The geometry of the Rupelian and Chattian depositional bodies in the Lower Rhine district and its border area: implications for Oligocene lithostratigraphy

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Three profiles are constructed through the Oligocene succession of the borderland between Belgium, Germany and the Netherlands. The profiles illustrate the geometric relationships between Rupelian and Chattian successions and the lateral and vertical variations within the Rupelian and Chattian deposits. The end-Rupelian profile between Central Belgium and the Achterhoek area in the Netherlands shows a rather uniform thickness distribution. This is in sharp contrast to the fault controlled sedimentation during the Chattian as represented on an end-Chattian profile between the same areas. Within the Chattian succession several lithostratigraphic units can be identified and correlated using a dense net of geophysical well logs. Remarkably similar subdivisions are found in the different tectonic blocks, suggesting eustatic sea-level fluctuations. In the central part of the subsiding area the Chattian deposits are largely continental to deltaic. Laterally, these deposits developed into marine glauconitic sediments. The end-Chattian profile between Bonn and Asten in the Netherlands runs approximately parallel with the subsidence axis. The cyclicity expressed by facies alternations due to a periodically shifting coastline can be correlated over the different blocks again suggesting the involvement of eustatic controls. On this last profile, an anomalous geometry is due to SE-NW stress-induced movements along the Variscan Aachen overthrust. The three lithological profiles are meant to represent a frame for formal stratigraphic subdivisions and nomenclature.

Key words: Rupelian, Chattian, stratigraphy, eustacy, tectonics.

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The objective of the paper is to discuss the lithological and geometrical framework of the Rupelian and in particular the Chattian deposits in the Lower Rhine area and its border areas in Belgium and the Netherlands. The present nomenclature for both the Rupelian and the Chattian deposits is determined by national traditions and any attempt to improve it will have to relate to the geometry of the different lithological units. On the other hand the proposed lithological correlations in this paper respect the presently available biostratigraphic data.

In the North Sea basin two main areas of thick Oligocene deposits occur (map 4 in Vinken 1988). The northern area which covers the central part of the North Sea has thicknesses up to 1000 m. The southern area, including our study area, is situated mainly over the central and southern Netherlands and the Lower Rhine area. There the Oligocene can reach up to 500 m in

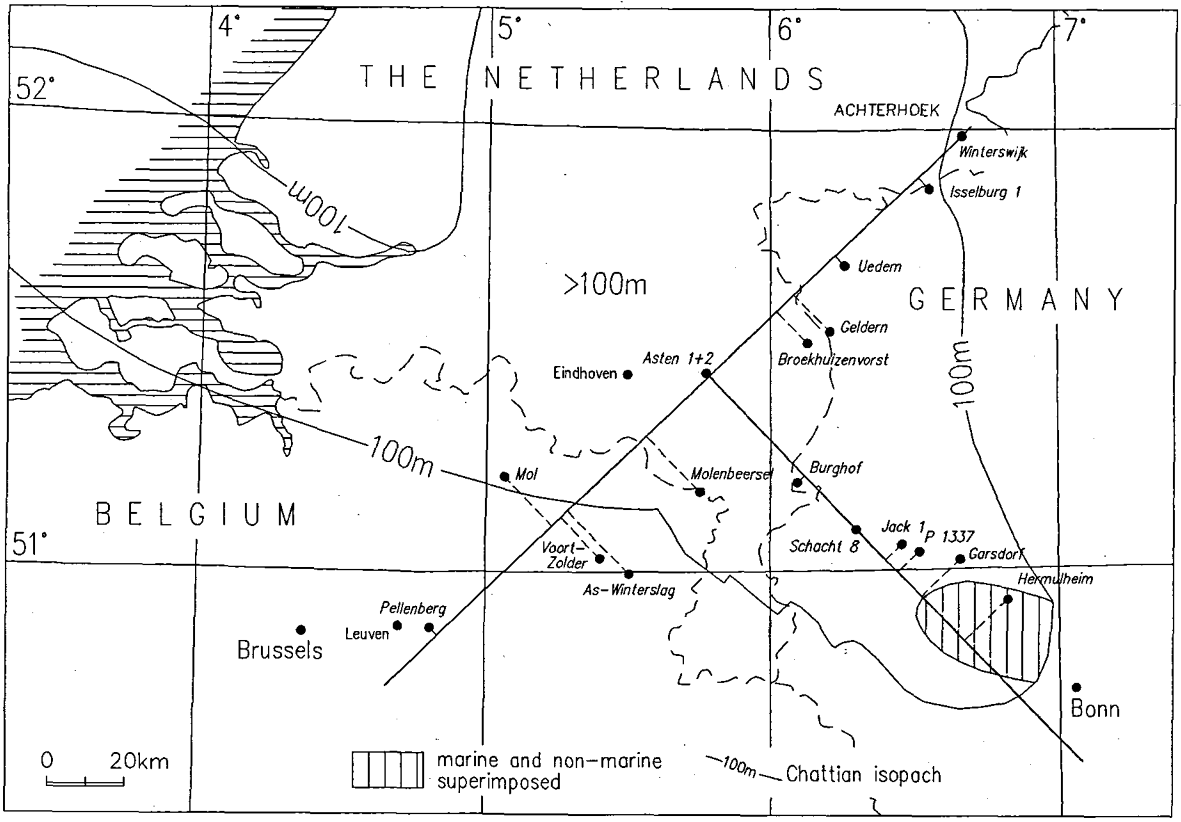

Fig.1. Location map and situation of profile lines and wells.

thickness. Data from the northern area are almost exclusively obtained by oil companies. The data in the area under investigation are obtained from the brown coal exploitation, coal mining, water wells, geothermal energy prospects and general reconnaissance and mapping efforts by the national and regional geological surveys.

Methodology

Several hundreds of wells with geophysical logs, mainly resistivity and natural gamma ray records, and in some cases with core descriptions and paleontological and sedimentological sample analyses, have been examined in northern and northeastern Belgium, in the southern Netherlands, the Lower Rhine area and the Achterhoek area in the eastern Netherlands. Furthermore improved well logging techniques allowed reinterpretation of logs from the fifties and the sixties recorded with different equipment and in a different log presentation.

A selection of representative wells is plotted along two profile lines in Figure 1. One profile line is oriented NE-SW and spans the area between Leuven in Belgium and Winterswijk in the Achterhoek in the Netherlands. Along this line, two flattened sections have been constructed, one representing the situation at the end of the Rupelian and the other representing the Oligocene succession at the end of the Chattian. The second profile, striking NW-SE, is perpendicular to the first and spans the area between Bonn in Germany and Eindhoven in the Netherlands. Along this profile line only the situation of the Oligocene deposits at the end of the Chattian is represented. Both profile lines cover an area with thick Chattian deposits, which thin out in northeastern, southwestern and southeastern directions (Fig. 1).

The end Rupelian section

The Rupelian sections can be subdivided over the whole area in two sequences by a silty layer, the most coarse-grained layer within the clayey part of the Rupelian section and observable on all electric logs of the area. It is called the 'double layer' or 'db' after its characteristics in the outcrop area in Belgium. This coarse layer is the sequence boundary (SB2, Fig. 2) within the Rupelian on the Haq et al. (1987) curve (Vandenberghe & Van Echelpoel 1987, Vandenberghe et al. 1998).

Lowstand deposits are present in the lower Rupelian sequence but they are not always clearly distinguishable on the geophysical well logs. Calibrations in outcrop and shallow cored wells in Belgium and the Achterhoek allow identification of these deposits as fine glauconitic marine sands containing many reworked microfossils (Ruisbroek Formation in Belgium, Onder Rupelien of van den Bosch (1996) in the Achterhoek area) passing eastwards and southeastwards into lagoonal deposits containing a.o. green clays, and marls and sands containing brackish water molluscs (Continental Tongrian deposits of the Belgian 1:40 000 geological maps or the Borgloon Formation (Maréchal & Laga 1988) in Belgium). These lowstand deposits are situated in zone NP22 and are between 5 and 20 m thick. For a discussion of the discrepancy between the stratigraphic position of the base of the Rupelian stratotype section and the base of the Rupelian as the lowermost stage of the Oligocene, the reader is referred to Stover & Hardenbol (1993), Brinkhuis & Visscher (1995) and Berggren et al. (1995). The transgressive surface is situated approximately at the boundary between zones NP22 and 23 and is associated with phosphorites in the offshore facies and with flint pebbles in the nearshore facies. Towards the basin centre it is immediately overlain by a clay layer, called the Boom Clay Formation in Belgium and the Septarienton in Germany, but towards the coastal area it grades into sandy deposits.

The basal part of the Boom Clay consists of a silty clay (called the Belsele Waas Member in Belgium) which grades upwards into a coastal sand unit called the Berg Sands in Belgium and the Walsum Sands in Germany. Slightly higher in the section and in the more nearshore area, the lower part of the Terhagen Member grades into a sand unit called the Kerniel Sands in Belgium and unnamed in the Lower Rhine area. In this coastal facies, the clay layer that intervenes between the Kerniel Sands and the Berg or Walsum sands is marly and characteristically contains numerous *Nucula compta* shells. This clay, which is often informally named the *Nucula* clay is also known under the name of the Kleine-Spouwen Clay in Belgium and the Ratingen Clay (see Lange 1995) in the Lower Rhine area. In the marine facies this marly clay corresponds approximately to the clay with septarialevels S10 and S20 (sensu Vandenberghe & Van Echelpoel 1987). Towards the marine facies the sandy units gradually disappear but in the intermediate area the marly basal clay can still be recognised through a specific geophysical log signature in the base of the clay section, which over its whole thickness is called Boom Clay in this marine facies area. If Kerniel Sands separate the main clay section from a lower Kleine-Spouwen or Ratingen Clay only the upper main clay mass is commonly called Boom Clay. The lower se-

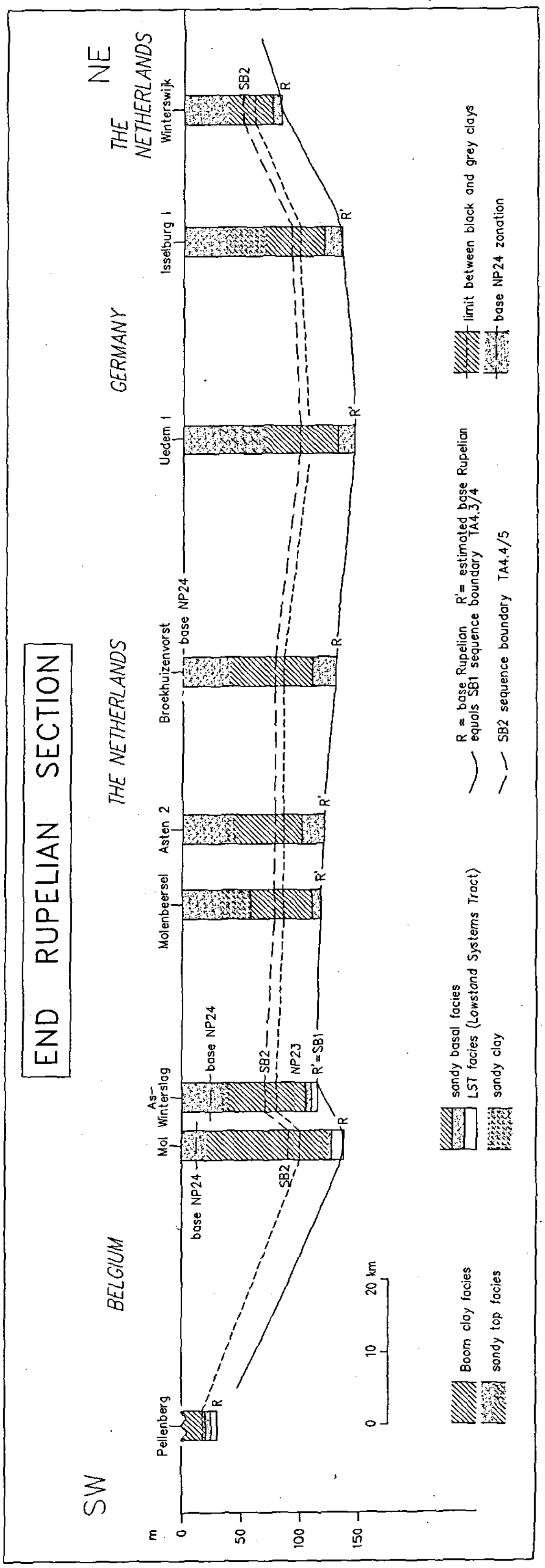

Fig.2. End Rupelian flattened section between Leuven and Winterswijk. The sequence boundary codes TA4 refer to Haq et al. (1987).

quence as a whole has a very uniform thickness and details of the clay layering can be traced over the whole area.

The upper sequence displays somewhat more variation in lithology than the lower sequence. Apparently a more sandy facies, fine-grained and containing some clay and glauconite,generally devoid of molluscs, develops from the border area in Belgium towards the basin centre. This sandy facies is deposited in a shallower marine environment than the clay. Taking into account the position of the boundary between zones NP23 and NP24 it becomes clear that the sedimentation rate varied strongly during deposition of this upper sequence. Indeed the thickness between the SB2, an isochronous level, and the NP23-NP24 boundary, is 76 m in the Mol well, only 46 m in the As-Winterslag wells and less than 20 m in the Sophia-Jacoba Shaft 8. The sedimentation in that time interval remained mainly clayey until the end of the NP23 time, when it became sandy. It must be concluded that a central area was uplifted gradually during this interval of about 2 million years, with reduced sedimentation and with water depth reduced by several tens of metres, from about 50 to 100 m to probably around 20 to 30 metres. This reduction of water depth occurred over the whole area, including the border areas, as demonstrated by the sandy facies in the top of the Mol well and other wells in North Belgium. Between the start of zone NP24 and the end of Rupelian time, an interval estimated at somewhat more than a million years, the situation in the central area is reversed, with increased sedimentation implying a subsidence in this area. The sediments remain however of a shallow marine facies. The border areas were being eroded already at the end of the Rupelian and the early Chattian as demonstrated by the combination of the burial history of the Boom Clay and the presence of reworked Chattian foraminifera on top of the eroded Boom Clay in the Antwerp area and in North Belgium (Vandenberghe & Laga 1986). Apparently the subsidence of the central area, which was considerable during the Chattian, began in the late Rupelian. It was preceded by local uplift in the Middle Rupelian.

The Chattian stratigraphic nomenclature

The Chattian stratigraphic nomenclature in the study area has been developed in several different ways. In Belgium and the Netherlands, a twofold division into Voort Sands and Veldhoven Clay is in use (NAM/RGD 1980, Maréchal & Laga 1988). Recently in the Netherlands the Someren Member was defined on top of both the Voort and the Veldhoven Clay Members (van Adrichem Boogaert & Kouwe 1997). In the Lower Rhine area Veldhoven Schichten, Grafenberg Schichten and Köln Schichten are all used (Fig. 11 in Hilden 1988). A biostratigraphic threefold division A-C,

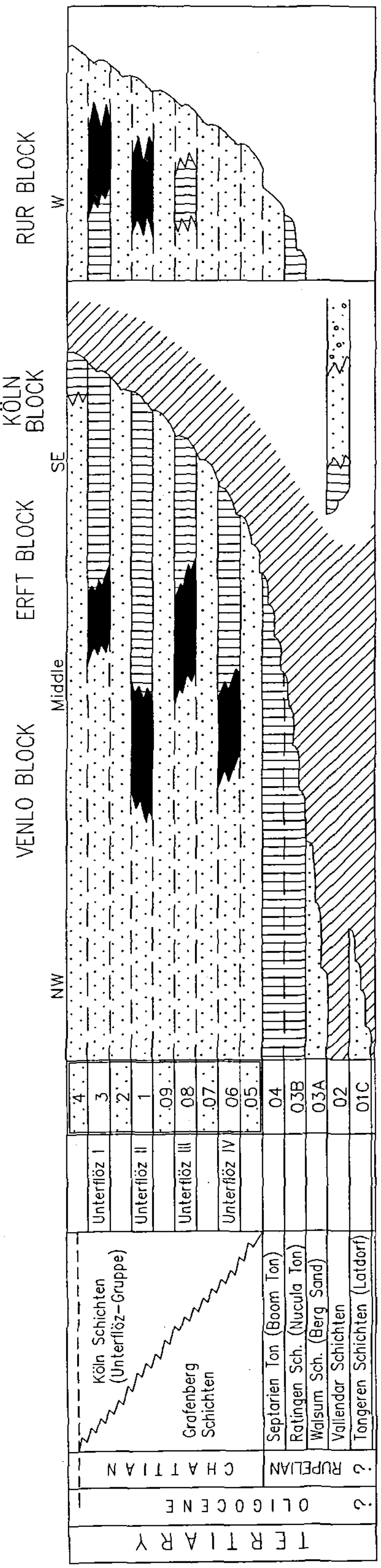

Fig.3. The stratigraphic nomenclature of the Chattian deposits in the Lower Rhine area (modified after Hager 1977). Note the uncertain stratigraphic position of the Tongeren deposits at the Eocene-Oligocene transition.

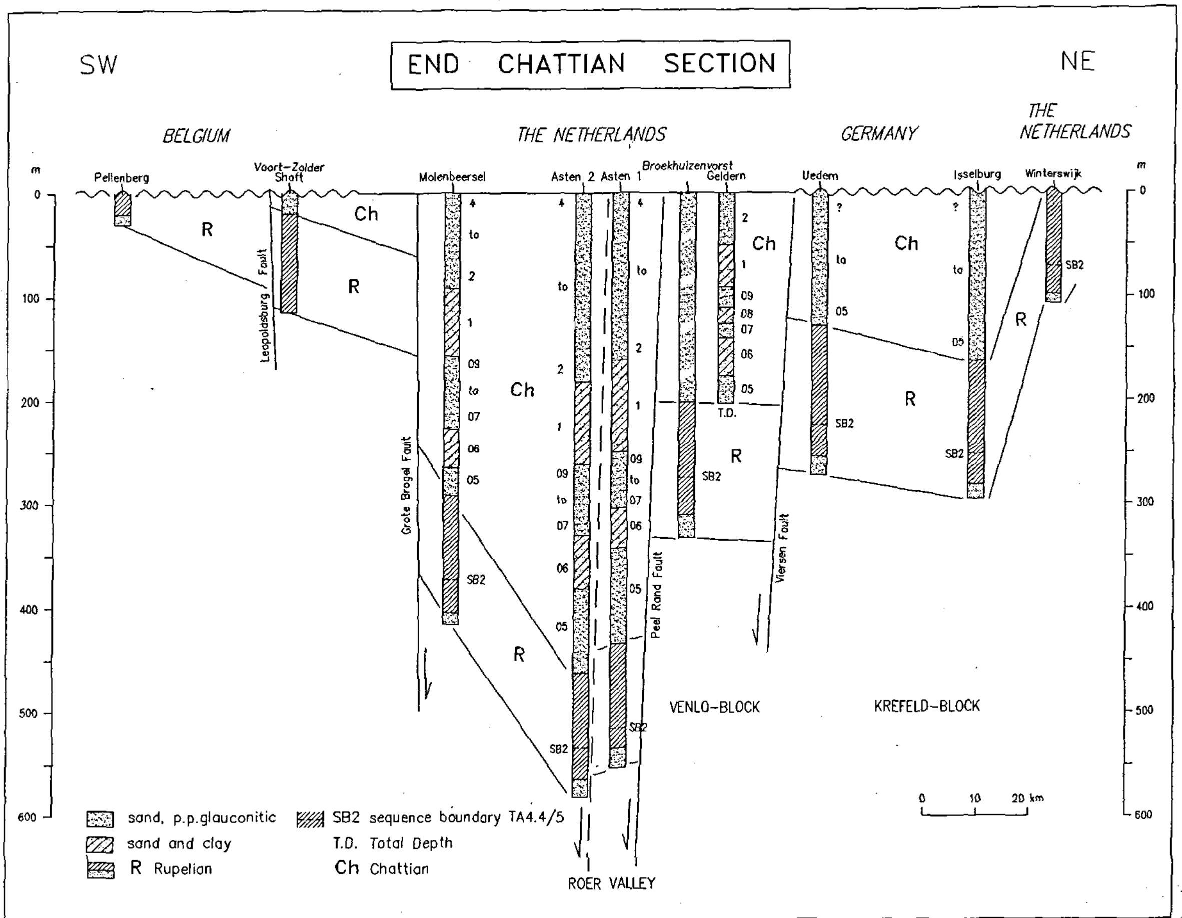

Fig.4. The End Chattian flattened section between Leuven and Winterswijk.

based on the mollusc families *Pecten* and *Chlamys*, has been proposed by Anderson et al. (1971). A twofold division into Eo- or Lower Chattian and Neo- or Upper Chattian was proposed in the Lexique Stratigraphique (Hinsch 1956). The Kasseler Meeressand is considered a.o. as a lithostratigraphic unit within the Eochattian and the Grafenberg Sand as a.o. a lithostratigraphic unit within the Neochattian although the terms Grafenberg Schichten and Braunkohlen Sande have also been used. Gliese (1971) has introduced the term Köln Schichten or Unterflöz Gruppe for the sediment series of Chattian and Early Miocene underlying the main lignite bearing Ville Schichten or Hauptflözgruppe (Fig. 11 in Hilden 1988).

A traditional approach using well defined reference stratotypes is difficult to apply as the older stratotypes have been defined in small and now degraded outcrops and as almost all boreholes are drilled destructively with heavy muds and high speed. Also the burial-related alteration may introduce non-stratigraphic distinctions between units. It is probable in this respect that the white Köln or Frechen Quarzsand Schichten on the Köln block are the altered equivalents of the more deeply buried Grafenberg Sands in the Erft block in the north. Furthermore also biostratigraphy is difficult as the widespread presence of lignites has enhanced the general decalcification. For all these reasons the different terms in use are difficult to be compared with each other and therefore no attempt was made to present the different terms together in a stratigraphic table.

However, given the enormous amount of geophysical well logs, up to 40 wells per km^2 in the lignite exploitation area of the Lower Rhine and up to 20 wells per km^2 outside the exploitation area, a logical approach is to define geophysical stratigraphic units through correlation between wells. In fact Schneider & Thiele (1955, 1965) have already used a lithologic alternation of sands and clays for the stratigraphic subdivision, based on well samples and inspired by the concept of the rhythmicity introduced earlier by Breddin (1952, 1955). However, their study was lim-

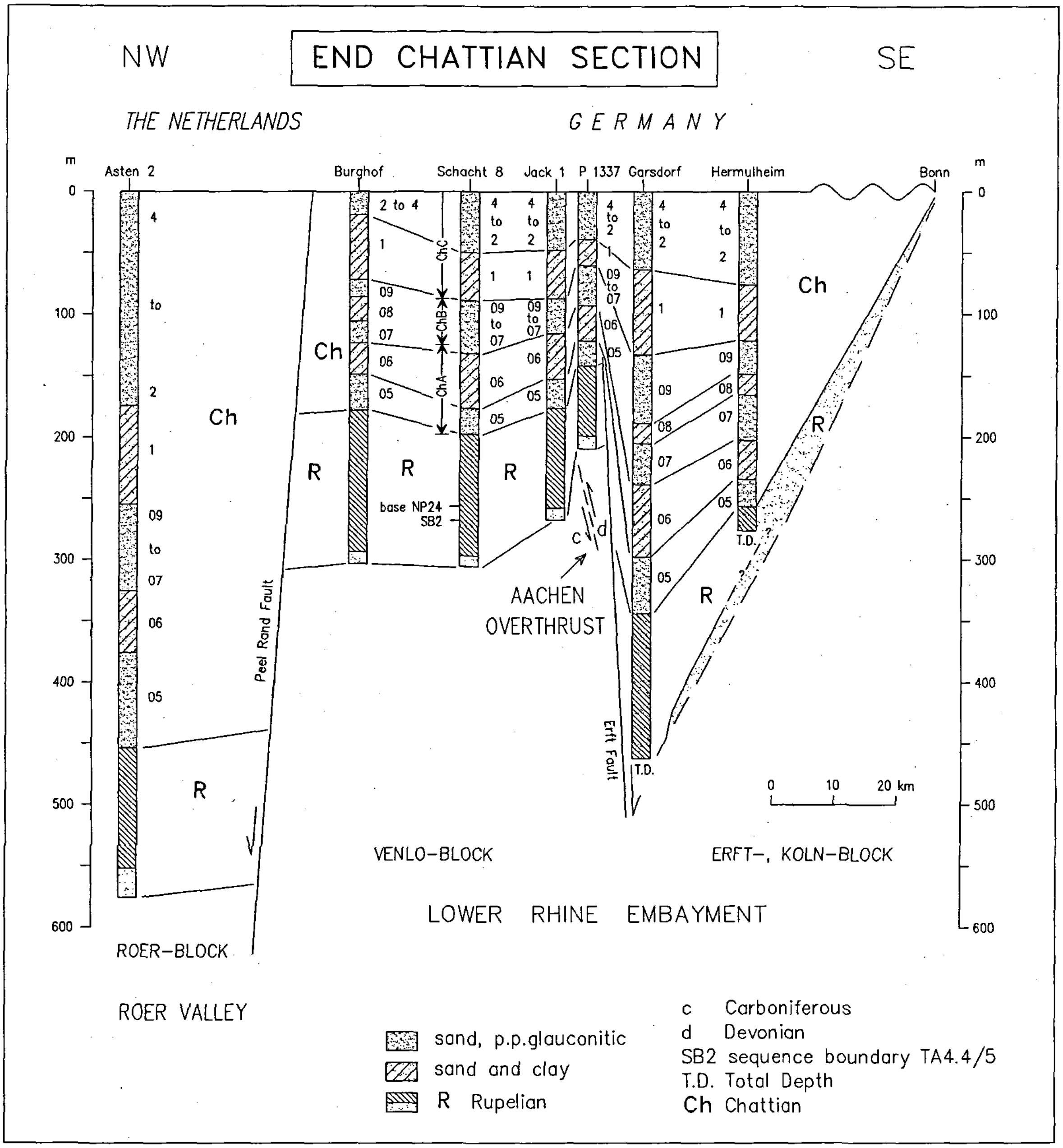

Fig.5. The End Chattian flattened section between Asten and Bonn. In Schacht 8 the Chattian subdivisions A,B and C could be determined.

ited to the Köln block and they had not yet the geophysical well logs at their disposal. Therefore, Hager (1977) adapted the original Schneider & Thiele system and extended it to the whole Lower Rhine area. His correlations were based on the very dense network of geophysical logs and over the limited area of the Lower Rhine the correlated surfaces were considered to be isochrons (Fig. 1 in Hager 1977). Nine lithological units are recognised in the Chattian (Fig. 3) and coded 05 till 09, and 1 to 4. The basal unit 05 is a sandy deposit and the overlying 06 is a brown coal and clay unit. Such alternations of sand and browncoal and clay are repeated another three times (07 till 3) and a sandy unit (4) occurs again at the top. The sand unit 2 has the largest southward extension. The sands are fine-grained marine glauconitic sands, weathered to more or less quartzitic sands when exposed to severe weathering, as occurs under Quaternary gravel terraces on the tectonic high Köln block. The clays represent the mud infill of creeks crossing the swamps and dewatering the Sieg river into the sea. The swamp vegetation itself later developed into lignites.

The End Chattian profiles between Leuven and Winterswijk and between Asten and Bonn

In contrast to the End Rupelian profile the Chattian profile is strongly faulted (Figs 4 & 5). The different thicknesses of the same intervals in the Chattian succession across the faults testify that the faulting and subsidence took place during the Chattian. The Chattian normal faulting indicates a stretching of 3% perpendicular to the subsidence axis and a subsidence

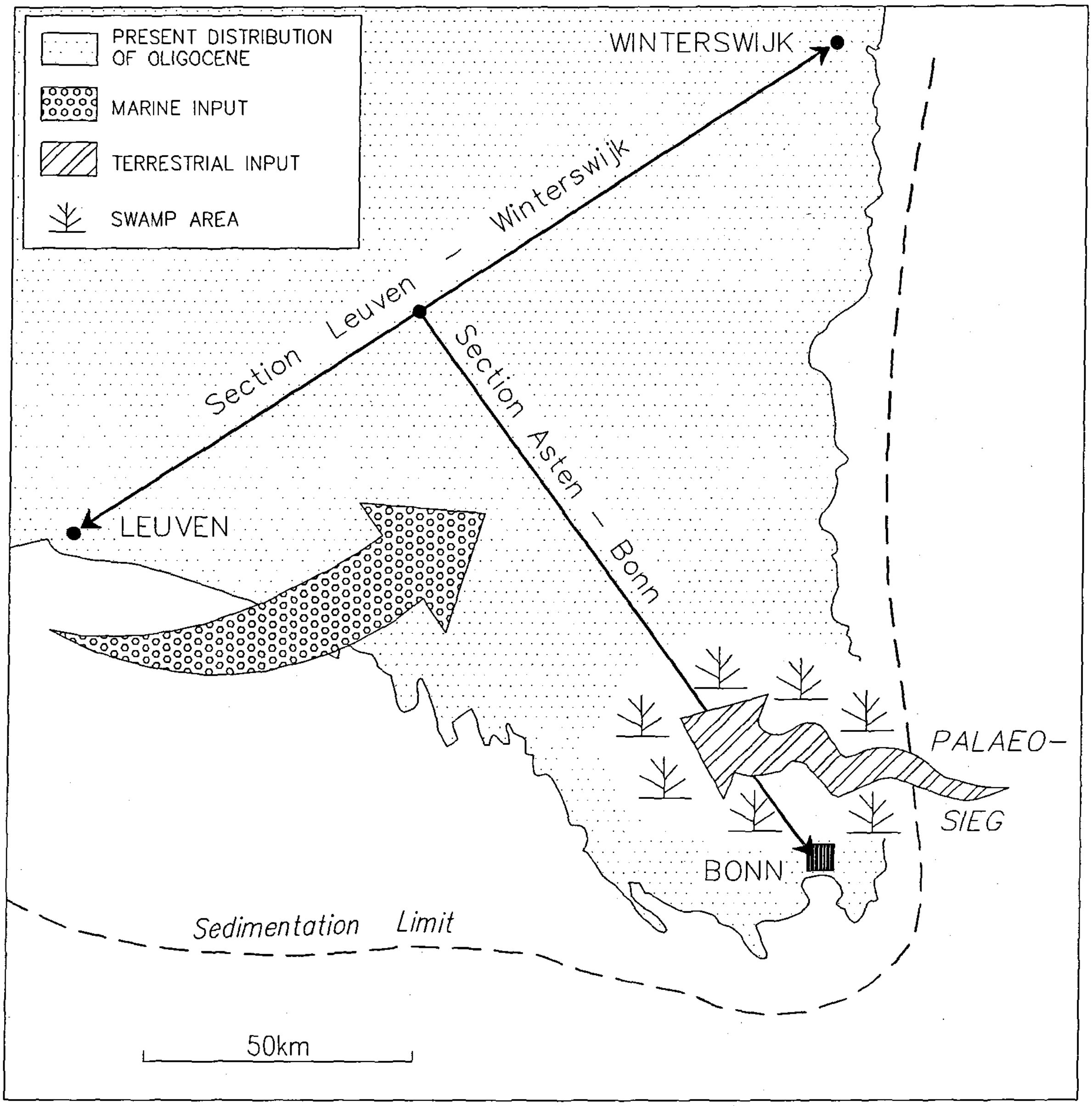

Fig.6. Paleogeographic sketch of the Chattian sedimentary environment.

of about 500 metres (Knufinke & Kothen 1997). During the Miocene the area subsides another 300 metres but without lateral stretching. Sediments and lignite seams cross the Chattian normal faults without changes in thickness, indicating that the faulting was pre-Miocene.

Non-marine creek clays and lignites alternate with marine fine-grained sands. The muds and lignites represent the deltaic filling of the accommodation space created by tectonic subsidence and were derived from the Sieg river discharge. Around the muddy delta, fine-grained glauconitic marine sands were deposited. They were transported into the subsiding area from the west (Fig. 6). It can be inferred from the thickness and lithology distribution (Figs 4, 5) that the Sieg was draining over the Köln, Erft and Venlo Blocks into the Roer Block. This drainage pattern explains the mainly marine sandy deposits of Chattian A,B and partly C over the Krefeld Block.

The alternation between deltaic and marine deposits can easily be detected by geophysical logs towards the mouth of the Sieg as the deltaic deposits consist there of more than 50% clay and lignite whilst towards the north, in the Roer Valley, the sandy character becomes gradually more pronounced, untill the sediments develop into fully marine sandy deposits. However, clayey sediments are dispersed far enough in front of the delta to be detected by the sensitive geophysical logs. Such gradual transition from the deltaic sediments into fully marine sediments could be established because of the very close net of geophysical wells in that area. In this way even the dominantly sandy Molenbeersel and Asten wells can be subdivided according to the modified Schneider & Thiele coding presented in Figure 3. The absence of the units 08 and 3 in these wells is also expected, based on the distribution of the deltaic sediments as represented in Figure 3. During these time intervals the delta was located more to the west than to the northwest (Asten, Molenbeersel). The less subsiding Krefeld and Venlo Blocks were situated more marginally. They did not receive sufficient clayey fine sediments to develop a subdivision like on the Roer Block.

A remarkable observation on the end Chattian profiles is that the different Schneider & Thiele intervals are present over different tectonic blocks but are developed with different thicknesses. Apparently the alternation of deltaic and marine conditions at a particular location is controlled by a mechanism other than the vertical tectonic movements, which controlled only the thickness of the intervals. It is suggested that the facies alternations were mainly caused by eustatic sea-level variations and that the Chattian is composed of 4 to 5 eustatic cycles.

On the Venlo-, Erft- and Köln- blocks (Fig. 5), the effect of Chattian tectonics are greatly simplified.The anomalous uplifted geometry of the deposits just north of the Erft fault on the Asten-Bonn section is due to the influence of the Variscan Aachen thrust fault underlying the area with a strike almost perpendicular to the graben border faults.

Conclusions

During the time of the earliest Rupelian sequence (base Rupelian SB1 till double layer SB2) tectonic movements were absent and the basin was receiving clay-rich sediments. During the early part of the later Rupelian sequence, above the double layer SB2, at least parts of the later graben area were slightly uplifted, but by the start of the NP24 zonation in the Late Rupelian, the graben area started to subside and was filled in by fine-grained glauconitic sands pointing to a shallower water than during the clay sedimentation in the early Rupelian.

A subdivision of the Chattian succession is proposed which can be applied in the Belgian, Dutch and German parts of the Lower Rhine area. The subdivision is based on a sedimentary model that explains the observed composition and distribution of Chattian sediments in the area. The repeated interfingering of marine sands and deltaic deposits is interpreted to be controlled by eustatic sea-level changes and tectonic block movements. This can be used to establish a genetically understood lithostratigraphy. Furthermore it also explains why sections can be incomplete or different over different tectonic blocks and why biostratigraphic data alone would not sort out the stratigraphy of the Chattian over this complex area.

The similarity of the strata in so many well logs around the Rupelian-Chattian and the Chattian-Miocene boundary strongly suggests that no important hiatus occurs at these two boundaries in the basin centre.

Dansk sammendrag

Der er konstrueret 3 profiler gennem de Oligocæne aflejringer i grænseområderne mellem Belgien, Tyskland og Holland. Dette område går tværs hen over det nedre rhinske sænkningsområde. Profilerne er baseret på korrelationer mellem mange geofysiske borehulsmålinger, og deres kalibrering ved hjælp af borekerner og palæontologiske data.

Profilerne illustrerer de geometriske sammenhænge mellem Rupelien og Chattien aflejringerne og deres interne laterale variationer. Et profil, der er "flattened" (planeret) til top-Rupelien, mellem det centrale Belgien og Achterhoek området i Holland viser en temmelig ensartet tykkelses fordeling. Op imod toppen kan indflydelsen fra den begyndende hævning af dele af Nedre Rhin graven spores, og den efterfølgende indsynkning afledes ud fra variationerne i tykkelser og litologi i bestemte intervaller.

Dette er i skarp modsætning til den forkastnings kontrollerede aflejring i løbet af Chattien, sådan som det er vist på et profil fra top-Chattien i de samme områder. I den centrale del af sænkningsområdet er Chattien aflejringerne hovedsagelig kontinentale til deltaiske. Til siderne udvikles aflejringerne som marine glaukonitholdige sedimenter. Ud fra deres relative indhold af sand og ler kan der identificeres flere uformelle litologiske enheder indenfor disse Chattien aflejringer. De kan korreleres ved hjælp af et tæt net at geofysiske borehuls målinger især i det tyske brunkuls indvindings område. Bemærkelsesværdigt ensartede underinddelinger kan findes i de forskellige tektoniske blokke, blot med varierende tykkelser i de forskellige blokke. Disse iagttagelser fører til den antagelse, at eustatiske havniveau ændringer kontrollerer cyklisiteten i aflejringerne medens tektonikken kontrollerer tykkelsen af enhederne.

Et profil, der er "flattened" (planeret) til top-Chattien, mellem Bonn og Asten i Holland ligger vinkelret på det foregående og omtrent parallel med Nedre Rhin områdets indsynkningsakse. Den cyklicitet, der viser sig i facies variationerne som følge af den periodisk skiftende kystlinie, kan igen korreleres mellem de forskellige blokke. Disse enheder har forskellige tykkelser over blokkene, og derfor foreslås det igen, at eustatiske ændringer har styret cykliciteten. På dette profil kan der iagttages en anormal geometri af de Oligocæne aflejringer, hvor den variskiske Aachen overskydning findes. Denne anomali er forårsaget af SØ-NV orienteret stress betingede bevægelser langs med denne variskiske overskydnings forkastning.

De tre litologiske profiler er tænkt som en ramme for den formelle stratigrafiske underinddeling og nomenklatur udvikling.

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