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LITHOSTRATIGRAPHY OF THE BRINKHEURNE FORMATION (OLIGOCENE, RUPELIAN) IN THE EASTERN PART OF THE NETHERLANDS

by

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The Brinkheurne Member, introduced in 1975 for Rupelian deposits in the eastern part of the Netherlands, is raised in rank to Brinkheurne Formation and subdivided into a lower Kotten Member and an upper Woold Member, each containing a lower calcareous part A and an upper non-calcareous part B. This fourfold division of the Brinkheurne Formation could be recognized in all available drillings in the Winterswijk area, also those with less favourable sampling. Thicknesses of the Formation appear to be predictable.

Within the Brinkheurne Fm ten levels of calcareous septaria occur, that accurately agree with such levels described from NW Belgium in the Boom Clay Formation. The rapid alternation of heavy, silty and bituminous bands described from Belgium is identical in the Winterswijk area. Depositional circumstances seem to have changed hardly during sedimentation of the Brinkheurne Member. The basal deposits of the Woold Member indicate a small transgression.

Biostratigraphical results (Elasmobranchii, Teleostei-otoliths, benthonic and planktonic molluscs), support the correlation between the two areas but should be elaborated in further detail.

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Contents:

SAMENVATTING

Door de talloze boringen die in oostelijk Nederland zijn verricht sinds het verschijnen van een meer gedetailleerde lithostratigrafie van het Tertiair (Van den Bosch, Cadée & Janssen, 1975) is de kennis van met name de oligocene afzettingen in dit gebied aanzienlijk toegenomen. Steeds werden de boringmonsters nauwkeurig op kleur en zanderigheid onderzocht. Zodoende werd een indeling verkregen in een onderste, meest blauwachtige klei en een bovenste, meest donkere klei met zwarte bitumineuze banden. Deze indeling bleek voor het gehele gebied op te gaan en was constant van dikte. Ook de vondsten van kalkseptariën werden nauwkeurig opgetekend, evenals het kalkgehalte van ieder monster. Uit dit laatste bleek dat zowel de onderste als de bovenste afzetting te verdelen was in een onderste kalkrijke klei en een bovenste kalkarme klei. De nauwkeurige overeenkomsten met NW België (Rupelstreek) (Vandenberghe, 1978) waren toen reeds overtuigend.

Als gevolg van deze ontwikkeling werd de behoefte steeds groter de vroegere "Afzetting" van Brinkheurne te verheffen tot Formatie van Brinkheurne, waardoor meer overeenkomst met de internationale opvattingen ontstaat en meer ruimte vrijkomt de Formatie verder onder te verdelen. In deze publicatie wordt dan ook de nieuwe rangorde Formatie van Brinkheurne ingevoerd, die bestaat uit twee nieuw benoemde afzettingen: de onderste Afzetting van Kotten, de bovenste Afzetting van Woold. Bovendien volgt nog een verdeling van iedere afzetting in twee gedeelten: A voor de onderste kalkrijke delen, B voor de bovenste kalkarme delen. Deze indeling van de Formatie van Brinkheurne in vier gedeelten blijkt in alle, ook minder goed bemonsterde, boringen herkenbaar te zijn (bijlage 2). Ook de "Afzetting" van Ratum wordt verheven tot Formatie van Ratum. Hierin zal in de toekomst ongetwijfeld een (deels regionale) onderverdeling aangebracht worden.

De Afzetting van Winterswijk blijft gehandhaafd en zal in de toekomst deel gaan uitmaken van een nog nieuw te benoemen grote, tot het Rupelien behorende formatie.

Door middel van droog geboorde boringen met een zware uitvoering edelmanboor (100 mm Ø) werd een fijne bandering van de Formatie van Brinkheurne vastgesteld. Deze bandering wordt in gespoelde boringen, als gevolg van vermenging, slechts incidenteel waargenomen. In werkelijkheid blijkt de klei zich voortdurend in vette, siltige en bitumineuze banden af te wisselen, waar de kalkige (septariën-)zones dan nog bij komen. Bovendien blijkt de klei in nagenoeg alle banden zeer fijn gelamineerd te zijn.

Vandenberghe (1978) toont een verband aan tussen de siltige en de bitumineuze banden. De bitumineuze banden volgen bijna altijd op een siltige band. Voor Winterswijk is dit slechts incidenteel vastgesteld, maar er moet op gewezen worden dat de siltige banden hier wel in aantal corresponderen, maar aanmerkelijk minder siltig zijn dan in NW België. De fijne laminatie wijst op een rustig en langzaam afzettingsmilieu. De siltige en bitumineuze banden zullen daarom minder direct met elkaar in vèrband staan en mogelijk een groot, bekkenomvattend systeem vertegenwoordigen, onder invloed van wisselende sedimentaanvoer van het vasteland. Het als gevolg van tektonische pulserende bewegingen bereiken van de bodem door de golfwerking lijkt een minder aannemelijke verklaring voor de siltige banden. Maar mogelijk heeft een dergelijke ritmische bodembeweging wel invloed op de sedimentaanvoer en is de bandering er meer indirect het gevolg van.

Alles overziende, kan een gedetailleerde lithologische opeenvolging worden vastgesteld. De Formatie van Ratum bestaat uit zanden, aan de top fijn en slibhoudend tot zwak kleiachtig, onderaan tot matig fijn of matig grof en zwak slibhoudend. Deze formatie vult tijdens de transgressie het

nog bestaande reliëf op. De dikte van de zanden varieert per gebied van 0 tot 17 m, maar 7 tot 10 m is normaal. Waar de formatie het dikst is, is het zand onderin het meest grof van korrel. In het noordelijk gebied is de top sterk gelaagd: zandige klei met talrijke dunne bandjes fijn zand. Glauconiet (verspoeld) komt in lagen voor, vooral aan de basis en aan de uiterste top. De Formatie van Ratum rust op diverse oudere afzettingen, vanaf Zechstein tot Turoon, en in het noorden op Eoceen.

De overgang naar de Formatie van Brinkheurne is vrij scherp. Deze formatie bestaat uit overwegend vette klei en is 47 tot 52 m dik. Het onderste deel bestaat uit zeegroene, blauwachtige of groengrijze klei ter dikte van 17 tot 22 m (Afzetting van Kotten), waarvan de onderste 7,5 tot 11 m kalkrijk (Deel A) en de bovenste 7-14 m kalkarm zijn (Deel B). Het bovenste gedeelte van de Formatie van Brinkheurne is donkerolijfgroen, donkergroengrijs of bijna zwart (bitumineus), in talloze banden afgewisseld, waarvan de onderste 6,5-9,5 m kalkrijk (Deel A) en de bovenste 18-22 m meest kalkarm zijn (Deel B). Dit is de Afzetting van Woold. Zie de standaardkolom op bijlage 1.

In het gehele traject van de Formatie van Brinkheurne komen zones met kalkseptariën voor, onafhankelijk van de hierboven genoemde kalkvrije of kalkrijke gedeelten. Er zijn 10 van deze septariënzones aangetroffen, die dezelfde nummers (S 1 t/m S 10) hebben gekregen als in NW België. Wordt in een boring geen septarie gevonden, dan is op die hoogte een kalkband of een dun traject kalkhoudende klei aanwezig. Iedere zone bevat kalkseptariën met een eigen karakteristieke habitus. De indruk bestaat dat deze septariën al spoedig na de vorming van het sediment verhard zijn. De septariënbanden zijn over zeer grote afstanden te vervolgen en zijn een goed correlatiemiddel.

Boven de S 10 wordt de Formatie van Brinkheurne afgesneden door de Afzetting van Winterswijk. Deze afzetting maakt deel uit van een complex van ca 130 m dikte, waaraan nog zeer weinig onderzoek is verricht. Het zijn overwegend middelgrijze kleien, die vrijwel altijd een percentage fijn kwartszand bevatten. Ongeveer halverwege is een pakket meer vette klei aanwezig, ter dikte van ca 50 m, met wederom talrijke zwarte banden. De onderste 30 m is overwegend sterk zandig. Er zijn zeker vier belangrijke septariënlagen in deze onderste 30 m aangetroffen. De afzetting is over het gehele traject min of meer kalkhoudend.

De stratigrafische positie van de basis van de Boom Klei Formatie in NW België en de Formatie van Ratum is reeds uitvoerig behandeld door Van den Bosch (1982), Gaemers (1984) en Janssen (1982). Uit deze onderzoekingen blijkt dat de Formatie van Ratum correleerbaar is met het onderste gedeelte van de Klei van het Waasland, de laagnummers 1 t/m 8, ofwel het traject onder de S 1. De Zanden van Berg (in strikte zin) zijn onder laagje 1 aangetoond. Ook uit de diverse gevonden fauna's valt af te leiden dat de Zanden van Berg ouder zijn dan de Formatie van Ratum. In genoemde publicaties wordt op de verdere gevolgen hiervan ingegaan.

Op bijlage 3 wordt een overzicht gegeven van de standaardsectie van de Boom Klei Formatie in NW België en van de Formatie van Brinkheurne in Oost-Nederland. Hoewel hiertussen een afstand van 200 km aanwezig is, met daarin de Peelhorst en de Rijndalslenk, is de correlatie duidelijk tot in de kleinste details. Vooral de Afzetting van Kotten komt nauwkeurig overeen met de Klei van het Waasland, boven S 1. Maar ook hoger in het profiel zijn grote overeenkomsten. In Oost-Nederland treden enkele kleine hiaten op.

Er zijn biozoneringen van verschillende groepen macro-fossielen bekend, waarmee de gedetailleerde correlatie tussen NW België en Oost-Nederland wordt ondersteund. Deze biostratigrafie zal zeker nog door de auteurs worden verfijnd en nader aan de praktijk worden getoetst. De resultaten zijn nu reeds van dien aard, dat een goede, gedetailleerde biostratigrafie over grote afstand mogelijk is.

Rond Winterswijk is de Formatie van Brinkheurne doorsneden met talloze breuken. Deze breuken zetten zich veelal door in miocene afzettingen, maar ook jongere bewegingen zijn bekend. Ook zijn zwakke golvende bewegingen waargenomen, zwakke plooien, die vooral nabij de grote breukzone Oeding-Plantegaarde-Lichtenvoorde steeds duidelijker worden. Deze zwakke plooistructuren veroorzaken een grillig verlopende dagzoom van de formaties.

Buiten de bovengenoemde grote breukzone is de Formatie van Brinkheurne vrij ongestoord afgezet, slechts enkele kleine hiaten wijzen op tektoniek tijdens de afzetting. In de breukzone wordt echter zelden een compleet profiel van de Formatie van Brinkheurne aangetroffen. Het is hier een chaotisch geheel van slechts fragmenten uit het totaal. Dit kan van plaats tot plaats weer anders zijn. Dit gebied is dan ook niet geschikt voor lithostratigrafisch onderzoek, maar kan er juist mee geïnterpreteerd worden. In figuur 5 is de ligging van de Formatie van Brinkheurne rond Winterswijk in beeld gebracht.

INTRODUCTION

The numerous deep and shallow borings made by the Rijksmuseum van Geologie en Mineralogie (RGM) within the framework of an investigation of the Tertiary deposits in the Winterswijk area, eastern part of the Netherlands, have lead to a considerable increase of the knowledge of e.g. the Oligocene deposits. In 1975 (van den Bosch, Cadée & Janssen) it was only noticed that the equivalent of the Boom Clay Formation in the eastern part of the Netherlands (named Brinkheurne Member by these authors) could be subdivided in a lower blue and an upper dark clay. Now a very detailed lithological stratification is known, that can be compared with the standard section described from the Boom area in Belgium (Vandenberghe, 1978). This knowledge enables very accurate predictions about nature and thickness of Brinkheurne Formation sequences. In practice the usefulness of this possibility was demonstrated convincingly.

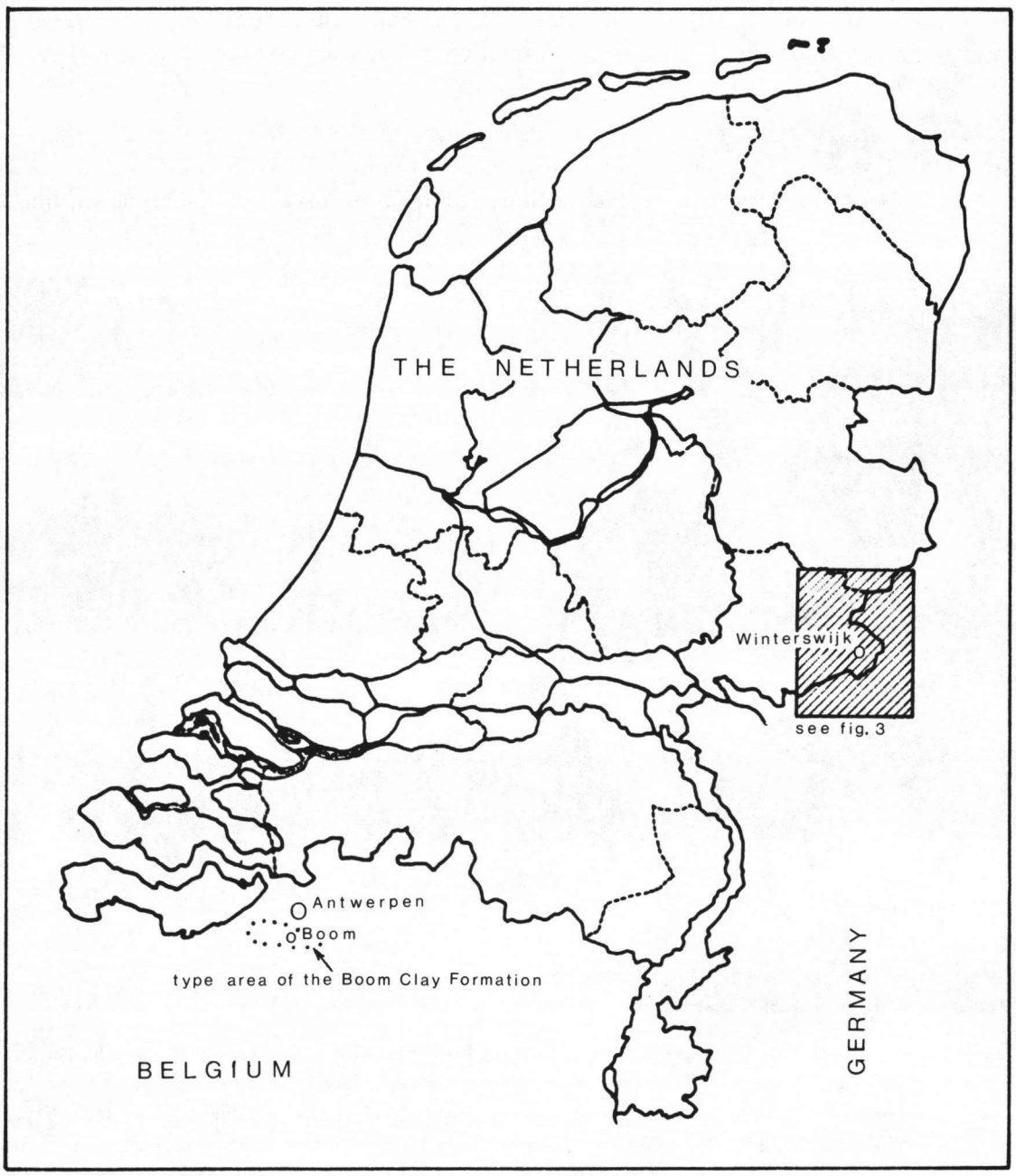
Also the need is felt to raise the rank of the former Brinkheurne Member to formation. In this way there will be a better agreement with international concepts, as well as more possibilities for a further subdivision of the unit, as is done in Quaternary geology for many years.

This paper also supplies many data for the interpretation of the paleoenvironment. Apart from a restricted number of considerations this subject is largely avoided in this study, however.

The geographical position of the investigated area in the eastern part of the Netherlands is indicated in text-fig. 1, together with the type area of the Boom Clay Formation in Belgium.

METHOD OF INVESTIGATION

After the publication of the first more detailed lithostratigraphy of the Rupelian deposits in the eastern part of the Netherlands (van den Bosch, Cadée & Janssen, 1975) much attention was paid to differences in colour between the lower and upper clay of the Brinkheurne Formation in new borings. This was very well possible with the obtained flush samples. Also every sample was tested with a 10% HCl solution, in which way calcareous zones could be distinguished from clays free of calcium carbonate. The position of calcareous septaria was carefully recorded. In this way soon a quite constant picture was obtained for the entire Winterswijk area. Septaria zones appeared to be present at fixed levels in the sections. Already in 1978 a subdivision was constructed showing many



Text-fig. 1. Position of the investigated area with regard to the type area of the Boom Clay Formation in NW Belgium.

Ligging van het onderzochte gebied in Oost-Nederland ten opzichte van het typegebied van de Boom Klei Formatie in NW België.

resemblances with the Rupel area sequence, as published by Vandenberghe (1978). A continuous flow of new, more and more detailed observations prevented publication of the results up to now. In 1980 the clay-pit complex of Brickworks De Vlijt near Winterswijk was intensively investigated by means of a number of dry borings to depths of 10 to 15 metres below surface. The excellent samples obtained in this way revealed the existence of a fine banding of the formation, resembling closely similar phenomena known from the Rupel area in Belgium. The upper 25 metres of the Brinkheurne Formation could be inspected very accurately in this way. The results were promising

to such a degree that in the years 1982, 1983 and 1984 also other locations were drilled in the same way in order to obtain comparable information about each part of the formation at least once.

These dry borings were made with a so-called auger of the edelman-type with a diameter of 100 mm. With this auger each metre of the sequence was continuously sampled in 6 to 8 pieces of almost undisturbed sediment (for further technical details see text-fig. 2). During drilling these

Text-fig. 2. The heavy bar with the auger is lowered into the bore hole with a tripod and a winch. The bar is rotated several times by means of a pair of chain tongs, until the auger is filled. Everything is lifted then and the long bar is put upright on a log besides the bore hole, during which the bar projects far beyond the top of the tripod. The clay sample is taken out of the auger with a crowbar and put aside, after which the procedure is repeated. The steel wire is attached to the head of the auger. In drillings deeper than 12 m an extension piece is added on top of the bar. This extension piece is connected by means of a wedge track, not by screw-thread; it can be removed in one manual exercise. Drillings to a depth of more than 15 metres can be made in this way by one or two persons.

De zware stang met de boor wordt door middel van een bok en een lier in het gat gelaten. Daarna wordt de stang met een kettingtang enkele keren rondgedraaid tot de boor vol is. Alles wordt opgehesen en de lange boorstang wordt rechtop naast het gat op een blok hout gezet, waarbij de stang boven de bok uitsteekt. De klei wordt met een breekijzer uit de boor gewrikt en weggelegd, waarna de handeling opnieuw begint. De staaldraad is aan de boorkop bevestigd. Bij dieper boren dan 12 m wordt een verlengstuk opgezet dat middels een spiebaan de stang kan laten draaien en zonder schroefdraad bevestigd is, zodat het verlengstuk met één handgreep af te nemen is. Een boring tot meer dan 15 m kan op deze manier door één of twee personen worden verricht.

large samples are put aside on a table consecutively. Every time a full metre of the section is drilled the samples are inspected and partly packed up and labeled for further research. The remaining parts of the samples are put together per meter of the sequence to be washed for an inspection of the fossil content. The fresh clay demonstrates its characteristics very well when broken. Descriptive criteria are the sand content and the colour. Differences in hue reflect the content of organic matter. It is necessary to observe differences in colour as soon as possible after the samples are brought to surface: they disappear quickly as a result of oxidation. Description of the sediment samples in the laboratory has to be done within a few weeks, as after this period discoloration of the clay will have reached the centre of the samples.

Practice has learned that 6 to 8 samples per metre are sufficient to recognize the banding of the formation. A lesser number of samples is inadequate. Also the application of a normal size auger (70 mm diameter) is reprehensible, as the banding of the clay is difficult to observe on smaller quantities of more strongly disturbed clay. In the laboratory the following characteristics of the samples are extensively described: colour, sand content, mica content, presence of calcareous matter (with 10% HCl) and the presence of e.g. pyrite and fossils. Sections drilled in the way described here yield very detailed profiles which can compete with sequences described from exposures. In flush borings the detailed banding of the sediment remains unnoticed, but careful sampling enables the observation of obvious calcareous levels, considerable dark layers or a single very sandy horizon. The lithostratigraphical subdivision applied in this paper was chosen in such a way that it may be recognized quite well in flush borings too.

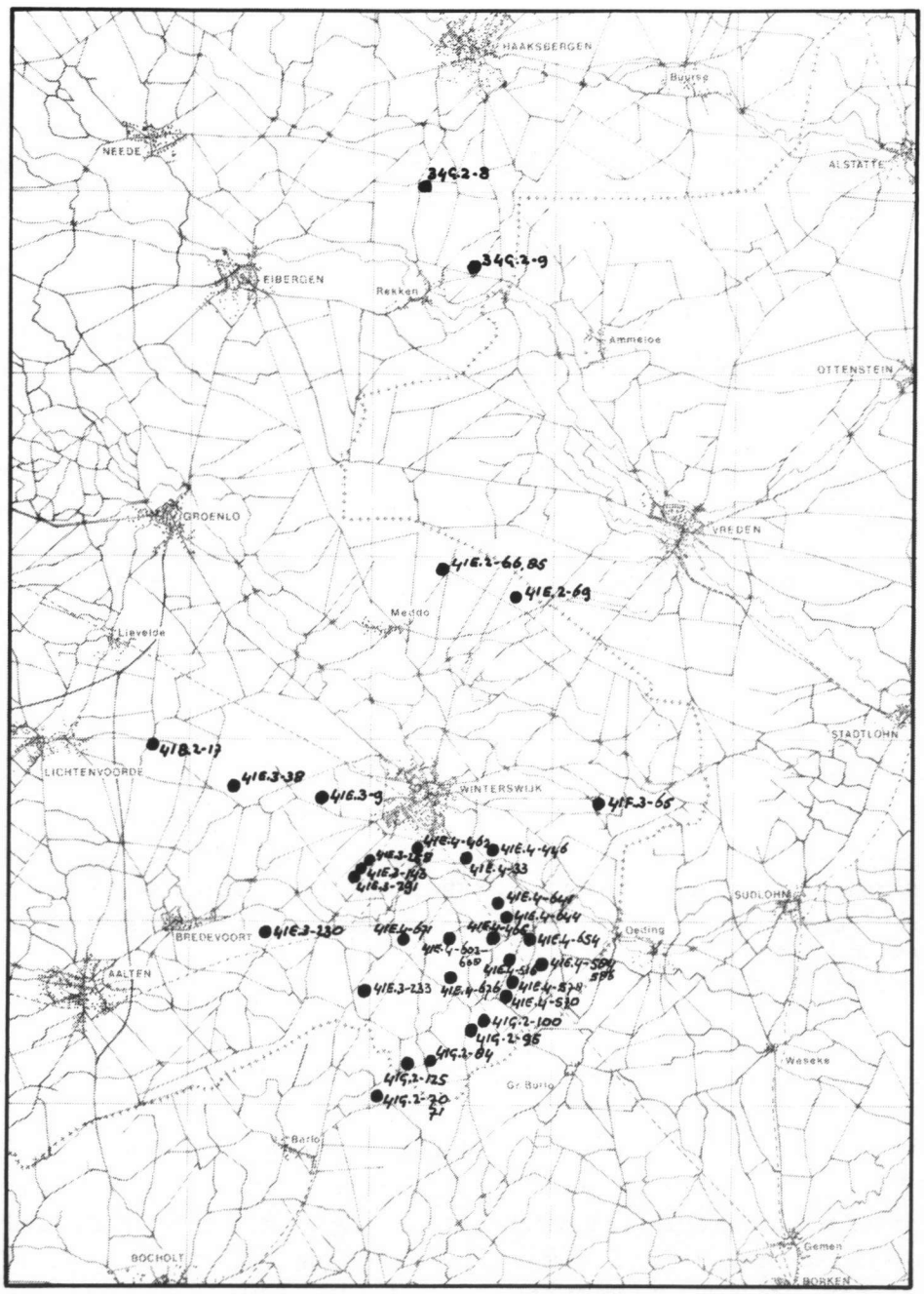
From the available drilled sections of the Brinkheurne Formation only a restricted number was used in this paper. Those borings were selected that contain relevant information, like septaria levels, complete thicknesses, lithological boundaries or other characteristics. The remaining drilled sections confirm the general picture. In text-fig. 3 the geographical position of the borings mentioned here is indicated. Boring numbers are file numbers of the Rijksmuseum van Geologie en Mineralogie. Also the old borings of the "Rijksopsporing van Delfstoffen" are included in this numbering.

LITHOLOGICAL SEQUENCE WITHIN THE RATUM AND BRINKHEURNE FORMATIONS

Enclosure 1 gives a standardized profile of the Ratum and Brinkheurne Formations, as it could be composed from some six dry drilled, accurately sampled borings. Enclosure 2 contains a number of selected drilled sections, scattered all over the area (text-fig. 3), regionally arranged and put together in such a way that the correlations are obvious. The observations from the sections given in enclosure 2 are included in the standardized profile of enclosure 1.

As can be seen on enclosure 2 the thickness of the Ratum Formation is very variable, as its deposits level the existing Mesozoic relief. NE of Winterswijk the Ratum Formation may reach thicknesses to over 17 m, but S of Winterswijk this is usually not more than 7 to 10 m. At Brinkheurne the Ratum Formation was deposited around a hard rock of Dogger age, a "crag" still reaching several metres into the Brinkheurne Formation. The height differences existing in the relief before deposition of the Ratum and Brinkheurne Formations in the Winterswijk area, as far as we know now, comprised some 20 to 25 m.

Within the Ratum Formation a changing development of the sedimentation can be observed. At those places where the deposit is thick the sand of the lowermost metres is usually coarsely



Text-fig. 3. Location of drillings mentioned in this paper in the eastern part of the Netherlands. For a general survey compare text-fig. 1.

Locatie van de in deze publicatie vermelde boringen in oostelijk Nederland. Voor overzicht zie tekst-fig. 1.

Scale/schaal 1:200.000.

grained (200-400 μm) and it often contains thin layers of reworked Mesozoic rock debris from the immediate neighbourhood. Upwards the grain-size quickly decreases and the sediment has a higher lutum content. The uppermost metres may be very fine-sandy and somewhat clayey, but can still be called sand (100-150 μm). In the northern part of the area, however, the uppermost part contains

a fine lamination of sandy clay and extremely thin sand streaks, which is absent in the southern part. A sandy clay is occasionally found at the base of the Ratum Formation.

Glauconite is frequently encountered in the quartz sands of the Ratum Formation, often concentrated in layers, especially near the top and the base. We gather that this glauconite was reworked from older formations; glauconite-bearing deposits of Eocene and especially Early Cretaceous age occur frequently in and around the area of investigation. The glauconite contents as given in the standardized section of enclosure 1 were adopted from boring number 41E.2-69 and therefore give a biased picture. In other borings the distribution is entirely different. Still it is striking that the top of the formation regularly contains a level with coarse glauconite grains, scattered in a very fine sediment.

Around Winterswijk the Ratum Formation overlies a variety of older deposits, ranging from Zechstein to Turonian, and everything in between. North of the area Eocene deposits are frequently present. At such places the base of the Ratum Formation contains several zones with reworked Eocene phosphoritic concretions and shark teeth. In forthcoming papers this formation will be described in more detail.

After the somewhat irregular deposition of the Ratum Formation a very regular and quiet sedimentation starts of usually very heavy clay, the Brinkheurne Formation. If complete, this clay may reach a thickness of about 50 metres.

This formation can easily be divided into two parts. The lower clay is characterized by its usually sea-green, bluish or greenish-grey colour, in alternating bands. The upper clay, on the contrary, is always dark olive-green, dark greenish-grey or almost black (bituminous), alternating in numerous bands. The basal part of the lower clay is mainly rich in calcareous matter, contrary to its higher parts. The same is true for the base of the higher clay with highest percentages of calcium carbonate, whereas only very little calcareous matter is present in the upper part. All over the sequence of the Brinkheurne Formation levels with calcareous septaria are present, independant from the fourfold division just described (calcareous - non calcareous - calcareous - non calcareous). Ten of such septaria levels were found.

The general lithological development of the Brinkheurne Formation as described above is constant all over the area of investigation and is very well recognizable in borings with a sampling interval of 1 to 2 metres. The septaria levels found support the picture. Calcareous septaria do not occur at any level, their presence is tied to thin, more or less calcareous layers, that can be traced and correlated over very large distances. Vandenberghe (1978) has demonstrated this phenomenon convincingly. The chance to hit such a concretion in a boring is quite small, but a light coloured calcareous band or a level of calcareous clay are always present; almost invariably these can be correlated with one of the known septaria levels. Such calcareous levels, as well as the septaria zones, are indicated in the sections.

The Brinkheurne Formation can be subdivided as follows (the lithostratigraphical denominations are elucidated below):

Brinkheurne Formation thickness 47-52 m	Woold Member dark clay with blackish bands thickness 25-30 m	Part B non calcareous	18-22 m
		Part A calcareous	6,5-9,5 m
	Kotten Member bluish clay thickness 17-22 m	Part B non calcareous	7-14 m
		Part A calcareous	7,5-11 m

On behalf of the Brickworks De Vlijt a survey was made of the septaria levels present in the Brinkheurne Formation of the Winterswijk area. In this survey the complete knowledge of the area is included. Heights are indicated according to the prognosis in boring 41E.3-291 (septaria levels with a high concentration of the nodules are indicated with x).

Number of septaria level	height above base		description
S 10	49.0 m		locally yellowish calcareous level, or scattered small and soft septaria, at the very top of the Brinkheurne Formation
S 9	44.5 m		scattered small and soft septaria or a thin calcareous level
S 8	42.0 m	x	large and thick septaria with calcite
S 7	41.0 m	x	large and thick septaria containing bright, unicoloured pyrite (S 7 and S 8 also occur combined, but then they contain multicoloured pyrite and calcite in alternation)
S 6	34.5 m		scattered spherical septaria with calcite (and siderite), with numerous burrows of unknown organisms, or a vague calcareous level
S 5	28.0 m		dark grey, flattened, very compact septaria, or a vague calcareous level
S 4	17.5 m	x	large and thick, light greyish septaria containing pyrite
S 3	7.0 m	x	thick septaria or a calcareous level
S 2	5.0 m		only a calcareous level
S 1	0.5 m	x	large and hard, or small and soft, light coloured septaria, or a yellowish very calcareous level

Each septaria level contains concretions of characteristic appearance, described in the above table. It should be noted however, that all observations, except those of S 6 to S 8, were made in boring sections, which means that only debris or fragments were seen.

A comparison of the above described septaria levels with those mentioned by Vandenberghe (1978) demonstrates complete identity with the Rupel area. The appearance of the septaria from levels S 4, S 5 and S 6 is strikingly similar. For the other zones it is especially the height in the section that agrees accurately.

During a large-scale clay digging action of Brickworks De Vlijt (close to boring 41E.3-258) it was noticed that in a restricted part of the clay-pit complex the septaria levels S 7 and S 8 are

separated by some 1.50 m of sediment. Elsewhere in the clay-pit S 7 and S 8 coincide and form a single layer with very numerous concretions, some of them internally with calcite, others with beautiful, multicoloured pyrite, alternating in clusters. The calcareous clay between the septaria contains many fish remains. This fish fauna differs from faunas in other horizons and is rather monotonous. At places where the two septaria zones occur at separate levels S 7 contains fine goldcoloured pyrite and S 8 exclusively calcite. The c. 1.50 m of clay in between contains a thin level with numerous compressed *Aturia* shells. This part of the section could not yet be studied in more detail.

From the above it is clear that the septaria consolidate soon after sedimentation. When the concretions of S 7 were washed out during the erosive phase that apparently took place they were consolidated to such a degree that no solution or deformation could affect the nodules. At that time the internal goldcoloured pyrite must have been oxidized and changed into multicoloured pyrite.

Apart from the two calcareous and the two non calcareous parts of the Brinkheurne Formation the entire sequence consists of a quick alternation of heavy clays and silty, sometimes strongly sandy clay bands; in the upper part furthermore numerous dark bituminous levels occur.

In the lower part, the Kotten Member, dark bituminous bands are almost completely absent; only above S 3 a vague somewhat darker band is present. The silty levels may be recognized by breaking fresh clay or by scraping with a knive. With regard to the usually very heavy clay the silty layers are not always distinct. Contrary to the Rupel area the percentages of particles above 50 μm are usually very low in the Winterswijk area. Between S 1 and S 2, however, two rather strongly sandy levels occur that may even be recognized in well-sampled flush borings. There is the impression that these sandy levels are more obvious in the southern part of the area of investigation than in the north. The mica content is a useful tool in the recognition of silty and sandy levels. In the heavy clay hardly any mica is present, whereas a visible quantity of fine-grained mica always occurs in the more silty parts. The mica content is indicated in the column of enclosure 1.

Careful application of 10% HCl demonstrates that the calcareous parts (A) of the clay consist in fact of a very fine lamination of calcareous and less calcareous, sometimes even non calcareous streaks. Quick alternations have been observed in thicknesses of some cm only.

Usually the few thin calcareous bands in the non-calcareous parts (B) correspond with a septaria zone. In cases where this is apparently not so, such a calcareous band may correspond with a septaria level elsewhere in the basin. At those places where part B of the Kotten Member is relatively thick one or two very thin calcareous bands are present below S 4. Occasionally small and soft calcareous nodules are found in these bands.

The upper part of the Brinkheurne Formation, the Woold Member, can be distinguished easily from the Kotten Member by its darker colour and the numerous bituminous bands. The boundary between the two members is sharp. At the base again a calcareous part is present (part A), but it is comparatively less important than the part A of the Kotten Member. Notable are three thick levels of heavy, very bituminous clay, that stress the contrast with the underlying deposit. Furthermore the intervals between S 6 and S 7 and also between S 9 and S 10 contain important bituminous bands.

Just like the Kotten Member the Woold Member contains numerous silty bands, but they are less well-developed than in the Belgian Rupel area. Only above S 5 two obvious, very sandy levels

were found. Vandenberghe (1978) demonstrated in the Rupel area that a bituminous band is often preceded by a silty level. This was only occasionally found in the Winterswijk area. It seems that these features occur more independantly here. In this context again it has to be noticed that near Winterswijk generally the deposit is much less silty than it is in the Rupel area, but the importance of the bituminous bands, on the contrary, seems to be greater. Many of the blackish bands demonstrate a lignitic appearance.

The origin of the large amount of organic matter is unknown. Vandenberghe (1978) supposed a supply of detritic plant material from the mainland, which is very probable. Also he presumed a part of the coal particles that are also present in the clay, to originate from northern England. It would be interesting to study this also in the Winterswijk area. The Woold Member could correspond with one of the older browncoal occurrences on the mainland.

With respect to the heavy and silty alternations Vandenberghe (1978) suggests an influence of rhythmic tectonical pulsation, as a result of which the wave base reaches the sea bottom from time to time, preventing sedimentation of fine-grained material and resulting in a concentration of coarser particles. The smaller particles, detritus and clay, he supposed to precipitate during periods of increased sea depth. In this model the bituminous bands are related to the granulometric rhythmicity.

In all dry drilled borings in the Brinkheurne Formation around Winterswijk (9 borings, of which 6 are discussed in this paper) the clay was found to be finely laminated. This lamination becomes apparent if clay pieces are broken perpendicularly to the stratification of the sediment. This clay lamination occurs as thin streaks, usually up to 1 mm in thickness, occasionally slightly more, without any visible granulometric gradation. This lamination is commonly present in the entire Brinkheurne Formation and is hardly or not disturbed by bioturbation. Independantly from the lamination the clay shows a faint joint structure.

The above described fine lamination points to a very quiet environment with low sedimentation rates during deposition of all levels. Therefore it may be suspected that banding of the clay was caused by a large, basin-wide system. Tectonical pulsation might have had its influence in this system, but probably in a more indirect way. Changes in sediment supply from the mainland might have been more important. Summarizing it may be concluded that the depositional circumstances during the deposition of the entire Brinkheurne Formation hardly changed. An important increase of sea depth during this period seems not very likely. Possibly the calcareous base (part A) of the Woold Member reflects a new transgression following a regression at the end of the Kotten Member deposition, just like part A of the Kotten Member.

Above septaria level S 10 the Brinkheurne Formation probably is cut off by the Winterswijk Member. The presence of a hiatus is presumed. The Winterswijk Member is part of a sequence with a thickness of some 130 m, that has hardly been investigated up to now. The member mainly consists of middle grey clays, almost always containing a percentage of very fine quartz sand. About halfway some 50 m of more heavy clay are present, containing many blackish bands again. The lower 30 m are mainly sandy. Especially this lower part is encountered in the Winterswijk area. The absence of blackish bands and the high sand content facilitate the distinction from the Woold Member. At least four important septaria zones were demonstrated in the lower 30 m of the Winterswijk Member.

STRATIGRAPHICAL POSITION AND RANK; LITHOSTRATIGRAPHICAL DENOMINATION

Gradually it has become clear that the Brinkheurne Formation is the time equivalent of the Belgian Boom Clay Formation, or "Boom Clay". This was extensively discussed by van den Bosch, Cadée & Janssen (1975) and other authors.

With respect to the stratigraphical position of the lower boundary of the formation interesting results were published by Janssen (1982) and van den Bosch (1982), from observations made in a clay-pit near St. Niklaas (NW Belgium). Below the basal sandy part of the Boom Clay Formation a rather coarse sand containing a characteristic Berg Sand fauna is present there; consequently *below* the so-called $R2^b$ deposit. The fauna from the Ratum Formation in the Winterswijk area must be younger than that from the Berg Sand, which lead van den Bosch (1982) to the conclusion that the Ratum Formation correlates with the sandy basal part of the Boom Clay Formation below septaria level S 1. This picture is confirmed now by the very good correlation between the Kotten Member and the "Waasland Clay". Below the Berg Sand in NW Belgium a deposit called Bassevelde Sand is present, with an entirely different fauna showing affinities with the "Tongrien supérieur" (van den Bosch, 1982; Gaemers, 1984).

For the lower part of the Boom Clay Formation, inclusive of the sandy part below septaria zone S 1 ($R2^b$) Vandenberghe (1978) applied the denomination "Waasland Clay". The upper dark clay he named "Putte Clay". These lithostratigraphical units, however, were only mentioned incidentally and not formally introduced and defined. The disadvantages of lacking or only vaguely described stratotypes were already extensively discussed in van den Bosch, Cadée & Janssen (1975, pp. 105 ff.). The absence of well-defined type sections induced the introduction of a local lithostratigraphy in the Winterswijk area, the application of which in other areas is emphatically not excluded.

At the time careful deliberation lead to the choice of "member" rank for the Brinkheurne unit. Soon this choice proved to be an unfortunate one, as it is hardly possible to subdivide a member in further detail. Below "member" follows the rank "bed", meaning strictly one layer, like e.g. the septaria zones (Hedberg et al., 1976), and not a complex of layers. A member comprises a number of beds showing a certain similarity or relation. A formation is a number of members belonging to one and the same sedimentation cycle. In this respect the subdivision of Tertiary deposits as introduced by the Rijks Geologische Dienst (1975) offers great difficulties in practice by the restricted number of formations.

It is proposed here to elevate the Brinkheurne Member to Brinkheurne Formation and to subdivide it into two members, viz. a lower, mainly bluish clay, the Kotten Member, and an upper, mainly dark clay with blackish bands, the Woold Member. The Ratum Member too is increased in rank to Ratum Formation, as it is not desirable to include it as a member in the Brinkheurne Formation on the ground of the original description of the Brinkheurne Member. Furthermore it is very likely that the need will arise to further subdivide the Ratum Formation into a number of members, as various sediment types are present in this deposit.

The Winterswijk Member will be maintained at its present rank, but in future it will certainly form part of an important new formation, which still has to be investigated and described extensively. The proposition that the Winterswijk Member is of Rupelian age (van den Bosch, Cadée & Janssen, 1975) still stands.

Below a survey of lithostratigraphical denominations, descriptions and locations of stratotype and reference sections is given.

Ratum Formation

See van den Bosch, Cadée & Janssen (1975, p. 6 ff, as Ratum Member).

Stratotype - Boring 41F.3-65 on the right bank of the Willink brook near Ratum, municipality of Winterswijk, depth 1.50-19.00 m below surface. Map-sheet 41F, coordinates X = + 96.115, Y = - 19.660. Height of surface c. 41 m + N.A.P. Location see text-fig. 3.

Brinkheurne Formation

See van den Bosch, Cadée & Janssen (1975, p. 10 ff, as Brinkheurne Member).

Stratotype - Boring 41E.4-446, at "Wassink", Brinkheurne, municipality of Winterswijk, depth 1.00-26.50 m below surface. Map-sheet 41E, coordinates X = + 93.305, Y = - 21.050. Height of surface c. 37.50 m + N.A.P. Location see text-fig. 3.

Members of the Brinkheurne Formation

Kotten Member, *new member*

Stratotype - Boring 41E.4-649 at Kotten, municipality of Winterswijk, depth 1.00-15.00 m below surface. Map-sheet 41E, coordinates X = + 93.860, Y = - 22.695. Height of surface c. 42.25 m + N.A.P. Location see text-fig. 3. A description of the sequence and a series of sediment samples are present in the RGM archives.

Concise description - sea-green, bluish or greenish grey heavy clay with silty bands and some calcareous septaria zones. The lower part of the clay demonstrates a calcareous stratification (part A), the upper part is mainly non-calcareous (part B). See for a more detailed description elsewhere in this paper. A composed standard section is to be found on enclosure 1.

Reference section - Boring 34G.2-9, clay-pit near Oldenkotte, Rekken, municipality of Eibergen, depth 2.25-(14.30) m below surface (lower boundary not reached). Map-sheet 34G, coordinates X = + 92.780, Y = 5.070. Height of surface c. 33.00 m + N.A.P. A lithological section is represented on enclosure 1. For location see text-fig. 3.

Woold Member, *new member*

Stratotype - Boring 41G.2-125, at "Meerdink", Woold, municipality of Winterswijk, depth 2.70-30.00 m below surface. Map-sheet 41E, coordinates X = + 91.120, Y = - 26.815. Height of surface c. 45.00 m + N.A.P. Location see text-fig. 3. A description of the sequence and a series of sediment samples are kept in the RGM archives.

Concise description - dark greenish-grey, dark olive-green or almost blackish heavy clay with numerous silty and numerous bituminous bands alternating. Some zones with calcareous septaria. The lower part of the clay is usually calcareous (part A), the upper part is mainly non-calcareous (part B). See elsewhere in this paper for a more extensive description. A composed standard section is to be found on enclosure 1.

Reference section - Boring 41E.2-85, at "Speets", Meddo, municipality of Winterswijk, depth 2.75-13.60 m below surface (overlying the Kotten Member). Map-sheet 41E, coordinates X = + 92.120, Y = - 13.300. Height of surface c. 39 m + N.A.P. See enclosure 1 for a lithological section. For location see text-fig. 3.

Note

The Winterswijk Member *does not belong to the Brinkheurne Formation. Its denomination remains unchanged*, see van den Bosch, Cadée & Janssen, 1975, p. 14 ff.

BIOSTRATIGRAPHY

Van den Bosch, Cadée & Janssen (1975) introduced two molluscan biozones within the Brinkheurne Formation, viz. the *Cyclocardia kickxi-Astarte kickxi* Assemblage-Zone (p. 64) in the lower part of the formation, and the *Serpula septaria-Ancistrosyrinx volgeri* Assemblage-Zone (p. 68) in the upper part. Also a list of mollusc species is given for both biozones. Correlations based on these characteristic mollusc associations were extensively discussed.

Nowadays we know that the *Cyclocardia kickxi-Astarte kickxi* Assemblage-Zone occurs from the base of the formation (S 1) upwards to at least several metres above the S 3 septaria zone. The upper boundary can not be indicated as macrofossils become very rare higher in the sequence. The same is also valid for NW Belgium (enclosure 3). In borings it was noticed that the interval between septaria zone S 4 up to about septaria zone S 5 regularly yields double-valved specimens of *Nucula* in life position. Hardly any further faunal elements are known from this part of the sequence.

The *Serpula septaria-Ancistrosyrinx volgeri* Assemblage-Zone is exclusively known in the Brinkheurne Formation from the interval between septaria zones S 8 and S 10 (e.g. in the clay-pit complex of Brickworks De Vlijt). Below S 8 the clay is extremely poor in fossils, only a very occasional *Nucula* shell is found. In NW Belgium this biozone was recognized e.g. in the construction pit for the Kennedy Tunnel at the right bank of the Scheldt river, in a part of the sequence certainly belonging to the section above zone S 8 (van den Bosch, Cadée & Janssen, 1975, p. 70).

Although these two biozones offer good possibilities for correlations a further subdivision and delimitation is desirable. Subdivision seems possible, as considerable differences were noticed in washing residues collected per metre in dry drilled borings.

Elasmobranchs (sharks and rays) present a more continuous picture. Van den Bosch (1980) described a fauna from the entire clay sequence, demonstrating considerable changes in the relative percentages of the species. The shark *Squalus alsaticus* for example increases in importance from 30% of the fauna in the Ratum Formation to 75% at the top of the Brinkheurne Formation. Further research will undoubtedly demonstrate the presence of several deflections in this line.

A useful subdivision of the Brinkheurne Formation into several biozones based on bony fish otoliths is available (Gaemers, in press), as well as a biozonation of planktonic gastropods (Pteropoda). In this latter zonation (Janssen & King, in press) the Brinkheurne Formation comprises only one zone, but the distribution of the pteropods suggests that a much more detailed zonation will be possible after some time. A combination of these four separate biozonations based on macrofossils gives very accurate results that will be elaborated and refined by their authors.

Considering the constant lithological rhythmicity of the sediment sea depth during the deposition of the Brinkheurne Formation has not changed markedly. Therefore the differences in faunal composition can not be explained by important changes in water depth.

LITHOSTRATIGRAPHICAL CORRELATION BETWEEN THE BOOM AREA (BELGIUM) AND WINTERSWIJK (THE NETHERLANDS)

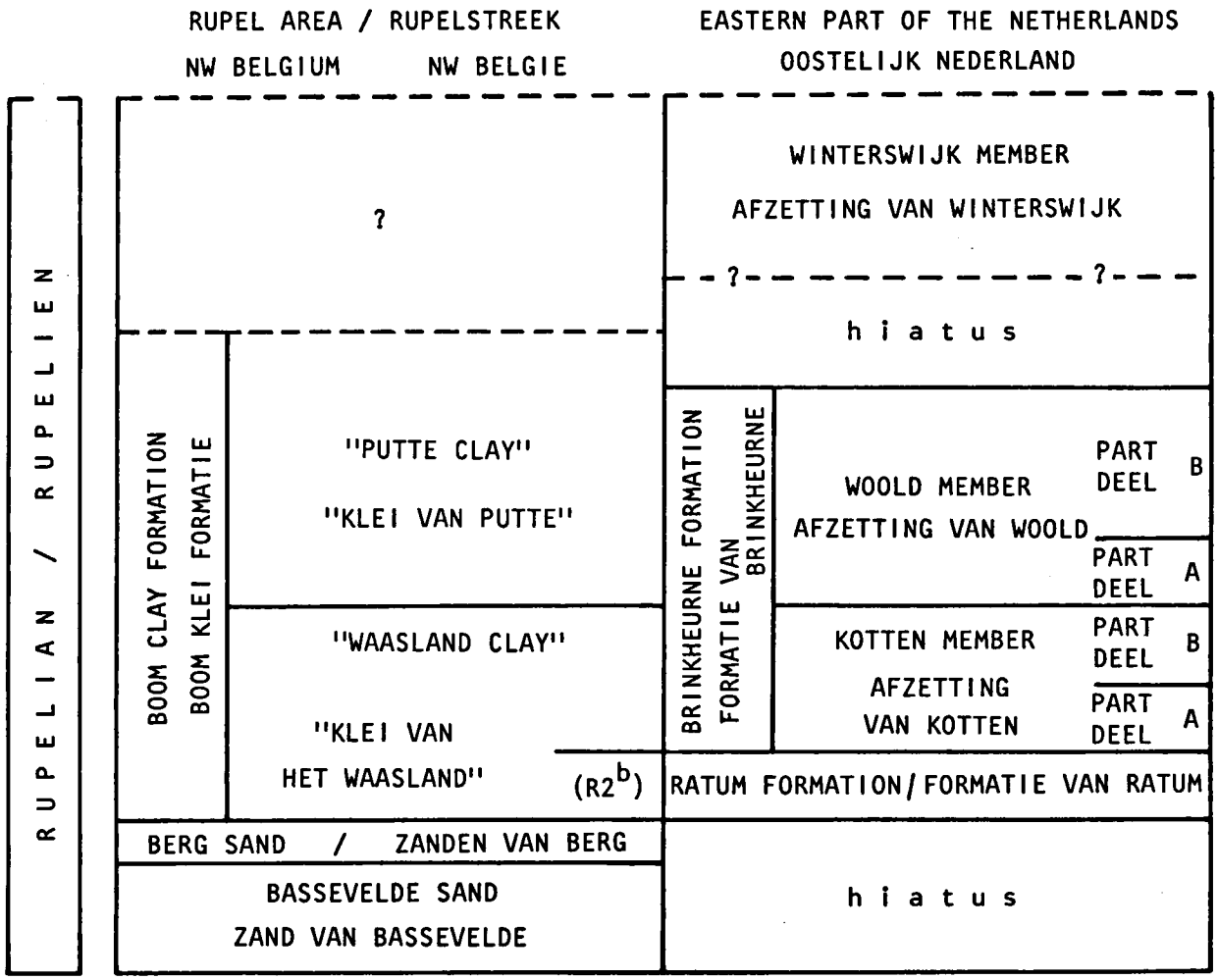
Vandenberghe (1978) demonstrated very convincingly that even minor details in the rhythmic succession of clay, silt and bituminous bands can be traced all over NW Belgium. The standard section composed by this author can very well be used and is therefore represented here on enclosure 3. This section was extended upwards with new, still unpublished data from borings in the river Scheldt North of Antwerp. I am very grateful to Dr Vandenberghe for his permission to use these data here.

Although the distance between the Boom-Antwerpen area and Winterswijk (with e.g. the Peelhorst and the Rhine Graben in between) is not less than 200 km the agreement between particularly the Waasland Clay and the Kotten Member is practically 100% (compare enclosure 3, both standard sections are reproduced at the same scale). Only minor differences may be observed, as for example septaria zone S 2 which is important in NW Belgium, but represented in the Winterswijk area by a calcareous zone only. The bed numbering valid in the Boom area can undoubtedly be adopted for the Winterswijk region as well.

The parts of the section below S 1 (bed numbers 1 to 8), however, do not agree. In Belgium this part is mainly clayey, whereas it consists of quartz sand with a higher or lesser degree of lutum near Winterswijk, enabling even the production of drinking-water! The deposit shows a more shallow character here and must have been situated close to an important supply route of sand. The stratigraphical correlation, however, was already demonstrated by van den Bosch (1982). Janssen (1982) found at St. Niklaas (NW Belgium) below bed number 1 a typical mollusc fauna of the Berg Sands, overlying Bassevelde Sand. This latter deposit was exposed during the construction of the Rupel tunnel at Ruisbroek. Near Winterswijk such deposits are absent, even as reworked elements. This may be an indication that the Winterswijk area was emerged at that time.

Above the boundary between the Waasland Clay and the Putte Clay, to be correlated with the boundary between the Kotten Member and the Woold Member, comparison becomes somewhat problematic. The calcareous part A agrees, but it is differently developed near Winterswijk. Possibly the very sandy beds 39 and 41 are still weakly reflected in the Winterswijk section. Further the basal part of the Woold Member near Winterswijk is mainly very bituminous. At the base of the Woold Member a part may be missing. The calcareous basal part does not agree with the sequence around Boom and other Dutch data. Bed nr 31 (upper level of the Kotten Member) contains a fossil concentrate, mainly consisting of foraminifers. This is an indication for a condensed sequence.

Septaria levels S 5 to S 10 agree with the Belgian section. It must be stressed that the external appearance of S 5 and S 6 septaria is completely identical in both areas. Banding between zones S 5 and S 7 seems to agree for the greater part. The interval between S 7 and S 8 is lacking in large parts of the Winterswijk area. The part between zones S 8 and S 10 is represented near Winterswijk by a condensed section. Above S 10 no deposits are known near Winterswijk that may belong to the Brinkheurne Member.



Text-fig. 4. Correlation of the Middle Oligocene deposits of NW Belgium and the eastern part of the Netherlands.
Correlatie van de midden-oligocene afzettingen van NW België en oostelijk Nederland.

The lithological correlation as suggested here on enclosure 3 is supported by the molluscan biozonation (van den Bosch, Cadée & Janssen, 1975), as indicated in the preceding paragraph.

Tectonical movements during the deposition of the Woold Member, locally interrupting the sedimentation, are obvious from small-scale hiatuses at the base of the Woold Member, between zones S 7 and S 8, and above S 10, as given in the standard section. But also in part B of the Kotten Member some complications occur. The thickness of this part may vary about 100% within the Winterswijk area. At places where part B is thinnest, a part below S 4 seems to be absent. It can not yet be decided which part exactly, more well-sampled borings will be necessary. At still other localities, however, part A of the Kotten Member is condensed on the contrary, which feature indicates a reversed movement. See for example the North-South survey on enclosure 2. Also in NW Belgium such small local hiatuses are present, possibly indicating a rhythmic relation (see Vandenberghe, 1978, p. 35, near S 4). This raises the impression that this feature represents undulating bottom movements, with a height of some metres, a wave length of several km and a time interval of many ten thousands of years. Lacking or condensed parts seem to be compensated by younger deposits thicker than normal.

Near Winterswijk it was demonstrated that gamma-ray logs reflect the stratification of the Brinkheurne Formation accurately. The RGM archives contain data from which it is obvious that such borehole logs are identical over large parts of the Netherlands, even in the smallest details. In samples from oil- and gaswells the subdivision Kotten Member A and B/Woold Member A and B is usually recognizable. For the time being it may prudently be concluded that the detailed lithological similarities of the Boom Clay Formation and the Brinkheurne Formation comprise a still much larger territory than is known now. Future papers on this subject will certainly follow.

DISTRIBUTION OF THE BRINKHEURNE FORMATION IN THE WINTERSWIJK AREA

The distribution of the Brinkheurne Formation in the area around Winterswijk given in text-fig. 5 needs some comment. As demonstrated by Harsveldt (1963) and van den Bosch (1981) the Winterswijk area is intersected by numerous faults. These faults continue into the Miocene deposits and at those places where still younger deposits are present they can sometimes be traced in these as well.

The deposition of the Brinkheurne Formation has been influenced, be it in a restricted way, by tectonics. The small (local) hiatuses in the sedimentary cycle are the results of these tectonics. For the time being to little information is available to demonstrate distinct separate movements per tectonical unit within the Brinkheurne Formation but some relations can be suspected.

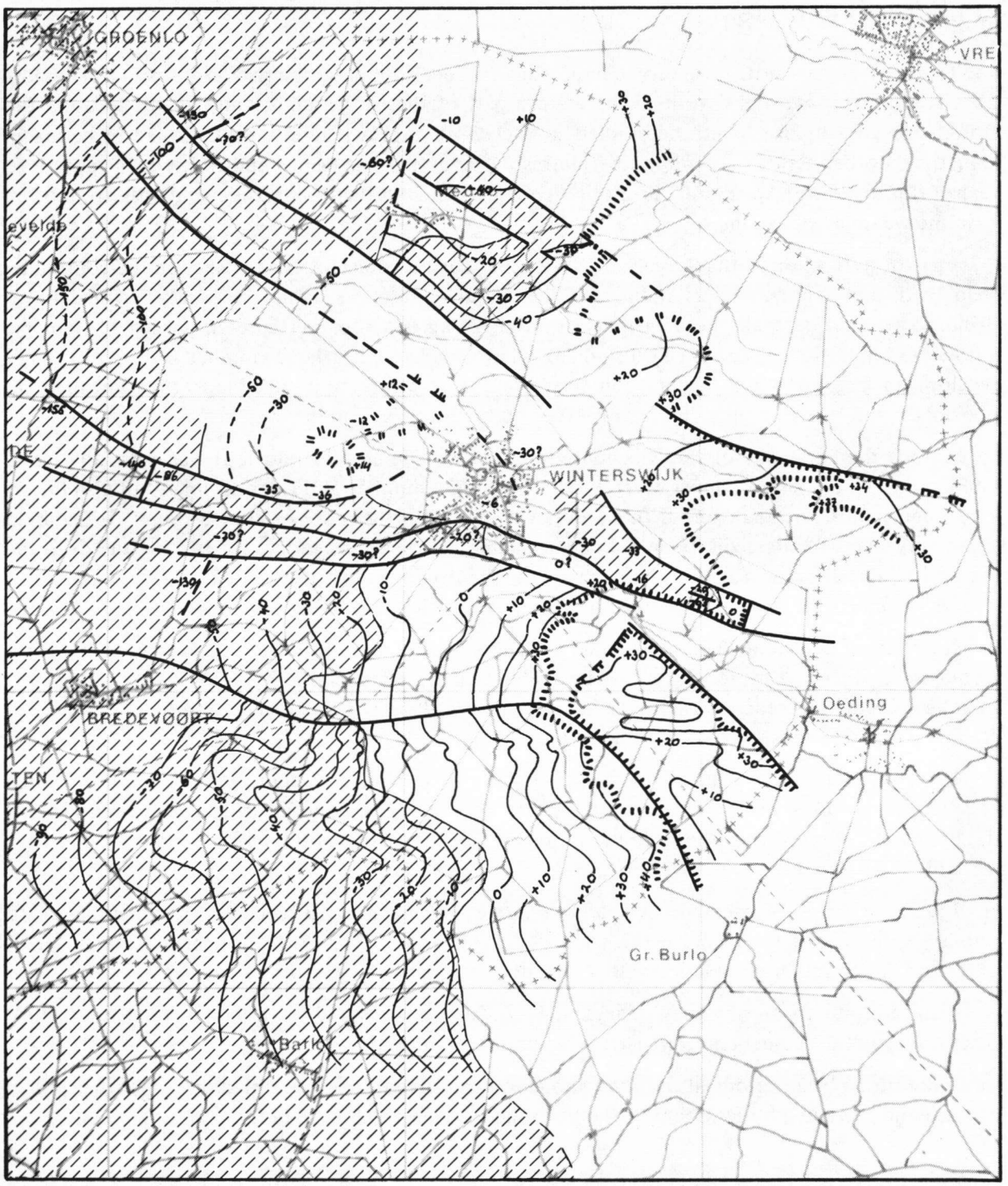
An exception is formed by the more or less E-W running strip around the fault zone Oeding-Plantengaarde-Lichtenvoorde, where Brinkheurne Formation deposits are only rarely complete. The formation is represented here by a rather chaotic sequence consisting merely of fragments of the sedimentation cycle. A quick alternation of uplifts and subsidences is present here and from place to place the picture may change. Therefore this region is not suitable for detailed stratigraphical studies, but it is very appropriate for interpretations of the tectonical movements.

South of the above mentioned fault zone much more detailed information is available. Weak folds in the Brinkheurne Formation could be demonstrated here (see text-fig. 5). These folds are stronger when the fault zone is situated more closely. This feature is obvious also in some previously published sections (van den Bosch, 1981, sections A-B, C-D). This weak fold structure together with the dip of the formation in a western direction causes an irregular outcrop pattern of the base of the formation (text-fig. 5). The same applies to the outcrop of the boundary with the overlying Winterswijk Member.

The depth lines of the base of the formation, as given in text-fig. 5, are not equally reliable all over the area. Especially NE of the Winterswijk village information is not so complete. The fault pattern is adopted from the geological outline map of Winterswijk 1 : 50.000 (van den Bosch, 1981). On this map deposits younger than the Winterswijk Member are neglected.

Text-fig. 5. Presence of Winterswijk Member and Brinkheurne Formation in the Winterswijk area. The lines indicate (in metres) the base of the Brinkheurne Formation with regard to N.A.P.

Aanwezigheid van de Afzetting van Winterswijk en de Formatie van Brinkheurne in het Winterswijkse gebied. De lijnen geven de basis van de Formatie van Brinkheurne aan in meters t.o.v. N.A.P.



boundary of the Brinkheurne Formation
grens van de Formatie van Brinkheurne

presence of the Winterswijk Member
voorkomen Afzetting van Winterswijk

ACKNOWLEDGEMENTS

This paper may not be a very comprehensive one, still it summarizes the results of almost 20 years of intensive field work in the eastern part of the Netherlands. Only at one location the Brinkheurne Formation could be studied in a clay-pit, everywhere else drillings had to be made, sometimes to dephts of over a hundred metres. Of course it has been impossible for the author to realize this all alone. Again and again other people assisted in the toiling, independantly from often extreme weather conditions.

First of all I want to thank Marjan Duitemeijer for her substantial assistance in the continuing field work and for her understanding for the frequent absences of her husband who had to go drilling again. Also to all those members of the Werkgroep voor Tertiaire en Kwartaire Geologie who, ever since the existence of this society, have made such a large number of auger borings, resulting in large amounts of data, I'm very grateful. It would be impossible to mention them all personally, but many of them have contributed to the investigation in his or her own way.

Among the personnel of the Rijksmuseum van Geologie en Mineralogie it was especially Mr H. Guldemond who assisted almost every year in making a number of deeper drillings, but also Messrs F. Jordens and C. Strang exerted themselves very well. Furthermore of course I have to thank all those very many Winterswijk people, being available whenever necessary, for turning the drill, the loading of lorries, even for overnight repairs on the drilling outfit in the field. Without them this research would not have been possible, also from a financial point of view.

Apart from the basic field work data were used, of course, available in the files of the Rijks Geologische Dienst. Additionally I have been able to sample numerous shotholes made for a seismic investigation of the Nederlandse Aardolie Maatschappij. This job took several months, during which Dr J. H. Germeraad assisted so conveniently.

Later also the deepboring Winterswijk-1 of the same company could be sampled, for which excellent conditions were offered. Furthermore "district Oost" of the Rijks Geologische Dienst donated well samples from the neighbourhood of Rekken in the autumn of 1983, for which I have to thank Mr T. Bruins.

I owe Dr N. Vandenberghe (Geological Survey of Belgium, Brussels) for his permission to publish here new data from the higher part of the Boom Clay Formation near Antwerp. This extended the correlation possibilities to a high degree.

I am grateful to Messrs A. W. Janssen, P. A. M. Gaemers and N. Vandenberghe for fruitful discussions on the subject and for (partly) reading the manuscript.

The editor of this periodical was kind enough to translate the manuscript shortly before printing, assisted and corrected by Dr Gaemers. To both these colleagues I'm thankful.

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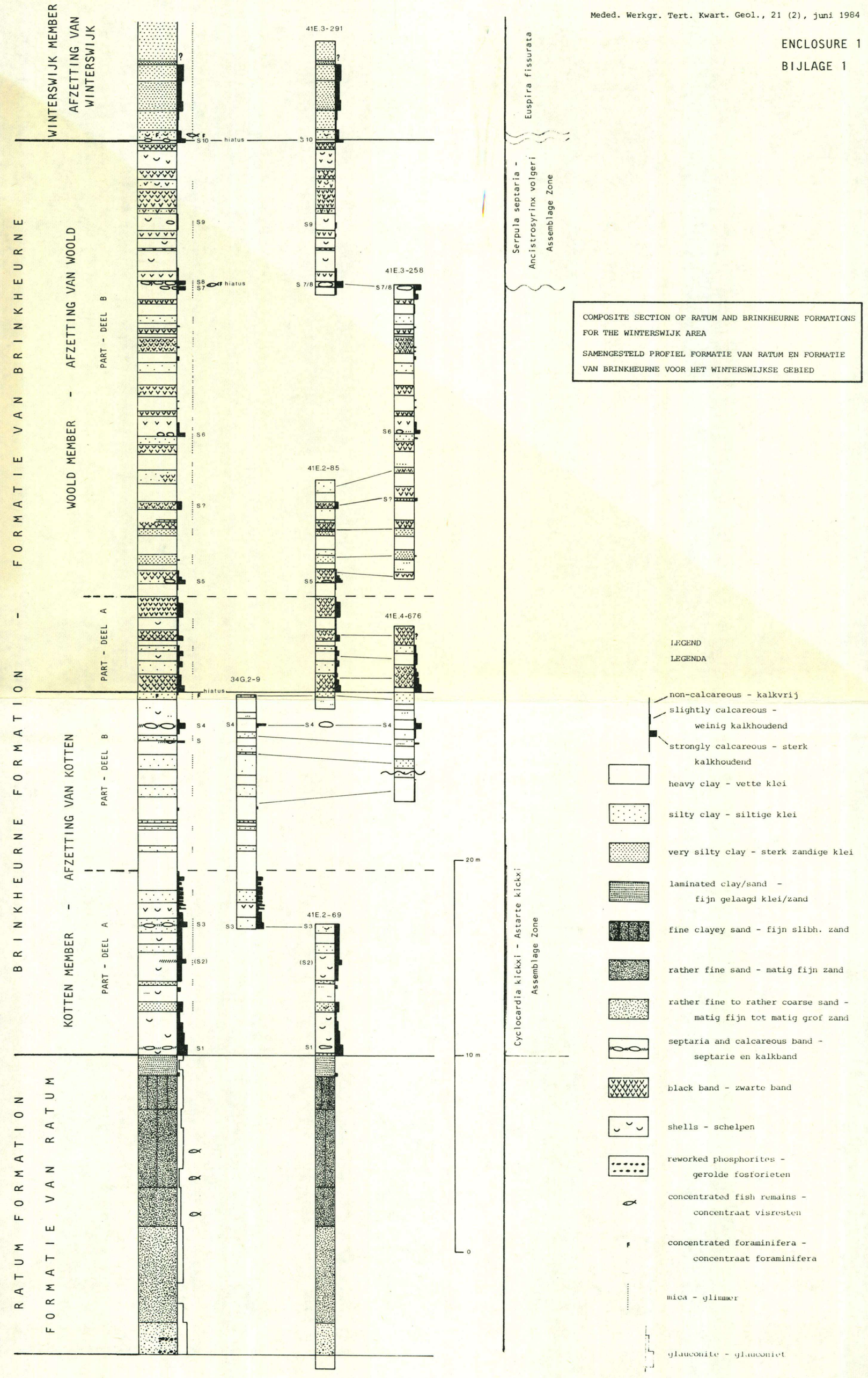
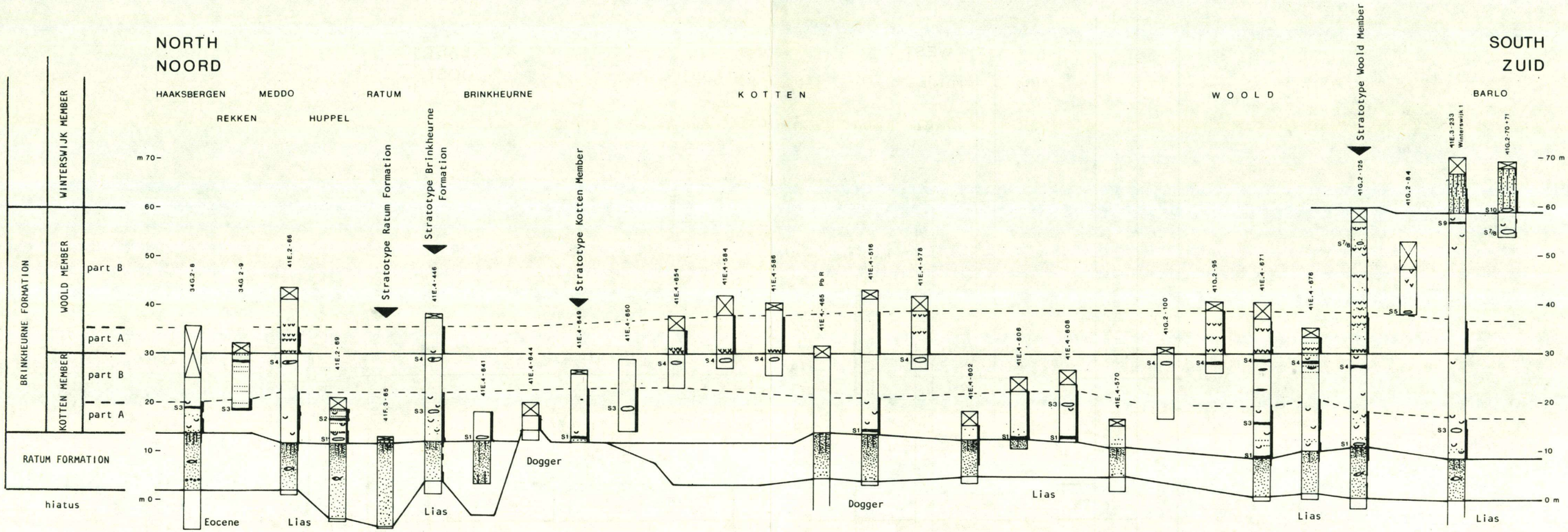
Meded. Werkgr. Tert. Kwart. Geol., 21 (2), juni 1984

ENCLOSURE 1

BIJLAGE 1

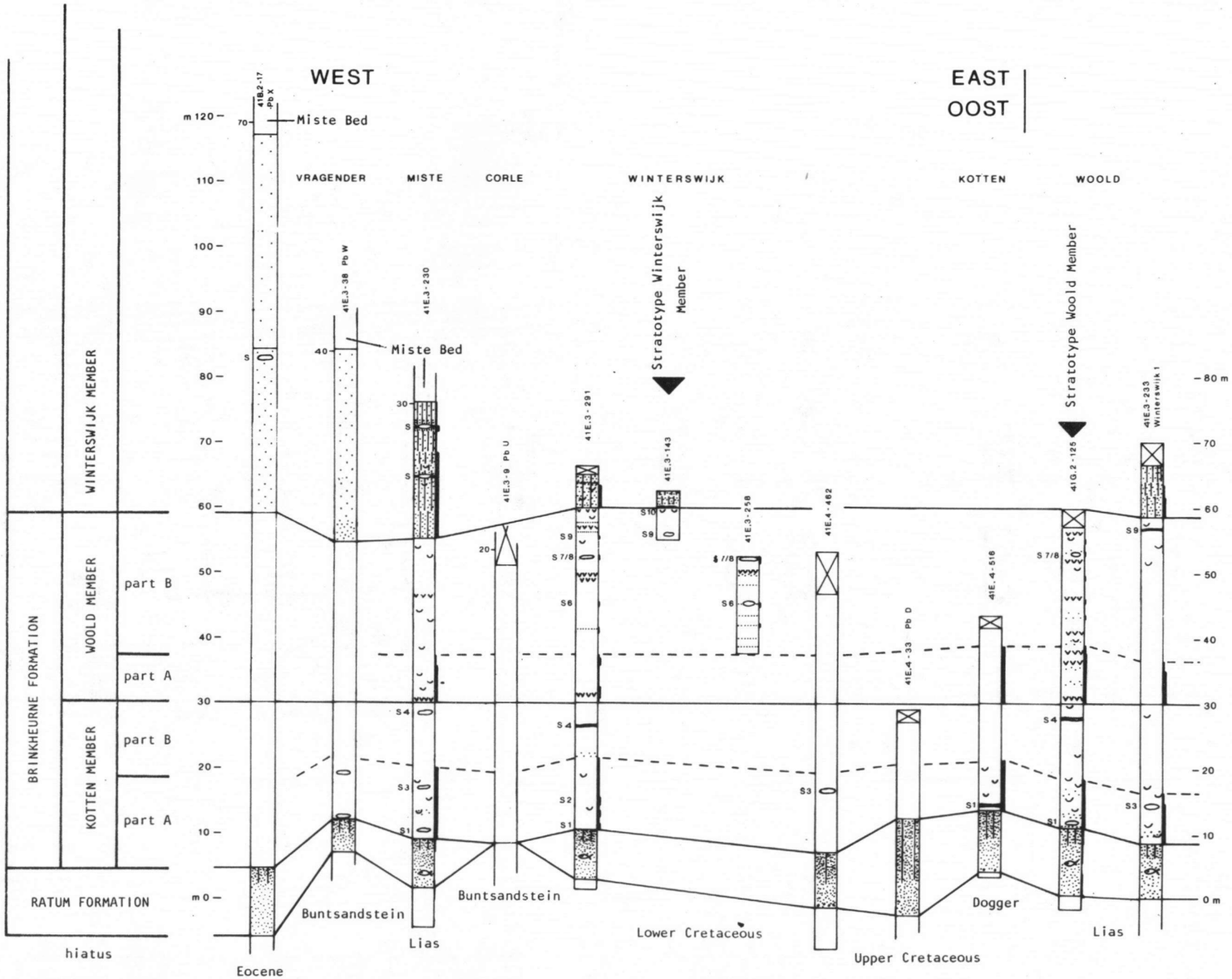




Several regionally arranged drilling sections of the Ratum and Brinkheurne Formations in the eastern part of the Netherlands. Locations are indicated in text-fig. 3	Diverse regionaal gerangschikte boorsecties van de Formaties van Ratum en Brinkheurne in oostelijk Nederland. De locaties zijn aangegeven in tekstfig. 3

ENCLOSURE 2
BIJLAGE 2

Mededel. Werkgr. Tert. Kwart. Geol., 21 (2), juni 1984



Several regionally arranged drilling sections of the Ratum and Brinkheurne Formations in the eastern part of the Netherlands. Locations are indicated in text-fig. 3

Diverse regionaal gerangschikte boorsecties van de Formaties van Ratum en Brinkheurne in oostelijk Nederland. De locaties zijn aangegeven in tekstfig. 3

Pycnodonta callifera

Cyclocardia kickxi - Astarte kickxi Assemblage Zone

Serpula septaria - Ancistrosyrinx volgeri Assemblage Zone

BOOM CLAY FORMATION - BOOM KLEI FORMATIE

"WAASLAND CLAY" - "KLEI VAN HET WAASLAND"

"PUTTE CLAY" - "KLEI VAN PUTTE"

BERG SAND S.S. ZANDEN VAN BERG S.S.

BASSEVELDE SAND ZAND VAN BASSEVELDE

Composite section of the Boom Clay Formation in the type area (after Vandenberghe, 1978)

Samengesteld profiel van de Boom Klei Formatie in de type-streek (naar Vandenberghe, 1978)

River Scheldt near Antwerpen (unpublished, with permission of Dr N. Vandenberghe)

Schelde bij Antwerpen, ongepubliceerd (met toestemming van Dr N. Vandenberghe

Composite section Winterswijk area

Samengesteld profiel Winterswijkse gebied

hiatus

PART - DEEL A

PART - DEEL B

KOTTEN MEMBER - AFZETTING VAN KOTTEN

WOOLD MEMBER - AFZETTING VAN WOOLD

WINTERSWIJK MEMBER AFZETTING VAN WINT.

RATUM FORMATION - FORMATIE VAN RATUM

BRINKHEURNE FORMATION - FORMATIE VAN BRINKHEURNE

Cyclocardia kickxi - Astarte kickxi Assemblage Zone

Serpula septaria - Ancistrosyrinx volgeri Assemblage Zone

Euspira fissurata

0 10 m 20 m

Mollusc biozonation after van den Bosch, Cadée & Janssen (1975)

Mollusken-biozonering naar Van den Bosch, Cadée & Janssen (1975)

LEGEND
LEGENDA

non-calcareous - kalkvrij
slightly calcareous - weinig kalkhoudend
strongly calcareous - sterk kalkhoudend
heavy clay - vette klei
silty clay - siltige klei
very silty clay - sterk zandige klei
laminated clay/sand - fijn gelaagd klei/zand
fine clayey sand - fijn slibh. zand
rather fine sand - matig fijn zand
rather fine to rather coarse sand - matig fijn tot matig grof zand
septaria and calcareous band - septarie en kalkband
black band - zwarte band
shells - schelpen
reworked phosphorites - geroide fosforieten
concentrated fish remains - concentraat visresten
concentrated foraminifera - concentraat foraminifera
mica - glimmer
glauconite - glauconiet

LITHOSTRATIGRAPHICAL CORRELATION BETWEEN THE BOOM CLAY FORMATION IN NW BELGIUM AND THE RATUM AND BRINKHEURNE FORMATIONS IN THE EASTERN PART OF THE NETHERLANDS. Compare text-fig. 1

LITHOSTRATIGRAFISCHE CORRELATIE TUSSEN DE BOOM KLEI FORMATIE IN NW BELGIE EN DE FORMATIES VAN RATUM EN BRINKHEURNE IN OOSTELIJK NEDERLAND. Zie tekstfig. 1

Meded. Werkgr. Tert. Kwart. Geol., 21 (2), juni 1984

ENCLOSURE 3
BIJLAGE 3