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INTEGRATED STRATIGRAPHIC ANALYSIS OF LOWER RUPELIAN DEPOSITS (OLIGOCENE) IN THE BELGIAN BASIN[1]

by

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(8 figures)

ABSTRACT.- Information from new borehole sections and cone penetration tests in the Rupelian type area has led to a reassessment of Lower Rupelian stratigraphy in the Belgian Basin. Deposits underlying the Boom Clay Formation in the type area are reclassified into the newly introduced Niel Sand Formation, including a lower Wintham Silt Member (new) and an upper Ruisbroek Sand Member (redefined). A new integrated stratigraphic framework is established for the Lower Rupelian, on the basis of grain-size, natural radioactivity, point resistance and calcareous nannoplankton data. These data are interpreted in terms of sequence stratigraphy. It is concluded that the lower part of the Rupelian stratotype is correlatable with the traditional «Upper Tongrian deposits» of Eastern Belgium, demonstrating once again the ambiguity of previous chronostratigraphic terminology.

RESUME.- Des informations fournies par des forages et des essais de pénétration implantés récemment dans la région-type du Rupelien nous ont incité à réévaluer la stratigraphie du Rupelien inférieur du Bassin belge. Les dépôts sous-jacents à la Formation de Boom appartiennent à la Formation de Niel, nouvellement introduite et comprenant de bas en haut le Membre de Wintham (nouveau) et le Membre de Ruisbroek (redéfini). Le nouveau cadre stratigraphique proposé intègre les données de la granulométrie, de la radioactivité naturelle, de la résistance de pointe et des nannofossiles calcaires. Les observations sont interprétées en termes de stratigraphie séquentielle. L'étude permet d'établir le synchronisme entre la partie inférieure du stratotype du Rupelien et les dépôts dits «tongriens supérieurs» de la Belgique orientale; elle souligne une fois de plus l'ambiguïté de la terminologie chronostratigraphique adoptée précédemment.

1.- INTRODUCTION

Situated at the margin of the Northwest European continental shelf, depositional conditions in the Belgian Basin changed repeatedly during the Cenozoic in response to sea level fluctuations. As a result the basin is marked by a very complex Palaeogene depositional history. As this history is extremely well documented in the sedimentological record, the Belgian Basin is among the few areas on the globe where Vail & Hardenbol's sequence-stratigraphic concepts can be clearly demonstrated. The Oligocene Boom Clay Formation seems to be the most appropriate and promising test case, because of its unique depositional regime, only weakly influenced by tectonic phenomena.

During the last decade considerable progress has been achieved in unraveling the stratigraphy and the depositional history of the Boom Clay Formation. These advances result from the work of Prof. Dr. N. Vandenberghe, who for the first time deciphered the rhythmic nature of the formation, as alternating clays and clayey silts, which can be traced bed by bed over most of northern Belgium (Vandenberghe, 1975, 1978 and 1981; Vandenberghe & Laga, 1986 and Vandenberghe & Van Echelpoel, 1988). As it is believed that the organic-rich Boom Clay represents an immature stage in

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source rock formation, the reconstruction of its diagenetic evolution is of major interest in understanding the phenomena controlling hydrocarbon formation and accumulation. Up to now special attention has been paid to the lithologic composition of the clays in quarries in the type region (the Rupel River area) and in northern and eastern adjacent areas, including grainsize analyses, and studies on the clay mineralogy and the organic matter content. Further work will focus mainly on the integration of new stratigraphic information on the Boom Clay Formation in the type area, obtained from recently developed classification methods (high resolution biostratigraphy, magnetostratigraphy, cyclo- and sequence stratigraphy) and on the deciphering of the stratigraphic relationship to supposed equivalents in the eastern part of the basin. The recently published study of Van Echelpoel & Weedon (1990) on Boom Clay cyclicity and its relation to Milankovitch orbital cycles has originated within the context of this new strategy.

The depositional history of the Boom Clay cannot be fully understood without detailed analysis of the underlying and overlying strata. A first attempt towards the elucidation of the stratigraphy of the underlying deposits in the type area was published by the author (Steurbaut, 1986). Evidence for the absence of a major hiatus at the base of the Boom Clay was found in the Niel borehole, where the basal part of the Clay and the top of the underlying Ruisbroek Sands yielded similar calcareous nannofossil associations. However, due to the absence of detailed information, these and many other lithological and sedimentological phenomena could not be satisfactorily understood.

Very recently, a large amount of extremely detailed new borehole data have become available from the type area. This, and the awareness of the importance of an integrated approach, based on much more refined insights into basin analysis and sequence stratigraphy, form the conceptual basis of the present paper.

2.- RECAPITULATION OF THE RUPELIAN STAGE CONCEPT

The term Rupelian turns up for the first time in stratigraphic literature in 1849, at the presentation of Dumont's report on the geological map of Belgium (Dumont, 1849, p. 370). The main reason for its introduction was to regroup the clayey sands and overlying stiff clays, previously included in Dumont's «système Tongrien» (the «glaise et sable» overlying the green sands with *Ostrea ventilabrum:* Dumont, 1839, p. 473), into a new two-fold system. From the original definition it is clear that the stiff clays outcropping along the Rupel River («les argiles fossilifères de Rupelmonde, de Boom,...») represent the upper part of Dumont's «système Rupelien». But what is meant by its lower part is less clear, as only few lithostratigraphic details were given. However, it seems reasonable to believe, following the opinions of some eminent predecessors, including Halet (1936, 1937) and Gulinck (1965), that the grey clayey quartz sands underlying the sandy clays in the Rupel area (the Ruisbroek sands) match Dumont's Rupelian concept.

At the International Geological Congress in Washington D.C. in 1989, the term Rupelian was officially accepted as a stage name and incorporated in the global standard chronostratigraphic scale. Consequently, a stratotype should be designated, as none was originally defined by Dumont. The most logical place for which is somewhere within the type area. However, this kind of reasoning seems not to be fashionable anymore nowadays. During the last years important shifts have arisen in stratigraphic philosophical thinking, especially concerning the significance of chronostratigraphic units and their stratotypes. Many of the recommendations expressed in the International Stratigraphic Guide on these particular topics (Hedberg, 1976) have been abandoned now. According to the Guidelines of the International Commission on Stratigraphy (Cowie *et al.,* 1986), one of today's main tasks in stratigraphy lies in the development of a chronostratigraphic framework for the global geologic time scale, through the selection and definition of Global Boundary Stratotype Sections and Points (GSSP). Such a Boundary Stratotype Section and Point is the «designated type of a stratigraphic boundary identified in published form and marked in the section as a specific point in a specific sequence of rock strata and constituting the standard for the definition and recognition of the stratigraphic boundary between two named global standard stratigraphic (chronostratigraphic) units» (Cowie *et al.,* 1986: 5). Various specific requirements have to be fulfilled by candidates for a GSSP (for a summary of the guidelines thereto, see Cowie *et al.,* 1986: 6). It might be pertinant, to mention that, according to the philosophy of the International Commission on Stratigraphy, there should be continuity of sedimentation through the boundary interval and that no disconformities or unconformities are tolerated close to a GSSP. This means that the areas where most, if not all, of the Palaeogene stages have been defined (the shallow shelf areas of Western Europe with their highly fossiliferous, but discontinuous sedimentation) will not be considered suitable for the designation of such «golden spikes». I do agree with this modern approach. In fact, I assume that this new philosophy can be made compatible with the classic, historically based concepts, if the auxiliary stratotype points (ASP) are chosen in the original «type areas» of the subjacent and superjacent units involved.

3.- OBSERVATIONS IN THE RUPELIAN TYPE REGION, THE RUPEL RIVER AREA

3.1.- Sections studied

The location of the boreholes is shown on Fig. 1. Details of their lithostratigraphy and biostratigraphy are given in Figs. 2 to 6. Borehole data are taken from the files of the Belgian Geological Survey. The abbreviation B.G.D. means that the borehole was drilled on behalf of the Belgian Geologische Dienst (= Belgian Geological Survey).

Niel borehole (Fig. 2): B.G.D. borehole 43W-270 (VII), drilled in the clay pit De Neef-Landuyt in 1962; terminated at 43 m depth; map-sheet 15/7-8; coordinates: x = 148.557, y = 199.240, z = + 1.55 m O.P. The Niel borehole section, between 13.20 and 29.50 m depth, was proposed as a holostratotype section for the Ruisbroek Sand Member (Steurbaut, 1986: 55-56). Samples for calcareous nannoplankton analysis were collected by the author from a series of core samples held by the Survey. The results from these investigations were discussed in Steurbaut (1986: 55-56, tab. 2; reshown here in Fig. 2).

Terhagen borehole (Fig. 2): B.G.D. borehole 58W-213 (III), drilled in the clay pit De Beuckelaar in 1962; terminated at ca. 43 m depth; map-sheet 23/3-4; coordinates: x = 152.132, y = 197.252, z = +11.19 m O.P. The Terhagen borehole section, between 25.80 and 37.80 m depth, was proposed as a parastratotype section for the Ruisbroek Sand Member (Steurbaut, 1986: 58). The results from the calcareous nannoplankton analysis were also commented on by the author (op. cit.: 70, tab. 4; reshown here in Fig. 2).

Hingene-Wintham borehole (Fig. 2): B.G.D. borehole 42E-212 (IXb); map-sheet 15/5-6; coordinates: x = 145.325, y = 200.725, z = ca.+1 m. This 80 m deep borehole was terminated in the Lede Sand Formation, penetrating 9.00 m of Quarternary sands, 21.25 m of Rupelian clays and sands, 40 m of

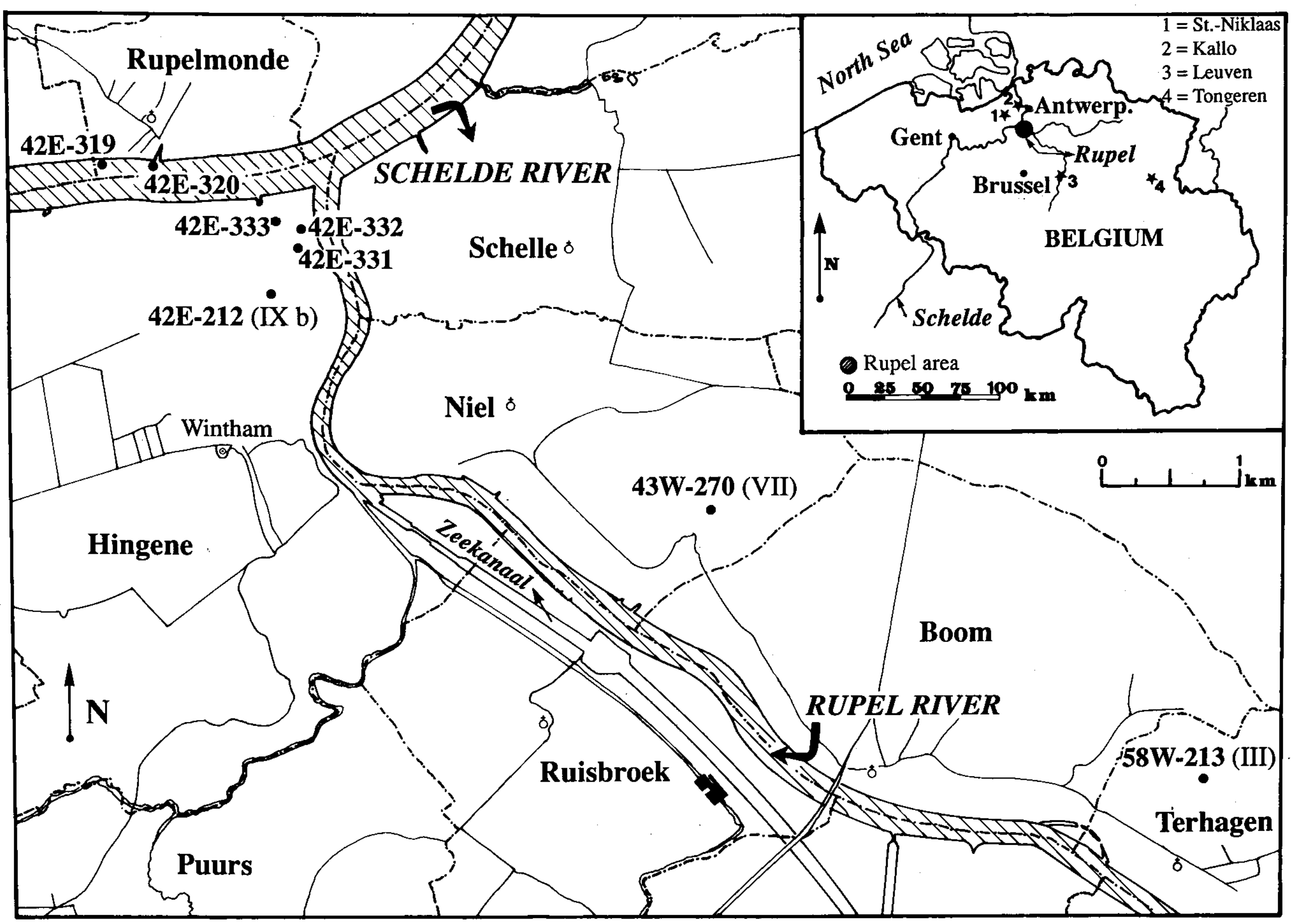

Fig. 1.- Location of studied borehole sections.

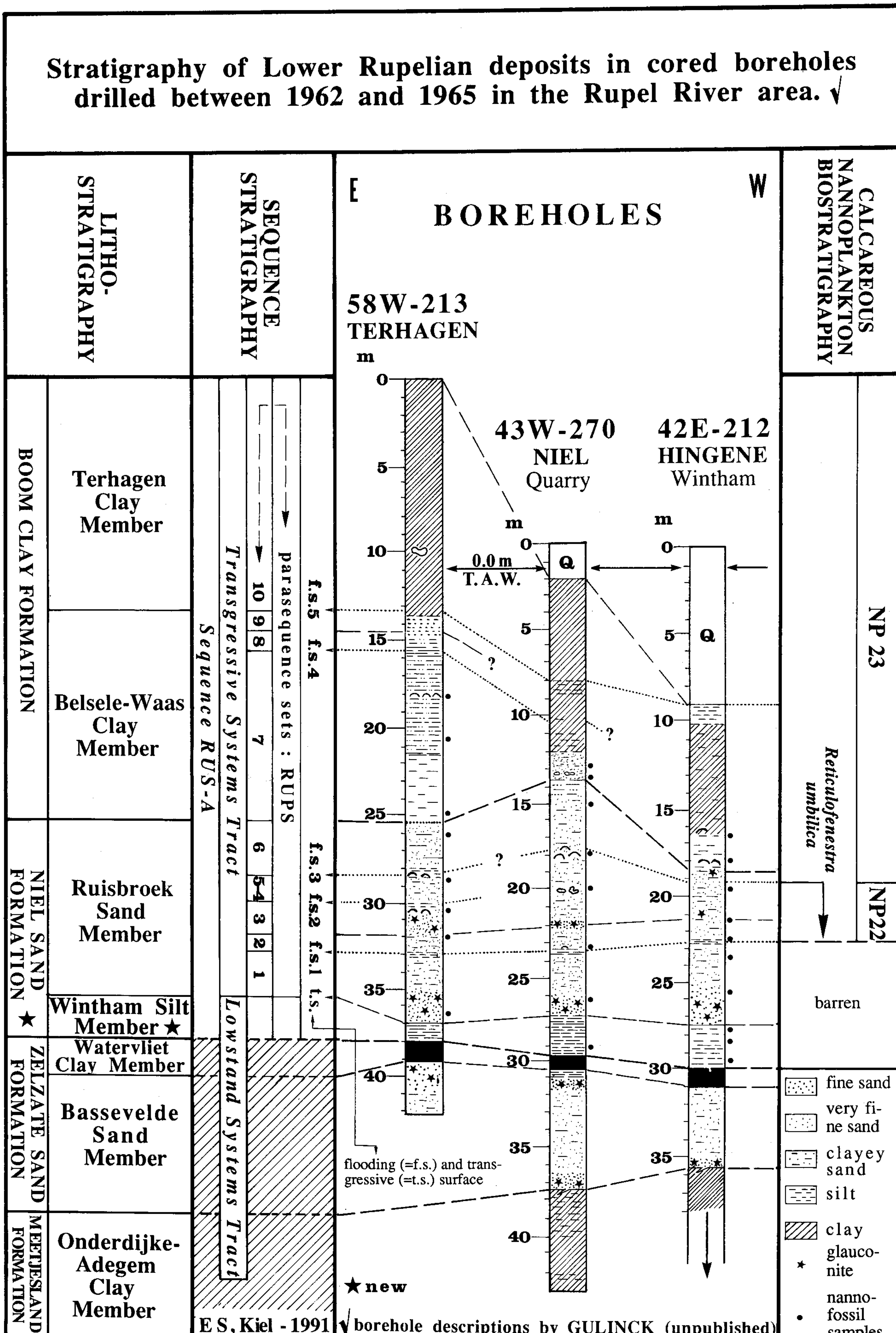

Fig. 2.- Stratigraphy of Lower Rupelian deposits in cored boreholes drilled between 1962 and 1965 in the Rupel River area.

alternating Upper and Middle Eocene clays and sands (Watervliet Clay to Asse Clay) and 10 m of slightly clayey sands (Wemmel and Lede Sands). The uppermost 31 m has been sampled by the author at approximately 0.50 m intervals. The results from the calcareous nannoplankton investigation are presented in Fig. 2.

Hingene-Zeekanaal boreholes: a large number of relatively shallow boreholes have recently been drilled on the west bank of the Rupel River, north of the hamlet of Wintham (Hingene), as part of a reconnaissance study for renovation works on the «Zeekanaal» (see Fig. 1). A deep sounding (cone penetration) test was made at approximately 3 m distance from each borehole. Boreholes and penetration tests have been carried out by the «Bestuur voor Geotechniek, Gent» in autumn 1990 (see Fig. 3). Three boreholes were selected for calcareous nannofossil analysis (see below). Samples were collected by Dr. De Geyter at approximately 0.50 m intervals, and were made available to the author. Cone penetration curves were supplied by the above mentioned institute.

borehole 42E-331 (= B5): map-sheet 15/5-6; coordinates: x = 145.600, y = 201.050, z = +1.54 m O.P.; terminated at 30 m depth;

borehole 42E-332 (= B14): map-sheet 15/5-6; coordinates: x = 145.600, y = 201.175, z = +5.56 m O.P.; terminated at 30 m depth;

borehole 42E-333 (= B34): map-sheet 15/5-6; coordinates: x = 145.425, y = 201.250, z = +1.12 m O.P.; terminated at 30 m depth;

Rupelmonde boreholes (Fig. 4): in spring 1991, two boreholes and additional cone penetration tests have been carried out by the «Bestuur voor Geotechniek, Gent» in the bottom of the Schelde River at Rupelmonde, as part of the above mentioned reconnaissance study for renovation works on the «Zeekanaal».

borehole 42E-319 (= B1): map-sheet 15/5-6; coordinates: x = 144.200, y = 201.650, z = +0.04 m (Schelde River bottom); no samples studied;

borehole 42E-320 (= B3): map-sheet 15/5-6; coordinates: x = 144.575, y = 201.625, z = +0.68 m (Schelde River bottom); terminated at 20 m depth. Samples were collected by the author at approximately 0.50 m intervals.

3.2.- Trends in lithology and lithostratigraphic classification

a.- Investigation methods

Granulometric analyses are among the most currently and successfully applied methods for studying grain-size evolution in outcrop and borehole sections. However, as continuous borehole cores are often lacking (too expensive), other investigation methods have been developed for surveying the subsurface. Detailed information on the lithologic composition of the subsurface can be gained through the interpretation of geophysical well log and deep sounding (cone penetration) tests.

Geophysical well logs.- Gamma ray logs, resistivity and sonic or acoustic logs are extremely sensitive lithology indicators. This sensitivity to subtle lithological changes is the basis for their use in correlation. Gamma ray logs in particular give a fairly reliable indication of lithology, are simple and easily interpretable, and are not affected by depth, pressure or other borehole variables. This is the main reason why such logs have been run for practically all recently drilled boreholes in the Belgian Tertiary.

The gamma ray log is a record of a formation's radioactivity. Natural radiation in rocks comes essentially from three sources: the naturally occurring radioactive elements of the thorium family, the uranium-radium family, and the radioactive isotope of potassium ^{40}K. Each of these elements emits gamma rays spontaneously, which can be detected by a scintillation counter. Clays and shales have by far the strongest radiation among sediments, because of their rather high potassium content. Uranium is derived from acid igneous rocks. It can form soluble salts which are present in river and sea water, which may be fixed and pass into sediments through chemical precipitation in acid or reducing environments, through adsorption by organic matter, plankton, shells,... or absorption by phosphates. As it is always associated with secondary components uranium is irregularly distributed, forming irregular peaks on the logs. These peaks indicate uranium concentrations, uranium-enriched phosphates or uranium-enriched organic matter, which frequently occur around unconformities. Thorium is present in typically heavy minerals, such as thorite, monazite, zircon and epidote. Thorium minerals seem to be regularly distributed in most naturally-occurring clays and shales.

Gamma ray logs are recorded in terms of the API unit (American Petroleum Institute unit). The API unit is defined in a reference well in the grounds of the University of Houston, Texas. The well contains specially-mixed high-radioactivity concrete surrounded by equally special low-activity concrete. An API unit is 1/200 of the difference between the radioactivities of the two concretes. The Houston standard reference well also serves for callibrating gamma ray tools. When such a tool is tested, the API unit is 1/200 of the deflection between the low and high values for

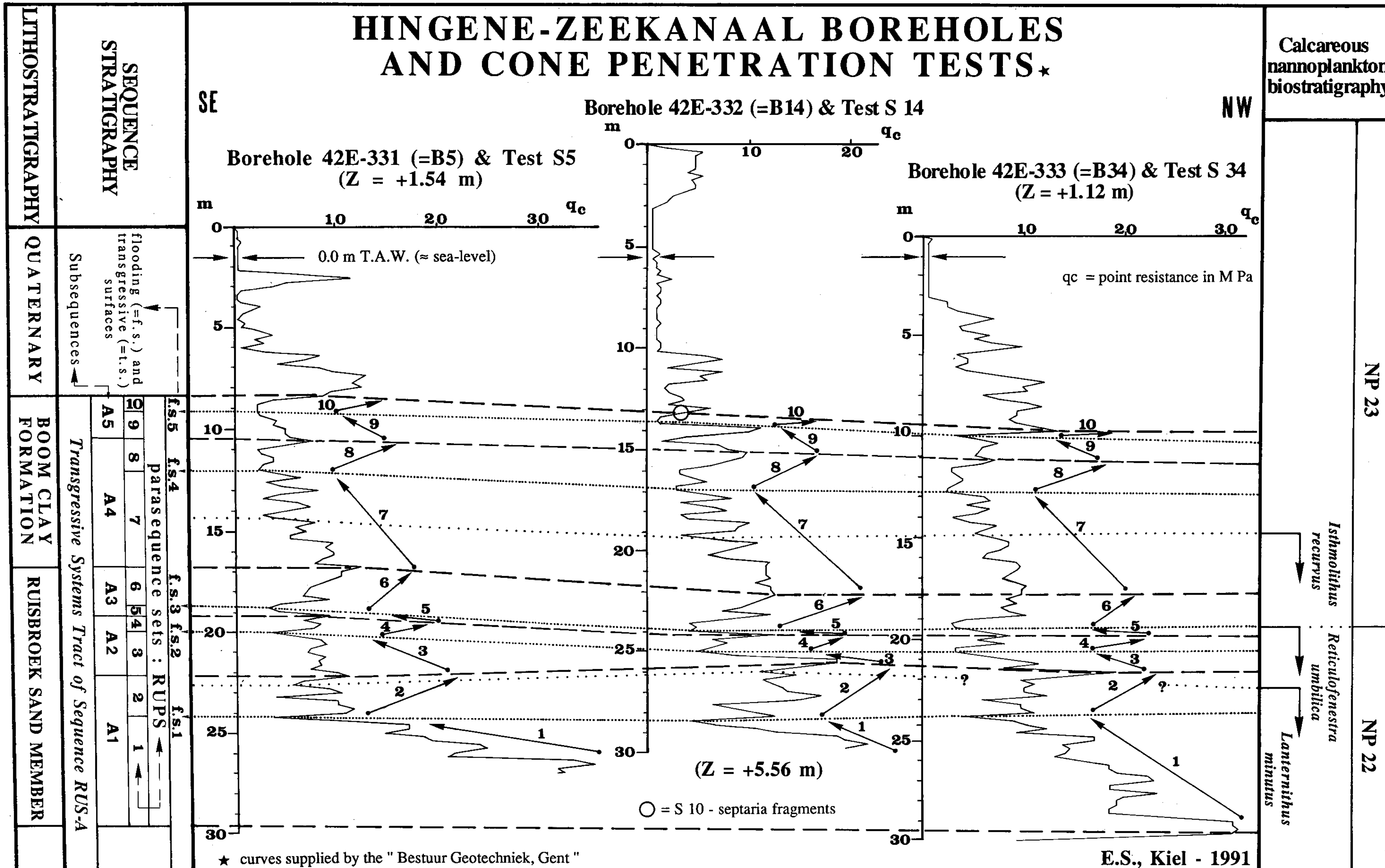

Fig. 3.- Stratigraphic interpretation of the Hingene-Zeekanaal borehole sections and cone penetration curves.

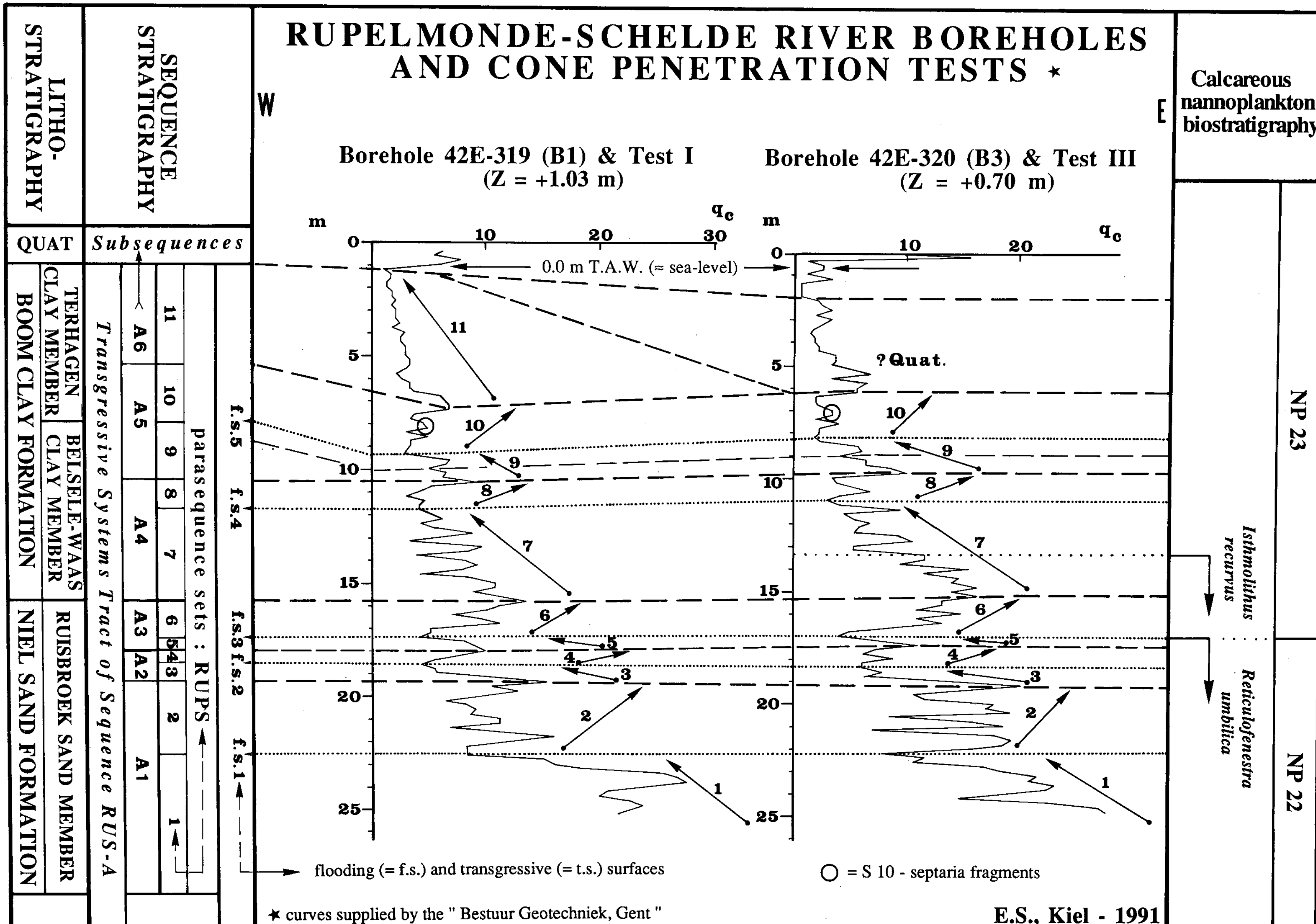

Fig. 4.- Stratigraphic interpretation of the Rupelmonde-Schelde River borehole sections and cone penetration curves.

that particular tool. For more detailed information on the different aspects of natural radioactivity and the use of geophysical well logs the reader is referred to the excellent work of Rider (1986).

Cone penetration tests.- Accurate subsurface data can also be gathered from cone penetration tests. These tests are currently used in engineering geology, because they allow determination of the physical properties of soils and consequently soil stability and its suitability for construction. The methodology is rather simple and consists of driving a metal rod, called penetrometer into the ground and measure the resistance to penetration (see Sanglerat, 1972 for more details).

Two different components are measured during the test: the point (cone) resistance (qc in bar, in MN/m^2 or MPa) and the local side friction (fs in bar or MN/m^2). These measurements are carried out every 20 cm preferably. The different penetration test data are displayed in diagrams. The point resistance (qc) or the side friction of both are plotted on the abscissa and the depth of penetration on the ordinate axis of the diagram (see Figs. 3 & 4). The data can be interpreted qualitatively and quantitatively. The numeric size of the point resistance is a diagnostic criterion, although one should not forget that it depends on various factors, such as the friction characteristics and the stiffness of the soil, the deformation and shattering capacity of the individual grains, which are determined by the shape and roughness of the grains, the groundwater pressure, the distribution of the grains, etc... Plotted against depth the cone resistance gives a fairly good picture of the stratification. For non consolidated soils or deposits, low resistances are generally encountered in fine grained sediments (clay, silt) and high resistances in coarser grained material (sands, gravel). If the overall conditions of the subsurface are known than it is quite easy to identify lithologies and their trends. As a consequence, extremely detailed correlations can be made on the basis of cone penetration diagrams, especially when the subsurface consists of tabular, laterally constant units (see Figs. 3-4).

b.- Reclassification of the Lower Rupelian deposits

Up until now the Rupelian Stage has in a sense been equated with the Boom Clay Formation (the Rupel clays auct.). However, according to Dumont's original definition, this is not completely correct as also the underlying Ruisbroek Sands have also to be incorporated in the Rupelian (see chapter on the Rupelian Stage concept). The term Ruisbroek Sand Member was introduced by Steurbaut (1986: 55-66) to describe the predominantly sandy unit underlying the Boom Clay Formation in the Rupel River area. This includes a very thin basal micaceous clayey silt and an overlying succession of greenish glauconitic fine sands, clayey fine sands and silts. This unit was given member status and grouped together with the Watervliet Clay Member and the Bassevelde Sand Member into the Zelzate Sand Formation.

Recent investigations have shown that this classification cannot be upheld, the lithology of the Ruisbroek Sands being quite different, and generally much clayier than the underlying Bassevelde Sands. It is also suggested, for lithological and depositional reasons, that the basal silty unit should no longer be incorporated in the Ruisbroek Sand Member, but given separate status and named Wintham Silt Member. When this unit is present, its lower and upper limits are always sharply defined, marking unconformities. The junction with the underlying Watervliet Clay is especially sharp and locally deeply bioturbated. The Wintham Silt Member and the redefined Ruisbroek Sand Member are to be included in the newly introduced Niel Sand Formation.

Niel Sand Formation

Name.- Niel, small village 3 km Northwest of Boom (Fig. 1).

Rank.- new formation, introduced to include the Wintham Silt Member (new) and the redefined Ruisbroek Sand Member.

Type area.- «Rupelstreek», area South of Antwerp, extending along the River Rupel.

Stratotype.- the Niel borehole: B.G.D. 43W-270 VII; map-sheet 15/7-8; x = 148.557, y = 199.240, z = 1.55 m O.P. (Fig. 2).

Depth level of unit: from 13.20 m to 29.50 m below surface;

Thickness: 16.30 m;

Lithology: upper 14 m consist of glauconitic fine sands, clayey sands and silts, calcareous in the uppermost half, resting on a 2.45 m micaceous clayey silt with lignitic discolorations (plant remains ?);

Overlying unit: a clayey silt, with a more sandy basal part, representing the base of the Boom Clay Formation; the junction is characterised by change in lithology and, according to Gulinck, small sandstone concretions;

Underlying unit: hard, green clay considered to represent the Watervliet Clay Member; the junction is sharp;

Macrofossils: not yet studied, mentioned in the borehole description (at 17.50 m broken shells; at 20.00 m shells and rather large foraminiferids; at 23.50 m shells and *Ditrupa*);

Microfossils: 8 samples were investigated for nannofossils; the uppermost 1 m the Ruisbroek Sand Member belongs to Martini's nannoplankton

zone NP 23; the remainder, except for the lowermost 5 m which are barren, is assigned to zone NP 22(see Fig.2).
Distribution.- recorded in the subsurface of Northern Belgium, except for the extreme South-East (Leuven and Tongeren areas); thicknesses highly variable, up to 25 m in the Aarschot area.
Junctions.- the junction with the underlying Watervliet Clay Member is sharp and locally deeply burrowed. The top is marked by an abrupt change in lithology and in the Sint-Niklaas area by a compact reworked phosphatised shell bed, representing a minor hiatus.
Biostratigraphy.- the Ruisbroek Sand Member is attributable to NP 22, except for the uppermost 2 m in the Rupel area which belongs to NP 23. No data are available for the underlying Wintham Silt Member, except for the extreme top in borehole 42E-331, dated NP 22.
Depositional environment.- the Niel Sand Formation was deposited in a fairly open marine shelf environment with normal salinities.
Correlation with other units.- see below.
Age.- the Niel Sand Formation is of Early Oligocene age. It is assumed to belong to the Rupelian, because of its lithology and geometric position, which correspond very well to the indications in Dumont's definition of the Rupelian system.
References.- Steurbaut, 1986, p. 55-60.

Wintham Silt Member.

Name.- Wintham, small village 3 km West of Niel, on the left bank of the Rupel River (Fig. 1).
Rank.- new member, previously incorporated in the Ruisbroek Sands.
Type area.- «Rupelstreek», area South of Antwerp.
Stratotype.- Hingene-Wintham borehole: B.G.D. 42W-212 (IXb); map-sheet 15/5-6; x = 145.325, y = 200.725, z = 1 m O.P. (Fig. 2).
Depth level of unit: from 27.55 m to 30.00 m;
Thickness: 2.45 m;
Lithology: greyish green micaceous silt with dark discolorations due to the presence of amorphous pyrite;
Overlying unit: glauconitic sand of the Ruisbroek Sand Member; junction sharp;
Underlying unit: Watervliet Clay Member; junction sharp, with several deep vertically arranged bioturbations;
Fossils: no calcareous fossils have been recorded yet; dinoflagellate studies are in progress.
Distribution.- recorded from the Rupel River area, where it is 1 to 2.50 m thick; difficult to identify in other parts of the basin, because of lateral changes in lithology; might be missing in certain areas.
Junctions.- see section on the stratotype.
Biostratigraphy.- calcareous nannofossils have been recorded from the top in borehole 42E-331, indicating the lower part of NP 22; dinoflagellate studies are in progress.
Depositional environment.- according to the dinoflagellates, deposited in normal shallow marine conditions.
Correlation with other units.- still imperfectly understood, although it seems to be a marine, deeper water lateral equivalent of the semi-marine to fluviatile Kerkom Sand and Boutersem Sand Members.

Ruisbroek Sand Member.

Name.- Ruisbroek, small village 2 km South of Niel and 2 km West of Boom (Fig. 1).
Rank.- member, described by Steurbaut in 1986 (p.55) but redefined here to include the glauconitic sands and clayey sands, excluding the basal silty unit, for which the name Wintham Silt is newly introduced. The Ruisbroek Sands have erroneously been labeled Bassevelde Sands by several authors (see below in references).
Type area.- «Rupelstreek», area South of Antwerp.
Stratotype.- the Niel borehole: B.G.D. 43W-270 VII; map-sheet 15/7-8; x = 148.557, y = 199.240, z = 1.55 m O.P. (Fig. 2).
Depth level of unit: from 13.20 m to 27.25 m;
Thickness: 14.05 m;
Lithology: fine glauconitic sand passing upwards into clayey sand; occurrence of shell beds in the upper half of the unit;
Overlying unit: sandy base of the Boôm Clay Formation (see description of Niel Sand Formation);
Underlying unit: Wintham Silt Member (see above);
Macrofossils: a few shell beds were mentioned by Gulinck in the original borehole description, however without any comment;
Microfossils: no nannofossils have been found in the lower part of the unit; the upper part belongs to NP 22, except for the topmost 1 m which is attributable to NP 23.
Distribution.- the Ruisbroek Sand Member has been recorded in the whole of Northern Belgium, except for the extreme Southeast (Leuven and Tongeren areas); thickness highly variable.
Junctions.- see description of the Niel Sand Formation.
Palaeontological data.- the lower part of the Ruisbroek sands, exposed at Ruisbroek during the construction of the Rupel tunnel, yielded rich fish faunas, studied by Gaemers (1984).
Correlation with other units.- according to its nannoflora and fish fauna, the Ruisbroek Sand Member has to be correlated with the Oude Biesen Sand and Marl Member.

References.- the Rupel tunnel deposits (Ruisbroek Sands) were studied or cited by Van den Bosch, Cadee & Janssen (1975), Janssen (1981), Van den Bosch (1981), Gaemers (1984) and Van den Bosch (1984), but were usually erroneously attributed to the Bassevelde Sands.

c.- Cyclicity

Recent studies on cyclic sedimentation have led to the identification of distinct types of cycles, which can be arranged in hierarchical systems (Ramsbottom, 1977, p. 282; Melnyk & Smith, 1989, p. 432). This is also true for the present investigation. At least three different cycle types are recognised in the Lower Rupelian deposits of the type area. The first type (?fifth order), which has been identified in the Boom Clay Formation by Prof. Vandenberghe as early as the beginning of the 1970s has a very small wavelength (about 1 m). This small scale cyclicity is due to the presence of constantly alternating beds of clay and clayey silt. This alternating sedimentation pattern is believed to have originated from changes in bottom-water turbulence, which seem to be related to glacio-eustatic water depth fluctuations (Van Echelpoel & Weedon, 1990). These in turn are caused by variations in earth's orbital parameters (the 1 m cycle probably driven by variations in eccentricity which has a periodicity of 100 Ka). Grain sizes do not remain constant within this cyclic sedimentation pattern, but oscillate between lower and higher values, and hence compose larger cycles (subcycles, 4th order). These in turn form part of larger third order cycles.

Two large third order cycles are recognised in the Rupelian deposits of the type area. The lowermost cycle (labeled RUC-A = Rupelian cycle A) relates to the Ruisbroek Sand Member and the lower part of the Boom Clay Formation (bed 1 to (including) bed 38). It can be subdivided into 6 subcycles (see section on sequence stratigraphy). The uppermost one (RUC-B) which corresponds to the upper part of the Boom Clay Formation (from bed 39 upward) has not yet been studied in detail.

3.3.- Sequence stratigraphic interpretation

Since the first papers on sequence stratigraphy in the middle of the 1970s, a lot of progress has been made in understanding the relations between land-based stratotypes and global coastal onlap cycles. Detailed integrated stratigraphic studies have been carried out for the Gulf Coast Palaeogene Stages (see Baum & Vail, 1988, p. 319, fig. 13). These have led to the identification of a sequence of stratigraphic events, which has been used in the latest Cenozoic chronostratigraphic and eustatic-cycle chart (Haq, Hardenbol & Vail, 1988, p. 94-95). The relationships with the stratotypes of the Northwest European Palaeogene standard stages are less well understood. The present investigation forms part of a continuing programme of research on stratotypes of the internationally accepted Palaeogene standard stages, defined in Belgium. It initially aims at a more accurate positioning of the Rupelian Stage within a sequence-stratigraphic framework. The sequence-stratigraphic concepts and terminologies used here have been thoroughly discussed by Van Wagoner and colleagues in the Special Publication no. 42 of The Society of Economic Paleontologists and Mineralogists (1988), and will therefore not be commented on anymore.

The sequence-stratigraphic interpretation of the Lower Rupelian deposits of the type area results from detailed analysis of cone penetration curves, in combination with lithological and micropalaeontological investigation of borehole sections (see Figs. 2 to 6).

The basal silty beds of the Niel Sand Formation, named Wintham Silt Member, mark the onset of Rupelian deposition in the Belgian Basin. These beds rest unconformably on the Watervliet Clay. The nature of the junction between both marine units (sharp, with several deep vertically arranged burrows) indicates a rather important non-deposition event. This major unconformity is considered to represent the lower type 1 sequence boundary of sequence RUS-A (= the lowermost Rupelian sequence A). The Wintham Silt Member seems to consist of at least 2 (sometimes 3) coarsening upward progradational parasequences. It is overlain, rather sharply, by fining upward fine glauconitic sands. The surface separating these glauconitic sands from the underlying Wintham Silt is interpreted as a transgressive surface, and the Wintham Silt itself as lowstand systems tract. The transgressive sands, highly glauconitic at the base, have been redefined as the Ruisbroek Sand Member. They show a general fining upward trend and are therefore considered to represent the transgressive systems tract of sequence RUS-A. However, the cone penetration curves (Figs. 3 & 4) do not show a straight pattern. Various small sectors can be recognised, of which the point resistance oscillates between maximum and minimum values. Again in each smaller sector the variations are not linear but show a serrated pattern, due to alternation of finer and coarser beds, forming couplets. Each couplet, which includes a finer and a coarser bed, represents a parasequence.

The point resistance decreases upwards from the base of the Ruisbroek Sands to a minimum value at about 6 m above its base. Above this prominent peak the point resistance again increases. This minimum, which corresponds to the most fine-grained stratum in this interval, is interpreted as a flooding surface (labeled f.s.1). The lowermost interval, characterised by decreasing resistances, due to a fining upward lithology, forms parasequence set 1. The upper unit with increasing resistance and coarsening upward lithology is labeled parasequence set 2. Parasequence sets 1 and 2 constitute subsequence A1. Two additional subsequences A2 (including parasequence sets 3 and 4, separated by flooding surface f.s.2) and A3 (including sets 5 and 6, separated by f.s.3) are recognised in the Ruisbroek Sand Member from the type area (see Fig. 8 for the position of the subsequences and their subdivisions). The base of the Boom Clay Formation coincides with the base of the next overlying subsequence A4, which is still included in the transgressive systems tract of sequence RUS-A. Thus, in this interpretation, the base of the Boom Clay is not believed to correspond to a sequence boundary. In the lowermost 5 m of the Clay the point resistance decreases, due to a fining upward lithology. This interval (labeled parasequence set 7) is overlain by a very stiff clay, whose base represents flooding surface f.s.4. Higher up in parasequence set 8, the point resistance again increases, because of a coarsening upward lithology. Two additional subsequences A5 and A6 have been identified in sequence RUS-A. The transition between the Belsele-Waas Clay and the overlying Terhagen Clay is located within A5 (see Fig. 4). A6 can be subdivided into two parasequence sets (see Vandenberghe & Van Echelpoel, 1988: bed 11 to 38). The lowermost set 11 is characterised by decreasing point resistances, resulting from a fining upward trend Therefore set 11 is interpreted as the terminal part of the transgressive systems tract of sequence RUS-A, whereas set 12 represents its highstand systems tract. The turnover between both sets is located within bed 21 of Vandenberghe. As the grainsize of the latter is the lowest of the whole sequence, this level is considered to be the maximum flooding surface.

Sequence RUS-A is overlain by the next fining upward interval, starting with bed 39 of Vandenberghe. This interval is believed to represent the transgressive systems tract of the second Rupelian sequence (labeled RUS-B), and the base of bed 39 its type 2 sequence boundary. The stratigraphy of this part of the Boom Clay has not been studied here, but will be summarised in a following paper.

3.4.- Calcareous nannoplankton events

The calcareous nannoflora of the Ruisbroek Sand Member and the lower part of the type Boom Clay Formation has already been commented on by the author in a previous paper (Steurbaut, 1986). Among the stratigraphically useful nannoplankton events mentioned were: the last occurrence of *Isthmolithus recurvus* at about 5 m above the base of the Boom Clay, and the last occurrence of *Reticulofenestra umbilica* at about 1 m below its base, which led to the conclusion that the topmost 1 m of the Ruisbroek Sands belonged to NP 23. This has been confirmed by the present investigation. In fact, these bio-events could be more tightly defined using the new lithostratigraphic and sequence stratigraphic classifications.

The present investigation has shown that the last occurrence of *R. umbilica* is coincidant with, or very close to, flooding surface f.s.3. This means that the upper part of subsequence A3 (parasequence set 6) and the overlying part of sequence RUS-A (A4 to A6) belong to NP 23. The underlying units A1,A2 and the lower part of A3 are attributable to NP 22. This is in essence new, as until now no nannofossils were recorded from the basal part of the Ruisbroek Sand Member. Samples from this interval in borehole 42E-331 (27.0-29.5 m depth) and from the underlying sandy clay (probably the top of the Wintham Silt at 29.5-30.0 m) yielded *Reticulofenestra bisecta, R. umbilica* and *Isthmolithus recurvus*. The co-occurrence of these species, together with the absence of *Ericsonia formosa* and *Pontosphaera zigzag* refers to nannofossil zone NP 22.

The last occurrence (= LO) of *Lanternithus minutus* and *Isthmolithus recurvus* appear to be reliable and useful events for subdividing Martini's (1971) standard calcareous nannoplankton zones NP 22 and NP 23. The LO of *L. minutus,* which precedes the LO of *R. umbilica,* can be used to subdivide NP 22, although it has to be said that *L. minutus* is rather irregularly distributed through the Lower Rupelian deposits of Belgium. Its LO practically coincides with the top of subsequence A1 (see Fig. 3). The last occurrence of *I. recurvus,* which in the study area lies a few metres above the LO of *R. umbilica,* has been utilised to subdivide NP 23 (Steurbaut, 1986 and Steurbaut in Perch-Nielsen, 1986, p. 278). It falls within parasequence set 7 of A4 and seems to be close to the middle of parasequence 13 (see Fig. 8).

4.- COMPARISON WITH ADJACENT AREAS IN BELGIUM

4.1.- The Sint-Niklaas area

The Boom Clay has systematically been excavated in the Sint-Niklaas area since the early 1930s (Halet, 1938). Today excavation has been continued in one single claypit at Sint-Niklaas (Belsele) (map-sheet 15/5-6; x=132.725, y=205.000).

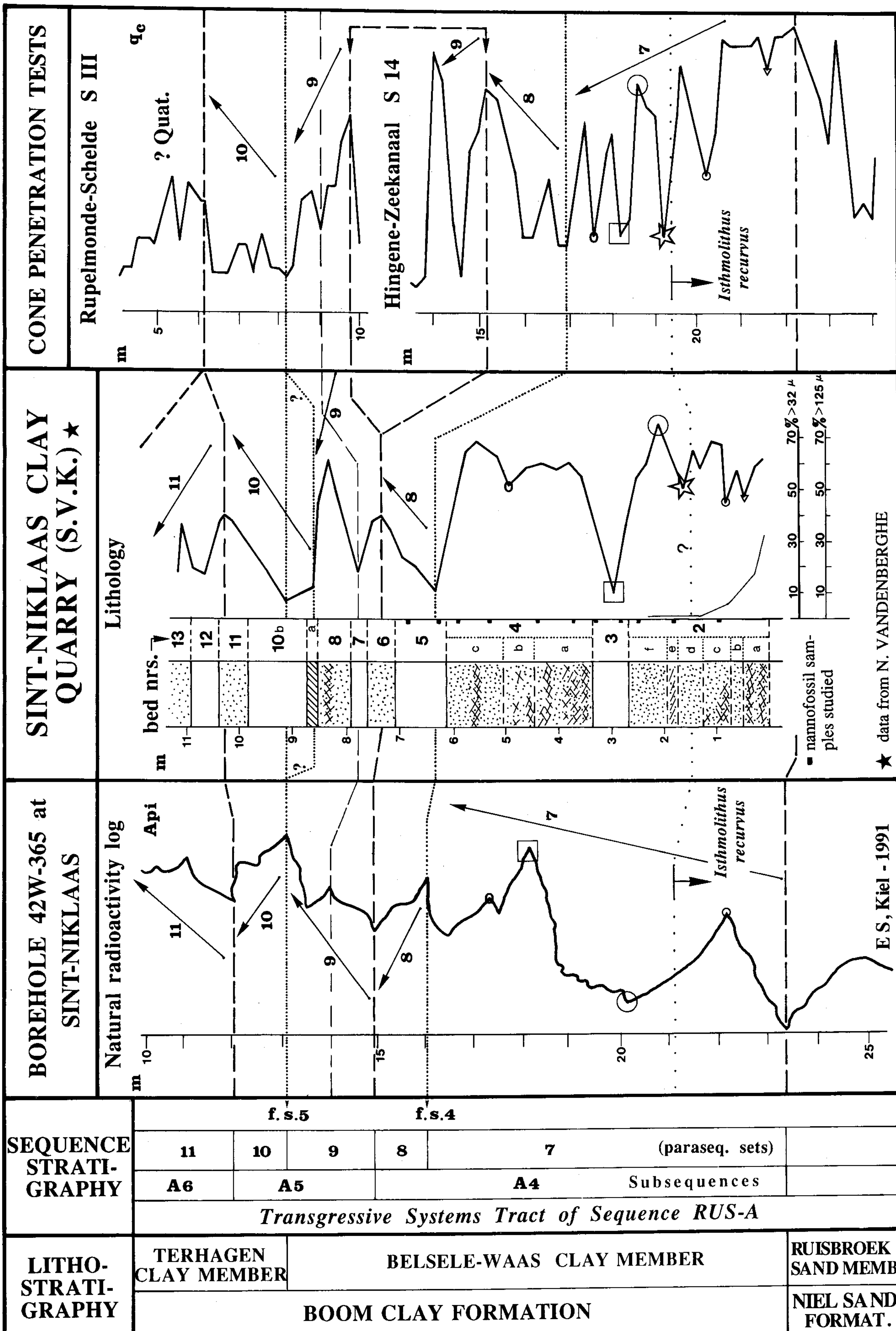

Fig. 5.- Correlation of the Boom Clay Formation between the Rupel River area and the Sint-Niklaas area.

1.- Sint-Niklaas (Belsele) claypit

Here the basal beds of the Boom Clay Formation are exposed whose special lithology has proved to be extremely suitable for brickmaking (somewhat coarser, poorly calcareous and septaria-free material). These beds were given separate status by Vandenberghe & Laga (1986) and grouped in the Belsele-Waas Clay Member. Detailed information on previous sedimentological and palaeontological work on the Sint-Niklaas claypit is given by Janssen (1981) and will not be discussed here anymore.

The Belsele-Waas Clay Member presents the typical Boom Clay rhythmicity, although its lithology is slightly different from that in higher parts of the Clay. One of the major concerns was to analyse the nature of this rhythmicity and to see if it could be related to phenomena observed in the Rupel River area. The results of the present investigation are summarised in Fig. 5. As these are clearly displayed in this figure, only few further comments will be given. However, note that each peak of the grainsize distribution curve from the Sint-Niklaas outcrop can be correlated with a peak in the cone penetration curves from the Rupel area. This is to be expected and quite logical, as the Boom Clay succession is laterally constant and there is a first order relation between grainsize and point resistance. Consequently, it was demonstrated that beds 2, 3 and 4, which constitute the coarser base of the Boom Clay Formation are correlatable to parasequence set 7. The low grainsize peak in bed 3 and the two overlying high grainsize peaks in bed 4 (4a and 4c) are clearly expressed in the penetration curves. Bed 5, which is the most prominent clay bed of the Belsele-Waas Clay was proved to correlate with the base of parasequence set 8 (parasequences 16 and 17). The position of the lower part of set 10 which contains S1-septaria in the Rupel area, corresponds exactly to that of bed 10a, the septaria-free S1 level.

The contact of the Boom Clay Formation with the Niel Sand Formation is no longer exposed in the outcrop section. Fortunately, it has been well documented by Janssen (1981). This, together with information gained from the newly drilled borehole a few km East of the claypit will be discussed in next chapter.

2.- Borehole 42W-365 at Sint-Niklaas

A 111 m deep borehole was recently drilled a few km East of the Sint-Niklaas claypit on behalf of the Belgian Geological survey (map-sheet 15/5-6; x = 134.739, y = 205.061). The section between 18 and 49.4 m depth was cored and sampled by the author. Geophysical well logs were made available by Dr. P. Laga.

The results from the integrated study of the lithology, calcareous nannoplankton and the natural radioactivity are shown on Fig. 6. Note the occurrence of a considerable hiatus at the base of the Niel Sand Formation. The junction with the underlying Watervliet Clay is sharp and locally burrowed, and represents the lower type 1 sequence boundary of sequence RUS-A. This boundary is overlain by a 2.5 m thick heterogenous Wintham Silt Member, which seems to consist of 2 progradational parasequences. the contact with the overlying Ruisbroek Sand Member was not visible due to core loss, although the somewhat coarser glauconitic sand at 43.20 m depth indicates its proximity. A general fining upward trend is recognised in the Ruisbroek Sand from 43 to about 32.5 m, followed by coarsening upward lithologies. The lower part, characterised by increasing natural radioactivity, is believed to correspond with parasequence set 1, the upper part with set 2, and the most fine-grained level at about 32.5 m depth with flooding surface f.s.1. Together they constitute subsequence A1. This attribution is supported by the nannofossil data (last occurrence of *Lanternithus minutus* at 26.30 m depth). Somewhat coarser sand is recorded from 26 to 23.3 m depth. This can be subdivided into a lower part with fining upward lithology and increasing radioactivity and an upper part with coarsening upward lithology and decreasing radioactivity, corresponding respectively to parasequence sets 3 and 4. Together these form subsequence A2.

A detailed correlation may be established between the upper part of the borehole section and the Sint-Niklaas claypit. The 5 cm thick phosphatised shell bed recorded from 23.25 to 23.30 m depth in the borehole has been described from the outcrop (Janssen, 1981, p. 21). In the borehole this level is overlain by fine to medium-grained glauconitic sand fining upwards to about 22.7 m, then, higher up, coarsening upward to about 20 m. Above this level grainsizes decrease again. According to the geometric position and the nannoflora data, the somewhat coarser interval from 23.25 to 18.20 m correlates with bed 2, and the clayey sand which comes in at 18.10 m with bed 3. The same trends in lithology have been recognised in boreholes from the Rupel area. It seems that the base of the Boom Clay correlates with the base of subsequence A4. This means that subsequence A3 is missing in the Sint-Niklaas area. Evidence was sought in the lithology and the nannofloras from the beds underlying the phosphatic nodule bed. The last specimens of *R. umbilica* were recorded at 23.38 m, immediately beneath the phosphatic nodule bed. In the Rupel type area this event is located within A3 at the base of parasequence set 6. Hence, subsequence

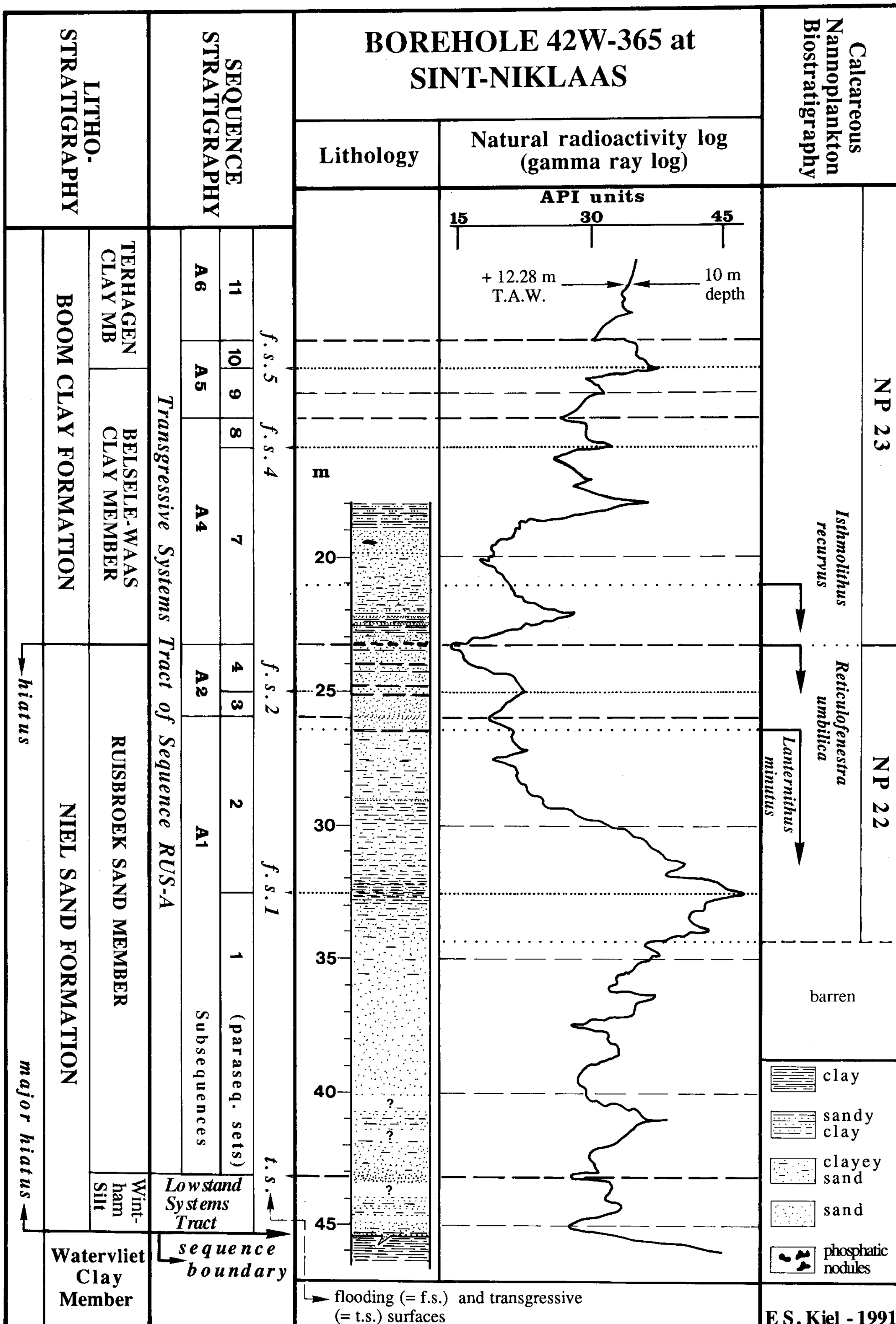

Fig. 6.- Stratigraphy of the Lower Rupelian deposits in the Sint-Niklaas borehole.

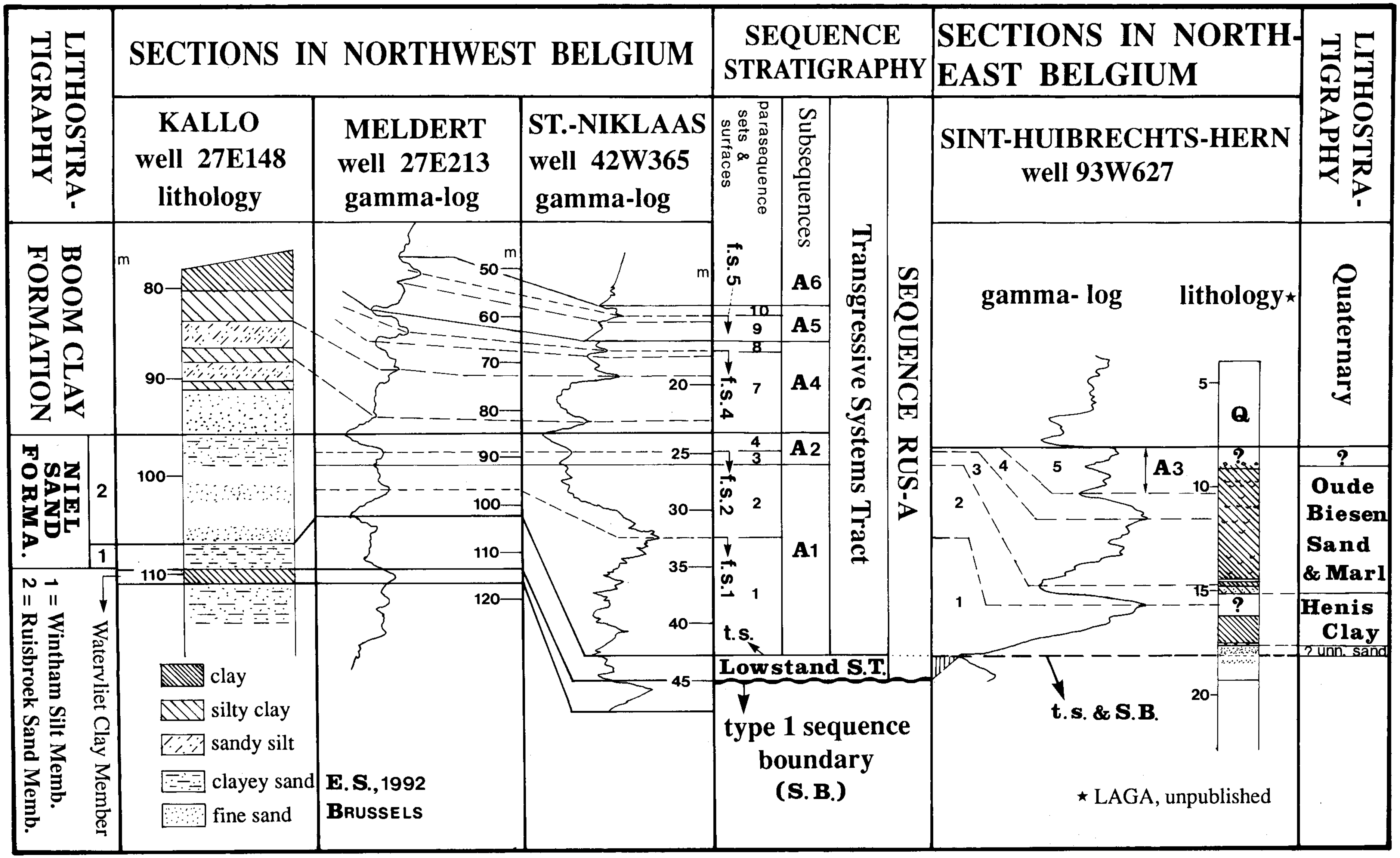

Fig. 7.- Correlation of the Lower Rupelian deposits in boreholes in Northern Belgium.

A3 or a part of it must be missing in the Sint-Niklaas borehole. This would also explain the presence of rather coarse sand beneath the phosphatised shell bed in the claypit, which would correspond with the coarser top of A2.

From the foregoing it can be concluded that the base of the Boom Clay Formation does not represent a sequence boundary in the Sint-Niklaas area, but forms part of the transgressive systems tract of sequence RUS-A. A minor hiatus occurs at the base of the Clay, probably due to local uplift, which eroded subsequence A3, leaving a compact phosphatised shell bed.

4.2.- The Kallo area

The latest updated version of the Upper Eocene and Lower Oligocene stratigraphy of the Kallo borehole section was published by the author in 1986. The conclusions, re-interpreted here in terms of sequence stratigraphy, can be summarised as follows: occurrence of a sequence boundary at the base of the Niel Sand Formation at about 110 m depth; presence of a 2.5 m thick heterogeneous Wintham Silt, representing the lowstand systems tract of sequence RUS-A; occurrence of a 12 m thick transgressive Ruisbroek Sand Member, with a rather coarse and glauconitic base at 107.5 m (= transgressive surface); presence of a rather coarse sand at the base of the Boom Clay Formation at 95.5 m, representing the base of parasequence A4. No more detailed correlations can be made with the Rupel and Sint-Niklaas areas because of the discontinuous character of the Kallo borehole data. However, in order to demonstrate the correlation potential of gamma ray logs and the continuity in deposition between the different study areas, the gamma ray log from the Melsele borehole 27E-213, located a few km South of the Kallo borehole is figured (map-sheet 15/1-2; x = 142.900, y = 212.700) (Fig. 7).

4.3.- The Brabant (Leuven-Tienen) area

The Oligocene deposits from the Brabant area have been extensively studied by Van den Broeck (1893). A brief review, including numerous new observations was given by Glibert & de Heinzelin (1954).

In the eastern part of the area, 10 to 15 km East of Leuven (Galgenberg-Boutersem), the Lower Oligocene consists of the Hoogbutsel Bed, represented by lagoonal sand and stiff clays known for their rich vertebrate faunas, overlain by the Boutersem Sand (and Marl) Member. The latter is a heterogenous deposit, containing in its type area, in ascending order: a basal *Bithinia* and *Limnea* Marl Bed, *Cyrena* sands and, *Chara* rich clays capped by unfossiliferous clays. Several samples from the Boutersem sands have been examined for nannofossils, although none were recorded (Steurbaut, 1986). The Boutersem succession is overlain, rather sharply, by the Henis Clay, a green clay with a sandy heterogeneous base, containing marly nodules. This clay is covered by a pebble bed and the fossiliferous Berg Sands. However, according to Van Den Broeck (1893, p. 271-272), the pebble bed is often missing and replaced by an alternation of sands and stiff clays (labeled R1m by Van den Broeck).

A few km more west and northwards, between Pellenberg and Kerkom (see Glibert & de Heinzelin, 1954, fig. 2 for exact locations), occur rather coarse cross-bedded quartz sands with a gravel base, including small green reworked clay chips from the underlying clayey top of the Neerrepen sand (and not the Henis Clay!). These predominantly fluviatile sands are the infill of a hugh channel cut deeply into these Neerrepen sands (Gullentops, 1990: 89). The cross-bedded Kerkom sands are overlain by brownish organic-rich and lignitic sands («les sables chocolatés de Heyde et de Mont-Saint-Martin», Van den Broeck, 1882, p. CX). These chocolate-coloured sands for which the name Mont-Saint-Martin sands is reserved, sometimes directly rest on a *Bithinia* marl bed, which is also known to underlie the Boutersem Sand Member more to the East. Marine quartz sands occur above the chocolate-coloured sands in the hills around Leuven. These sands, informally named Heide Sands, are based by a pebble bed and overlain by a somewhat similar quartz sand, the Berg sands. Both units are again separated by a prominent pebble bed.

This stratigraphic information can be interpreted in terms of sequence stratigraphy, although not in much detail. The Boutersem Sand Member, and the Kerkom Sands, including the uppermost «sables chocolatés» are considered to represent the lowstand systems tract of sequence RUS-A. The unconformable contact with the underlying Neerrepen sands should represent the type 1 sequence boundary of RUS-A. The surface underlying the sandy and glauconitic base of the Henis Clay and in the West the Heide Sand is interpreted as the transgressive surface, the overlying units as the lower part of the transgressive systems tract. The Henis Clay seems to be correlatable with subsequence A1, the overlying clayey R1m deposits with subsequences A2 and A3. The R1m clays however are mostly missing, being ripped up and replaced by a pebble bed. The overlying Berg Sand would then represent the next step in the transgressive systems tract (subsequence A4). The Heide sands and the overlying Berg Sands of the Leuven area are characterised by basal pebble beds and

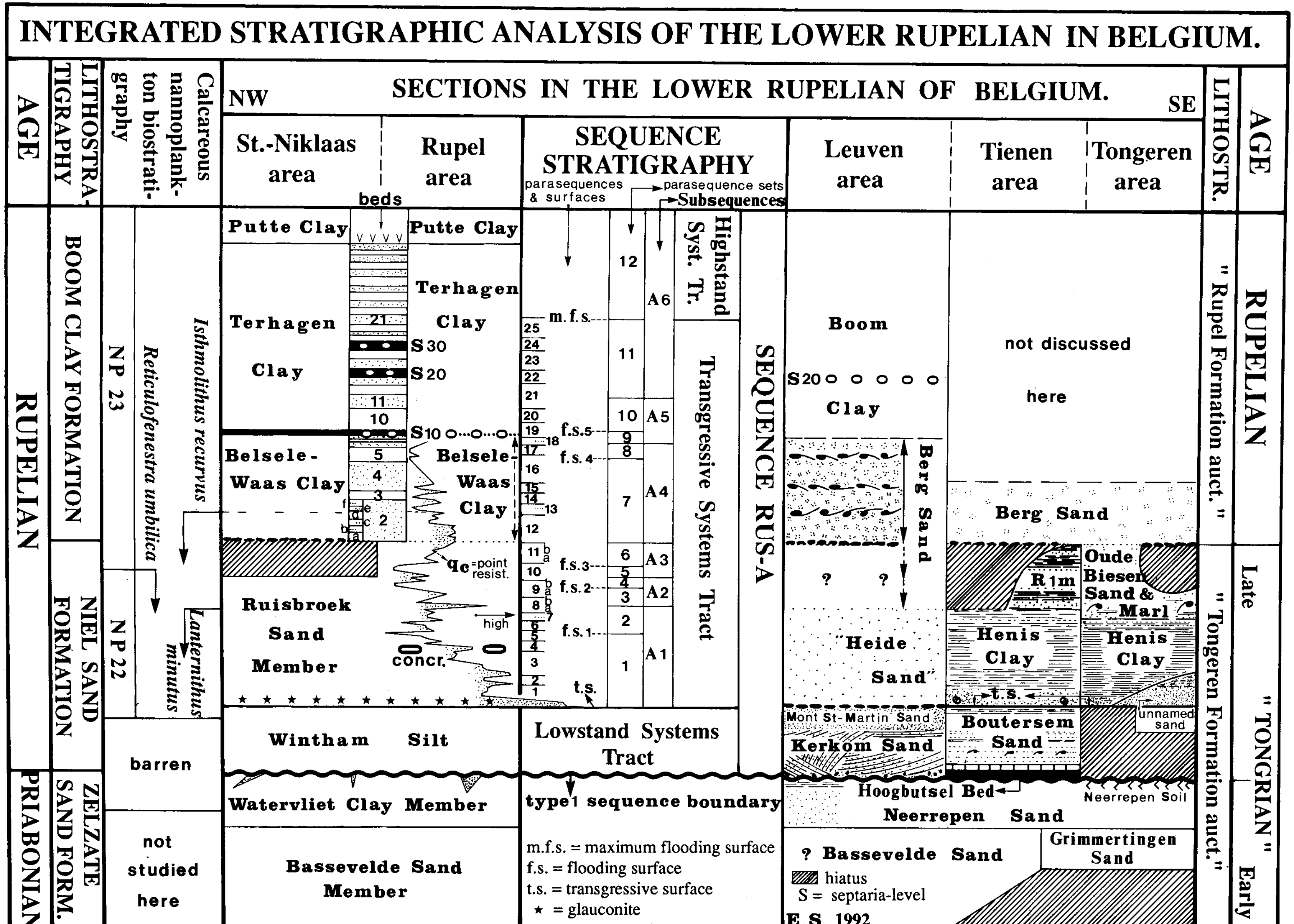

Fig. 8.- Integrated stratigraphic analysis of Lower Rupelian deposits in Belgium.

important shell beds. These are considered to represent the different steps in the transgressive systems tract of sequence RUS-A, but the exact relationship between these events and the Rupelian parasequence sets and subsequences are still imperfectly understood.

4.4.- The Tongeren area

The Lower Oligocene of the Tongeren area has been discussed in extenso by Van den Broeck & Rutot (1883) and Janssen, Van Hinsbergh & Cadee (1976). In the northern Bilsen area, the Neerrepen sands are unconformably overlain by a 2 to 3 m thick glauconitic fine to medium-grained sand, gradually passing upwards in clayey sand (labeled Tg2a). This unit, for which no distinct name exists, is covered by the Henis Clay. In the surroundings of Tongeren, about 10 km southward, the unnamed sands have not been recorded, as the Henis Clay directly rests on the Neerrepen soil, developed on top of the Neerrepen Sands (Buurman & Jongmans, 1975).

The Henis Clay, which reaches a maximum thickness of about 9 m, generally consists of a homogenous compact green clay with 1 or 2 «septaria» levels, although it can also be represented by an alternation of stiff clay banks and quartz sands (Van den broeck & Rutot, 1883, p. 52). Thin sand beds always occur on top of the Henis Clay. These are overlain by an alternation of whitish shelly marls and whitish quartz sands, labeled Oude Biesen Sands and Marls, which in turn are covered by the Berg Sands. The transition between the Henis Clay and the Oude Biesen Sands and Marls is mostly gradual, whereas the contact between the Oude Biesen succession and the Berg Sands is usually often, but not always marked by a pebble bed (see Janssen *et al.*, 1975, p. 86). In their type locality the Berg sands rest directly on the Henis Clay. Reworked parts of the Oude Biesen Sands and Marls are found in the basal layers of the Berg Sands.

The surface underlying the unnamed basal sand body in the North and the basal beds of the Henis Clay in the South is interpreted as a type 1 sequence boundary of sequence RUS-A. This surface which is also the transgressive surface, is overlain by a transgressive succession, including in ascending order the unnamed sands, the Henis Clay, the Oude Biesen Sands and Marls and the Berg Sands, representing the transgressive systems tract of sequence RUS-A. These units are rather heterogeneous, except for the Berg Sands, and characterised by alternating sands and clays or marls. Each sand and clay or sand and marl couplet is believed to represent a parasequence. The grouping of these parasequences in parasequence sets and subsequences is still tentative, as no detailed grainsize analyses or cone penetration tests are available yet. However, according to the lithological descriptions from sections in the Tongeren area, and the gamma ray log from the Sint-Huibrechts borehole 93W-627 (5 km W of Bilsen; map-sheet 34/1-2, x = 226.487, y = 169.037; see Fig.7), the basal unnamed sands and the overlying Henis Clay should correlate with parasequence set 1. The upper part of the clay, which is more sandy, and the lower part of the Oude Biesen Sands and Marls should represent parasequence set 2. The presence of *Lanternithus minutus* in the Oude Biesen Sands and Marls from the Galgenberg-Berg section also points in that direction. The upper part of the Oude Biesen unit should correspond to subsequences A2 and A3, and the overlying, fining upwards, Berg Sands should probably correlate with the base of A4 (parasequence set 7).

5.- CONCLUSIONS

Over the last decades the term Rupelian has frequently been misused in literature on the type area, being solely associated with the Boom Clay Formation or the Rupel clays auct. This is quite astonishing as Dumont in the original definition stated that the clayey sands underneath the Rupel clays form part of the «Système Rupelien» or the Rupelian Stage. This sandy unit, for which the term Niel Sand Formation is newly proposed, is subdivided into a lower newly defined Wintham Silt Member and an uppermost redefined Ruisbroek Sand Member.

This new extended version of the Rupelian Stage consists of 2 complete third order sequences, labeled RUS-A and RUS-B. The uppermost sequence RUS-B, which in the type area begins at the type 2 sequence boundary at the base of bed 39 of he Boom Clay Formation, has not been studied in the present paper. In the type aea the lowermost sequence, RUS-A, extends from the type 1 sequence boundary at the base of the Niel Sand Formation to the type 2 sequence boundary at the base of bed 39 of the Boom Clay Formation. It can be subdivided into a lower lowstand, an intermediate transgressive and an upper highstand systems tracts (see Fig. 8).

The lowstand systems tract is represented in the type area by the Wintham Silt Member, which seems to consist of 2 to 3 progradational parasequences. Its biostratigraphic position is still imperfectly understood. Calcareous nannofossils have been recorded from the top in one single section, indicating the lower part of NP22. The remaining part, which is non-calcareous, has been sampled for dinoflagellate analysis (work in progress).

The transgressive systems tract, which is underlain by the transgressive surface, consists of the Ruisbroek Sand Member and the lower part of the Boom Clay Formation. The overlying part of the Boom Clay, between bed 21 and the top of bed 38 represents the highstand systems tract of sequence RUS-A. The transgressive and high-stand systems tracts can be subdivided into 6 fourth order sequences or subsequences, each consisting of 2 parasequence sets. Each set, which as a whole corresponds to fining or coarsening upward lithologies, consists of smaller units, interpreted as parasequences. This alternating sedimentation pattern of thin clay-sand or clay-silt couplets is believed to result from glacio-eustatic water depth fluctuations, caused by variations in earth's orbital parameters (the 1 m cycle probably by variations in eccentricity which have a periodicity of 100 Ka).

The Ruisbroek Sand Member includes subsequences A1, A2 and A3, which can be further subdivided into 11 parasequences. Useful biostratigraphic events in this transgressive succession are: the last occurrence of *Lanternithus minutus* at the top of A1, and the last occurrence of *Reticulofenestra umbilica* at the base of parasequence set 6, within A3. This means that the Ruisbroek Sand Member belongs to NP22, except for the uppermost 2 m which are NP23. The base of the Boom Clay Formation correlates with the base of A4. It is locally marked by a phosphatised shell bed (e.g. in the Sint-Niklaas area) which is believed to be due to erosion of subsequence A3. Thus, the base of the Boom Clay Formation does not correspond with a sequence boundary, but represents the onset of an important new transgressive pulse, with local erosion.

The base of the Boom Clay Formation, beds 2 to 4 of the Belsele-Waas Clay Member, correlates with parasequence set 7. The latter can be subdivided into five parasequences (numbered 12 to 16). The last occurrence of *Isthmolithus recurvus* is located within set 7, just below the middle of parasequence 13. Bed 5 which is the most prominent clay bed of the Belsele-Waas Clay can be correlated with set 8. The overlying somewhat coarser interval, including bed 6 to 8 correlates with set 9, the Terhagen Clay Member with set 10 and 11. The overlying beds have not been studied in much detail, although interpretation of existing data allows 36 or 37 parasequences in sequence RUS-A to be identified (2 or 3 in the Wintham Silt, 25 in the overlying transgressive and 9 in the highstand systems tracts).

Biostratigraphic and sequence stratigraphic data from the type area provide a reliable basis for the interpretation of the Oligocene deposits in Eastern Belgium. The Boutersem Sand Member, including the basal Hoogbutsel Bed, and the Kerkom Sand Member, including the overlying chocolate-coloured Mont-Saint-Martin Sands, are considered to be the updip correlatives of the Wintham Silt Member. The overlying Heide Sand in the Brabant area and the Henis Clay and the Oude Biesen Sand and Marl Member in the extreme East are correlated with the Ruisbroek Sand Member. The Berg Sand Member and the Belsele-Waas Clay Member, which frequently have a basal pebble bed or phosphatised shell bed, mark the onset of a new transgressive pulse within sequence RUS-A.

The present investigation shows that the lower part of the Rupelian stratotype can be correlated precisely with the traditional «Upper Tongrian deposits» of Eastern Belgium, demonstrating once again the ambiguity of previous chronostratigraphic terminology.

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