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Fossil-Lagerstätten

Storm shell beds of *Nanogyra virgula* in the upper Jurassic of France

By

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With 10 figures and 2 tables in the text

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Abstract: *Nanogyra virgula* shell beds from two localities in the Kimmeridgian of France have been generated by storms of varying intensities. The shell beds reflect different degrees of proximality and can be arranged along an onshore-offshore gradient. The near-monospecific nature of the shell beds is due to early diagenetic solution of aragonitic shells prior to reworking by storms. Storm beds of the Schistes de Chatillon (Boulonnais) are mainly proximal and were deposited on the nearshore shallow shelf, whilst storm beds of the Marnes à *Exogyra virgula* (Aquitaine Basin) record a more distal development in a quiet basin.

Key words: Storm shell beds, degree of proximality, cyclicity, Ostreacea, trace fossils, diagenesis, Kimmeridge, Boulonnais, Aquitaine Basin.

Zusammenfassung: Nanogyren-Schille aus dem Kimmeridge des Boulonnais und Aquitanischen Beckens werden als das Produkt von Stürmen unterschiedlicher Intensität und Erosionskraft gedeutet. Unterschiede in ihrer Mächtigkeit und Internstruktur lassen eine Einteilung in proximale und distale Sturmlagen zu. Die Vorherrschaft von *Nanogyra virgula* in den Schillagen ist nicht auf ökologische Faktoren zurückzuführen, sondern auf die frühdiagenetische Lösung aragonitischer Schalen im Sediment. Die Sturmschille der Schistes de Chatillon (Boulonnais) haben vorwiegend proximalen Charakter und wurden im küstennahen flachen Schelf abgelagert; die Sturmschille der Marnes à *Exogyra virgula* (Aquitanisches Becken) sprechen für distale Lage in einem ruhigen Becken.

Introduction

The oyster *Nanogyra virgula* occurs abundantly in fine-grained siliciclastic and carbonate sediments of the Kimmeridgian of western and northwestern Europe. The shells are found either scattered throughout the sediment, or they are concentrated in beds, lenses, or pods. Although very conspicuous, these shell accumulations have received relatively little attention. When

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discussing the environmental history of the Kimmeridgian of the Boulonnais, AGER & WALLACE (1966) assumed that the *Nanogyra virgula* coquinas of the Schistes de Chatillon represent autochthonous banks of cemented oysters. ZIEGLER (1969) studied *Nanogyra virgula* concentrations from numerous localities in western Europe and concluded that they represent in-situ accumulations of the oysters, most of them living attached to sea weed. Studying Upper Jurassic *Nanogyra* from the Aquitaine Basin of southwestern France, GAUTRET (1982), in contrast, distinguished between scattered *Nanogyra virgula* occurrences, interpreted as autochthonous and undisturbed, and parautochthonous shell beds, formed by in-situ reworking and winnowing by currents. The purpose of this paper is to investigate the sedimentology and biostratinomy of *Nanogyra virgula* accumulations in order to clarify their mode of formation. It will be shown that, at the two localities studied, *Nanogyra virgula* shell beds in fact most likely represent storm shell beds. This mode of formation probably also applies to most other *N. virgula* shell beds.

Localities and material

Kimmeridgian *Nanogyra virgula* concentrations were studied at the following two localities and stratigraphic levels in France (Fig. 1):

(1) Marnes à *Exogyra virgula* (mutabilis zone) at Pointe du Rocher south of La Rochelle (Charente-Maritime), and

(2) Schistes de Chatillon (autissiodorensis zone) at Cap Gris Nez, north of Boulogne-sur-Mer (Pas-de-Calais).

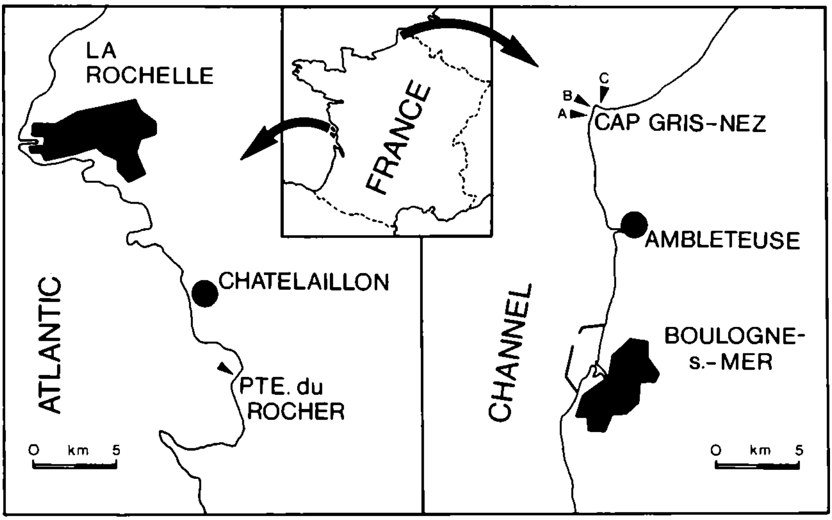

Fig. 1. Locality map. Arrows indicate cliff sections studied.

At Cap Gris Nez *Nanogyra virgula* shell beds are intercalated between siliciclastic sediments, whilst at Pointe du Rocher they occur in argillaceous-calcareous sediments.

The two stratigraphic levels were measured and sampled in detail (Fig. 3, 5). Polished sections and thin-sections were used to study faunal composition and biofabrics of shell beds.

Additional material was obtained from road cuts through the Marnes à *Exogyra virgula* northwest of Yves, south of Chatelaillon-Plage (Charente-Maritime) and from the lower part of the Schistes de Chatillon at Cap Gris Nez and the upper part of the Calcaire de Moulin Wilbert (eudoxus zone) between Boulogne-sur-Mer and Wimereux.

Mode of life of *Nanogyra virgula*

Like nearly all living and fossil oysters, *Nanogyra virgula* (Fig. 2) became cemented to a firm substrate when settling after the planktonic larval stage. Unlike in most other oysters, however, the hard substrate played a significant role only at the juvenile stage. An autecological analysis of *N. virgula* (Fürsich & Oschmann, 1986) showed that the oysters were recliners on soft sediment. This assumption, which contradicts Ziegler's (1969) view that

Fig. 2. Common growth forms of *Nanogyra virgula* (Defrance) ranging from arcuate (a) to arcuate-elongate (b) to bilobate (c). x 1.5. Marnes à *Exogyra virgula*, road cut northwest of Yves, south of Chatelaillon (southwestern France).

N. virgula was preferentially attached to sea weed, is supported by the following observations:

(1) The size of the attachment area is very small (less than 10 mm^2 in 80% of individuals studied) and therefore could not support fully grown individuals.

(2) The helicospiral growth pattern of *N. virgula* as opposed to the planispiral growth pattern of *N. nana*) is incompatible with a permanently cemented mode of life.

(3) The left valve of *N. virgula* exhibits a cup-shaped cross-section and is frequently thickened in the region of the dorso-ventral axis, thus facilitating a stable position on a soft substrate.

(4) In addition, the curved elongate shape of many specimens helped to stabilize the shells on the substrate.

Nanogyra virgula therefore belongs to the oysters which secondarily became adapted to life on soft substrates (Seilacher 1984). The species corresponds to Seilacher's (1984, text-fig. 4) outriggered recliners. This mode of life is in agreement with the well-developed self cleansing mechanism of oysters (Stenzel 1971) which enabled them to live on a soupy, muddy sea floor. A mud-reclining life habit was also the prerequisite for accumulation of the oysters in shell beds.

The Marnes à *Exogyra virgula* section

(Fig. 3)

At Pointe du Rocher, several meters of silty marl and argillaceous micrite are exposed at the cliff. They contain numerous shell beds and lenses of *Nanogyra virgula* which alternate with less fossiliferous horizons. *N. virgula* is by far the most abundant fossil. It occurs in different states of preservation ranging from articulated specimens to disarticulated but complete shells, to fragmented shells and shell debris. Other benthic elements include the bivalves *Anomia, Corbulomima, Gervillella, Nicaniella, Myophorella, Cucullaea, Plectomya rugosa, Trigonia, Camptonectes, Chlamys strictus, Protocardia, Liostrea, Pinna,* several heterodonts, cerithiid gastropods, *Dentalium,* several species of serpulids (*Cyclo-, Tetra-* and *Dorsoserpula*) foraminifera (e.g. *Ammobaculites, Pseudocyclammina, Verneuilina, Textularia, Dentalina, Lenticulina*) and some ostracods. Most of the benthic macrofaunal elements occur scattered between the shell beds, whereby aragonitic faunal elements are, in most cases, preserved as steinkerns. Small *Procerithium*-like gastropods commonly found in the *Nanogyra* shell beds are preserved with recrystallized shells. The same is true of the occasional occurrence of *Trigonia, Myophorella,* and *Gervillella* within the shell beds. Faunal elements occurring between the shell beds are often articulated and sometimes occur, near the base of the section, in clusters (e. g. *Gervillella*) suggesting minimum post-mortem disturbance. Ammonites (e.g. *Orthaspidoceras*) preserved as steinkerns are found at several levels.

Apart from body fossils, trace fossils are common throughout the sequence. Most abundant are *Thalassinoides suevicus* (two size classes), *Chondrites* sp., and *Planolites* sp.. *Rhizocorallium irregulare* was encountered at one level only.

The fine-grained sediments and the trace fossil composition (deposit-feeders dominating) point to a low energy environment. The benthic macrofauna is typical of a low energy sea floor of shallow to intermediate depth. Soft substrate conditions are indicated by forms such as *Nanogyra virgula,*

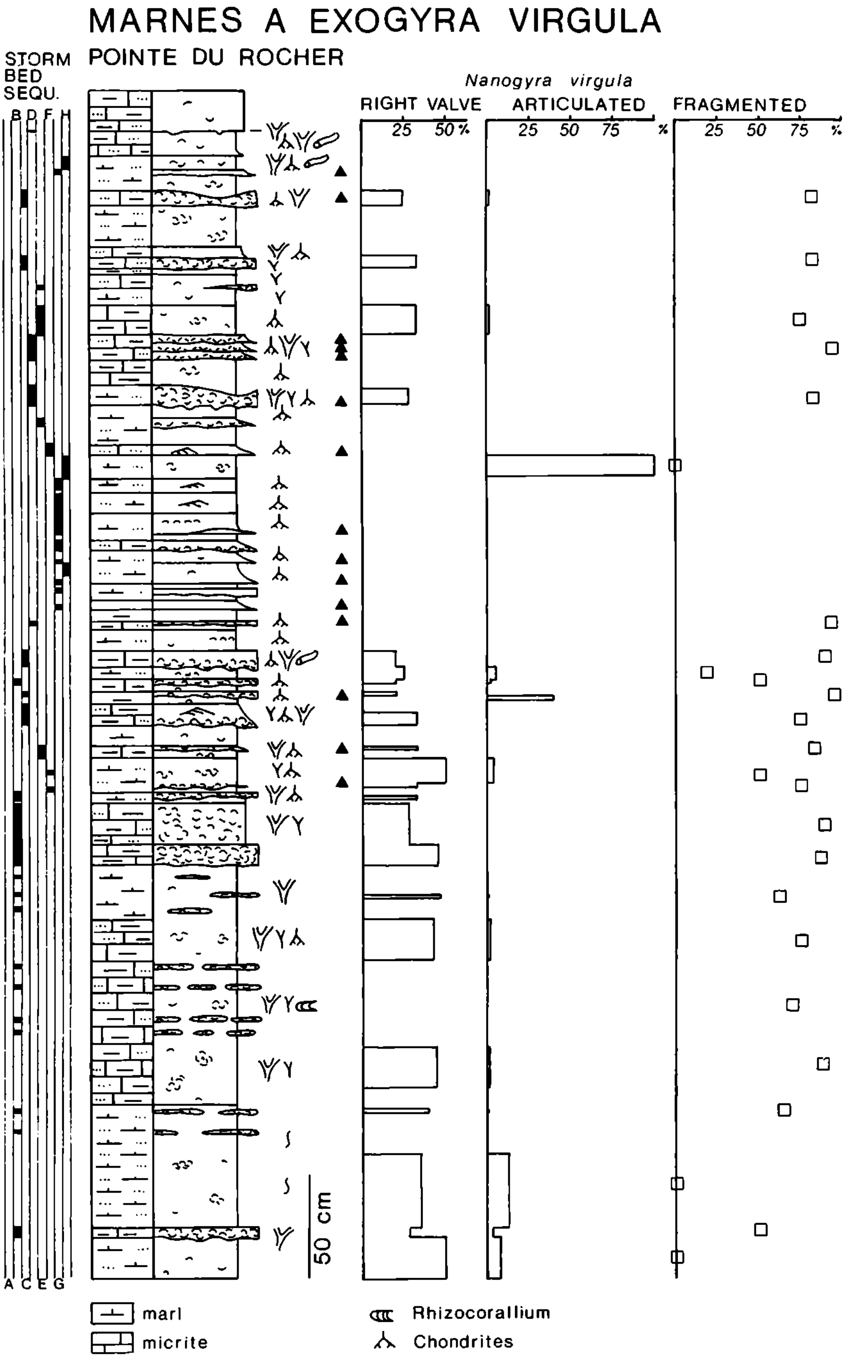

Fig. 3. Section through the Marnes à *Exogyra virgula* at Pointe du Rocher, south of La Rochelle. For key see also Fig. 5. The letters A–H of the storm bed sequence refer to

Protocardia, Corbulomima, and *Nicaniella,* which form characteristic communities in Upper Jurassic shelf environments (e.g. FÜRSICH 1977).

Consequently, the environment of the Marnes à *Exogyra virgula* can be interpreted to represent fully marine low energy conditions. In the Aquitaine Basin, this facies is generally regarded as basinal, situated between carbonate platforms (e.g. HANTZPERGUE & MAIRE 1981).

The only feature which, at first glance, contradicts this interpretation, are the *Nanogyra virgula* shell beds indicating high energy conditions.

Types of skeletal accumulations

The skeletal accumulations vary between several mm and 10 cm in thickness. Most of them exhibit a sharp, rarely flat, more commonly undulating base. In some cases, the sharp base has been disrupted by bioturbation (mainly *Thalassinoides*) and shell material was piped downwards into the underlying mud. The skeletal accumulations consist either of complete, but disarticulated shells, of broken shells, or of a mixture of both. Sometimes, the bioclastic debris is sand-sized and smaller. The skeletal accumulations form continuous shell beds, lenses, or pods. Shell beds may be uniform in thickness when traced within the outcrop, or lenticular. In one case, wave ripples are developed on the top of a shell bed. In some beds, shells are randomly oriented (Fig. 4 a), others exhibit large-scale cross-bedding, yet others consist of laminated or possibly hummocky cross-stratified arenitic shell debris with scattered shells in a preferred convex-up position (Fig. 4 c). In pods shell orientation is dominantly vertical to oblique (Fig. 4 e). Commonly, shell beds are graded. Grading is often discontinuous and a lower coarser part of shells and large shell fragments can be separated from an upper part consisting of fine, commonly laminated shell debris (Fig. 4 b).

Bioturbation nearly invariably modified the primary biofabric of the skeletal accumulations. While *Planolites* and *Thalassinoides* occur

Fig. 4. Skeletal accumulations in the Marnes à *Exogyra virgula* at Pointe du Rocher, south of La Rochelle. Length of bar: 1 cm. Black bars indicate shell orientation (convex-down, oblique to vertical, and convex-up). a: *Nanogyra* shell bed with erosive base and faint traces of crossbedding. Shell orientation random (78 readings). Note that matrix between shells is arenitic in the lower part of the shell bed and largely micritic in the upper part. b: Couplet of *Nanogyra* lumachelle and laminated skeletal debris grading upwards into silty marl. Note bioturbation by *Chondrites* (light-coloured) in the laminated silt and by *Planolites* (dark). c: Undulous laminated (possibly hummocky cross-stratified) skeletal debris with erosive base and scattered *Nanogyra* shells in preferred convex-up orientation (78 readings). d: Graded laminated (possibly hummocky cross-stratified) skeletal silt overlying undulating erosion surface. Note bioturbation by *Chondrites* (two size classes). e: Shell pods of *Nanogyra virgula* caused by bioturbation (mainly *Thalassinoides*). Preferred shell orientation is vertical to oblique (100 readings).

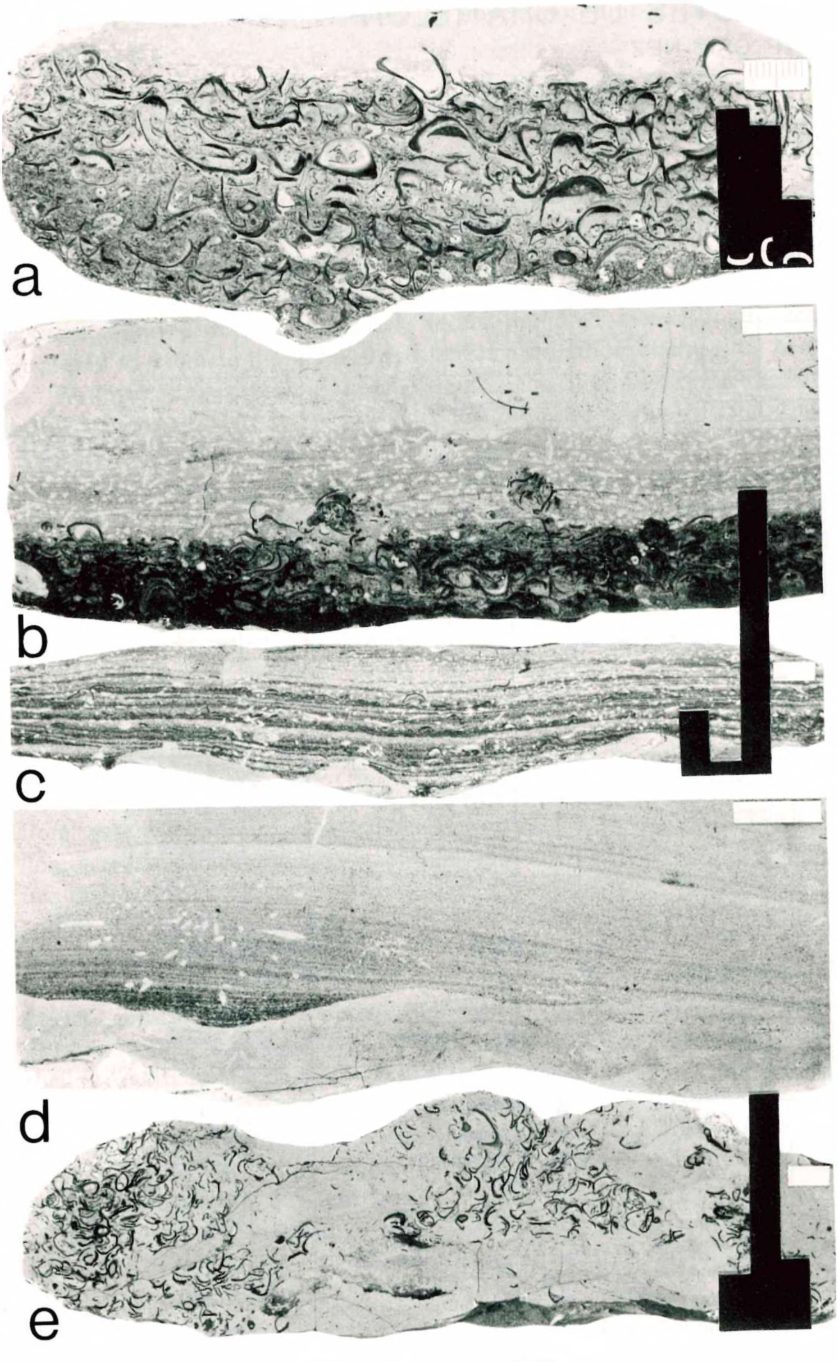

Fig. 4 (Leg. see p. 146)

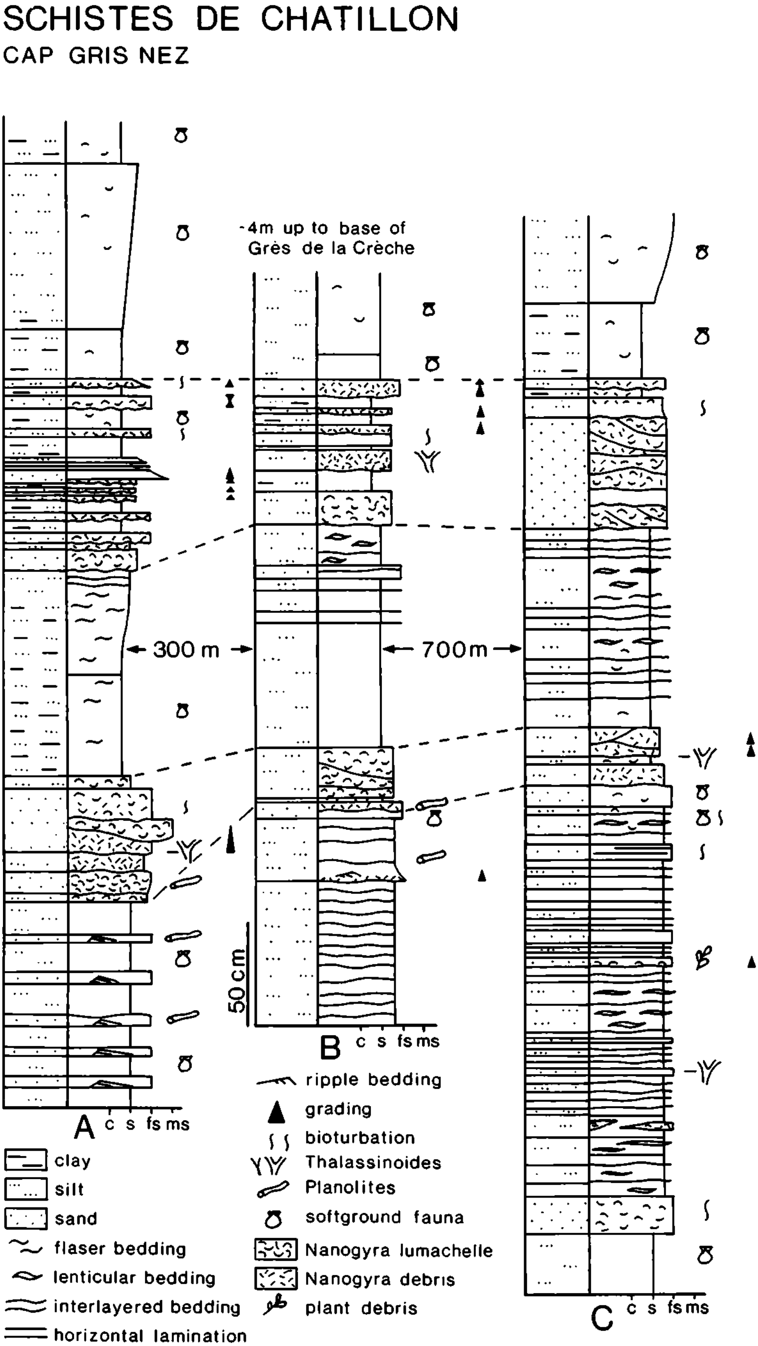

Fig. 5. Sections through the upper part of the Schistes de Chatillon at Cap Gris Nez, Boulonnais. c: clay; s: silt; fs: fine sand; ms: medium sand.

throughout, *Chondrites* is confined to the upper, more fine-grained parts of the shell beds.

The Schistes de Chatillon sections

(Fig. 5)

The Schistes de Chatillon are an argillaceous silty unit intercalated between the sandy Grès de Chatillon (below) and Grès de la Crèche (above). At Cap Gris Nez, *Nanogyra virgula* shell beds occur both in the lower and upper part of the unit, while the central part does not contain any skeletal accumulations. Three sections, each several hundred meters apart, were measured to evaluate the vertical and lateral distribution of the shell beds.

The lower part of the measured sections (Fig. 5) consists of lenticular-bedded or coarsely interlayered silt with intercalations of rippled sandstone. They are followed by several shell beds, together up to 60 cm in thickness, which are overlain by lenticular- or flaser-bedded argillaceous silt and siltstone. This unit is topped by about 90 cm of sandy shell beds, sharply overlain by argillaceous silt. The latter grades within 4 to 5 meters into the sandy Grès de la Crèche.

Several beds are bioturbated; recognizable trace fossils include *Planolites* and *Thalassinoides suevicus.*

The argillaceous or fine sandy silt without sedimentary structures frequently contains a benthic fauna of small bivalves and gastropods. Aragonitic elements are invariably preserved as steinkerns, the calcitic *Nanogyra* with shell. The benthic fauna can be regarded as in-situ reworked relics of former communities. Table 1 gives the dominant taxa of six samples taken from various levels of the sequence. Except for sample (f), which is dominated by *Nanogyra virgula*, the samples are characterized by shallow infaunal suspension-feeding bivalves (*Corbulomima, Protocardia, Isocyprina*) and/or the endobyssate bivalve *Musculus autissiodorensis.* The specialized oyster *Nanogyra virgula* and the mobile gastropod *Procerithium* are the only members of the epifauna. Numbers of species range from 9 to 13. The microfauna consists of ostracods and some foraminifera *(Lenticulina, Trochammina).* The fauna is very typical of Upper Jurassic low energy shallow shelf environments with soft substrates (e.g. Oschmann 1985).

The shell beds, in contrast, consist overwhelmingly of shells of *Nanogyra virgula*; rare admixtures are *Anomia, Nanogyra nana* and large *Gervillella.* The shell beds are thus mono-or near-monospecific accumulations of *Nanogyra virgula* in different states of preservation.

The overall environment of the Schistes de Chatillon appears to have been the shallow shelf below fair-weather wave base. At certain levels, tidal influence seems likely (evidenced by lenticular, flaser and interlayered bedding), at others, where a low diversity benthic fauna is developed, low energy conditions appear to have prevailed. Levels with *Nanogyra* shell beds,

Table 1. Dominant taxa of six statistical samples from the Schistes de Chatillon, Cap Gris Nez. Samples a–c and d–e can be grouped to represent different associations. A: original shell material aragonite; C: original shell material calcite.

sample	rank position 1	2	3	4	5
a	*Corbulomima suprajurensis* (A) 27.0%	*Musculus autissiodorensis* (C/A) 16.2%	*Isocyprina* sp. (A) 16.2%	*Protocardia* sp. (A) 10.8%	*Nanogyra virgula* (C) 5.4%
b	*Musculus autissiodorensis* (C/A) 29.5%	*Corbulomima suprajurensis* (A) 27.3%	*Protocardia* cf. *intexta* (A) 6.8%	*Nicaniella* sp. (A) 4.5%	*Isocyprina* sp. (A) 4.5%
c	*Musculus autissiodorensis* (C/A) 28.2%	*Corbulomima suprajurensis* (A) 24.3%	*Nanogyra virgula* (C) 21.8%	aporrhaid gastropod (A) 6.4%	isocyprinid bivalve (A) 5.1%
d	*Corbulomima suprajurensis* (A) 45.2%	*Nanogyra virgula* (C) 11.9%	*Nicaniella* sp. (A) 9.5%	*Protocardia* sp. (A) 7.1%	"*Cyrena*" sp. (A) 4.7%
e	*Corbulomima suprajurensis* (A) 52.2%	*Nanogyra virgula* (C) 10.4%	*Protocardia* sp. (A) 10.4%	aporrhaid gastropod (A) 8.9%	*Nicaniella* sp. (A) 4.4%
f	*Nanogyra virgula* (C) 38.6%	*Procerithium* sp. (A) 37.5%	*Corbulomima suprajurensis* (A)7.6%	ampullinid gastropod (A) 4.4%	fusiform gastropod (A) 4.3%

in contrast, record high energy events. At the top, the Schistes de Chatillon grade into the Grès de la Crèche which indicate high energy nearshore conditions (see AGER & WALLACE 1966, 1970; OSCHMANN 1985).

Types of skeletal accumulations (Fig. 6)

Most skeletal accumulations in the Schistes de Chatillon are shell beds varying in thickness from 0.5 to 50 cm. Nearly all of them have a sharp, usually erosive base. Skeletal elements range from sand-sized bioclasts (partly of echinoderm origin) to fragmented *Nanogyra*, to complete but disarticulated shells. Some shell beds are mud-supported, but most are shell-supported; the latter are usually densely packed, often as a result of compaction (evidenced by distorted and/or broken shells, the fragments of which are still in place). Stacking and imbrication of shells can be frequently observed. Composite shell beds, in which successive beds cut erosively into the underlying one, are common. Many shell beds are graded. Discontinuous grading is rare. In general, the biofabric is not as strongly modified by bioturbation as in the Marnes à *Exogyra virgula*. The matrix between shells varies from biomicrite, biopelmicrite to fine sandy calcarenite. In some shell beds the lituolid Foraminifera *Ammobaculites* and *Trochammina* constitute a significant part of the bioclastic material. Examples of skeletal accumulations are shown in Fig. 6.

Discussion

Origin of skeletal accumulations

Sediments and benthic fauna indicate a low energy environment of the Marnes à *Exogyra virgula* and a low to intermediate energy environment of the Schistes de Chatillon. In both sections *Nanogyra virgula* skeletal accumulations represent high energy events leading to concentration of the shells. These high energy events are most likely due to storms.

Polished slabs and thin-sections show that the shell beds do not represent autochthonous layers of cemented *Nanogyra virgula* as suggested by AGER & WALLACE (1966). Erosional basal contact, abundant graded bedding and the fragmented nature of many shells also contradict ZIEGLER's (1969) view that they represent in-situ concentrations of oysters living attached to sea weed. Moreover this mode of life is unlikely for reasons given above.

In contrast, the following features strongly point to a storm origin of most shell beds:

(1) Most shell beds exhibit an erosive base (e.g. Fig. 4 b, c).

(2) Many shell beds are graded (e.g. Fig. 6 c).

(3) In several cases, grading is discontinuous showing a couplet of complete/broken shells in the lower half and sand/silt-sized particles in the upper half.

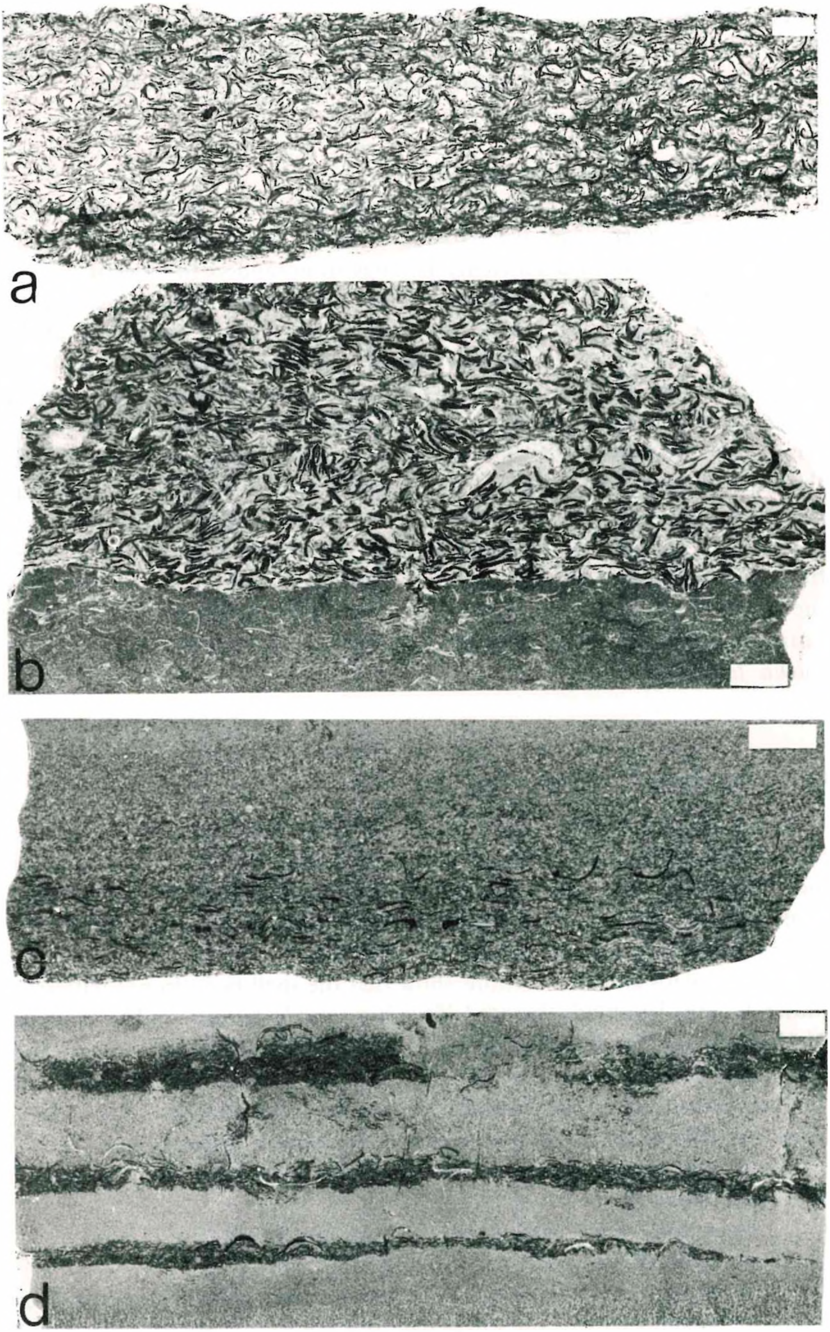

Fig. 6 (Leg. see p. 153)

This is particularly true of shell beds in the Marnes à *Exogyra virgula.*

(4) Biofabrics often show imbricated or stacked shell indicative of high energy processes. Moreover in some thin shell beds most shells are in a current-stable convex-up orientation, whilst random orientation in others may point to rapid dumping by storm flows.

(5) Occasionally sedimentary structures reflect a decrease of the energy level within shell beds or couplets. In couplets, for example, lower parts with densely packed, randomly oriented shells are overlain by wave rippled skeletal sand which grades into laminated silt and finally into structureless marl (e.g. Fig. 4 b).

(6) Within shell beds trace fossil density generally decreases from top to the base.

This is particularly true of *Chondrites,* whilst the abundance of *Thalassinoides* does not vary significantly within shell beds. This density decrease indicates that the shell beds were deposited very rapidly and that bioturbation extended downwards from a level where rate of sedimentation was sufficiently low to allow colonisation by a benthic fauna.

Such features are commonly present in storm deposits in modern (e.g. Reineck & Singh 1972, Kumar & Sanders 1976, Nelson 1982) and in ancient shelf sediments (e. g. Goldring & Bridges 1973, Aigner 1979, 1982, Kelling & Mullin 1975, Kreisa 1981, Kreisa & Bambach 1982, Hunter & Clifton 1982). The varied features of the skeletal accumulations suggest different levels of storm intensity. Storm effects have been demonstrated to decrease with increasing water depth (e. g. Hayes 1967, Aigner & Reineck 1982) and, similar to turbidites, to vary laterally from proximal to distal (Aigner 1982). Using this concept, the skeletal accumulations of the Kimmeridgian have been arranged as shown in Fig. 7. A to G represent a sequence of decrease in bed thickness, in grain size, and consequently in energy level, which is here interpreted as a decrease in storm influence.

Bed type A consists of composite (amalgamated) shell beds which record several episodes of erosion and deposition. In Fig. 8 from the Schistes de Chatillon for example, 13 such episodes can be recognized. Such beds are most likely of nearshore shallow water origin. With increasing water depth, bed thickness (Fig. 7 B) and size of bioclasts decreases (D–E). In the same direction grading becomes more prominent (C-E) and is often discontinuous (C, D). Distal storm beds consist of thin, laminated or wavy layers of

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Fig. 6. *Nanogyra virgula* shell beds from the Schistes de Chatillon at Cap Gris Nez, north of Boulogne-sur-Mer. Length of bar: 1 cm. a: Densely packed *N. virgula* in mainly silt matrix. Dense packing enhanced by compaction. b: Shell bed of fragmented *N. virgula*, small heterodont bivalves, and rare large shells overlying silt containing shells of softground faunal elements (e. g. *Corbulomima, Protocardia*). c: Graded shell bed of *Nanogyra virgula* with sharp erosive base. d: Three thin shell beds of *N. virgula* in places disrupted by bioturbation.

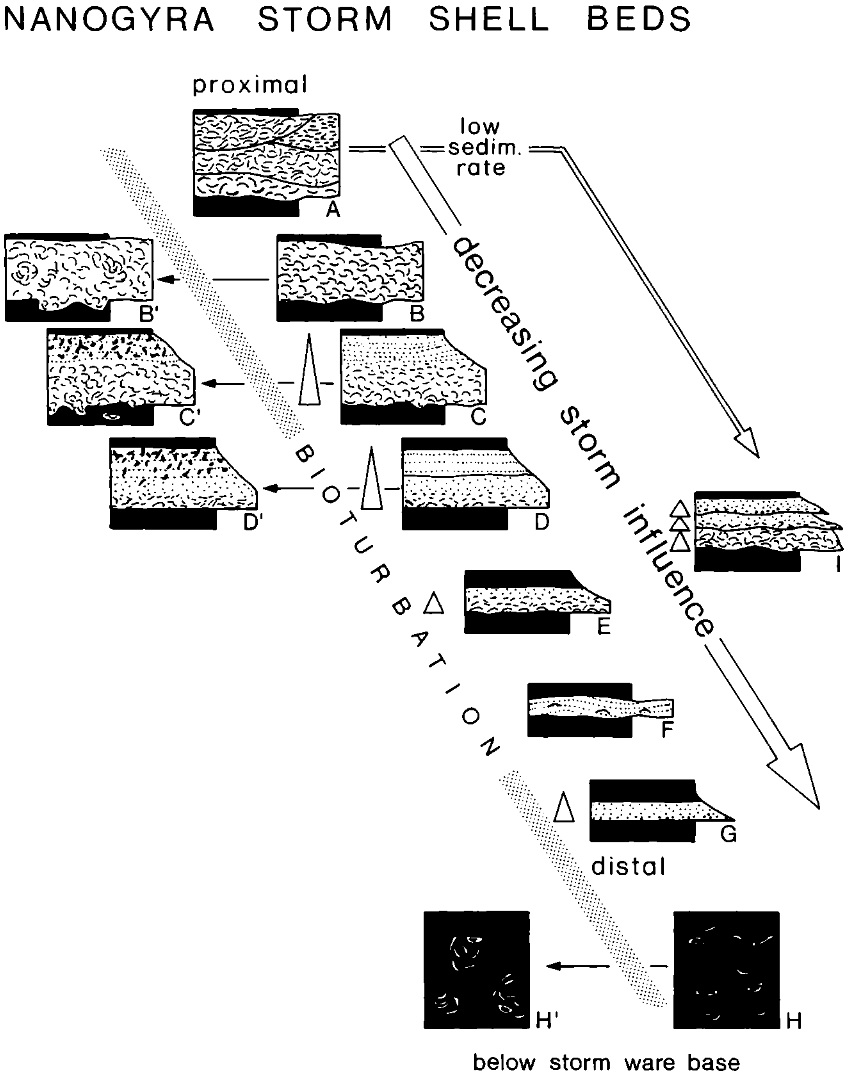

Fig. 7. *Nanogyra virgula* storm shell beds arranged according to their degree of proximality. For explanation see text. Triangles denote graded bedding.

bioclasts (F, G) and frequently were deposited by storm-induced currents (G). Marlstone or argillaceous siltstone with predominantly articulated *Nanogyra* specimens in low density (H) are interpreted as representing the more or less undisturbed habitat of the oysters below storm wave base.

This sequence can be modified by several processes: For example, low rates of sedimentation may lead to composite shell beds in more

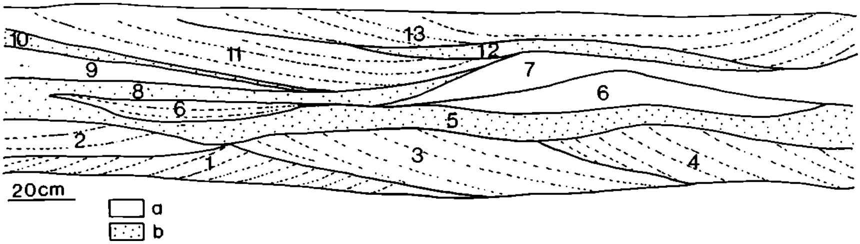

Fig. 8. Sketch of amalgamated *Nanogyra virgula* shell bed evidencing at least 13 phases of erosion and deposition. Schistes de Chatillon, Cap Gris Nez, section C. a: shells and shell debris; b: silty fine sand. This bed is interpreted as proximal storm bed.

offshore deeper waters (I). Bioturbation often distorted the primary shell bed character, in particular the degree of packing, the biofabric, and the erosive contact to the underlying sediment (B'–D'). Below storm wave base, bioturbation may lead to concentration of shells in pods, in which shells are either randomly oriented or preferentially vertically to obliquely arranged (H').

The sharp base of most skeletal accumulations points to erosion prior to deposition of the overlying bed. The presence of pre-depositional *Thalassinoides* burrows at some levels (the majority of *Thalassinoides* are post-depositional) indicates that erosion cut down to levels of moderately firm sediment, which enabled casting of the horizontal *Thalassinoides* networks by the storm deposit.

From all storm shell beds, the following idealized sequence of events can be modelled (Fig. 9; see also Garcia-Ramos *et al.*, 1983):

(A) Background sedimentation took place in an environment below fair weather wave base. The soft substrate was colonised by a specialised epifauna (*Nanogyra virgula*) and a variety of infaunal bivalves.

(B) During a storm, part of the soft substrate was eroded and winnowed away, while *Nanogyra* shells were concentrated in packstones or grainstones. Storm waning led in some cases to deposition of finer-grained, graded shell debris. After the storm, fine-grained clastic (Boulonnais) or carbonate particles (Aquitaine Basin) settled from suspension.

(C) Repopulation of the sea floor by burrowing organisms led to intensive bioturbation with downward decreasing density, which frequently modified the primary character of the skeletal accumulation.

Problems in interpreting proximality of storm shell beds

Fig. 7 shows an attempt to arrange *Nanogyra virgula* storm shell beds along an onshore-offshore gradient reflecting decreasing storm influence. However, there are several factors which may complicate a straightforward

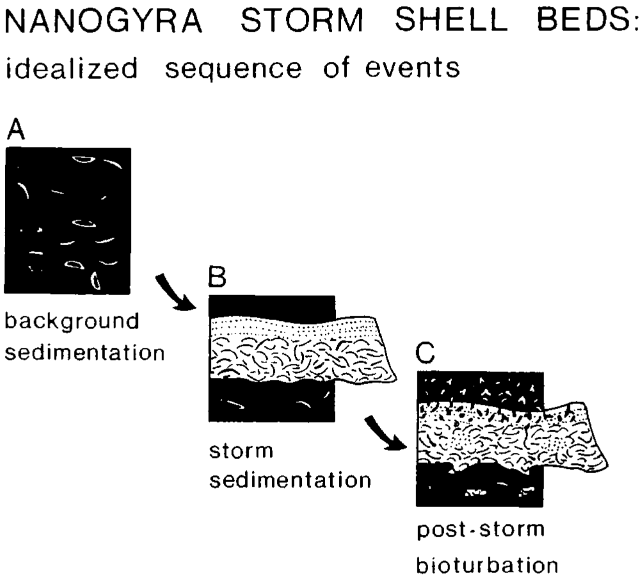

Fig. 9. *Nanogyra* storm shell beds: idealized sequence of events. For explanation see text.

relationship based on decreasing grain size, decreasing bed thickness etc. Firstly, storms vary considerably in intensity, and beds deposited by successive storms at a specific point along an onshore-offshore transect may exhibit proximal or distal characters. Secondly, the thickness of a storm shell bed is related to the amount of biogenic hard parts available, which in turn depends only partly on the erosional capacity of the storm (thus reflecting its intensity), but also on the time elapsed since the last storm, the rate of sedimentation between storms, and the population density. Furthermore, diagenetic effects may play an important role, especially early diagenetic shell solution (see below).

Thirdly, the degree of fragmentation of shells cannot necessarily be used to infer the onshore-offshore position of a storm bed, but depends also on the autochthonous or allochthonous nature of the biogenic hard parts. For example, slight winnowing by the distal reaches of a storm may have produced shell beds composed of complete *Nanogyra* provided the sea floor was densely populated. Such autochthonous distal shell beds contrast with also distal, but allochthonous graded layers of shell debris and bioclasts, which have been deposited by storm-induced flows. Both features may become mixed and result in storm layers of marked bimodal grain size distribution (e. g. Fig. 7 F). Thus "proximality" should not be evaluated for single beds, but rather for sequences of beds, which give more accurate trends.

Cyclicity recorded by storm shell beds

Despite the problems involved in interpreting the proximality of storm shell beds an attempt was made to chart *Nanogyra* storm shell beds in the studied sections according to their degree of proximality (for classification see Fig. 7). The resulting storm bed sequence in the Marnes à *Exogyra virgula* (Fig. 3) suggests some kind of cyclicity reflected in bundles of predominantly proximal shell beds alternating with bundles of distal shell beds. At least two causes are conceivable for such cycles: The cycles either reflect climatic changes, for example an alternation of relatively calm periods with periods of stronger storms, or transgressive-regressive changes in the bathymetry of the basin. The evidence from a single small section, however, is not sufficient to draw far-reaching conclusions.

Nanogyra shell beds in the Schistes de Chatillon sections may also record some cyclicity, but not so much by changes in their proximality, but by the alternation of levels free of shell beds with levels of *Nanogyra* shell beds (Fig. 10). Again more data are needed before conclusions can be drawn.

Causes for the near-monospecific nature of shell beds

Many shell beds consist exclusively of valves of *Nanogyra virgula*. In the Boulonnais, occasional other macrofaunal elements are *Nanogyra nana*, large *Trigonia* and *Anomia*. In the Pointe du Rocher section, small cerithiid gastropods are common in some shell beds. Rarely, large *Trigonia* or *Gervillella* occur as single specimens. In contrast, the silt and argillaceous silt between *Nanogyra* shell beds at Cap Gris Nez contain an abundant fauna of bivalves and some gastropods. Whilst the shell bed fauna is – except in very few cases – calcitic, the fauna of the silt consists overwhelmingly of aragonitic species now preserved as steinkerns. Of the commoner species only *Nanogyra virgula* (representing between 5 and 38% of the fauna) and *Musculus autissiodorensis* have their shell preserved (Table 1). The latter species apparently had a two-layered calcitic-aragonitic shell with the calcitic part being very thin so that the preserved shells are very fragile.

Consequently it seems likely, that the dominance of *Nanogyra virgula* in the shell beds does not reflect particular ecological conditions, but can be explained by the early diagenetic solution of aragonitic shells prior to reworking by storm processes. The shell bed fauna is therefore the diagenetically distorted relic of communities inhabiting the soft sea floor. Only in a single case (Fig. 6 b) within the Schistes de Chatillon, this softground fauna escaped shell solution. As a result, the shell bed overlying this particular horizon contains also numerous valves of aragonitic bivalves and reflects the original composition of the shelly fauna.

Whilst reworking of a fauna by storm processes may, in some cases, enhance its preservation potential (e. g. AIGNER 1977; see also the preserved cerithiid gastropods in *Nanogyra* shell beds within the Marnes à *Exogyra virgula*), the present example demonstrates that the timing of reworking is crucial: If reworking takes place after dissolution of aragonite, the resulting shell beds do not record the original faunal composition (see also KREISA & BAMBACH 1982).

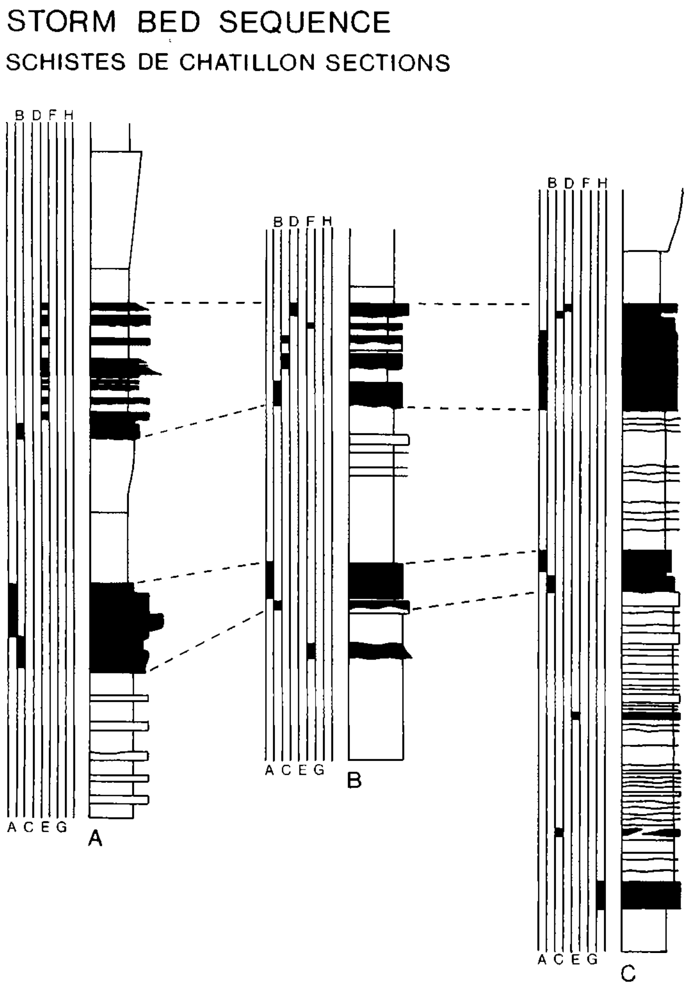

Fig. 10. Storm bed sequence in the Schistes de Chatillon sections showing cyclic arrangements of shell beds. The letters A–H refer to storm beds of different proximality (see Fig. 7). Black: *Nanogyra virgula* shell beds.

Nanogyra virgula shell beds and associated sediments from the Aquitaine Basin and the Boulonnais: a comparison

In Table 2 some important features of the shell beds and associated sediments are listed. They clearly demonstrate that, at Cap Gris Nez, the shell beds were deposited largely as proximal storm beds in a shallow nearshore environment, whilst at Pointe du Rocher, a more distal development of storm beds in an offshore, deeper and quieter environment is documented. The shallow nearshore position of the Schistes de Chatillon is supported by (1) a dominance of siliciclastic silts and sands; (2) the more proximal development of storm shell beds; (3) sedimentary structures between shell beds possibly indicating tidal influence; and (4) the lower degree of bioturbation pointing to higher rates of sedimentation and reworking. The dense packing of many shell beds in the Schistes de Chatillon is partly a diagenetic feature. Distorted shells illustrate a degree of compaction that was apparently higher in the argillaceous silt and silty clay at Cap Gris Nez than in the argillaceous lime muds at Pointe du Rocher. The scarcity of benthic fauna between the shell beds at the latter locality also reflects a deeper, more basinal position of that area compared to the Boulonnais.

Table 2. Features of *Nanogyra virgula* shell beds and associated sediments from the Schistes de Chatillon and Marnes à Exogyra virgula.

	Schistes de Chatillon (Cap Gris Nez section)	Marnes à *Exogyra virgula* (Pointe du Rochers section)
sediment	largely siliciclastic (argillaceous silt - fine sandy silt)	argillaceous-micritic
sedimentary structures (between shell beds)	common	-
benthic fauna	common	rare
shell beds:		
thickness	0.5-50 cm	0.2-10 cm
internal structure	complex/simple	simple
development of couplets	rare	common
degree of packing	low-very high	low-high
grading	occurs	abundant
bioturbation	occurs	abundant
environment	nearshore shallow shelf	offshore basin

Conclusions

(1) Skeletal accumulations in the Kimmeridgian of the Boulonnais and the Aquitaine Basin consist nearly exclusively of valves or valve fragments of the reclining oyster *Nanogyra virgula.*

(2) Shell beds show graded bedding, erosive base, and imbrication, i. e. features well known from modern and ancient storm deposits.

(3) Three stages in the development of storm shell beds can be distinguished: background sedimentation, storm sedimentation, and post-storm bioturbation.

(4) The wide variety of features allows the arrangement of skeletal accumulations along a gradient reflecting decreasing storm influence. The skeletal accumulations range from amalgamated storm shell beds (proximal) to graded layers of shell debris (distal).

(5) The vertical sequence of storm beds exhibits a cyclicity, which is either of climatic origin, or reflects small-scale transgressive-regressive phases.

(6) The near-monospecific nature of most shell beds is due to very early diagenetic solution of aragonitic faunal elements prior to their reworking by storms.

(7) A comparison between the two localities shows that the depositional environment was the nearshore shallow shelf in the case of the Schistes de Chatillon and an offshore basin in the case of the Marnes à *Exogyra virgula*.

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