1. INTRODUCTION

1.1. Purpose of study

The Oligocene nannoplankton has been less studied than that of any other interval of the Tertiary. Much argument has been going on about the planktonic foraminiferal zonations and the position of the boundaries of that interval. It was hoped that a careful study of the calcareous nannoplankton might result in a more satisfactory subdivision of the Oligocene and allow worldwide correlation.

The following program was made before the present study was started:

1. Electron and light microscope study of the calcareous nannofossils from the below listed sequences. Summation of the data accumulated provides a relatively complete record of the Oligocene interval.

A. JOIDES Hole 5 from the Blake Plateau as base.

B. JOIDES Hole 6 and Hole 3.

C. Trinidad, type localities of the zones of BOLLI (1957).

D. Barbados, Lower Oligocene which is absent from Trinidad.

E. Gulf coast; a complete section through the Oligocene as a check for the established zonation.

Type Oligocene area in Europe:

F. Latdorfian of pit Treue IV near Helmstedt.

G. Rupelton of Germany (brick yard Alversdorf, near Helmstedt).

H. Boom clay of Belgium, type locality for the Rupelian, near Boom.

I. Chattian section from Glimmerode near Kassel.

K. Monte Cagnero section as a Mediterranean Oligocene section which is continuous and contains abundant planktonic foraminifera.

2. Correlation of nannofossils and planktonic foraminiferal zones for this interval.

3. Establishing the position of the European and U.S. Gulf Coast stages in the new zonal scheme as far as possible.

1.2. History of European and American stages and limits of the Oligocene

BEYRICH (1854) introduced the term Oligocene for sediments which he thought to be younger than the Eocene and older than the Miocene of LYELL (1833) and which are the result of a great marine transgression in Northern Europe. The following stages were mainly defined in the 19th century in Northern Germany, in Belgium, in the Paris Basin, and in the U.S. Gulf Coast Province.

Tongrian (DUMONT, 1839) for the sables de Grimmertingen, sables de Neereppen and sables de Vieux Joncs (Belgium). Fully marine.

Rupelian (DUMONT, 1849) for the sables de Berg and the argile de Boom (Belgium). Fully marine.

Stampian (D'ORBIGNY, 1852) for the beds from the argile vert de Romainville to the calcaire d'Etampes (Paris Basin). Marine, brackish to limnish.

Sannoisian (MUNIER CHALMAS & DE LAPPARENT, 1893) for the marnes supra-gypseuses and the calcaire de Sannois (Paris Basin). Brackish to limnish.

Latdorfian (MAYER-EYMAR, 1893) (also sp. Lattorfian) for the beds at Latdorf, Northern Germany. Molluscs described by KOENEN. 1889–94. Fully marine.

Chattian (FUCHS, 1894) for the sands of Kassel at the Gelbe Berg near Nieder-kaufungen. Fully marine.

Eochattian (HUBACH, 1922, published 1957) for the lower Doberg Schichten, Doberg near Bünde. Based on pectinids. Fully marine.

Neochattian (HUBACH, 1922, published 1957) for the upper Doberg Schichten, Doberg near Bünde. Based on pectinids. Fully marine.

Vichsburgian (MURRAY, 1952) for beds of the age of the type Vicksburg Formation.

Chickasawhayan (MURRAY, 1961) for sediments of the age of the Chickasa-whayan Formation as originally defined by the *Shreveport Geological Society* (1934) including the Chickasawhay Limestone and the Paynes Hammock Sands.

The Aquitanian (MAYER-EYMAR, in GRESSLY & MAYER, 1853) was first placed in the Miocene, afterwards transferred to the Oligocene by MAYER-EYMAR (1958) but is now considered to belong to the Miocene by the majority of the invertebrate paleontologists.

Most of the stages mentioned above were conceived as cycles in the sedimentary history, i.e. as the result of transgressions and regressions. Many local basins developed and the sea intermittently inundated various parts of northern Europe. The result was a complex pattern of mostly shallow water deposits. Correlation between the different basins was attempted by means of molluscs and other macrofossils. This difficult task was hampered by great variations in facies, the lack of long sections especially across the boundaries, and by national traditions. There has not been much agreement on the use of the stages; some geologists prefer to use the set Latdorfian, Rupelian, Chattian, others chose Sannoisian and Stampian. In the U.S.A. the Vicksburgian stage (and the Chickasawhayan which is used only rarely) are applied only in the Gulf coast area. In California a set of local stages were established and are still used. The arguments on the position of the stage boundaries and on the correlation of the stages only ceased for a few decades at the beginning of this century.

1.3. Planktonic foraminifera in biostratigraphy

In the middle of this century, the usefulness of planktonic microfossils for bio-stratigraphy was realized. BRAMLETTE & RIEDEL (1954) and DEFLANDRE & FERT (1954) emphasized the stratigraphic value of calcareous nannofossils. BOLLI (1957) published a subdivision of the Cretaceous to Miocene of Trinidad based on planktonic foramini-fera which later proved to be applicable in many parts of the world. BLOW & BANNER (in EAMES & al., 1962) added some zones in the uppermost Eocene and lower Oligo-cene (see fig. 1) based on samples from Tanzania. EAMES & al. (1962) also lowered the Oligocene-Miocene boundary from the top of the *Globorotalia kugleri* Zone as given by BOLLI (1957) to the base of the *Globigerina ampliatura* Zone (where BOLLI (1957) drew the Eocene-Oligocene boundary). They also indicated that Oligocene deposits were absent from the Caribbean-Gulf Coast area except for some deposits in the Dominican Republic and in Mexico. These statements caused strong reactions and

BOLLI 1957, 1966	BLOW 1969	BAUMANN & ROTH, 1969	ROTH & HAY 1967	BRAMLETTE & WILCOXON 1967	ROTH this paper
Globorotalia kugleri	N.4 Gr. kugleri-Gs. quadri-lobatus primordius	Globorotalia kugleri		Triquetrorhabdulus carinatus	Triquetrorhabdulus carinatus Sphenolithus belemnos
Gg. ciperoensis ciperoensis	N.3 Globigerina angulisuturalis	Gg. cipero. ciperoensis		Sphenolithus ciperoensis	Sphenolithus ciperoensis- Triquetrorhabdulus carinatus
Globorotalia opima opima	N.2 Gg. angulisuturalis/ Gr. opima opima	Globorotalia opima opima		Sphenolithus distentus	Sphenolithus distentus- Sphenolithus ciperoensis
Globigerina ampliapertura	P.20/N.1 Gg. sellii/ Pseudohast. barbadoensis	Globigerina euapertura		Sphenolithus predistentus	Sphenolithus predistentus- Sphenolithus distentus
		Globigerina angiporoides angiporoides	Reticulofenestra laevis	Helicosphaera reticulata	Reticulofenestra laevis
Cassigerinella Chipolensis/ Hastigerina micra	P.19 Gg. sellii /Pseudohast. barbadoensis	Gg. sellii	Syracosphaera clathrata		Cyclococcolithus margaritae
			Cyclococcolithus margaritae		
	P.18 Gg. tapuraensis	Globigerina gortanii gortanii	Ericsonia subdisticha		Ericsonia subdisticha
	P.17 Gg. gort. gortanii				
Globorotalia cerroazulensis	P.16 Cribrohantkenina inflata	Globorotalia cerroazulensis	Isthmolithus recurvus	Isthmolithus recurvus	Isthmolithus recurvus

Fig. 1. Correlation of Upper Eocene-Lower Miocene planktonic foraminiferal and nannoplankton zones.

stimulated further research on this problem and on Oligocene deposits and fossils in many parts of the world. SAITO & BÉ (1964) described planktonic foraminiferal assemblages from the U.S. Gulf Coast which could be compared to the Oligocene faunas from Tanzania and are certainly of Oligocene age. SAUNDERS & CORDEY (presented as paper at the Caribbean Conference, 1965, published 1969) found lower Oligocene planktonic foraminifera in the Bath Cliff section on the island of Barbados, W. I. BOLLI (1966) summarized the state of planktonic foraminiferal zonation and introduced the *Cassigerinella chipolensis- Hastingerina micra* Zone for the interval of BLOW & BANNER'S *Globigerina "oligocaenica"* (= *G. sellii*) Zone. Up to now it has still not been possible to reach full agreement on the zonal scheme to be used for the Eocene to Oligocene nor on the definition of the upper and the lower boundaries of the Oligocene.

1.4. Biology, ecology and biostratigraphic applications of calcareous nannoplankton

Calcareous nannoplankton is a general term for coccoliths and related calcareous elements (discoasters, sphenoliths etc.). Coccoliths are produced by microscopic flagellate algae, generally referred to as coccolithophores, which live mainly in the euphotic zone of the sea. Only one genus with very simple coccoliths occurs in fresh

water. The life history of the few well studied species (see PARKE & ADAMS, 1961; BRAARUD, 1963) indicates that skeletal plates of entirely different shapes are produced during the various phases of life history. Isolated elements of the same organism formed at different stages of their life history are sometimes assigned to different species or even genera, e.g. *Crystallolithus hyalineus* GAARDER & MARKALI is the motile phase of the non-motile *Coccolithus pelagicus* (WALLICH) SCHILLER as demonstrated by PARKE & ADAMS (1961). Coccolithosphores reproduce mainly asexually, so that a mutant species might reproduce in great numbers before an exchange of genetic material with non-mutant relatives occurs. This explains the sudden appearance of certain species which do not seem to have evolved gradually from known ancestors. It is also one of the reasons for the rapid rate of evolution in many groups of nanno-fossils. Sudden changes in the nannofossil assemblages are observed more often than gradual ones. Thus, a great number of distinct markers are available in most parts of the Tertiary to Recent. Calcareous nannoplankton occurs in great numbers in many sediments (10^{10} specimens per cc. in many deep sea oozes). Even sediments from shallow water often contain enough nannofossils for study. The influence of the environment on the nannoplankton is difficult to evaluate for fossil assemblages. More discoasters were found in Oligocene open marine sediments from the tropical, subtropical and Mediterranean region than in Oligocene shallow water deposits of Belgium and Northern Germany, but it is difficult to determine to what extent the influence of temperature or the local environment was decisive for such differences. In general, shallow water deposits are richer in *Braarudosphaeraceae*, coccolithophorids producing pentagonal plates (see MARTINI, 1965). In the oceans of the present time most species have a distinct temperature range, e.g. *Coccolithus pelagicus* is restricted to cooler water, *Umbilicosphaera mirabilis* to subtropical to tropical temperatures (see MCINTYRE & BÉ, 1967). Tertiary relatives of *Coccolithus pelagicus* now referred to as *Ericsonia muiri* (BLACK) seem to be more abundant in sediments from tropical regions than from boreal regions. EDWARDS (1968) derived a Tertiary temperature curve for New Zealand from the abundance of certain nannoplankton genera which are related to modern genera with known temperature ranges.

There are some disadvantages to the study of nannoplankton and its application in stratigraphy. The small size of these fossils makes high quality optical, often electron optical equipment indispensable for their study. Calcareous nannofossils are easily reworked into younger deposits and are usually not damaged during erosion and transportation. Rupelian sediments from Northern Germany, for instance, contain Cretaceous coccoliths in a most beautiful state of preservation; not even in the electron microscope can any damage be detected.

Many species of nannofossils have a worldwide distribution. Only a few show considerable differences in ranges, such as members of the genus *Chiasmolithus* which occur abundantly in the Oligocene of New Zealand (Edwards, personal communication) but are absent to very rare in the American and European Oligocene studied so far. Only in the Oligocene from the central Apennines (see fig. 12) *Chiasmolithus* is relatively more abundant; the absence of other Eocene species excludes reworking as a possible explanation of this fact.

Calcareous nannoplankton is very useful for establishing detailed worldwide zonations and biostratigraphic datum levels. This has already been amply demonstrated by MARTINI (1958, 1959), STRADNER (1958, 1959), BRÖNNIMANN & STRADNER (1960), BRAMLETTE & SULLIVAN (1961), HAY (1964) and other authors. In 1967, HAY, MOHLER, ROTH, SCHMIDT & BOUDREAUX summarized the state of nannoplankton zonation, formally defined some zones which had been suggested by others and introduced a number of new ones. ROTH & HAY (in HAY & al., 1967) introduced four Oligocene nannoplankton zones which were the result of a careful study of 8 samples from the Oligocene interval of Blake Plateau JOIDES Hole 5 done by the author while at the Institute of Marine Sciences of the University of Miami. Of these four zones (see fig. 1) the *Syracosphaera clathrata* Zone was dropped later because a more extended range of the species was observed in other sections (ROTH & al., 1968, ROTH 1969a). During the study of upper Oligocene samples from Trinidad it was realized that the three zones (*E. subdisticha*, *Cc. margaritae*, *R. laevis* Zones) only covered the lower and middle Oligocene. It was not attempted by HAY & ROTH (in HAY & al. 1967) to define upper Oligocene zones as no sufficiently continuous sections of this interval were known. BRAMLETTE & WILCOXON (1967) suggested one zone for the lower and middle Oligocene (*Helicosphaera reticulata* Zone) and four zones for the middle and upper Oligocene of Trinidad and some JOIDES Blake plateau cores (Holes 3 and 4). These zones were found to be useful and were redefined and emended by the author in BAUMANN & ROTH (1969). They are mainly based on the evolution of sphenoliths and on some other very easily recognizable species like *Triquetrorhabdulus carinatus* and *Helicopontosphaera ampliaperta*. A total of seven zones could thus be established for the Oligocene and the lowermost Miocene. Only two intervals can be distinguished with the light microscope in the lower and middle Oligocene, a lower one with *Cyclococcolithus formosus* and an upper one without it (see p. 35). The uppermost middle Oligocene (*Sphenolithus predistentus-Sphenolithus distentus* Zone) and the upper Oligocene can be subdivided into zones using only light microscopy.

The Oligocene nannoflora includes a great number of species which range from the Eocene into the lower and middle Oligocene where they disappear, e.g. *Cyclococcolithus formosus*, *Isthmolithus recurvus*, *Lanternithus minutus*, *Reticulofenestra umbilica*, and *Discoaster tani nodifer*. The scarcity of discoaters in the lower half of the Oligocene is very characteristic. Only small species of the genera *Cyclococcolithus*, *Coccolithus* and *Reticulfenestra* make their first occurence in the lower to middle Oligocene. The genus *Reticulfenestra* is flourishing and produces many different species in the lower and middle Oligocene; only a few of them range into the upper Oligocene. A rapid evolution of the sphenoliths from *Sphenolithus predistentus* to *Sphenolithus distentus* and to *Sphenolithus ciperoensis* begins in the uppermost middle Oligocene. The basal cycle of elements in *Sphenolithus predistentus* grows and the bifurcating limbs of the stem become stronger and thus result in *Sphenolithus distentus* (see p. 870, pl. XIII, figs. 3, 7).

These two processes continue resulting in *Sphenolithus ciperoensis* with an even larger basal cycle which extends far over the base of the stem and with a very short connection between the base and the bifurcation point in bifurcating specimens. All the above mentioned species of sphenoliths produce non-bifurcating specimens which

only show the enlargement of the basal disc in the course of evolution. The origin of *Sphenolithus belemnos* is less clear; it probably arose from *Sphenolithus ciperoensis* by addition of small apical spine elements to the single spine present in the first mentioned species. In the uppermost part of the middle Oligocene the *Discoaster deflandrei* group started to evolve more rapidly, giving rise to *Discoaster saundersi* and *D. lidzi* in the upper Oligocene and to *D. nephados, D. trinidadensis, D. aulakos* and *D. divaricatus* in the lower Miocene. *Triquetrorhabdulus carinatus* first appears closely below the Oligocene-Miocene boundary and continues into the Miocene where it evolved into other blade shaped species like the lower Miocene *Rhabdothorax serratus* (BRAMLETTE & WILCOXON) n.comb. [= *Orthorhabus serratus* BRAMLETTE & WILCOXON, 1967, pp. 114–115, pl. 9, figs. 5–10, = *Triquetrorhabdulus martinii* GARTNER 1967, p. 6, pl. 10, fig. 1] and the middle Miocene *Triquetrorhabdulus rugosus* BRAMLETTE & WILCOXON [= *Ceratolithus? farnsworthii* GARTNER, 1967, pp. 5–6, pl. 9, figs. 1–4].

1.5. Modern attempts to subdivide and correlate the American and European stages

1.5.1. U.S. Gulf Coast stages

After the sequence of seven nannoplankton zones was established in cores from the Blake Plateau, in Trinidad, and on Barbados, the nannoplankton from the Vicksburgian of Alabama was studied. CHEETHAM (1957, 1963), working on cheilostomate bryozoans from the Upper Eocene-Lower Oligocene of the Gulf Coast area introduced two zones, the *Floridana antiqua* Zone (for the Cocoa Sand Member and the Pachuta Marl Member of the Yazoo Clay, Jackson Group, upper Eocene) and the *Spondylus dumosus* Zone (Shubuta member of the Yazoo Clay and Red Bluff Clay). The latter shows more affinities to the Vicksburgian than to the Jacksonian and was thought to be intermediate between the two. Thus, he drew the Eocene-Oligocene boundary at the base of the Shubuta Clay which has been placed in the Upper Eocene by most authors (see MURRAY, 1961). DEBOO (1965, 1966, 1967) studied the microfauna (benthonic and planktonic foraminifera, ostracods) of many sections in Alabama and Mississippi and subdivided the *Spondylus dumosus* Zone into a lower *Cribrohantkenina inflata* Subzone (Shubuta), and an upper "*Cythereis*" *blanpiedi* Subzone (Red Bluff). He drew the Jacksonian-Vicksburgian boundary at the base of the *Spondylus dumosus* Zone, i.e. at the base of the Shubuta Clay, and the Eocene-Oligocene boundary at the base of the Red Bluff Clay. As mentioned above SAITO & BÉ (1964) compared the planktonic foraminifera from the Vicksburgian with those from the *Globigerina sellii* Zone in Tanzania. LEVIN & JOERGER (1967) distinguished three biostratigraphic units based on nannoplankton in the upper Eocene-Oligocene of Alabama: Unit I (Cocoa through Shubuta) with *Discoaster barbadiensis, D. saipanensis* and *Pemma papillatum*, unit II (Red Bluff Clay) with *Isthmolithus recurvus* and *Micrantholithus basquensis*, and Unit III (Mint Springs and Marianna). Their Unit I contains species which are considered to indicate an Upper Eocene age in many parts of the world (e.g. present in the Priabonian, see PROTO-DECIMA, 1969). ROTH (1969a) found three Oligocene

FORMATION	MEMBER	ZONES				
		Cheetham 1957	Deboo 1965	Blow 1969	Levin & Joerger 1967	Roth this paper
Chickasawhay	Chickasawhay Limestone			N.2–N.3		Sphenolithus distentus– Sphenolithus ciperoensis
Byram	Bucatunna Clay					Reticulofenestra laevis
	Glendon Limestone					
Marianna	Marianna Limestone		Lepidocyclina mantelli	P.19	unit III	Cyclococcolithus margaritae
Red Bluff	Red Bluff Clay	Spondylus dumosus	"Cythereis blanpiedi"	P.18	unit II	Ericsonia subdisticha
Yazoo	Shubuta	dumosus	Ch. inflata	P.17 / P.16	unit I	Isthmolithus recurvus
Yazoo	Pachuta	Floridana antiqua			unit I	
	Coccoa Sd.	antiqua				

Fig. 2. Rock stratigraphic and biostratigraphic units in the U.S. Gulf coast area.

nannoplankton zones in Alabama (see p. 826). BLOW (1969) places the Red Bluff Clay and the lower Marianna Limestone in his Zone P. 18, the upper part of the Marianna in his Zone P. 19 and the Chickasawhay limestone in his Zone N. 3.

1.5.2. California stages

It has not been possible so far to establish the Oligocene nannoplankton zones here described in California. LIPPS (1967, 1968) indicates the presence of *Cyclococcolithus margaritae* in the Zemorrian stage, together with *Discoaster adamanteus*, *Reticulofenestra* (= *Apertapetra* of LIPPS) which might indicate a Middle Oligocene age. *Triquetrorhabdulus carinatus* and *Sphenolithus belemnos* occur in beds from the Saucesian and indicate a late Oligocene to early Miocene age for that stage. Samples from the Upper Eocene-Lower Oligocene from the Santa Cruz Mountains studied by the author proved to be too poor for detailed zonation.

1.5.3. European stages

Because the seven Oligocene nannoplankton zones could be found in many tropical and subtropical areas in the Caribbean and Gulf Coast Provinces (see ROTH, 1969a) it was attempted to distinguish these zones in the more northern type sections or type areas of the European Oligocene stages. The aim was to express the biostratigraphic extent of these stages in terms of nannofossil zones and to determine the boundaries of the Oligocene. Other fossils have been used to subdivide the Oligocene and to correlate deposits assigned to different stages which are in part age-equivalent.

The foraminiferal genus *Miogypsina* was employed by DROOGER (1960) for the correlation of beds of Chattian, Aquitanian and Vicksburgian age (ACKERS & DROOGER, 1957). *Lepidocyclina, Nummulites* and other larger foraminifera served as markers in the Near and Far East (see EAMES & al., 1962, VAN DER VLERK, 1955, and ADAMS, 1967) but they are rare or absent in the European type sections of the Oligocene. The nummulites from the Lower Oligocene of North Germany are small and have few characteristic features. They are assigned to different species by different authors (*Nummulites germanicus, N. orbigny, N. concinnus, N. prestwichianus* u.o.) or considered as ecologically influenced variants (see PAPP, in ANDERSON & al., 1969). Therefore they are not suitable for correlation of small units over long distances. Molluscs have been mainly used to define the stages and correlate the beds belonging to them. They proved to be of limited value for correlation over long distances because they were too dependent on the local environment at the time of deposition (facies fossils). The subdivision of the Chattian based on pectinids established by HUBACH (1927, 1957), GÖRGES (1941, 1951) and ANDERSON (1958, 1961, 1962) could not be followed outside Northern Germany and the lower Rhine valley. Smaller benthonic foraminifera are useful markers in local basins as demonstrated e.g. by SPIEGLER (1965) for the German Rupelton. This zonal scheme of the German Rupelton however cannot even be used with reliability for the Rupelian of Belgium. GROSSHEIDE & TRUNKO (1965) could not subdivide the thick Chattian sections at Doberg and Astrup using benthonic foraminifera where six local biostratigraphic units could be established with pectinids (HUBACH, 1922, 1957). STAESCHE & HILTERMANN (1940) introduced a system of "micropaleontological stages" for the Tertiary of Northern Germany which are based on microfossil assemblages and which are still in use for stratigraphic (surface and subsurface) work. Outside the North German basin it has not been possible to correlate these "micropaleontological stages" with other units (zones, stages). Ostracods are very useful in shallow water Oligocene deposits for correlation within one basin (see MOOS, 1963, 1965, 1966, 1968) or for correlation of brackish deposits (see GRAMANN 1968) but proved to be of little value for long distance correlation. Most of the Oligocene vertebrate remains come from continental sequences that can not yet be correlated in a satisfactory manner with the marine European Oligocene deposits.

After publication of the Oligocene zonation by ROTH & HAY (in HAY & al., 1967) the author studied two samples from well Hantkensbüttel Süd 32 in Northern Germany received from E. Martini. *Ericsonia subdisticha* (Roth & Hay) was found for the first time in Europe in the sample Hantkensbüttel Süd 32, 267–276 m below surface from the Latdorfian clay. Since *Discoaster barbadiensis* and *Discoaster saipanensis* are absent, it was assigned to the *Ericsonia subdisticha* Zone. In a higher sample from the Neuengammer Gassand (Hankensbüttel Süd 32, 258–267 m below surface) a poor assemblage was found with *Cyclococcolithus bollii* which is typical for the uppermost *Ericsonia subdisticha* Zone and the *Cyclococcolithus margaritae* Zone of other regions (see ROTH, 1969b). These results stimulated further research on nannoplankton in Northern Germany. MARTINI & RITZKOWSKI (1968) studied the nannofossils from molluscan fillings from the Koenen Collection. They could prove that molluscs from the type Latdorfian contain nannoplankton belonging to the *Ericsonia subdisticha* Zone and thus corroborating the early Oligocene age of the *Ericsonia subdisticha* Zone

assumed by ROTH & HAY based on planktonic foraminifera. The nannoplankton assemblages found in some other molluscs which were thought to be of lower Oligocene age by KOENEN (1889–1894) belong to the middle Eocene *Chiphragmalithus alatus* Zone (= *Chiphragmalithus quadratus* Zone of HAY & al., 1967) and to the upper Eocene *Discoaster tani nodifer* Zone (see MARTINI & RITZKOWSKI, 1968). KOENEN carefully separated the different localities and made it possible to distinguish the lower Oligocene localities from the Eocene localities which originally were all described as lower Oligocene. On the other hand, percentages of Lower Oligocene molluscs surviving from the Eocene or ranging into the Rupelian are only conclusive if the Eocene and Lower Oligocene localities all mentioned in KOENEN as lower Oligocene are separated. KRUTSCH & LOTSCH (1957) postulated that the Latdorfian beds are of Late Eocene age. They reached their conclusion because it is possible to correlate the near-shore Latdorfian beds with deeper water sediments assigned to the uppermost Upper Eocene (or Eocene 5) "micropaleontological stage" of STAESCHE & HILTER-MANN (1943) using microfossils and electrologs. These conclusions are refuted because the Latdorf beds are Lower Oligocene by definition. MAYER-EYMAR defined the Latdorfian as lowermost Oligocene stage; BEYRICH (1856) mentioned the "Lager von Engeln" as Lower Oligocene which can be correlated with the type Latdorfian and the Silberberg Formation in pit Treue IV, see p. 818). Good Latdorfian sections occur near Helmstedt and the nannoplankton studied by MARTINI & RITZKOWSKI (1968), ROTH (in BAUMANN & ROTH, 1969) and MARTINI (1969) is identical with nannoflora from the type localities of the *Ericsonia subdisticha* and the lowermost *Cyclococcolithus margaritae* Zones (see fig. 13) from the Blake Plateau, W. Atlantic. The "Obere Schönewalder Schichten" of Brandenburg which contain small nummulites considered to indicate an Eocene age by JARZEVA, LOTSCH & NEMKOV (1968) furnished a nannoplankton assemblage which is indicative for the *Ericsonia subdisticha* Zone (see range charts in LOCKER, 1968, MARTINI, 1969). The Upper Eocene *Isthmolithus recurvus* Zone is missing in Brandenburg. The sands of Grimmertingen, type formation of the lower Tongrian, belong to the *Ericsonia subdisticha* Zone (MARTINI & MOORKENS, 1969) and the Tongrian can thus be correlated at least in part with the Latdorfian.

BRAMLETTE & WILCOXON (1967) place the Rupelian in their *Sphenolithus predistentus* Zone and *Sphenolithus distentus* Zone (see p. 837). The very thick and famous Chattian sections at Doberg and Astrup (see ANDERSON & al., 1969) are devoid of calcareous nannoplankton. It is thus impossible to draw any conclusion on the age of the Neochattian based on nannoplankton. The type Chattian is according to HUBACH (1922) of the same age as the middle part of the Eochattian. The Chattian section from Glimmerode is probably assignable to the Eochattian but further research is in progress (see RITZKOWSKI, 1965). BERGGREN (1969) and BLOW (1969) studied planktonic foraminifera from the Rupelian and Chattian of Northern Germany and Belgium. The species they used for the assignment of the stages to planktonic foraminiferal zones (illustrated by BERGGREN, 1969) are all small and not very distinctive. The same is the case for the planktonic foraminifera illustrated and listed by KIESEL, LOTSCH & TRÜMPER (1969) from the Rupel of the German Democratic Republic. Still, BERGGREN (1969) and BLOW (1969) place the Rupelian in Zone P. 19 based on the concurrence of *Globigerina angiporoides* and *Globigerina ouachitaensis ciperoensis*. The Eochattian of

Astrup belongs to Zone P. 20/N. 1 according to BERGGREN (1969) who relies on transitional forms from *Globigerina opima nana* to *Globorotalia opima opima* and specimens intermediate between *Globigerina angustumbilicata* and *G. angulisuturalis*. According to BERGGREN (1969) it is not possible to assign the Neochattian to standard planktonic foraminiferal zones. BLOW (1969) places the Eochattian into his Zone P. 19 (later part), Zone P. 20/N. 1 and N. 2 (part?) and the Neochattian into his Zone N. 2 and N. 3, without giving any information on the planktonic foraminifera present nor the exact position of the samples studied.

In the framework of the present study zones and datum levels are preferred to stages as means of worldwide correlation because of the following reasons already pointed out by HORNIBROOK (in press):

1. There has not yet been much agreement on the definitions of the Tertiary stages in Europe and the U.S.A. For many stages good type sections are lacking. Some of the type beds have been deposited under ecologic conditions which exclude fossils that can be used for long distance correlation.

2. It has not been possible to find many criteria for adequate correlation of the Oligocene stages outside their type region. Many fossil groups are endemic or very influenced by facies. Planktonic organisms which are the best means of world wide correlation for the Tertiary known so far are practically absent.

3. There is nothing to be gained if European stages are established elsewhere if the fossil composition and facies are entirely different, especially as long as a set of well defined stages in Europe has not been agreed upon. Some of the stages are age-equivalent and for some others the exact age relationships are not yet known.

1.6. Main results of the present study

A total of seven nannoplankton zones are defined and correlated with the existing planktonic foraminiferal zones and stages (see figs. 1, 3).

The European and American stages are expressed in terms of nannoplankton zones as follows:

Latdorfian: *Ericsonia subdisticha* Zone to lowermost part of the *Cyclococco-lithus margaritae* Zone.

Lower Tongrian: *Ericsonia subdisticha* Zone.

Rupelian: *Cc. margaritae* Zone to *Sphenolithus predistentus–Sphenolithus distentus* Zone.

Chattian: *Reticolufenestra laevis* Zone to *Sphenolithus predistentus–Sphenolithus distentus* Zone.

Vicksburgian (including Red Bluff): *Ericsonia subdistiacha* to *Reticulo-fenestra laevis* Zone.

Chickasawhayan: *Sphenolithus distentus–Sphenolithus ciperoensis* Zone.

In addition to the zones ten datum levels are introduced as first order correlation surfaces (not to subdivide zones). Some of these datum levels approximate important boundaries, some of them should be used to define these boundaries. These datum levels can be supplemented by others wherever it factilitates long-distance correlation.

AGE		ZONE	CRITERIA FOR DEFINIG THE ZONAL BOUNDARIES
MIOCENE	Early	Triquetrorhabdulus carinatus– Sphenolithus belemnos	base Helicopontosphaera ampliaperta
			base Sphenolithus belemnos
OLIGOCENE	Late	Sphenolithus ciperoensis Triquetrorhabdulus carnatus	
			base Triquetrorhabdulus carinatus
		Sphenolithus distentus– Sphenolithus ciperoensis	
			base Sphenolithus ciperoensis
	Middle	Sphenolithus predistentus– Sphenolithus distentus	
			base Sphenolithus distentus
		Reticulofenestra laevis	
			base Reticulofenestra laevis
		Cyclococcolithus margaritae	
			base Cyclococcolithus margaritae
	Early	Ericsonia subdisticha	
EOCENE	Late	Isthmolithus recurvus	top Discoaster barbadiensis

Fig. 3. Age, zones and the criteria for defining the zonal boundaries
of the Late Eocene-Early Miocene

The following major datum levels can be found worldwide:
– Highest occurrence of *Discoaster barbadiensis* (Eocene-Oligocene boundary).
– Highest occurrence of *Cyclococcolithus formosus* (Lower-Middle Oligocene boundary).
– First occurence of *Sphenolithus ciperoensis* (Middle-Upper Oligocene boundary).
– First occurrence of *Sphenolithus belemnos* (Oligocene-Miocene boundary).

1.7. Typification

In accordance with the standard practice for carbon replicas, the holotypes, paratypes and the hypotypes of the species described are electron microscope photographic negatives. All the type negatives are deposited at the Basle Natural History Museum and identified by the author's negative numbers and, in square brackets, by the Basle Museum type collection numbers. The Basle Museum is also the depository for the type negatives of the species described by ROTH & HAY (in HAY & al., 1967) and ROTH (1969a). Because the Basle Museum type collection numbers were not listed in those papers, a key with the author's negative numbers and the Basle Museum numbers follows below.

ROTH & HAY in HAY et al. (1967):

IMS-J 501-164 = [A 780]	IMS-J 501-226 = [A 790]	IMS-J 504-127 = [A 800]
IMS-J 503-646 = [A 781]	IMS-J 503-622 = [A 791]	IMS-J 501-168 = [A 801]
IMS-J 503-706 = [A 782]	IMS-J 501-453 = [A 792]	IMS-J 507-091 = [A 802]
IMS-J 501-381 = [A 783]	IMS-J 505-277 = [A 793]	IMS-J 501-044 = [A 803]
IMS-J 501-311 = [A 784]	IMS-J 507-173 = [A 794]	
IMS-J 501-012 = [A 785]	IMS-J 503-696 = [A 795]	ROTH (1969a):
IMS-J 501-451 = [A 786]	IMS-J 507-184 = [A 796]	A 600 380 = [A 804]
IMS-J 501-449 = [A 787]	IMS-J 507-044 = [A 797]	A 800 307 = [A 805]
IMS-J 502-194 = [A 788]	IMS-J 507-245 = [A 798]	A 821 207 = [A 806]
IMS-J 501-320 = [A 789]	IMS-J 507-048 = [A 799]	A 827 119 = [A 807]

1.8. Acknowledgments