Radiolaria, Globochaetae. Many of the beds also contain a more or less large proportion of bioclasts from the Jurassic platform. Several truncature surfaces highlight the existence of a piling-up of slumped levels.

According to LE HEGARAT (1971), this level corresponds to the lower part of the paramimounum sub-zone (lower part of the Upper Berriasian).

1.3. Level 3 (locally about 9 m.)

This level is represented by a small cliff made of massive bioclastic limestones which disappears towards the East. Here again, we have a mud flow made up of a mixture of infralittoral bioclastic sands originating from the inner domain of the Jura platform and hemipelagic ooze with sponge spicules. This mixture is however heterogeneous and, on the outcrop, all the intermediate facies from biosparites with large bioclasts to micrites with sponge spicules may be observed. Contrary to Level 1, there are however no pelagic ooze mud pebbles.

Among the foraminifers, one notes: the same association as that in the first level, but with Everticyclammina cf hedbergi (Maync), Trocholina cf odukpaniensis Dessauvagine, Coscinophragma cribosum (Reuss), Pseudocyclammina lituus (Yoko.), Charentia cuvillieri Neumann and Clypeina jurassica Favre. We may note that ALLIOT et al (1964) had identified Pfenderina globosa (Pfender). This reworking association, especially the youngest forms, seems to indicate the neighbourhood of the Dil discontinuity (Upper Berriasian, picteti sub-zone) or the levels which are immediately above.

1.4. Level 4 (about 25-30 m.)

This level begins by about 4 meters of marls over-topped by grey, slumped argillaceous limestones similar to those of Level 2 (hemipelagic micrites with sponge spicules and quartz). A good? outcrop is visible on the northeastern slope of the Serre de Jayon, along the road to Marignac (Fig. E1).

1.5. Level 5 (about 20 m.)

This level is represented by marl-limestone alternations (fine micrites with Calpionellids and Radiolaria, facies FO) characteristic of pelagic deposits. Synsedimentary reworking still exists in this series (presence of slumped beds) but the sediments here are autochthonous or only slightly displaced, to the contrary of what is observed in the underlying levels. Berriasella (Picteticeras) picteti, B(P)evoluta, Fauriella rarefurcata at the base, Calpionellopsis oblonga, Berriasella calypso, Fauriella montelsi, F.boissieri have permitted the datation of this level of the picteti and callisto sub-zones (LE HEGARAT, 1971). At the top, we have found Thurmanniceras cf. thurmanni of the Basal Valanginian.

1.6. Level 6

This level, very poorly outcropping to the North of the Serre de Jayon crest, corresponds to yellowish argillaceous limestones and thick, marly intercalations with pyritaceous ammonites. A transition to Lower Valanginian marls (pertransiens zone) is observed to the North of the Serre de Jayon. This level, mainly marly intercalations with pyritaceous ammonites, corresponds precisely to the **Chamaloc fossiliferous level**.

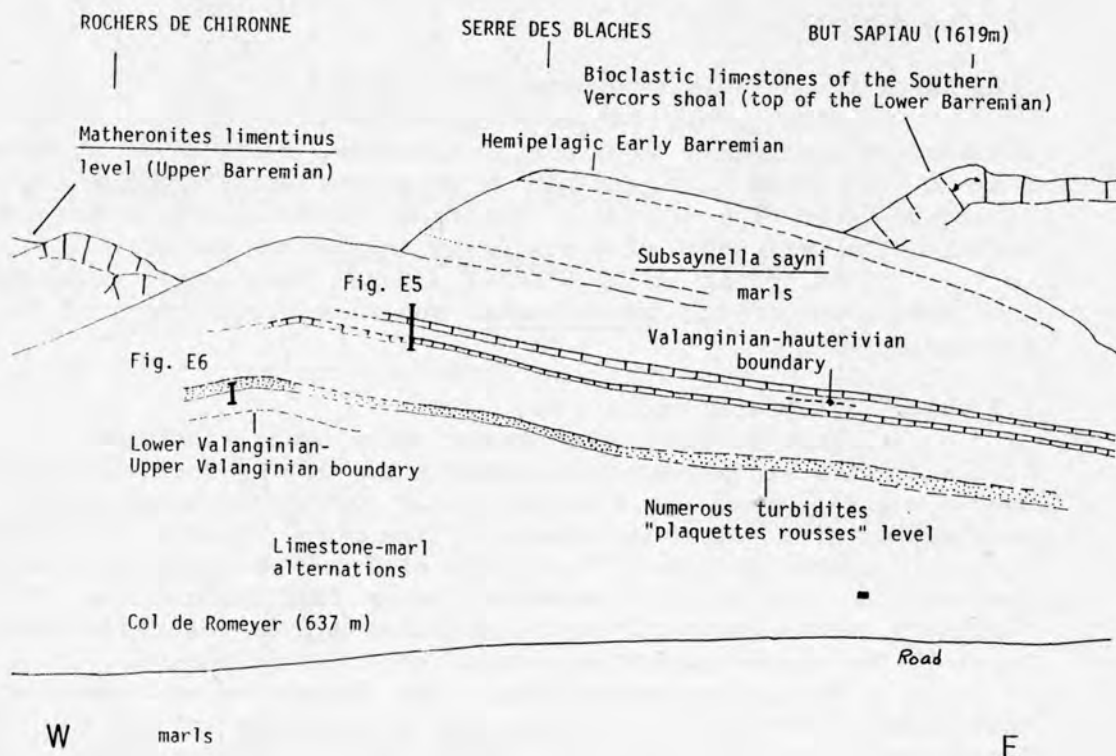


Fig. E 2 : General view of the Col de Romeyer-Serre des Blaches section

2. CONCLUSIONS

- 1) The Berriasian in the region visited between Marignac and Romeyer is made up of two superposed sedimentological entities : at the base, deposits reworked by the force of gravity, at the top, autochthonous or slightly displaced sediments. The particularly distinct boundary between the two is situated in the Picteti sub-zone, that is to say in the neighborhood of the D11 discontinuity (probably above) of the Jura platform.
- 2) The reworked sediments correspond to a variably-proportioned mixture of elements of various origins : inner platform, outer platform, hemipelagic basin, pelagic basin. They are deposited at the bottom of a very large submarine canyon, several tens of kilometers long, which already existed at the Tithonic, across the Vocontian basin to the North-east of Sisteron, and was named "**Canyon de Céüse**" by BEAUDOIN.
- 3) Among the bioclasts found in the mud-flows, one finds numerous large-sized foraminifera reworked from the F5 and F8 facies of the Jura platform. Up until the beginning of the Upper Berriasian, the reworked sediments of the Vocontian basin therefore contained elements originating from the inner domain and margin of the Jura platform.
- 4) The ages assigned to the different reworked levels are only of comparative interest. It is not possible to know, in particular, whether the filling up of the Céüse canyon occurred throughout all the Middle Berriasian or whether it was very rapid, in the picteti zone.

SECOND STOP : COL DE ROMEYER VALANGINIAN SECTION (Fig. E2 To E6)

Location: Mens 1-2 (1/25000).

This section is situated in the ravines of the eastern slope of the ridge joining the Col de Romeyer (637 m) to the Serre de la Blache (953

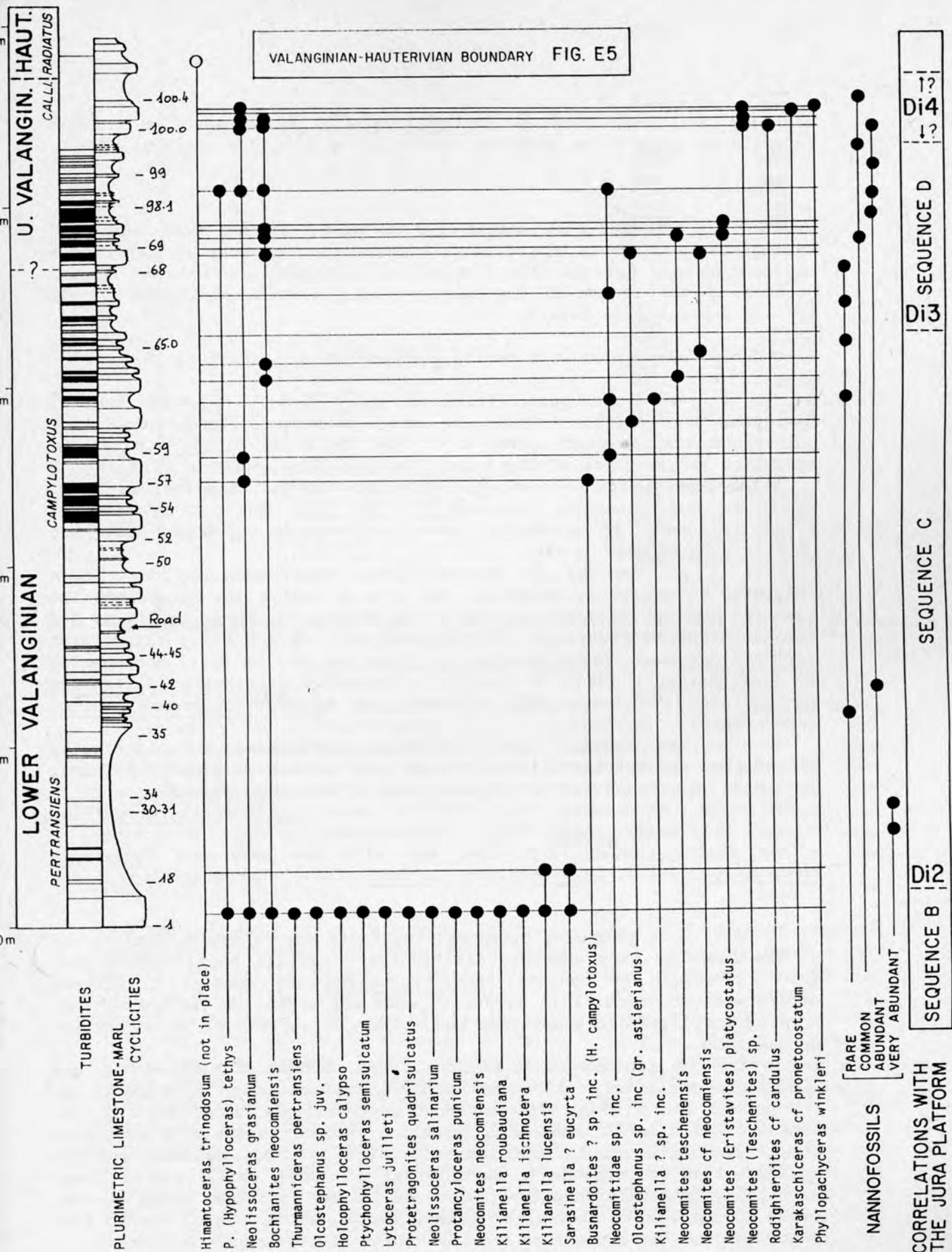


Fig. E3 : Very schematic representation of the Col de Romeyer section (Diois), repartition of Ammonites, abundance of Nannoconus, correlations with the Jura platform.

m). Only the lower part of the section will be observed up to the Valanginian-Hauterivian boundary located at an altitude of about 800 m.

1. DESCRIPTION

This section, almost 500 m thick, is the most beautiful Valanginian section of the Diois. It has been measured in detail for this excursion, but all the results of analyses are not yet known. Because of the length of the section, only certain particular points will be described in detail.

1.1. Early Valanginian with pyritaceous ammonites (Bank 1 to 15)

Above the Upper Berriasian, which closely resembles that of Marignac, the section begins by marl-limestone alternations which correspond precisely to Level 6 of the Serre de Jayon. Pyritaceous ammonites are found as of the base. They are very abundant in a 6 to 8 m. thick level which corresponds regionally to the **Chamaloc level**, of which the type locality situated 1,5 km from the Col de Romeyer, presently covered by vegetation, was discovered by Ch. LORY (1860) and described by PAQUIER (1900).

At the Col de Romeyer, only some specimens have been collected so as not to devastate the outcrop before the excursion. The list of species collected, probably incomplete, is given in Figure E4. This association is typical of the basal part of the Early Valanginian pertransiens zone: Thurmanniceras pertransiens is, in fact, accompanied by T.cf.thurmanni (Pict. & Camp.), by numerous Kilianella (Kilianella roubaudiana d'Orb. especially frequent) and by Protancyloceras punicum (Arn.-Saget).

The pelagic marly-limestones correspond to radiolaria, Globochatae and Calpionellid biomicrite with a rich Calpionellid fauna. J. REMANE has recognized two associations of the Early Valanginian :

- The first, at the base (1-3, fig. E4), with Tintinopsella carpathica Murg. & Fil. and T. longa (Col.), characteristic of Upper D3-E zones,
- the second, above (8-9, fig. E4) with the same and Remaniella cadischiana (Col.), Calpionellites darderi (Col.) characteristic of the E zone.

More generally speaking, two facts may be established:

- 1) The fauna is very unevenly distributed : certain beds contain very few individuals or species (Phylloceratidae are dominant), whereas others are very rich. This diversity does not appear to be due here to varying fossilisation conditions but rather to variations in population composition.
- 2) In the pyritaceous ammonite level, the number of individuals and species progressively increases up to a maximum which appears to be reached at bed 5 (Fig E4) and then progressively decreases. If one assumes that a marl-limestone alternation represents sediment deposited over a period of about 20000 years (§ F.2.2, p. 35), maximum ammonite concentration corresponds to an interval of about 100000 years. These particular intervals, regularly observed in the Vocontian basin series, could correspond to **biological crises** during which fauna renewal took place through the appearance and subsequent disappearance of species.

1.2. The Lower Valanginian (level 16 to 68 probably)

Above the marl-limestone alternations at the base of the section, one observes marls over-topped by argillaceous limestones

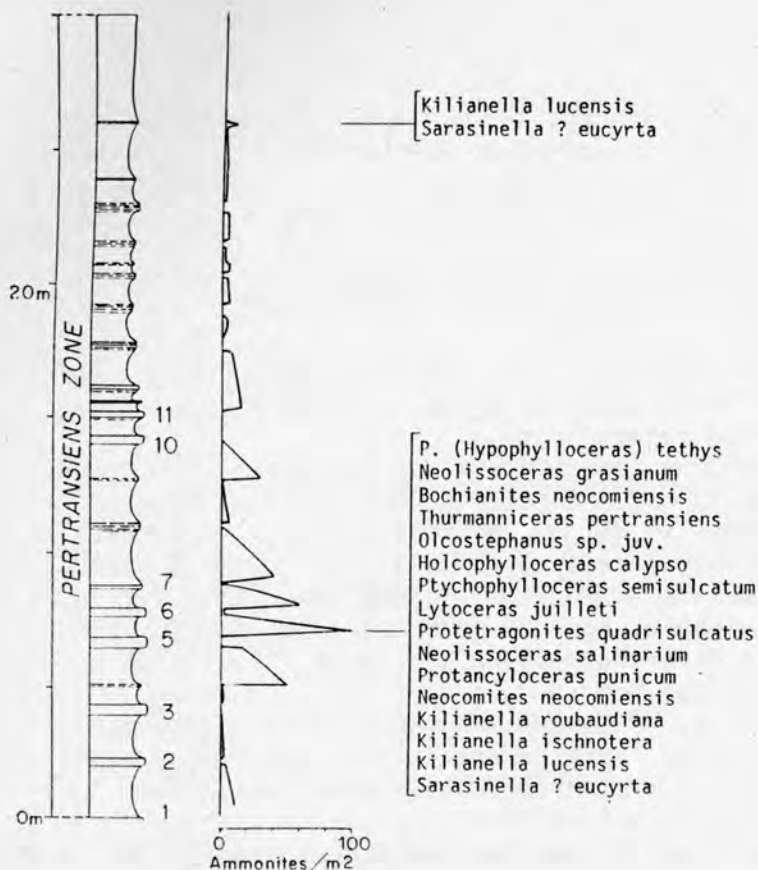


Fig. E 4 : The Early Valanginian of the Col de Romeyer section. Level with pyritaceous ammonites of the pertransiens zone.

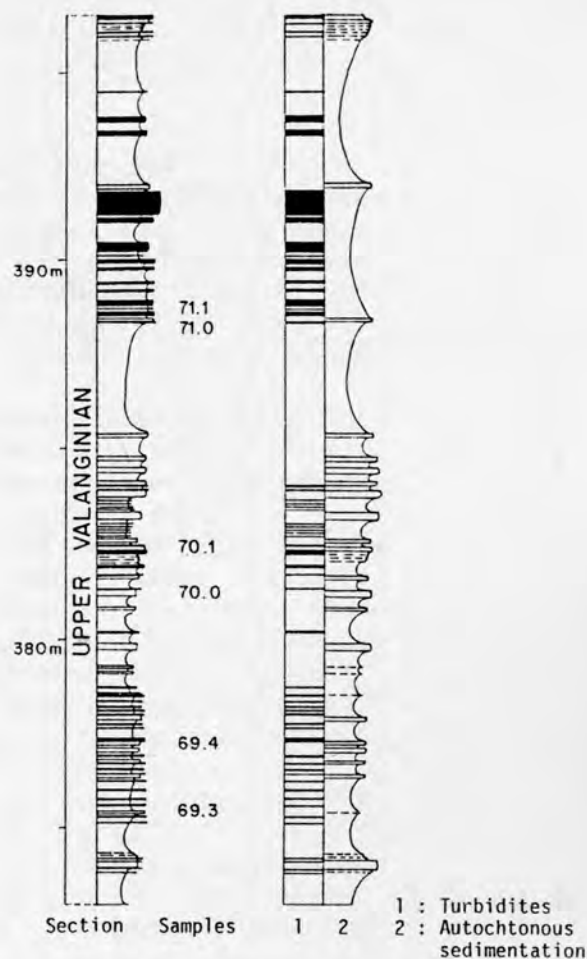


Fig. E 6 : Col de Romeyer section. detail of the section showing the turbidites inserted in the autochthonous deposits. on the right : turbidites and autochthonous banks are separated.

(about 355 m in all).

The marls (about 95 m) contain, at their base, a final pyritaceous ammonite level which has given forth Sarasinella ? eucyrta (Sayn) and several Kilianella lucensis (Sayn) characteristic of an already fairly high part of the pertransiens zone. Above this basal level, the ammonites disappear. The microfauna is poorly preserved, except for at the base, the sample 30-31 which contains : Reophax stellatus Neagu, Gaudryina praedividens Neagu, Gaudryina tuchaensis Antonova, Dorothia kummi Zedler, Lenticulina muensteri (Roemer), Frondicularia Verneuilina acutimarginata Neagu and Spirillina minima Schacko. In this level, the Ostracods are frequent : Parexophthalmocythere berriasensis Donze, Protocythere paquieri Donze and Protocythere entremontensis Donze. At the top (sample 65.0) the microfauna is also abundant : Lenticulina muensteri (Roemer), L. nodosa (Reuss), L. ouachensis multicella Bart., Bett. & Bolli, Gaudryina tuchaensis Antonova, Dorothia kummi Zedler and D. praehauteriviana Dieni & Massari.

The Nannoconus are frequently abundant (24-25, 30-31): Nannoconus cornuta, N. steinmanni, N. globulus, Conusphaera mexicana, Cruciellipsis cuvillieri, Calcicalatina oblongata, Parhabdololithus embergeri, Micrantolithus holschulzii, M. obtusus, Braarudosphaera sp gr africana.

The marls display 3 features: 1) marl-limestone alternations subsist in this very argillaceous environment (alternations of dark and light marls are highly visible on the outcrop); 2) the existence of slumped levels in the marls; 3) the appearance of very fine reddish turbidites ("**plaquettes rousses**"), containing bioclasts from circalittoral outer platform environments (*Pseudotextulariella salevensis* Char., Brön., & Zanin., *Citaella ? favrei* Char., Brön. & Zanin.).

The argillaceous limestones (about 260 m.) are represented by thin limestone-marl alternations which may be grouped together in cycles which are several meters to ten meters thick.

The reddish turbidites, centimeter- to decimeter-sized, are fairly rare at the base but become so numerous at the top that they sometimes make up small scarps which are apparent in the topography. Some of them also contain foraminifera from circalittoral outer platform environments but most of them are made up of sponge spicules. In most cases, no graded bedding is visible, however, at times, in the thickest turbidites, graded bedding is observed between the large spicules at the base and the small spicules at the top.

Over the first 135 m, the argillaceous limestones and marls are themselves reworked by gravity (arrangement in fine millimeter-sized laminae). This is probably the reason for the fact that no well-preserved ammonites have been encountered.

Over the top 120 m, the reworking of argillaceous limestones appears to be less substantial. Ammonites are more frequent (Fig. E3) and the series becomes more marly.

The Early Valanginian-Upper Valanginian boundary has not been precisely determined. It has been located thanks to the appearance of Neocomites (Eristavites) platycostatus (SAYN) but could be situated a bit lower.

The relative abundance of ammonites, the decrease in reworkings and the stratigraphic level allow correlation of the Jurassic platform Di3 discontinuity with the base of the more marly level (near the altitude 320 m, Fig. E3).

1.3. The Upper Valanginian (level 69 to few meters above 100.4)

It displays 4 main features.

- a) Marly sedimentation is preponderant;
- b) The facies progressively become more pelagic and synsedimentary reworking on the slopes appears to progressively disappear. Throughout this series, the autochthonous marl-limestone alternations become very regular and typical of Vocontian basin pelagic facies.
- c) Ammonites become very frequent at the top of the series where they are represented by a rapid multiplication of Bochianites in almost all of the beds and by the great abundance of Neocomitidae (notably Teschenites) in certain beds.
- d) Nannofauna are the same as in the Lower Valanginian, but we constate the disappearance of Nannoconus cornuta.
- d) Turbidites are very numerous and fairly thick (up to several decimeters thick at the base of the Upper Valanginian). They make up a scarp which is highly visible in the topography (Fig. E2). They consist exclusively of sponge spicules **reworked from hemipelagic facies**.

Above this level, the turbidites become very rare and then **disappear entirely 40 m below the Valanginian-Hauterivian boundary** (they are lacking in most of, if not all of the callidiscus zone).

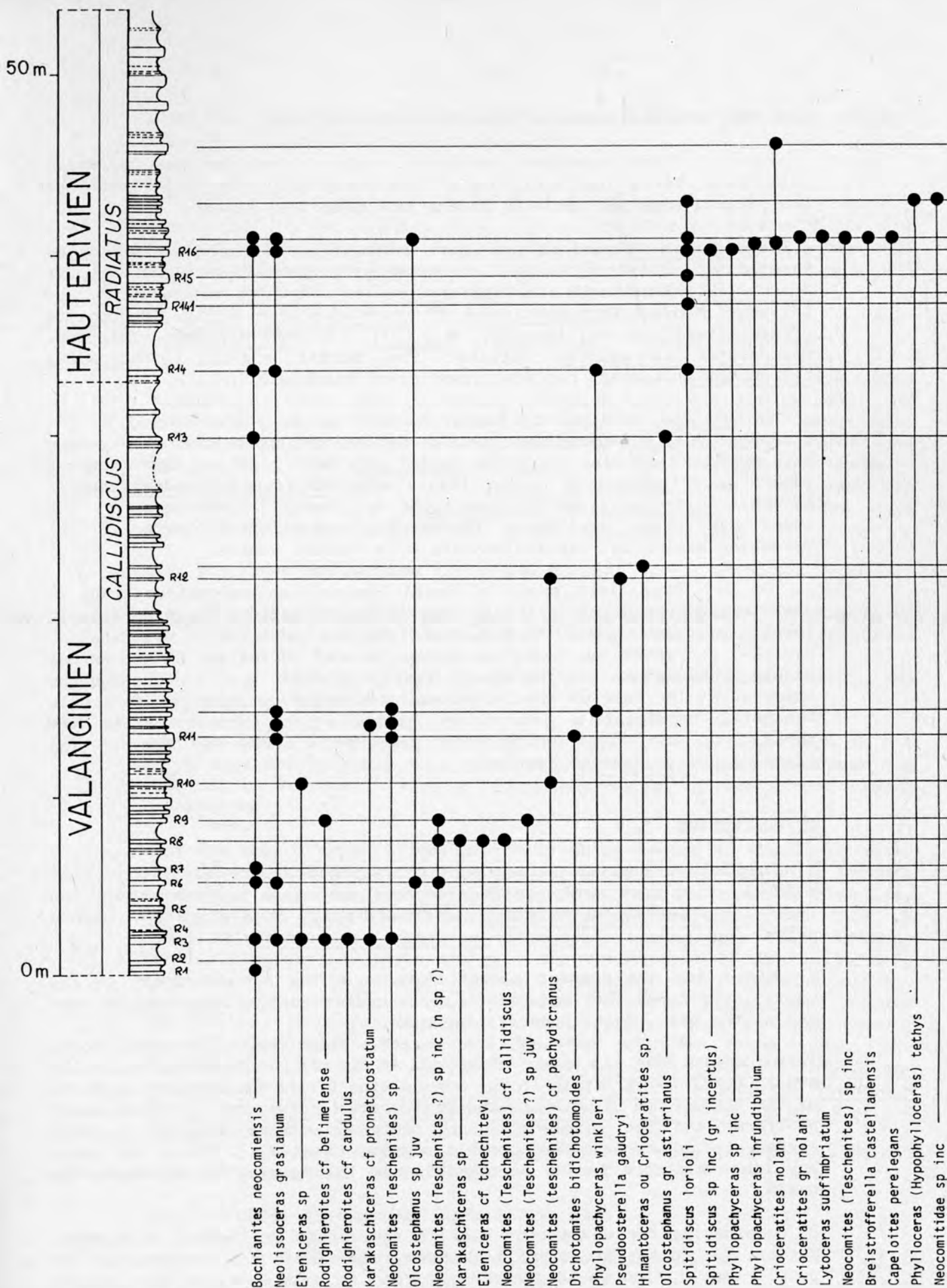


Fig. E 5 : The Valanginian-Hauterivian boundary of the Col de Romeyer section. Distribution of the ammonites.

1.4. The Valanginian-Hauterivian boundary (Fig. E5)

It is found in a small marly flat located between two small calcareous scarps highly visible in the topography (Fig. E2). Ammonites are very numerous, especially in the two calcareous scarps.

- The callidiscus zone of the Upper Valanginian is characterized by an association of which the most characteristic species are Eleniceras cf tchecchitevi Breskovski, Rodighieroites cf cardulus Company, R. cf belimense Mandov, Karakaschiceras cf pronetocostatum (Felix), Neocomites (Teschenites) cf callidiscus, N. (T.) cf pachydicranus Thieuloy, Pseudoosterella gaudryi Nickles. The boreal migrant Dichotomites bidichotomis (Kemper) has been found in this association.

- The radiatus zone of the Basal Hauterivian is characterized by the disappearance of Valanginian species and by the appearance of numerous new species including Spitidiscus lorioli (Kil.), S. sp gr incertus (d'Orb.), Crioceratites nolani (Kil.), Breistrofferella castellanensis (d'Orb.). Spitidiscus and Crioceratites are found in abundance at the base. Capeloites perelegans (Matheron), exceptionally rare in the Vocontian basin, is represented here by a typical sample.

This first group of Basal Hauterivian calcareous beds is over-topped by more marly levels covered by vegetation. These more marly levels (cf. the section on the road from Col de Rousset to Chamaloc, Fig. E7) represent the Vocontian domain lateral equivalent of the **Marnes Bleues d'Hauterive**. It therefore clearly appears that the hardground observed at the base of the latter in the Gorges du Nant region and in Neuchâtel represent a sedimentary hiatus which corresponds to the deposit of the first Hauterivian calcareous cycle of beds of the Chamaloc-Col de Rousset section.

2. CONCLUSION

1) The Col de Romeyer Valanginian corresponds to an autochthonous or slightly displaced marly or argillaceous carbonate sedimentation. The reworking observed can be explained by a deposit on a slightly-inclined slope.

2) Turbidites are present almost throughout the series except in the callidiscus zone. They are especially abundant in the campylotoxus zone and at the base of the Upper Valanginian.

At the base of the series, they contain circalittoral foraminifera from the outer platform. At the top, only sponge spicules are found. This variation in the composition of the constituent elements of the turbidites illustrates the progressive submersion of contemporary platforms and the retrograding of facies on their margins (a fact already established in the Jurassic platform sections). There are never any **inner platform facies reworked in the Valanginian of the Vocontian basin.**

3) Considering the C sequence and its equivalent in the Col de Romeyer series, turbidites are especially rare at the base and numerous at the top. A correlation would therefore appear to exist between the maximum progradation of platform facies and the turbidite maximum in the basin.

THIRD STOP : HAUTERIVIAN SECTION ON THE ROAD TO COL DE ROUSSET (CHAMALOC) (Fig. E7 and E8)

Location: Die 3-4 (1/25000)

This section, situated along the road to Col de Rousset, corresponds to the extension of the Col de Romeyer to the Serre des Blaches section. The lower and upper parts of the section have been the subject of detailed research in regards to fauna. The central part has been the subject of only a fairly rapid exploration.

1. DESCRIPTION :

This section is about 300 m. thick. It begins in the Upper Valanginian, below the last small scarp of the callidiscus zone, and ends in the Early Barremian at the base of very thick hemipelagic facies. It is represented by a succession of limestone-marl alternations with pelagic facies. There is no transition between the pelagic Hauterivian limestones (radiolaria limestones) and the reworked hemipelagic Barremian limestones (fine-grained biosparite mixed with biomicrite with Sponge spicules).

1.1. The Lower Hauterivian (level 140 to 227)

The Valanginian-Hauterivian boundary has not been precisely set ; only the framework has been set thanks to bed-to-bed correlations with the Col de Romeyer section.

Above the first group of Hauterivian calcareous beds, two lithologic entities are observed:

- **at the base**, a marly entity which corresponds to a large part of the loryi zone and probably to a part of the radiatus zone (by comparison with Col de Romeyer). It is a lateral equivalent of the **Marnes Bleues d'Hauterive**.

- **at the top**, a more calcareous entity which begins in the loryi zone, continues in the nodosoplicatum zone and ends at the top, which becomes more marly again, in the cruasense zone. All of the index species i.e. Crioceratites loryi (Sarkar), Lyticoceras gr nodosoplicatum (Kil. & Reb.) and Cruasicerias cruasense (Torcapel), having been found in this section. However, we note the enormous development of the loryi zone compared to the nodosoplicatum and cruasense zones. Because of the previously presented correlation between limestone-marl alternations and astronomical 20000-year cycles, it would appear that we have here a substantial disparity in the lifespan of each of these zones. The Nannofauna is sometimes abundant : Nannoconus steinmanni, Conusphaera mexicana, Cruciellipsis cuvillieri, Calcicalatina oblongata, Parhabdolithus embergeri, Micrantolithus holschulzii, M. obtusus. Lithraphidites bollii appears between the banks 230 and 330.

This calcareous entity corresponds to a lateral equivalent of the "**Pierre Jaune de Neuchâtel**".

1.2. The Upper Hauterivian (Bank 227 to 332)

It is made up of three lithologic levels.

- **At the base** (sayni zone), an entity in which marly beds and limestone beds are of about the same thickness. Grioceratites duvali (Lev.) and Subsaynella sayni (Paq.) appears in this level.

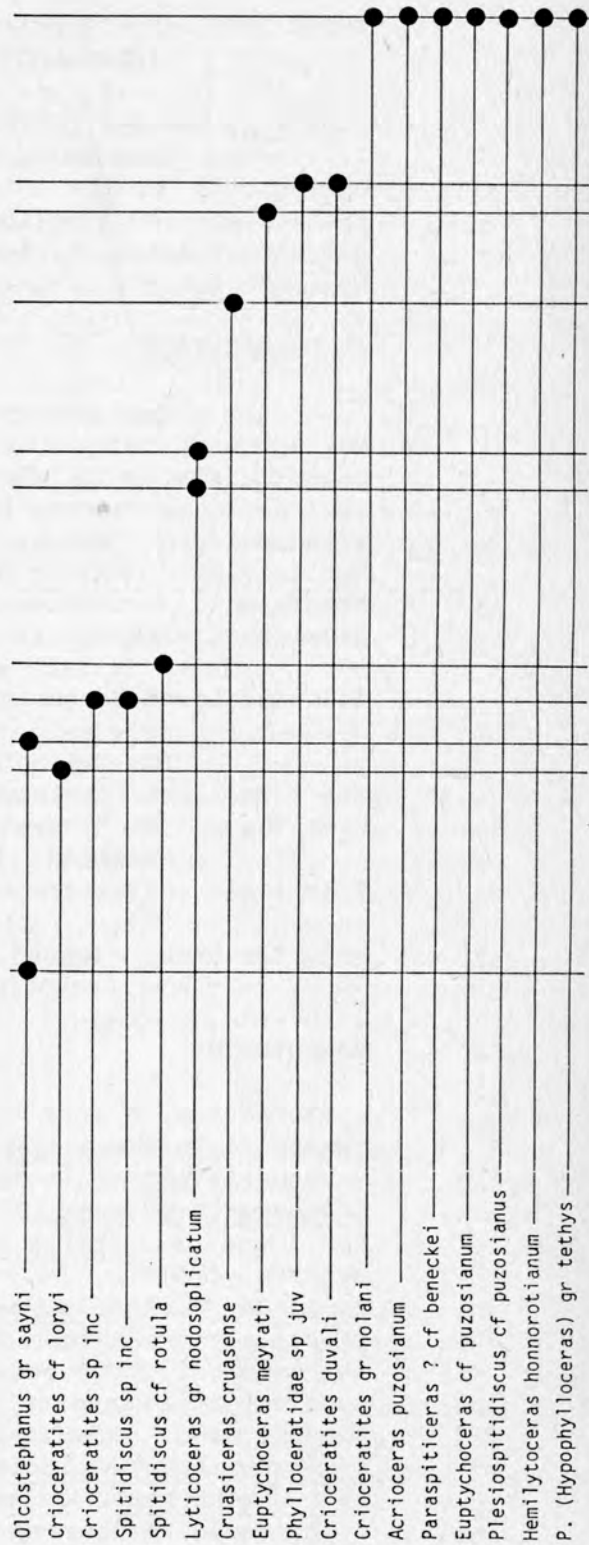
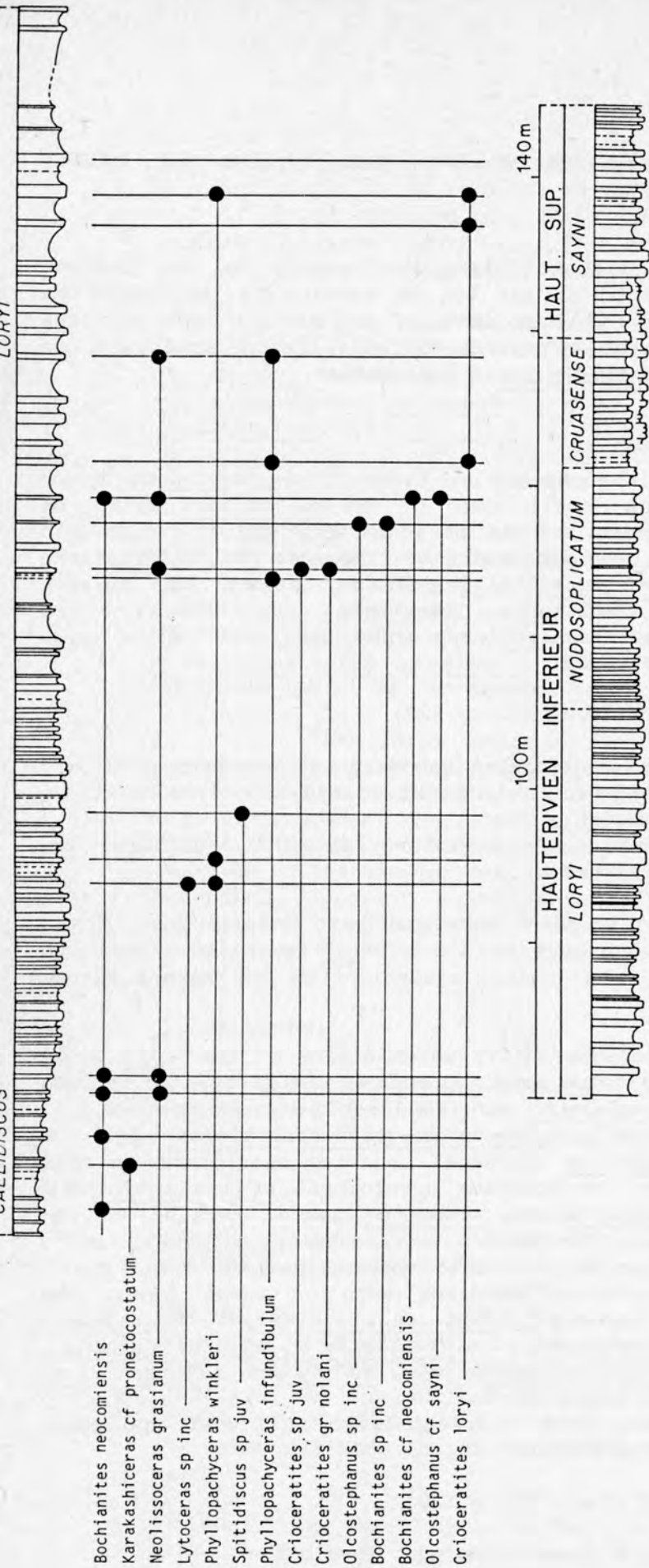


Fig. E 7 : The Hauterivian section along the Chamaloc-Col de Rousset road (first part). Distribution of the ammonites.

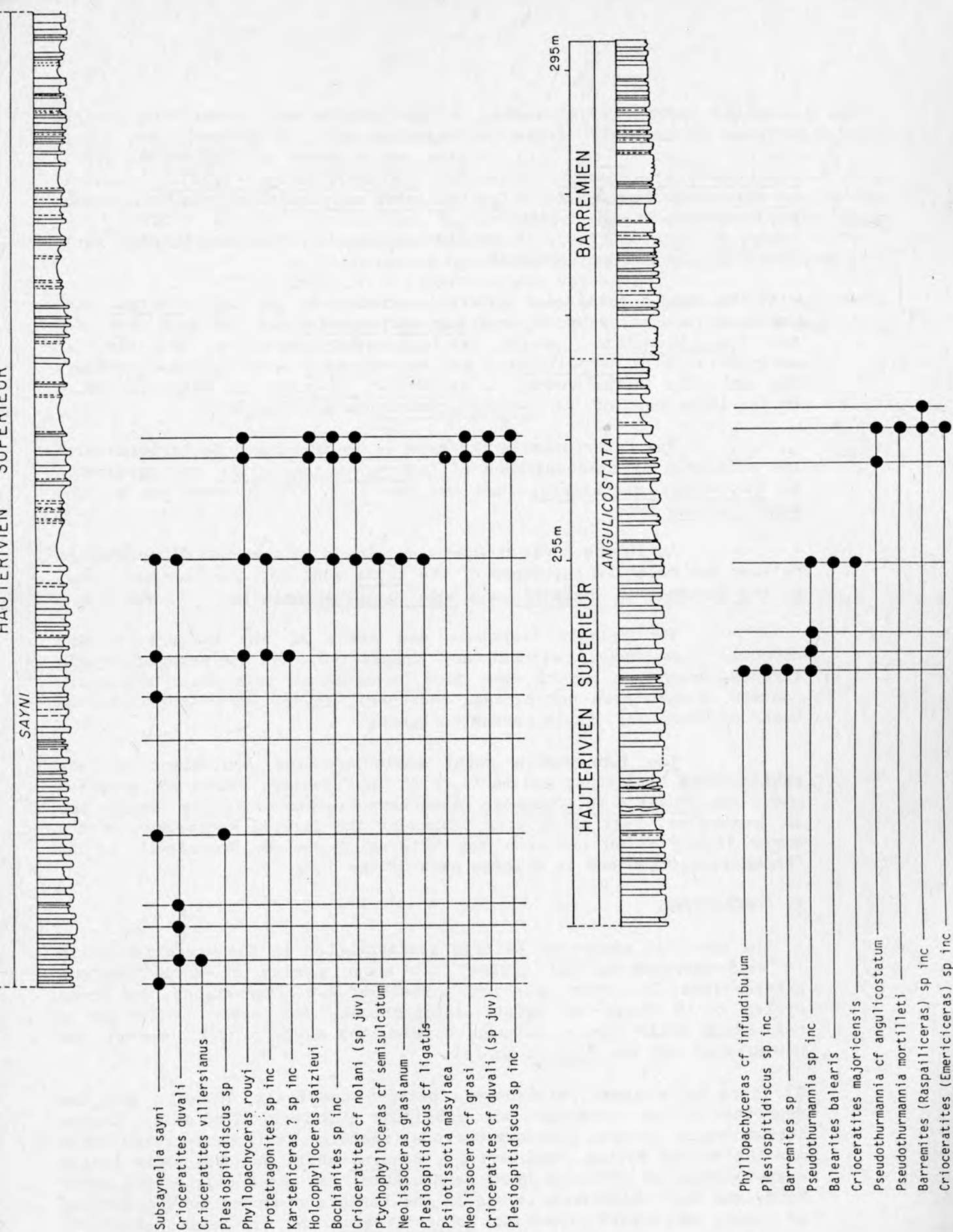


Fig. E 8 : The Hauterivian section along the Chamaloc-Col de Rousset road (second part). Distribution of the ammonites.

- In the middle (sayni zone), a thick marly level containing several pyritaceous ammonite levels (S. sayni marls) with Crioceratites duvali (Lev.), C. cf nolani (Kil.), Plesiospitidiscus cf ligatus (d'Orb.), Phyllopachyceras rouyi (d'Orb.), Holcophylloceras saiziei (Kil.), Karsteniceras ? sp inc, and Psilotissotia masylaea (Coq.), an conspicuous but extremely rare species.

Subsaynella sayni (Paq.) is abundant in the first meters of the marly level but has not been encountered above.

- At the top, a calcareous entity in which only the angulicostata zone has been recognized up to now. Pseudothurmannia are abundant here, but the P. angulicostata species has only been found at the top, in association with Raspailiceras and Emericiceras whose presence conveys the proximity of the Barremian. Balearites balearis has only been found in the lower part of the Pseudothurmannia level (Fig. E8).

The Nannofauna is the same as in the Lower Hauterivian with the exception of disappearance of Lithraphidites bollii and appearance of Nannoconus circularis, both in the bank 330 at the top of the angulicostata zone.

As in the Early Hauterivian, there is a marked disproportion between the relative thickness of the sayni zone and the terminal zones of the Hauterivian (balearis and angulicostata zones).

The pelagic limestone and marls of the Hauterivian are directly over-topped, without any transition, by hemipelagic argillaceous limestones (up to bank 333), undated at this point but which contain, above Serre des Blaches (Romeyer), in the marls equivalent to those of Level 346, Early Barremian fauna.

The Subsaynella sayni marls are the equivalent of the argillaceous limestones and marls, rich in Toxaster, which are situated above the Cruasiceras cruasense calcareous limestones in the Vercors and in Chartreuse. They could also represent the lateral equivalent of the marly levels which over-top the "Pierre Jaune de Neuchâtel" in La Chambotte section and in a large part of the Jura.

2. CONCLUSIONS

1) The cyclical nature of pelagic sedimentation in the Vocontian basin is well-conveyed on all scales: 1st order cycles of marl-limestone alternations, 2nd order cycles on a scale of 4-5 alternations, 3rd order cycles on a scale of twenty alternations, 4th order cycles on a half-stage scale (cycle included between the marls of the base of the Hauterivian and the S. sayni marls).

2) There is a clear relationship between the basin deposits and the deposits on the Jurassic and subalpine platform. The marly levels correspond to drowned platform periods (Chamaloc Early Hauterivian marls and the Marnes Bleues d'Hauterive ; S. sayni marls and the marly levels over-topping the "Pierre Jaune de Neuchâtel" in the Jura). On the other hand, the most calcareous levels in the basin correspond to the periods of lowest sea level (Chamaloc nodosoplicatum and cruasense limestones and "Pierre Jaune de Neuchâtel").

3) At the Hauterivian-Barremian boundary, the transition from pelagic to hemipelagic facies is abrupt. This event is contemporaneous with a very

substantial acceleration of the sedimentation rate: in the Die region 140 m thick for the Upper Hauterivian, 1000 to 2000 m for the Early Barremian.

This event is undoubtedly linked to the major tectono-sedimentary crisis in this region, manifestations of which are perceptible from the top of the Hauterivian to the beginning of the Upper Barremian and notably marked by:

- exceptionally high sedimentation rates and the birth of a shoal in the Southeastern Vercors;
- the drastic decrease or total absence of the Early Barremian and the Upper Hauterivian in the Jura and along the Isère fault.

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