UTRECHT MICROPALEONTOLOGICAL BULLETINS

C. W. DROOGER, P. MARKS AND A. PAPP

SMALLER RADIATE NUMMULITES OF NORTHWESTERN EUROPE

5

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by

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CONTENTS

Preface

After the completion of J. P. H. KAASSCHIETER's monograph on the "Eocene Foraminifera of Belgium" (1961), an extensive collection of smaller radiate *Nummulites* from the Belgian Eocene remained without specific determination in the collections of the Utrecht Geological Institute. KAASSCHIETER had found that naming these fossils on the basis of the existing literature would lead to very unsatisfactory results. He felt that a tremendous lot of work in measuring and counting should be needed to arrive at a still dubious ultimate result, for which reason he preferred to leave his collections as an heritage to a later generation.

Since a rapid survey of the material shows no clear pattern of development within this group of *Nummulites,* no single student dared undertake the work. It was not until early 1963, while A. PAPP stayed in Utrecht for three months, that he and P. MARKS developed a working scheme and put everybody available, some fifteen people altogether, to work.

At the end of these three months the results confirmed the previous opinion that the Eocene and Early Oligocene smaller *Nummulites* of the North Sea basin showed a peculiar evolutionary pattern and that they were of dubious stratigraphic value. Because of these rather disappointing conclusions the work slowed down, although at various time intervals additional data were gathered. Eventually, however, the evolution pattern and the stratigraphic results were considered to be certainly worth publishing in the context of renewed interest and activities around the Nordic Paleogene.

The final version, to be found on the following pages, is the result of a teamwork in which it has become impossible to find back who did what, even for the members of the group.

Utrecht, February 1970

Chapter I

INTRODUCTION

Since approximately the middle of the 19th century the *Nummulites* as a group have been considered to characterize the Older Tertiary (or Paleogene, or Nummulitique). In addition, many of the described specific units in this group of larger foraminifera were allocated a chronostratigraphic index value for the successive stages of the Paleogene. Specialists have constantly been active in constructing lineages for all these species, in which in recent years H. SCHAUB (1951—1968) advanced farthest. When we regard these efforts of making the species of *Nummulites* into useful index fossils, some striking conclusions may be drawn:

1. that the species concept is generally a very narrow one, which causes rather indistinct and often artificial lineages;
2. that nearly all these lineages are within the range from Early Paleocene to Middle Eocene (Lutetian) up to an acme in size of *Nummulites* individuals. The small species of the younger part of the Eocene and from the Oligocene are commonly disregarded;
3. that the lineages are typical for the Mediterranean province. The species of these lineages occurring in the northern basins are thought to have been occasional invaders from the south, such as *N. planulatus* in the Late Ypresian and *N. laevigatus* in the Lutetian.

It appears that the *Nummulites* species of the northern basins, and especially the later ones, give little support either to the theories of evolution of the group, or to the *Nummulites* zones that should fit in with the stages. Nevertheless the classical stratigraphy of the Older Tertiary was founded in northwestern Europe. Many of the stage names of the Paleogene, which are still in use in, and often outside, Europe were named in the previous century after outcrops in the basins of the north. These outcrops did not belong to clear continuous sections, but they were put in succession after their description from a number of localities that are widely scattered geographically.

As a consequence, many more stage names exist than we would need today, and the discussions on their correlation are voluminous and ever increasing. For the interval following the Lutetian, i.e. Late Eocene and Oligocene, the following names were available and in more or less common use: Auversian, Ludian, Sannoisian and Stampian of the Paris basin; Bartonian from the Hampshire basin in southern England; Ledian, Wemmelian, Assian, Tongrian and Rupelian from the Belgian part of the North Sea basin; and finally Lattorfian and Chattian from Germany.

Correlations between these units, even within a single basin, are severely hampered by facies differences within these shallow-marine to continental deposits, differences which were ill understood, especially by earlier authors. In more recent years some general surveys appeared for the Paris basin (e.g. BLONDEAU, CAVELIER, FEUGUEUR and POMEROL, 1965) and for Belgium (e.g. BATJES, 1958; KAASSCHIETER, 1961; GULINCK, 1969), but a large number of correlation problems has remained until today. The latest synthesis dealing with all northern basins is that of CURRY, GULINCK and POMEROL (1969).

In most discussions the various species of smaller *Nummulites* still play their part, even though some of the stages are completely devoid of these organisms. So the Middle to Upper Oligocene interval (Stampian, which is more or less equivalent to Rupelian and Chattian) never contains an autochthonous *Nummulites* fauna in the northern basins, while also the stages based on continental deposits and sediments of aberrant salinities (Ludian, Sannoisian) can be left out of consideration.

The species most commonly reported from the deposits immediately following the northern Lutetian s.str. (i.e. Auversian, Ledian) is *N. variolarius* (LAMARCK). For the younger Eocene deposits there is a wealth of specific names, such as *N. orbignyi, N. wemmelensis, N. prestwichianus* and *N. rectus,* but for the Early Oligocene (Tongrian, Lattorfian) there is again more agreement, expressed in the specific name *N. germanicus.* With a few exceptions — in later years CURRY (1937) and BLONDEAU (1966) — very little paleontological background has been given to the specific determinations. The group of species is considered to be rather characteristic for an area which is thought to extend eastwards from the Hampshire, Paris and North Sea basins, at least as far as southern Russia (e.g. NEMKOV, 1964).

In the Mediterranean belt most Upper Eocene and Oligocene species are equally small, but they are generally reported under other specific names, such as *N. fabianii, N. incrassatus, N. vascus, N. intermedius, N. bouillei.* They extend to higher stratigraphic levels and even to the top of the Oligocene (BUTT, 1966), and many of them belong to the same morphological group of radiate *Nummulites* as the nordic forms.

The vast quantity of smaller *Nummulites* from the Belgian Eocene, gathered mainly by KAASSCHIETER in the years 1953—54, had been given a rapid survey by this author. He quickly abandoned the group because he found — which is confirmed by this study — that attempts to identify the *Nummulites* specifically were thwarted by the fact that forms, to which different specific names had been given, were found together in samples which seemed to contain homogeneour assemblages. This embarrassing result from a non-typological approach of specific units, became still more unpleasant when it appeared that several of the renowned typological species showed up in an irregular manner in the collections, seemingly irrespective of the assumed stratigraphic order. Some doubt as to the biostratigraphic value of the famous *Nummulites* species seemed to be warranted.

In order to solve these problems it was considered necessary that the assemblages should be treated somehow statistically, which would involve a tiresome and painstaking work of measuring and counting. After careful consideration a number of features were selected for such a biometrical analysis, and the work was carried out according to a uniform scheme (see chapter VI).

Participating during the first stage of the work were A. PAPP (Vienna), TH. ARNOLD BIK (The Hague), A. A. BUTT (Lahore), C. W. DROOGER, R. FELIX (Wageningen), T. FREUDENTHAL (Bordeaux), J. HARDENBOL (Houston), J. E. VAN HINTE (Calgary), P. MARKS, J. E. MEULENKAMP, TH. L. MOORKENS (Wietze), R. C. TJALSMA, J. G. VERDENIUS (Djakarta), C. C. VERVLOET (Calgary) and P. N. WEBB (Lower Hutt), at that time all together in Utrecht March—May 1963. After some years the gathering of data for a set of check samples was resumed with some younger collaborators: A. R. FORTUIN (Amsterdam) and M. A. KHAN (Karachi).

Apart from the extensive collection of Belgian surface material, collected by J. P. H. KAASSCHIETER (Denver) and D. A. J. BATJES (Tokyo), additional material was available from a number of borings in this country, thanks to M. GULINCK (Brussels). From the adjoining part of the Netherlands, material from some borings was made available by J. H. VAN VOORTHUYSEN (Haarlem). Scattered material from various places in the German part of the North Sea basin was assembled by A. PAPP. For comparison there was material from southern England, collected by C. W. DROOGER and R. FELIX during two different sampling trips, which both had been directed by D. CURRY (Bournemouth). From the Paris basin some samples from important localities had been taken by J. E. VAN HINTE, or sent to Utrecht by C. POMEROL and A. BLONDEAU (Paris). Finally some samples from the Biarritz section in SW France could be incorporated, material collected on various occasions by members of the Utrecht staff, as well as two samples from the Upper Oligocene of the Aquitaine basin brought to Utrecht by A. A. BUTT.

Grateful acknowledgements are due to all colleagues not belonging to the

Utrecht group, who kindly furnished material and information for the investigation.

Part of the numerous scatter diagrams were made by E. DE MULDER, H. DE VRIES and J. SCHIPPER; most of the calculation work was carried out by T. FREUDENTHAL and M. M. DROOGER; the illustrations were taken care of by J. P. VAN DER LINDEN, A. VAN DOORN and P. HOONHOUT.

Chapter II

STRATIGRAPHY AND SAMPLES

Much of the surface material from Belgium comes from isolated outcrops. The same holds true for most of the German and French occurrences. The available sections have mainly been derived from borings in Belgium and the Netherlands. The material from southern England is also from continuous sections, this time from coastal cliffs.

In order to evaluate the relative age of the samples in our widely scattered material, a stratigraphic framework will be given, as it was thought plausible some ten years ago. Some more recent ideas will be dealt with separately at the end of this chapter. For more details on the local lithostratigraphy the reader is referred to the more specialized literature.

Belgium

A critical review of the literature on the Belgian Eocene was published by KAASSCHIETER (1961), on the Oligocene by BATJES (1958). Other more recent publications of smaller scope are those of GULINCK (1965, 1969) and of DROOGER (1964, 1969). Several papers appeared in the proceedings of the "Colloque sur l'Eocène", recently held in Paris, and edited by C. POMEROL as memoirs 58, 59 and 69 of the Bureau de Recherches Géologiques et Minières.

Additional information on most of our Belgian samples can be found in the papers of KAASSCHIETER and BATJES. Sample numbers are those of these authors, or they are numbers of the Utrecht collections.

The Middle Eocene (Lutetian) is represented in Belgium by the Brussels Formation (= Sands of Brussels), often referred to as Bruxellian in the older literature. These Sands of Brussels are generally thought to correspond only to the lower part of the typical Lutetian of the Paris basin. In this concept the higher parts of the Lutetian are supposed to be lacking probably due to erosion, since reworked elements of its fauna are present at the base of the overlying formation. The Sands of Brussels are found in the central part of Belgium, east of a line running roughly NNE-SSW along the capital, the so-called Senne line. The sands contain a well developed, fully marine microfauna, described by KEIJ (1957) and KAASSCHIETER (1961).

Nummulites laevigatus, index fossil of the Lutetian, occurs mainly in the

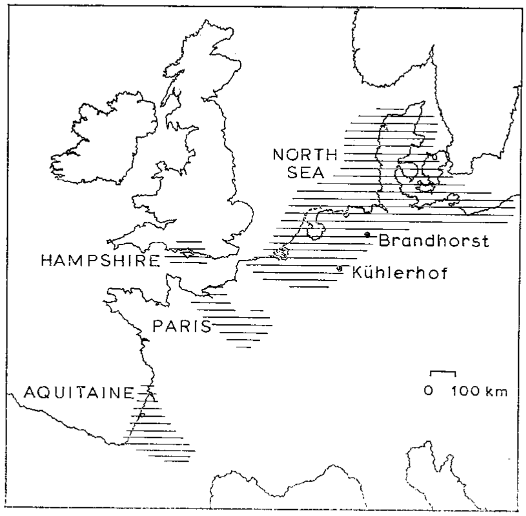


Fig. 1. The Tertiary basins of northwestern Europe, outline based on Late Eocene marine sedimentation.

higher part of the formation. Representatives of the smaller *Nummulites* have hardly ever been reported (BLONDEAU and CURRY, 1963). In this paper they will be dealt with from Nalinnes (THB 1192), which locality lies close to the southern limit of the present-day extension of the formation. The "sands" at Nalinnes are generally thought to be a more coastal equivalent of the main body of the Sands of Brussels, amongst other things because of the wealth in bryozoans.

In western Belgium younger Eocene formations are not underlain by the Sands of Brussels, but by members of the Panisel Formation, which latter formation is commonly supposed to be older than Lutetian. However, according to KAASSCHIETER its higher members might well be lateral equivalents of the Sands of Brussels, west of the Senne line. This would be especially true for the Sands of Vlierzele, at many places the topmost member of the Panisel Formation. These Vlierzele Sands are commonly barren, and possibly they originated in a kind of Wadden environment (GULINCK, 1952).

The Sands of Vlierzele occur only once in our *Nummulites* record: boring Asse, sample from 45—46 m.

The next higher unit of the Belgian Eocene, which overlies both Brussels and Panisel Formations, is formed by the Lede Formation, represented by the Sands of Lede. These fully marine sands that transgressively cover the earlier deposits,

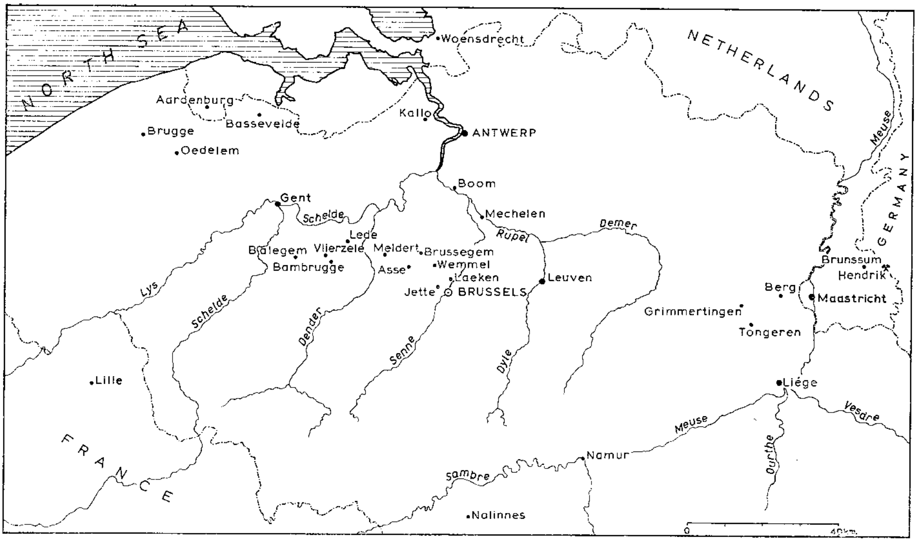


Fig. 2. Localities in the Belgian-Dutch part of the North Sea basin.

are found exposed in a roughly east-west striking belt. There is a slight, general dip towards the north. The basal part frequently contains reworked elements from the Lutetian. On the basal few meters near Brussels earlier authors have based the Sands of Laeken, or rather the Laekenian of the literature.

Generally the Lede Formation consists of calcareous sands with at many places some intercalated indurated fossiliferous sandy limestones. The sands contain a rich marine microfauna (Keij, 1957; Kaasschieter, 1961), which indicates a warm, shallow-water environment.

Nummulites variolarius, of common occurrence, is generally considered to be the typical species for the Ledian, the stagename corresponding to the Sands of Lede. Near Lede, the type locality of the stage, the present day exposures show decalcified sands, but the former sandpit Steenberg near Bambrugge is commonly considered to show the best exposure. Our samples ZD 1012, 1013 and 1016 have been taken in this exposure. Additional surface samples come from Balegem (ZG 1025) and Meldert (MC 1040). Furthermore *Nummulites*-bearing samples were available from all three investigated borings: Brussegem (29.75 m), Mechelen (61.20 m) and Asse (five samples in the interval from 38 to 44 m). Finally, ZB 1021A from Vlierzele is one of our check samples, added during the final stages of the investigation.

The highest part of the Belgian (Upper) Eocene is commonly subdivided into three lithostratigraphic units, which KAASSCHIETER combined as members of the Asse Formation. These members are the Sands of Wemmel, the Clays of Asse and the Sands of Asse. Two local stages were based on the former two members, the Wemmelian and the Assian respectively. Until a few years ago it was quite generally accepted that these two units, Sands of Wemmel and Clays of Asse were mainly lateral equivalents of one another. As a stage name for both the English term Bartonian was used most commonly, but there is no accepted opinion on its delimitation.

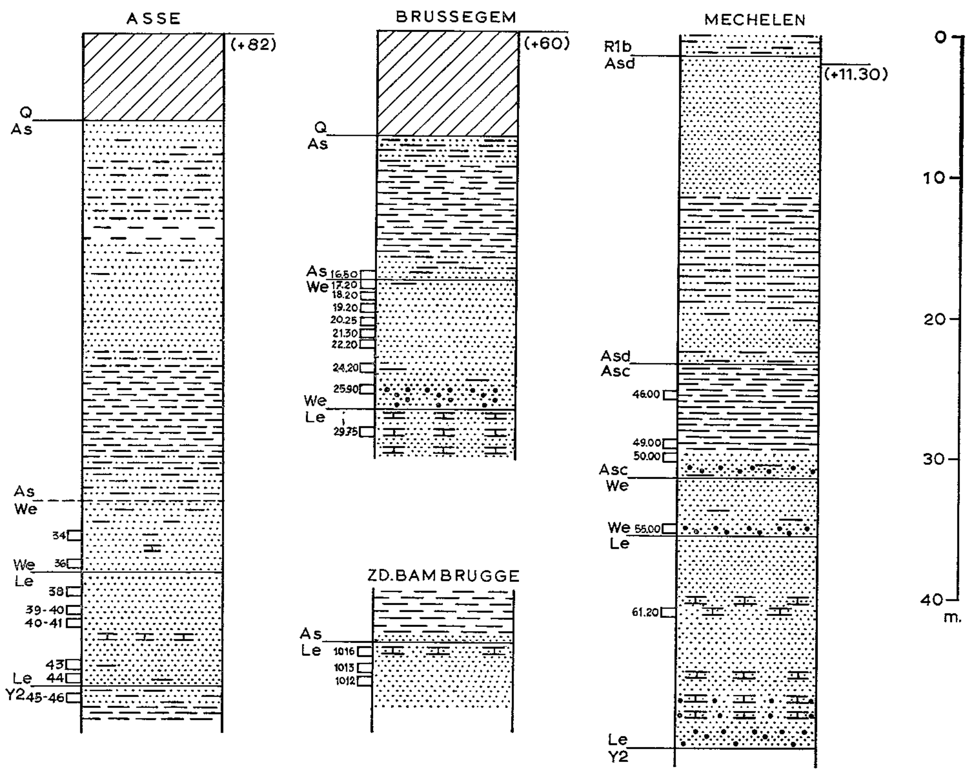


Fig. 3. Stratigraphic columns of the borings Brussegem, Mechelen and Asse, and the quarry Steenberg at Bambrugge.

KAASSCHIETER for instance included the underlying Sands of Lede in his Bartonian, but this is not the rule in Belgium. Today there is serious doubt whether any of these units is contemporaneous with the English Bartonian.

There would have been a minor regression following the deposition of the Sands of Lede, after which the Sands of Wemmel were laid down in a great part of the northern Belgian area. These sands may be regarded as deposits close to the southern rim of the basin, being replaced upwards and laterally by the Clays of Asse (see KAASSCHIETER, 1961, map 18). These Sands of Wemmel are again rich in microfauna (KEIJ, 1957; KAASSCHIETER, 1961), which frequently contains *Nummulites*. They have been recorded as *N. orbignyi* and/or *N. wemmelensis*.

Near the type locality of the Wemmel Sands, in the suburbs of Brussels, no permanent exposures are left. The best sample from the Wemmel area (BG 48, results of two sets of individuals), had been taken in 1961 in an excavation along the highway north of Brussels. Furthermore there are two samples from waterborings: Wemmel 14 (10.50—11.00 m) and Wemmel 16 (7 m). Another sample of less distinct provenance, marked "Heysel" was provided by PAPP. The boring Brussegem yielded eight samples from the Wemmel Sands in the interval 17.20—25.90 meters. From boring Asse two samples (34 and 36 m) and from Mechelen one (55 m) could be used. Added later are the results of sample BS 1260 from Jette.

The Clays of Asse commonly overlie the Sands of Wemmel, but in the area west of Antwerp the latter seem to have wedged out completely. These marine clays are strongly glauconitic, especially at the base, where they often form the so-called "bande noire". The microfauna of the Asse Clays, mainly found in its lower part, is not markedly different from that of the Wemmel Sands. Again *N. orbignyi* and *N. wemmelensis* have been reported, most frequently from the basal part of the member.

The only good exposure of the Clays of Asse, the claypit at Oedelem, furnished three samples (BRB 1054, 1056, 246) with *Nummulites*, all from the basal part in or near the bande noire, which part is no longer exposed today. BW 1273 was taken at Wemmel, again from the basal Asse Clays.

Furthermore, there were three samples in the interval 46—50 m from the boring Mechelen, and another one from the Brussegem well (16.50 m), all taken near the sandy glauconitic base of the clays. Three check samples also come from this sandy lower part, ZA 1244 from Ghent, and two samples from the boring Kallo at 178 and 179 meters.

In northwestern Belgium the Asse Clays are covered without a sharp boundary by a sequence of alternating sands and clays, which are often referred to as the Sands of Asse (KAASSCHIETER, 1961), or more recently as the "Complexe argilo-sableux de Kallo" (GULINCK, 1969). This unit has never been found well exposed at the surface; most of the information is coming from older and not very reliable borings. Although locally fossils have been reported, amongst which

N. orbignyi, most of the sequences have been reported unfossiliferous. Actually, neither KEIJ nor KAASSCHIETER mentioned a microfauna from these sands and clays.

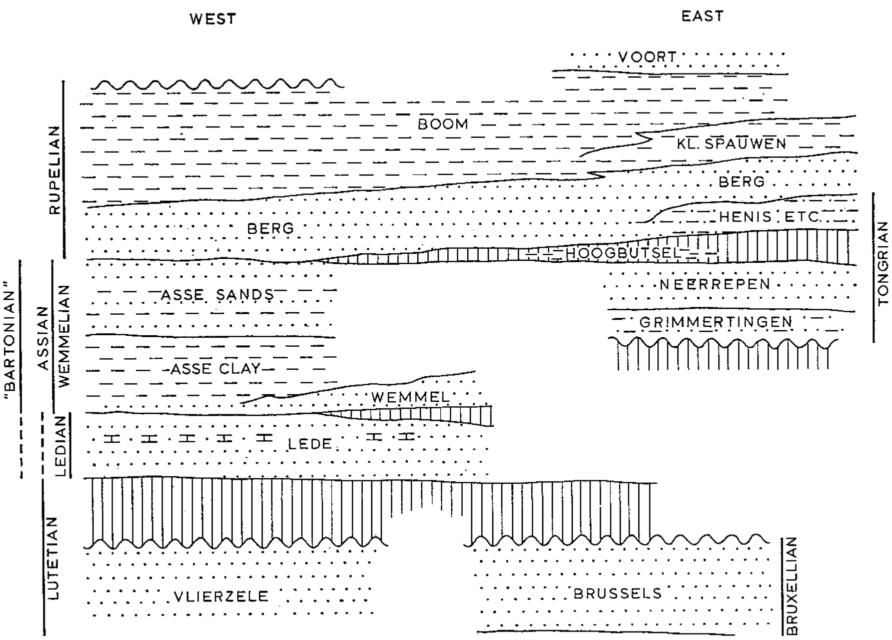


Fig. 4. Correlation of Middle Eocene to Middle Oligocene stratigraphic units in Belgium, after BATJES, KAASSCHIETER and DROOGER (1958—1964).

Not only is the base of this Asse Sands Member indistinct, also its top is not clear. In borings in northwestern Belgium the unfossiliferous series of sands and clays grades upwards into fossiliferous Boom Clay, the main element of the Middle Oligocene. In this sterile interval one would expect to find lateral equivalents of the Tongeren Formation (Tongrian of authors) and of the Sands of Berg, both well known from NE Belgium, and commonly considered to represent the classical Lower Oligocene and the basal part of the Middle Oligocene respectively. In NW Belgium the presence of both these units has been repeatedly claimed on rather scanty fossil evidence from borings.

During our investigation of 1963 no *Nummulites* of this Eocene-Oligocene intermediate interval could be studied. However, frequent representatives were recently encountered in a boring at Kallo, near Antwerp, at 124.40 meters, certainly deriving from the Sands of Asse to Sands of Berg interval (clayey-sandy complex of Kallo), but unfortunately the state of preservation was far too poor for an identification (DROOGER, 1969, p. 26, pl. 5, fig. 6). From equivalent strata of this complex, the so-called Sands of Bassevelde (GULINCK, 1969) in the boring Bassevelde itself at 22 meters, better preserved *Nummulites* were found, the analysis of which could be added as a check sample during the final stage of our work.

The Tongeren Formation shows its characteristic sediments in northeastern Belgium only. Although the formation gave its name to the Tongrian Stage of the literature, BATJES (1958) showed this to be a rather unfortunate choice as the type for a stage. The formation consists of a considerable number of rather local members, which correspond to various environments from (in)distinctly marine to brackish and continental. These members can be united into two groups, the Lower and Upper Tongeren Formation respectively. Probably there is a considerable sedimentary break between both parts. BATJES suggested that the Lower Tongeren Formation would be contemporaneous with the Asse Sands of northwestern Belgium, whereas he preferred to regard the members of the Upper Tongeren Formation as lateral equivalents of the Middle Oligocene Berg Sands and Boom Clay in the region of Mechelen, farther west. Microfaunas are absent or poor, many of those present in the Upper Tongeren Formation of brackish character.

Until recently, no *Nummulites* had been found in the Tongeren Formation in Belgium, but from the adjoining Dutch South Limburg in the mineshaft Hendrik IV, BATJES (1958) described as *N. germanicus* an assemblage from the basal member of the formation, the Sands of Grimmertingen which immediately overlie the Cretaceous. The poor microfauna shows remarkable similarities to that of the Asse Formation, and much less to those of the Middle Oligocene formations. It is considered probable that the *Nummulites* of Kallo (124 m) and of Bassevelde (22 m), mentioned above, originate from equivalents of the Grimmertingen Member in NW Belgium (DROOGER, 1969; MARTINI, 1969).

None of the higher units of the Oligocene in the North Sea basin ever yielded autochthonous *Nummulites*.

As a compilation of the above data on the various Belgian stratigraphic units, our figure 4 mainly summarizes the ideas of BATJES (1958), KAASSCHIETER (1961) and DROOGER (1964). With respect to the various opinions prevailing some ten years ago, this view is extreme in two respects: the first in placing the Vlierzele Sands at the same level as the Sands of Brussels, the second concerning the correlation of the Tongeren Formation of northeastern Belgium with the

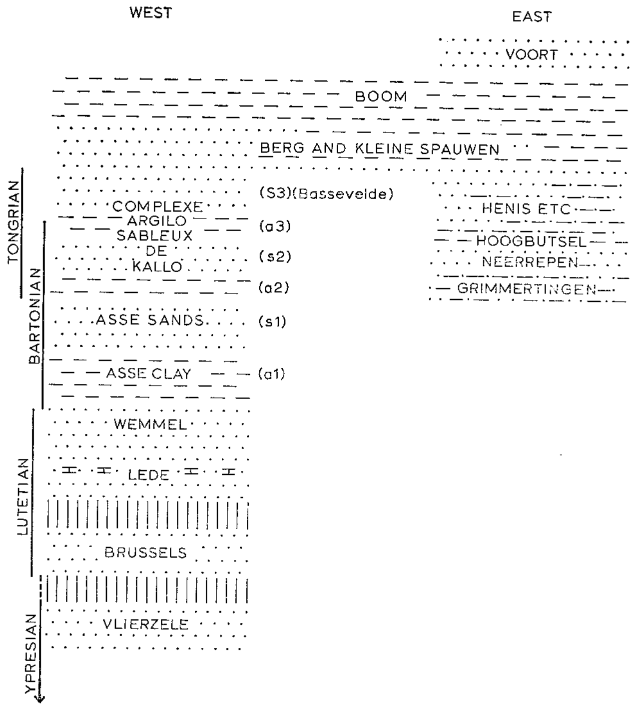


Fig. 5. Correlation of Belgian Middle Eocene to Middle Oligocene stratigraphic units, modified after CURRY, GULINCK and POMEROL (1969).

lithostratigraphic units in the northwestern part of the country. In earlier work the Tongrian is commonly thought to be a unit (Lower Oligocene) lying in time fairly well in between the Upper Eocene "Bartonian" and the Middle Oligocene Rupelian. Here the Lower Tongeren Formation is thought to be contemporaneous with mainly the Asse Sands, hence of Eocene age, whereas the units of the Upper Tongeren Formation are placed on a line with the Middle Oligocene of the Mechelen-Antwerp area.

During the last few years several new ideas on correlations have been published, ideas for an important part based on microfaunistic evidence: *Nummulites* (BLONDEAU et al, 1968), planktonic foraminifera (BRÖNNIMANN et al., 1968) and nannoflora (MARTINI and RITZKOWSKI, 1969). Some of these ideas are expressed in our figure 5, drawn after a compilation given recently by CURRY, GULINCK and POMEROL (1969). Compared with figure 4, one of the major changes is that not only are the Sands of Lede correlated with part of the Lutetian of the

Paris basin (POMEROL, 1961), but also the Sands of Wemmel are thought to correspond to the topmost "zone" of this French Middle Eocene stage.

Higher up in the section we today meet with a widely distributed opinion that the base of the Oligocene coincides with the base of the Sands of Grimmertingen and of corresponding deposits in Germany, usually called there Lattorfian. As a consequence the Belgian Upper Eocene, equivalent to the English Bartonian, would become restricted to the Asse Clay (?) and all or part of the Asse Sands, as yet without positive evidence.

It may be doubted on paleogeographic and microfaunistic evidence (KAASSCHIETER, 1961) whether, at least the basal part of the Asse Clays can be assigned an age different from that of the Wemmel Sands. If not, the Bartonian would become further reduced in the Belgian sequence to an entirely barren interval of higher Asse Clays and Asse Sands. The concept of the latter unit as given by KAASSCHIETER (1961), is narrowed down by GULINCK (1969) who only correlated his member s_1 of the Clayey-sandy complex of Kallo to the Asse Sands. Furthermore opinions differ on the chronostratigraphic position of member s_3 of this complex (= Sands of Bassevelde), whether it is to be correlated with the Upper Tongrian of Tongeren (GULINCK, 1969), or to the Grimmertingen Sands of the Lower Tongrian (DROOGER, 1969; MARTINI, 1969).

The Netherlands

Material from two borings, just across the Belgian frontier, was used for additional data. Lithostratigraphic terms used in these borings for the intervals of interest to us, were directly derived from the adjoining part of northwestern Belgium.

From the boring Woensdrecht D 17 (see KAASSCHIETER, 1961), only two samples from the Sands of Brussels (360.50 and 361.70 m) were found to be suitable for our investigation. One of them clearly shows the presence of two different *Nummulites* species: *N. laevigatus* and *N. variolarius* of the literature.

Three closely spaced samples from strongly glauconitic sands were taken from boring Aardenburg III (boring Biezen, 33—36.50 m). These sands have been recorded as Sands of Wemmel, but in our opinion these deposits might just as well be incorporated in the Asse Clays.

Finally there was the sample taken from the shaft of the coal-mine Hendrik IV (194—195 m), described by BATJES (1958), and thought to have been derived from the Oligocene Sands of Grimmertingen.

Germany

Stratigraphy of the German Eocene is nearly entirely based on subsurface observations which are rather rough. Commonly the subdivision is lithological and insufficiently correlated with the classical stages elsewhere. Since no *Nummulites* from this Eocene were available there is no need for continuing this discussion.

More important is the classical Lower Oligocene, since it yielded the type of *N. germanicus*. The stage involved is the Lattorfian (or Latdorfian) after a village in Eastern Germany (D.D.R.). The value of this stage has been disputed in the literature, and it was placed in the Upper Eocene (i.e. KRUTSCH and LOTSCH, 1957), in a position identical to that of the Lower Tongeren Formation in the review of BATJES (1958). However, *N. germanicus* was not described from Latdorf, but from Westeregeln near Magdeburg. We had material from another classical locality, Brandhorst, situated close to the famous outcrops of the Doberg (Chattian), near Bünde in Western Germany (D.B.R.). According to more recent reviews of German authors (GRAMANN, 1968; MARTINI and RITZKOWSKI, 1969), all these deposits had better be left in the Oligocene.

Another sample with *Nummulites* came from the boring Kühlerhof (448—460 m) near Erkelenz (see INDANS, 1956), again from the same "Lower Oligocene".

Hampshire basin, southern England

The sections of Middle-Upper Eocene strata in southern England contain several *Nummulites*-bearing levels. In this century they have been especially studied by CURRY (1937).

The most important and continuous sections of this Eocene are in the cliffs of Barton on the south coast of the mainland, and along Alum Bay and Whitecliff Bay, at the western and eastern coast of the Isle of Wight, respectively. On Wight the beds are steeply inclined and well exposed. The major lithostratigraphic units involved are from bottom to top the Bracklesham Beds, Barton Beds and Headon Beds. The latter, for the major part referred to as Lower Oligocene, are mainly of brackish and freshwater origin and of no interest for our investigation.

From the chronostratigraphic point of view the Barton Beds are most important because they are typical for the Bartonian, a stage name much abused on the continent. The Bracklesham Beds of mainly deltaic environment are rather different from one place to the other. Most of the sediments are fluviomarine of various origins with fully marine intercalations that contain *Num-*

mulites laevigatus and/or *N. variolarius.* Especially Whitecliff Bay on Wight shows a rather marine succession of the Bracklesham Beds.

At this eastern end of the Isle of Wight the Upper Bracklesham Beds contain levels with abundant *N. variolarius,* for which reason they have been correlated with the Lede Sands of Belgium and the Sands of Auvers in the Paris basin, and in recent years with part of the typical Lutetian. Our sample EG 1 from Whitecliff Bay (Fisher bed 17) is the only one investigated from these Upper Bracklesham Beds. No sufficient numbers of *Nummulites* were available from the higher units in eastern Wight.

In contrast the Upper Bracklesham Beds of Alum Bay are of more continental origin. But here the Barton Beds on top contain several *Nummulites*-bearing horizons. According to CURRY (1937) the presence of *N. prestwichianus* defines the base of the Lower Barton Beds, or Barton Clay, but it is replaced by *N. rectus* in the higher levels of these Lower Barton Beds.

The published details of the lithostratigraphy of this part of the section at Alum Bay, and our own fieldnotes are not well comparable. This may be due to variable thicknesses of the layers in the high cliffs and to the rapid flattening of the dip at this spot.

In our series of samples, from bottom to top EG 165—170, the pebble bed and the upper level with septaria could be used as index levels in the comparison (see CURRY, 1937, opposite p. 232). Our lowermost sample EG 165 approximately coincides with the base of the Barton Beds, and hence it should contain *N. prestwichianus.* EG 168 was taken near the septaria level, so it should contain *N. rectus.* EG 169 and 170 are still higher up in the realm of *N. rectus.*

Samples EG 114A—117A were taken from the same interval of Lower Barton Beds at Alum Bay, but the individual samples are hard to place with respect to those of the other series. The lowermost one EG 114A is from the base of the Barton Beds, EG 117A should contain *N. rectus.*

From the series at Barton a succession was sampled directly west of Chewton Bunny, Highcliffe. The samples with *Nummulites* (EG 150, 151, 155, bottom to top) derive from an interval of some five meters, again in the Lower Barton Beds. They are from members A2 and A3 (see CURRY, 1937), which means that the lowermost level with *N. prestwichianus* of CURRY is not represented in our material, only those of *N. rectus.*

Paris Basin, France

Although, or perhaps because, the Paris basin is the classical region for the Eocene, nowhere can one find a more confused literature about the correlations and age assignments of its numerous lithostratigraphic units. This is especially true for the Upper Eocene deposits (e.g. FEUILLEE, 1964).

The Middle Eocene is represented by the Lutetian Stage, which is commonly subdivided into four or five members, called zones (I—IV b of ABRARD, 1925), some of which seem to be different mainly because of the effect of environmental influences during the deposition.

In the lower members (I and II) *N. laevigatus* is the *Nummulites* species with index value. In the second of these members it is accompanied by *N. variolarius.* Also the higher part of the Lutetian (III, IVa) was found to contain *N. variolarius,* but here we find a rich fauna of Miliolidae instead of *N. laevigatus* (BLONDEAU et al., 1965). The newly encountered occurrences of *N. variolarius* by several geologists both in the Lower and in the Upper Lutetian, have caused serious doubt as to the index value of this species (BLONDEAU and CURRY, 1963). It was one of the reasons why POMEROL (1961) correlated the Belgian Ledian with the French Upper Lutetian.

POMEROL and BLONDEAU kindly sent some samples of this French Upper Lutetian, in which, however, we failed to find *Nummulites.* Only material sent recently by BLONDEAU did contain a small number of individuals, which are used as a check sample: locality Fercourt (Oise), base of the Upper Lutetian, zone IV with *Orbitolites.*

The Upper Eocene consists of a great number of local lithostratigraphic units, and their mutual relations have been a source of constant discussion. They are united to stages in many different ways. For instance, FEUILLEE (1964) reported eight or nine different interpretations of the term Bartonian in the Paris basin. Several reviews have been given by French authors during the last few years (e.g. POMEROL, 1964; and BLONDEAU et al., 1965), which reviews will serve as a basis for this paper.

These authors recognize but one stage for the entire Upper Eocene, for which they select the term Bartonian. They subdivide this stage into three substages, which are from bottom to top the Auversian, the Marinesian and the Ludian. It is the Auversian which is of special interest for our investigation because of its *Nummulites,* and its much disputed value as a stage (BLONDEAU and POMEROL, 1968).

Two zones, or rather groups of members, are distinguished within the Auversian of the Paris basin. At the base the Formation of Mont-Saint-Martin with a somewhat brackish microfauna, is thought to announce the new, Late Eocene transgression following the regression at the end of the Lutetian in the Paris basin. The upper "zone" of the Sands of Auvers-Beauchamps unites a variety of local lithostratigraphic units, amongst which the Sands of Auvers, undoubtedly the type of the Auversian. These are current-bedded calcareous sands with pebbles and numerous fossils, amongst which *N. variolarius.* Commonly the Sands of Auvers at their type locality are considered to be *locus typicus* for this species of *Nummulites.*

For comparison four samples, from bottom to top FR 563—566, were available from a section measuring some 12.50 meters from the typical exposure of the Sands of Auvers in the Bois-du-Roi, near Auvers-sur-Oise (DE LAPPARENT, 1964, p. 29). Sample FR 1036, added later, has been taken at the same locality.

The middle substage of the French Bartonian is the Marinesian, which also contains *N. variolarius* at certain places, but which we leave out of consideration because the stagename has hardly ever been used outside the Paris basin. The same applies to the upper substage, the Ludian, which shows less open marine conditions and which does not contain *Nummulites.*

Actually, the higher Upper Eocene *Nummulites* of the literature *(N. orbignyi, N. prestwichianus, N. rectus)* have never been reported from the Paris basin.

Aquitaine basin, France

Small radiate *Nummulites* are known to occur in the Upper Eocene and Oligocene of SW France, especially from the Biarritz section. Actually, the cliffs of the latter town formed the best continuous section, in which only the topmost part of the Oligocene is thought to be lacking (e.g. BOUSSAC, 1911a).

In this famous section the Oligocene is seen to overlie the Upper Eocene with a sharp contact between the Lou Cachaou and the Villa Belza. The Lower Oligocene, generally named Lattorfian by the earlier authors, forms the protruding hard rocks in front of the old town of Biarritz (Port Vieux, Atalaye, Rocher de la Vierge). These rocks consist of indurated calcareous sandstones in which *Nummulites* are the most conspicuous fossils.

The Middle Oligocene (Rupelian-Chattian? for BOUSSAC) of this section consists of similar rocks, those of the Villa Eugénie below, those of the Phare Saint-Martin and the Chambre d'Amour higher up. Smaller radiate *Nummulites* occur throughout. The upper part of the section at Chambre d'Amour becomes more marly, with the *Nummulites* more restricted to individual coarser layers.

According to BOUSSAC we are dealing with the same species of radiate *Nummulites* throughout the section: *N. vascus* and *N. bouillei.* They would be accompanied by *N. intermedius* of the *fabianii*-group. *N. variolarius* has been reported from the Eocene part of the section.

For comparison with our nordic material we only used two samples from the Oligocene. One (FR 650) was taken during an excursion from the so-called Lattorfian of the Rocher de la Vierge from the hard calcareous sandstones.

The second sample (FR 534) comes from the northern end of the cliffs of the Chambre d'Amour from one of the coarser layers. It is stratigraphically situated towards the top of this Oligocene section. These beds are probably older than those in the region of Dax and Saint-Géours de Maremme.

During the final stage of the work the results of two samples were added. These samples (Aq 18 and 19) had been taken from the much disputed locality of the Uppermost Oligocene at Escornebéou near Dax. The sample numbers are those of Butt (1966).

Chapter III

GENERIC DESIGNATION

The smaller *Nummulites* of the Eocene of northwestern Europe clearly show the general features that are typical for the genus in a broad sense: they are planispiral, more or less distinctly involute, with lamellar walls, double septa and a marginal cord. They are characterized by their small size, which is commonly less than five mm in diameter, and by the restricted number of whorls, usually three to five in megalospheric forms. They all belong to the group of radiate species, in which the sutures of the final whorl, seen from the outside, show a regular, straight, curved or somewhat sinuous pattern between the periphery and the umbilical centre. This centre may have a more or less developed umbonal boss, but other types of surface ornamentation, such as a pattern of pustules, is commonly absent.

Within this group of radiate species, belonging to the nordic areas, two vaguely delimited groups are usually distinguished:

1. Species with a relatively thick test and narrow whorls,
2. Species with a relatively thin test and whorls more rapidly increasing in height.

It should be emphasized that both groups show perfect intergradation. Representatives of both occur from the Paleocene onwards and all over the world.

In America the species of both groups that occur in this continent from Eocene to Miocene, have usually been placed in the genus *Operculinoides* HANZAWA 1935, though species that resemble our second group were often placed in *Operculinella* YABE 1918. Both these names never became popular in Europe.

For our group of thin *Nummulites* the Russian author GOLEV (1961) introduced the name *Neooperculinoides*, for which he used *N. orbignyi* as an example. Apart from the thin test and the increase in spiral height, the more or less evolute character of the final whorl is thought to be characteristic for this genus.

EAMES, BANNER, BLOW and CLARKE (1962) revived the old name *Palaeonummulites* SCHUBERT 1908, which was based on the dubious species *Nummulina pristina* BRADY, originally reported from the Belgian Carboniferous, but probably derived from some unknown locality of the Belgian Eocene.

In the more recent literature there are two tendencies to classify the Nummulitidae at the generic level. In the "splitters" group (e.g. SIGAL 1952, GOLEV 1961) it is hard to differentiate the many genera or subgenera. Actually, the vague morphological boundaries led COLE (1964, in LOEBLICH and TAPPAN) to the "lumping" extreme, of recognizing only one genus, *Nummulites* LAMARCK 1801 (or *Camerina* BRUGUIERE 1792 in his older publications), to include nearly all planispiral Nummulitinae, even *Operculina* D'ORBIGNY and *Assilina* D'ORBIGNY.

The various morphological features of our specimens, some of which will be discussed in the next chapter, show no clear divergencies from the features described for typical *Nummulites*. The small size and the low number of whorls are considered unrealistic characteristics for a generic separation of the nordic group of species, if we keep in mind that the Paleocene *Nummulites* have similar features, and also that small *Nummulites*, whether immature or adult, were constantly present throughout the Eocene. The fairly rapid increase in height of the whorls could be another reason for separating part of our forms from the genus *Nummulites*. However, such a procedure would cause a highly artificial boundary within our homogeneous group of assemblages.

As a consequence we prefer to retain the generic name *Nummulites* for all our nordic populations.

Chapter IV

SOME GENERAL MORPHOLOGICAL OBSERVATIONS

There is no need for a detailed qualitative description of all our *Nummulites*. We will confine ourselves to a small number of relevant data, which may give a general insight into the morphology of the nordic group.

The diameter of the protoconch of microspheric individuals is usually hard to measure exactly; it is around 15 μ, seemingly independent of the protoconch size of the accompanying megalospheres. The protoconch of these macrospheric specimens is much more variable. Individual values of about 30 μ have been measured, but maximal values amount to over 250 μ. The average values for the samples are rather variable. At the lower end of this variation some 50 μ is not rare, which diameter is remarkably small since the mean value of 100—120 μ had been reached already by the Paleocene *N. fraasi*.

The outer surface of the marginal cord shows a clear pattern of minute longitudinal anastomizing grooves. These grooves are thought to correspond with the marginal canal plexus below. Transverse sections of the cord show a radiate, diverging pattern of lines. Regeneration of the marginal cord and its grooves was sometimes observed.

No aperture was observed in final chambers; in earlier ones basal intercameral openings were evidently formed by resorption.

On the periphery towards the final chambers the grooved pattern of the marginal cord gradually disappears, which shows that the grooves originate from a combination of protoplasma streams and continued layering on the earlier parts of the test. The walls appear lamellar with fine pores. Lamellae of the side walls frequently wedge out in polar direction.

The septa are double with intraseptal canals or sheet-like open spaces which communicate with the canals of the marginal plexus. This plexus becomes more complex with the increase in number of later chambers in the same coil, which observation could be made in median sections.

Starting from the intraseptal canals minute, repeatedly bifurcating offshoots (trabeculae) could be seen in the interior of the shell-wall of the chambers in front. These trabeculae possibly had some function during the building of the wall of the newly formed chamber.

Especially the thicker tests frequently show an umbonal boss or pillar (e.g. in the material from Auvers), from which the sutures of the last whorl can be seen radiating to the periphery. The surface between the sutures is smooth. In the thinner tests the central boss is weaker or absent. The surface is commonly smooth again with radiating sutures. Occasionally the sutures of earlier whorls remain visible from the outside, especially in larger specimens of the microspheric generation. Some specimens, especially from the sample "Heysel", show spirally arranged, simple pillars. Pillars of earlier whorls merge with the central boss.

Thick individuals with narrow whorls are most distinctly involute. The successive laminae reach the polar centre at both sides where they form the more or less protruding umbonal masses or pillars. Such thicker forms are closest to the original idea of *Nummulites*. Nevertheless, it could be seen in individuals with undamaged later chambers that the lamellae of the last-formed three or four chambers often do not reach the centre. This is in a way intermediate to the configuration of lamellae found in thinner tests.

The absence, or rather very thin character, of the umbonal part of the lamellae is much more prominent in thinner tests. For this reason these forms commonly lack a central boss and have a semi-involute appearance.

Especially in the thinner species there is clear difference between microspheric and megalospheric specimens. With the same thickness the individuals of the B-generation have a considerably larger diameter than the accompanying A-forms. In contrast such differences in size and relative thickness of the test are much less apparent or even absent in the assemblages with thicker individuals.

Chapter V

THE EARLIER DESCRIBED SPECIES

As mentioned before, the size and relative thickness of the test and the corresponding relative height of the whorls were the main features for distinguishing the various species of smaller nordic *Nummulites*. The original authors of these species of the 19th century usually gave hardly any other information. They were equally reticent in giving remarks on the type locality and level. As to the former, one often has a choice between a number of geographic names, as to the latter one can only make a more or less fair guess. For further information we have to rely on later authors, whose remarks frequently equally lack the exact information we should like to have.

The more the non-specialist reads about the nordic *Nummulites* species, the more trouble he has to distinguish them morphologically. In later publications differences between species are based on different features, such as size and relative thickness of the test, diameter of the protoconch, shape of the chambers and of septa in median sections, pattern of the sutures, height of the successive whorls. Sometimes these features are well demonstrated by the figured specimens, but very few exact data are given about variation in the assemblages. Occasionally average values of certain characteristics are given without mentioning the width of variation, however. Adjectives in degrees of comparison are an important constituent of all descriptions and discussions. Exact values are rare, and little is said about variation between different assemblages of the same species. Only ROZLOZSNIK (1929), who studied several samples of the same species, reported many minor divergencies between the separate assemblages.

Most of the later authors agree on the theory that *N. variolarius* constituted the original stock of nordic *Nummulites*. The other species would be various descendents, according to most specialists they all would be degenerates. Especially the decrease in relative thickness of the test in the course of time would demonstrate this degeneration.

Before starting to enumerate the earlier described species of the literature we have to call to mind the constantly recurring discussion, whether microspheric and macrospheric "species" should be given one name or two separate ones. Although tending to accept the former view we will try to record all specific names given to A and B forms separately, because it is occasionally uncertain which two forms actually belong together. As a matter of fact little further attention will be paid to the microspheric forms, because our study deals mainly with the more numerous megalospheres.

Nummulites variolarius (LAMARCK)

Lenticulites variolaria LAMARCK, 1804, Ann. Mus. Hist. Nat. Paris, vol. 5, p. 187.
Nummulina variolaria (Lamarck), ROZLOZSNIK, 1929, Geol. Hung., fasc. 2, p. 95, pl. 7, fig. 14.
Nummulites variolarius (Lamarck), CURRY, 1937, Proc. Geol. Ass., vol. 48, p. 240; BLONDEAU, 1966, Bull. Soc. géol. France, ser. 7, vol. 8, p. 912, pl. 18, fig. 5, 7, 18, 25.

Original description. The most interesting remark in LAMARCK's original description is that the species "ressemble à des pustules naissantes de petite vérole ou de rougeôle". This gives at least the impression of a rather thick species, which is the common interpretation of later authors. Most of these later authors agree that the name given by LAMARCK, applies primarily to A-forms, because they consider *N. heberti* as the accompanying microsphere.

Type locality and level. No type level was indicated by LAMARCK and for the type locality one had to choose between Grignon, Chaumont and Betz, all three in the Paris basin. According to POMEROL (1964, p. 164) Grignon and Chaumont refer to deposits of Lutetian Age, only Betz should be placed in the Auversian. *Nummulites* from these three localities never received the additional attention that would have clarified the characteristics of *N. variolarius,* although forms from Betz were again commented upon by D'ARCHIAC and HAIME (1853). There is a distinct preference in the literature to consider Auversian forms as typical for the species (ROZLOZSNIK, 1929; CURRY, 1937; BOMBITA, 1968). Now that small *Nummulites,* referred to as *N. variolarius,* have been re-discovered in the French Lutetian (CURRY, 1961), a decision has to be taken on the basis of topotype material of any of the three original localities. Selecting Betz as the type locality, will certainly cause least confusion with regard to the previous literature. Although no material from Betz was available we consider for the time being that from Auvers conspecific. Anyhow, when referring to *N. variolarius* of the Paris basin most authors consider material from Auvers, which certainly is of stratigraphic importance, because Auvers is the type locality of the Auversian.

Discussion. According to ROZLOZSNIK's discussion (1929, p. 95—97) the French *N. variolarius* (i.e. the A-forms from Auvers) would have a strong umbonal boss, close to which the sutures would occasionally bifurcate towards the periphery. The marginal cord is said to be thick, in median section approaching the height of the proximal chamber lumen. The septa are radial and but slightly curved; the chamber shape in section is broadly sigmoid to rhombic. ROZLOZSNIK noticed variation in the species, thereby going so far as to recognize Belgian and English races.

Curry (1937) adds that the species is small and strongly lenticular, with four whorls of regular coiling, while the height of these whorls would not increase with growth.

Blondeau (1966) observed that Auversian and Marinesian representatives of *N. variolarius* are larger than those from the French Lutetian (median diameter of 1.5 mm against 1 mm). All Belgian and English forms would be of the smaller type. Only Blondeau's figures, which refer to the larger "Bartonian" types of the Paris basin, are given in our synonymy list. The internal features enumerated by Blondeau show no differences between both groups, which is not fully in accordance with our own observations. For the protoconch diameter this author gives a range of 75—110 μ, with a median value of 90 μ for both groups together.

The most remarkable feature in our material from Auvers, which we consider at the moment as closest to the original *N. variolarius*, is the relatively large size of the protoconch, averaging some 125 μ in diameter.

Nummulites variolarius minor d'Archiac and Haime

Nummulites variolarius (Lamarck) var. a *minor* d'Archiac and Haime, 1853, Descr. anim. foss. Inde, Paris, p. 146.

Original description. This variety was evidently meant for the Belgian representatives of the species, because of their size, smaller than that of the French forms. This is clear from the essentials of the original description: "Atteignant rarement un millimètre de diamètre; surfaces unies ou presque lisses".

Type locality and level. The localities given by the original authors are Laecken and the surroundings of Brussels in Belgium, Cassel (Nord) in France. Although it has been suggested that this variety was meant for the forms encountered in the Sands of Lede, we might just as well be dealing with representatives of older populations, derived from the Sands of Brussels.

Discussion. Rozlozsnik (1929, p. 95—97) adds little to the scanty information given above. In these Belgian forms the chambers would be more curved than in French specimens. Evidently the varietal name was meant for A-forms. According to Blondeau (1968) this smaller form, which in his opinion is identical to *N. variolarius* var. *minima* de la Harpe from the French Alps, is widely distributed: in the Alpes Maritimes, in the Lutetian of the Paris basin and in the Ledian of Belgium.

Nummulites variolarius gandinus (Rozlozsnik)

Nummulina variolaria gandina de la Harpe, Rozlozsnik, 1929, Geol. Hung., fasc. 2, p. 96, 176, 177.

Original description. ROZLOZSNIK (1929, p. 96) reports two different types of B-forms in his material from the Citadel of Ghent. One would correspond to the normal type (probably meant *N. heberti*), the other resembles the A-forms, distinguished as var. *Gandina*, which he had found in the collection of DE LA HARPE. The latter would be different from the typical forms of the species mainly by the thinner marginal cord in section $\pi = \frac{1}{4}$—$\frac{1}{3}$. The entire test would be smaller and less solid than in *N. variolarius minor.* The septa are strongly curved in the inner whorls, straighter with peripheral curvature in the outer whorls. The chambers are higher than broad.

Type locality and level. The "Citadelle de Gand", which locality probably corresponds with deposits of the Sands of Lede.

Discussion. The original name was based on unpublished material in DE LA HARPE's collection, but ROZLOZSNIK's name should be added as that of the author of the name *gandinus.* Although ROZLOZSNIK's description mainly refers to B-forms, it is thought preferable to preserve DE LA HARPE's types and thus connect the name with the macrospheric individuals. This *N. variolarius gandinus* is the most common Belgian form, probably unseparable from *N. variolarius minor* of D'ARCHIAC and HAIME. For both we may conclude that the average protoconch size is smaller than that in the French assemblages from Auvers. Whether such a differentiation is valid relative to all forms of the French Lutetian — it is to those of Fercourt — is as yet to be left open because of our scanty information about these older assemblages of the Paris basin. Anyhow, differences in average protoconch size between Lutetian and Auversian forms have not been mentioned by BLONDEAU (1966).

As long as more details are lacking we have to agree with PAPP (1969) that the recently described *Nummulites paravariolarius* JARZEVA from the D.D.R. by JARZEVA, LOTSCH and NEMKOV (1968) is identical with *N. variolarius gandinus.*

Nummulites heberti D'ARCHIAC and HAIME

Nummulites heberti D'ARCHIAC and HAIME, 1853, Descr. anim. foss. Inde, Paris, p. 147, pl. 9, fig. 14, 15; ROZLOZSNIK, 1929, Geol. Hung., fasc. 2, p. 95.

Original description. This specific name is clearly meant for a B-form, which by its original authors is brought already in connection with *N. variolarius.* The test is said to be 3 mm in diameter with a thickness of 2 mm. The spiral increases more rapidly in height than it does in *N. variolarius.* There are six whorls, the first, second and sixth being less high than the intermediate ones. 24 chambers occur in the third convolution.

Type locality and level. Again we are faced with the localities Laecken and

Brussels; regarding the description it may be assumed that *N. heberti* originated from the Sands of Lede.

Discussion. ROZLOZSNIK correctly stressed that if the French and Belgian representatives are to be differentiated, *N. heberti* belongs to the Belgian race, and not to *N. variolarius* in the sense of the populations from Auvers. These microspheric individuals are hardly bigger than the accompanying megalospheric forms. CURRY (1937, p. 240) notes that H. DOUVILLE considered the best criterion for *N. variolarius* the approximately equal size of A- and B-forms. The septa of *N. heberti* would be more upright, in *N. variolarius* more inclined, which difference may be correlated with a greater laxity in the whorls of *N. heberti.*

Nummulites pristinus (BRADY)

Nummulina pristina BRADY, 1874, Ann. Mag. Nat. Hist., ser. 4, vol. 13, p. 226, pl. 12, fig. 1—5.
Palaeonummulites pristinus (Brady), EAMES, BANNER, BLOW and CLARKE, 1962, Cambridge Univ. Press, p. 50, pl. 1, fig. F-H.

Original description. Some of the details are: diameter 0.8 mm, thickness 0.35 mm, relation diameter/thickness fairly constant 9/4.

Type locality and level. Quarry Fond d'Arquet near Namur, from limestones of the Carboniferous.

Discussion. By some error the type locality was incorrectly stated. The specimens of BRADY, sent to him by VAN DEN BROECK, probably are from some unknown Eocene locality in Belgium. EAMES et al. (1962) place the species in the vicinity of *N. wemmelensis.* However, in our opinion the great relative thickness rather points to *N. variolarius.* Since there is no clue to the type locality, the species name might best be regarded as a *nomen dubium,* though EAMES et al. revived it for re-establishing the genus *Palaeonummulites* SCHUBERT, 1908, of which it is the type species.

Nummulites rectus CURRY

Nummulites rectus CURRY, 1937, Proc. Geol. Ass., vol. 48, p. 241, pl. 20, fig. 1—3, pl. 21, fig. 11.

Original description. "The name is taken from the upright nature of the septa". The test is somewhat greater than that of the Belgian *N. variolarius,* it is less inflated, the sutures are sinuous and the septa in section start upright, even sloping forwards proximally, and bend back sharply when the marginal cord is reached. There are 4—4½ whorls, tight in the beginning, noticeably more lax in the final part of the test. The A- and B-forms are closely similar and the species name is not clearly linked by its author to one or the other generation.

Type locality and level. Barton cliffs, horizon A3 of the Lower Barton Beds. Other localities mentioned are Alum Bay and Whitecliff Bay at both ends of the Isle of Wight, where the species was derived again from the higher part of the Lower Barton Beds.

Discussion. N. rectus is a form morphologically intermediate between the group of thick species (*N. variolarius c.s.*) and that of thin species (*N. wemmelensis c.s.*), both in the relative thickness of the test and in the starting lax character of the spire. CURRY (1937, p. 243) considers *N. rectus* to be one of the products of degeneration of the more globose *N. variolarius.* He reports to have found intermediate forms between both types in assemblages from the Sands of Lede near Bambrugge in Belgium, which intermediate character is confirmed by BLONDEAU (1966, p. 914). *N. rectus* seems to be restricted to the Hampshire basin.

Nummulites wemmelensis DE LA HARPE and VAN DEN BROECK

Nummulites planulata (Lamarck) var. a, *minor* D'ARCHIAC and HAIME, 1853, Descr. anim. foss. Inde, Paris, p. 143, pl. 9, fig. 10.

Nummilites wemmellensis DE LA HARPE and VAN DEN BROECK, 1881, in DE LA HARPE, Abh. Schweiz. Pal. Ges., vol. 7, p. 168, pl. 6, fig. 52—57.

Original description. DE LA HARPE and VAN DEN BROECK placed the *planulatus minor* variety of D'ARCHIAC and HAIME in the synonymy of their new species.

The description of 1853 is vague: test half of the size of *N. planulatus*, but with all of the latter's external and internal features. "La lame spirale et les cloisons sont d'une extrême délicatesse". Localities given are the Isle of Wight, Jette and Laeken, in all their vagueness.

In 1881 an important remark is: "La petite espèce plane de Laecken . . . que nous avons appelée *N. wemmellensis*". This points to a flat form.

From the published correspondance with T. R. JONES, it appears that DE LA HARPE considered this species to be polymorphic. It shows the following variants:

1. Type: diameter 2—3 mm, shape irregular, lenticular, mucronate in the centre, surface smooth. Localities given are Wemmel and Jette, but type locality of the species is Laecken.
2. var. *plicata:* 1—2 mm, lenticular, depression in the centre, surface plicated. Locality Ghent.
3. var. *granulata:* 1—2 mm, flat, surface granulated. Locality Brussels, Park Saint Gilles.
4. var. *minor:* 1 mm, lenticular, smooth, regular. Locality given Breendonck.

5. var. *prestwichiana:* 1—2 mm, flat, smooth, regular. English variant.

Type locality and level. Although Laecken is given, the name (with incorrect orthography) is derived from the village of Wemmel. Since both localities Laken and Wemmel are northwestern suburbs of Brussels nowadays, we had better stick to the latter locality for our guess of the type deposits, which then most probably are the Sands of Wemmel. Anyhow, the latter designation fits in best to the described flat forms.

Discussion. In nearly all later publications the name *N. wemmelensis,* typical for the A-form, is suppressed in favour of *N. orbignyi,* the specific name for a form that probably represents the corresponding microspheric generation. Although all later authors agree that *N. wemmelensis* is one of the flat species, already DE LA HARPE's remarks show its variation. According to CURRY (1937, p. 239) *N. wemmelensis* averages two millimeters in diameter and 0.65 mm in thickness. The whorls are not completely embracing. There are four convolutions, the marginal cord is thin, the septa are curved throughout and the protoconch would be relatively large. The test is said to be biconical or lenticular, according to whether or not a central boss is present. It may be added that individuals with a distinct umbonal boss often also show granulations along the sutures, where those of the chambers and those of the earlier spiral sutures cross one another. Another typical feature of this species is the lax spire. BLONDEAU (1966) reports that he never found *N. wemmelensis* alone, but always accompanied by a minor percentage (1—2 %) of *N. variolarius.* He found the diameter of the protoconch to be of the same order as in *N. variolarius:* 0.1—0.12 mm.

Nummulites orbignyi (GALEOTTI)

Operculina orbignyi GALEOTTI, 1837, Mém. Cour. Acad. Belg., vol. 13, p. 54, pl. 3, fig. 13.
Nummulites orbignyi (Galeotti), DE LA HARPE, 1883, Abh. Schweiz. Pal. Ges., vol. 10, p. 168, pl. 6, fig. 42—51; CURRY, 1937, Proc. Geol. Ass., vol. 48, p. 239, pl. 20, fig. 13; BLONDEAU, 1966, Bull. Soc. géol. France, ser. 7, vol. 8, p. 915, pl. 28, fig. 22, pl. 29, fig. 29.

Original description. "Coquille très aplatie, mince", is the most important statement in GALEOTTI's original description.

Type locality and level. "Terrains fluvio-marins supérieurs, formation inframarine ou tritonienne, système supérieur ou calcaréo-sableux, du plateau de Forêts, province de Brabant", which may be interpreted as Sands of Wemmel, near Forest, suburb of Brussels.

Discussion. The typical B-form is stated to be quite different from its megalospheric companion. Its representatives are much larger, reaching six mm in diameter, but they are of comparable thickness. The central boss is generally well developed in younger forms. Larger forms become somewhat evolute with irregular outline and thickened marginal cord. The whorls increase rapidly in height, the chambers are up to three or four times as high as broad, with fairly upright septa in the lower part of the section, but strongly curving backwards near the periphery. BLONDEAU (1966) remarks that *N. orbignyi* is a degenerate of *N. variolarius*, "qui reprend le caractère de Nummulite cordelée" (p. 917).

Nummulites prestwichianus (JONES)

Nummulina planulata var. *prestwichiana* T. R. JONES, 1862, In Fisher, Quart. Jour. Geol. Soc. London, vol. 18, p. 93.

Nummulites prestwichianus (Jones), CURRY, 1937, Proc. Geol. Ass., vol. 48, p. 242, pl. 20, fig. 7—9, pl. 21, fig. 10.

Original description. From JONES' description it follows that the test is "discoidal, smooth and flat, rarely in any degree biconvex". Diameter 2—5 mm, thickness 0.35 mm. The septa are gently sigmoid. There are three, proportionately wide whorls, the outer one taking half of the width of the test. The chambers are twice as high as broad, neatly curved.

Type locality and level. Clay with green sand at Alum Bay, Wight, which is bed no. 29 of Prestwich. This layer is nowadays considered to mark the base of the Lower Barton Beds. Other localities are Highcliffe, Barton, and Whitecliff Bay on Wight, where the species occurs in the same relative stratigraphic position as at Alum Bay (see CURRY, 1937).

Discussion. This seems to be the thinnest of all nordic species. The sutures show a sigmoid curvature as found in *N. rectus*, but more strongly pronounced (CURRY, 1937, p. 243). The sutures may be thickened where they meet the spiral suture of the previous whorl. Successive convolutions increase rapidly in height. Both A- and B-forms are included in the original description. *N. prestwichianus* is considered to be another degenerate of the archaic nordic *N. variolarius* stock (CURRY, 1937; BLONDEAU, 1966).

Nummulites germanicus (BORNEMANN)

Amphistegina nummularia REUSS (not *Camerina nummularia* BRUGUIERE), 1856, Sitzungsber. K. Akad. Wiss. Wien, math.—naturw. Kl., vol. 18, p. 238, pl. 4, fig. 46—50.

Nummulina germanica BORNEMANN, 1860, Zeitschr. d.d. geol. Ges., vol. 12, p. 158, pl. 6, fig. 3—9.

Nummulites germanicus (Bornemann), FRANKE, 1925, Abh. Ber. Mus. Nat. Heimatk. Naturw. Ver. Magdeburg, vol. 4, p. 190, pl. 6, fig. 73; BATJES, 1958, Verh. Kon. Belg. Inst. Natuurw., no. 143, p. 169, pl. 12, fig. 12, pl. 13, fig. 1—7.

Original description. The individuals are 2—5 mm in diameter and they are commonly rather flat. The sutures are radial, weakly curved, "am Rücken sickelförmig nach hinten gekrümmte Linien". The third convolution would have between 18 and 24 chambers. BORNEMANN already observed the trabeculae. He made the very reasonable statement that because under the name *N. germanicus* "sehr verschiedene Formen zusammengefasst wurden, so schien es doch nicht rathsam, dieselben in verschiedene Spezies zu trennen, indem die extremen Gestalten, die scheibenförmige und die linsenförmige Varietät durch Zwischenformen vollständig in einander übergehen".

Type locality and level. Described from Westeregeln near Magdeburg (D.D.R.) from beds of the "Unteren Oligozäns von BEYRICH dem belgischen Tongrien inférieur gleichgestellt". That means that the age is thought to be Early Oligocene or Lattorfian.

Discussion. Nummulites germanicus is a much disputed species, mainly because of our scanty knowledge of its morphological features. BORNEMANN already noted a considerable variation in relative thickness of his *N. germanicus.* Both A- and B-forms were described, the latter being relatively flattest. Also our scarce German material shows wide variation. Variants with rather tight coiling (e.g. BORNEMANN, fig. 9) that resemble *N. variolarius,* seem to intergrade with forms that show very lax spirals (e.g. BATJES, fig. 5, 6). Especially the latter variants are most conspicuous in the literature, which gave rise to much of the discussion whether *N. germanicus* is really different from *N. orbignyi-wemmelensis.* BATJES (1958) and DROOGER (1969) thought it most likely that both forms are conspecific. CURRY (1966, p. 444) even suggested that *N. germanicus* might be synonymous with the flattest nordic species *N. prestwichianus* (and both identical with the Mediterranean *N. tournoueri*), and thus constituting one species ranging from Upper Eocene to Middle Oligocene.

In Germany the species has been repeatedly mentioned as an index fossil of the (Early) Oligocene, but one cannot escape the impression that the determination usually was *N. germanicus* because the beds involved were thought to be Oligocene in age for other reasons. BATJES (1958) remarked that his material (Dutch South Limburg, Sands of Grimmertingen) resembles *N. wemmelensis.* The suggestions that the Lower Tongeren Beds (BATJES, 1958) and the Lattorfian (KRUTSCH and LOTSCH, 1957) would be of Late Eocene age, does not necessarily imply that *N. germanicus* should be contemporaneous with typical *N. wemmelensis.* BATJES parallelized the Lower Tongeren Beds mainly with the Sands of Asse, a unit overlying the Sands of Wemmel and the Clays of Asse in northwestern Belgium. Hence, *N. germanicus* could still be the youngest nordic *Nummulites* whether of Oligocence age or not, and conspecific with *N. wemmelensis* or not.

For the possible relationship between *N. germanicus* and *N. concinnus* JAR-

ZEVA, reported also from the D.D.R., the reader is referred to PAPP's publication (1969).

Mediterranean smaller radiate species

Apart from the species enumerated above, which were all originally described from the northwest European basins, some similar striated forms have to be mentioned from the Mediterranean Eocene-Oligocene. Exact data are again scarce. A review of some of the most important forms was given by LANTERNO and ROVEDA (1957), mainly on the basis of the original material in the collections of DE LA HARPE. There are but few additional pertinent data to be found in the literature (e.g. BLONDEAU, 1968). We will confine ourselves to mentioning the most important features. For synonymies the reader is referred to the paper of LANTERNO and ROVEDA, or to the earlier literature.

Several couples of species have been recognized, those met with most frequently in the literature are:
N. ramondiformis (A) — *N. incrassatus* (B),
N. boucheri (A) — *N. vascus* (B), and
N. tournoueri (A) — *N. bouillei* (B).

The next table with details on the macrospheric forms of two of the couples was extracted from the paper of LANTERNO and ROVEDA.

	N. ramondiformis DE LA HARPE	*N. boucheri* DE LA HARPE
Range diameter	2.1—4.5 mm	1.8—3.6 mm
Average diameter	3.17 mm	2.68 mm
Range thickness	1.0—2.5 mm	0.7—1.2 mm
Average thickness	1.55 mm	0.85 mm
Surface	smooth to slightly plicate	smooth
Protoconch diameter	150—300 μ	"petite ou moyenne"
Whorls	4—6	3—5
Rel. height marg. cord	$\frac{1}{3}$—$\frac{1}{2}$	$\frac{1}{3}$—$\frac{1}{2}$
Septa	inclined	straight, outer part curved.
Umb. boss	present	not mentioned

The above analysis gives a typological difference between a thick and a thin "species", which may be supplemented by a similar analysis of the microspheric counterparts, *N. incrassatus* and *N. vascus* respectively.

The *ramondiformis* group has a thickness/diameter ratio of about 0.50, the *boucheri* group of 0.30 in megalospheric forms, to 0.20 in the *vascus* forms. The scatter diagram given by LANTERNO and ROVEDA for this diameter/thickness ratio shows separate clusters for the microspheric forms, but hardly so for the individuals of the A-generation. There seems to be little doubt that the megalospheres of both couples show complete intergradation. The other differences, cited in the above table are thought to be irrelevant. The size of the protoconch in *N. boucheri* is not given, but we suspect it to be of the same order of magnitude as in *N. ramondiformis*.

The *N. ramondiformis-incrassatus* group of thick forms seems to be known from the Middle Eocene upwards into the Oligocene, whereas its flatter decendant couple *N. boucheri-vascus* appears as a frequent group from the base of the Oligocene upwards. The latter pair *N. boucheri-vascus* is especially known from the various Oligocene deposits of the Biarritz section.

Another species of this group would be *N. chavannesi* DE LA HARPE. According to BLONDEAU (1968) this form would resemble *N. ramondiformis*, but with a lax spiral. The thickness/diameter ratio would be again about 0.50, the average protoconch diameter 200 μ. The species would be restricted to the Eocene, Lutetian-Priabonian interval.

From the Oligocene part of the Biarritz sequence DE LA HARPE (1879) described yet another couple of small and flat *Nummulites: N. tournoueri* (A) — *N. bouillei* (B), which has a more open, operculinid, spire than has the couple *N. boucheri-vascus*. According to BOUSSAC (1911) both couples occur together in the Biarritz Oligocene, with the non-radiate, but reticulate-granulate couple *N. fichteli-intermedius*, but they are also reported from the Upper Eocene together with the ancestor of *N. intermedius*, i.e. *N. fabianii*, well-known species from the type Priabonian of Italy. *N.tournoueri* would have a thickness/diameter ratio of 0.30, and an average protoconch diameter of again 200 μ (BLONDEAU, 1968).

The very flat and operculinid *N. tournoueri-bouillei* might be the last surviving *Nummulites* species in the Aquitaine basin, since it has recently been reported by BUTT (1966, pl. 8, fig. 19—21) from the Late Oligocene deposits of Escornebéou, together with *Lepidocyclina morgani* and *Miogypsina complanata*.

Regarding the Upper Eocene of Biarritz, it may finally be remarked that already DE LA HARPE (1879) mentioned the presence of *N. variolarius*, the only nordic species that has been frequently cited from Middle-Upper Eocene deposits of the Mediterranean region.

One might expect that the Eocene-Oligocene suite of smaller radiate species of, for instance, Biarritz, would be related to, and therefore morphologically hardly different from, the nordic group of species, notwithstanding the completely different names. Actually, some forms have been brought in connection with nordic forms already by the earlier authors. More recent examples are *N. boucheri* and *N. germanicus* by LANTERNO and ROVEDA (1957), and *N. tournoueri* with *N. germanicus* and *N. prestwichianus* by CURRY (1966).

Another flat species of Europe is *N. budensis* HANTKEN (1875, p. 85, pl. 12, fig. 4) from Hungary, which equally shows great similarity with nordic forms, but which has never been restudied on the basis of ample topotype material.

Recently described forms from the Soviet Union (GOLEV, 1962) again seem to form a similar group. The new taxonomic units *Neooperculinoides vialovi*, *Nummulites languidus* and *N. chavannesi* subsp. *planus* are all radiate species, reported together by GOLEV with *N. prestwichianus* and *N. orbignyi*. All these forms of Turkmenistan show a protoconch of considerable size, ranging from 120 to 250 μ. Also the Ukrainian forms, with new species *N. concinnus* and *N. paravariolarius*, described by JARZEVA (1960), are probably related, but as yet not well comparable with our data.

Chapter VI

METHODS OF INVESTIGATION

With the heterogeneous data on the various described species at hand it was tried to predict which of the evolutionary trends reported elsewhere (e.g. SCHAUB, 1963) might be applicable to the nordic forms.

1. Increase in size of the test. This may be true in a general sense for the microspheric generation. For the A-forms, however, there is very little indication in this direction to be found in the earlier descriptions. All megalospheric tests are reported to be small. Moreover, several authors express the opinion that we are dealing with a degenerating stock, which implies that increase in size could hardly be expected. Finally it may be emphasized that transport of the individuals, either during life or after death, or both, which in our opinion was frequently the case in our sandy material, should have influenced by sorting the maximal and the average size of the test in the assemblages.

2. Decrease in relative thickness of the test in the course of time. At least for the described Belgian forms such a rule seems to be roughly true. However, it is clear from CURRY's description (1937), that this does not hold true for the English succession from *N. variolarius* via *N. prestwichianus* to *N. rectus.*

3. Increase in the degree in which successive whorls become higher. This may be seen as a feature that is probably somehow correlated with the decrease in relative thickness of the test. As a consequence there is no need to be surprised that the later Belgian species have laxer whorls than the earlier ones.

4. Increase in diameter of the protoconch in megalospheric specimens. Such a trend is not apparent from the older descriptions. If we should have to include the French forms of *N. variolarius* from Auvers in the group of North Sea species, it is, as a general rule, likely to be invalid.

5. Changes in whatever way in the shape of the individual chambers in median section. Several differences have been reported, such as in relative height of the chambers, and in shape of the septa. All the resulting chamber types are intergrading and all show a similar pattern. Several types even occur in a single individual. There seems to be little possibility of recognizing an evolutionary change in pattern. No other changes have been reported in the literature than those which seem to go together with changes in the laxity of the spirals.

6. Changes in the number of chambers per whorl. Again no clear trend was apparent before the investigation had to start.

7. Changes in the relation between the thickness of the marginal cord and the height of the underlying lumen of the chambers. In *N. variolarius* of Auvers the relative thickness of the marginal cord is reported to be large, whereas it is smaller in the younger and more nordic forms.

In the evaluation of all these features and their possible changes in the course of time, we have to be aware that differences of environment could have played a part, even if genetically based trends were present. Both the trends and the environmental influences might have acted on the ultimate measurable results of the individual features. Recently some authors have claimed that size and thickness of the test could be a function of environment, expressed by these authors mainly in sediment types.

According to VEILLON and VIGNEAUX (1960) flatter *Nummulites* types would be favoured by calcareous-sandy environments, whereas lenticular forms occur preferentially in marly-calcareous sediments, globular types in rather marly-sandy deposits. The delimitation of these sediment types and that of the *Nummulites* types are equally vague. All forms would decrease in numbers with the increase in clayey admixture. POMEROL (1961) gives an example in which increase in the clay content in the sediment coincides with a decrease in size of *N. laevigatus* individuals. For the younger *Nummulites*, however, he does not show any relation. NEMKOV (1962) visualizes his ideas by giving an idealized cross section that shows bigger forms in shallower sandy and calcareous deposits, smaller ones in deeper clayey sediments. The forms of calcareous deposits would be bigger and flatter than those of the sandy material, which is not in so very clear agreement with the observations of VEILLON and VIGNEAUX.

Evidently environmental influences on size and relative thickness of the test are suspected, but authors give as yet no uniform relation. The sedimentological data of our own assemblages are certainly not better, so that no clarification of the environment-*Nummulites* relation may be expected from our data.

For the investigation of our material it had to be decided which features were to be chosen to be measured or counted. We aimed at some 50 observations per feature and per sample. Since this would involve a tremendous lot of work a careful choice was made amongst the possible measurable characteristics. Those features were to be chosen from which a change with time could be expected. Another factor that influenced our choice concerned the amount of possible bias. The chance of subjective interpretation of the characteristics should be minimized, because the gathering of the data had to be done by many people, most of whom were unfamiliar with *Nummulites*.

Most of the observations were to be based on median sections and consequently the material was prepared by splitting. Fortunately the specimens were sufficiently well preserved to allow splitting by means of the heating-cooling method, thus avoiding the time consuming sectioning process. The splitting was done by heating the available specimens of a sample on a simple stainless steel spoon over a Bunsen burner till red glow; and then dropping them in a small china bowl filled with cold water. If necessary this process was repeated once or twice. The results were very satisfactory, nearly all specimens splitting almost invariably along the marginal cord of successive whorls. After decantation of the water the halves were then picked at random and mounted in a Chapman-slide, each half being glued in one of the numbered compartments. The whole process of picking and mounting of about sixty halves from one sample took a few hours.

Most of the specimens proved to be hollow, or they contained a filling of clay or pyritous matter, which could be easily removed with brush or needle if necessary. Calcite filling was occasionally present, but this did not seriously impede either the splitting or the measuring.

Measurements were taken with Leitz Greenough binocular microscopes with ocular micrometers of 10 mm subdivided into 200 parts. After checking it appeared that measurements made with different microscopes did not differ notably.

Standard forms were used for recording the measurements and counts per numbered individual, following the numbers in the Chapman-slides.

The following parameters were chosen and recorded (see also figure 6):

A. The largest diameter in microns of the half test. This measurement was made only from undamaged, or only slightly damaged specimens.

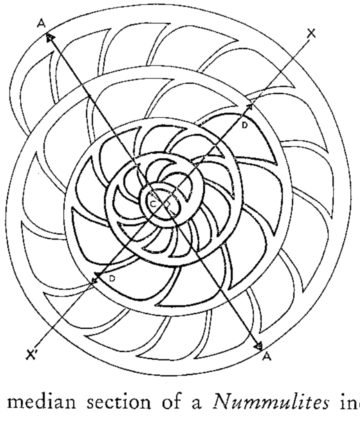


Fig. 6. Schematic drawing of a median section of a *Nummulites* individual to show parameters A, C, D and E (E = 19).

B. The largest thickness in microns of the half test. This was done only for specimens with measurement of A.

C. The inner diameter of the protoconch in μ, measured along a line through its centre, at right angles to the line X—X′, which goes through the centres of protoconch and second chamber.

D. The outer diameter of the first two coils in microns, measured along the line X—X′.

E. The number of chambers composing the first two whorls, up to and including the last one whose base is cut by the line X—X′, and excluding from the number the protoconch and second chamber.

A and B were chosen, not because anything was expected from their absolute values, but because A/B, or rather 2B/A would give a measure for the relative thickness of the test. This last ratio was deemed necessary to compute because the first reconnaissance gave the impression that this ratio would change in the course of the development of the group.

The internal features expressed in C, D and E were chosen partly because of the relative ease of measuring and counting, so that no notable differences were to be expected between the results of different persons.

The choice of C is self evident, since the size, or rather the diameter, of the protoconch is considered to show a steady increase in the evolution of the various Mediterranean lineages of *Nummulites* (Schaub, 1963). The inner diameter was thought to be slightly better measurable than the outer diameter.

Measuring of D may meet with more criticism, because it is not comparable with data from the literature. However, there are distinct advantages of our way of measuring. The absolute values of this parameter enable comparisons being made between individuals or assemblages at seemingly equal ontogenetic stages. Hence, D is a factor independent of mechanical sorting agents, which might have influenced the means of A and B. It might be argued that three whorls would have given better results than two, but here the small size and the frequent damage of already the third coil, necessitated the restriction.

In itself D may not be seen as a pure expression of the relative increase in height of successive whorls. For this we should have measured the successive whorls separately, which would have caused a much greater amount of work. Actually some measure may be found in the comparison of D and C. D/C may be considered an approximation of the degree of laxity of the spire.

Finally the E counts give results of another parameter, which can immediately be compared because they reflect again a definite ontogenetic stage, which is the same for all individuals. E is related to the number of chambers per coil or per $\frac{1}{4}$ or $\frac{1}{2}$ of a coil, as found in the literature. Our data are not well comparable with those of earlier authors which were commonly based on the third or later convolutions. The reason for this deviating method is the same as for D, the small size of most individuals. Of course, it is not true that E values give a direct idea about the height/width relation of the individual chambers, though in practice a high value usually corresponds with relatively narrow, high chambers, a low number with relatively broad and low chambers. Actually, the relation between D/C and E would give a much better indication of the relative height of the spiral chambers.

The shape of chambers and septa appeared extremely difficult to express numerically. Several methods were tried, but they appeared to give very inexact results, to be rather time consuming, and too hard to employ by many people. After some experiments they were thought not to give data of real importance for our material, for which reason these measurements were abandoned.

Also the relation between the height of the marginal cord and the height of the coil was not computed, because it would have involved the measuring of another two factors, whereas the chance of ultimate results of real importance was thought negligible. Observations were kept at the qualitative level. The same was done for the evaluation of the central pillar, granules or septal sutures. They are not recorded because the observations appeared unsystematic and seemingly meaningless.

As a result, data were assembled for evaluation of possible trends mentioned in the beginning of this chapter under 1, 2, 3, 4 and 6, whereas those of 5 and 7 were abandoned from the onset. For the latter a qualitative test was considered sufficient if results of the other parameters would give an idea of trends.

The observations were primarily made on a sufficient number of megalospheric individuals. In many samples the number of 50 observations could not be obtained; they are dealt with just as well. Also with sufficient numbers the total of the observations shows considerable variation for various reasons. Occasional samples yielded considerable numbers of B-forms, which were measured as well, but these measurements are not dealt with. Because of the extremely small size of the primordial chambers in B-forms, observations of C, D and E are of dubious value. Generally the earlier authors extensively described the external features of these microspheric individuals, so that we saw no reason to repeat them.

The observations on the standard sheets were frequently compiled in histograms and scatter diagrams, some of which figure in the following chapters. For all measured features means were calculated per sample, in many cases with their corresponding standard errors. Also these means were plotted in scatter diagrams. Ranges, means and standard errors are given in the tables, reproduced in the appendix.

Since it appeared impractical, or at least too expensive, to print all standard sheets, many details remain obscure in our paper. The Chapman slides and the forms are stored in the micropaleontological collection of the Geological Institute of the State University of Utrecht, and they are available for future brain-waves of other micropaleontologists.

Chapter VII

VARIATION IN INDIVIDUAL SAMPLES AND MEANS OF SINGLE FEATURES

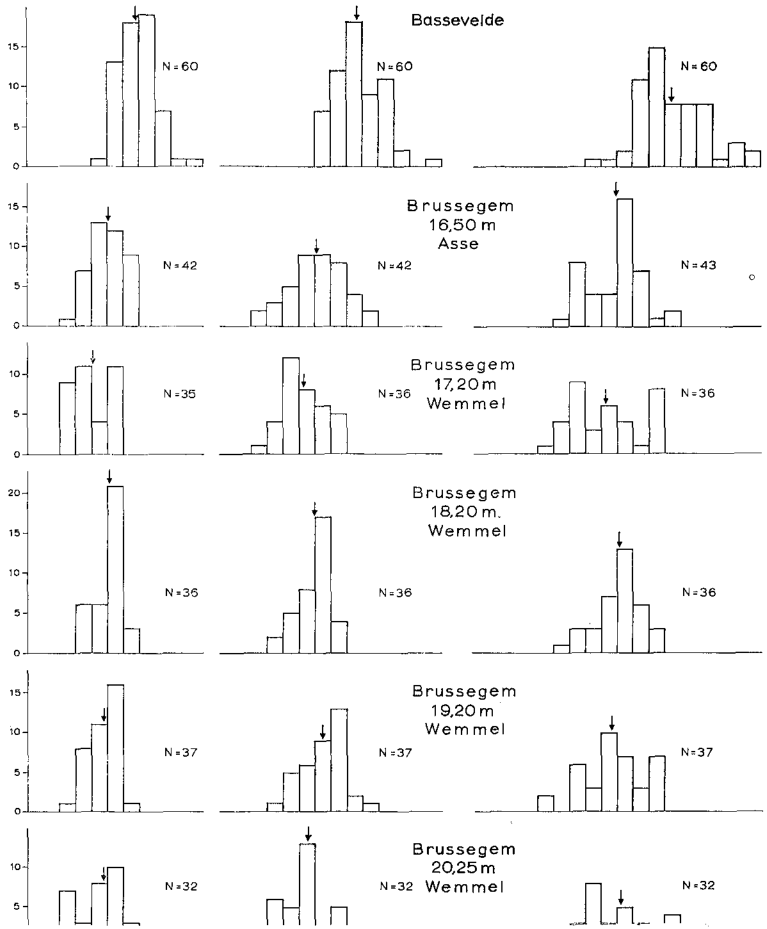
First of all we have to consider the influence of bias on the results of counts and measurements. For three samples a double set of observations was available, for each sample gathered by two different persons on the same material. The results are quite instructive and considered sufficient as an estimate of possible bias.

Measurement of A, the diameter of the test, evidently was free from bias. The ranges recorded are only slightly different and the means are practically identical. This is certainly not the case with B, half thickness of the test. Evidently measuring of halves, put on edge, allowed for widely diverging observations, probably due to insufficient experience of part of the observers. Anyhow, maximum and minimum values of the range show systematic shifts, and so do the means. The minimum difference in one pair of means is some 10 % of the smaller value, the maximum, however, as much as 35 %. Since in the latter case we are dealing with very thin individuals of large diameter it is thought that such a deviation of 35 % may be considered extreme. Actually, in smaller and thicker individuals the difference appeared smallest. Of course these different records strongly influence the calculated values of 2B/A, of which only the means have been entered in the appendix ($\overline{2B/A}$ with its standard error, and $2\overline{B}/\overline{A}$). For two of the samples the difference between $\overline{2B/A}$ values amounts to some four times the standard error, in the most aberrant example, however, it is as much as 40 % of the smaller value. It should be remarked that this "thin" assemblage remains extremely thin even when this enormous impact of bias is included.

Anyhow, we have to be very careful in our conclusions on the average relative thickness of the tests. If we consider the possibility of deviation of some 20 % because of bias during the observations, this is considered to provide a sufficiently safe margin to give reliable comparisons.

As to the internal features C, D and E, especially the counts of the latter number appeared to show no serious differences in all three cases. The maximal difference in one set of $\overline{E}$ values amounts to less than 1.5 times the standard errors of the means.

Measurements of D give some differences in range, but differences in means are again less than 1.5 σ_M. For C, however, the results are more variable. For one sample there was no notable difference, but for the other two there are



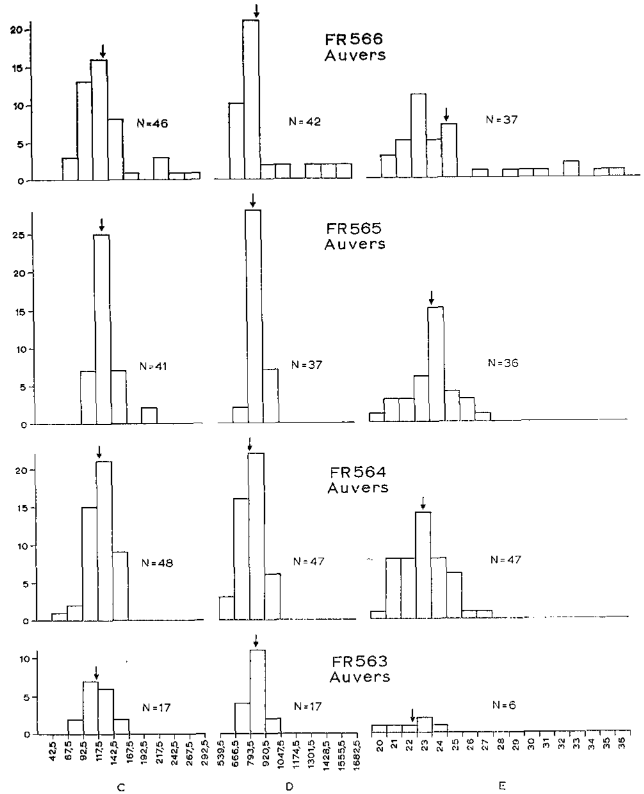


Fig. 8. Histograms of C, D and E values of the measured *Nummulites* individuals from four samples in stratigraphic order from the Sands of Auvers at Auvers-sur-Oise.

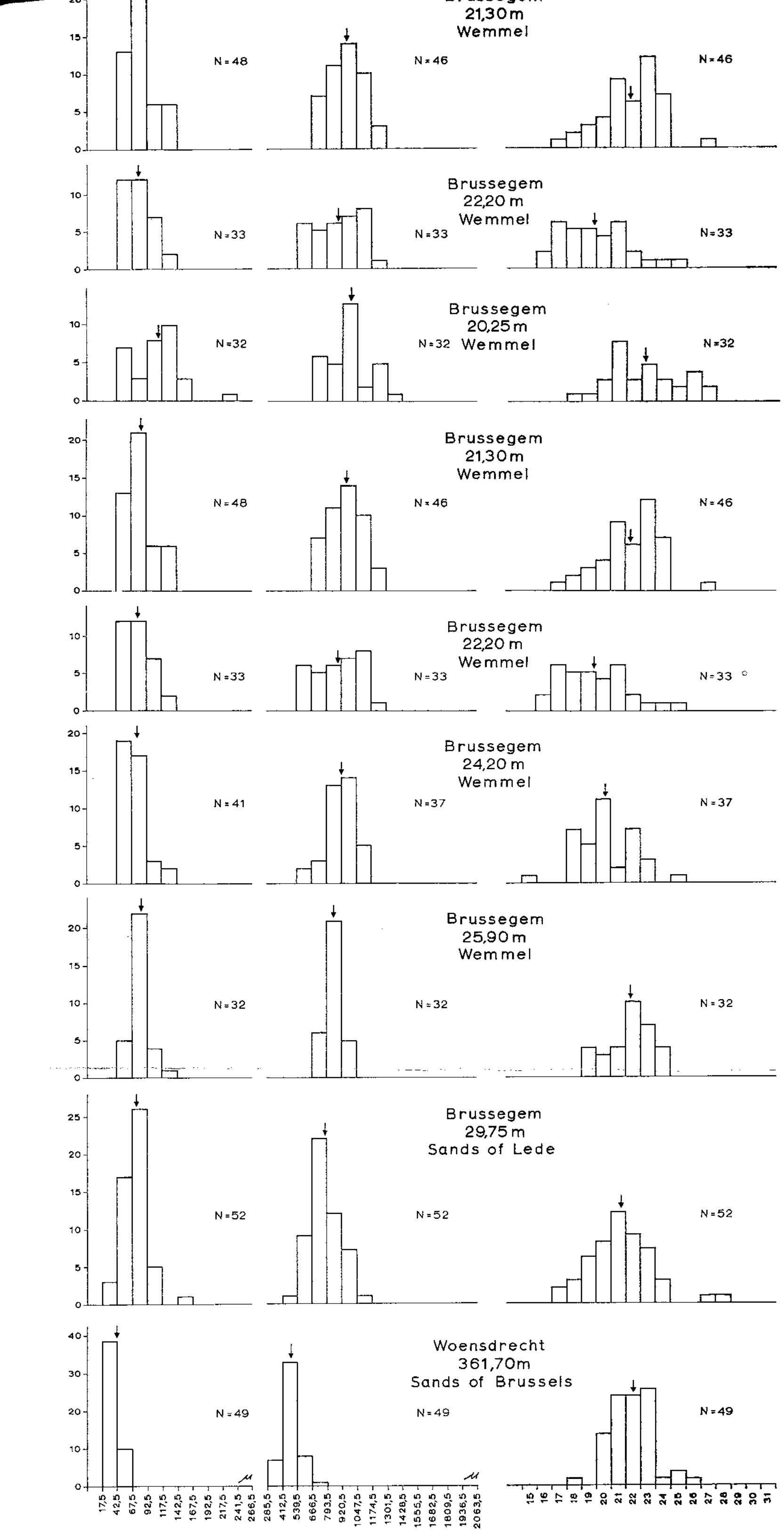


Fig. 7. Histograms of C, D and E values of the measured *Nummulites* individuals from sample Woensdrecht 361.70 m, the ten Brussegem samples and that from Bassevelde.

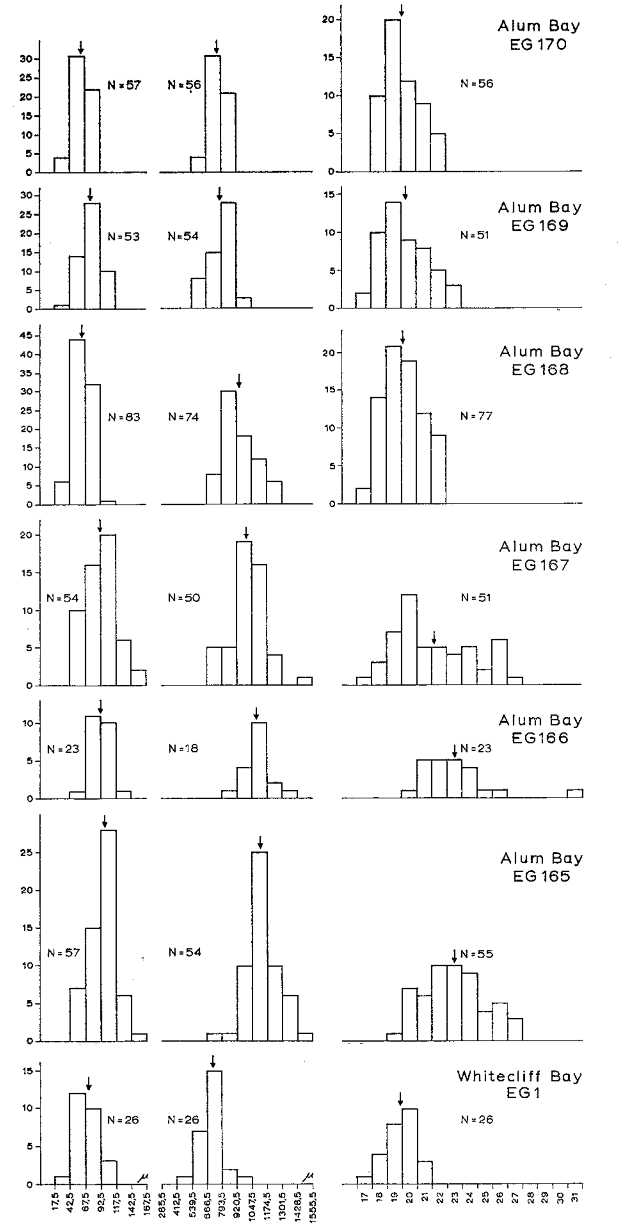


Fig. 9. Histograms of C, D and E values of the measured *Nummulites* individuals from sample EG 1 at Whitecliff Bay and six samples in stratigraphic order from the Lower Barton Beds at Alum Bay, Isle of Wight.

more considerable systematic differences. In one case it amounts to 3 σ_M, in the other to as much as 6 σ_M. In the latter case the source of the error could be traced: one of the investigators had measured along the X—X′ line instead of measuring at right angles to the line. He arrived at distinctly lower values.

As a whole it is considered correct to estimate the usual range of $\pm$ 2 σ_M of the means to be sufficient for safe conclusions, unless we would be dealing with conclusions based on a difference with one mean or a very small number of them.

For one sample (BG 48, Wemmel) two sets of individuals were dealt with by two persons. The differences between the pairs of means were well within the limits outlined above. Only in the measurements of B systematic differences are probably due to bias. Both sets of means have been entered in the scatter diagrams of the next chapter.

Since most of our following conclusions will be based on mean values of the parameters it was checked whether the assemblages were tolerably homogeneous. Also a superficial check was made on the relative skewness of the distributions.

Only for one sample was it clearly evident that it consisted of a mixture of two different populations. In the Woensdrecht boring at a depth of 361.70 meters two groups of over 40 individuals each, show distinctly different means and commonly well separated ranges for all features. Most striking is the difference in protoconch diameter with means of 35.8 μ (range 25—63 μ) and 424.3 μ (range 241—584 μ), which range difference suffices for the assignment of every encountered individual to one or the other group. The sample was derived from the Sands of Brussels, and not from its base either (KAASSCHIETER, 1961), so that reworking may be considered unlikely. The smaller forms belong to the so-called *N. variolarius* group, the bigger ones are distinctly unrelated to all others, one of the reasons being their very high $\overline{C}$ value and very low $\overline{D/C}$ value of 4.61. This group probably belongs to what is called *N. laevigatus* in the literature.

Heterogeneous character of all other assemblages is hard to prove. Nevertheless, the assemblages do not invariably show unimodal curves, and mixtures of somewhat different populations may sometimes be suspected.

No special attention was paid to the variation of the diameter of the test. As may be seen in the appendix from the position of the mean relative to the extremes of the range of A, most curves will be somewhat skewed, with the mode towards the smaller individuals. This is probably without any significance, because of the fractioning of the wash residues (*Nummulites* of the smallest not being considered) and our negative selection as to very small individuals because they do not show sufficient numbers of whorls to measure a D value. Maximal values of A show a tendency to increase towards younger strata, but the individuals rarely reach 3 millimeters. Also there is a trend towards greater $\overline{A}$ values, to be dealt with in the next chapter.

More attention was given to the frequency distributions of C, D and E, because these features should be free, if not from all environmental influence, at least from sorting agents during life or after death. Because some samples were known to show rather peculiarly irregular curves, it was tried whether heterogeneous assemblages could be sorted out by means of the coefficients of variation. This coefficient was calculated for E in some twenty examples. V values showed a variation from 5 to 15, with the irregular curves rather irregularly distributed in this interval. These high V values are probably due to the fact that many curves, though more or less normal, are rather flat. Relative to this influence the effect of the irregularity of curves is evidently insufficient.

To visualize the shape of the curves and the changes with time they are figured for three of the continuous stratigraphic sections with four or more samples in unmistakable superposition. For C and D we rather strongly reduced the number of classes, which were kept the same for all histograms. In contrast, each unit of the E scale has been entered separately, thereby causing too high a number of classes with respect to the numbers of observations. As a result the histograms of E often get a ragged appearance which has no significance.

In figure 7 the C, D and E histograms are pictured for the ten assemblages from the Belgian boring Brussegem, ranging from Sands of Lede below, upwards to the base of the Asse Clays. At the bottom of this suite a distinctly older assemblage from the Sands of Brussels (Woensdrecht 361.70 meters) has been added, and on top a distinctly younger one from the Sands of Bassevelde ("Lower Tongrian") of its type locality. These two additional samples suggest a general change of all parameter values with time, increase of C and D and possibly of E. It should be kept in mind, however, that these additional samples are rather extreme in their respective age groups. Both in the oldest and in the youngest strata, Sands of Brussels and "Lower Oligocene" respectively, we may choose other assemblages that rather confirm the picture of the ten Brussegem samples: that of a pattern fluctuating in time for all three parameters.

At Brussegem some increase in C and D may be concluded from bottom to top, but it is not very convincing. The E histograms do not allow any suggestion of trend.

The histograms of C and D are tolerably normal, without clear preference for positive or negative skewness, which appreciation is further supported from C and D histograms (not figured), in which we shifted the classes with half an interval. In some samples there is a suggestion of a heterogeneous assemblage (17.20 m and 20.25 m). If true, various explanations are possible, of which washing together of representatives of different populations — either of equal age or heterochronous — may be most plausible because of the character of these sandy shallow marine sediments (see KAASSCHIETER, 1961).

The same types of histograms and a similar fluctuating pattern if put in stratigraphic order, are demonstrated by the assemblages of both other Belgian borings, Asse and Mechelen, for which reason they are not reproduced in separate figures (see also next chapter).

The four successive samples from Auvers in the Paris basin (figure 8) show quite regular histograms for the lower three samples, but a very strange frequency distribution for all three parameters in the topmost one (calculated V highest of all: 15.7). In this upper sample the curves of the lower three samples are repeated, but there is a distinct tail of 5 to 8 specimens towards the higher values in all three histograms. No definite cluster of such aberrant specimens can be shown, possibly due to the low numbers of observations. Anyhow, these histograms are not the reflection of the usual type of homogeneous population. Reworking of older material would be quite reasonable to expect because of the current-bedded types of sediments at Auvers, but the aberrant forms would not compare nicely to, for instance, a random group of *N. laevigatus* individuals of France (see BLONDEAU, 1965) or to a group of our Woensdrecht population, because of too low C values. We might just as well be dealing with aberrant morphotypes of *N. variolarius,* the species we expect at Auvers, which might be given a separate name, e.g. *N. ramondiformis.*

Finally, figure 9 shows the histograms of C, D and E of six successive assemblages from the Lower Barton Beds at Alum Bay in the Isle of Wight, with the assemblage of EG 1 from the Upper Bracklesham Beds of Whitecliff Bay added at the bottom. Although of rather different width all histograms show a fairly normal pattern without suggestions of mixtures of populations. It may be noted immediately that all three parameters show decreasing values from bottom to top in the Alum Bay section. The topmost ones again strongly resemble those of the oldest sample EG 1 from Whitecliff Bay.

Regarding all material we may consider our assemblages as tolerably homogeneous, even though in some we suspect that individuals of morphologically adjoining or somewhat different populations have been mixed. The frequency distributions are commonly not strongly skewed, and certainly not systematically so, either positive or negative. Therefore, it is considered acceptable to use mean values of C, D and E in our further comparison of the samples and assemblages. Some additional care has to be taken regarding possible conclusions based on single samples or on too narrow an interpretation of significances based on standard errors.

Evidently there are no clear evolutionary trends in C, D and E that are valid for all nordic *Nummulites.* Suggestions of increase in all three parameters in the course of time in the North Sea basin, are distinctly contradicted by the successive populations from Alum Bay in the Hampshire basin. We have to expect a much more complex development pattern, if there is a general one at all. Another suggestion seems to be that every basin had its own development of *Nummulites*, and that there are no general rules that would cover all these evolution courses.

Since the histograms suggest that there is some correlation between the internal features C, D and E, we had better consider the trends again on the basis of a bivariate representation of the data in scatter diagrams, which will be given in the next chapter.

Chapter VIII

TRENDS BASED ON THE COMBINATIONS OF MEANS

As might be expected already from the histograms of figure 7, all scatter diagrams based on the means of parameters show that the data from the four borings in Belgium and the Netherlands (scatter diagrams 12 and 19), are insufficient to demonstrate satisfactorily any trend in the development of the parameters involved.

In broadening the number of data by incorporating all other, single samples of the North Sea basin, we have to take their original stratigraphic assignment for granted, even if reasonable doubt may exist about the position of some of them. Hence in all diagrams the same notation will be given for samples from a stated stratigraphic unit. These stratigraphic units (with the number of samples between brackets) are:

△ "Lower Oligocene" (3)
× Clays of Asse (8)
□ Sands of Wemmel (19)
○ Sands of Lede (12)
▽ Sands of Brussels or Sands of Vlierzele (4).

For the samples of the other basins the symbols are:

× Oligocene Biarritz, Aquitaine basin (2)
× Sands of Auvers, Paris basin (4)
○ Barton Beds, Hampshire basin (13)
◆ Upper Bracklesham Beds, Hampshire basin (1).

After the analysis of the data, assemblages from ten additional samples were measured and counted as a check on the assumed general results. These samples (see locality details in chapter II and further remarks in chapter IX) have been entered in the scatter diagrams as well, but with different symbols. For the North Sea basin they are:

▲ "Lower Oligocene" (1)
⊗ Clays of Asse (3)
■ Sands of Wemmel (1)
● Sands of Lede (1).

For the French basins they are:

⊠ Upper Oligocene Escornebéou, Aquitaine basin (2)
⊗ Sands of Auvers (1)
■ "Upper" Lutetian, Fercourt, Paris basin (1).

Altogether 76 samples have been analysed. The following discussion was primarily based on the results of the first set of 66 samples. Remarks on the ten check samples are added if they amplify the general picture. A discussion of the results from these check samples is given separately in chapter IX.

Amongst the samples from the Barton Beds three were treated twice (see previous chapter), and the results of both sets of observations have been entered in some of the scatter diagrams (with broken lines between the points).

In all scatter diagrams lines connect samples from the same boring or the same outcrop, in stratigraphic order. The direction from bottom to top in this order is indicated by arrows.

In some of the scatter diagrams crosses are given as an average estimate of $\pm\, 2\, \sigma_M$ of the means involved.

Relative thickness of the test

If we consider the relation between $\overline{A}$ and $\overline{B}$ of all North Sea assemblages (figure 10) we get the impression of no correlation at all. Especially if we leave out the means of both samples with very small *Nummulites* from the Brussels Sands of Woensdrecht, we get a fairly homogeneous cluster with minimal cor-

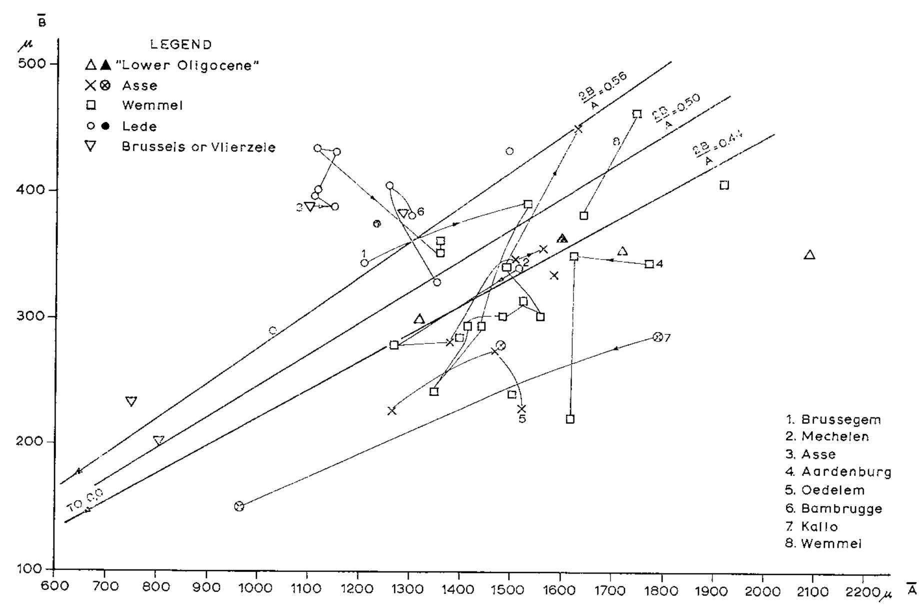


Fig. 10. Mean values of test diameter and thickness for the *Nummulites* assemblages of the North Sea basin.

relation. Most averages of the diameter range from 1 mm to 2 mm, and the relative thickness $\overline{2B/A}$ varies between 0.275 and 0.785. Within the given, restricted range of test size, increasing values of $\overline{A}$ are not accompanied by evident increase, decrease or stability of $\overline{B}$.

Yet the distribution of the samples with respect to relative age is not haphazard. If we draw the lines 2B/A = 0.56 and 2B/A = 0.44, we get three fields with difference in relative thickness. It now appears that values of $\overline{2B/A}$ greater than 0.56 are found in 13 samples, all belonging to the lower stratigraphic units: Sands of Lede, Brussels and Vlierzele. On the other hand, 20 samples with values smaller than 0.44 all belong to the higher units from Sands of Wemmel to "Lower Oligocene". In the area in between both these lines 13 samples have been plotted, three of which from the deeper units, and 10 from the higher ones.

If we draw the line 2B/A = 0.50 we get the following numbers of samples with respect to this line and to their relative stratigraphic position.

$\overline{2B/A}$	>0.50	<0.50	total
Lede and older	14	2	16
Wemmel and younger	5	25	30
total	19	27	46

We may assume, as a hypothesis, that mean relative thickness of the test as expressed in both categories divided at the value 0.50, is independent of the stratigraphic position of the samples. A chi-square test then informs us that the distribution found cannot be due to random sampling. Significant deviation from the hypothesis of independence has a probability far greater than 99 %. All the available check samples strengthen this conclusion.

Evidently there is an overall decrease in mean relative thickness of the test from the lower stratigraphic units to the higher ones. No further conclusions can be drawn. For instance, we cannot further differentiate between the groups of samples from the three higher stratigraphic units separately.

This general conclusion does not mean that we can place a single sample stratigraphically into one of both groups of lithostratigraphic units on the basis of its $\overline{2B/A}$ value. The above table shows the presence of quite a number of exceptions, and on the basis of these data an assumption that one out of three means below 0.50 might correspond to an assemblage from the Sands of Lede group of formations, cannot be ruled out. In our opinion such a chance of error and incorrect age assignment would not be acceptable to any stratigrapher. Moreover, we should be very skeptic about the reliability of a single mean. Especially our measurements of B are very rough, not without bias, shown to be very different from one investigator to the other. And there is no basis to evaluate the means because standard errors seem to be of dubious value. There is no theoretical need that normal distributions underlie the total of A or of B values per sample. The latter type of distribution may also be doubted for the values of 2B/A, as may be seen below.

The valid conclusion seems to be that $\overline{2B/A}$ values of all North Sea samples form a homogeneous group in the scatter diagram without dependence of $\overline{A}$ on $\overline{B}$, or reverse. In this group of North Sea *Nummulites* the mean relative thickness of the test shows a decrease with time, i.e. there is a trend towards thinner tests. This is of little practical stratigraphic value for single samples, though in the literature the relative thickness of the test has been used as the primary feature for specific determination of the North Sea *Nummulites*, on which in turn the stratigraphic assignment of deposits was based.

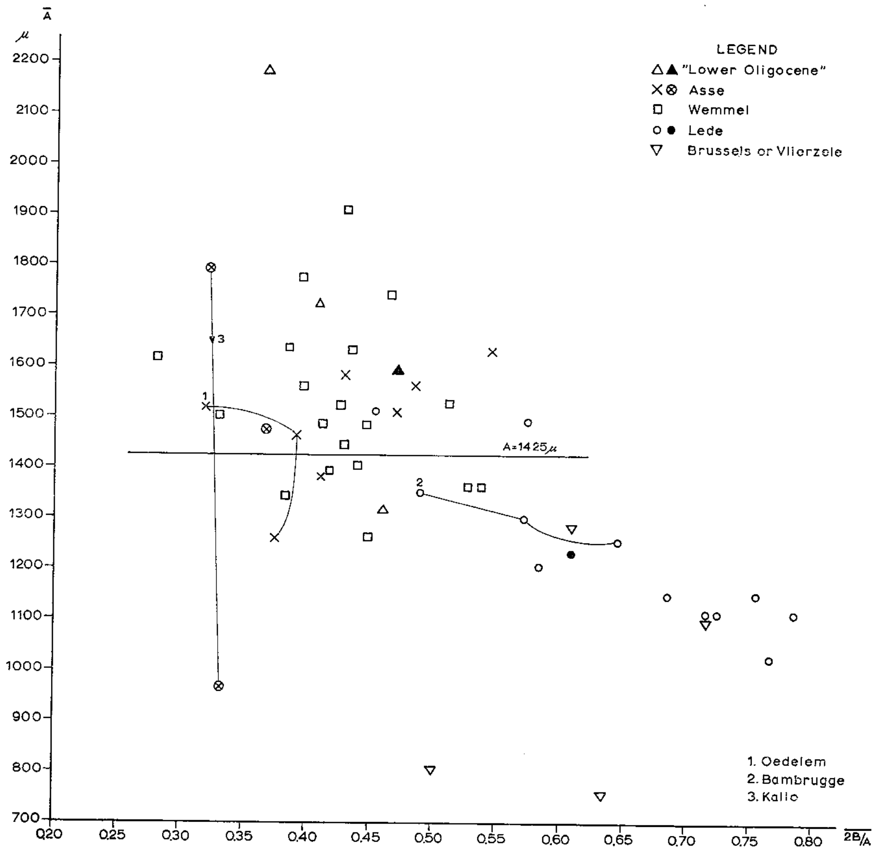


Fig. 11. Mean values of relative thickness and diameter of the test for the *Nummulites* assemblages of the North Sea basin.

Relation between the relative thickness and the diameter of the test

The relation between $\overline{2B/A}$ and $\overline{A}$ for all samples of the North Sea basin is shown in scatter diagram 11. Again both samples from Woensdrecht (and the check sample from the Kallo boring at 178 m) are somewhat apart because of the very small size of their individuals, but as a whole the cluster is fairly homogeneous, elongate, and a negative correlation is suggested. The correlation coefficient calculated from the means of all 46 samples amounts to —0.628, which means that it is of distinct significance.

In other words, within the group there is a tendency for the mean relative thickness to be smaller with a greater mean diameter of the test, and reversed. The scatter diagram of figure 12 shows that the data of the four borings separately, suggest but a slight stratigraphic value of this relation.

Here, it becomes worth while to see whether such a negative correlation between relative thickness and diameter is equally valid for the individuals within single samples. For three of the samples, derived from different strati-

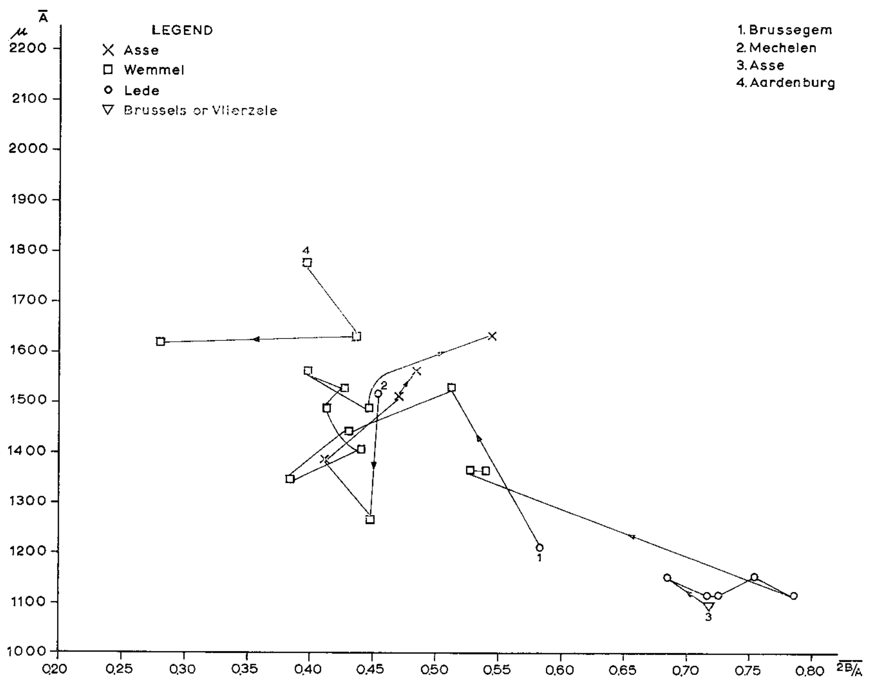


Fig. 12. Mean values of relative thickness and diameter of the test for the *Nummulites* assemblages of the borings Brussegem, Mechelen, Asse and Aardenburg III. Arrows point to the higher samples.

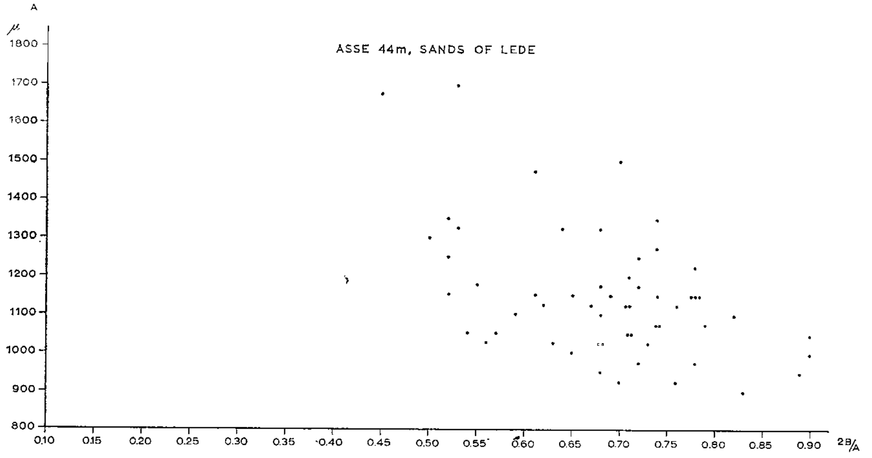


Fig. 13. Relative thickness and diameter of the test for the *Nummulites* individuals from sample Asse 44 m, from the Sands of Lede.

graphic units, the relation between A and 2B/A is given in figures 13—15. All three scatter diagrams show that there is a weak negative correlation between both parameters, similar to that found for the means of all samples. It is very clear that especially the individuals with extreme diameter (e.g. fig. 13 and 15) visualize the negative character of the correlation. Notwithstanding the very wide scatter, growth lines with a negative trend might be constructed for all three of the samples. These growth lines would be roughly parallel.

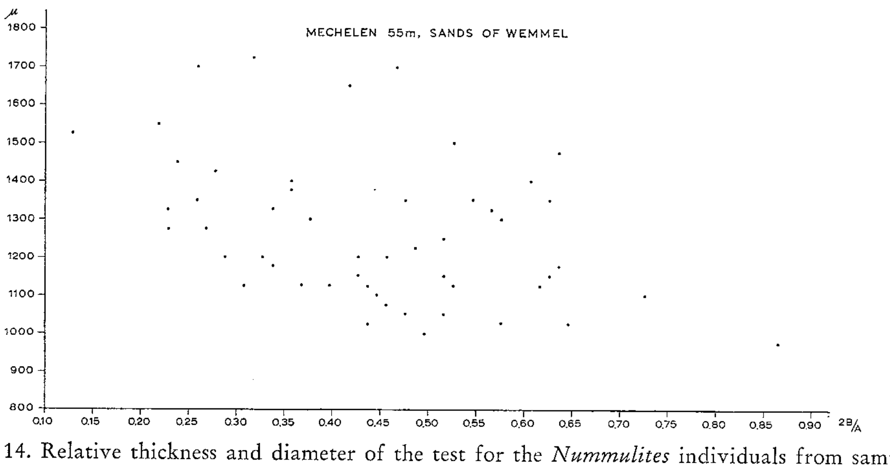


Fig. 14. Relative thickness and diameter of the test for the *Nummulites* individuals from sample Mechelen 55 m from the Sands of Wemmel.

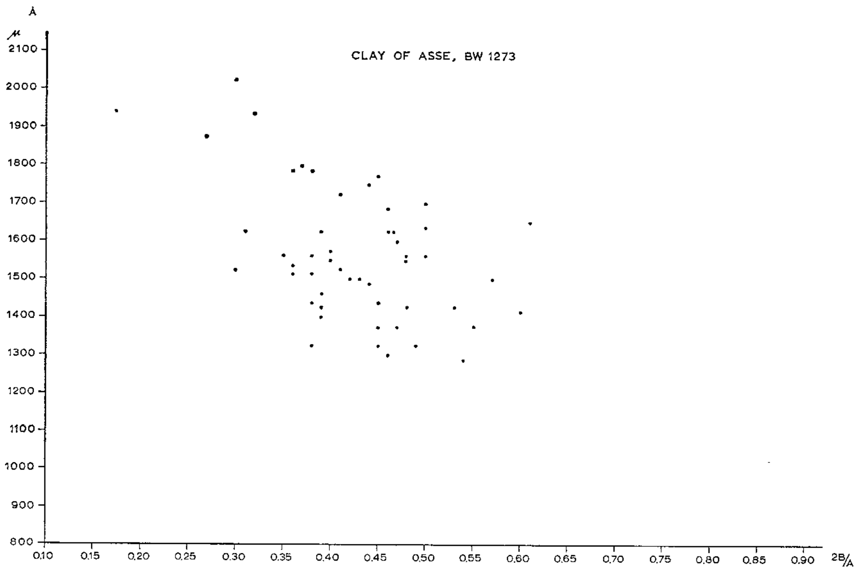


Fig. 15. Relative thickness and diameter of the test for the *Nummulites* individuals from sample BW 1273 from the Clay of Asse.

During ontogeny the individuals evidently tend to grow faster in a radial sense than they do in thickness. Although it is sometimes weak this tendency is manifest throughout the group, and as a consequence it is reflected in the $\overline{2B/A}$ to $\overline{A}$ scatter, because different samples (e.g. those of diagrams 13 to 15) occupy different parts of the entire field. Actually the wide variation shown in figure 14 gives an overlap with the scatter fields of figures 13 and 15, in which the groups of individuals are farthest apart.

The values of $\overline{A}$

So far we hardly included time relations in our discussion of the negative $\overline{2B/A}$ — $\overline{A}$ correlation, but because we find this correlation to be dependent on growth of individual tests, we now become suspicious about the stratigraphic implication of the $\overline{2B/A}$ decrease with time shown earlier. Are the $\overline{A}$ values independent of the stratigraphic units, i.e. of time? If not, the stratigraphic value of $\overline{2B/A}$ becomes more dubious.

For a rough test we split the group of $\overline{A}$ values at a median value of 1.425. We then get the following distribution with respect to size and age.

	$\overline{A}<1.425$	$\overline{A}>1.425$	total
Lede or older	14	2	16
Wemmel or younger	9	21	30
total	23	23	46

Again the hypothesis that $\overline{A}$ is independent of both larger stratigraphic units has to be rejected. The chi-square test gives a probability of over 99 % that the distribution found cannot be due to a random sampling effect, but the data show that there is a general increase in test diameter from the Brussels-Lede units below to the Wemmel Sands and higher units. Again $\overline{A}$ values of single samples are of little use for stratigraphic conclusions, because of the great number of exceptions.

Because of this trend of increase in $\overline{A}$ with geologic time and because of the negative $\overline{2B/A}$ — $\overline{A}$ correlation, the $\overline{2B/A}$ trend towards lower values loses still more of its value. We may expect from these relations to find a decrease in $\overline{2B/A}$ roughly to go together with the general increase in $\overline{A}$ in stratigraphic order of samples. Actually, this seems to be true for the examples of figures 13 to 15 put in stratigraphic order, for the net result of the borings Asse and Brussegem (figure 12), and in the comparison of the groups of samples from Bambrugge (typical Sands of Lede) and from Oedelem ("typical" Asse Clays), seen in figure 11. Because of the many exceptions we need not be surprised that it is not visible in the data from the borings Mechelen and Aardenburg III.

There might have been an evolution in our North Sea *Nummulites* towards greater average size and relatively thinner tests, as the data suggest. But since size may have depended on environmental factors, such as sorting, we have to be very cautious with such an evolutional picture. The observed trends might be due to overall environmental changes in the basin in the course of time, instead of being due to evolution. Our scanty knowledge of the environments during the deposition of the respective stratigraphic units will have to put an end to our discussion. The more so, if we recall that many age (or rather formation) determinations of samples depended primarily on the relative thickness of the *Nummulites* they contained. This completes the circle of reasoning.

External features of the English populations

A first glance at the scatter diagrams $\overline{A}$ — $\overline{B}$ (figure 16) and $\overline{A}$ — $\overline{2BA}$ (figure 17) shows them to be less distinct than the corresponding diagrams for the North Sea *Nummulites.*

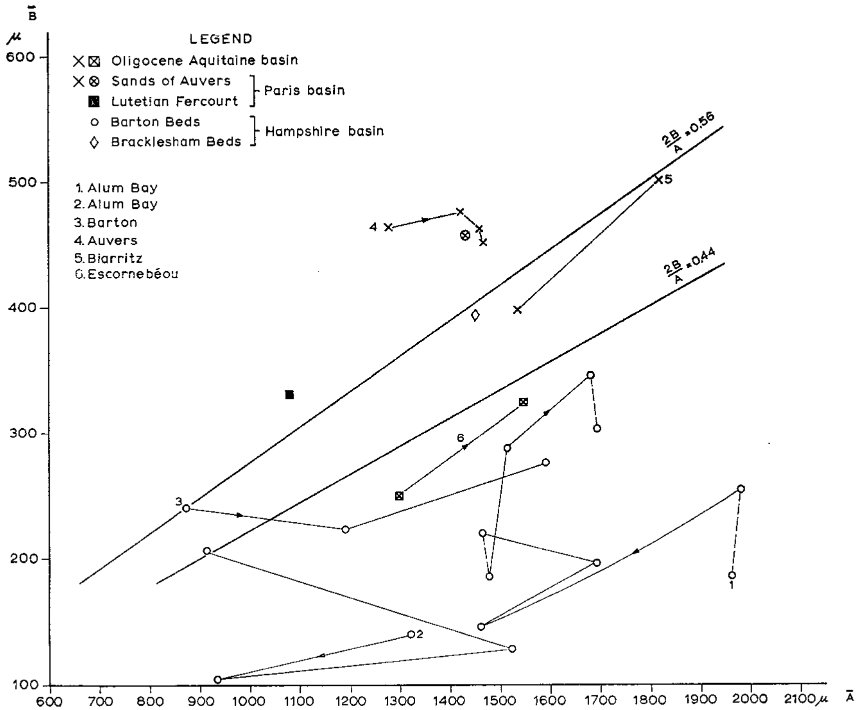


Fig. 16. Mean values of test diameter and thickness for the *Nummulites* assemblages from the Hampshire, Paris and Aquitaine basins.

The English group is formed by 13 samples from the Hampshire basin. The first obvious conclusion of the $\bar{A}$ — $\bar{B}$ diagram is that the samples show a very wide scatter, half their number lying outside the scatter periphery of the North Sea material. The English assemblages are peculiar because of extremely low values for the average relative thickness of the test in part of them. Nearly the entire group is below the line 2B/A = 0.44. In diagram 17 it is still better visible that the assemblages from the lower part of the Barton Clay of Alum Bay contain individuals with very thin tests with $\overline{2B/A}$ smaller than 0.25. In contrast with the general trends towards thinner tests suggested for the North Sea forms, higher populations from the Barton Beds of Alum Bay show greater average test thickness. However, the three samples from Barton itself show the opposite direction of development. For all data together again some negative correlation between $\bar{A}$ and $\overline{2B/A}$ is suggested in fig. 17, but data are certainly too scarce for the peculiar results to be brought in connection with environmental factors. Because of the combination of an average $\bar{A}$ value and a great relative thickness of the test also the single sample from the Upper Bracklesham Beds of Whitecliff Bay does not fit in with the trend of thickening suggested by the assemblages in the supposedly younger Barton Beds of Alum Bay.

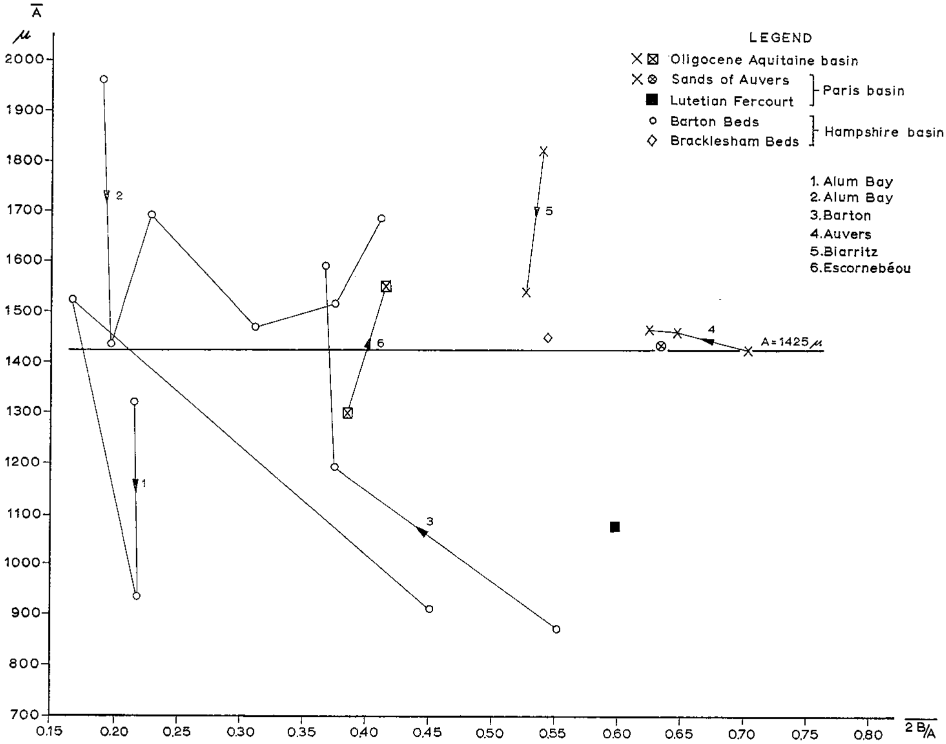


Fig. 17. Mean values of relative thickness and diameter of the test for the *Nummulites* assemblages from the Hampshire, Paris and Aquitaine basins.

If we suppose, because of the homogeneous clusters for the North Sea samples, that all these *Nummulites* belonged to a single stock of closely related forms throughout their stratigraphic range, we have to conclude that the group of populations from the English Barton Beds belonged to a different stock. At least half of the averages found, are plotted outside the range of the Belgian *Nummulites* from the Wemmel Sands and Asse Clays, which units have been considered contemporaneous with, or at least stratigraphically closest to, the Barton Beds. Also the suggestion of a trend towards greater relative thickness in the Barton Beds of Wight (also advanced by CURRY, 1937), which is opposed to the trend in the North Sea *Nummulites*, favours the idea of a separate group of populations following its own way of evolution, unless all differences should be due to environmental factors.

External features of the French populations

In both the scatter diagrams 16 and 17 the samples from Auvers are seen to show little variation. They show a moderate average diameter of about 1.5 mm and a fairly great relative thickness of the test between 0.60 and 0.75. In both diagrams they are slightly outside the scatter periphery of the North Sea samples, but closely adjoining the areas in which we mainly find the populations of the Brussels-Lede group. From the stratigraphic point of view this fits in with the classic correlation ideas which wish to parallelize the Sands of Auvers with the Sands of Lede. However, also the single check sample from the Lutetian of Fercourt correlates well with those of the Lede Sands.

Both samples from the Oligocene of Biarritz have been plotted in the central strip of the $\overline{A} - \overline{B}$ diagram of the North Sea forms ($0.56 > \overline{2B/A} > 0.44$). In relative proportions of the test they cannot be shown to differ from the nordic group. Both samples from the topmost Oligocene of Escornebéou again belong to the group of thinner *Nummulites*, resembling the Asse-Wemmel group of populations in Belgium.

The relation between $\overline{C}$ and $\overline{D}$ in the North Sea basin

The combinations of the mean protoconch size and the mean diameter of the first two whorls are shown for all North Sea samples in scatter diagram 18. The data of the four borings are given once more separately in diagram 19.

The cluster of diagram 18 looks fairly homogeneous with some data slightly remote: both samples from Woensdrecht lower left, three Oligocene ones (Hendrik IV, Kühlerhof and check sample Bassevelde) upper right. Because these samples are extreme also as to their stratigraphic position, they are thought not to disturb the idea of a homogeneous group throughout time and space.

Both diagrams 18 and 19 show that there is distinct positive correlation between $\overline{C}$ and $\overline{D}$. For the data of all 46 samples of our primary investigation the correlation coefficient has been calculated: $r = +0.805$, significant at a nearly 100 % probability level, and with a fairly high degree of correlation.

If we fit with the method of least squares rectilinear regression lines to the cluster, both lines are fairly close together. The drawing of various D/C lines in diagram 18 shows that these lines are oblique to the reduced major axis and to one of the calculated regression lines, whereas the other regression line with direction b_{CD} is roughly parallel to the adjoining D/C lines.

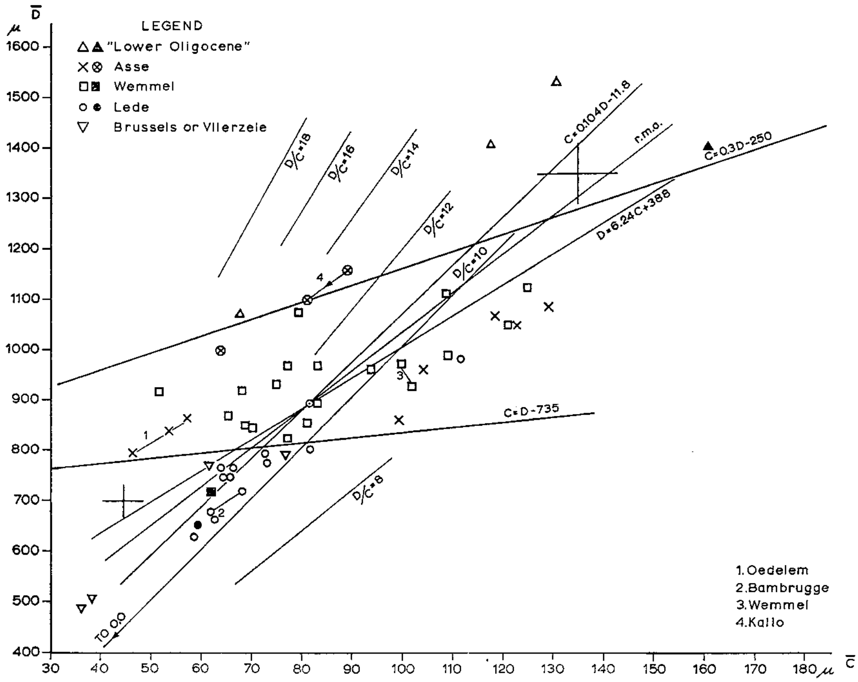


Fig. 18. Mean values of protoconch diameter and diameter of the first two whorls for the *Nummulites* assemblages of the North Sea basin. Crosses give average values for $\pm 2\ \sigma_M$.

Closer inspection shows that the samples have not a random distribution. With but a single exception (the lowest sample from the boring Mechelen, thought to have been derived from Lede Sands) all samples from the lower stratigraphic units (Vlierzele, Brussels, Lede) occupy a small part of the scatter field at the lower left end of the diagram. All these assemblages are characterized by low values of $\overline{C}$ (smaller than 90 μ) and of $\overline{D}$ (smaller than 800 μ). $\overline{D/C}$ values range from slightly less than 10 to somewhat over 14. All samples from the higher stratigraphic units occupy a much wider field. Samples with $\overline{C}$ values comparable to those of the Lede group have higher $\overline{D}$ values, but the field is also extending to the right hand side of the diagram because of much higher $\overline{C}$ values. As a consequence also the $\overline{D/C}$ range widens roughly between the lines $D/C = 8$ and $D/C = 18$. Asse Clay samples are found both in the left and right part of this field. The same applies to the samples from the Wemmel Sands. The three "Oligocene" samples occur towards or at the top of the scatter periphery.

We may even construct visually two lines which divide the scatter field into

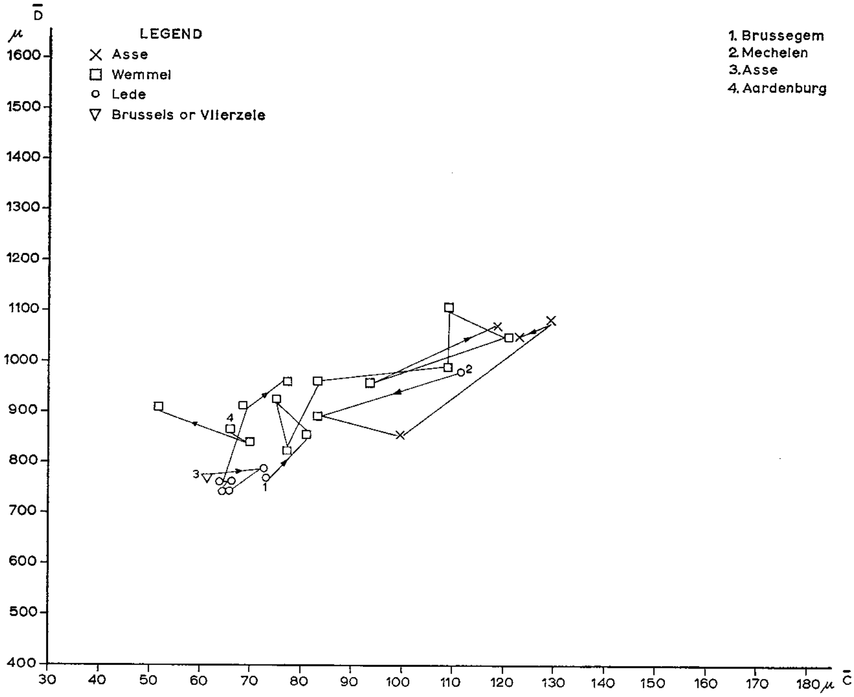


Fig. 19. Mean values of protoconch diameter and diameter of the first two whorls for the *Nummulites* assemblages of the borings Brussegem, Mechelen, Asse and Aardenburg III. Arrows point to the higher samples.

three parts in such a way that each part mainly contains samples of comparable stratigraphic units. Below the line $C = D - 735$ we find 15 samples of the three lower units (Vlierzele, Brussels, Lede). Above the line $C = 0.3D - 250$ only the three Oligocene samples are found. In between both lines we find all 27 samples from the Wemmel Sands and the Asse Clays and a single one from the Lede Sands, mentioned already. Although it is remarkable that as many as three of the six check samples do not fit in with the pattern, they certainly do not disturb our general conclusion.

Evidently $\overline{D/C}$ is not a useful factor to differentiate age groups of samples by means of absolute values. The average remains more or less constant for all stratigraphic groups (one of the regression lines nearly coinciding with $D/C = 10$), but at every level there is wide variation and the average $\overline{D/C}$ does not show a clear change with time. Yet there is a relation in which development seems to go toward widening of the $\overline{D/C}$ scatter over the entire width of the field toward higher $\overline{D}$ and higher $\overline{C}$ values.

The crosses with $\pm 2\sigma_M$ for $\overline{C}$ and $\overline{D}$, given in diagram 18, show that the differences between successive samples of the borings (figure 19) are often statistically significant. Commonly they denote increase in $\overline{C}$ or $\overline{D}$ or both together, but set-backs do occur, especially in $\overline{C}$.

These $\pm 2\sigma_M$ crosses also contain a warning that we should not expect to be able to give a stratigraphic assignment to a single sample with the help of the lines and fields constructed in diagram 18. This is equally apparent from the check samples, although all three deviating samples have such σ_M values that their field position is not completely certain.

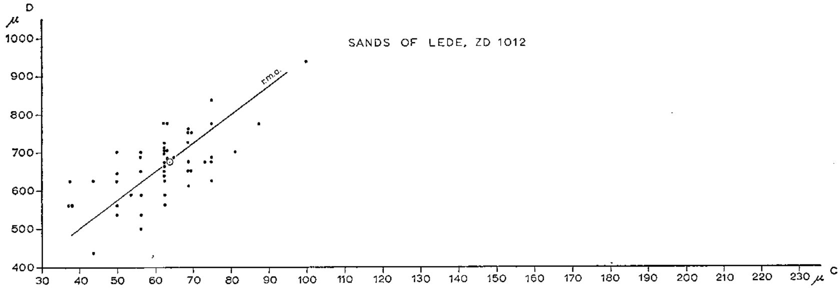


Fig. 20. Protoconch diameter and diameter of the first two whorls for the *Nummulites* individuals from sample ZD 1012 from the Sands of Lede.

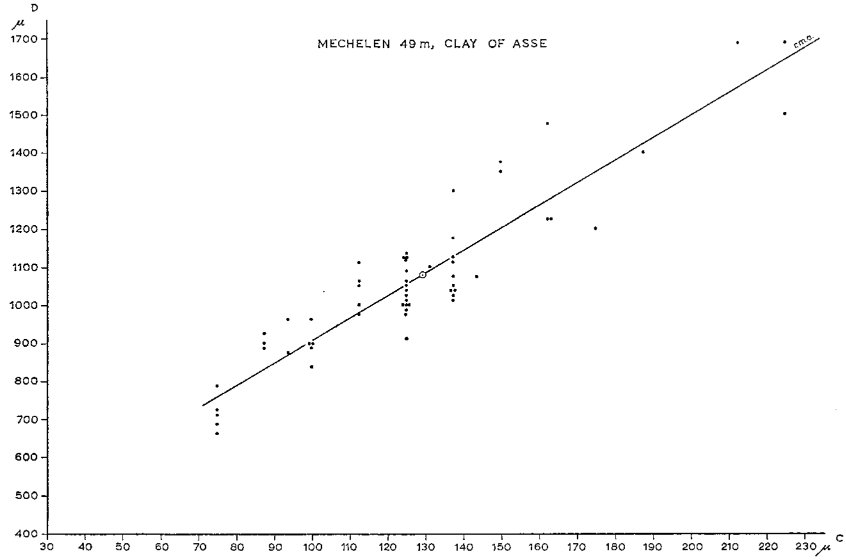


Fig. 21. Protoconch diameter and diameter of the first two whorls for the *Nummulites* individuals from sample Mechelen 49 m from the Clay of Asse.

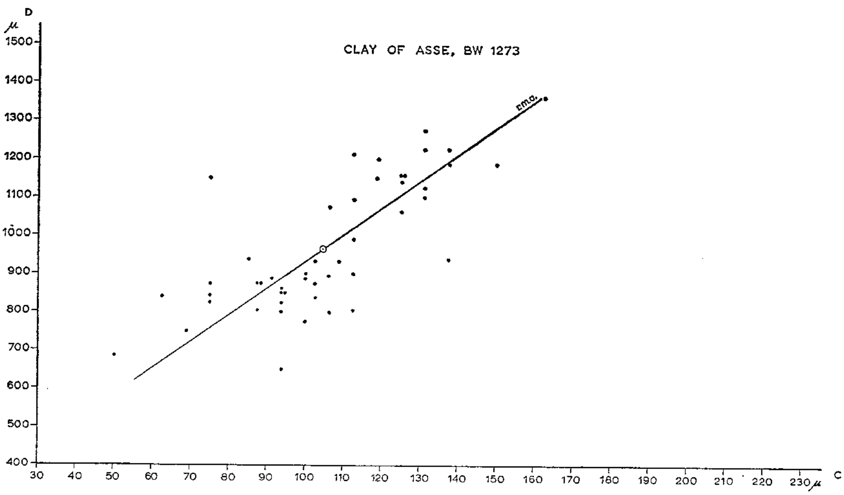


Fig. 22. Protoconch diameter and diameter of the first two whorls for the *Nummulites* individuals from sample BW 1273 from the Clay of Asse.

Three scatter diagrams (figures 20—22) have been added to show that there is also good correlation between C and D within single samples. The trends of the elongate clusters are roughly parallel to those in the $\overline{C} - \overline{D}$ diagram. Variation in the samples also supports the conclusions drawn from the means. In the assemblage from the Lede Sands (figure 20) C and D show a restricted range of variation as compared to that seen in both other figures, based on assemblages from the basal Asse Clays. In the latter samples the C and D values are higher and they show a much wider variation. In figure 22 there is even an indication of two clusters which might correspond to a mixture of somewhat different populations.

If we would fit reduced major axes to all three assemblages we find them to cut the D axis well above the origin. Such a direction fits better in with the b_{DC} regression line of figure 18 than with both other lines of central tendency of this diagram. Although rather far-fetched we might suppose the b_{DC} line to approach the trend of variation within single samples (D dependant on C), whereas b_{CD} rather gives the direction of evolution of the entire group (C dependant on D). This non-statistical and non-mathematical explanation of both regression lines, will become strengthened in our discussion of the D-E relations below.

So $C = a' + b_{CD} D$ would approach the path of evolution of the entire group. $D = a'' + b_{DC} C$ is closer to the major axis of variation within single samples but not with that of all populations in a single stratigraphic unit.

The $\overline{C}/\overline{D}$ relation outside the North Sea basin

In scatter diagram 23 we see that all the English samples fit fairly well together. They are lying within the scatter field of the North Sea samples. A stratigraphic trend can be concluded only for the sections from the Barton Beds of Wight, a trend obviously opposite to that concluded for the North Sea material. It shows a reduction of both $\overline{C}$ and $\overline{D}$ in upward stratigraphic order. The samples from Barton and from Whitecliff Bay again seem to contradict such a general conclusion.

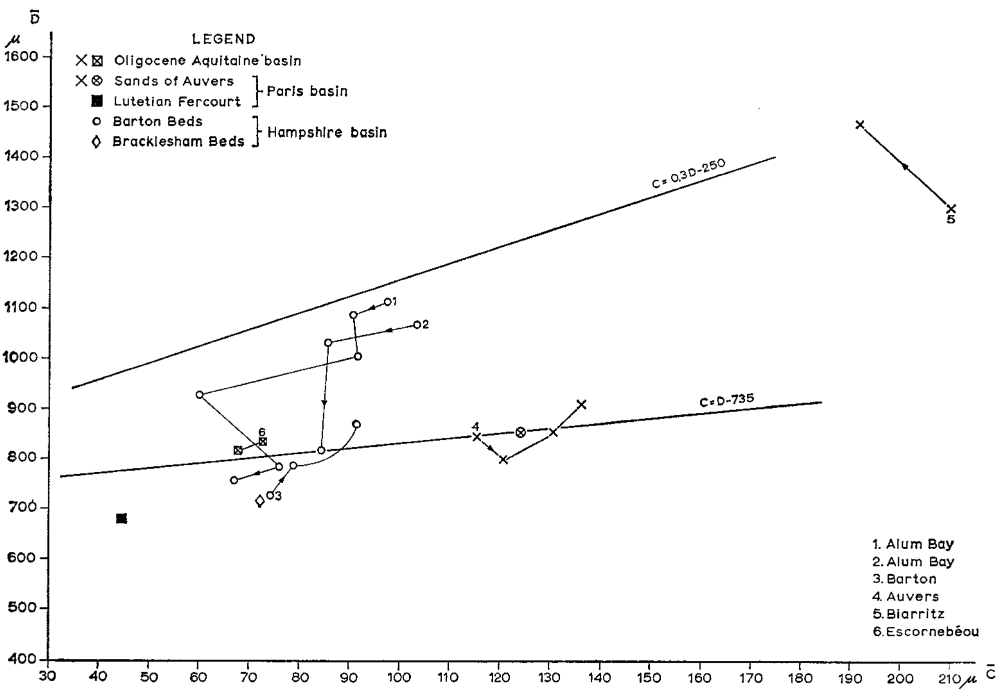


Fig. 23. Mean values of protoconch diameter and diameter of the first two whorls for the *Nummulites* assemblages from the Hampshire, Paris and Aquitaine basins.

The assemblages from Auvers in the Paris basin are grouped closely together near the lower C = D — 735 line. Most important is that they are well outside the scatter field of the North Sea samples. Their $\overline{D/C}$ values are comparitively small, smaller than 8. It is remarkable that the check sample from the Lutetian of Fercourt is far remote from those of the Auvers group. Its position is very close to that of the Belgian Brussels-Lede group.

The samples from the French Oligocene of Biarritz exhibit average $\overline{D/C}$ values, but these samples are also aberrant because of very high $\overline{C}$ values, which bring them well to the right of the North Sea scatter, but not necessarily in a position discontinuous with that of the Oligocene representatives of the latter group.

The picture is further complicated by both check samples from the Upper Oligocene of Escornebéou. Their position is far away from that of the Biarritz samples, suggesting no relation at all. Their situation amongst the Belgian Wemmel-Asse group and the English Barton group cannot be due to relationship for both stratigraphic and geographic reasons.

The relation between $\overline{D}$ and $\overline{E}$ in the North Sea basin

The overall picture of the $\overline{D/C}$ relation for the North Sea basin was that of

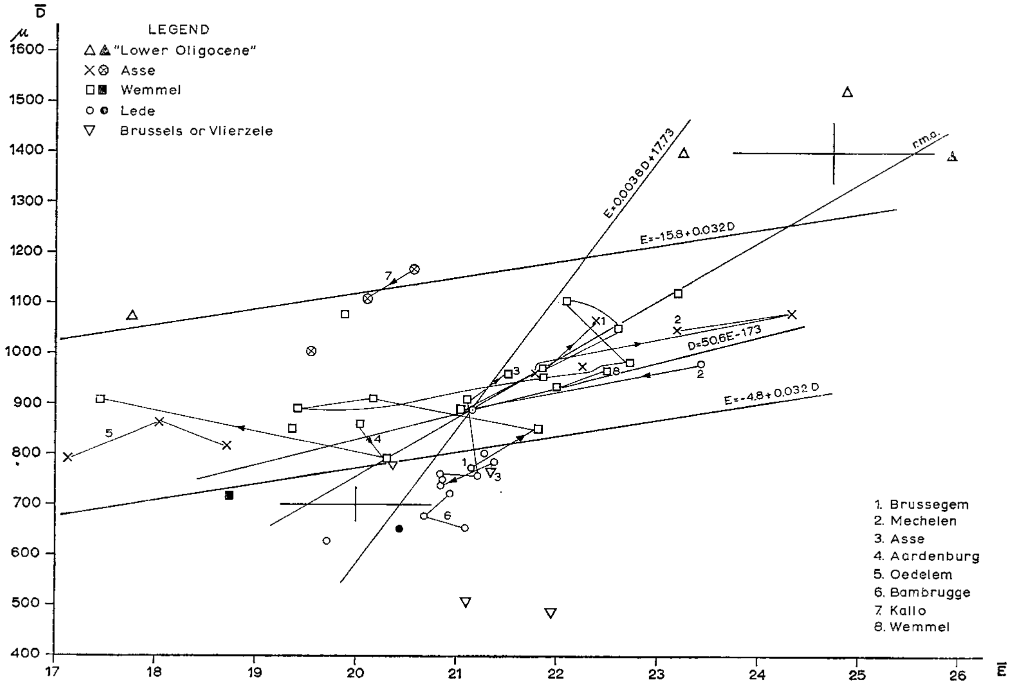


Fig. 24. Mean values of the diameter of the first two whorls and the number of chambers in these whorls for the *Nummulites* assemblages of the North Sea basin. Crosses give average values for $\pm$ 2 σ_M.

widening variation in $\bar{C}$ together with a general increase in $\bar{D}$. As a consequence we are not surprised that we are able to construct in the $\bar{D}$—$\bar{E}$ scatter diagram of figure 24, three similar fields due to the trend in $\bar{D}$. Nevertheless it is unexpected that the samples fall apart in exactly the same way with the single one from the Mechelen well as an exception. This time only two of the six check samples are, only slightly, outside the expected field.

Again we see that the samples from the lower stratigraphic units (Vlierzele, Brussels, Lede) are grouped fairly well together in the basal part of the diagram. With low $\bar{D}$ values they have average $\bar{E}$ values, roughly between 19.5 and 22.0. In the higher stratigraphic units the samples show with increasing $\bar{D}$ a very wide scatter of $\bar{E}$ values. The pattern above the lower line ($E = 0.032D - 4.8$) is different from that in the $\bar{D}$ against $\bar{C}$ scatter in figure 18, because $\bar{E}$ values both lower and higher than those of the Lede group are nearly equally well represented. The range they show is from 17 to 25. Since E observations and consequently $\bar{E}$ calculations evidently allowed fewest deviations in absolute values between the large number of observers, there cannot be the slightest doubt that this picture is realistic. The "Oligocene" samples are again at the top of the scatter periphery.

Notwithstanding the elongate shape of the cluster positive correlation is less strict than in the $\bar{D}$—$\bar{C}$ relation. The correlation coefficient is $+ 0.438$, which is still significant at a 95 % probability level. As might be expected from the low value of the correlation coefficient, both regression lines calculated by the method of least squares, form a considerable angle with one another. Only one, with direction b_{ED} cuts obliquely through all three fields, which indicates that it gives a better representation of the average path of development of the group than the line based on direction b_{DE}, which appears to be nearly parallel to the lines that delimit the fields, lines which had been chosen visually. Over its entire length in the diagram this most horizontal of both regression lines is within the field of the Asse-Wemmel assemblages. One is tempted to regard this

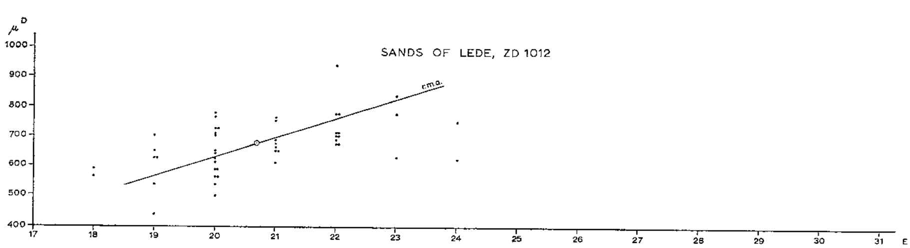


Fig. 25. Diameter of the first two whorls and the number of chambers in these whorls for the *Nummulites* individuals from sample ZD 1012 from the Sands of Lede.

line as an approximation of the variation within one stratigraphic unit, i.e. during one restricted time interval.

Actually, the D—E variation within single samples shows a fairly good positive correlation of both parameters. The reduced major axes in the three arbitrarily chosen examples (figures 25—27) really show courses closest to that of the regression line with direction b_{DE} in the $\overline{D}$—$\overline{E}$ diagram.

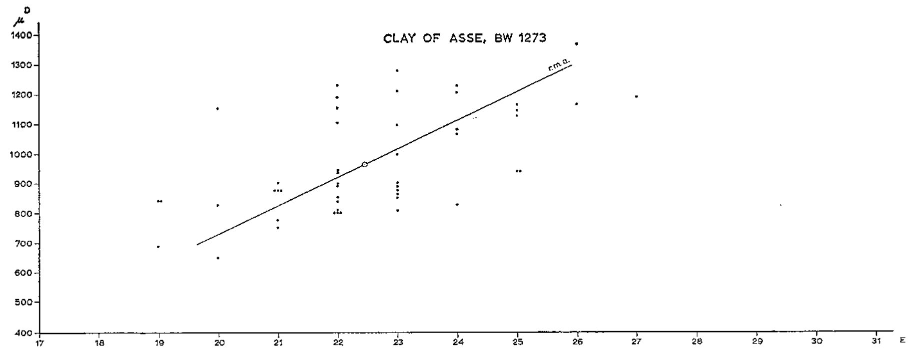


Fig. 26. Diameter of the first two whorls and the number of chambers in these whorls for the *Nummulites* individuals from sample BW 1273 from the Clay of Asse.

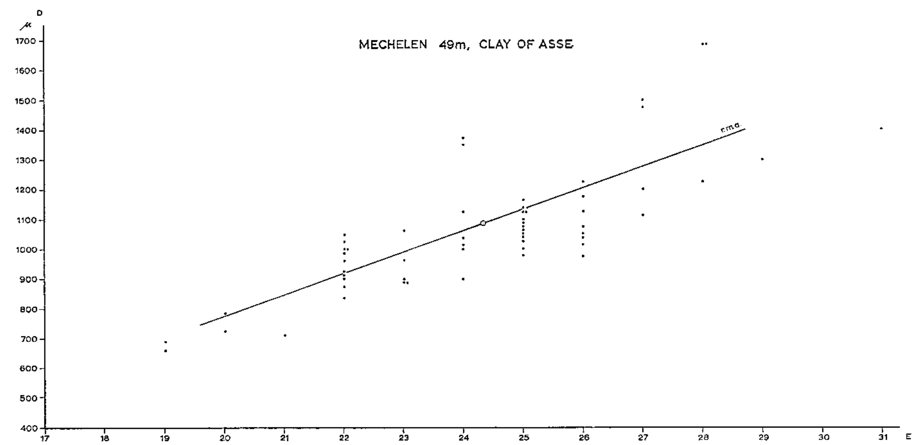


Fig. 27. Diameter of the first two whorls and the number of chambers in these whorls for the *Nummulites* individuals from sample Mechelen 49 m from the Clay of Asse.

Again there is no statistical or mathematical basis, but we may suppose that $D = a''' + b_{DE}E$ fits better in with the variation in single samples and with that at one time "level", so that in populations D would depend on variation of E. On the other hand, it would be $\bar{D}$ that independently increased in the course of evolution, causing $\bar{E}$ ($E = a'''' + b_{ED}D$) and possibly $\bar{C}$ ($C = a'' + b_{CD}D$) to follow. Although based on a trivial interpretation of regression lines these relations are close to those that seem to control either variation or evolution of these inner parameters in our North Sea *Nummulites.*

The $\bar{D}$-$\bar{E}$ relation in the English and French samples

The English material in the scatter diagram of figure 28 mainly lies in the central field constructed in diagram 24. Some of the samples come in the lower field. Again the anomalous character of the sample suites of Alum Bay is demonstrated. This time there is a suggestion of reduction of $\bar{E}$ with time, the chambers become smaller in number, and so relatively lower.

The assemblages from Auvers are once more grouped close together. They are outside the scatter periphery of the North Sea data, this time because of

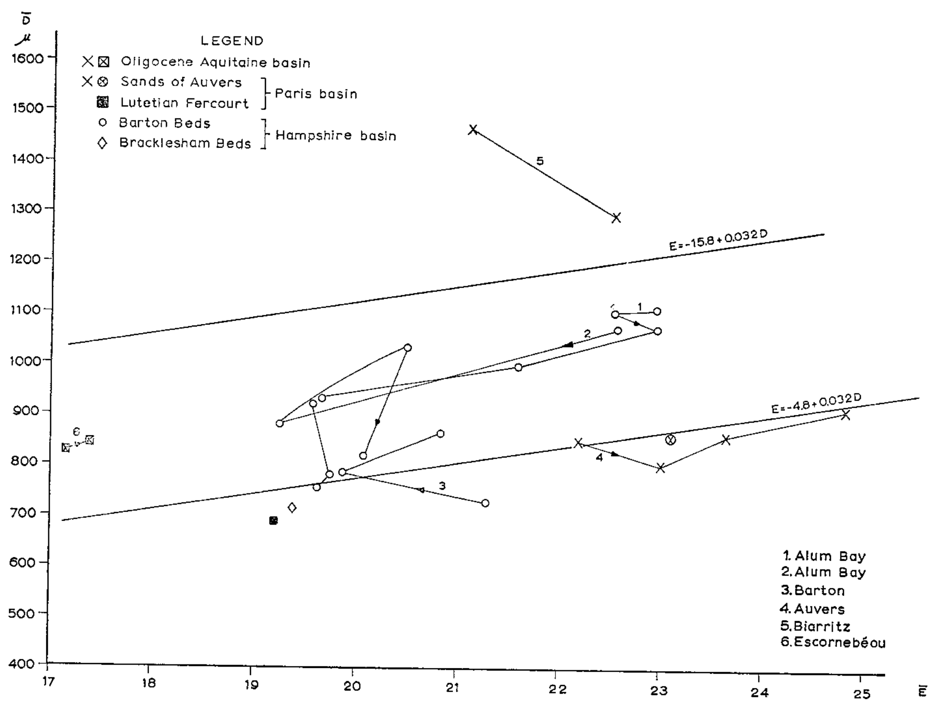


Fig. 28. Mean values of the diameter of the first two whorls and the number of chambers in these whorls for the *Nummulites* assemblages from the Hampshire, Paris and Aquitaine basins.

relatively high $\bar{E}$ values for the corresponding $\bar{D}$. The Fercourt check sample is again well apart, in position very close to that of the single sample from the English Bracklesham Beds.

The Oligocene samples of the Biarritz section occur in the field of the "Oligocene" samples of the North Sea. Again the Escornebéou samples are widely different because of very low $\bar{E}$ values, which rather correspond to those of some of the Asse-Wemmel samples of the North Sea.

Altogether there is a suggestion of the existence of very different stocks of *Nummulites* populations, even at different times in one and the same basin.

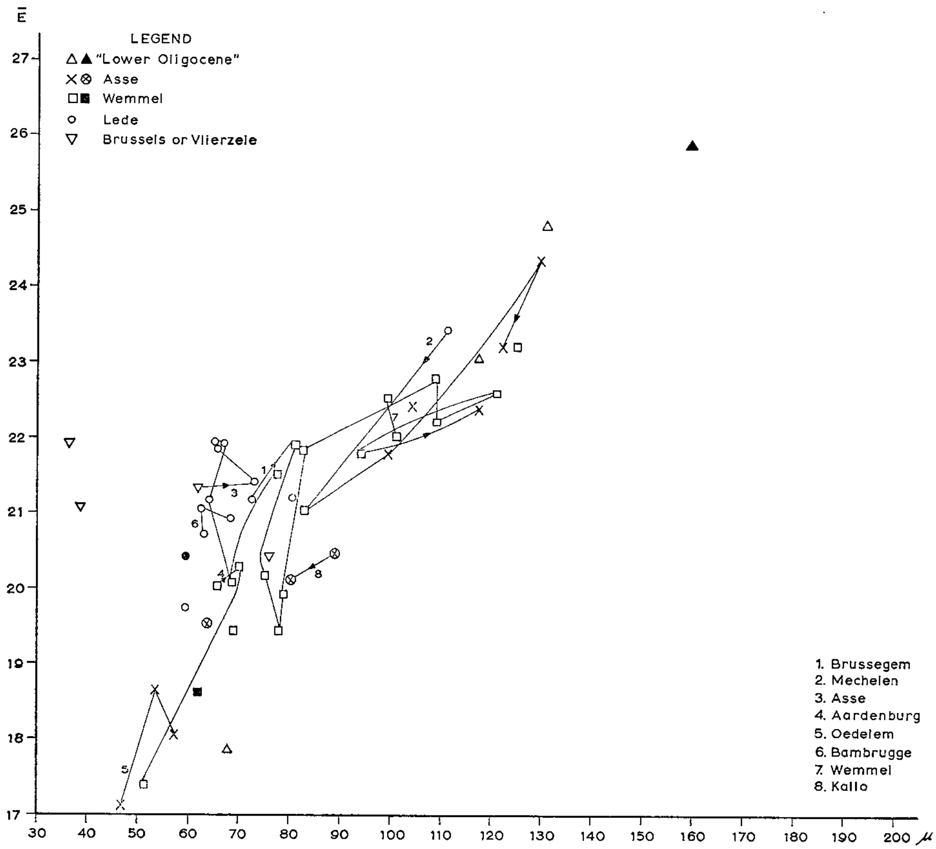


Fig. 29. Mean values of protoconch diameter and the number of chambers in the first two whorls for the *Nummulites* assemblages of the North Sea basin.

The relation between $\bar{C}$ and $\bar{E}$ in the North Sea basin

As a whole, scatter diagram 29 of the couples of mean protoconch diameter and mean number of chambers in the first two whorls shows a good positive correlation ($r = +0.765$).

Nearly all samples fill an elongated field, the shape of which is defined by the data on the samples from the higher stratigraphic units. Both Woensdrecht samples from the Sands of Brussels stand apart because of relatively low $\bar{C}$ values in combination with average $\bar{E}$ numbers. Yet these data are not completely aberrant, because the majority of the other samples from the lower stratigraphic units up to the Lede Sands, cluster near the middle of the scatter field, lying also somewhat to the left because of their relatively low $\bar{C}$ values. The extremely wide variation of $\bar{C}$—$\bar{E}$ points is entirely due to the material from the higher stratigraphic units. The distribution of points corresponding to each of these three units (Wemmel, Asse, "Oligocene") ranges over the entire field.

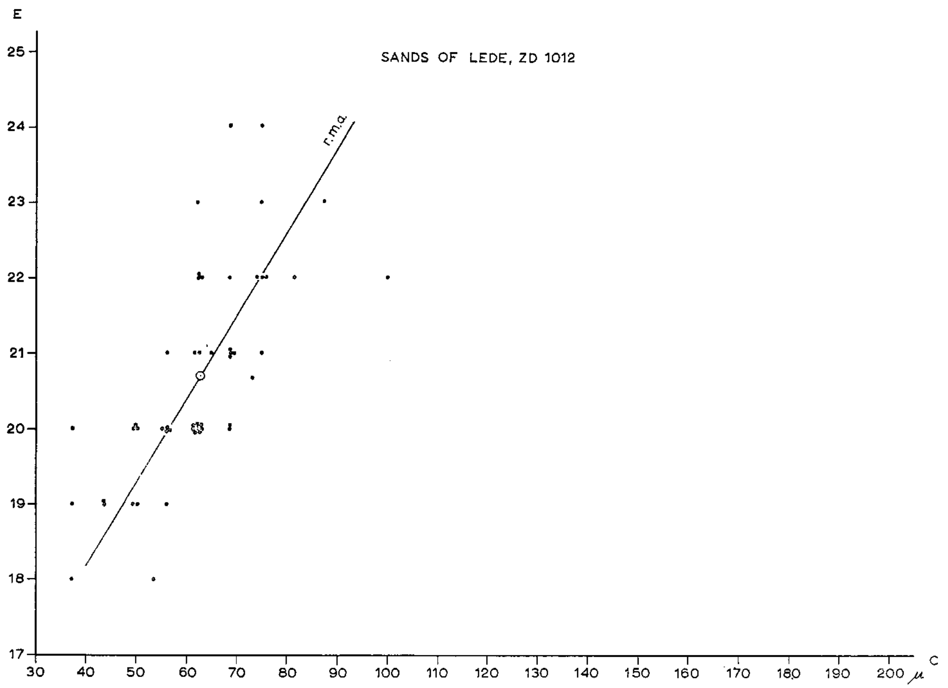


Fig. 30. Protoconch diameter and the number of chambers in the first two whorls for the *Nummulites* individuals from sample ZD 1012 from the Sands of Lede.

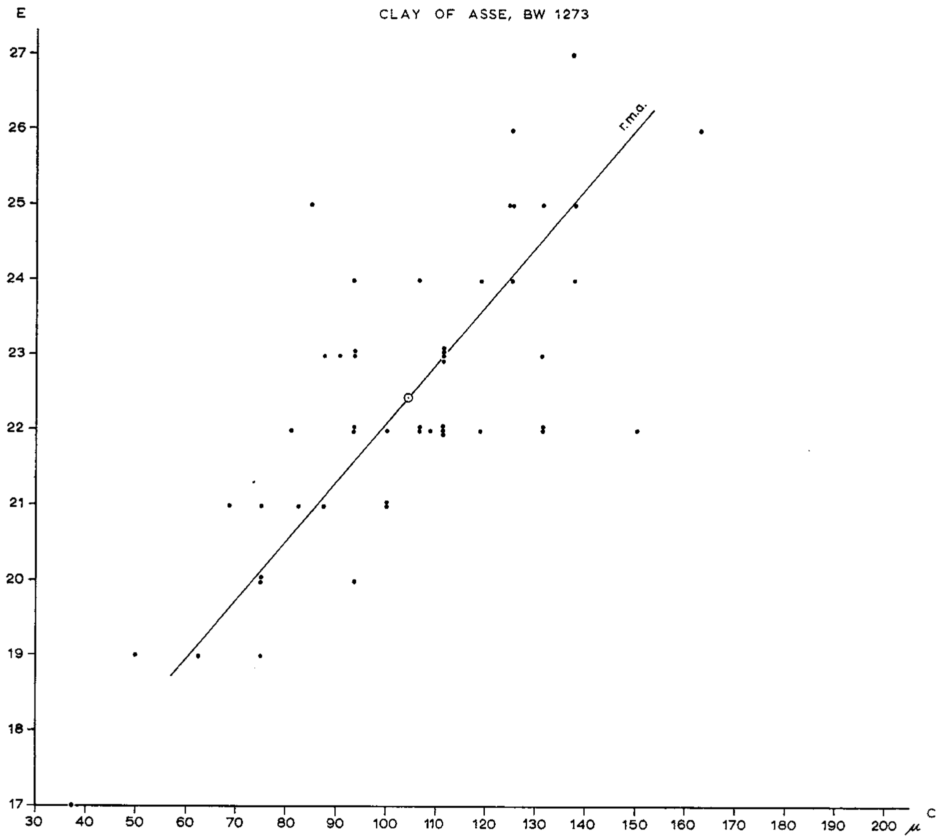


Fig. 31. Protoconch diameter and the number of chambers in the first two whorls for the *Nummulites* individuals from sample BW 1273 from the Clay of Asse.

Evidently the samples of various stratigraphic units, or groups of units, can be much less easily disentangled in the $\overline{C}$—$\overline{E}$ diagram, than it could be done in those for $\overline{C}$—$\overline{D}$ or for $\overline{D}$—$\overline{E}$.

No rectilinear regression lines have been calculated, mainly because the scatter suggests a curvilinear regression. Figures 30 and 31 show the C—E relation in single samples. Again there is a good positive correlation. The reduced major axes of both samples, taken together, might suggest again a curvilinear regression for the $\overline{E}$—$\overline{C}$ scatter.

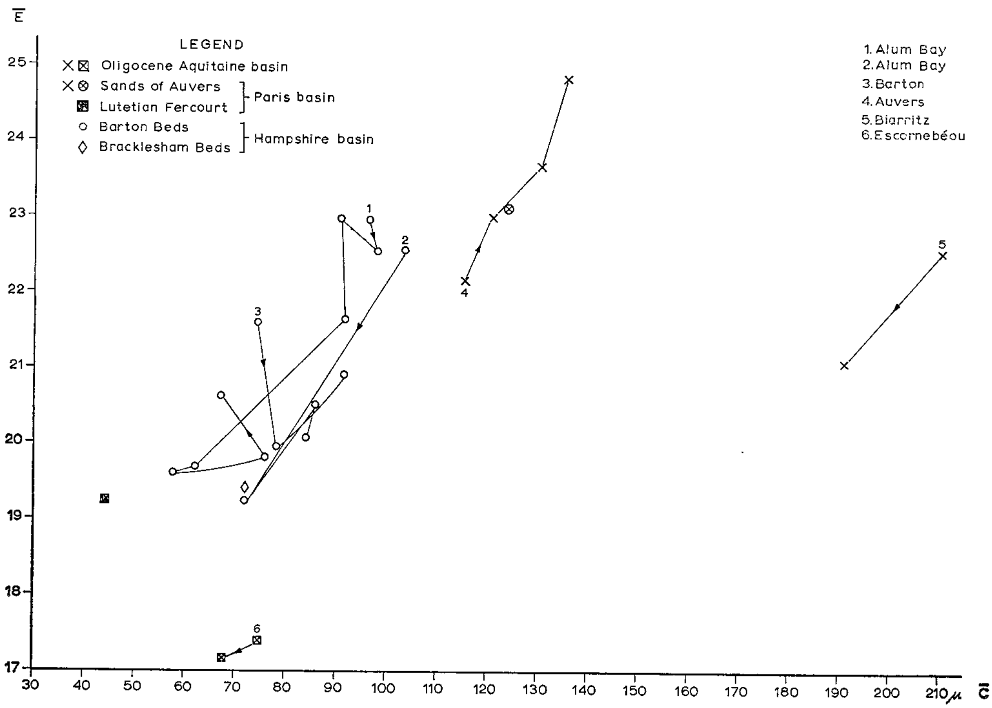


Fig. 32. Mean values of protoconch diameter and the number of chambers in the first two whorls for the *Nummulites* assemblages of the Hampshire, Paris and Aquitaine basins.

$\bar{C}$-$\bar{E}$ in the Hampshire basin and in the French samples

In diagram 32 the field of $\bar{C}$—$\bar{E}$ points of the English samples and that for the material from Auvers coincide with different parts of the scatter field of the North Sea samples. The English samples show considerable variation but evidently they form a homogeneous group. So do the Auvers samples, but that from the Lutetian of Fercourt stands far away.

Only the data from the Oligocene of the Biarritz section are standing well apart from all others, because of their very high $\bar{C}$ values combined with an average $\bar{E}$. In contrast, the Escornebéou check samples again show a more normal position, close to the lower extreme of the North Sea scatter field.

The relation between $\overline{D/C}$ and $\bar{E}$

Before starting on the investigation it was thought that the average D/C might be a promising factor to show by an increase of values with time, the expected

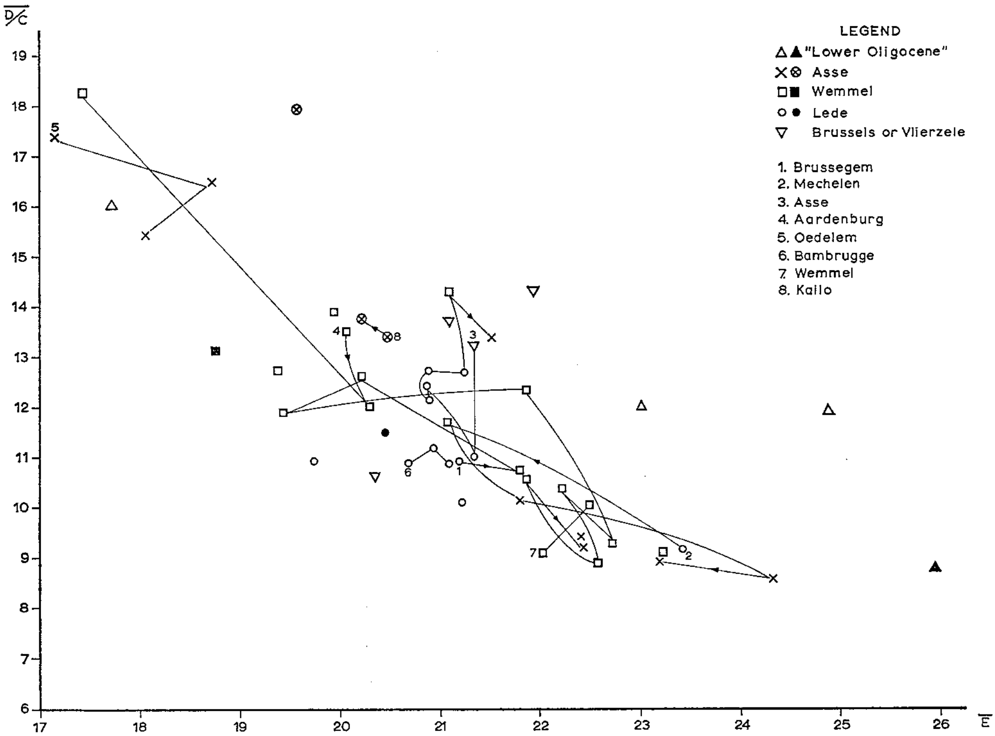


Fig. 33. Mean values of the D/C ratio and the number of chambers in the first two whorls for the *Nummulites* assemblages of the North Sea basin.

changes toward a greater relative laxity of the spire. However, it was concluded already from the $\overline{C/D}$ relation in figure 18 that absolute values of $\overline{D/C}$ are of little stratigraphic importance. This may also be seen in diagram 33. This diagram shows that the relation between $\overline{D/C}$ and $\overline{E}$ is one of negative correlation ($r = -0.777$).

Evidently all samples from the North Sea together may again be considered to belong to a homogeneous group, in which there is a tendency for laxer spirals to go together with lower numbers of chambers, and vice versa, at least as far as mean values are concerned. For single samples (figures 34—36) some extreme individuals give the impression of negative correlation. Apart from these the scatters are mainly parallel to the E axis with a more or less constant range of D/C. The relation between the number of spiral chambers and the degree of tightness of the spiral is less apparent in single samples than it is for the means of these parameters for all samples together.

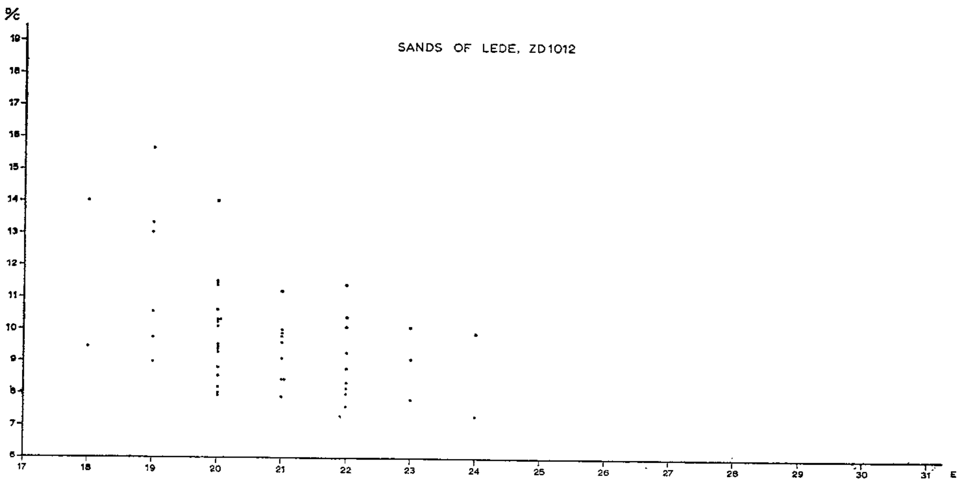


Fig. 34. D/C ratio and the number of chambers in the first two whorls for the *Nummulites* individuals from sample ZD 1012 from the Sands of Lede.

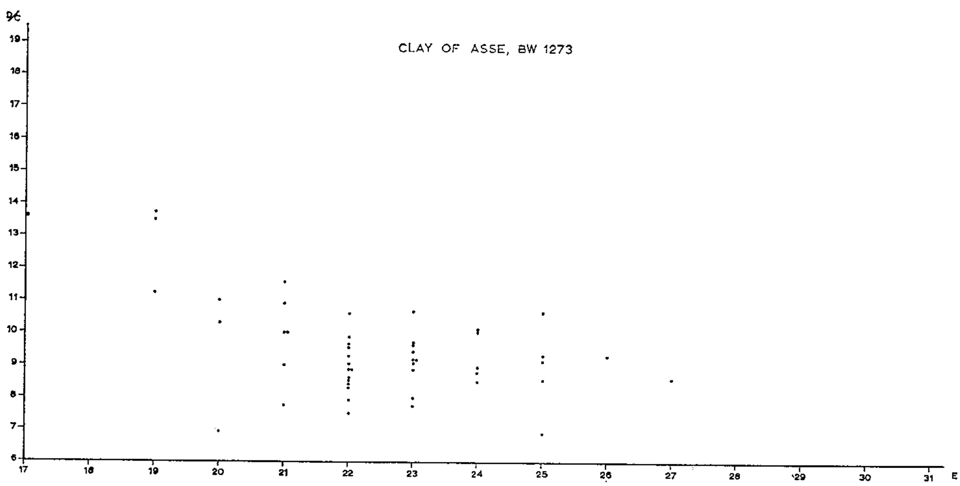


Fig. 35. D/C ratio and the number of chambers in the first two whorls for the *Nummulites* individuals from sample BW 1273 from the Clay of Asse.

Moreover, there is no obvious trend in the $\overline{D/C}$—$\overline{E}$ relation from older to younger deposits. As we knew already, the hypothesis that spirals get laxer with time simply is not true. And there is both increase and decrease in $\overline{E}$ toward higher stratigraphic units.

Points corresponding to samples of the lower stratigraphic units are found to

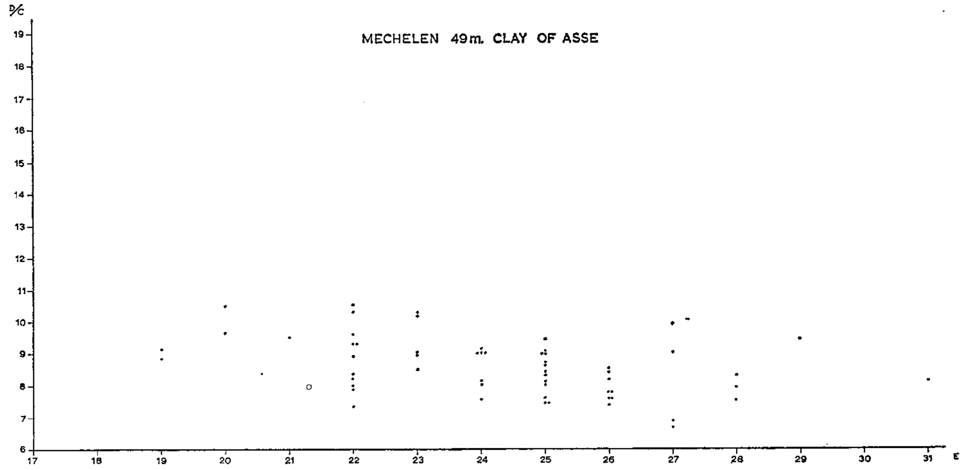


Fig. 36. D/C ratio and the number of chambers in the first two whorls for the *Nummulites* individuals from sample Mechelen 49 m from the Clay of Asse.

cluster in the centre of the scatter field. On the basis of this group of data alone there would be no reason to suspect the negative correlation exhibited by the data from all samples together. The elongate character of the scatter field is again entirely due to the younger samples, which show the very wide variation both in $\overline{D/C}$ and in $\overline{E}$. Individual samples from all three higher stratigraphic units come widely apart to either side of the central cluster.

One gets the impression that occasionally very local stocks developed rather independently of one another in smaller areas within the basin. For instance, from the remote grouping together of the three samples from the Asse Clays of Oedelem and the one from Ghent, together with one of the samples from nearby Aardenburg (Wemmel Sands?) in the upper left part of the diagram, whereas other Asse Clay samples are plotted far away. But this impression is not consistent with the distribution of, for instance, the "Oligocene" samples, because the only "Oligocene" sample in this northwestern corner of the diagram is from the German locality Brandhorst, whereas the one from the check sample of nearby Bassevelde is most remote of all in the opposite corner of the diagram.

The English and French samples in their $\overline{D/C}$-$\overline{E}$ relation

In diagram 37 the scatter field of the English samples appears to correspond roughly to the North Sea field, without showing the latter's extreme values. A negative correlation is hardly apparent, if at all.

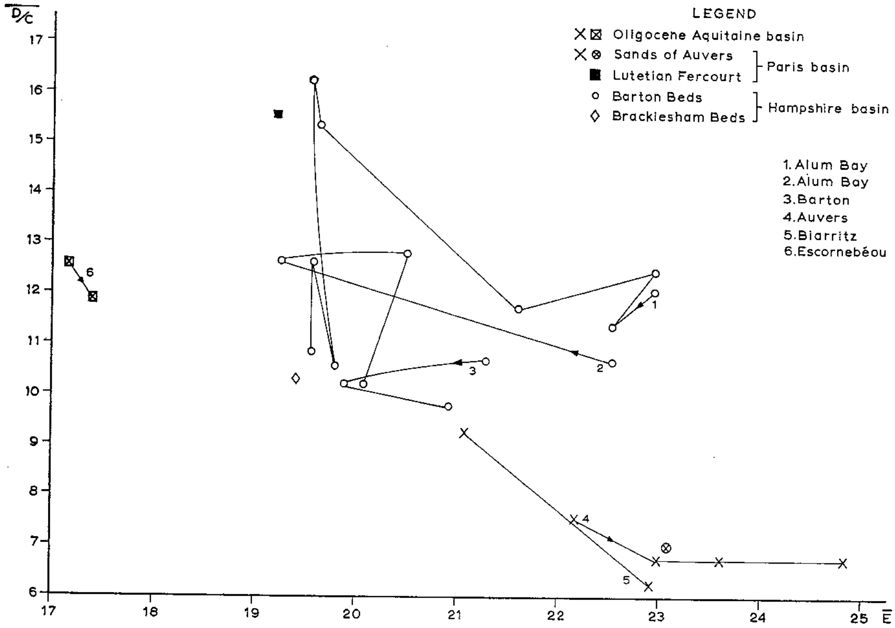


Fig. 37. Mean values of the D/C ratio and the number of chambers in the first two whorls for the *Nummulites* assemblages of the Hampshire, Paris and Aquitaine basins.

The French samples from both Auvers and Biarritz are close together and mainly outside the scatter fields of the North Sea and Hampshire data. The relatively low $\overline{D/C}$ values cause this separate position. Regarding the fact that in most other scatter diagrams the Auvers group and both Biarritz samples are lying well apart, their grouping together in diagram 37 is thought to be rather accidental and not to reflect a close relationship between both groups. The Fercourt check sample fits best to the English and Belgian groups, whereas now the Escornebéou samples are most aberrant because of low $\overline{E}$ values combined with an average $\overline{D/C}$.

Relative test thickness versus protoconch diameter

Scatter diagram 38 visualizes for the North Sea samples the first example of a relation between external and internal features. It might be expected that both means $\overline{2B/A}$ and $\overline{C}$ are independent of one another. Actually no correlation can be shown from the strange scatter field. The diagram becomes more logical after drawing the horizontal line $2B/A = 0.55$. Above it we only find represented samples, though not all, from the lower stratigraphic units (Vlierzele, Brussels,

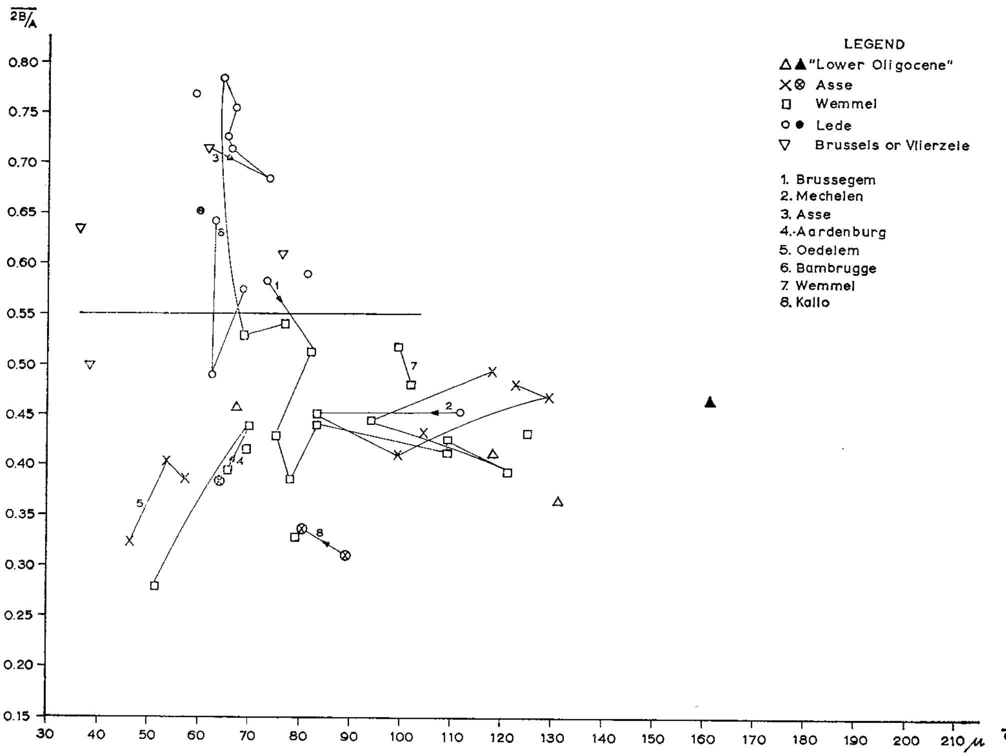


Fig. 38. Mean values of relative test thickness and protoconch diameter for the *Nummulites* assemblages of the North Sea basin.

Lede), which pertains to the fact that the older *Nummulites* are commonly relatively thicker than the later ones. The latter figure below the line 2B/A = 0.55, where they show much wider variation in $\overline{C}$.

Diagram 39 is the corresponding figure for the other areas involved. The samples from Auvers show thick *Nummulites*, but with much greater mean protoconch diameter than the North Sea assemblages with the same relative thickness. Many English assemblages from the basal part of the Barton Beds of Alum Bay are aberrant again because of their extreme thinness. The Biarritz samples are far outside the fields of all others because of their high $\overline{C}$ values, whereas those from Escornebéou fit well into the fields of English and younger Belgian assemblages.

More cannot be concluded from these scatter diagrams except that certain groups of populations are probably not related to others.

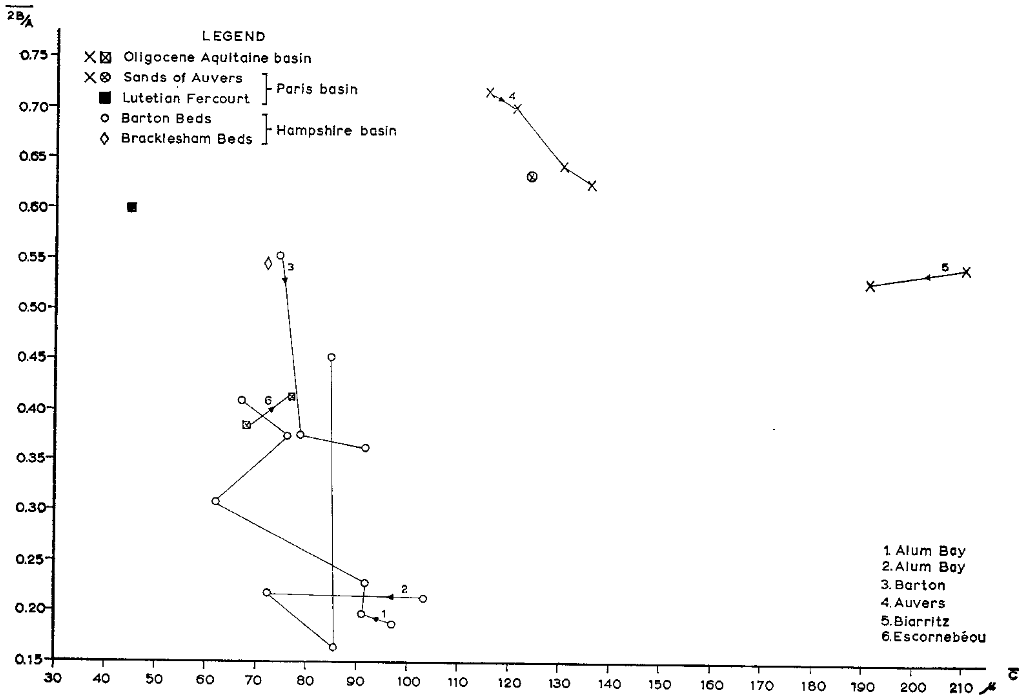


Fig. 39. Mean values of relative test thickness and protoconch diameter for the *Nummulites* assemblages of the Hampshire, Paris and Aquitaine basins.

$\overline{2B/A}$ and $\overline{D}$ in the North Sea assemblages

Because of the rough trend to decrease the average relative thickness of the test with time, and the increase in the mean diameter of the first two whorls in the same sense, some negative correlation might be expected to occur in the $\overline{2B/A}$—$\overline{D}$ scatter diagram of figure 40. Such a correlation is suggested indeed, but it appears to be rather poor with r = —0.533. Possibly the underlying regression is curvilinear rather than rectilinear, but data in the upper half of the diagram are relatively scarce. Actually, the older samples are mainly found in the lower right part of the figure, those from the "Oligocene" occur in the top part.

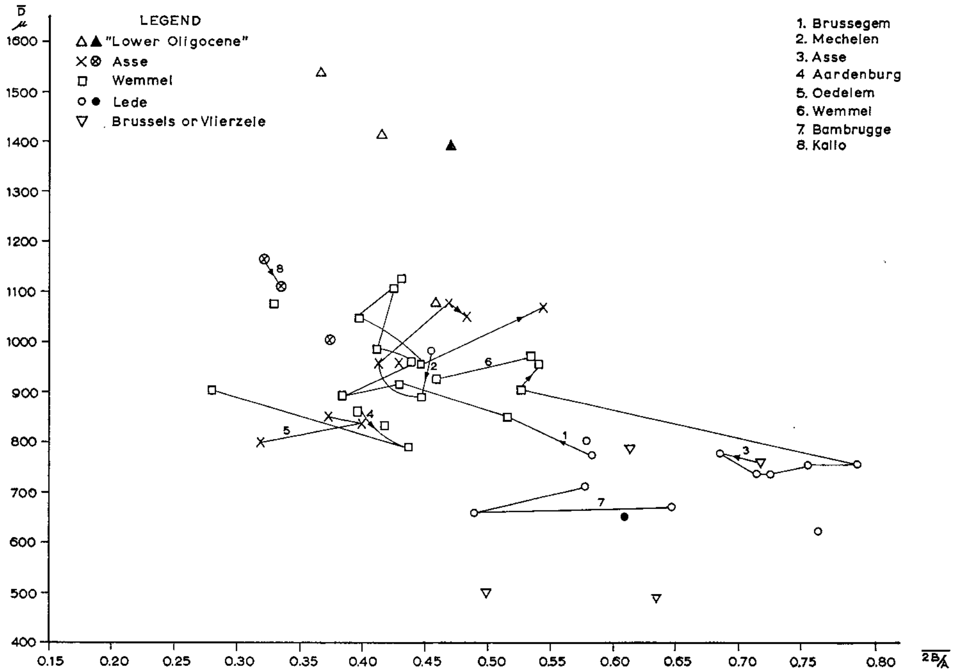


Fig. 40. Mean values of relative test thickness and diameter of the first two whorls for the *Nummulites* assemblages of the North Sea basin.

$\overline{2B/A}$ and $\overline{D}$ for the English and French assemblages

If we take into account the assumed stratigraphic positions of the various groups of samples, the data on French and English assemblages in diagram 41 are in better accordance with those from the North Sea basin than it was found to be the case in most other diagrams.

The samples from Auvers and Fercourt in the Paris basin adjoin in the scatter field those from the lower Belgian stratigraphic units, as might be expected from the assumed Middle Eocene age of both groups. The Oligocene samples from the Biarritz section fit in best with those of the nordic "Oligocene", but those from Escornebéou disappear in the general cluster of North Sea forms. Finally, the area with the assemblages from the English Barton Beds shows an overlap with that of the samples from Wemmel Sands and Asse Clays in Belgium and Holland, extending beyond it because of the samples with extremely thin tests from Alum Bay.

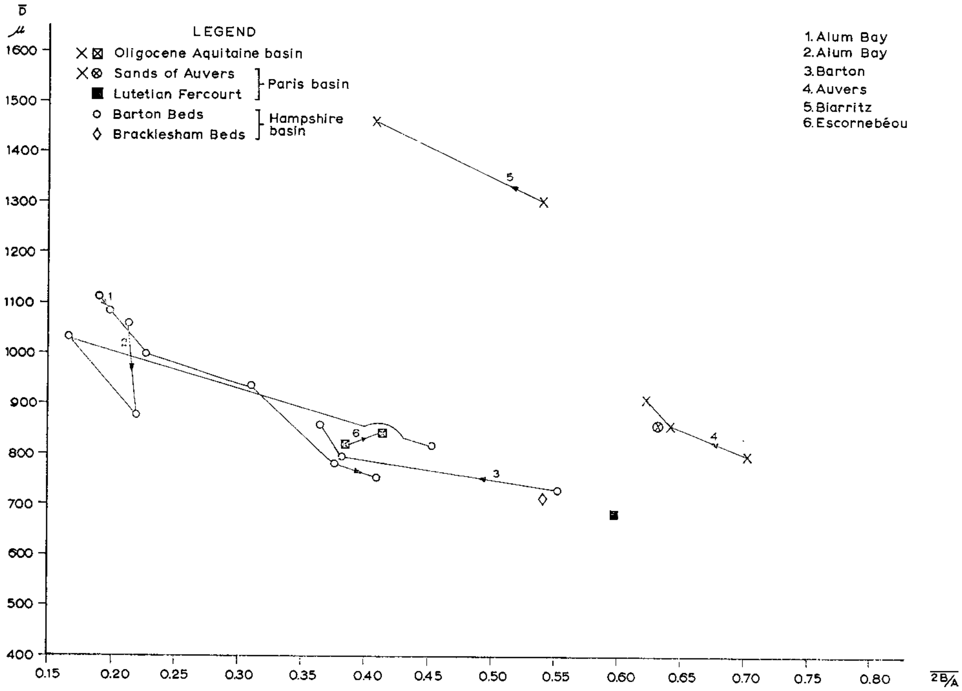


Fig. 41. Mean values of relative test thickness and diameter of the first two whorls for the *Nummulites* assemblages of the Hampshire, Paris and Aquitaine basins.

$\overline{D/C}$ against $\overline{2B/A}$

It was expected before we started on the investigation that D/C might not only be a measure for the laxity of the spiral, but that it would be closely connected with the relative thickness of the test. It has been shown already that $\overline{D/C}$ values do not show a clear trend in the course of time, variation starting wide and becoming still wider in younger stratigraphic units. The idea that the suggested decrease in relative thickness, which was actually found to be true in a rough way, might relate to spirals becoming laxer can hardly be corroborated from diagram 42. The expected opposition of a thin test with loose coiling against a thick test with tight coiling is but vaguely suggested. The slight negative correlation for the North Sea samples, suspected from the diagram, is reflected in the r value of —0.175, which is hardly significant, if at all. It looks likely that the negative correlation may be better for the younger samples alone, leaving out those from the Lede Sands and older, but this suggestion was not checked any further.

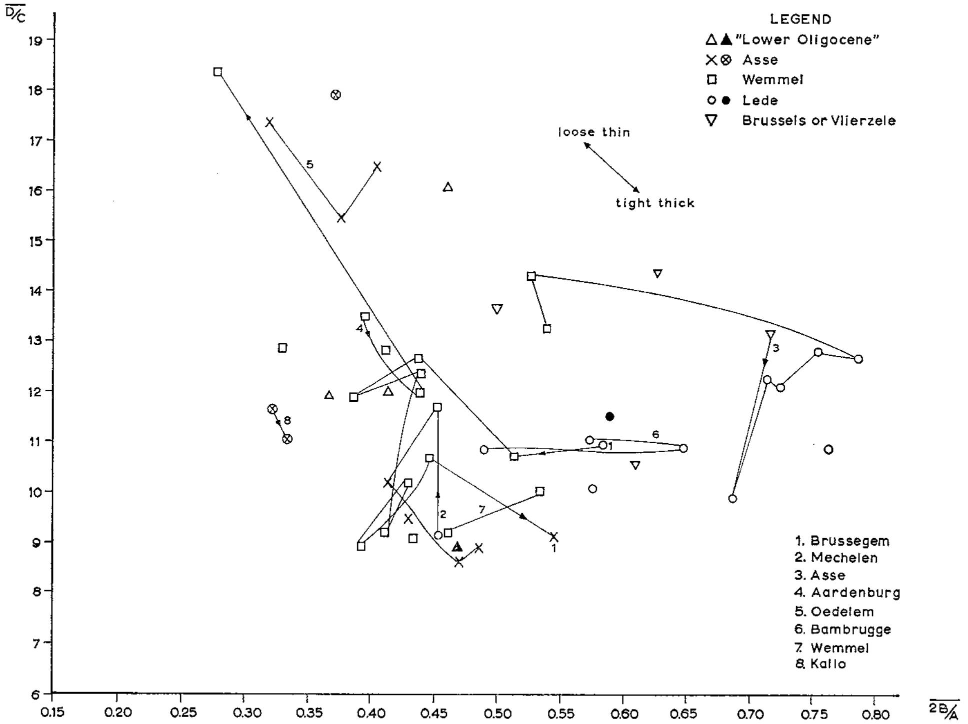


Fig. 42. Mean values of D/C ratio and relative test thickness for the *Nummulites* assemblages of the North Sea basin.

Figures 43—45 show the dubious correlation of D/C and 2B/A in the assemblages of three of the samples.

Little need be said about the assemblages from outside the North Sea. In diagram 46 those from Auvers and that from Rocher de la Vierge, are beyond the scatter periphery of the North Sea samples because of their very low $\overline{D/C}$ values. Those from the lower part of the Alum Bay section again demonstrate their extremely low relative thickness of the test.

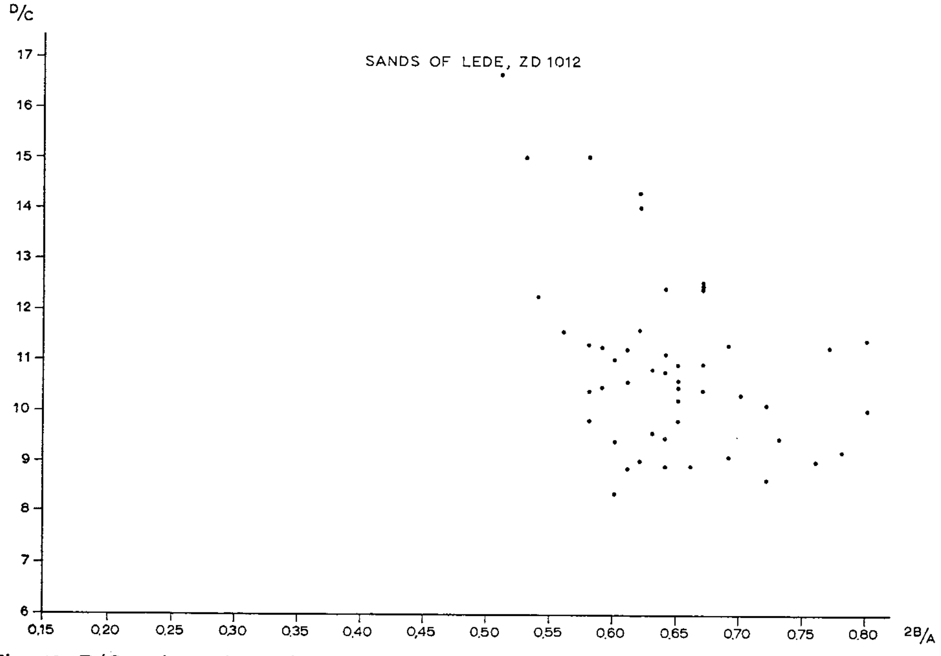


Fig. 43. D/C ratio against relative thickness of the test for the *Nummulites* individuals from sample ZD 1012 from the Sands of Lede.

Fig. 44. D/C ratio against relative thickness of the test for the *Nummulites* individuals from sample BW 1273 from the Clay of Asse.

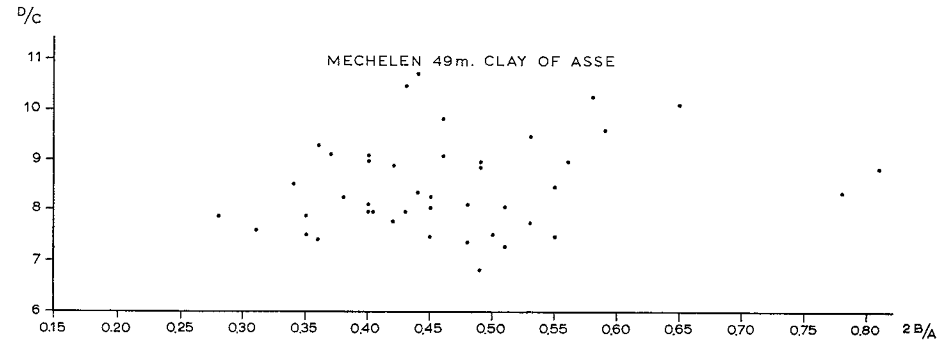


Fig. 45. D/C ratio against relative thickness of the test for the *Nummulites* individuals from sample Mechelen 49 m from the Clay of Asse.

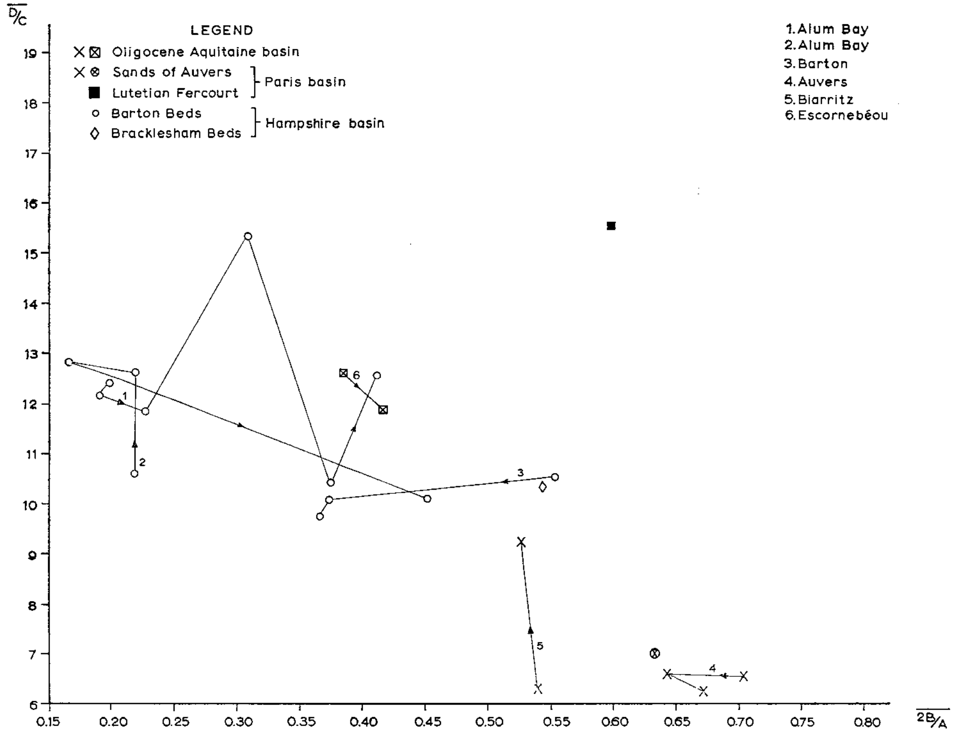


Fig. 46. Mean values of D/C ratio and relative thickness of the test for the *Nummulites* assemblages of the Hampshire, Paris and Aquitaine basins.

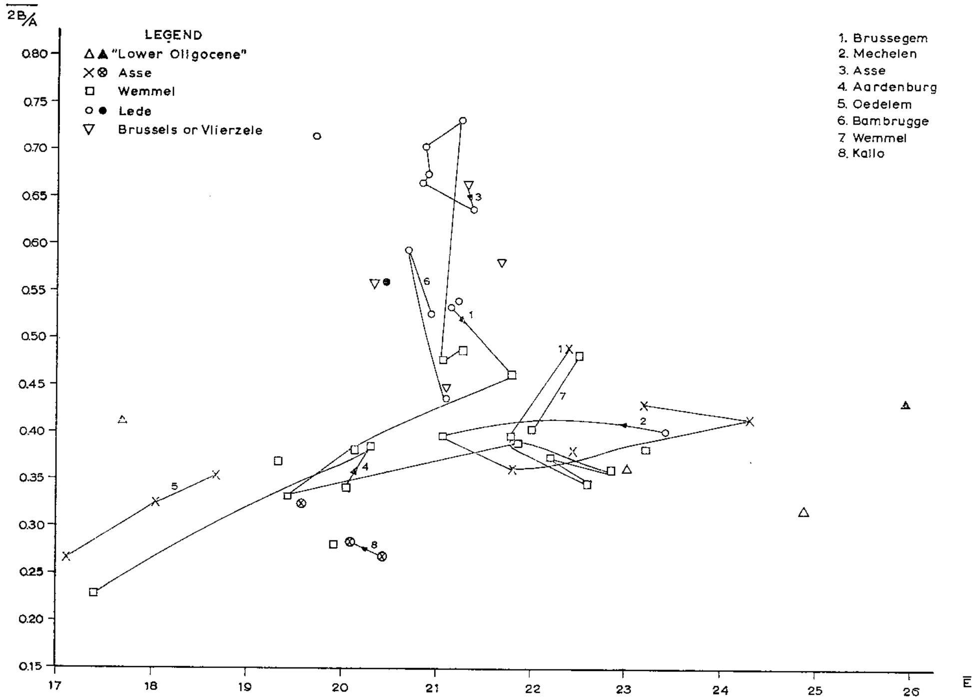


Fig. 47. Mean values of relative test thickness and number of chambers in the first two whorls for the *Nummulites* assemblages of the North Sea basin.

$\overline{E}$ and $\overline{2B/A}$

After the poor correlations, if any, of the mean values of external versus internal features, that have been dealt with above, little can be expected from our final comparison, that of $\overline{E}$ values against those of mean relative thickness of the tests. Scatter diagram 47 shows that the rather narrow $\overline{E}$ variation in the samples from Lede Sands and older is followed by a very wide variation of $\overline{E}$ at lower $\overline{2B/A}$ levels.

In diagram 48 the only fact worth repeating is the aberrant position of the Auvers samples, this time because of their relatively high $\overline{E}$ values.

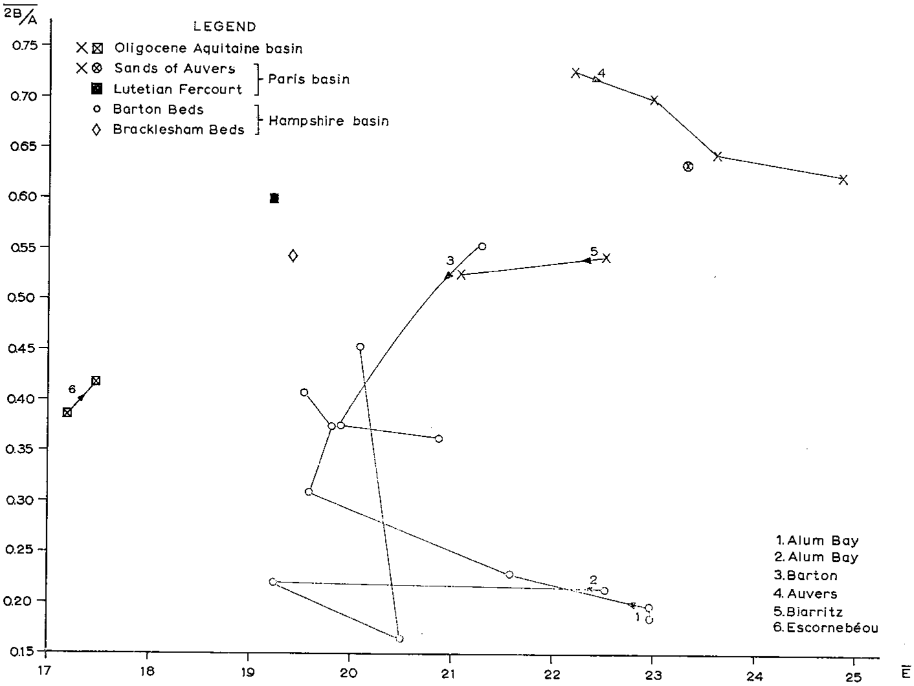


Fig. 48. Mean values of relative test thickness and number of chambers in the first two whorls for the *Nummulites* assemblages of the Hampshire, Paris and Aquitaine basins.

Chapter IX

THE CHECK SAMPLES

From the first set of 66 samples it appeared that several stocks of populations could be recognized and that certain trends were likely to be present. As a check on these conclusions 10 additional samples were analysed, the results of which have been incorporated in the previous chapter. These results were rather embarrassing because they caused a further complication of the supposed pattern.

Three of the six Belgian check samples fit in perfectly with the previously obtained picture, those from the "Oligocene" of Bassevelde, from the Asse Clays of Ghent, and from the Sands of Lede at Vlierzele. Especially the Bassevelde sample is important, because with its extreme values it supports the separate field of "Oligocene" samples in the most important diagrams 18 and 24, which so far contained only three assemblages.

Both samples from the Asse Clays of the Kallo boring are more difficult to reconcile with the earlier conclusions. Their external size parameters $\overline{A}$ and $\overline{B}$ are strongly different from one sample to the other (figure 10), but in $2\overline{B/A}$ they are very close together (figure 11). In all other respects they come close together in the scatter diagrams. It is remarkable that in diagrams 18 and 24 they are within or close to the field of "Oligocene" samples because of high $\overline{D}$ values relative to the accompanying $\overline{C}$ or $\overline{E}$. Regarding the standard errors of the means, however, this position is not embarrassing. For Kallo 178 m these errors are very high because there were but very few specimens big enough to observe D and E.

A similar aberrant position in diagrams 18 and 24 was found for the sample from the Wemmel Sands at Jette, this one lying in the field of the Lede samples, but again so close to the dividing lines that its position is not unambiguous. The number of observations is small and those on the exterior are lacking.

As a whole the group of Belgian check samples cannot deny the general picture obtained from the first set of 46 samples. They only contain an additional warning not to expect that single samples may be placed stratigraphically by any of the deduced trends of the North Sea *Nummulites.*

Very interesting are the check samples from France. Primarily it was observed that the additional sample from the Sands of Auvers fits in very well with the tight and separate cluster of the earlier samples from this locality, which stresses the independence of this group.

It appeared very hard to obtain material of the by now notorious Middle or

Upper Lutetian smaller radiate *Nummulites*, so-called *N. variolarius*, of the Paris basin. After some samples appeared to be devoid of this species, a small number of specimens was obtained from a sample taken at Fercourt (Oise) by BLONDEAU. Notwithstanding the low number of observations it is apparent that the assemblage of Fercourt is widely different from those of Auvers, especially so in its internal features, because they give mean values that are all much smaller than those typical for the Auversian group of assemblages. In many features this Fercourt assemblage fits much better to the Belgian Brussels-Lede group of assemblages.

Finally both samples from the uppermost Oligocene of Escornebéou in the Aquitaine basin revealed an extra complication. They appeared to be strongly different from both Oligocene samples of the Biarritz section. This is very remarkable since the stratigraphic gap between the beds at Chambre d'Amour and at Escornebéou, both in the southwestern part of the Aquitaine basin, is commonly considered to be narrower than that between the sampled levels of Rocher de la Vierge and Chambre d'Amour. In some respects the Escornebéou assemblages are close to those from the Belgian Wemmel and Asse units, which certainly cannot reflect relationship. It may seriously be doubted whether the Escornebéou *Nummulites* really descended from those of the older Biarritz populations. Further study of the smaller *Nummulites* of the Aquitaine basin contains the promise of interesting results.

Even though our number of data for populations outside the North Sea basin is relatively small, we get the impression that successive stocks of smaller radiate *Nummulites* in the Hampshire, Paris and Aquitaine basins might be independent of one another, whereas the North Sea assemblages seem to form a single homogeneous group.

Chapter X

POPULATION GROUPS, EVOLUTION AND SYSTEMATICS

Reviewing the diagrams of chapter VIII we may conclude from the fairly homogeneous clusters they exhibit, that the smaller *Nummulites* of the North Sea basin all belonged to a single stock of populations, all related to one another throughout Eocene and Oligocene time. Those assemblages which appear to be situated somewhat remote in the scatter fields (Woensdrecht, "Oligocene") are equally extreme in their stratigraphic position. In contrast, most of the English and French assemblages are frequently so far away from the various corresponding North Sea clusters that we may safely conclude that their populations were not closely related to those of the low countries.

Within the North Sea group evolution was certainly not stagnant because in a general sense all of the measured features are changing in the course of time.

In a rough way there are interrelated trends towards greater mean diameter of the test and towards lower values for its relative thickness. On the average, individuals tended to become thinner and somewhat larger. We had better limit ourselves to this general statement, not only because of the considerable amount of inaccuracy in our thickness measurements, but also because of the dependence in ontogeny of relative thickness on size. The latter feature was probably in turn influenced by environmental agents, which may be thought responsible for the large number of observed exceptions on this general rule: towards greater and thinner tests. Eventually it is even possible that these trends have nothing to do with evolution of the group, but that they reflect a steady change of environment throughout Eocene and Oligocene time, the nature of which escaped our attention.

More promising are the trends observed in the internal characteristics. All three, protoconch diameter (C), diameter of the first two whorls (D) and the number of chambers in these two convolutions (E) show an interrelated increase in average values from the older to the younger formations. This combined increase is not only true for the means (diagrams 18 and 24), but also within single samples all relations between these internal parameters of individuals show positive correlation. It has been argued in the previous chapters that the interdependence of these three features within single samples is different from that of the total group of means throughout time.

Actually the scatter diagrams suggest that within one population D depends both on C and on E. In other words, the diameter of the first two whorls of individuals would be a function of the size of the initial chamber and of the number of instars needed to fill the two whorls, both relations being again of positive correlation. However, it seems that in the course of geologic time the mean value of D is the parameter which is increasing independently, going together with higher values of $\overline{C}$ and of $\overline{E}$, but also with lower values of the latter two parameters, especially of $\overline{E}$. It appears that the increase in $\overline{D}$ in the course of evolution is combined with an excessive widening of the variation of mean protoconch diameter and of mean number of spiral chambers. As a result the positive $\overline{C}$—$\overline{E}$ correlation (diagram 29) does not reflect along its axis a trend from older to younger, but the older populations cluster near the centre of the field, whereas the younger ones at both extreme ends cause its elongate shape. Likewise there is no general trend to greater average laxity of the spirals (expressed in $\overline{D/C}$). Variation just widens with spirals becoming both laxer and tighter than before.

In the literature the development of nordic *Nummulites* has commonly been considered as a degeneration of some Middle Eocene *N. variolarius* stock. Although we risk a semantic discussion the general increase in internal size parameters reflects a development, claimed to be progressive in other *Nummulites* groups rather than a general decline. There is no reason to regard the North Sea *Nummulites* as a stock that after its invasion in Middle Eocene time was degenerating until its extinction at some level in the Early Oligocene.

The conclusion of one homogeneous but evolving group of populations in the North Sea basin, raises new problems concerning the taxonomic presentation of the results. After the elaborate analysis of variation it would be a step backward if we expressed the observations again on the basis of a typological species concept. Taking the populations as a basis of our systematics we are faced by the fact that there are no clear-cut morphological demarcation lines because of the intricate interrelation of C, D and E. On the other hand, giving only a single specific name to all populations because of their intergradation, would lump away for the non-specialist all the differences we observed.

The lines drawn in figures 18 and 24, which cause a threefold subdivision of the scatter fields, and which were based primarily on the absolute values of $\overline{D}$, certainly cause a morphological grouping of assemblages, which has a background in evolution and in gross stratigraphy. Different specific names for these groups would be appropriate, and they are easily found in the literature.

However, do we want to express in taxonomy the wide horizontal variation of $\overline{C}$ and $\overline{E}$ in figures 18 and 24, in for instance the middle field? There is no doubt that morphologically the extremes to the left and to the right are widely different, but they are again linked by numerous intermediates, and this time along a line that may reflect environmental influences. There is no clear connection between smaller groups of assemblages and different lithostratigraphic units. Data are insufficient to say, for instance, that Asse Clay samples mainly occur at both ends of the middle field, whereas those from the Wemmel Sands would rather occupy an intermediate position. It simply is not true in detail and thus we might easily be led to a re-evaluation of the original lithostratigraphic determination, because sometimes one gets the impression that the sediments encountered might be interpreted either way, Wemmel or Asse (e.g. in boring Aardenburg). We had better stick to the original stratigraphic assignment of the samples, because with any other solution we enter into wishful thinking or circular reasoning.

Whatever wide the variation may seem to be, it still might be explained as the expression of variability of populations in one stratigraphic interval. Actually the D-E and D-C variation in single samples certainly does not extend along the path of evolution of the group (approximated by the more vertical of the regression lines, based on the independent variable $\overline{D}$), but it is closer to the more horizontal ones which make a much smaller angle with the axis of elongation of the central fields. Hence, it is conceivable that random variation, or rather differences in variation caused by environmental factors, might have had the effect of shifting the means along the longer axis of the field. So the wide variation in a horizontal sense of the means in figures 18 and 24 could be due to ecological factors at one time level. We have to stop our arguing here because we have no idea about the actual ecological differences, our sedimentological information of the samples being extremely poor.

As a result we may assume that the near-horizontal variation within the middle and upper fields of figures 18 and 24 may have been caused by ecological factors within a restricted time interval, whether this resulted in local and/or temporary stocks or not. Certainly there is no reason to suspect the presence of parallel lineages in the North Sea basin, which could easily be the conclusion of specialists on *Nummulites* of the earlier literature.

In this way of reasoning the extreme populations could easily be honoured by subspecific names, but this procedure would have the disadvantage that we are multiplying the number of vague boundaries between formal taxonomic units.

For the low $\overline{D}$ value group, which corresponds to the lower stratigraphic units (Vlierzele, Brussels and Lede), the name *N. gandinus* (pl. 1, fig. 4—11) seems most appropriate, because we prefer to avoid the specific name *minor*, which was too much abused in the older literature. Because of their extreme position one might even separate both assemblages of the Woensdrecht boring as a very small-sized "precursor" of *N. gandinus* (pl. 1, fig. 4—7), but we had better wait for more evidence so that theory is not taxonomically expressed in advance of well documented facts.

For the middle $\overline{D}$ group of populations from the Asse Clays and Wemmel Sands, the name *N. orbignyi* is appropriate, though primarily based on microspheric individuals. If one wants to use the name of the megalospheric generation it would be *N. wemmelensis.* We will refrain from naming the small $\overline{C}$-$\overline{E}$ and large $\overline{C}$-$\overline{E}$ groups. It would not be easy to find appropriate names in the literature, and there are enough specific names in the genus *Nummulites* to prevent us from introducing new ones. If necessary one might refer to the extreme groups as "small $\overline{C}$-$\overline{E}$ and large $\overline{C}$-$\overline{E}$ races", or as Oedelem and Mechelen races, respectively (pl. 2, fig. 1—8).

Finally the four assemblages from the various stratigraphic units, thought to be of Early Oligocene age, are really morphologically different, partly because of the highest $\overline{D}$ values. As a name we have *N. germanicus* (pl. 4, fig. 1—8), which may include the entire morphological range between the extremes from Brandhorst (small $\overline{C}$-$\overline{E}$) and from Bassevelde (large $\overline{C}$-$\overline{E}$). In figure 49 we clearly see that the populations from Kühlerhof and Hendrik fill the morphological gap between those from near-contemporaneous Brandhorst and Bassevelde, showing distinct overlap. There is no reason to think that at Kühlerhof two different populations are mixed, as is done by Papp (1969, p. 59, 62), who excludes the small C-D-E forms at Kühlerhof from the majority of the larger forms. One might again refer the extreme populations to different races, but

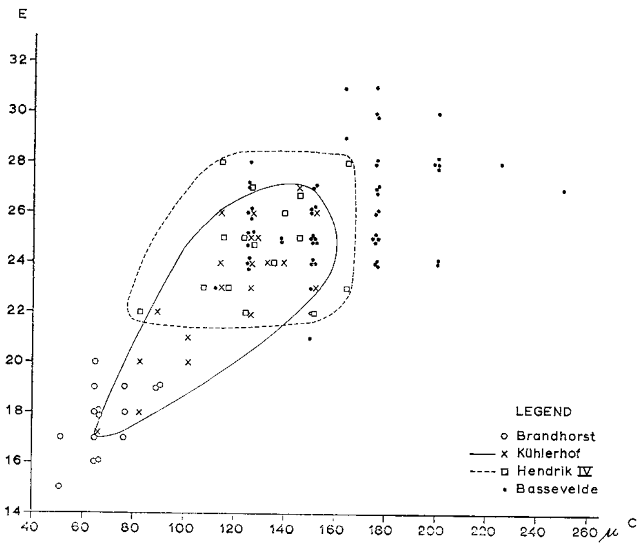


Fig. 49. Protoconch diameter and number of chambers in the first two whorls for the *Nummulites* individuals from the samples Kühlerhof, Hendrik IV, Brandhorst and Bassevelde.

already BORNEMANN (1860) seems to have included them both in his species. Also PAPP (1969) refuses to express the wide morphological variation he observed in German Oligocene assemblages in terms of different specific names.

If we now turn our attention to the Paris basin we see that all assemblages of Auvers cluster well, but that they are definitely outside the North Sea scatter fields, both for $\overline{C}$-$\overline{D}$ and for $\overline{E}$-$\overline{D}$. Assemblages with comparable $\overline{C}$-$\overline{E}$ values do occur in the North Sea material (Asse, Wemmel, Oligocene), but these have much higher $\overline{D}$ values. Actually, compared with the Belgian populations, the low $\overline{D/C}$ ratio is typical for the French *N. variolarius*, if we consider the "Auversian" (= from Auvers) *Nummulites* to typify this species (pl. 1, fig. 16—19). *N. variolarius,* thus delimited, does not occur in the North Sea basin. Whether we wish to consider the high C-D-E variants of the topmost Auvers sample as an admixture of yet another species, is as yet a matter of taste. If doing so, it has to be checked whether *N. ramondiformis* really is the most suitable name.

Although based on but few individuals, the assemblage from the Lutetian of Fercourt is different from those of Auvers. Actually it is closest to the oldest Belgian group, and therefore the name *N. gandinus* seems to be the most correct one for these Lutetian forms of the Paris basin (pl. 1, fig. 1—3). Data on other Lutetian assemblages in the literature lack sufficient detail to ascertain whether we are dealing with a local evolving stock, or whether we have to regard *N. variolarius* from Auvers as a new, later immigrant. Regarding the fact that no author (except BOMBITA, 1968), ever distinguished the Lutetian and Auversian forms on the basis of internal features, we presume that we are dealing with one homogeneous, evolving group, of which we had only extreme forms at our disposal.

If the Fercourt assemblage is placed in *N. gandinus,* the same procedure would be valid for the single sample from the Bracklesham Beds of the Hampshire basin (pl. 1, fig. 12—15). Also this assemblage, formerly referred to as *N. variolarius,* better fits in with the *N. gandinus* group of the North Sea basin than with the typical *N. variolarius* from Auvers.

There is a wide morphological gap between this *N. gandinus* assemblage from Whitecliff Bay and those following next higher in the Hampshire stratigraphy, derived from the base of the Barton Beds at Alum Bay. We are faced not only with an unbridged morphological gap, but still more embarrassing is the development of the group higher up in the Lower Barton Beds, at least if these assemblages are related, which seems plausible from the successive histograms (figure 9). We then have to acknowledge a trend towards lower $\overline{C}$, $\overline{D}$ and $\overline{E}$ values, hence completely opposite to the trends concluded for the evolving group of the North Sea basin. Actually, we sampled the sequence of Alum Bay a second time because we did not trust our first set of observations. The ultimate result of this development in the Barton Beds is morphologically again close to the assemblage of *N. gandinus* of Whitecliff Bay. Data for this higher group are still more confusing, because from the comparable stratigraphic levels at Barton (in which the basal forms of Alum Bay do not occur in our record) the assemblages again seem to show an increase in $\overline{C}$ and $\overline{D}$.

As to the absolute values of the internal features these English assemblages are not different from those of the North Sea basin. The majority of the pairs of means plot the assemblages in the Wemmel-Asse field of *N. orbignyi* of the low countries, trending upwards in a stratigraphic sense to the field of *N. gandinus.*

The interpretation of these observations cannot be unambiguous because of too small a number of partly contradictory data. The observed trend could be conceived to be due to environmental circumstances alone. Especially the plotted points for the lower samples in figures 23 and 28 suggest a trend parallel to the boundaries of the central field, but towards the highest samples the trend rather takes the direction of what was thought to be the evolutionary path in the North Sea populations, but here in opposite direction.

Although expressed in different terms this remarkable suite of populations of the Hampshire basin has been well recognized by Curry (1937). As yet the best thing we can do is to consider these English forms as a separate stock, amongst others, as stated by Curry, because of the more sinuous character of sutures and septa. The oldest population from Whitecliff Bay may be referred to as *N. gandinus*, the next higher one, *N. prestwichianus* (pl. 3, fig. 5—8) would already be typical for the Hampshire basin, characterized by its extremely thin test, which really is much thinner than ever encountered in the North Sea material. Intermediates between *N. gandinus* and *N. prestwichianus* are lacking, though Curry claims them to be present amongst the Belgian *N. gandinus* material (from Bambrugge) and in a museum sample from the topmost Bracklesham Beds at Huntingbridge. Evidently *N. prestwichianus* develops into the so-called *N. rectus* from the higher part of the Lower Barton Beds (pl. 3, fig. 1—4), which in its internal measured features is again close to populations intermediate between *N. gandinus* and *N.orbignyi*, but distinguishable to Curry, by the somewhat sinuous course of the septa.

Little can be said of the few populations of the Aquitaine basin. Both assemblages from the Oligocene of Biarritz are distinctly different from all nordic populations, because of high $\overline{D}$ and very high $\overline{C}$ values combined with average $\overline{E}$. *N. tournoueri-bouillei* was originally described from this section, but according to authors this couple occurs together with the tighter-coiled *N. boucheri-vascus.* We were unable to distinguish two different groups of specimens in our samples, so that both quoted species evidently were based on a narrow typological species concept (pl. 5, fig. 5—8).

More interesting is the fact that the *Nummulites* from the Upper Oligocene of Escornebéou are completely different. If both Aquitaine groups are related we might suppose here a case of "degeneration", because of the much lower values of $\overline{C}$, $\overline{D}$ and $\overline{E}$ at Escornebéou. It has to be remarked that these Upper Oligocene assemblages fairly well resemble those of the "small $\overline{C}$-$\overline{E}$ race" of *N. orbignyi,* as found for instance at Oedelem. Because of the wide stratigraphic separation it is most unlikely that there could be any relationship between the populations of Oedelem and Escornebéou (pl. 5, fig. 1—4).

This strong resemblance of unrelated forms contains a warning that further research of the smaller *Nummulites* on the basis of the measurable internal features may bring together completely unrelated stocks of remote areas and different time levels. Of course, it would not be difficult to find additional morphological features on the basis of which we can differentiate such forms (e.g. the *N. rectus* group of the Hampshire basin from *N. gandinus),* but in this way we will end by recognizing the general law that every population is different from all others, which then may become expressed in as many different taxonomic units. Actually this is the way — the "evolution" of paleontologists — many promising groups of fossils went through because of the increasing knowledge of morphological details acquired by the specialists, until they became incomprehensible to everybody outside the minor circle of highly evolved specialists.

As a consequence, we now doubt whether BUTT's determination (1966) of the Escornebéou *Nummulites* as *N. bouillei* is correct; we certainly won't name them *N. orbignyi,* but we prefer to leave the naming undecided pending further research of the smaller *Nummulites* of the Aquitaine basin.

Evidently there is no general law which underlies the evolution of all smaller radiate *Nummulites.* There may be a certain development on a regional scale in some basin, but it is very unlikely that we can recognize such an evolutionary pattern with its stratigraphic implications in other basins or regions.

As a general conclusion concerning the smaller nordic *Nummulites* it seems reasonable to suppose that at some time during the Middle Eocene, the Paris, Hampshire and North Sea basins were inhabited by a closely related stock of smaller radiate *Nummulites,* probably invaders from elsewhere, which at the moment can be brought together under the name *N. gandinus.* Afterwards the three basins each had its own development of the original stock. In the North Sea basin the group probably survived longest with the successive widely variable "more progressive" population groups of *N. orbignyi* and *N. germanicus.* A

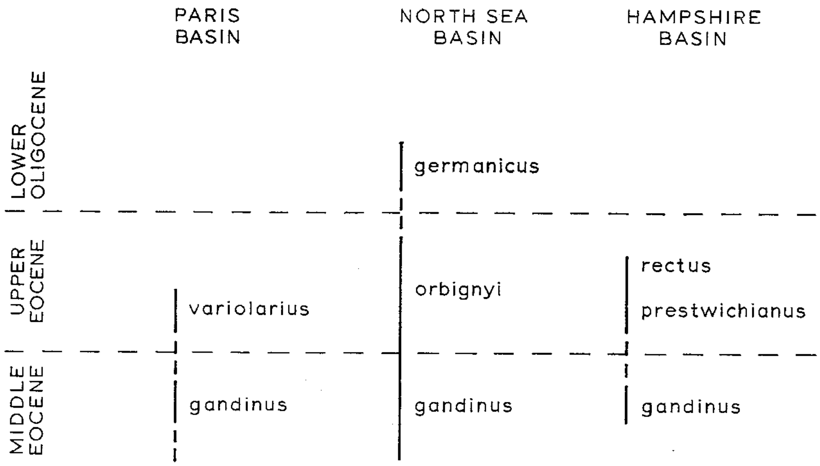


Fig. 50. Lineages of smaller radiate *Nummulites* in terms of species names for the Paris, Hampshire and North Sea basins.

different way of progression was shown in the Paris basin if we are allowed to link *N. variolarius* to the earlier *N. gandinus* of this area. In the Hampshire basin the ill-known development from *N. gandinus* to *N. prestwichianus* still might be seen as progressive because it would imply increase in all internal parameters. The further development towards *N. rectus* looks like returning to the characters of the ancestral *N. gandinus* stock, but it should be realized that we are translating our observations in trivial words, which have no more than a trivial and semantic meaning. Finally, it looks very likely that both population groups that seem to be present in the Oligocene of the Aquitaine basin, are unrelated to the nordic forms, and even to one another.

Chapter XI

STRATIGRAPHIC CONCLUSIONS

It has become very clear from the preceding chapters that the smaller radiate *Nummulites* of the Middle-Late Eocene and Oligocene are of negligible value for interregional chronostratigraphic correlation. Even within a single basin they are not very reliable for detailed correlations, though probably not much worse than other groups of fossils, if we take care of a sufficiently wide margin of error.

As a consequence the threefold morphological subdivision of the *Nummulites* of the North Sea basin has a distinct value for the age relations of the groups of assemblages, but it is of little importance for the individual samples. Even if the evolution would have been more strict, — i.e. more strongly overruling the random variation —, the statistical errors are too large for a decision whether a sample close to a boundary line belongs to one or the other group. We therefore need not be embarassed that some of our check samples just come within a field where we did not expect them.

Possibly the only case of doubt on the original stratigraphic designation may be on that of sample Mechelen 61.20 m, stated to be from the top of the Lede Sands, but which according to all its parameters would figure much better as an assemblage from the Sands of Wemmel.

As to the larger stratigraphic units the *Nummulites* do give some suggestions. Primarily the assemblages of *N. gandinus* from the Sands of Brussels (+ Vlierzele) and Sands of Lede are morphologically so close to one another that we cannot differentiate these deposits (possibly except Woensdrecht). So there is nothing against the idea of Pomerol (1961) to parallelize the Sands of Lede with the Lutetian of the Paris basin. But as yet very little pleads in favour of this idea either, because of our scanty accurate knowledge of the smaller French Lutetian *Nummulites*.

There is no clear morphological gap between the assemblages of *N. gandinus* and *N. orbignyi*, but we cannot expect stratigraphic gaps, which certainly are present, to be reflected in the rough data on our *Nummulites*. They do not show the stratigraphic gap between the Sands of Brussels and Sands of Lede either.

Yet the data on *N. orbignyi* have a certain stratigraphic importance. They show the Sands of Wemmel and the basal Asse Clays to contain the same variable group of assemblages, different from those of the Lede Sands. This would imply that these deposits are distinctly different in age, thus younger, than the Lede

Sands, and moreover, that they belong to the same stratigraphic time interval. Evidently they support the idea of earlier authors that Wemmel Sands and basal *Nummulites*-bearing Asse Clays are units which in time are mainly lateral equivalents. There is no argument from the *Nummulites* in favour of the recent assumption that the Wemmel Sands represent the top of the French Lutetian in Belgium, but there is no evidence either that they would be contemporaneous with the Auversian of Auvers or the Bartonian of the Hampshire basin. All these deposits must be considered post-Ledian, but they cannot be compared on the basis of their *Nummulites.* If the Sands of Wemmel are placed at the top of the Lutetian (sensu Pomerol et al.), the same should be done with the basal part of the Asse Clays.

As a consequence the English Bartonian would be comparable in Belgium with the barren deposits that locally overlie the lower Asse Clays: higher Asse Clays, Asse Sands and/or the major part of the Clayey-sandy deposits of Kallo, up to the fossiliferous levels of Bassevelde and Grimmertingen, of presumably Early Oligocene age, and which contain *N. germanicus.*

If we include in this Oligocene group of populations also that from Brandhorst because of the similar variants in the other assemblages, there is no great morphological gap between the Late Eocene *N. orbignyi* and the Early Oligocene *N. germanicus.* These last *Nummulites* of the group, to be found after a long absence in the record (all or part of the Bartonian) are probably not new immigrants, but more likely remnants of the old stock, which survived the Late Eocene in some as yet unknown corner of the North Sea basin.

If the near-barren sediments of Asse and Kallo really represent the major part of the nordic Upper Eocene, environmental conditions during sedimentation evidently were rather adverse to most organisms. Possibly these conditions compare with those in stagnant marine water masses, which therefore did not permit benthonic life and which may have caused calcareous skeleton material of planktonic organisms to become rapidly dissolved (Drooger, 1969). Actually, such conditions would not be so hypothetic for the North Sea basin. They probably were not so much different from those during the deposition of the Middle Oligocene Boom Clays. Only during the latter time did the anaerobic conditions commonly start somewhat deeper below the aerated upper part of the water masses, i.e. below, instead of above, the surface of the sediment, so that it was not prohibitive for bottom-dwelling organisms.

The assumption of such unfavourable bottom conditions in the offshore part of the basin, together with the commonly underestimated effect of breaks in the record of the more near-shore sediments, may oblige us to re-consider drastically our ideas of a rather "continuous" Eocene-Oligocene sedimentary series of Belgium (e.g. Curry et al., 1969).

Probably the exposed sequence consists mainly of wide gaps in the sedimentary record. In the past we have been tempted too much to consider all deposits to fit a continuous time interval. And deposits that contain comparable faunas with certain "index fossils" (i.e. species in common) of different basins were situated at strictly the same level in time. Correlation of a sediment of one place with a break elsewhere, was generally avoided, whereas such practice now seems to be much more realistic.

For instance there is no reason to suppose that the Sands of Lede in Belgium are contemporaneous all over the region, nor that their typical deposits should have a counterpart in the Paris basin. And considering the descriptions of the glauconitic lower part of the Asse Clays and its so-called "bande noire", one meets with an enormous variety of sediment types grading into those thought to be more typical for the Wemmel Sands. It is quite probable that these Asse and Wemmel deposits differ strongly in age from one place to the other, though admittedly all have to fit into a wide time interval that will exclude that of most of the underlying Sands of Lede. Such an explanation would give a better understanding of how the populations of *Nummulites* from the lower Asse Clays could be so widely different morphologically, as for instance the assemblages of Oedelem, of Kallo and of Mechelen.

The same reasoning may be applied to the fossiliferous so-called "Lower Oligocene". Since it is considered plausible from the continuous variation in the morphological character of our *Nummulites* that locally in restricted near-shore niches in the basin the Eocene benthonic shallow water fauna could survive and continue to develop, there is no reason to suppose that the "sudden" fossiliferous invasions like those of Bassevelde, Grimmertingen, Brandhorst, Helmstedt, Latdorf, etc. are strictly of the same age. They may very well reflect strongly heterochronous "moments" within a much longer time interval that bridges the hypothetic Eocene-Oligocene boundary. Whether these deposits are really Oligocene, or still topmost Eocene, is an irrelevant question.

It may seem disappointing that the renowned species of smaller *Nummulites* of the basins of northwestern Europe do not allow for clear stratigraphic correlations, because their value has been too strongly overrated in the past. However, it is well to realize once more that the Eocene-Oligocene deposits of these basins are so much provincial, that even the sporadic planktonic elements, recorded recently (BRÖNNIMANN et al., 1968; MARTINI, 1969) lack convincing arguments to consider such deposits as a basis for an international chronostratigraphic scale.

APPENDIX

In the appendix the main results of measurements and countings are given as a compilation of the data sheets. At some places certain items, especially on range or standard error, have not been entered, because the original investigator of the sample had not entered them in the compilation. Unless the date were needed for the plotting of scatter diagrams such details were not retrieved at the end.

For each sample are given from top to bottom the lithostratigraphic unit, the sample number, the locality name, and the depth in meters if the sample was derived from a boring. For check samples the *locality name* is written in italics.

For every feature the number of observations is given as N. For the directly computed features the mean is accompanied by the range (R) and for the internal features by the standard error of the mean (σ). For the ratios two different values are entered, that calculated from the ratios of all individuals (e.g. $\overline{D/C}$) with its standard error, as well as the ratio of the partial means (e.g. $\bar{D}/\bar{C}$).

All data on A, B, C and D are given in microns. It will be evident from the following tables that for the ranges the last digit of the recorded numbers does not correspond to a degree of accuracy in the measurement. If a reader might be interested in this degree of accuracy he may easily calculate it from the recorded numbers.

North Sea basin

Strat. unit Number Locality depth	Lede Brussegem 29.75	Wemmel Brussegem 25.90	Wemmel Brussegem 24.20	Wemmel Brussegem 22.20	Wemmel Brussegem 21.30
$\overline{A}$	1206	1530	1443	1346	1411
R	837—1650	1092—1867	1041—2438	1041—1778	990—2032
N	57	32	35	34	40
$\overline{B}$	344	392	292	255	297
R	250—488	279—508	191—406	191—318	178—406
N	57	32	39	34	49
$\overline{2B/A}$	0.584	0.513	0.429	0.384	0.440
σ	0.011	0.015	0.018	0.011	0.013
$2\overline{B}/\overline{A}$	0.570	0.512	0.404	0.379	0.422
$\overline{C}$	73.0	80.9	75.1	77.7	82.9
σ	2.7	2.9	2.8	4.2	3.3
R	38—152	57—133	51—140	44—127	57—140
N	52	32	41	33	48
$\overline{D}$	776	851	920	890	966
σ	20	13	19	33	20
R	527—1067	673—1016	635—1168	597—1206	737—1245
N	52	32	37	33	46
$\overline{D/C}$	10.94	10.75	12.70	11.90	12.36
σ	0.31	0.28	0.34	0.34	0.30
$\overline{D}/\overline{C}$	10.63	10.51	12.26	11.45	11.65
$\overline{E}$	21.15	21.78	20.16	19.42	21.84
σ	0.30	0.27	0.32	0.39	0.29
R	17—28	19—24	15—25	16—25	17—27
N	52	32	37	33	46

North Sea basin

S.u. Nr. Loc. d.	Wemmel Brussegem 20.25	Wemmel Brussegem 19.20	Wemmel Brussegem 18.20	Wemmel Brussegem 17.20	Asse Brussegem 16.50
$\overline{A}$	1483	1526	1561	1489	1635
R	1016—1956	1118—2070	1143—2337	1143—2032	990—2463
N	32	36	36	36	37
$\overline{B}$	302	318	304	331	452
R	229—394	241—508	229—457	229—495	
N	32	36	36	36	38
$\overline{2B/A}$	0.412	0.425	0.397	0.445	0.545
σ	0.012	0.015	0.013	0.011	0.013
$2\overline{B}/\overline{A}$	0.404	0.416	0.389	0.445	0.552
$\overline{C}$	109.3	109.5	121.0	94.0	118.0
σ	6.6	3.9	5.1	4.7	4.4
R	63—241	51—159	70—159	51—140	63—165
N	32	37	36	35	42
$\overline{D}$	991	1110	1050	958	1070
σ	32	28	21	27	38
R	699—1422	762—1473	762—1245	619—1232	571—1524
N	32	37	36	36	42
$\overline{D/C}$	9.27	10.40	8.93	10.67	9.21
σ		0.28	0.25	0.31	0.22
$\overline{D}/\overline{C}$	9.06	10.14	8.66	10.20	9.06
$\overline{E}$	22.72	22.22	22.61	21.81	22.41
σ	0.41	0.31	0.24	0.36	0.26
R	18—27	18—25	19—25	18—25	19—26
N	32	37	36	36	43

North Sea basin

S.u. Nr. Loc. d.	Lede Mechelen 61.20	Wemmel Mechelen 55.00	Asse Mechelen 50.00	Asse Mechelen 49.00	Asse Mechelen 46.00
$\overline{A}$	1516	1270	1381	1511	1560
R	975—2175	975—1725	1000—2175	950—2125	975—2475
N	46	51	52	44	53
$\overline{B}$	341	280	281	346	368
R	200—475	100—475	175—450	250—500	175—575
N	46	51	52	44	53
$\overline{2B/A}$	0.455	0.448	0.412	0.470	0.483
σ	0.011	0.021	0.012	0.016	0.015
$2\overline{B}/\overline{A}$	0.450	0.440	0.407	0.457	0.472
$\overline{C}$	111.4	82.9	99.7	129.5	122.6
σ	3.7	3.4	3.8	4.3	3.8
R	38—178	38—165	38—165	76—228	44—178
N	58	59	60	60	60
$\overline{D}$	982	895	960	1083	1050
σ	22	23	24	28	23
R	483—1397	584—1283	571—1321	673—1714	521—1448
N	58	59	60	58	60
$\overline{D/C}$	9.17	11.72	10.19	8.59	8.83
σ	0.25	0.35	0.32	0.12	0.19
$\overline{D}/\overline{C}$	8.82	10.79	9.63	8.36	8.57
$\overline{E}$	23.43	21.03	21.78	24.32	23.20
σ	0.28	0.29	0.30	0.31	0.30
R	18—27	18—28	18—26	19—31	17—27
N	58	58	60	59	60

North Sea basin

S.u. Nr. Loc. d.	Vlierzele Asse 45—46	Lede Asse 44	Lede Asse 43	Lede Asse 40—41	Lede Asse 39—40	Lede Asse 38
$\overline{A}$	1099	1150	1109	1117	1151	1115
R	825—1450	900—1700	875—1300	925—1575	925—1700	950—1500
N	51	56	41	47	45	45
$\overline{B}$	390	392	397	404	433	437
R	275—500	300—525	275—500	325—575	325—550	325—575
N	51	56	41	47	45	45
$\overline{2B/A}$	0.718	0.687	0.717	0.726	0.755	0.786
σ	0.014	0.014	0.016	0.012	0.016	0.016
$2\overline{B}/\overline{A}$	0.709	0.681	0.716	0.723	0.752	0.783
$\overline{C}$	61.5	73.3	65.4	64.9	66.5	63.9
σ	2.3	2.2	3.2	2.7	3.4	3.3
R	32—89	32—102	25—121	25—102	25—114	25—127
N	51	54	41	47	45	45
$\overline{D}$	769	783	746	747	761	761
σ	16	17	19	15	20	22
R	572—1016	419—1016	533—1130	572—991	483—1156	546—1105
N	50	53	41	47	45	44
$\overline{D/C}$	13.20	10.94	12.34	12.17	12.78	12.71
σ	0.41	0.28	0.49	0.43	0.48	0.52
$\overline{D}/\overline{C}$	12.51	10.69	11.41	11.51	11.44	11.91
$\overline{E}$	21.32	21.37	20.85	20.89	20.86	21.23
σ	0.25	0.23	0.28	0.25	0.21	0.24
R	17—25	18—25	18—26	17—23	18—24	17—25
N	50	53	38	45	43	44

North Sea basin

S.u.	Wemmel	Wemmel	Wemmel	Wemmel	Wemmel
Nr.					
Loc.	Asse	Asse	Aardenburg	Aardenburg	Aardenburg
d.	36	34	35.45—36.5	35—35.45	33—33.5
$\overline{A}$	1361	1362	1775	1623	1618
R	1050—1800	1050—1950	1143—2210	1270—2007	1308—2095
N	48	51	32	38	24
$\overline{B}$	354	364	346	351	223
R	225—475	250—500	254—444	241—444	127—317
N	48	51	32	38	24
$\overline{2B/A}$	0.528	0.540	0.395	0.437	0.279
σ	0.015	0.012	0.012	0.013	0.010
$2\overline{B}/\overline{A}$	0.520	0.535	0.390	0.433	0.276
$\overline{C}$	68.4	77.2	65.7	70.0	51.6
σ	3.4	4.1	2.4	3.0	2.9
R	25—114	32—152	32—89	38—127	32—83
N	48	51	32	38	24
$\overline{D}$	911	960	864	795	911
σ	27	31	21	20	36
R	597—1333	546—1575	584—1105	572—1092	660—1295
N	48	51	32	38	24
$\overline{D/C}$	14.36	13.33	13.51	11.99	18.29
σ	0.51	0.49	0.40	0.39	0.64
$\overline{D}/\overline{C}$	13.31	12.44	13.15	11.36	17.66
$\overline{E}$	21.06	21.51	20.03	20.29	17.39
σ	0.33	0.35	0.32	0.39	0.27
R	16—26	16—27	16—23	15—24	16—20
N	46	51	30	35	23

North Sea basin

S.u. Nr. Loc. d.	Brussels Woensdrecht 361.70 (I)	Brussels Woensdrecht 361.70 (II)	Brussels Woensdrecht 360.50	Brussels THB 1192 Nalinnes	Lede ZG 1025 I Balegem	Lede MC 1040 Meldert
$\overline{A}$	2490	749	803	1282	1027	1495
R	1950—3250	500—1025	625—1000	1054—1714	787—1460	1333—1778
N	45	49	59	18	24	31
$\overline{B}$	611	235	202	385	389	435
R	400—750	125—350	100—300	317—508	330—470	330—533
N	45	49	59	22	25	33
$\overline{2B/A}$	0.492	0.635	0.500	0.611	0.764	0.578
σ	0.011	0.020	0.013	0.014	0.013	0.012
$2\overline{B}/\overline{A}$	0.491	0.628	0.504	0.601	0.757	0.582
$\overline{C}$	424.3	35.8	37.8	75.9	58.7	81.4
σ	11.2	1.4	1.0	2.2	2.9	2.9
R	241—584	25—63	25—51	63—89	32—95	51—127
N	47	49	59	22	25	32
$\overline{D}$	1953	488	503	794	625	799
σ	40	11	9	12	18	15
R	1346—2485	343—711	317—673	698—914	444—787	635—1029
N	44	49	59	22	25	32
$\overline{D/C}$	4.61	14.32	13.73	10.59	10.94	10.13
σ	0.12	0.47	0.38	0.25	0.37	0.31
$\overline{D}/\overline{C}$	4.60	13.57	13.29	10.45	10.65	9.82
$\overline{E}$	30.89	21.94	21.08	20.35	19.72	21.22
σ		0.21	0.18	0.31	0.32	0.30
R	26—38	18—26	19—26	17—23	17—23	16—24
N	44	49	59	20	25	32

North Sea basin

S.u. Nr. Loc. d.	Lede ZD 1012 Bambrugge	Lede ZD 1013 Bambrugge	Lede ZD 1016 Bambrugge	Lede ZB 1021A *Vlierzele*	Wemmel BG 48 Wemmel	Wemmel BG 48 Wemmel
$\overline{A}$	1259	1350	1301	1231	1745	1640
R	1079—1562	1194—1753	1143—1600	910—1534	1377—2142	1170—2220
N	50	41	36	34	51	41
$\overline{B}$	406	331	384	377	465	382
R	317—508	254—457	279—483	286—494	306—638	255—510
N	50	46	60	34	50	41
$\overline{2B/A}$	0.648	0.490	0.577	0.61	0.534	0.457
σ	0.009	0.013	0.009	0.01	0.010	0.010
$2\overline{B}/\overline{A}$	0.645	0.491	0.597	0.61	0.533	0.465
$\overline{C}$	63.2	62.5	67.9	59.8	99.6	102.0
σ	1.8	1.9	2.7	1.8	3.2	5.2
R	38—102	38—95	38—102	39—104	51—191	51—204
N	49	45	36	49	50	41
$\overline{D}$	677	667	722	651	973	930
σ	13	12	14	12	23	
R	444—952	559—889	571—965	494—858	689—1607	660—1330
N	49	45	36	49	50	41
$\overline{D/C}$	10.90	10.88	11.07	11.51	10.07	9.16
σ	0.25	0.25	0.39	0.28	0.30	0.32
$\overline{D}/\overline{C}$	10.70	10.68	10.62	10.81	9.77	9.15
$\overline{E}$	20.69	21.09	20.92	20.44	22.50	22.0
σ	0.20	0.18	0.33	0.19	0.25	0.28
R	18—24	19—25	18—27	18—23	19—27	19—26
N	49	45	36	49	48	41

North Sea basin

S.u. Nr. Loc. d.	Wemmel Heysel	Wemmel 14 Wemmel 10.5—11	Wemmel 16 Wemmel 7	Wemmel BS 1260 *Jette*	Asse ZA 1244 *Ghent*
$\overline{A}$	1390	1503	1922		1478
R	1016—1778	1105—1994	1549—2476		728—2028
N	25	29	49		13
$\overline{B}$	284	241	409		272
R	190—432	152—317	305—533		182—390
N	26	29	50		13
$\overline{2B/A}$	0.417	0.330	0.432		0.374
σ	0.025	0.012	0.009		0.03
$2\overline{B}/\overline{A}$	0.409	0.321	0.426		0.368
$\overline{C}$	69.1	79.2	124.8	62	64
σ	3.4	3.3	3.3	1.1	4.4
R	44—114	44—114	63—178	32—104	26—104
N	25	29	50	17	32
$\overline{D}$	851	1078	1126	718	1002
σ	26	40	22	27	40
R	660—1219	724—1575	673—1460	520—884	572—1560
N	25	29	50	15	32
$\overline{D/C}$	12.72	13.87	9.15	13.20	17.90
σ	0.44	0.41	0.14	0.58	1.10
$\overline{D}/\overline{C}$	12.32	13.60	9.02	11.58	15.66
$\overline{E}$	19.36	19.90	23.21	18.73	19.56
σ	0.47	0.27	0.31	0.36	0.36
R	15—24	17—23	18—27	16—21	16—24
N	22	29	48	15	32

North Sea basin

S.u. Nr. Loc. d.	Asse BRB 1056 Oedelem	Asse BRB 246 Oedelem	Asse BRB 1054 Oedelem	Asse *Kallo* 178	Asse *Kallo* 179
$\overline{A}$	1518	1465	1262	967	1790
R	1143—1880	851—1956	521—1803	520—2200	1404—2366
N	24	28	28	30	26
$\overline{B}$	230	275	228	148	287
R	127—406	165—470	140—305	80—200	208—390
N	24	28	29	44	26
$\overline{2B/A}$	0.319	0.403	0.377	0.334	0.321
σ	0.037	0.032	0.024	0.015	0.015
$2\overline{B}/\overline{A}$	0.303	0.375	0.362	0.306	0.32
$\overline{C}$	46.7	53.7	56.9	80.3	89
σ	2.4	2.8	2.2	3.2	2.8
R	25—70	32—76	38—83	40—143	52—130
N	24	28	29	46	50
$\overline{D}$	797	840	857	1104	1165
σ	42	30	25	70	27
R	381—1156	508—1105	635—1206	700—1400	702—1690
N	24	27	29	10	50
$\overline{D/C}$	17.37	16.49	15.43	13.74	13.42
σ	0.83	0.77	0.49	0.77	0.29
$\overline{D}/\overline{C}$	17.06	15.64	15.06	13.74	13.27
$\overline{E}$	17.12	18.70	18.03	20.10	20.46
σ	0.23	0.31	0.27	0.42	0.25
R	15—20	15—22	16—21	16—23	15—24
N	24	27	29	20	50

North Sea basin

S.u. Nr. Loc. d.	Asse BW 1273 Wemmel	L. Oligocene Brandhorst	L. Oligocene Kühlerhof 448—460	Grimmert-ingen Hendrik IV 194—195	Basseveld *Basseveld* 22
$\overline{A}$	1582	1317	1721	2188	1596
R	1308—2057	1130—1524	1359—2540	1511—3302	1125—2400
N	50	18	20	16	60
$\overline{B}$	338	300	355	356	367
R	229—508	229—381	254—445	305—445	275—600
N	50	13	20	12	60
$\overline{2B/A}$	0.430	0.460	0.413	0.366	0.467
σ	0.011	0.021		0.020	0.011
$2\overline{B}/\overline{A}$	0.427	0.455		0.325	0.460
$\overline{C}$	104.5	67.7	117.5	130.6	161
σ	3.7	2.5		5.2	4
R	38—152	51—89	64—152	83—165	113—250
N	50	18	20	16	60
$\overline{D}$	966	1074	1409	1534	1389
σ	26	30		58	32
R	521—1384	826—1245	1058—1803	1105—2159	1075—2000
N	50	15	20	16	60
$\overline{D/C}$	9.48	16.07	12.0	11.90	8.80
σ	0.21	0.55		0.41	0.16
$\overline{D}/\overline{C}$	9.24	15.85		11.75	8.65
E	22.44	17.73	23.00	24.87	25.95
σ	0.28	0.35	0.59	0.48	0.27
R	17—27	15—20	17—27	22—28	21—31
N	50	15	20	16	60

Hampshire basin

S.u. Nr. Loc.	Bracklesham EG 1 Whitecliff B.	Barton EG 114A Alum Bay	Barton EG 115A Alum Bay	Barton EG 116A Alum Bay	Barton EG 117A Alum Bay
$\overline{A}$	1449	1321	934	1523	909
R		1075—1887	900—987	1162—1875	725—1175
N	26	23	4	9	39
$\overline{B}$	392	140	102	128	207
R	292—508	87—219	87—137	69—181	100—312
N	26	23	4	9	40
$\overline{2B/A}$	0.544	0.216	0.218	0.165	0.452
σ	0.013	0.010	0.033	0.010	0.019
$2\overline{B}/\overline{A}$	0.541	0.212	0.217	0.168	0.455
$\overline{C}$	72.0	103.7	71.9	85.6	84.5
σ	3.2	4.0	10.4	5.1	3.2
R	38—114	69—137	50—94	62—106	56—162
N	26	23	4	10	42
$\overline{D}$	721	1069	881	1034	821
σ	17	16	57	31	16
R	533—952	906—1212	750—962	937—1200	612—1075
N	26	23	4	10	42
$\overline{D/C}$	10.34	10.63	12.63	12.78	10.12
σ	0.35	0.43	1.55	0.60	0.33
$\overline{D}/\overline{C}$	10.02	10.30	12.26	12.08	9.71
$\overline{E}$	19.38	22.52	19.25	20.50	20.07
σ	0.20	0.35	1.02	0.76	0.21
R	17—21	19—25	16—21	17—25	18—23
N	26	23	4	10	42

Hampshire basin

S.u. Nr. Loc.	Barton EG 165 Alum Bay	Barton EG 166 Alum Bay	Barton EG 167 Alum Bay	Barton EG 168 Alum Bay	Barton EG 169 Alum Bay	Barton EG 170 Alum Bay
$\overline{A}$	1966	1464	1696	1469	1518	1692
R	1075—2775	937—2175	825—2275	650—2350	975—1987	825—2325
N	52	12	42	76	40	57
$\overline{B}$	185	145	190	219	288	344
R	100—275	75—225	125—300	100—450	200—375	175—450
N	57	12	43	83	36	55
$\overline{2B/A}$	0.190	0.197	0.228	0.311	0.375	0.411
σ	0.005	0.013	0.006	0.010	0.009	0.010
$2\overline{B}/\overline{A}$	0.188	0.198	0.224	0.298	0.380	0.407
$\overline{C}$	96.7	90.7	91.5	61.9	76.0	62.1
σ	2.7	2.7	3.4	1.4	2.2	1.5
R	50—150	62—125	44—150	37—100	41—106	37—87
N	57	23	54	83	53	57
$\overline{D}$	1116	1088	1003	936	781	759
σ	18	26	20	16	13	8
R	712—1475	887—1325	669—1500	675—1262	540—937	600—887
N	54	18	50	74	54	56
$\overline{D/C}$	12.05	12.48	11.71	15.33	10.48	12.59
σ	0.34	0.39	0.34	0.27	0.20	0.31
$\overline{D}/\overline{C}$	11.54	11.99	10.96	15.13	10.28	12.23
$\overline{E}$	22.96	22.96	21.65	19.57	19.80	19.63
σ	0.28	0.47	0.36	0.15	0.22	0.16
R	19—27	20—31	17—27	17—22	17—23	18—22
N	55	23	51	77	51	56

Hampshire basin

S.u. Nr. Loc.	Barton EG 150 Highcliffe	Barton EG 151 Highcliffe	Barton EG 155 Highcliffe
$\bar{A}$	872	1189	1596
R	575—1100	800—1700	900—2625
N	39	15	41
$\bar{B}$	240	222	277
R	100—425	125—300	175—450
N	39	15	40
$\overline{2B/A}$	0.552	0.374	0.367
σ	0.019	0.012	0.014
$2\bar{B}/\bar{A}$	0.551	0.373	0.347
$\bar{C}$	74.0	78.7	91.4
σ	3.1	3.2	2.7
R	37—100	62—100	62—150
N	39	15	43
$\bar{D}$	728	788	868
σ	19	14	12
R	437—950	712—887	687—1062
N	33	15	43
$\overline{D/C}$	10.58	10.19	9.73
σ	0.38	0.36	0.24
$\bar{D}/\bar{C}$	9.84	10.01	9.50
$\bar{E}$	21.27	19.87	20.88
σ	0.44	0.25	0.22
R	14—26	18—22	18—24
N	33	15	43

Paris basin

S.u. Nr. Loc.	Lutetian *Fercourt*	Auvers FR 1036 *Auvers*	Auvers FR 563 Auvers	Auvers FR 564 Auvers	Auvers FR 565 Auvers	Auvers FR 566 Auvers
$\overline{A}$	1081	1437		1425	1458	1462
R	832—1300	1118—1742	1225—1325	950—1750	1050—1800	1250—1675
N	6	37	2	38	15	8
$\overline{B}$	331	455		477	462	453
R	234—416	312—624	425—500	300—650	350—575	350—550
N	6	37	2	48	15	8
$\overline{2B/A}$	0.598	0.633	0.729	0.703	0.643	0.624
σ	0.022	0.018		0.021	0.024	0.036
$2\overline{B}/\overline{A}$	0.612	0.632		0.669	0.633	0.620
$\overline{C}$	44.7	124	115.5	121.1	130.6	136.1
σ	2.1	2.7	4.5	3.0	3.1	6.5
R	39—52	78—182	75—150	62—162	94—200	75—275
N	9	51	17	48	41	46
$\overline{D}$	685	855	847	799	858	913
σ	23	10	14	12	11	37
R	598—858	702—1066	725—950	600—962	775—987	687—1625
N	9	51	17	47	37	42
$\overline{D/C}$	15.50	7.02	7.55	6.64	6.68	
σ	0.63	0.15	0.33	0.14	0.15	
$\overline{D}/\overline{C}$	15.31	6.88	7.33	6.59	6.57	6.71
$\overline{E}$	19.22	23.09	22.17	23.00	23.67	24.86
σ	0.21	0.19	0.55	0.22	0.26	0.64
R	18—20	19—27	20—24	20—27	20—27	21—36
N	9	51	6	47	36	37

Aquitaine basin

S.u.	Oligocene	Oligocene	Oligocene	Oligocene
Nr.	FR 650	FR 534	AQ 18	AQ 19
Loc.	Rocher Vierge	Ch. d'Amour	*Escornebéou*	*Escornebéou*
$\overline{A}$	1820	1533	1300	1552
R	1350—2350	1000—2750	936—1716	1025—2275
N	34	25	59	59
$\overline{B}$	500	398	250	323
R	350—750	150—750	150—400	200—600
N	36	49	59	59
$\overline{2B/A}$	0.540	0.527		
σ	0.019	0.034		
$2\overline{B}/\overline{A}$	0.549	0.520	0.384	0.415
$\overline{C}$	210.4	191.5	68	75
σ	6.5	15.2	2.1	3.3
R	137—312	62—412	38—125	50—175
N	36	38	59	59
$\overline{D}$	1302	1468	823	833
σ	25	73	21	22
R	875—1562	725—2187	550—1475	550—1475
N	33	33	59	59
$\overline{D/C}$	6.27	9.24	12.54	11.85
σ	0.15	0.67	0.30	0.33
$\overline{D}/\overline{C}$	6.19	7.67	12.17	11.11
$\overline{E}$	22.53	21.09	17.16	17.38
σ	0.36	0.41	0.17	0.21
R	18—26	17—25	13—20	15—20
N	34	33	56	58

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PLATE 1

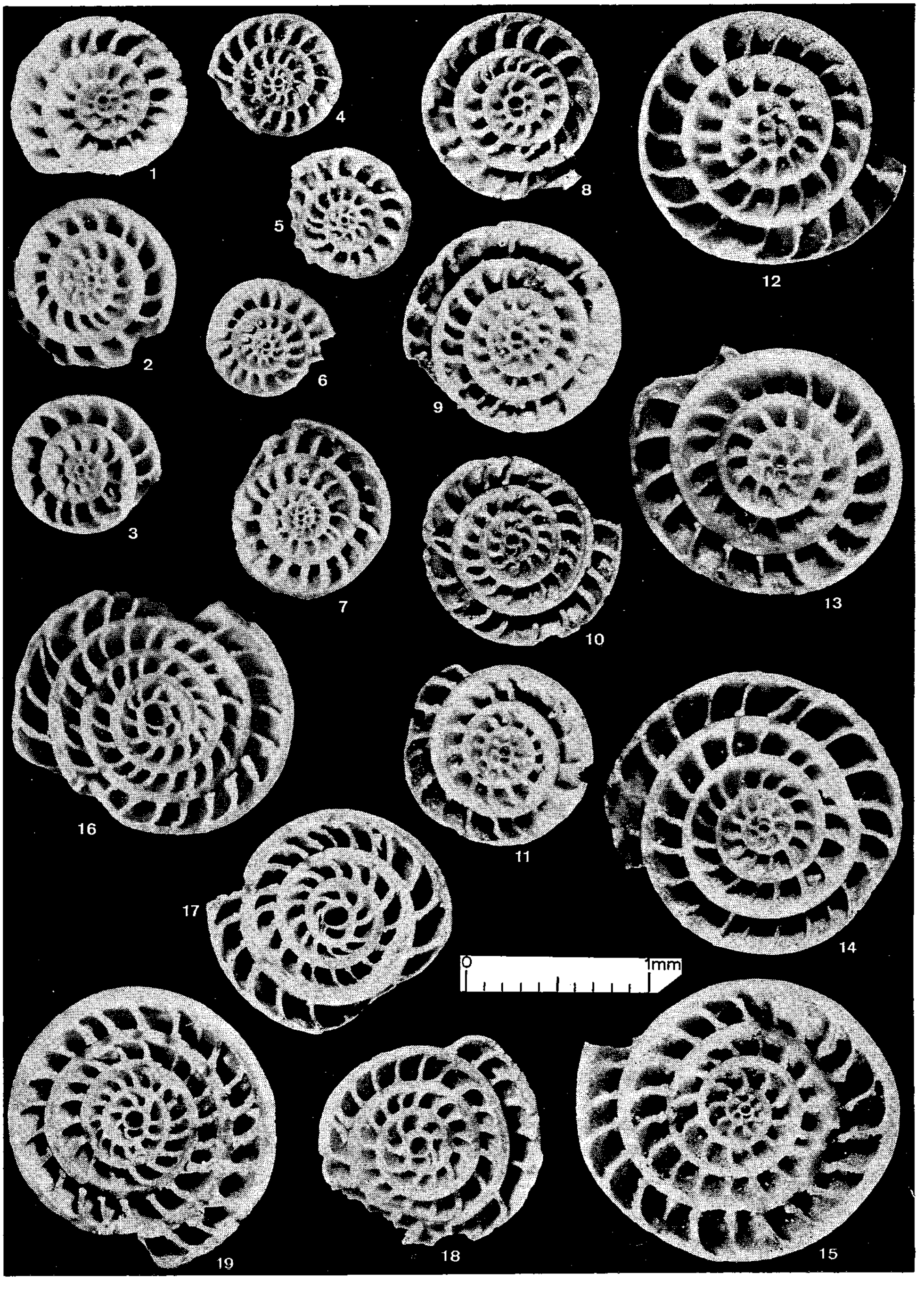

PLATE 1

All figures X 26, arranged in such a fashion that the protoconch-deuteroconch are on a vertical line. Decreasing protoconch size within a sample with ascending figure numbers.

Figs. 1—3: *Nummulites gandinus* (ROZLOZSNICK)
Fercourt, from a sample with $\overline{D}$ = 685μ; $\overline{D/C}$ = 15.50; $\overline{C}$ = 44.7 μ; $\overline{E}$ = 19.22.

Figs. 4—7: *Nummulites gandinus* (ROZLOZSNICK)
Woensdrecht, boring at 361.70 m. From a sample with $\overline{D}$ = 488 μ; $\overline{D/C}$ = 14.32; $\overline{C}$ = 35.8 μ; $\overline{E}$ = 21.94.

Figs. 8—11: *Nummulites gandinus* (ROZLOZSNICK)
Bambrugge, ZD 1012. From a sample with $\overline{D}$ = 677 μ; $\overline{D/C}$ = 10.90; $\overline{C}$ = 63.2μ; $\overline{E}$ = 20.69.

Figs. 12—15: *Nummulites gandinus* (ROZLOZSNICK)
Whitecliff Bay, Isle of Wight, EG 1. From a sample with $\overline{D}$ = 721 μ; $\overline{D/C}$ = 10.34; $\overline{C}$ = 72.0 μ; $\overline{E}$ = 19.38.

Figs. 16—19: *Nummulites variolarius* (LAMARCK)
Auvers, FR 564. From a sample with $\overline{D}$ = 799 μ; $\overline{D/C}$ = 6.64; $\overline{C}$ = 121.1 μ; $\overline{E}$ = 23.00.

PLATE 2

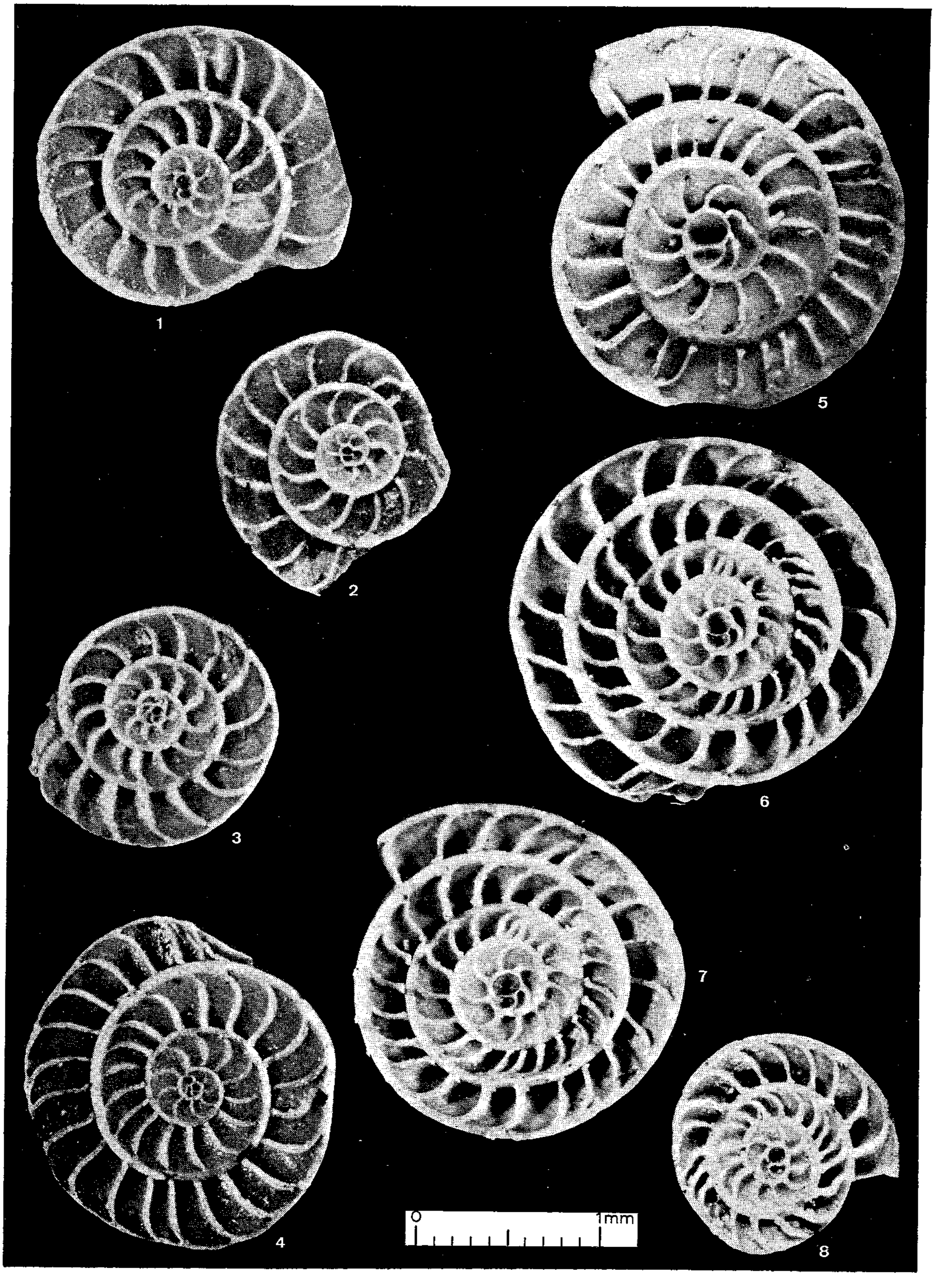

PLATE 2

All figures X 26, arranged in such a fashion that the protoconch-deuteroconch are on a vertical line. Decreasing protoconch size within a sample with ascending figure numbers.

Figs. 1—4: *Nummulites orbignyi* (GALEOTTI)
Oedelem, BRB 1056. From a sample with $\overline{D} = 797\mu$; $\overline{D/C} = 17.37$; $\overline{C} = 46.7\ \mu$; $\overline{E} = 17.12$.

Figs. 5—8: *Nummulites orbignyi* (GALEOTTI)
Boring Mechelen 49 m. From a sample with $\overline{D} = 1083\ \mu$; $\overline{D/C} = 8.59$; $\overline{C} = 129.5\ \mu$; $\overline{E} = 24.32$.

PLATE 3

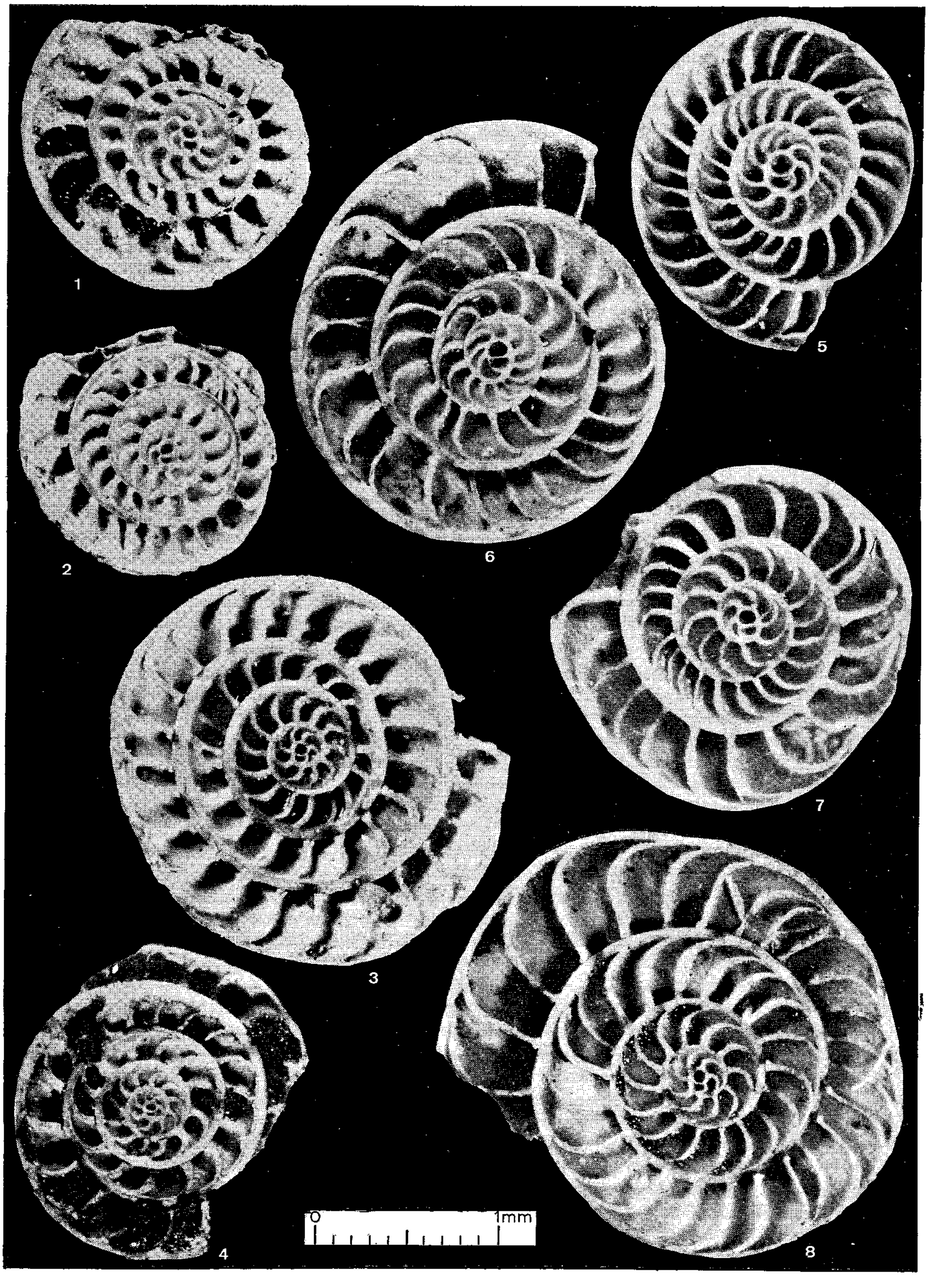

PLATE 3

All figures X 26, arranged in such a fashion that the protoconch-deuteroconch are on a vertical line. Decreasing protoconch size within a sample with ascending figure numbers.

Figs. 1—4: *Nummulites rectus* CURRY
Alum Bay, Isle of Wight, EG 170. From a sample with $\overline{D} = 759\ \mu$; $\overline{D/C} = 12.59$; $\overline{C} = 62.1\ \mu$; $\overline{E} = 19.63$.

Figs. 5—8: *Nummulites prestwichianus* (JONES)
Alum Bay, Isle of Wight, EG 165. From a sample with $\overline{D} = 1116\ \mu$; $\overline{D/C} = 12.05$; $\overline{C} = 96.7\ \mu$; $\overline{E} = 22.96$.

PLATE 4

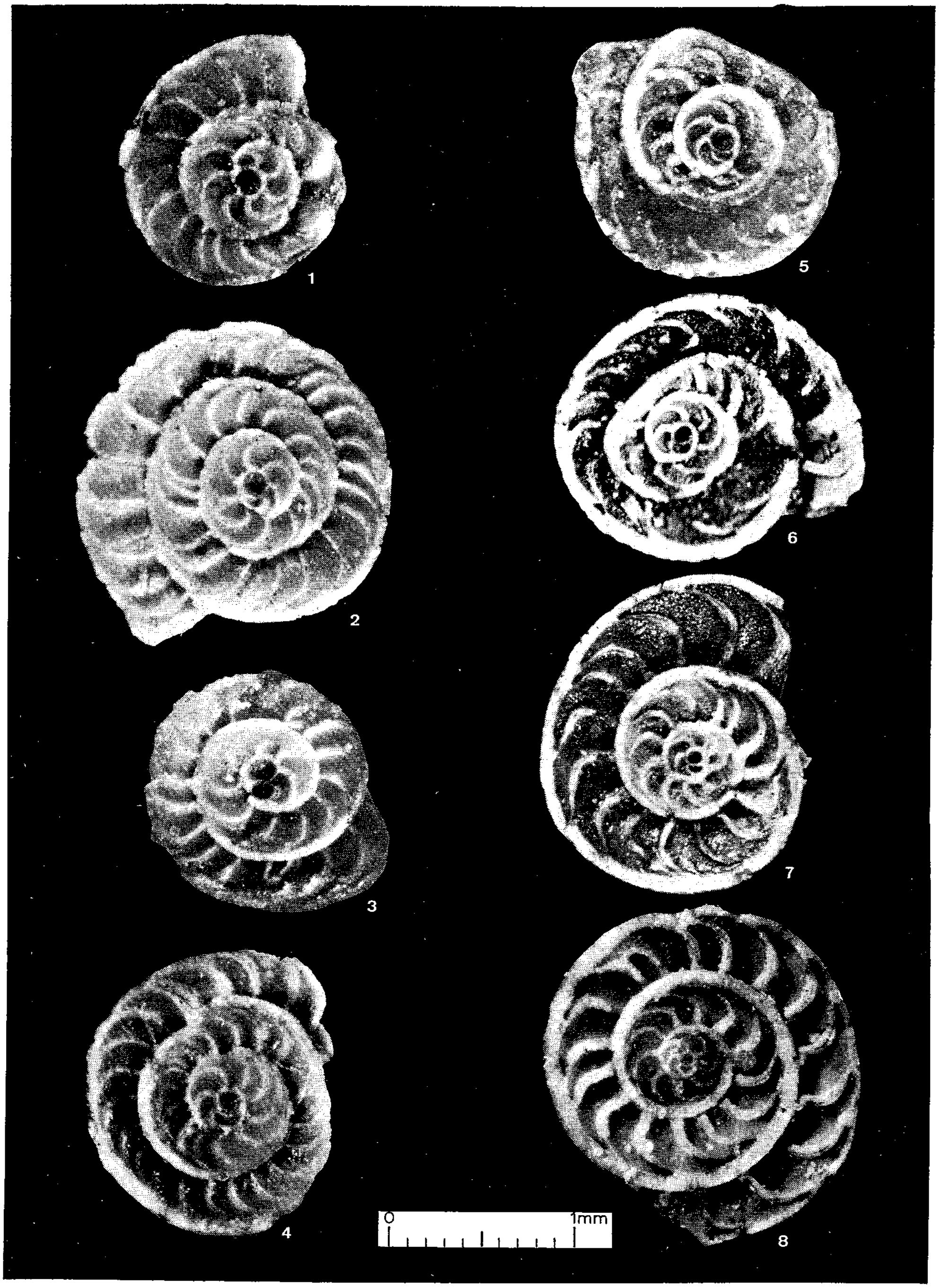

PLATE 4

All figures X 26, arranged in such a fashion that the protoconch-deuteroconch are on a vertical line. Decreasing protoconch size within a sample with ascending figure numbers.

Figs. 1—4: *Nummulites germanicus* (BORNEMANN)
Boring Bassevelde at 22 m. From a sample with $\overline{D} = 1389\ \mu$; $\overline{D/C} = 8.80$; $\overline{C} = 161.0\ \mu$; $\overline{E} = 25.95$.

Figs. 5—8: *Nummulites germanicus* (BORNEMANN)
Vahrenkamp (Brandhorst) near Bünde, W. Germany, sample No. DL 242.

PLATE 5

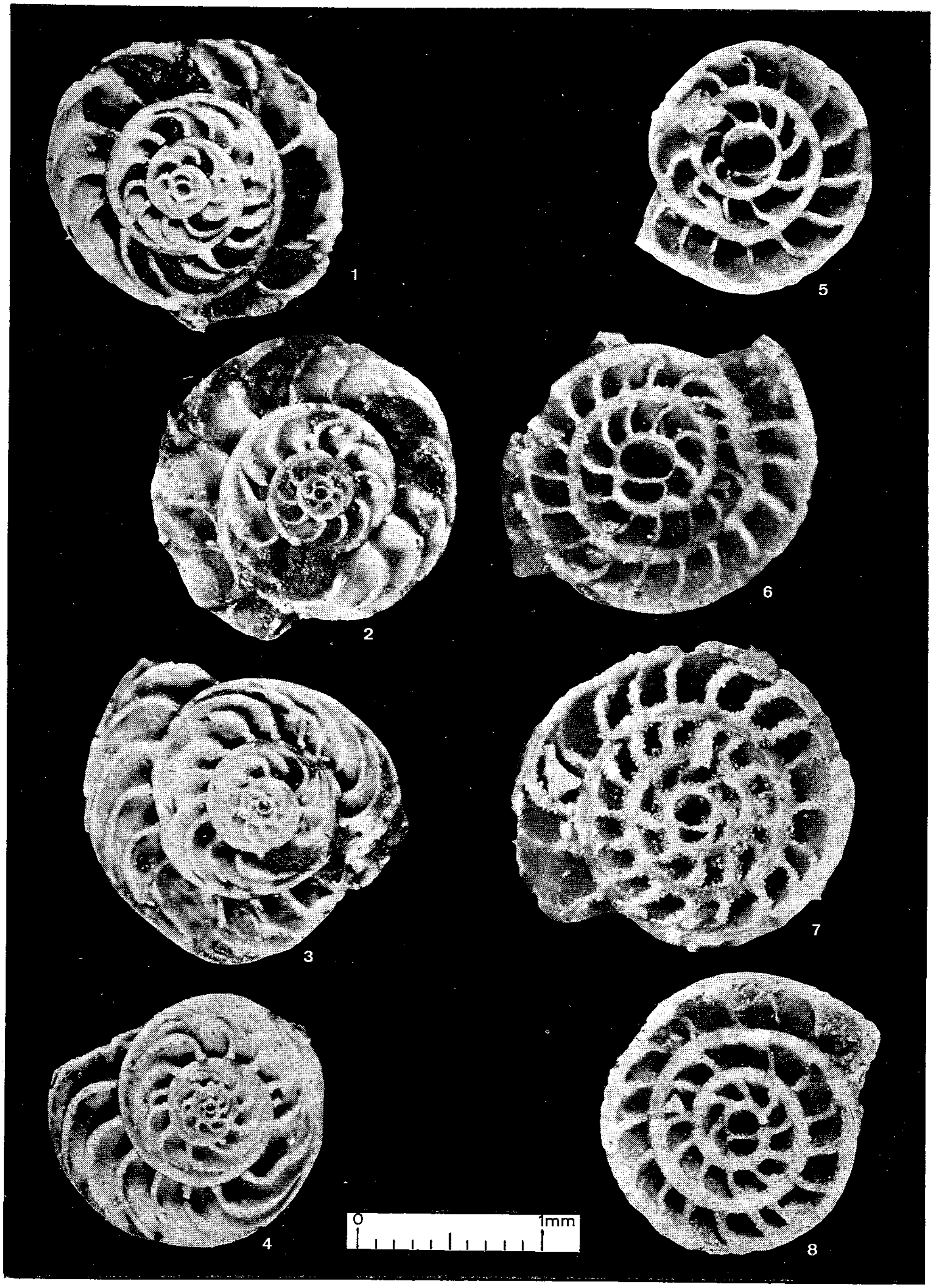

PLATE 5

All figures X 26, arranged in such a fashion that the protoconch-deuteroconch are on a vertical line. Decreasing protoconch size within a sample with ascending figure numbers.

Figs. 1—4: *Nummulites "tournoueri-bouillei"*, Escornebéou, Landes, AQ 19. From a sample with $\overline{D} = 833\ \mu$; $\overline{D/C} = 11.85$; $\overline{C} = 75.0\ \mu$; $\overline{E} = 17.38$.

Figs. 5—8: *Nummulites "tournoueri-bouillei"*, Rocher de la Vierge, Biarritz, FR 650. From a sample with $\overline{D} = 1302\ \mu$; $\overline{D/C} = 6.27$; $\overline{C} = 210.4\ \mu$; $\overline{E} = 22.53$.

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