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# Statistical Approach to the Problem of Alternating Beds of Limestone and Marl (Upper Oxfordian of the French Jura)

By ERIC DAVAUD and AUGUSTIN LOMBARD<sup>1)</sup>

## ABSTRACT

The series investigated consists of alternating micritic limestone and marls, Upper Oxfordian in age, which have been deposited in the Jura province. There is very little variation among the microfacies, and the carbonate rocks classification criteria do not yield meaningful lithologic subdivisions. Objective classification methods (cluster analysis) have been used and they have succeeded in distinguishing 8 biofacies, based on the faunal content of the samples.

A simple statistical analysis shows the relationships between fauna and marls (interstrata) and limestones (strata). The vertical evolution of biofacies is more regular for the marls than for the limestones. By contrast the succession of the biofacies of marls and limestones, taken in stratigraphic order, does not show any regularity and could be considered as a random succession. All these points seem to demonstrate that this series cannot be considered as the result of continuous sedimentation with periodic mineralogical or faunal changes but as the result of interference between two sedimentary processes. For example: continuous deposition of thin terrigenous and biogenic material forming the marly interbeds, with episodic sliding of carbonate rich material from the basin edges.

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## 1. Introduction

The succession of fine grained limestone strata and interstrata of marls presents an important sedimentological problem which has not yet received an appropriate answer. Several genetic hypotheses have been proposed but few – to our knowledge – are based on sufficient data to allow a decisive choice, mainly due to the scarcity of fauna and the monotony of lithofacies. There is no evidence of any clear genetic process, as in the analogous alternating series of clastic sediments.

This paper does not offer a definitive answer but does show that for the Upper Oxfordian of the Southern Jura mountains detailed and systematic observations of a semi-quantitative nature may throw new light on the genesis of this type of formations.

### 1.1 *Traditional genetic hypothesis*

Many authors have been puzzled by the apparent rhythmicity of these series, and have tried to explain it by a climatic influence (BRÜCKNER 1951) or by epirogenic oscillations (DUFF et al. 1967; COTILLON 1963). In both cases, they admit the autochthony of the sediments. The variation of lithology and fauna is due to cyclical changes in bathymetry, terrigenous deposits (NOËL 1968) and chemistry of the environment and also to diagenesis in the sediments (ZIEGLER 1958). Other authors stress the analogy with alternating series of sandstone and shales or limestones and shales, as in flysch or “schistes lustrés”. They postulate a similar mechanism of sedimentation (SEIBOLD 1953; MEISCHNER 1964; LOMBARD 1956, 1966, 1972): the limy material settles originally on platforms from which it flows downslope as density currents. Each flow spreads out over a wide area and forms a stratum of allochthonous and resedimented material. The interstratal bed of thin terrigenous or pelagic material is deposited between the flows. The apparent cyclicity of the formation is the result of two different types of sedimentation.

### 1.2 *The formation of “calcaires litéés” (Upper Oxfordian)*

The section studied in this paper is located near the village of Champfromier, in the valley of the Valserine (Dept. of Ain, France, Sheet St-Julien en Genevois. No.1: 857.20/140.20. See Fig. 1 and 2). It is paleogeographically located between sponge bioherms (SW) and a reef (NE).

The beds are formed of micritic limestone and their thickness never exceeds 50 cm. Macro- and microfauna are scarce except in some bioclastic beds. No grading has been observed. Interbeds are composed of marls showing bioturbation. Their thickness varies from a few centimeters to few meters (see Fig. 8).

ENAY, in his monograph of the Oxfordian (1966, p.129–131), gives a detailed description of the macrofauna, without expressing any opinion as to the origin of the “litage”. However, he does point out that this formation is part of a positive sequence (p.293); these marl–limestone alternating beds lie above the marly beds of Effingen

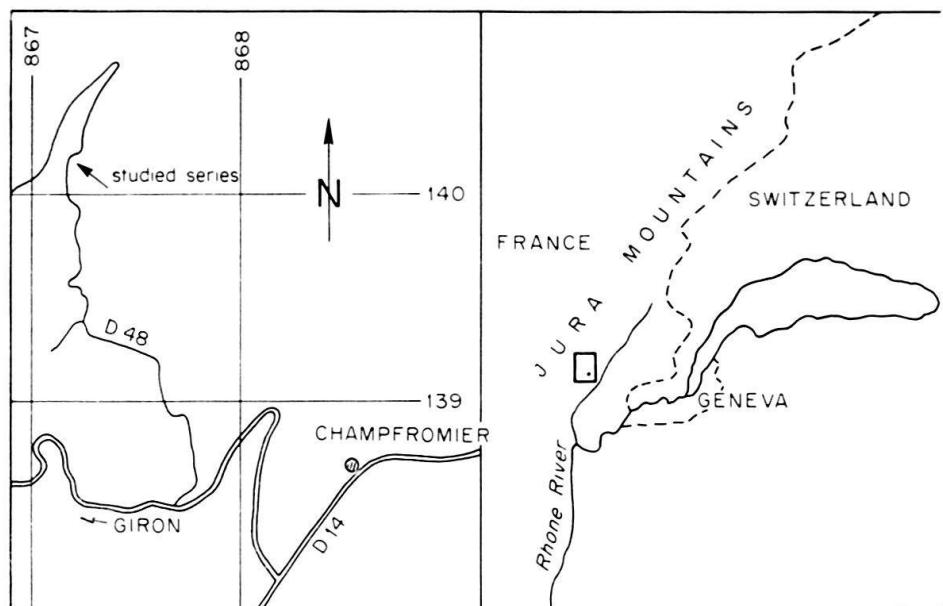


Fig. 1. Locality map.

and Geissberg Fm. and are overlain by sublithographic limestones. He notes that the "calcaires lités" formation shows an overthickness in this area.

### 1.3 Sampling

Over a total thickness of 100 m, 268 samples have been collected by selecting one sample from each bed and interbed. We postulate that each sample has a mineralogical and paleontological content that is representative of the stratonomic unit (bed or interbed) from which it was collected.

This hypothesis has been verified several times by taking five samples from a given bed or interbed and looking for possible vertical or lateral variations within the unit.

Microscopic observations have been made on thin sections and codified for statistical treatment.

## 2. Microfacies

The classification of FOLK (1959) was too general to be applied here. It was decided to use automatic classification methods which have been successfully applied by many authors to limestone descriptions (BONHAM-CARTER 1967; PURDY 1963; JAQUET 1973).

Each sample is characterized by its mineralogical and/or faunal content and then systematically compared to all the other samples. A coefficient of similarity is calculated between all pairs of samples which are then classified into groups by cluster analysis.

Obviously the quality and the geological significance of such a classification relies upon the choice of the descriptors. Hence we have discarded any ambiguous, difficult to observe or invariant descriptor as well as those which are too closely intercorrelated.

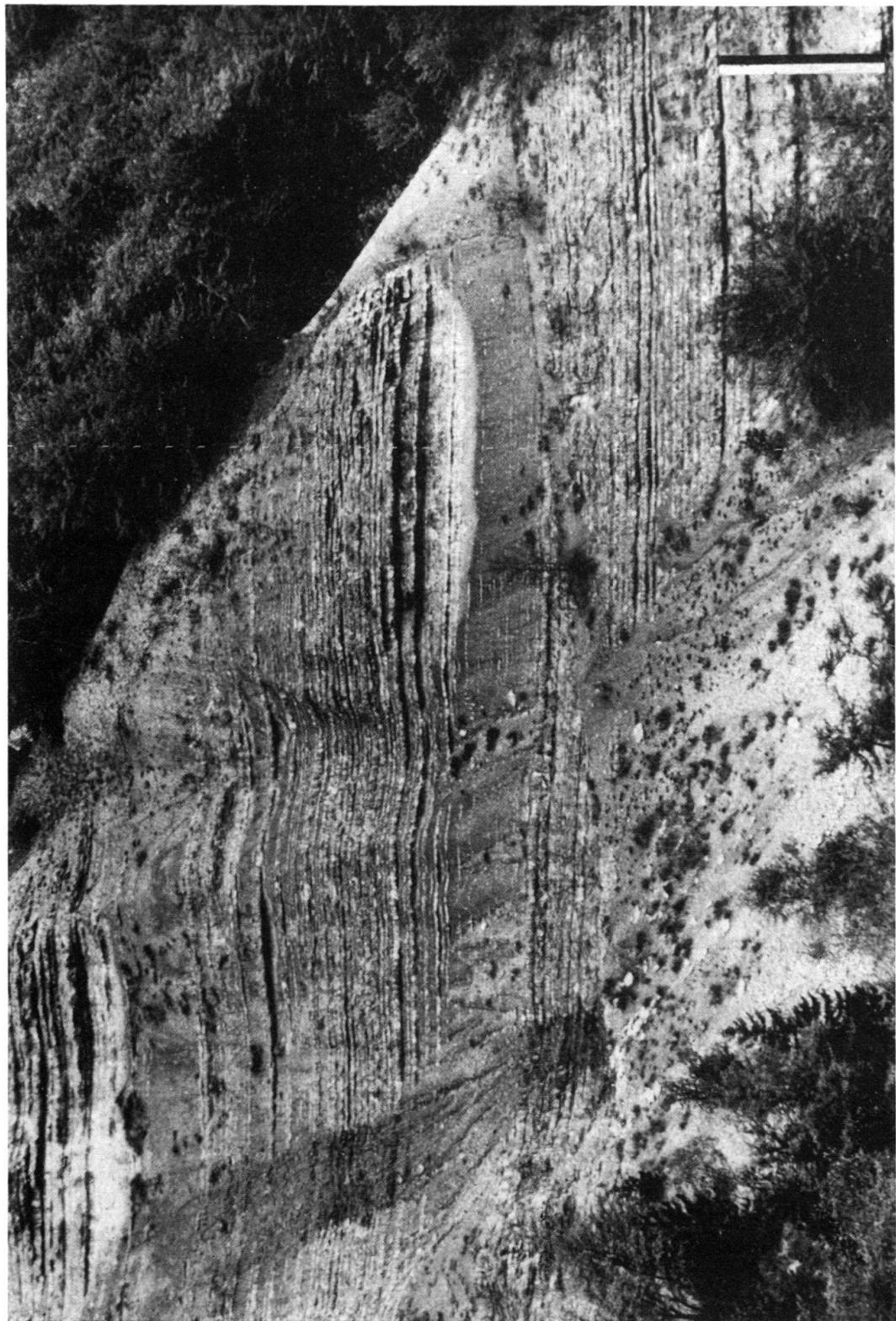


Fig. 2. Upper part of the section studied in this paper (scale bar: 10 m).

### 2.1 Fauna and microfauna

The following groups and genera have been selected for the microfacies description:

1. Pellets
2. Fragments of pelecypods shells
3. Fragments of brachiopods shells
4. Sponges spicules, mostly monaxonones
5. Serpulids
6. Oncoids, often associated with nubecularids
7. Bryozoans
8. Echinoderms, mostly fragments of crinoids, perforated or corroded with a crust of nubecularids
9. Ostracods, with thin, smooth valves; no ornaments
10. Organisms incertae sedis: dark micritic and circular sections, with vacuolar margin.  
They may be related to fecal pellets (*Coprus*? see MAGNE & MASCLE 1962)
11. Algae, free or sometimes as crusts on shell fragments. Often associated with nubecularids
12. Rectangular limestone fragments, broken parts of pelecypods shells

#### Foraminifera

13. *Nodosaria*, type 1: small forms, hyaline test, unilinear-chambered, thick walls, elongate chambers. Some could be represented by the genus *Dentalina*
14. *Nodosaria*, type 2: small forms, uniserial, wall hyaline, generally poorly preserved. Subspherical chambers nearly always pyritised
15. Agglutinated: thick walls, related to genera *Haplophragmoides* and *Ammobaculites*
16. *Textularia*-like forms
17. *Bolivina*: small sections of biserial foraminifera, hyaline walls aff. genus *Bolivina*. Chambers often pyritised
18. *Quinqueloculina*
19. *Glomospira*
20. Nubecularids. Generally forming a crust on crinoids fragments, sometimes free
21. *Spirillina*
22. *Lenticulina*

Other genera of foraminifera have been observed, but are too scarce to be used for the classification: *Ophthalmidium*, *Cyclogyra*, *Lagena*, *Discorbis*, *Trochammina*, *Nodobacularia*, *Glomospirella*.

### 2.2 Countings

Countings have been made for all descriptors excluding the first seven (see 2.1) by investigating all the slide and dividing by its surface. The reproducibility of these countings evidently depends on the concentration of the fauna in the sediment. Controls between several thin sections from the same sample show a rather good agreement between the observed frequencies. Nevertheless, one has to be extremely cautious with low frequencies. Statistical tests based on descriptor countings show

that they follow Poisson, negative binomial or unidentified distributions. Descriptors following a Poisson distribution should not be submitted to any kind of quantitative analysis because their values are entirely random. However, we assume that the countings of all the other descriptors are fairly representative of the real faunal content of the samples.

The classification we have used is based on the presence or the absence of the descriptors, not on their frequency.

### 2.3 Mineralogical elements

The main constituent is low magnesium calcite, as a very fine micritic matrix, which forms 80% of the beds and 50% of the interbeds. Part of this matrix might consist of coccoliths as these organisms have been observed under the scanning microscope.

Clay minerals form 10 to 40% of the sediment. As shown by X-ray diffraction there is no change in the composition or relative amount of the clay minerals from bottom to top of the section.

*Detrital quartz* is scarce, but present in all samples. The grains are very small and sharply angular. Their maximal length never exceeds 60  $\mu$ .

*Pyrite* is omnipresent, in clusters of various dimensions, seldom as idiomorph crystals. The amount of this mineral has been measured by systematic point-counting, as was the quartz.

*Glauconite* is rare in the strata and more frequent in the interstrata where it appears as very small sub-circular clouds (40–50  $\mu$ ).

*Dolomite* only occurs in some strata made of rather coarse bioclastic material (pelecypods, oncoids, bryozoans and serpulids).

The only mineralogical descriptors used in this study are quartz and pyrite which can be measured without sophisticated techniques.

## 3. Analysis of the microfacies – Introduction

The first question one has to ask is whether there are fundamental faunal and mineralogical differences between strata and interstrata sediments. In order to give an objective answer we have split the sample population into two subpopulations (strata and interstrata) and checked by several methods whether the differences are significant.

### 3.1 Frequency of the faunal descriptors

Table 1 shows the frequencies of various faunal descriptors in the strata and interstrata. It seems that several among them occur more frequently in one unit rather than the other. This may be checked by a  $\chi^2$  test, the results of which are given in the last column of Table 1. It shows that 10 descriptors out of 22 tend to predominate in one or other of the two stratonomic units.

Sponges spicules, bryozoans, algae(?), nubecularids and ostracods are specific to the strata. *Nodosaria* 1 and 2, *Textularia*, *Bolivina* and limestone chips are more frequent in the interstrata.

Table 1. *Frequencies of faunal descriptors.*

|                     | Occurrences<br>in strata | Occurrences in<br>interstrata | Total relative<br>frequencies (%) | Chi square * |
|---------------------|--------------------------|-------------------------------|-----------------------------------|--------------|
| Pellets             | 60                       | 63                            | 46                                | 0.60         |
| Sponges             | 16                       | 4                             | 7                                 | <u>7.12</u>  |
| Oncoids             | 2                        | 2                             | 1                                 | 0.00         |
| Brachiopods         | 6                        | 1                             | 2                                 | 3.40         |
| Pelecypods          | 10                       | 6                             | 6                                 | 0.85         |
| Serpulids           | 11                       | 5                             | 6                                 | 2.07         |
| Bryozoans           | 7                        | 1                             | 3                                 | <u>4.32</u>  |
| Algae (?)           | 14                       | 4                             | 6                                 | <u>5.41</u>  |
| Echinoderms         | 49                       | 45                            | 35                                | 0.04         |
| Nodosaria 1         | 34                       | 49                            | 31                                | <u>5.22</u>  |
| Nodosaria 2         | 13                       | 49                            | 23                                | <u>29.94</u> |
| Agglutinated Foram. | 30                       | 42                            | 27                                | 3.71         |
| Textularia          | 12                       | 26                            | 14                                | <u>6.94</u>  |
| Bolivina            | 28                       | 71                            | 37                                | <u>33.76</u> |
| Quinqueloculina     | 31                       | 28                            | 22                                | 0.04         |
| Glomospira          | 56                       | 51                            | 40                                | 0.07         |
| Nubecularids        | 19                       | 2                             | 7                                 | <u>14.00</u> |
| Spirillina          | 40                       | 47                            | 33                                | 1.49         |
| Lenticulina         | 74                       | 70                            | 54                                | 0.00         |
| Ostracods           | 70                       | 36                            | 40                                | <u>15.37</u> |
| Organisms inc.sed.  | 26                       | 25                            | 19                                | 0.00         |
| Fragments           | 29                       | 57                            | 32                                | <u>15.86</u> |

\* significant values are underlined ( $p = 0.05$ )

Other descriptors seem to be ubiquitous, although our test is based only upon the presence/absence of the descriptors. We may infer that some of them, although being present in both stratonomic units, are more abundant in one rather than in the other. This assumption could not be verified statistically, because the frequencies do not follow a normal distribution, but the stratigraphic logs of the quantified faunal descriptors do support this assumption in certain cases as we shall show in section 3.4.

At this stage, we suggest that there is a faunal differentiation between strata and interstrata.

### 3.2 *Relations between faunal descriptors (R-mode analysis)*

Analysis of the thin sections gives a first intuitive idea of the more evident faunal associations, although it does not assess the degree of association. This subjective evaluation has been completed by the statistical method called "R-mode analysis",

which computes similarity coefficients between a great number of numerical or binary variables and yields a graphic representation of their interrelationships. The similarity coefficient has to be chosen with due regard to the type of data. It is not advisable to use the Pearson's product-moment coefficient, for part of our data is binary (absent-present) and the other is numerical and does not follow a normal distribution.

Under these conditions, matching coefficient may be used. The ratio expressed by JACCARD (1908) is:

$$r_{kj} = \frac{np}{np + npa} \quad \text{where}$$

$r_{kj}$ : measurement of the similarity or association between the  $k^{\text{th}}$  and the  $j^{\text{th}}$  descriptor.

$np$ : number of samples wherein the two descriptors are present.

$npa$ : number of samples wherein only one of the two descriptors is present.

This coefficient is 1 when the two descriptors always occur together and 0 when they never coexist. It is computed between all the descriptors taken two by two. The resulting matrix is then submitted to a cluster analysis, whereby the intercorrelations between the descriptors are graphically portrayed by a dendrogram.

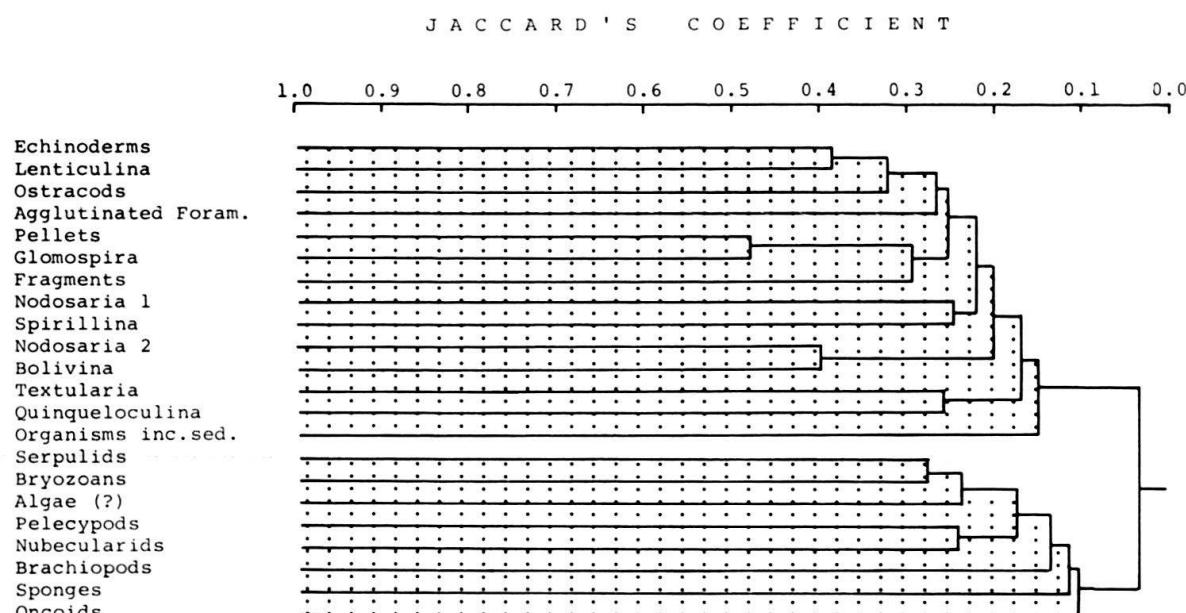


Fig. 3. Dendrogram showing the interrelationships between faunal descriptors. The level of associativity between two descriptors is expressed by vertical lines.

### 3.3 Discussion of the results

The dendrogram (Fig. 3) shows clearly two great faunal groups which seem to have different ecological implications. The first group consists of serpulids, bryozoans, uncertain forms connected with algae, fragments of pelecypods, of brachiopods, spicules of sponges, nubecularids and oncoids. All these forms are indicators of shallow water depth.

The second group is more important and includes essentially: foraminifera, fragments of ostracods, echinoderms, organisms *incertae sedis* and pellets. Their ecologic significance is not well known, but it is generally admitted that *Bolivina*,

*Lenticulina* and *Nodosaria* belong to a deeper environment. Fauna of the first group are coarser than those of the second. A granulometric differentiation is interfering with the bathymetric one. It should be noted that the fauna more specific to the beds (see 3.1) falls into the first group, with the exception of ostracods. The ubiquitous organisms and those from the interbeds belong to the second group.

The dendrogram (see Fig. 3) shows three further strong associations:

1. Pellets – *Glomospira* (similarity: 0.46)
2. *Nodosaria* type 2 – *Bolivina* (0.38)
3. Crinoids – *Lenticulina* (0.37)

In the first two cases, one may suggest that the associated organisms lived in the same environment, the pellets having an organic origin. In the third case, the association is the result of a symbiosis between *Lenticulina* and crinoids.

These observations lead us to presume that there is an initial bathymetric differentiation between the strata and interstrata.

### 3.4 Vertical variations of the faunal abundance index

Curves of frequency variation for the various quantified descriptors (see 2.2) have been traced, to show in a more subtle manner the differences between strata and interstrata. These curves have been smoothed<sup>2)</sup> by a five term equation, as proposed by DAVIS & SAMPSON (1967). In this way, minor oscillations are eliminated and interpretation is made easier.

Figure 4 shows the variation of the faunal abundance index for three of the most representative descriptors. The dotted curves express data from interstrata, the continuous ones from the strata.

*Spirillinae* yield the highest frequencies in the lower half of the series. The zone of greatest variations in amplitude is common for both the strata and interstrata curves, but there is never a correspondance between the maxima. The higher frequencies are always in the interstrata.

*Lenticulinae* do not show any sympathetic variation between the two curves, but the zones showing extreme values are the same for the strata and the interstrata. These organisms seem to predominate in the strata.

Ostracods are also more frequent in the strata and fluctuate all along the section. In detail, the curves show an independent evolution although the general trend is the same.

Most other faunal descriptors show similar characteristics. Some prefer one stratonomic unit and are scarce in the other (i.e. nubecularids in the strata, *Nodosaria* and organisms *incertae sedis* in the interstrata). Only *Glomospira* shows sympathetic variations between strata and interstrata.

As a general rule, it may be concluded that variations of faunal frequency in the strata rarely correspond to those in the interstrata. In other words, the increase of fauna from one interstratum to the next has not the slightest influence on the faunal abundance of the intermediate stratum. However, the zones of major and minor

<sup>2)</sup> After equal spacing interpolation.

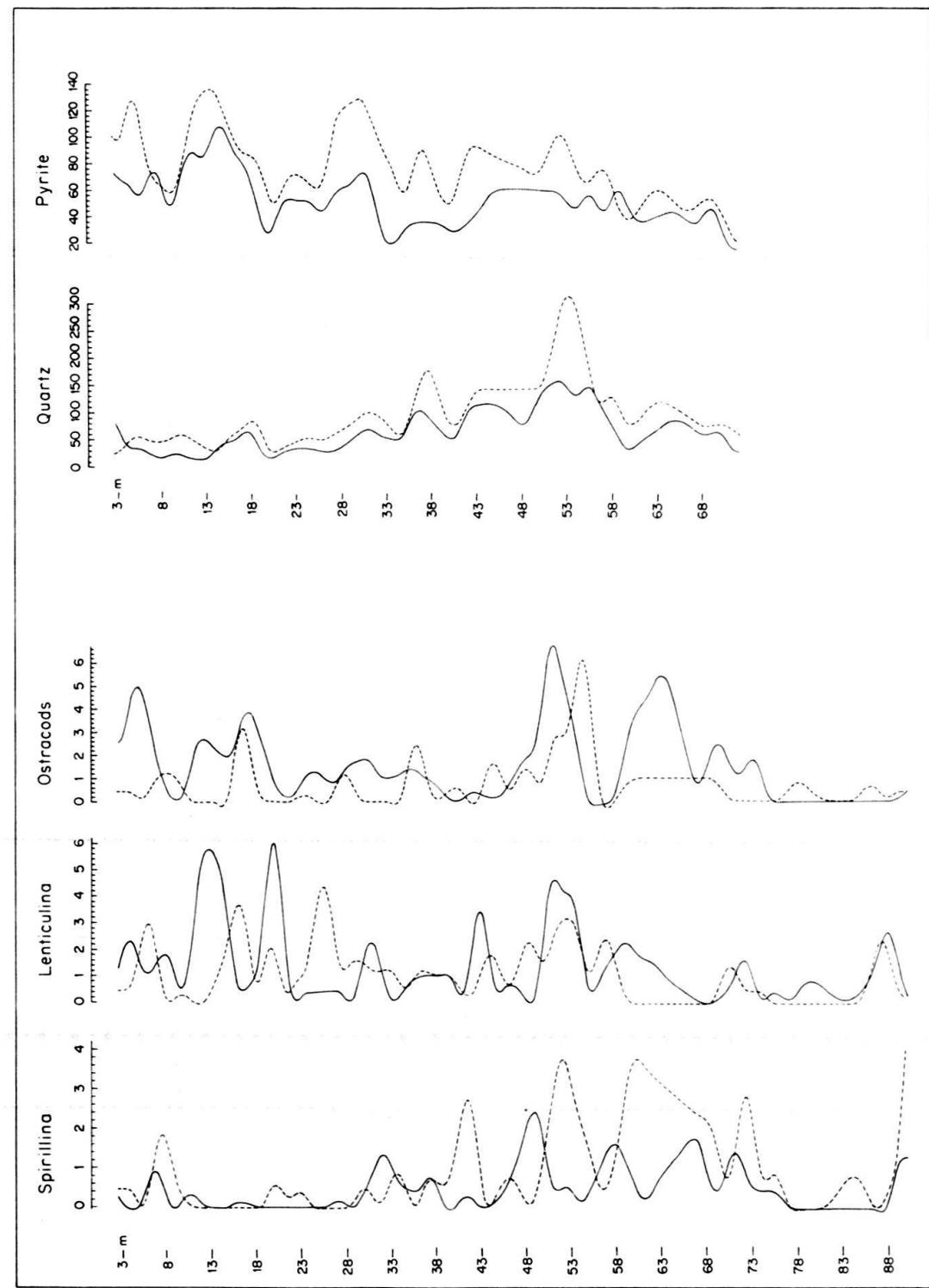


Fig. 4. Vertical variations of the faunal and mineralogical abundance index. The dotted curves are established on data coming from the interstrata, the continuous ones on data coming from strata. The faunal index is the mean number of individuals counted in one square centimeter. The mineralogical index is the number of grains observed in two square centimeters. Vertical scale in meters.

oscillations of the two curves coincide in most cases (echinoderms, *Spirillina*, *Lenticulina*, etc.).

We are forced to admit the existence of two kinds of variations: one, with large wave-lengths in strata and interstrata (general trend); the other, disturbing fluctuations (local trend) whose amplitude is large enough to mask the general trend. The large-scale variations of the fauna may be due to changes (periodical or not) in the physiography, bathymetry, chemistry or rate of sedimentation of the environment. However, it is more difficult to explain the origin of the temporary fluctuations and their independent influence upon the fauna of the strata and interstrata. The erratic character of these variations and the absence of covariation between the two curves suggest that these fluctuations may be due to the sampling or counting method or to the low observed values (Poisson distribution, see 2.2).

Keeping in mind these restrictions we conclude that significant qualitative (3.1 and 3.3) and quantitative (3.4) differences in faunal content exist between the two stratonomic units. The passage bed-interbed is therefore an important change which has a syngenetic origin.

### 3.5 Vertical variations of the mineralogical index

Figure 4 shows both the remarkable covariation between the amount of quartz or pyrite in the strata and in the interstrata as well as the greater abundance of these minerals in the interstrata. This covariation can be diversely interpreted. In the hypothesis based on a biotrital autochthonous and uninterrupted sedimentation of the carbonates, one could suppose that the rate of carbonated sedimentation is systematically greater for the strata than for the interstrata. This view is supported by the fact that bioturbation is always more intense in the interstrata. However one could also imagine that the limestone is allochthonous and had less quartz originally, or that it bore an equal amount but lost some during transportation.

In accordance with these interpretations Figure 5 shows that the amount of quartz in a stratum is a linear function of its amount in the underlying interstratum.

### 3.6 Sample classification into various biofacies (Q-mode analysis)

The method used to objectively classify the samples into groups has already been described in section 2. The coefficient used to measure the similarity between two samples is that of SOKAL & MICHESTER (1958). Our choice is based on the fact that this coefficient is also a sign of likeness when a given descriptor is simultaneously absent in two compared samples. Thus, the value of the similarity between two azoic micrites will be maximum, while it would have been zero had JACCARD's coefficient been used.

Eight sample groups result from the cluster analysis. Their specific character is based upon the relative frequency of each descriptor in every group. It is graphically reported in Figure 6 in diagrams which we call the *spectrum of the biofacies*.

It is evident that the descriptors giving an individualisation to a group are those which appear either very seldom or very frequently.

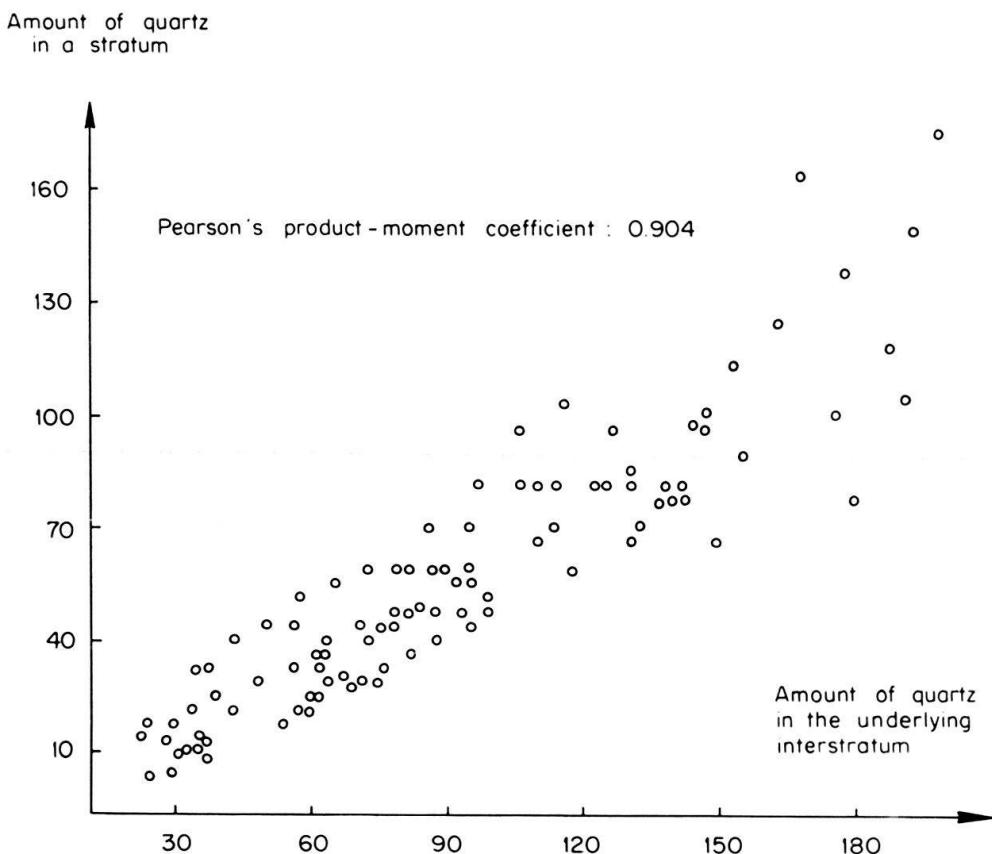


Fig. 5. Relationship between the amount of quartz in a given stratum and its amount in the underlying interstratum. The values are expressed as number of grains in one square centimeter.



Fig. 6. Spectrum of the biofacies. The eight sample groups (biofacies) are characterized by the relative frequency of each descriptor. For example, nubecularids appear in 75% of the samples belonging to biofacies 8 and are never present in the other biofacies.

By convention, only the last ones have been used to give a name to each of these groups:

1. Azoic micrite
2. Micrite with ostracods
3. Biopelmicrite with *Glomospira*, *Bolivina*, *Nodosaria* type 1
4. Biomicrite with *Nodosaria* type 2, *Bolivina* and *Lenticulina*
5. Biomicrite with *Bolivina*, ostracods and *Spirillina*
6. Biopelmicrite with *Glomospira*, limestone fragments and *Lenticulina*
7. Biomicrite with ostracods, *Spirillina*, *Lenticulina* and spicules
8. Biomicrite with *Lenticulina*, echinoderms, nubecularids and algae(?)

Some descriptors are common to several groups, others are specific to one only (sponges, echinoderms, etc.), suggesting that the groups are not entirely independent faunal entities. There must exist some kind of relationships, possibly hierarchical, which can be substantiated by calculating a new coefficient of similarity between the groups rather than between the samples as above.

The coefficient of euclidean distance appears to be the best. Based upon the mean frequencies of each descriptor inside each group, it gives the distance between the eight biofacies in a  $n$  dimension space (here,  $n = 22$ ). The coordinates of these eight biofacies are given by the relative frequencies of each descriptor:

$$c_{ik} = 1 - \sqrt{\sum_{j=1}^n \frac{(f_{ij} - f_{kj})^2}{n}} \quad \text{where}$$

$c_{ik}$  = coefficient of similarity between the  $i^{\text{th}}$  and the  $k^{\text{th}}$  biofacies

$f_{ij}$  = relative frequency of the  $j^{\text{th}}$  descriptor of the  $i^{\text{th}}$  biofacies.

The square root represents the distance between one point whose coordinates are  $(f_{i1}, f_{i2}, \dots, f_{in})$  and another point whose coordinates are  $(f_{k1}, f_{k2}, \dots, f_{kn})$ .

The dendrogram of Figure 7 gives the intergroup relations and the relative importance of each biofacies. It also discloses the existence of two supergroups. The first includes biofacies 1, 2 and 3 which are characterized by the scarceness of fauna and the second, biofacies 4 and 5 which have several common descriptors. Dissimilarity increases from the group 1 to the group 8.

Let us consider the value of such a classification. The groups which have been defined above may differ only slightly such as in the presence or absence of a descriptor allowing a sample to pass from one biofacies into the other. Nevertheless, according to this method, it is possible to classify several, rather monotonous microfacies into groups in an objective way. Other classifications, that of FOLK (1959) in particular, are too general or not sufficiently discriminating to be used in cases such as ours.

In conclusion, we suggest that the biofacies we have individualized have a meaning, keeping in mind that these subdivisions are frail.

### 3.7 Stratigraphic distribution of the biofacies

The stratigraphic distribution of the biofacies in the strata and interstrata is given in Figure 8 with separate logs for each. The passage from strata to interstrata is often

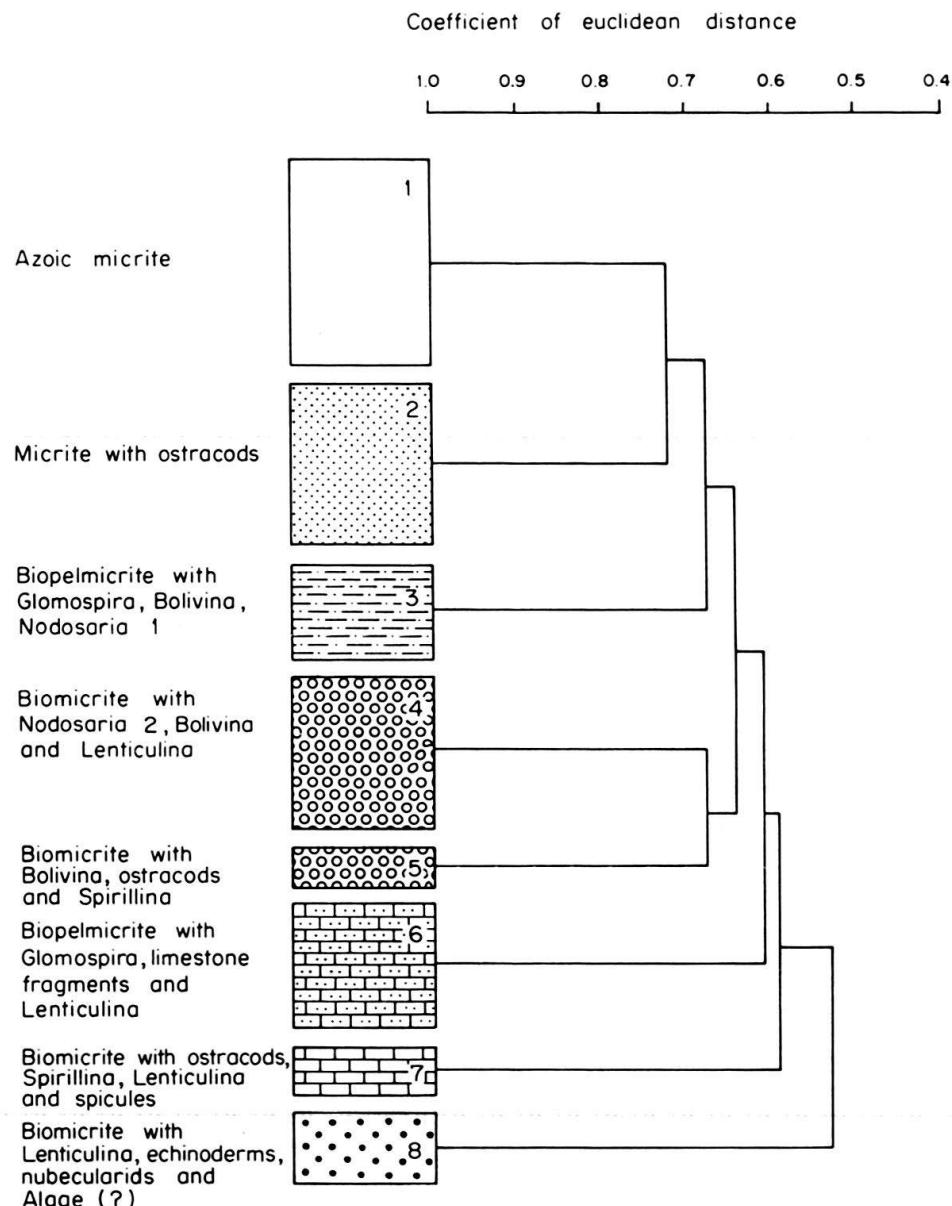


Fig. 7. Dendrogram showing relationships between sample groups determined by cluster analysis. The level of similarity increases from right to left and is indicated by the value of the distance coefficient. The surface attributed to each group is related to the number of samples belonging to this group.

marked by a change of biofacies. Exceptions are present for samples from zones where bed limits are poorly defined.

Biofacies 7 and 8 occur only in strata, while biofacies 4, 5 and 6 seem to be specific of the interstrata.

Groups 1, 2 and 3, with characteristic faunal scarcity, are common to strata and interstrata but appear rarely simultaneously in the same stratigraphic intervals.

Table 2 gives the percentage of the various biofacies in the two stratonomic units, as well as their relative total frequency as shown in the dendrogram of Figure 7. These percentages do not take into account bed and interbed thickness but only the number of samples from a given biofacies with respect to the total number of samples.

Table 2. Distribution of biofacies.

|               | Frequencies in strata | Frequencies in interstrata | Total relative frequencies |
|---------------|-----------------------|----------------------------|----------------------------|
| Biofacies 1   | 28 %                  | 21 %                       | 23 %                       |
| Biofacies 2   | 22                    | 11                         | 18                         |
| Biofacies 3   | 7                     | 14                         | 12                         |
| Biofacies 4,5 | 8                     | 26                         | 22                         |
| Biofacies 6   | 9                     | 28                         | 13                         |
| Biofacies 7   | 12                    | 0                          | 5                          |
| Biofacies 8   | 14                    | 0                          | 7                          |

The analysis of the logs of Figure 8 leads to the following observations: The interstrata in the bottom two thirds of the section show a slow facies evolution, with each step represented by several consecutive samples. From bottom to top, the following sequence is observed:

- a) azoic micrite (1)
- b) ostracods micrite (2)
- c) *Nodosaria*, *Bolivina* and *Lenticulina* biomicrite (4 and 5)
- d) *Glomospira*, *Lenticulina* and fragments pelmicrite (6)

Following a section of apparently random variations, the last twenty meters of the series seem to show a condensed repetition of the a-c succession.

By contrast, the vertical distribution of biofacies in the strata does not show the same slow evolution: The facies change more rapidly and apparently in a random manner.

The transition matrixes (Table 3) give the observed frequencies for passing from one biofacies to the next and the theoretical frequencies expected if biofacies succession were random (see SELLEY 1970). In order to test whether observed biofacies successions differ from random succession, a  $\chi^2$  is computed and expressed as a probability to allow comparisons between the transition matrixes<sup>3)</sup>. This probability could be interpreted as a measure of the degree of disorder in a time series. This statistical step indicates the existence of preferential successions and confirms our first observations.

The highest values of the interstrata matrix (Table 3a) systematically occur along the diagonal. This means that each biofacies tends to succeed to itself. This tendency is much less marked among the strata biofacies (Table 3b).

In short, there is a slow and regular trend in the succession of the interstrata biofacies, which is less evident in the strata, as proved by the higher value of the chi-square probability. On the other hand, if bed and interbed successions are tallied in the same

<sup>3)</sup> Markov chain analysis cannot be used for this purpose: The matrixes are not stationary and many transitions are never observed.

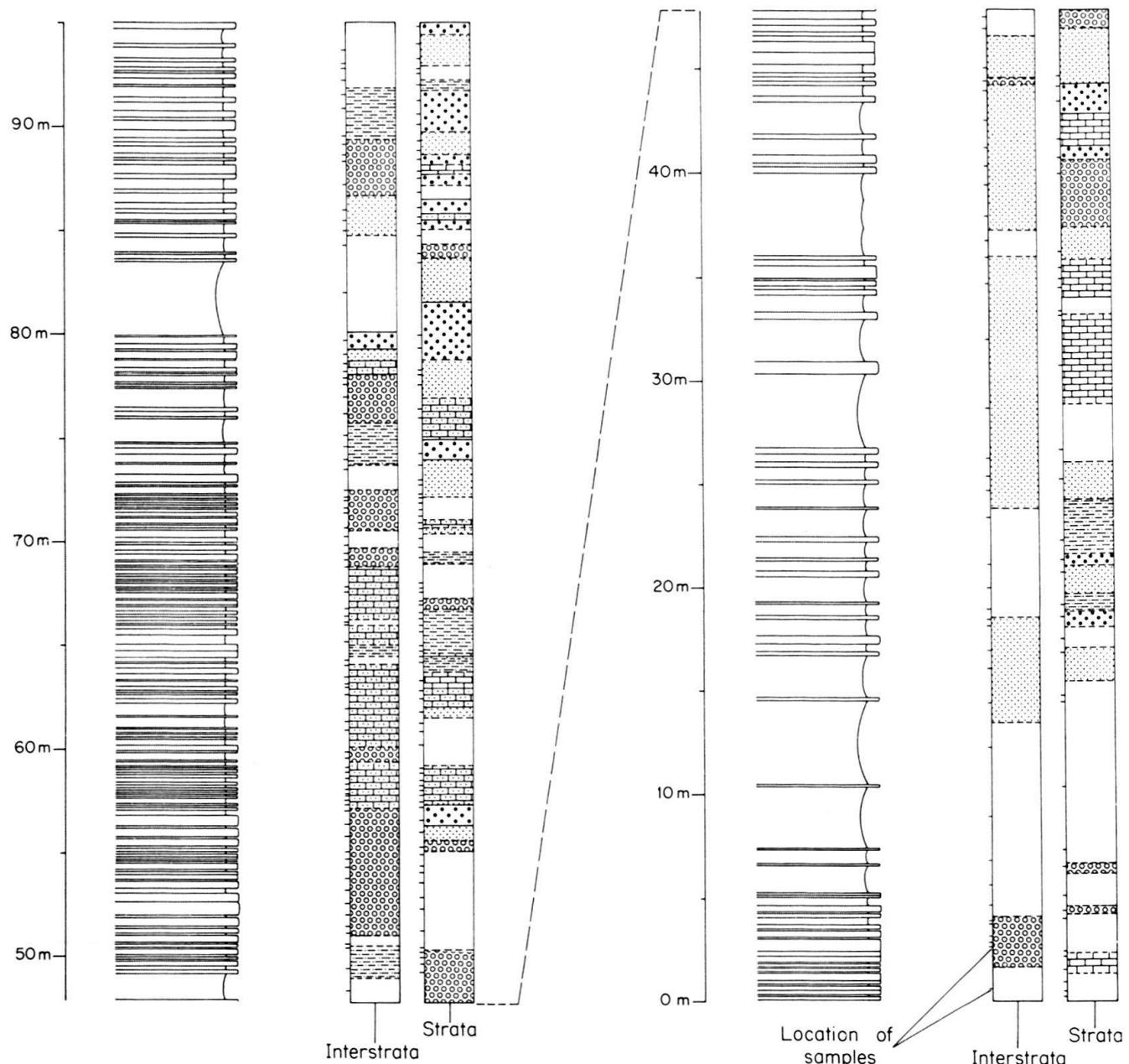


Fig. 8. Simplified stratigraphic distribution of the biofacies. The bottom of the series is at 0 m, the top at 95 m. For the meaning of symbols, see Figure 7. Facies between tick-marks are interpolated.

transition matrix (Table 3c), biofacies pass into one another in a random fashion (low value of *chi-square*). This means that appearance of a biofacies in a stratum is not related to the presence of a given biofacies in the underlying interstratum, and the facies of a stratum does not influence the facies of the next overlying interstratum.

The following points should be stressed:

1. The passage stratum–interstratum is usually marked by a biofacies change.
2. Some biofacies occur predominantly in strata or predominantly in interstrata.
3. Changes of biofacies are rather scarce in the interstrata (slow evolution) and much more frequent in the strata.

Table 3a. *Interstrata transition matrix.*

| B I O F A C I E S |          |          |          |           |           |      |
|-------------------|----------|----------|----------|-----------|-----------|------|
|                   | 1        | 2        | 3        | 4,5       | 6         | S.T. |
| Biofacies 1       | 9<br>(4) | 3<br>(3) | 3<br>(3) | 6<br>(6)  | 2<br>(5)  | 23   |
| Biofacies 2       | 2<br>(3) | 7<br>(2) | 2<br>(2) | 4<br>(4)  | 0<br>(3)  | 15   |
| Biofacies 3       | 3<br>(3) | 2<br>(2) | 6<br>(2) | 2<br>(4)  | 3<br>(3)  | 16   |
| Biofacies 4,5     | 3<br>(5) | 2<br>(4) | 3<br>(4) | 16<br>(7) | 5<br>(6)  | 29   |
| Biofacies 6       | 5<br>(4) | 2<br>(3) | 2<br>(3) | 1<br>(6)  | 14<br>(5) | 24   |
| S.T.              | 22       | 16       | 16       | 29        | 24        |      |

L E G E N D  $H_0$  hypothesis tested by  $\chi^2$  : the occurrence of a given biofacies (columns) does not depend on the previous biofacies (rows)  
 (3) predicted value assuming a random arrangement of biofacies  
 S.T. sum of transitions D.F. degree of freedom

Table 3b. *Strata transition matrix.*

| B I O F A C I E S |           |          |          |          |          |          |          |      |
|-------------------|-----------|----------|----------|----------|----------|----------|----------|------|
|                   | 1         | 2        | 3        | 4,5      | 6        | 7        | 8        | S.T. |
| Biofacies 1       | 17<br>(9) | 7<br>(8) | 2<br>(2) | 3<br>(3) | 0<br>(3) | 3<br>(2) | 2<br>(4) | 34   |
| Biofacies 2       | 5<br>(7)  | 7<br>(6) | 0<br>(1) | 4<br>(2) | 3<br>(2) | 1<br>(2) | 7<br>(3) | 27   |
| Biofacies 3       | 3<br>(2)  | 3<br>(1) | 0<br>(0) | 0<br>(0) | 0<br>(0) | 2<br>(0) | 0<br>(1) | 8    |
| Biofacies 4,5     | 5<br>(2)  | 2<br>(2) | 0<br>(0) | 2<br>(0) | 0<br>(0) | 0<br>(0) | 1<br>(1) | 10   |
| Biofacies 6       | 2<br>(3)  | 1<br>(3) | 2<br>(0) | 0<br>(0) | 5<br>(1) | 0<br>(0) | 1<br>(1) | 11   |
| Biofacies 7       | 2<br>(3)  | 4<br>(3) | 0<br>(0) | 0<br>(1) | 1<br>(1) | 4<br>(1) | 2<br>(1) | 13   |
| Biofacies 8       | 0<br>(4)  | 5<br>(3) | 3<br>(0) | 0<br>(1) | 2<br>(1) | 0<br>(1) | 4<br>(2) | 14   |
| S. T.             | 34        | 29       | 7        | 9        | 11       | 10       | 17       |      |

Table 3c. *Strata and interstrata transition matrix.*

|               | B I O F A C I E S |           |          |            |           |          |          |      |  |
|---------------|-------------------|-----------|----------|------------|-----------|----------|----------|------|--|
|               | 1                 | 2         | 3        | 4,5        | 6         | 7        | 8        | S.T. |  |
| Biofacies 1   | 16<br>(13)        | 7<br>(10) | 3<br>(6) | 20<br>(11) | 7<br>(7)  | 1<br>(1) | 1<br>(3) | 55   |  |
| Biofacies 2   | 6<br>(9)          | 8<br>(6)  | 5<br>(4) | 9<br>(7)   | 3<br>(5)  | 2<br>(1) | 4<br>(2) | 37   |  |
| Biofacies 3   | 7<br>(5)          | 3<br>(4)  | 4<br>(2) | 1<br>(4)   | 6<br>(3)  | 1<br>(0) | 2<br>(1) | 24   | Computed $\chi^2$ : 55.63 with 42 D.F. |
| Biofacies 4,5 | 17<br>(12)        | 13<br>(9) | 4<br>(5) | 7<br>(10)  | 2<br>(6)  | 1<br>(1) | 6<br>(3) | 50   | $\chi^2_{0.05}$ : 58.12                |
| Biofacies 6   | 6<br>(8)          | 6<br>(6)  | 7<br>(3) | 3<br>(6)   | 10<br>(4) | 2<br>(0) | 0<br>(2) | 34   | Chi square probability : 0.077452      |
| Biofacies 7   | 0<br>(1)          | 2<br>(1)  | 1<br>(0) | 2<br>(1)   | 2<br>(0)  | 0<br>(0) | 0<br>(0) | 7    | $H_0$ is accepted                      |
| Biofacies 8   | 3<br>(4)          | 3<br>(3)  | 2<br>(1) | 4<br>(3)   | 1<br>(2)  | 1<br>(0) | 3<br>(1) | 17   |  |
| S. T.         | 55                | 42        | 26       | 46         | 31        | 8        | 16       |      |  |

4. There is a marked absence of regularity in the biofacies stratigraphic succession when beds and interbeds are considered together. This suggests that the processes of strata formation are independant from those of the interstrata. In this case, the studied series appears to be the result of interference between two different sedimentary processes.

#### 4. Conclusions

According to these observations, it is now possible to reconsider the genesis of the alternating limestone–marl beds of the “calcaires lités” formation.

In the first hypothesis, the alternances would be due to periodical variations in the marine environment or in the terrigenous influx. This hardly applies to our series, because the faunae should vary periodically with changes of these two main sources. The biofacies succession should be more regular. The slow evolution in the interstrata should exist simultaneously in the strata.

According to our second hypothesis, the strata are due to a process of allochthonous sedimentation and density flow. Yet no classic features such as graded bedding, flow structures or sole marks are present in the strata to support to this mechanism.

However, this process explains reasonably the following points:

- the alternating stratification of the two main lithofacies;
- the non-parallel evolution of the strata and interstrata biofacies;
- the absence of regularity in the biofacies stratigraphic succession when beds and interbeds are considered together;

- the disturbed succession of the strata biofacies, which could be explained by the close arrival of turbid suspensions coming from different environments or by their distal or proximal origin;
- the presence of specific biofacies in either stratonomic unit;
- the presence of shallow water faunae in some strata and their absence in the next interstratum;
- the overthickness of the series as mentioned by ENAY (1966) in this region.

These observations lead us to adopt a model of allochthonous sedimentation for the strata deposition as it best explains the variations of fauna and mineralogy we have observed.

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