STRATIGRAPHIC NOMENCLATURE OF THE NETHERLANDS

by

Nederlandse Aardolie Maatschappij B.V.

and

Rijks Geologische Dienst

Verhandelingen van het
Koninklijk Nederlands Geologisch
Mijnbouwkundig Genootschap

Deel 32, 1980

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PREFACE

Between 1858 and 1867 W. C. H. Staring published the first geological map of The Netherlands. Although the interest in the geology of The Netherlands predates these maps, Staring's work heralded a period of increasing knowledge in Dutch stratigraphy.

In 1903 the 'Rijksopsporing van Delfstoffen' was established. It performed boring campaigns in various areas of the country and published its final report in 1918. Since that date only limited deep-drilling took place until the early forties when hydrocarbon exploration was started in the eastern Netherlands. In 1947, the Nederlandse Aardolie Maatschappij started its activities and in the period of 1947-1978 more than 500 exploration and appraisal wells were drilled. A wealth of stratigraphic data became available and on various occasions summaries were published, notably in 'Geologie en Mijnbouw' and the Verhandelingen van het Koninklijk Nederlands Geologisch en Mijnbouwkundig Genootschap.

The present volume compiles the latest knowledge on the stratigraphy of the Dutch subsoil. It is the result of more than thirty years of work by various geologists who worked or are still working with NAM. However, this publication would not have been possible without the active cooperation of the Rijks Geologische Dienst in providing data to the chapters dealing with the post-Chalk sequence.

In 1975, the Rijks Geologische Dienst summarized the stratigraphic nomenclature of the Upper Tertiary and Quaternary of The Netherlands. The present volume completes this work by adding the definitions of the older stratigraphic units. It is hoped that this contribution to the Dutch stratigraphy will be a very welcome one.

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(General Manager, Nederlandse Aardolie Maatschappij B.V., Assen)

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1. INTRODUCTION

1.1. GENERAL

The Nederlandse Aardolie Maatschappij (NAM) started its activities in 1947. Originally the work of NAM was concentrated mainly in the east of The Netherlands, where, in a concession which was granted in 1948, it was applied in developing what was called the Schoonebeek structure. The stratigraphic nomenclature for this area was adopted largely from the German one, as used across the border in some oil fields that were already in production at that time.

In those years, wire-line logging was still in its infancy and micropalaeontology was the only reliable correlation tool. From 1947 onwards this method was so successfully applied in the subsurface of The Netherlands that in 1949 NAM started its own in-house biostratigraphic section. Again, German palaeontological data provided a solid base for these investigations. In accordance with German practices, a heavy emphasis was given to age correlations, whereas biofacies influences (practically unknown at that time) were somewhat discarded. Microfaunal units were indicated by international stage names, as apparent from various publications by NAM-stratigraphers, e.g., HAANSTRA (1963), KEIZER & LETSCH (1963).

However, long sections of the studied column did not provide sufficient micropalaeontological data for a biozonation, e.g., the Permo-Triassic. Here, a lithostratigraphic nomenclature was applied, and again it followed largely German practices. Many of these names have become well-established in the Dutch nomenclature (e.g., BRUEREN, 1959; VISSER, 1963).

During the sixties, developments and refinements to the wire-line logging tools took place so that gamma ray, sonic velocity and formation density logs in particular could be considered as truly reflecting the lithological developments of the penetrated sequences. In combination with descriptions of cutting and sidewall samples as well as conventional cores, the lithostratigraphy of the Dutch subsoil slowly unfolded.

Within NAM's geological group, a formal lithostratigraphic nomenclature was gradually introduced during the early seventies. This nomenclature has always been and continues to be a system with emphasis on practicability of mapping. As such it is continuously being improved upon in order to provide the most satisfactory means for further work on oil and gas exploration and production in The Netherlands. The present paper summarizes the progress made up to 1978. Future revisions and additions are certainly not excluded.

The pre-Cenozoic lithostratigraphy, treated in the chapters 3-9 of this publication, was prepared by the Nederlandse Aardolie Maatschappij B.V. (NAM). Although Shell Internationale Petroleum Maatschappij B.V. (SIPM) and the Rijks Geologische Dienst (RGD) were consulted on a number of points, NAM takes full responsibility for the opinions expressed in these chapters.

The description of the post-Chalk sequence, described in the chapters 10-13 of this publication, was prepared jointly by the RGD and NAM. The latter company provided most of the subsurface data for the Paleocene-Oligocene part of the Cenozoic succession, whereas the Neogene-Quaternary part was furnished by the RGD.

1.2. AIM AND SCOPE

In order to manage in an efficient manner the ever-increasing amount of stratigraphic data emanating from the subsurface of The Netherlands, geologists of the NAM developed a stratigraphic nomenclature with the following objectives:

- reflect the current stratigraphic understanding,
- follow closely the traditional stratigraphic subdivisions in neighbouring countries,
- be suited to satisfy the needs of many geologists with different stratigraphic backgrounds,
- make use of the tools that have become readily available, such as wire-line logs,
- be formatted for mechanical/computerized data handling.

The stratigraphic nomenclature, as presented here, is based on the data gathered from some 500 wells drilled during the last 30 years.

Whilst putting emphasis on the lithological expression of the strata, one should realize that the biostratigraphic framework gives assistance in regional correlation studies. The micropalaeontologically and palynologically derived chronostratigraphic scheme of The Netherlands provides the means to appreciate lateral facies changes, the extent of unconformities, conceptual sedimentological models, etc.

In the formal definitions of the lithostratigraphic units, age considerations now play hardly any role. However, in subsurface work lithological identities (especially in exploration wells) are sometimes difficult to demonstrate with absolute certainty. Here, biostratigraphic data can give considerable

assistance. However, it is realized that such means of identification of lithostratigraphic units provides only indirect evidence, not truly lithostratigraphic criteria.

The lithostratigraphic nomenclature, as applied by NAM, was and is a practical system for portraying satisfactorily the rock-framework of The Netherlands. Although a multitude of units has been named, every attempt was made to keep the nomenclature as simple as possible. For example, topographic names used as the geographic component of formation names are often repeated in one or more of the member names. It is realized that such a practice is contrary to the rules laid down in the International Stratigraphic Guide (HEDBERG, 1976). Furthermore, and also for practical purposes, no attempt has been made to change the rank of the recognized units as customarily used in NAM's subsurface practices. Certain units described as members could easily qualify for formational rank, and vice versa.

Many names given in this publication have been copied (and translated) from the nomenclature established in the surrounding countries. Such names have been maintained as they are well-established and traditionally used. By designating reference sections from The Netherlands, these units will have a clear meaning for Dutch stratigraphy.

The lithological control in subsurface work is often provided by drilling cuttings only. In view of the uncertainties in data derived from these, wire-line log data have been applied for the definition of boundaries between the units rather than interpreted lithology. The quoted depth figures have been derived from the gamma ray logs, where available, as read from derrick floor or ground level (see enclosures). These figures have not been corrected for hole deviations, nor have structural dips been taken into consideration. In all cases, it has been attempted to select vertical wells for the reference sections from areas of very low to negligible structural dip.

In general, the units have been defined from areas with the most complete succession, as known to-date. Gaps, due to erosion and/or non-deposition, are mentioned only where relevant for the definition of the units.

1.3. ACKNOWLEDGMENTS

This publication has been possible only by the ample support of the management of the Nederlandse Aardolie Maatschappij B.V.

The co-operation of various other oil companies, active in The Netherlands, is gratefully acknowledged. A number of reference sections could be selected with their permission.

The assistance provided by the Rijks Geologische Dienst was of great help. Their continued interest and co-operation, especially in providing data on the Dutch Cenozoic, should be mentioned especially.

P. HEYBROEK was responsible for collecting all the data given in this publication. For more than a year he worked on this fact-gathering mission and only by his unflagging interest could the manuscript be completed.

Many geologists in NAM, SIPM and RGD were involved in the here-presented nomenclature. Although not all mentioned, their cooperation is acknowledged. The assistance of the following geologists is to be reported especially: H. A. VAN ADRICHEM BOOGAERT (chairman of the working group Tertiary of the RGD), J. P. H. KAASSCHIETER (SIPM), A. J. KEIJ (SIPM), W. J. LETSCH (NAM), P. MARON (NAM).

Mrs. B. VAN WESTING-PAYNE (NAM) has spent a good amount of her time on the English corrections.

Finally, permission for publication was granted by ESSO Exploration Inc., Nederlandse Aardolie Maatschappij B.V. and Shell Internationale Petroleum Maatschappij B.V.

2. CODES FOR STRATIGRAPHIC UNITS

2.1. GENERAL

In 1975, NAM introduced a coding system for stratigraphic units. This system has since proven to be a simple and reliable tool for mechanical data handling. The stratigraphic nomenclature of the Dutch subsurface has been adapted to the prerequisites of this system.

Three categories of lithostratigraphic units are recognized, viz. group – formation – member. For a relatively complicated nomenclature, as in use for the Dutch subsoil, these categories may seem to offer too little flexibility as no units of intermediate status (e.g., subgroup) are allowed. However, actual use has demonstrated that the above scheme satisfies fully the description of the rock sequences.

A *group* name has been given to sequences of two or more contiguous formations which have significant stratigraphic features in common. The boundaries between the groups have been chosen at places of distinct lithological change. In most cases these changes occur across regional or subregional unconformities, which can be recognized by various means of

subsurface studies, e.g., biostratigraphy, petrophysics, geophysics.

A *formation* is defined as the primary unit in the Dutch lithostratigraphic hierarchy, based on its mappable rock characteristics. As all units are defined as subsurface units, identification by means of wire-line logs was a prerequisite. For that purpose those types of logs were selected which reflect lithology in the most appropriate way, e.g., gamma ray log, sonic velocity log, formation density log. For older wells, such logs were not then available and, consequently, SP (spontaneous potential) and/or resistivity logs had to be used. The wire-line log data have been supplemented by studies of well samples (cuttings, sidewall samples, cores, etc.) in order to gain the best approximation of a lithologically defined unit.

A *member* has been distinguished as a lithological subdivision of a formation, but in this system of subsurface units heavy emphasis is again placed on its wire-line log character. As the member is defined here as the lowest unit in the stratigraphic hierarchy, distinctive beds are coded as members, e.g., Copper Shale. Also tongues and lentils, when formally named, are regarded as members, as these units are only 'specially shaped forms of members' (HEDBERG, 1976, p. 35).

2.2. UNIT CODES

At group level a two-digit code is applied, e.g., RØ for the Upper Rotliegend Group, ZE for the Zechstein Group.

Each formation within a group is distinguished by the addition of two more digits, e.g., RØSL for the Slochteren Sandstone Formation, ZEZ1 for the Zechstein 1 Formation.

At member level a fifth digit is added, e.g., RØSLU for the Upper Slochteren Sandstone Member of the Slochteren Sandstone Formation, ZEZ1C for the Z1 Carbonate Member of the Zechstein 1 Formation.

Although not in use as yet, the coding system allows for a change to six digits to gain the possibility to recognize and code units of intermediate rank (subgroups, etc.) or of beds (e.g., of individual sand bodies for hydrocarbon production purposes).

In this way all lithostratigraphic units recognizable in the Dutch subsoil have been coded, with the exception of units at member level in the Miocene-Recent Upper North Sea Group. It is felt that as this system has been developed primarily for application in subsurface work, coding of other units, such as the Quaternary surface formations and members, is not as yet warranted.

2.3. BOUNDARY CODES

The boundaries between the recognized lithostratigraphic units are placed at positions of lithological change, but also here clear distinction on wire-line logs is a prime prerequisite. For coding purposes the lower boundaries only have been named, the tops automatically coincide with the base of the directly succeeding units.

For the boundaries a 4-digit alpha-numerical code was introduced. The first two digits are identical to those of the group to which the boundary belongs. The next two digits give by means of an ascending number the approximate stratigraphic position of the boundary within the group (numbered from bottom to top). The base of a group always carries the number 01, irrespective of the lowest formation or member in the group at a particular place, e.g., RØ01 is the base of the Upper Rotliegend Group irrespective of whether the Silverpit Claystone Formation or the Slochteren Sandstone Formation is the lowest unit in the Group.

Within a group the boundaries are then given the numbers 02-98; 99 being reserved for those cases where for practical purposes the top of a lithostratigraphic unit has to be indicated, e.g., Top Basement = BM99.

The boundary code always carries an inseparable relationship to the lithostratigraphic unit to which it belongs, e.g., RØ40 is everywhere in The Netherlands the base of the Upper Slochteren Sandstone Member, ZE41 is always the base of the Zechstein 3 Formation (see also text figs. 4-16).

A fifth digit can be added to these boundary codes to indicate the area within the North Sea region where the boundary is recognized on the same criteria. In case no fifth digit is added the boundary is identical throughout the region. For the Dutch situation, the fifth digit N means applicable only in The Netherlands, e.g., RØ41N is throughout The Netherlands recognized as the basal boundary of the Upper Slochteren Sandstone Member. In adjacent countries, such as Great Britain and/or Germany, the boundary, although perhaps recognized, may be defined on different criteria.

2.4. UNCONFORMITIES

Since STILLE's publication of 1924, tectonic movements (and resulting unconformities) have been distinguished by a widely accepted nomenclature, e.g., Saalian movements (and unconformity), Sub-Hercynian movements (and unconformity). This nomenclatural scheme has proved to be most satisfactory in describing the tectonic evolution of northwestern Europe, as demonstrated recently by P. A. ZIEGLER (1978).

The relationship between periods of tectonic movement and the observed unconformities is, however, often difficult to establish. In cases where there is only a small age difference between deposits immediately underlying and overlying an unconformity, the naming is generally straightforward. However, with increasing age differences of the deposits at the unconformity, such name-giving becomes more and more

subjective. In this instance, conclusions are dependent on the regional tectonic evolution as interpreted by a particular geologist or stratigrapher.

Without denying the value of such interpretative judgements, it is thought preferable to introduce a purely descriptive system for mechanical data handling, i.e. to name unconformities, by reference to the immediate *overlying* sedimentary sequence. In this publication most of the major unconformities are named after the group of strata, which immediately overlies the unconformity. This system is considered logic because the definition at the group level of hierarchy is strongly dependent on the presence of (sub-) regional unconformities. In some cases, subregional unconformities have been recognized within a particular group, e.g., the so-called Sub-Hercynian Unconformity within the Chalk Group. In this example, although the presence of this hiatus is acknowledged by most investigators, the actual recognition is dependent on criteria from various sources, such as micropalaeontology and geophysics. This hiatus can rarely be recognized on lithological evidence alone.

Therefore, taking the above considerations into account, the following scheme has been established for the naming of the major (sub-)regional unconformities. The prefix 'UC' represents the term unconformity. This is followed by two digits which represent an abbreviation for the overlying sequence (at group level):

UCNU = Base Upper Tertiary Unconformity
UCNM = Base Oligocene Unconformity (formerly often indicated as the 'Pyrenean Unconformity')
UCNL = Base Tertiary Unconformity ('Laramide Unconformity')
UCCT = Intra-Chalk Unconformity ('Sub-Hercynian Unconformity')
UCKN = Base Cretaceous Unconformity ('Late Kimmerian Unconformity')
UCJT = Intra-Jurassic Unconformity ('Mid-Kimmerian Unconformity')
UCAT = Base Jurassic Unconformity ('Early Kimmerian Unconformity')
UCRN = Intra-Triassic Unconformity ('Hardegsen Unconformity')
UCZE = Base Zechstein Unconformity
UCRØ = Base Upper Rotliegend Unconformity
UCPB = Base Lower Rotliegend Unconformity

3. LIMBURG GROUP (DC)

General – During the Carboniferous, sedimentation took place over practically the whole area of The Netherlands. Despite appreciable subsequent erosion, a thick sequence of these deposits is preserved in the major part of the country and its offshore areas.

With the exception of the southernmost part of The Netherlands, these Carboniferous sediments are known principally from their position immediately below their subcrop against the Base Upper Rotliegend, or younger unconformities. Such deposits represent almost unequivocally the Upper Carboniferous, and are described in this paper as the *Limburg Group*. It consists of a sequence of predominantly clastic deposits, representing an overall regressive sequence, beginning with marine sediments and grading upwards into a paralic type. The latter environment, extending over most of northwestern Europe (both in space and time), was characterized by sedimentation under hot, humid conditions, with tropical forests covering the environments of fluvial floodplains, moors, deltas, back-swamps and coastal flats (VAN WIJHE & BLESS, 1974). In the youngest parts of the Limburg Group, there are definite indications of a gradual change to more arid climatic conditions.

The Limburg Group, as encountered in wells and coal mines in The Netherlands, consists of a thick and monotonous alternation of silty shales, sandstones and coal beds, the whole amounting to some thousands of metres. The Group is extensively known from the southern part of the Dutch province of Limburg, where the former coal-mining activities of The Netherlands were concentrated. A detailed stratigraphic subdivision for this area was formally introduced by VAN AMEROM (1975). For the rest of the country, the Group is almost exclusively known from hydrocarbon exploration wells.

Usually these wells are discontinued after 100 metres or less penetration into the Limburg Group and, consequently, add little to the stratigraphic knowledge of the Group. Deeper penetration has been gained at only a few scattered locations, but the limited number of these wells do not allow for a detailed stratigraphic scheme, comparable to the one proposed for the coal-mining district of Limburg. For these reasons, a broad lithostratigraphic frame only is presented, allowing for a more detailed subdivision at a later date.

Because so few control points of deep penetration into the Limburg Group are available in The Netherlands, biostratigraphic dating methods play an important role in the determination of the relative stratigraphic position of the sediments encountered in well sections. The study of miospores, from both ditch cuttings and core samples, provides a very

useful tool for an approximate subdivision of the Westphalian (in a chronostratigraphic sense covering most of the known part of the Limburg Group).

Most of the satisfactory control points are located in the eastern part of The Netherlands, along the German border, and for that region a more formal subdivision of the upper part of the Limburg Group into three units of formational rank is presented. However, the basal boundary of the oldest formation cannot be defined due to lack of deep penetration. For the remaining part of The Netherlands, the upper (generally coal-bearing) part of the Group is distinguished as the Coal Measures, again with no defined lower boundary. Lack of sufficient control points with satisfactory stratigraphic penetration prevents a further subdivision of this thick (>1000 m) sequence.

The upper boundary of the Limburg Group is marked by a regional unconformity at the contact with the overlying Rotliegend groups. This unconformity marks a long period of uplift and erosion during approximately latest Carboniferous – Early Permian. The general uplift that ended sedimentation of the Limburg Group is inferred to have been preceded by weaker positive movements during latest Westphalian – Stephanian times, as indicated schematically on text fig. 4.

Name – Named after the Dutch province of Limburg.

Definition (text fig. 4) – A group of clastic formations, with common coal beds towards the upper part, delimited at the top by the erosion surface that marks its contact with the Lower or Upper Rotliegend Group (or younger sequences). Marine, fossiliferous beds occur frequently in the lower part and decrease markedly in number upwards.

The base of the Limburg Group cannot be defined for the major part of The Netherlands due to lack of sufficiently deep well penetration. In the southernmost part of the country and in adjoining areas of Belgium, the base is taken at the top of the so-called Visé Limestone (generally regarded as of Dinantian age). These carbonates were only encountered in a few Dutch wells near the Belgian border, e.g., those of Woensdrecht, Houthem and Gulpen (BLESS ET AL., 1976).

Age – Late Carboniferous (Silesian).

Reference section – (for the upper part of the Limburg Group) Well Rijsbergen-1: 1353-2710 m, coord. N 51°31'44.4", E 04°41'21.6" (encl.1).

Subdivision – Only in the southern part of the Dutch province of Limburg are sufficient data available for a detailed stratigraphic subdivision (see VAN AMEROM, 1975). This subdivision is based on the recognition of a number of marine intervals, each characterized by particular fossil assemblages. These marine bands have, as yet, not been determined in other parts of The Netherlands. In the latter areas, the control points are too scarce for a formal subdivision, although in the eastern part of The Netherlands (easternmost Overijssel, southeastern Drenthe) the upper part of the Group has been subdivided, for practical purposes, into three units of formational rank. Here, this distinction was possible as a significant sandy interval is developed within a predominantly shaly sequence, hence (from top to bottom):

Barren Measures	(DCCR),
Tubbergen Sandstone Formation	(DCCT),
Productive Measures	(DCCP).

Because of its economic (gas-productive) importance the Tubbergen Sandstone Formation is introduced formally. However, it is felt that more control points on the under- and overlying shaly units are required before these can be classified properly.

Outside the eastern Netherlands and southern Limburg, no subdivision of the known upper part of the Limburg Group is proposed. The sequence is described as the *Coal Measures* (DCCM).

PRODUCTIVE MEASURES (DCCP)

Name – Name derived from the British stratigraphy, in which the major coal-bearing part of the Carboniferous is described as the Productive Coal Measures.

Definition – Sequence of predominantly silty shales, alternating with coal beds and some sandstones. Its base, at the contact with the more marine lower part of the Limburg Group, remains to be defined due to lack of control points. The correlative level in southern Limburg can be taken at the Sarnsbank Marine Band above which level the sequence is characterized by regular coal seams. The top of the Productive Measures is taken at the base of the lowest significant sandstone bed of the Tubbergen Sandstone Formation.

Age – Westphalian A to C.

Reference section – Well Tubbergen-8: 3094-3206 m (T.D., actual base not reached), coord. N 52°26'19.6", E 06°53'31.5" (encl. 2).

TUBBERGEN SANDSTONE FORMATION (DCCT)

Name – Named after the Dutch municipality of Tubbergen, in the easternmost part of the province of Overijssel. In this area the Tubbergen Sandstone Formation is an important gas-producing unit.

Definition – Sequence of sandstone beds rapidly alternating with subordinate shales and coal beds. The sandstone beds show an overall decrease in number towards the top of the

Formation. The top and bottom of the Formation are marked by the contacts with the predominantly shaly sequences of the Barren Measures and the Productive Measures, respectively.

Age – Late Westphalian B – Early Westphalian D.

Reference section – Well Tubbergen-8: 2434-3094 m, coord. N 52°26'19.6", E 06°53'31.5" (encl. 2).

BARREN MEASURES (DCCR)

Name – Name derived from the Barren Red Measures of the British stratigraphy in which it is applied to the highest part of the Carboniferous succession and characterized by the virtual absence of coal beds and by commonly occurring red colours.

Definition – Sequence of reddish brown and greenish grey, variegated silty shales, alternating with some sandstone beds. Plant remains and coaly particles are present, but coal beds are virtually absent.

The Barren Measures are located between the top of the highest significant sandstone bed of the Tubbergen Sandstone Formation and the erosion surface that marks the top of the Limburg Group.

Age – Late Westphalian C – Stephanian.

Reference section – Well Emmen-7: 3613-4134 m, coord. N 52°46'56.7", E 06°50'37.5" (encl. 3).

COAL MEASURES (DCCM)

Name – Name copied from the British stratigraphic nomenclature in which the Carboniferous paralic deposits, above the Millstone Grit and below the Permian, are named similarly.

Definition – Sequence of predominantly silty shales alternating with generally thin sandstone and coal beds. It occurs below the erosion surface overlain by Upper Rotliegend (or younger) deposits. It has an undefined base in the major part of The Netherlands. In southern Limburg this base is taken at the level of the Sarnsbank Marine Band, above which the sequence shows common coal seams.

Reference section (for the upper part) – Well Rijsbergen-1: 1353-2710 m (lower part of the Coal Measures not defined as yet), coord. N 51°31'44.4", E 04°41'21.6" (encl. 1).

4. LOWER AND UPPER ROTLIEGEND GROUPS

4.1. INTRODUCTION

After a long period of differential uplift and erosion following the deposition of the Limburg Group, sedimentation resumed in the Northwestern European Basin during the Early Permian with the terrestrial deposition of clastic and evaporitic sediments as well as volcanics. In northern Germany, these volcanic rocks often characterize the lower part of the so-called 'Rotliegend'; consequently this Rotliegend is customarily subdivided into two parts, namely Lower Rotliegend and Upper Rotliegend (FALKE, 1972). A regional unconformity is assumed to separate the two units, although its presence can seldom be confirmed in the terrestrial, often coarse-grained clastic sequences, which are notoriously scarce in fossil remains. Therefore, in German practice, the top of the volcanic beds is commonly assumed to mark this boundary which is, however, probably strongly diachronous.

The same definition is applied in Dutch stratigraphy to distinguish between the:

Upper Rotliegend Group,
Lower Rotliegend Group.

4.2. LOWER ROTLIEGEND GROUP (PB)

General – The *Lower Rotliegend Group* is of doubtful occurrence in The Netherlands. Some tuffaceous/?extrusive rocks penetrated in the wells Marslanden-1 (Placid) and Exloo-2 are tentatively correlated with the Lower Rotliegend Group, known from wells in the German Emsland, adjacent to the border with the eastern Netherlands (FABIAN ET AL., 1962). For this reason, the Lower Rotliegend Group has been included in the stratigraphic nomenclature of The Netherlands.

Name – Name derived from German stratigraphy, where it is commonly applied to the lower, volcanic part of the so-called Rotliegend.

Definition (text figs. 5, 6) – Sequence of clastic sediments with interbedded volcanics, in highly variable proportions, and situated between the erosion surface at the top of the Limburg Group and the base of the Upper Rotliegend Group delineated as the top of the uppermost volcanic bed of the

Lower Rotliegend Group.

Age – Early Permian.

Reference section – Not designated as yet for The Netherlands.

Subdivision – In Germany, adjacent to the Dutch border, the basal part of the Group is frequently developed as a clastic interval without volcanics, overlain by volcanic rocks often with clastic intercalations. Hence, the subdivision (from top to bottom) into:

Rotliegend Volcanics	(PBVØ),
Basal Rotliegend Clastics	(PBBA).

As no unequivocal examples of these units are known in The Netherlands, they should be regarded as informal units within the Dutch stratigraphic nomenclature. Consequently, no reference sections have been designated for these subdivisions of the Lower Rotliegend Group.

4.3. UPPER ROTLIEGEND GROUP (RØ)

General – The *Upper Rotliegend Group* represents a sedimentary sequence laid down under hot and arid climatic conditions. It is characterized by dune sands, wadi, sebkha, and desert lake deposits (GLENNIE, 1972).

The subdivision and nomenclature of the Upper Rotliegend Group follows closely the scheme presented by VAN ADRICHEM BOOGAERT (1976), which in turn was based on publications by STÄUBLE & MILIUS (1970) and RHYS (1974).

Name – Name derived from the German stratigraphy where it is applied to the upper, non-volcanic part of the Rotliegend sequence.

Definition (text figs. 5, 6) – Group of formations, comprising coarse- and fine-grained clastic sediments as well as evaporites. It is situated between the erosion surface at the top of the Limburg Group, or the top of the volcanics of the Lower Rotliegend Group, and the base of the Zechstein Group.

Throughout The Netherlands the upper boundary of the Rotliegend Group is taken at the base of the Coppershale, the lowest unit of the Zechstein Group. However, towards the basin-fringe the evaporite-carbonate succession of the Zechstein Group passes gradually into a predominantly clastic sequence, accompanied by a gradual disappearance of the Coppershale. However, on wireline logs, the Coppershale marker (or its equivalent) can always be distinguished by its higher gamma ray radiation.

Age – Early Permian.

Reference section – Well Slochteren-4: 2666-2856 m, coord. N 53°11′33.3″, E 06°45′15″ (encl. 4; also illustrated by STÄUBLE & MILIUS, 1970, fig. 3).

Additional reference section – Well Uithuizermeeden-1: 2875-3167 m, coord. N 53°26′59.1″, E 06°48′29.4″ (encl. 4).

Subdivision – The Upper Rotliegend Group is subdivided into a sandy-conglomeratic formation in a basin margin position, and a shaly-evaporitic formation in the basin centre, hence:

Slochteren Sandstone Formation	(RØSL),
Silverpit Claystone Formation	(RØCL).

The transition zone between these two formations occurs in an E-W trending belt across the northernmost part of the onshore Netherlands and continues into the offshore to approximately the northern part of the Indefatigable High in the British part of the North Sea. In this belt, sandy tongues of the Slochteren Formation and shaly tongues of the Silverpit Formation interfinger. Consequently, the stratigraphy of the transition zone is described (from top to bottom) as:

Ten Boer Claystone Member	(RØCLT),
Upper Slochteren Sandstone Member	(RØSLU),
Ameland Claystone Member	(RØCLA),
Lower Slochteren Sandstone Member	(RØSLL).

In the Ameland-Terschelling area, a tongue of the Silverpit Claystone Formation located at the base of the Upper Rotliegend Group is distinguished as the

Hollum Claystone Member	(RØCLH).

Within each of these claystone members the sand content shows a gradual increase towards the basin margin, and conversely, the sandstone members demonstrate an increase in shale content in a basinward direction. Consequently, the lateral delimitation of these members is ambiguous.

To reduce this ambiguity it is proposed to use the gamma ray log for the distinction between coarse and fine clastics. For the definition of a unit as a sandstone member, it is mandatory that it should contain more than 50% sand, otherwise it is classified as a claystone member. However, it should be realized that evidence from adjacent wells (e.g., in a field or a cluster) may justify a slight variation from this 50%-definition. Furthermore, it is recommended that an interval under consideration should have a minimum thickness of approximately 15-20 m.

SLOCHTEREN SANDSTONE FORMATION (RØSL)

Name – Named after the municipality of Slochteren where in 1959 the well Slochteren-1 found gas in the Upper Rotliegend Group, and, consequently, the Groningen field.

Definition – Sequence of usually pink to pale redbrown, otherwise yellowish or greyish, sandstones and conglomerates. The Formation overlies, unconformably, the Limburg Group or the volcanic beds of the Lower Rotliegend Group. In the area of Ameland and Terschelling it overlies a tongue of the Silverpit Claystone Formation, the Hollum Claystone Member. The Formation is overlain either by the redbrown claystones of the Silverpit Claystone Formation or by the black bituminous shales of the Coppershale Member of the Zechstein 1 Formation. Towards the basin centre interfingering between Slochteren Sandstone Formation and Silverpit Claystone Formation occurs.

Reference section – Well Slochteren-4: 2709-2856 m, coord. N 53°11'33.3", E 06°45'15" (encl. 4; also illustrated by STÄUBLE & MILIUS, 1970, fig. 3).

Subdivision – In an E-W belt across the northern Netherlands a tongue of the Silverpit Claystone Formation, the Ameland Claystone Member, subdivides the Slochteren Sandstone Formation into two members, namely:

Upper Slochteren Sandstone Member (RØSLU)
ref. section: Well Uithuizermeeden-1: 2949-3041 m, coord. N 53°26'59.1", E 06°48'29.4" (encl. 4),
Lower Slochteren Sandstone Member (RØSLL)
ref. section: Well Uithuizermeeden-1: 3058-3167 m (encl. 4).

The *Lower Slochteren Sandstone Member,* generally more conglomeratic than the upper member, extends far towards the basin centre, i.e. beyond the area of the Upper Slochteren Sandstone Member. In such a basinal situation it is overlain by the undivided Silverpit Claystone Formation (e.g., Well K 6-1, encl. 5). Elsewhere it is overlain by the Ameland Claystone Member.

The *Upper Slochteren Sandstone Member* is overlain, practically everywhere in The Netherlands, by another tongue of the Silverpit Claystone Formation, the Ten Boer Claystone Member.

SILVERPIT CLAYSTONE FORMATION (RØCL)

Name – Named after the Outer Silver Pit, an offshore deep in the British sector of the North Sea (RHYS, 1974).

Definition – Sequence of redbrown, silty, often anhydritic claystones with some sand- or siltstone stringers, and with rock salt intercalations in the basin centre proper. Its base overlies the Limburg Group, or the sandstone- conglomerate sequence of the Slochteren Sandstone Formation. Its top is marked by the base of the Coppershale Member of the Zechstein Group. Towards the basin margin the Silverpit Formation interfingers with the Slochteren Sandstone Formation.

Age – Early Permian.

Reference section – Well K 6-1: 3308-3636 m, coord. N 53°48'59.5", E 03°59'04.4" (encl. 5).

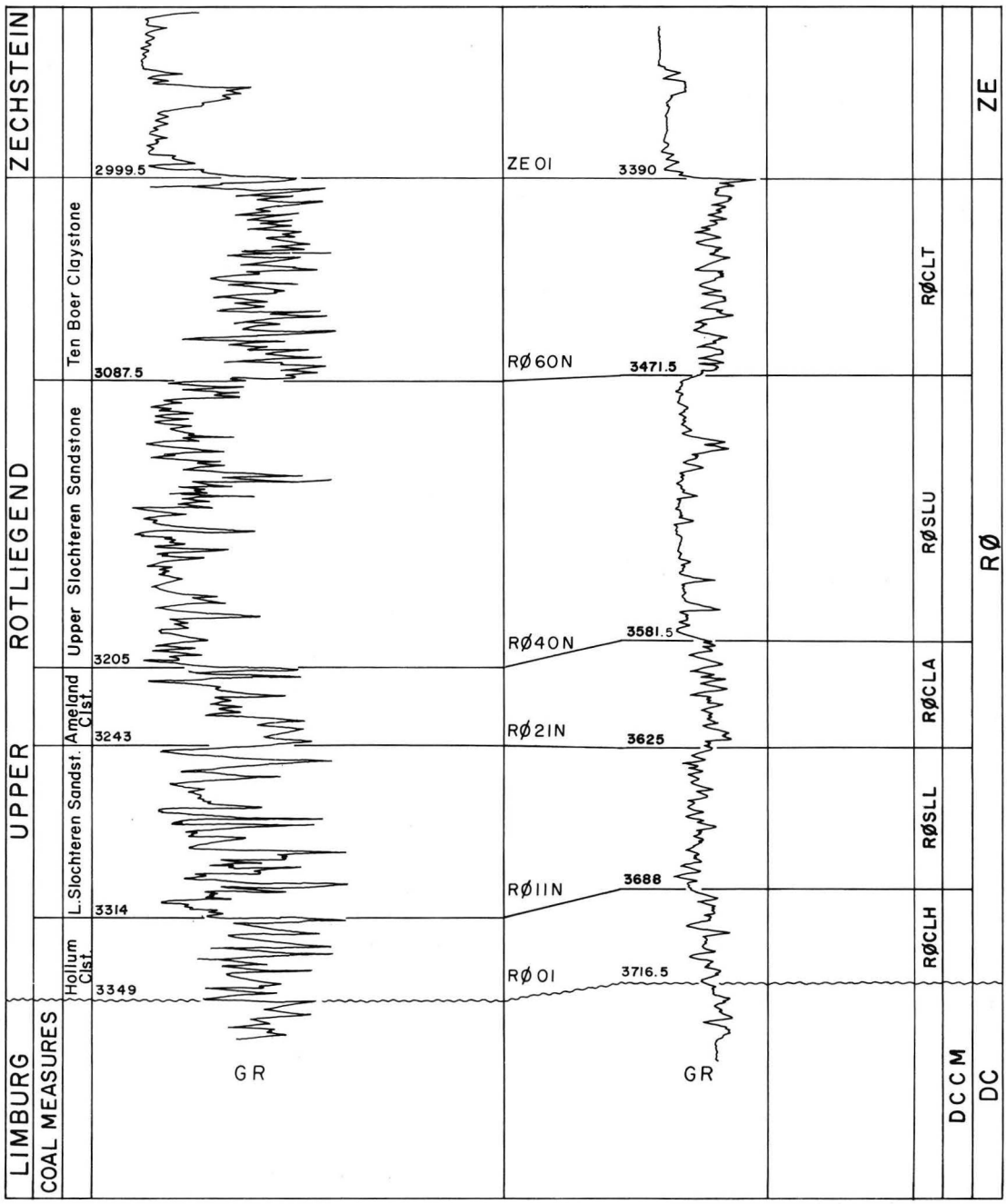
Subdivision – In the transition zone between the Silverpit Claystone Formation and the Slochteren Sandstone Formation, tongues of the Silverpit Formation protrude into the Slochteren Formation. The three most prominent tongues are described (from top to bottom) as:
Ten Boer Claystone Member (RØCLT)
ref. section – Well Slochteren-4: 2666-2709 m, coord. N 53°11'33", E 06°45'15" (encl. 4, also illustrated by STÄUBLE & MILIUS, 1970, fig. 3).
Ameland Claystone Member (RØCLA)
ref. section – Well Buren-1: 3581.5-3625 m, coord. N 53°27'25.5", E 05°48'29.7" (text fig. 1; also illustrated by VAN ADRICHEM BOOGAERT, 1976, fig. 5).
add. ref. section – Well Terschelling-1: 2881-3005 m, coord. N 53°23'35.3", E 05°15'57.6" (encl. 5).
Hollum Claystone Member (RØCLH)
ref. section – Well Hollum-Ameland-2: 3314-3349 m, coord. N 53°27'27.2", E 05°37'32.2" (text fig. 1).

The *Hollum Claystone Member* is a silty claystone tongue (with some sandstone beds) of the Silverpit Claystone Formation extending under the Slochteren Sandstone Formation in the region of the Dutch Wadden Islands of Ameland and Terschelling. In VAN ADRICHEM BOOGAERT's definition of the Ameland Claystone Member the BP/Gulf well Buren-1 was selected as the stratotype, but the poor quality of the illustrated gamma ray log prevented a full description. Comparison with nearby wells, e.g., Hollum-Ameland-2 (text fig. 1), suggests that in reality three units are present in Buren-1, viz.

an upper claystone,
an intermediate sand-shale sequence, and
a lower claystone containing some sandy beds.

The upper unit is given here as the reference section for the Ameland Claystone Member, whereas the lower one is correlated with the Hollum Claystone Member. The intermediate sequence is described as a distal tongue of the Lower Slochteren Sandstone.

The *Ameland Claystone Member* is a very silty develop-



(After Van Adrichem Boogaert, 1976, p.32)

Text figure 1 UPPER ROTLIEGEND STRATIGRAPHY ON THE ISLAND OF AMELAND, THE NETHERLANDS.

vert. scale 1:2500

DRAW. NR. G105.826

ment of the Silverpit Claystone Formation. Its southern limit runs in an approximate E-W direction from the northern part of the Indefatigable High across the island of Texel towards the northern part of the Groningen province.

The *Ten Boer Claystone Member* is a very silty to sandy shale tongue, frequently without the anhydritic component that characterizes the Silverpit Claystone Formation. Its southern limit passes from the north side of the Indefatigable High across the island of Texel into northernmost Drenthe and southern Groningen. Consequently, it distinctly oversteps the southern limit of the Ameland Claystone Member, and forms a broad belt, some 60 km wide N-S across the northeastern Netherlands.

In the basin centre, a tripartite subdivision of the Silverpit Claystone Formation is obvious due to a middle section with rock salt beds, viz.

Upper Silverpit Claystone Member (RØCLU)

ref. section – Well M 9-1: 3119-3258 m, coord. N 53°36'32.9", E 05°43'14.9" (encl. 5).

Silverpit Evaporite Member (RØCLE)

ref. section – Well M 9-1: 3258-3438 m (encl. 5).

Lower Silverpit Claystone Member (RØCLL)

ref. section – Well M 9-1: 3438-3507 m (encl. 5)

The *Lower* and the *Upper Silverpit Claystone Members* are silty, anhydritic shales with common siltstone streaks.

The *Silverpit Evaporite Member* is a sequence of silty, anhydritic claystones with halite streaks and beds. Its lower and upper boundaries are defined as the base of the lowest and the top of the highest halite bed, respectively. In the German literature, this evaporite-fine clastic sequence has often been described as the 'Haselgebirge', but as TRUSHEIM (1971) pointed out, correctly, the latter name should only be used for a tectonically induced salt/clay/sulfate breccia (VAN ADRICHEM BOOGAERT, 1976).

5. ZECHSTEIN GROUP (ZE)

General – After a period of terrestrial deposition comprising the Lower and Upper Rotliegend Groups, marine conditions returned to the Northwestern European Basin with the deposition of evaporites, carbonates and subordinate fine clastics. Along the basin margin a minor influx of coarse clastic sediments took place. These marine sediments, of Late Permian age, are described as the *Zechstein Group.*

For the Dutch subsoil, the subdivision and nomenclature of the Zechstein Group are similar to those applied in Germany (e.g., RICHTER-BERNBURG, 1955). The translations of the German names into the ones presented in this paper are based on VISSER (1955) and BRUEREN (1959).

The lower limit of the Zechstein Group is taken at the base of the Coppershale (or its log-correlative equivalent), a thin, black bituminous shale bed recognized over practically the whole of the Northwestern European Basin and providing an excellent marker horizon. From several outcrops in Germany, a basal Zechstein conglomerate of approximately 1 m thickness is described from below the Coppershale (HEIDORN, 1949). A similar conglomerate may well be present in the Dutch subsurface, but as no lithological distinction can be made between such a conglomerate and those often occurring in the Upper Rotliegend Group, all such beds have been included in the latter group.

The upper limit of the Zechstein Group is defined at the top of the uppermost distinct evaporite or carbonate bed in the Zechstein sequence. According to most German literature, the Group is to be terminated at the top of the uppermost anhydrite bed, the so-called Grenz Anhydrit (RICHTER-BERNBURG, 1955). This particular layer is frequently absent in the Dutch subsoil, but where present it is included in the Zechstein, provided it shows a thickness of at least 1 m, thus ensuring a clear expression on wireline logs. In view of its reduced thickness, no separate name is proposed for this bed in the Dutch nomenclature.

Immediately above the top of the Zechstein Group, as defined here, a red clayey sequence with anhydrite inclusions or stringers occurs. Some German authors (e.g., HEIDORN (1949)) include these beds in the Zechstein Group as representing a succession of residual salt clays originating from leaching of the uppermost evaporite beds of the Group. However, for practical purposes, it is recommended that these (commonly thin) clastic beds be included within the Lower Germanic Trias Group, so that the distinct boundary between the evaporite/carbonate beds of the Zechstein Group and the succeeding clastics of the next group is maintained easily throughout The Netherlands.

Name – Name derived from the German stratigraphic nomenclature where it is applied to the marine evaporite/carbonate sequence between the Rotliegend and the Germanic Trias.

Definition (text figs. 5, 6) – Sequence of evaporites and carbonates with some thin shale intercalations. The evaporites generally consist of anhydrites and salts, often strongly affected by subsequent halokinetic movements. Towards the basin edge, clastic beds gradually replace the evaporites and, to a lesser degree, the carbonates.

The succession is bounded at the base by the Coppershale (or its log-correlative equivalent), generally overlying the Upper Rotliegend Group, and at the top by the uppermost evaporite or carbonate bed below the clastics of the Lower Germanic Trias Group (or younger sequences).

Age – Late Permian.

Reference section – Well Rossum-Weerselo-3: 1235-1804 m, coord. N 52°21'03.6", E 06°54'38.3" (encls. 6, 7).

Subdivision – The subdivision of the Zechstein Group is based on the recognition of four evaporitic cycles, commonly named as Zechstein 1, 2, 3 and 4. The corresponding sediments are described (from top to bottom) as:

Zechstein 4 Formation (ZEZ4),
Zechstein 3 Formation (ZEZ3),
Zechstein 2 Formation (ZEZ2),
Zechstein 1 Formation (ZEZ1).

A completely developed Zechstein cycle consists of (from bottom to top): shales – carbonates – anhydrites – chlorides (halite and K-Mg salts) – anhydrites. In general none of the recognized cycles demonstrates such a complete development since one or more components are often absent.

It is assumed that the Zechstein cycles, and the main lithological elements within each cycle, were laid down in approximately isochronous intervals. However, within the carbonate-anhydrite bodies diagenetic changes by calcitisation of the anhydrites and by anhydritisation of the carbonates may have blurred the picture of a synchronous boundary between the carbonate and anhydrite members of each cycle.

The main lithologies within each cycle are distinguished here as members, irrespective of the lithological variations which may occur within each member. For example, the Zechstein 2 Carbonate Member embraces both the so-called Main Dolomite of a basin-margin position and the Fetid Limestone of the basin centre.

Towards the basin edge, the fourfold subdivision of the Zechstein Group is progressively obscured by the disappearance of the evaporite bodies and by the relative increase of the clastic intercalations. Such marginal sequences are described as:

Fringe Zechstein Formation (ZEFR)

Halokinetic movements of the salts have often disturbed large parts of the Zechstein sequence to such degree that the normal depositional arrangement cannot be recognized anymore. The nomenclature of such sequences falls strictly outside the scope of the presented stratigraphic scheme. However, for practical purposes, it was found advantageous to standardize the nomenclature of these halokinetically disturbed Zechstein sequences. Furthermore, a common denominator is proposed for distinctly leached beds at the top of the Zechstein Group, which are often found in wells where rocks younger than the Lower Germanic Trias succeed the Zechstein Group. These abnormal sequences are described at the end of this chapter.

ZECHSTEIN 1 FORMATION (ZEZ1)

Name – Name derived from the German stratigraphic nomenclature where it is customarily applied to the oldest evaporitic cycle of the Zechstein. The name 'Werra Series' is often used as a synonym.

Definition – The oldest evaporitic cycle of the Zechstein Group, consisting of a basal shale followed by carbonates – anhydrites – salts – anhydrites in a basin-margin position, and by carbonates – anhydrites in the basin centre.

The Zechstein 1 Formation is situated between the base of the Coppershale, the lowest member of the Zechstein Group, and the base of the carbonates of the Zechstein 2 Formation.

Age – Late Permian.

Reference sections – Because pronounced differences between the basin-margin and the basin-centre successions are apparent, two reference wells are presented:
- (basin-margin position) Well Rossum-Weerselo-3: 1407-1804 m, coord. N 52°21'03.6", E 06°54'38.3" (encl. 6).
- (basin-centre position) Well Vries-1: 3083-3122 m, coord. N 53°02'14.8", E 06°35'40.5" (encl. 6).

Subdivision – A complete evaporitic cycle is present in subbasins occurring along the basin margin, whereas in the basin centre the cycle is incomplete with the absence of salt beds, as exemplified by Rossum-Weerselo-3 and Vries-1, respectively. The nomenclature applied to these situations is as follows:

		Rossum – Weerselo-3	*Vries-1*
Z1 Upper Anhydrite Mbr.	(ZEZ1T)	1407-1435 m	-
Z1 Salt Member	(ZEZ1H)	1435-1725 m	-
Z1 Lower Anhydrite Mbr.	(ZEZ1A)	1725-1801 m	-
Z1 Anhydrite Mbr.	(ZEZ1W)	-	3083-3110 m
Z1 Carbonate Mbr.	(ZEZ1C)	1801-1803 m	3110-3121 m
Coppershale Mbr.	(ZEZ1K)	1803-1804 m	3121-3122 m

In practice the separation of the Z1 Anhydrite Member and the Z1 Carbonate Member is sometimes ambiguous. Therefore, it is proposed to combine these units, whenever necessary, into:

Z1 Anhydrite-Carbonate Member (ZEZ1B)

Reference section – Well Uithuizermeeden-1: 2828-2874 m, coord. N 53°26'59.1", E 06°48'29.4" (encl. 6).

The *Coppershale Member* is a thin, microlaminated, black

bituminous shale. It is usually recognized on wireline logs by a characteristic very high gamma ray reading.

The *Z1 Carbonate Member* commonly grades from argillaceous limestone at the base into crystalline dolomite at the top. Frequently it is very anhydritic, which explains the often gradational boundary with the following unit, the Z1 Anhydrite Member. Consequently, the boundary between these two units is sometimes ambiguous.

The *Z1 Anhydrite-Carbonate Member* is recognized in all those areas where a clear distinction between the Z1 Carbonate Member and the Z1 Anhydrite Member is hardly possible. This is due to anhydrite stringers in the equivalent of the Z1 Carbonate and carbonate intercalations in the overlying anhydritic beds.

The *Z1 Anhydrite Member/Z1 Lower Anhydrite Member* is often a solid body of anhydrite, but dolomitic stringers occur frequently, thus rendering its distinction from the Z1 Carbonate Member difficult.

The *Z1 Salt Member*, as recognized in some sub-basins along the basin margin, probably does not form one continuous salt body but consists of laterally separated lenses. However, for practical purposes, these salt layers are described under one denominator. In most occurrences halite is the only salt component present, but some local beds of potassium salts have been observed.

The *Z1 Upper Anhydrite Member* is a unit in which anhydrite is the dominant component with variable amounts of dolomite stringers.

ZECHSTEIN 2 FORMATION (ZEZ2)

Name – Name derived from the German stratigraphic nomenclature in which the second evaporitic cycle of the Zechstein is customarily indicated as the Zechstein 2 or 'Stassfurt Series'.

Definition – The second oldest evaporitic cycle of the Zechstein Group consisting of a carbonate – anhydrite – salt – anhydrite sequence, although locally the salt member may be absent. It is located between the top of the uppermost anhydrite member of the Zechstein 1 Formation and the base of the Grey Salt Clay Member, the lowest unit of the Zechstein 3 Formation.

Age – Late Permian.

Reference sections – The lithological development of this Formation differs markedly when basin-margin and basin-centre developments are compared. Consequently, two reference sections have been selected:
– (basin-margin position) Well Rossum-Weerselo-3: 1331-1407 m, coord. N 52°21'03.6", E 06°54'38.3" (encl. 6),
– (basin-centre position) Well Uithuizermeeden-1: 2548-2828 m, coord. N 53°26'59.1", E 06°48'29.4" (encl. 6).

Subdivision – The Zechstein 2 Formation does not demonstrate anywhere a development as a complete evaporitic cycle since the basal shale unit of such a cycle has nowhere been observed.

The subdivision of the Formation is as follows:

		Rossum – Weerselo-3	*Uithuizermeeden-1*
Z2 Roof Anhydrite Mbr.	(ZEZ2T)	1331-1335 m	2548-2553 m
Z2 Salt Member	(ZEZ2H)	1335-1358 m	2553-2818 m
Z2 Basal Anhydrite Mbr.	(ZEZ2A)	1358-1365 m	2818-2823 m
Z2 Carbonate Mbr.	(ZEZ2C)	1365-1407 m	2823-2828 m

The *Z2 Carbonate Member* is, in the basin centre, developed as a thin, finely laminated, argillaceous, blackish and often bituminous limestone, and distinguished in Dutch literature as the Fetid Limestone (VISSER, 1963). Towards the basin margin, this Member is usually a massive to thick bedded, light coloured, sometimes oolitic – bioclastic dolomite, and informally named the Main Dolomite (BRUEREN, 1959; VISSER, 1963). Transitional developments between these two lithological types commonly occur.

The Main Dolomite in particular may contain appreciable amounts of anhydrite but on wire-line log evidence the distinction between the Z2 Carbonate Member and the overlying Z2 Basal Anhydrite Member is generally not too difficult.

The *Z2 Basal Anhydrite Member* is generally developed as a body of relatively pure anhydrite.

The *Z2 Salt Member* is, in the basin centre, a thick monotonous halite sequence, often with potassium-magnesium salts towards the top.

The *Z2 Roof Anhydrite Member* is, generally, a thin and pure anhydrite sequence.

ZECHSTEIN 3 FORMATION (ZEZ3)

Name – Name derived from the German stratigraphic nomenclature in which the penultimate evaporitic cycle of the Zechstein is customarily described as the Zechstein 3 or the 'Leine Series'.

Definition – The third and penultimate evaporitic cycle of the Zechstein Group, consisting of a shale – carbonate – anhydrite – salt succession, with a gradual thinning of the carbonate member towards the basin centre and a similar disappearance of the salt towards the basin margin. It is located between the top of the Z2 Roof Anhydrite and the base of the Red Salt Clay Member, the basal unit of the Zechstein 4 Formation.

Age – Late Permian.

Reference sections –

Well Rossum-Weerselo-3: 1245-1331 m, coord. N 52°21'03.6", E 06°54'38.3" (encl. 7),

Well Uithuizermeeden-1: 2250-2548 m, coord. N 53°26'59.1", E 06°48'29.4" (encl. 7).

Subdivision – The Zechstein 3 Formation is never developed as a complete evaporitic cycle as the topmost anhydrite member is absent.

The subdivision of the Zechstein 3 Formation is as follows:

		Rossum – Weerselo-3	*Uithuizermeeden-1*
Z3 Salt Member	(ZEZ3H)	1245-1281 m	2250-2488 m
Z3 Main Anhydrite Mbr.	(ZEZ3A)	1281-1283 m	-
Z3 Anhydrite-Carbonate Mbr.	(ZEZ3B)	-	2488-2547 m
Z3 Carbonate Mbr.	(ZEZ3C)	1283-1327 m	-
Grey Salt Clay Member	(ZEZ3G)	1327-1331 m	2547-2548 m

The *Grey Salt Clay Member* is a thin, grey shale interval.

The *Z3 Carbonate Member* is a brownish, slightly argillaceous, dolomitic limestone to very fine crystalline dolomite, usually known by its German name of the Plattendolomit (the 'Platy Dolomite' of VISSER, 1955, and BRUEREN, 1959). It exhibits its thickest development near the basin margin and then thins gradually towards the basin centre where it completely disappears. This occurs combined with a complementary thickness increase of the overlying Z3 Main Anhydrite Member. The Z3 Carbonate Member frequently contains interbeds of anhydrite, often in combination with carbonate intercalations in the Z3 Main Anhydrite Member.

The *Z3 Anhydrite-Carbonate Member* is proposed for those cases where the combined carbonate and anhydrite units of the Zechstein 3 cycle are clearly separable from the under- and overlying units but where, due to anhydrite intercalations in the supposed equivalent of the Z3 Carbonate Member and to carbonate beds in the overlying anhydrite sequence, the distinction between these two members is too ambiguous to be maintained.

The *Z3 Main Anhydrite Member* is variable in lithological expression, as it is frequently developed as a relatively pure anhydrite body but can also include a high amount of dolomite intercalations.

The *Z3 Salt Member* is a solid salt sequence with frequently potassium-magnesium salts in its upper part. Within the highest part of the Member a thin anhydrite bed sometimes occurs, probably representing the topmost member of the complete evaporitic cycle of the Zechstein 3. Furthermore, this upper part of the Member demonstrates reddish shale intercalations similar to the Red Salt Clay Member of the Zechstein 4 Formation.

ZECHSTEIN 4 FORMATION (ZEZ4)

Name – Name derived from the German stratigraphic nomenclature in which customarily the last evaporitic cycle of the Zechstein is distinguished as the Zechstein 4 or the 'Aller Series'.

Definition – Fourth and last evaporitic cycle of the Zechstein Group, consisting of a shale – anhydrite – salt – occasional anhydrite sequence. It is located between the top of the Z3 Salt Member and the base of the clastics of the Lower Buntsandstein Formation.

Age – Late Permian.

Reference sections –

Well Uithuizermeeden-1: 2194-2250 m, coord. N 53°26'59.1", E 06°48'29.4" (encl. 7),

Well Rossum-Weerselo-3: 1235-1245 m, coord. N 52°21'03.6", E 06°54'38.3" (encl. 7).

Subdivision – The evaporitic cycle of the Zechstein 4 Formation is incomplete with the absence of the carbonate member. Frequently it shows a further incompleteness with the absence of the top anhydrite bed. This latter unit, in German terminology distinguished as the 'Grenz Anhydrit', is sometimes present in the Dutch subsoil but in such a thin development that no separate name is warranted.

The Dutch subdivision of the Zechstein 4 Formation reads as follows (from top to bottom):

		Rossum – Weerselo-3	*Uithuizermeeden-1*
Z4 Salt Member	(ZEZ4H)	1235-1238 m	2194-2246 m
Z4 Pegmatite Anhydrite Mbr.	(ZEZ4A)	1238-1240 m	2246-2247 m
Red Salt Clay Member	(ZEZ4R)	1240-1245 m	2247-2250 m

The *Red Salt Clay Member* is a red, often anhydritic shale. Towards the basin centre similar shale beds are common in the uppermost part of the Zechstein 3 Formation, but, in accordance with German usage, only the uppermost of these shale beds is described as the Red Salt Clay, the others being included in the Z3 Salt Member.

The *Z4 Pegmatite Anhydrite Member* is a distinct anhydrite unit (commonly with coarse halite crystals).

The *Z4 Salt Member* contains, locally, thin potassium salt

intercalations. In its upper part it shows, at some places, one or more interbeds of shale and anhydrite, including the so-called 'Grenz Anhydrit' of German literature.

FRINGE ZECHSTEIN FORMATION (ZEFR)

Name – Name introduced for the basin-margin development of the Zechstein Group, i.e. for the clastic-evaporite/carbonate alternation along the basin margin in which the four evaporitic cycles of the Zechstein are no longer recognizable.

Definition – Sequence of sandstones, shales and carbonates, commonly with some anhydrites, contained between the base of the Coppershale (or its log-correlative equivalent) and the top of the highest carbonate in the sequence, which is correlatable with the Z3 Carbonate Member of the Zechstein 3 Formation.

Age – Late Permian.

Reference section –
Well Q 11-1: 2720-2874 m, coord. N 52°25'06.7", E 04°21'36.0" (encl. 7).

Additional reference sections – Well Buurmalsen-1: 1972-2069 m, coord. N 51°54'18.8", E 05°18'49.2" (encl. 16),
Well Nederweert-1: 2583-2634 m, coord. N 51°18'41.9", E 05°46'14.7" (encl. 15).

Subdivision – The fourfold subdivision of the Zechstein Group in the basin centre looses its identity towards the basin margin, where an irregular succession of variable lithologies is developed. However, some members of the Zechstein 1 and 3 Formations are traceable into these marginal successions, viz. the Coppershale Member and the Z3 Carbonate Member; the latter in this basin-edge development is distinguished as the Upper Carbonate Member. Based upon the recognition of these two levels, the Fringe Zechstein Formation can be subdivided into:

	Q 11-1	*Buurmalsen-1*	*Nederweert-1*
Upper Carbonate Mbr. (ZEFRC)	2720-2736 m	1972-1989 m	2583-2592 m
Main Fringe Zechstein Mbr. (ZEFRL)	2736-2873 m	1989-2066 m	2592-2634 m
Coppershale Mbr. (ZEFRK)	2873-2874 m	2066-2069 m	-

The *Coppershale Member* is lithologically similar to its counterpart of the Zechstein 1 Formation, although it gradually looses its pronounced bituminous character towards the basin margin. However, throughout the area of the basin-edge development, this member is recognizable as a log-correlative level, although in some cases it does not warrant a formal name (e.g., Nederweert-1).

The *Main Fringe Zechstein Member* is a sequence of various lithologies, composed of shales, sandstones, carbonates and anhydrites. It often contains appreciable carbonate beds in its lower part, usually directly on top of the Coppershale Member.

The *Upper Carbonate Member* forms the top of the Fringe Zechstein Formation. Occasionally, distinct evaporite beds, e.g., anhydrites, occur somewhat higher in the clastic sequence above the Member, but for practical purposes such beds, correlatable with the Zechstein 3 and 4 evaporites, are included in the Lower Germanic Trias Group.

HALOKINETICALLY DISTURBED AND LEACHED ZECHSTEIN SECTIONS

Halokinetic salt movements have often disturbed the described Zechstein sequences, frequently beyond recognition of the depositional succession. For such disturbed sequences the following nomenclature is proposed:

- *Zechstein Salt* (ZESA) for the halokinetically disturbed sequences above the Z2 Basal Anhydrite Member, in which the depositional sequence of Z2 Salt to Z4 Salt is not recognizable anymore. Within this salt sequence the basal Zechstein 3 members (Grey Salt Clay, Z3 Carbonate and Z3 Main Anhydrite) together act as a rigid intercalation and, due to the halokinetic movements, are often broken and dispersed as 'floating slabs' in the salt sequence;
- *Upper Zechstein Salt* (ZESAU) for those cases where the basal Zechstein 3 members are recognizable but the basal members of the Zechstein 4 Formation are absent, thus rendering the recognition of the separate Z3 and Z4 Salt members impossible;
- *Lower Zechstein Salt* (ZESAL) for those salt sequences in which it is impossible to distinguish between Z2 and Z3 salts because the basal Zechstein 3 members are absent. The Zechstein 4 Formation is, however, complete (Red Salt Clay, Z4 Pegmatite Anhydrite and Z4 Salt) and in place.

Post-depositional alterations of the Zechstein sequence occurred at places where leaching affected the predominantly evaporitic succession. These effects are especially noticeable in cases where the Zechstein is overlain by rocks younger than the Basal Buntsandstein Member which depositionally follows on top of the Zechstein Group. The residual rocks formed by these leaching processes are distinguished as the *Zechstein Caprock* (ZECP), and usually consist of anhydrite and carbonate.

6. LOWER GERMANIC TRIAS, UPPER GERMANIC TRIAS AND BUNTER GROUPS

6.1. *INTRODUCTION*

The Germanic Trias was originally defined from the area in central Germany where it outcrops and was subdivided into Buntsandstein, Muschelkalk and Keuper, consecutively from bottom to top.

This tripartite subdivision, although often interpreted in a chrono-stratigraphic sense, is essentially of litho-stratigraphic origin and will be so treated in this publication.

By careful step-by-step correlation the recognition of these units was extended to the subsurface of northwestern Germany (TRUSHEIM, 1963; HERMANN, 1964). It should be realized that correlation was the prime purpose, and that the names of the main subdivisions were maintained despite sometimes pronounced lithological variations.

In the lithostratigraphy of the British onshore the classical tripartite subdivision as known from Germany is not recognizable. Here the Germanic Trias is subdivided into a (lower) Bunter or Bunter Sandstone and an (upper) Keuper Marl. Although names similar to the German ones have long been in common use for the British situation, the equivalence of both nomenclatures cannot be proven (RAYNER, 1967). Data from wells drilled in the British offshore sector of the North Sea have provided for a better understanding of the correlation between the British and the northwestern German units (GEIGER & HOPPING, 1968). Subsequently RHYS (1974) introduced an adapted version of the nomenclature for the British sector. Two groups were recognized: the (lower) Bacton Group and the (upper) Haisborough Group. The section equivalent to the Rhaet of the German authors was, however, included as the Winterton Formation within the Lias Group. For the units at formation and member level the German names were maintained where it was felt that an equivalence could be established and for all other cases new British names were introduced.

In The Netherlands, the nomenclature for the Germanic Trias was traditionally similar to the German one, especially for the rock sequences in basinal development. Along the basin margin more similarity to the British succession is seen and the subdivision there is comparable to the British one (text fig. 7).

Within the development of the Germanic Trias, two major groups of sediments are recognized: a lower clastic sequence and an upper series of clastics, carbonates and evaporites. These two are named (from top to bottom):

Upper Germanic Trias Group,
Lower Germanic Trias Group,

and are equivalent to the Haisborough and Bacton Groups of the British sector of the North Sea region, respectively.

The boundary between the Lower and Upper Germanic Trias Groups is taken at the level of the Hardegsen Unconformity, the most important break in sedimentation that can be recognized within the depositional succession of the Germanic Trias. This concept deviates from the classic Germanic tripartite subdivison, the more so since the level of the unconformity is located within the classic Buntsandstein succession. Such a major subdivision has been advocated, however, by some German authors (e.g., TRUSHEIM, 1963) and a similar importance has also been attributed to the unconformity by W. H. ZIEGLER (1975) and BRENNAND (1975).

One further deviation from the classic German concept of the Germanic Trias is introduced here by considering the topmost, predominantly open-marine beds (Sleen Shale Formation) as the basal unit of the Altena Group. Although these clayey sediments are of Triassic (Rhaetian) age, they belong clearly to the succeeding marine sequence.

6.2. LOWER GERMANIC TRIAS GROUP (RB)

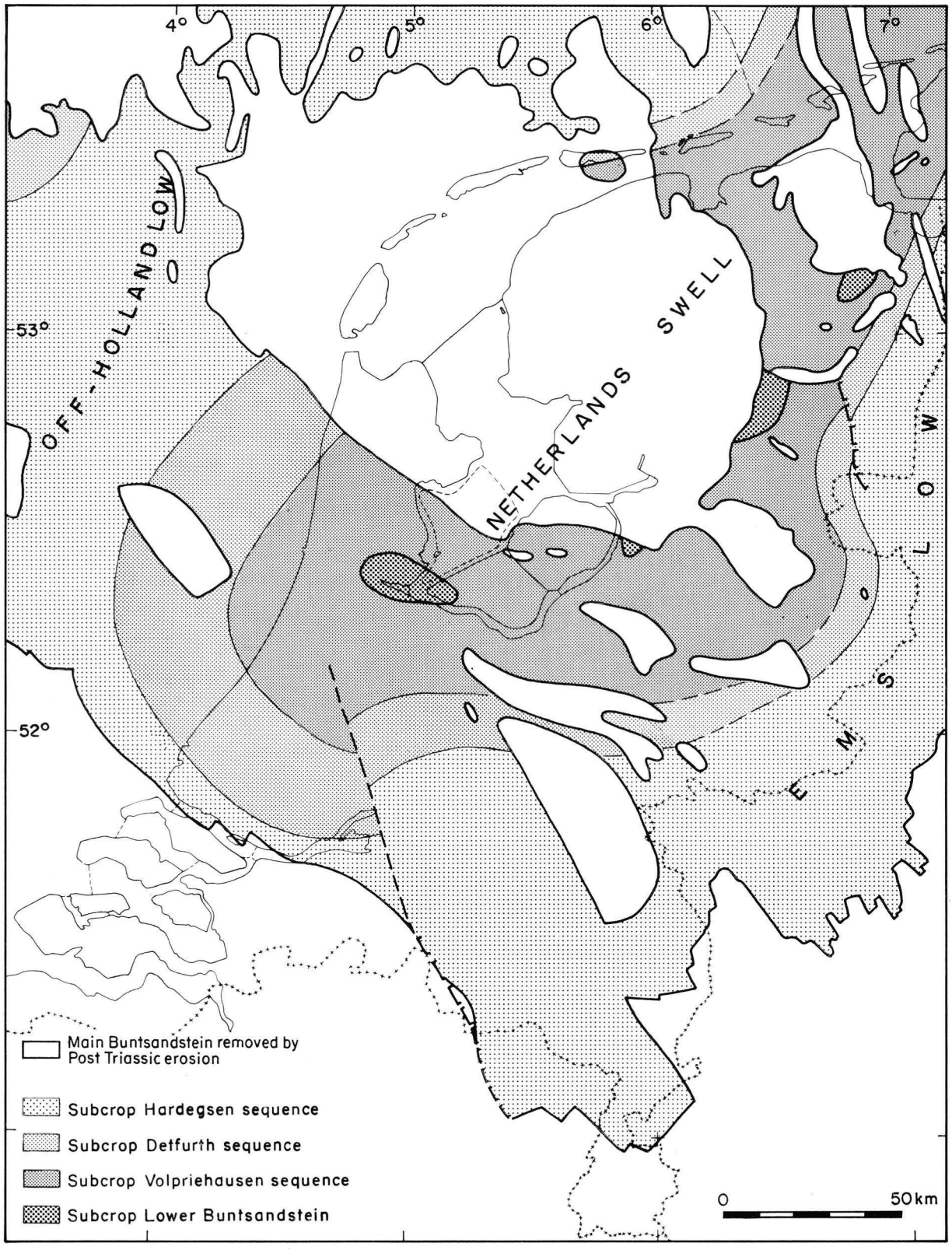
General – Withdrawal of the sea from the Northwestern European Permo-Triassic Basin towards the end of the Permian terminated the marine cyclic deposition of the Zechstein Group, and terrestrial conditions returned with the influx of continentally derived clastic sediments.

During the deposition of the Lower Germanic Trias Group, the main part of The Netherlands was occupied by a large domal swell, the *Netherlands Swell,* comparable to the similarly directed Hunte and Eichsfeld swells in Germany (text fig. 2). The Netherlands Swell was flanked in the east by the *Ems Low* and in the west by the *Off-Holland Low.* These swells and lows, with a general NNE-SSW strike, are a common feature of the southern margin of the Northwestern European Permo-Triassic Basin, with its ESE-WNW directed axis.

In order to maintain the relationship to the formerly applied nomenclature it was felt advantageous to continue the usage of most of the well-established German names. Consequently, the two major subdivisions of the Lower Germanic Trias Group are named (from top to bottom):

Main Buntsandstein Formation (RBSS),
Lower Buntsandstein Formation (RBSH).

After the deposition of the Lower Buntsandstein Formation, the differences in rates of subsidence, which caused the pre-



Text figure 2 Subcrop map below the Hardegsen Unconformity

sence of the highs and lows, became more pronounced and on the swells interruptions in sedimentation occurred by non-deposition and, occasionally, by appreciable erosion. Such breaks are common in the Main Buntsandstein sequence and become increasingly more important upwards. The uppermost one, the Hardegsen Unconformity (below the Solling sequence), is apparent by its considerable erosion of the underlying sequences in the area of the above-mentioned swells. In the centre of the Netherlands Swell in particular the Hardegsen erosion has removed even parts of the Lower Buntsandstein Formation, although in the adjacent lows the Hardegsen erosion is hardly noticeable. Thus, the choice of the Hardegsen Unconformity as a major level in the Germanic Trias stratigraphy becomes obvious for the separation of the Lower and Upper Germanic Trias Groups.

Along the margin of the Germanic Trias basin, the Hardegsen Unconformity (although assumed to be present) is hardly discernible. The equivalent of the Main Buntsandstein Formation, or sometimes the whole of the Lower Germanic Trias Group and the lower part of the Upper Germanic Trias Group, are developed as relatively massive sandstones, which for practical purposes form one unit, the so-called Bunter Group. This unit is followed by the marly-shaly equivalents of the Muschelkalk and Keuper Formations.

For practical purposes, it is proposed to apply the terminology of the Lower Germanic Trias Group to those areas where the individual shaly members of the Main Buntsandstein Formation can easily be recognized. Outside such basinal areas the Bunter terminology is more applicable. It is realized that in such a concept some units within the Bunter Group are correlatable with those of the Lower Buntsandstein and Röt Formations of the Lower and Upper Germanic Trias Groups. These have been allocated new names.

Name – The name 'Germanic Trias' is derived from the German stratigraphic nomenclature where it is commonly applied to denominate the whole of the sedimentary sequence between the evaporites and carbonates of the Zechstein and the marine shales of the Lias. In this paper, the prefix 'Lower' is applied to that part of the Germanic Trias that occurs below the so-called Hardegsen Unconformity.

Definition (text figs. 7,8) – Group of formations composed of sandstones, siltstones and shales (often anhydritic) and situated between the top of the uppermost distinct carbonate or evaporite bed of the Zechstein Group and the level of the Hardegsen Unconformity which forms the base of the clastic-carbonate-evaporite sequence of the Upper Germanic Trias Group.

Age – Skythian.

Reference section – Well Blijham-1 : 2732-3273 m, coord. N 53°05'41.1', E 07°04'40.2' (encl. 8).

Subdivision – Two formations are distinguished : a lower predominantly shaly sequence, and an upper alternation of sandstones and shales, viz. (from top to bottom) :

Main Buntsandstein Formation	(RBSS),
Lower Buntsandstein Formation	(RBSH).

LOWER BUNTSANDSTEIN FORMATION (RBSH)

Name – Name derived from the German stratigraphic nomenclature where the Buntsandstein is subdivided into a Lower, Middle and Upper Buntsandstein. In the here presented nomenclature, the Dutch Lower Buntsandstein Formation coincides with its German counterpart but the Middle and Upper Buntsandstein are not maintained any longer.

Definition – A monotonous sequence of silty, anhydritic, redbrown shales to claystones, with intercalated oolite-bearing beds towards the top; situated between the top of the uppermost distinct evaporite or carbonate bed of the Zechstein Group and the base of the lowest distinct sandstone of the Main Buntsandstein Formation.

As stated on page 20, the definition of the top of the Zechstein Group is somewhat ambiguous. However, by employing the qualification that the uppermost distinct evaporite or carbonate bed of the Zechstein Group must be at least 1 m thick, this ambiguity can normally be avoided.

Age – Skythian.

Reference section – Well Blijham-1 : 2898-3273 m, coord. N 53°05'41.1'', E 07°04'40.2'' (encl. 8).

Subdivision – A tripartite subdivision of the Lower Buntsandstein Formation is customarily applied, which is, from top to bottom :

		Blijham-1
Rogenstein Member	(RBSHR)	2898-3066 m
Main Claystone Member	(RBSHM)	3066-3251 m
Basal Buntsandstein Member	(RBSHB)	3251-3273 m

The *Basal Buntsandstein Member* is a succession of commonly very silty, anhydritic claystones, frequently with anhydrite stringers.

The *Main Claystone Member* consists of redbrown, silty, often anhydritic claystones. This monotonous sequence is characterized on wireline logs by a fairly monotonous gamma ray expression.

The *Rogenstein Member* is a sequence of claystones similar to those of the Main Claystone Member but containing several iron-stained oolite-beds. The base of the lowest of these beds forms the boundary with the Main Claystone Member. Three conspicuous oolite-beds situated in ap-

proximately the middle part of the Member, expressed on the available wire-line logs by three distinct readings of low gamma ray radiation and high sonic/resistivity response, are a characteristic feature.

MAIN BUNTSANDSTEIN FORMATION (RBSS)

Name – The name 'Buntsandstein' is derived from the German stratigraphic nomenclature. The interval corresponding most closely to the Main Buntsandstein Formation is, in German terminology, described as the Middle Buntsandstein. However, in Germany the top of the Middle Buntsandstein is commonly taken at the base of the Röt Evaporite, whereas the upper limit of the Main Buntsandstein Formation of The Netherlands is taken at the level of the Hardegsen Unconformity, i.e. at the base of the Solling sequence. Thus, to avoid confusion in the current nomenclature, the name Main Buntsandstein is introduced for Dutch usage.

Definition – Sequence of reddish brown sandstones, alternating with silty, often anhydritic claystones, and situated between the base of the lowest distinct sandstone bed of the Formation (on top of the Lower Buntsandstein Formation) and the base of the Solling sequence, equivalent to the level of the Hardegsen Unconformity.

The level of the Hardegsen Unconformity is marked by an overlying shale with one or more levels of high gamma-ray radiation (TRUSHEIM, 1961). Below this level, the Formation is frequently incomplete due to erosion.

Age – Skythian.

Reference section – Well Blijham-1 : 2732-2898 m, coord. N 53°05′41.1″, E 07°04′40.2″ (encl. 8).

Additional reference sections –

Well L 2-1: 3964-4205 m, coord. N 53°57′14.2″, E 04°30′46.6″ (encl. 8),

Well Eleveld-101 : 2525-2540 m, coord. N 52°57′28.0″, E 06°34′42.0″ (encl. 9).

Subdivision – The pronounced sandstone-claystone alternation of the Main Buntsandstein Formation enables a subdivision into a series of easily recognizable members, viz. :

The *Volpriehausen Sandstone Member* is a well defined sandstone unit, frequently with a distinct blocky character on the gamma ray logs.

The *Volpriehausen Clay-Siltstone Member* is a claystone body grading upwards into a siltstone. It overlies the Volpriehausen Sandstone Member with a sharp base, but its upper contact with the Detfurth Sandstone Member is a gradational one, not easy to define uniquely.

The *Detfurth Sandstone Member* usually consists of two distinct sandstone beds with an intercalated layer of reddish brown, anhydritic siltstone or silty claystone.

The *Detfurth Claystone Member* is a homogeneous, slightly silty, anhydritic claystone sequence.

The *Hardegsen Member* comprises an alternation of generally thin sandstones and very silty shales. In many areas this Member demonstrates an easily recognizable sandstone bed at its base, thus allowing for a local subdivision into :

	L 2-1
Hardegsen Claystone Member (RBSSA)	3964-4002 m
Hardegsen Sandstone Member(RBSSS)	4002-4009 m

The sandstone members of the Main Buntsandstein Formation, although well correlatable throughout most of The Netherlands, appear as thicker and more massive units towards the southern basin edge where the shaly members are generally thin and sandy. Along the basin margin proper, these shale members are barely developed and the sandstones form, in reality, one unit. In this case such a relatively massive sandstone body is denominated as the Bunter Sandstone Formation of the Bunter Group.

6.3. UPPER GERMANIC TRIAS GROUP (RN)

General – After the terrestrial sedimentary circumstances prevailing during the deposition of the Lower Germanic Trias Group, marine conditions returned to The Netherlands during the sedimentation of the Upper Germanic Trias Group. However, only occasionally open-marine deposition took place (part of the Muschelkalk Formation).

Name – The name 'Germanic Trias' is derived from the German stratigraphic nomenclature where it refers to the sedimentary sequence between the evaporites and carbonates of the Zechstein and the marine shales of the Lias. The

		Blijham-1	*L 2-1*	*Eleveld-101*
Hardegsen Member	(RBSSH)	2732-2748m	3964-4009 m	–
Detfurth Claystone Mbr.	(RBSSC)	2748-2783m	4009-4033 m	–
Detfurth Sandstone Mbr.	(RBSSD)	2783-2815m	4033-4085 m	–
Volpriehausen Clay-Siltstone Member	(RBSSP)	2815-2892m	4085-4158m	2525-2532 m
Volpriehausen Sandstone Member	(RBSSV)	2892-2898m	4158-4205m	2532-2540 m

prefix 'Upper' is applied to that part of the Germanic Trias that occurs above the so-called Hardegsen Unconformity.

Definition (text figs. 7, 8) – Group of formations composed of silty shales, evaporites, carbonates and some subordinate sandstones, and situated between the sand-shale sequence of the Main Buntsandstein Formation, or the predominantly sandy succession of the Bunter Group, and the fossiliferous shales of the Sleen Shale Formation.

Age – Skythian – Norian.

Reference section – Well L 2-1 : 2808-3964 m, coord. N 53°57′14″, E 04°30′46.6″ (encls. 9-13).

Subdivision – A distinct tripartite subdivision is recognized in the basinal development of the Upper Germanic Trias Group, viz. (from top to bottom):

Keuper Formation	(RNKP),
Muschelkalk Formation	(RNMU),
Röt Formation	(RNRØ).

Towards the basin margin the Muschelkalk and Keuper Formations remain recognizable, whereas the Röt Formation passes gradually into the sandy beds of the Bunter Group.

RÖT FORMATION (RNRØ)

Name – Name derived from the German stratigraphic nomenclature where it is applied as an alternative name for the so-called Upper Buntsandstein.

Definition – Sequence of evaporites' redbrown, silty, anhydritic claystones and occasional sandstones, and situated between the top of the sand-shale sequence of the Main Buntsandstein Formation and the base of the marls-carbonates of the Muschelkalk Formation. Within the Dutch subsoil, the Muschelkalk Formation shows a decreasing carbonate content towards the north and west, but the boundary with the Röt Formation remains discernible on wire-line logs by the lower gamma ray and higher sonic velocity response of the basal Muschelkalk compared to the claystones of the Röt Formation.

Age – Skythian – ?Anisian.

Reference section – Well L 2-1 : 3650-3964 m, coord. N 53°57′14.2″, E 04°30′46.6″ (encl. 9).

Additional reference sections – Well Eleveld–101 : 2241-2525 m, coord. N 52°57′28.0″, E 06°34′42.0″ (encl. 9);

Well K 17-1 : 1613-1807 m, coord. N 53°02′40.9″, E 03°37′05.6″ (encl. 9).

Subdivision – Throughout most of its depositional area, the Röt Formation has an evaporitic interval in its middle part, which allows for a basic threefold subdivision. In the basin centre, however, various members can be distinguished within the evaporitic series and the following subdivision is recognized:

	L 2-1	*Eleveld-101*
Upper Röt Claystone Member (RNRØU)	3650-3749 m	2241-2316 m
Upper Röt Evaporite Member (RNRØ2)	3749-3765 m	2316-2321 m
Intermediate Röt Claystone Member (RNRØM)	3765-3786 m	2321-2337 m
Main Röt Evaporite Member (RNRØ1)	3786-3929 m	2337-2447 m
Solling Claystone Member (RNRØS)	3929-3964 m	2447-2525 m

Towards the basin margin the evaporite interval cannot be subdivided, probably due to absence of the Upper Röt Evaporite Member, and there the member sequence is as follows:

		K 17-1
Upper Röt Claystone Member	(RNRØU)	1613-1709 m
Röt Evaporite Member	(RNRØE)	1709-1761 m
Solling Claystone Member	(RNRØS)	1761-1807 m

The *Solling Claystone Member* often shows a thin shale with a characteristically high gamma radiation at its base (TRUSHEIM, 1961). Within the Member occasional sand stringers occur, mainly in the lower part. Towards the basin margin these sandy intervals increase in importance and the distinction between the Solling and Hardegsen Members becomes less and less clear until both units pass into the Middle Bunter Sandstone Formation.

In southeastern Drenthe and the adjoining parts of Germany a somewhat thicker sandstone bed occurs at the base, or in the basal part of the Solling Member. As this level is gas-productive in some wells, a more detailed separate nomenclature can be applied for this area, viz.

		Eleveld-101
Upper Solling Claystone Member	(RNRØC)	2447-2513 m
Solling Sandstone Member	(RNRØB)	2513-2515 m
Lower Solling Claystone Member	(RNRØA)	2515-2525 m

The *Main Röt Evaporite Member* is usually a massive halite bed followed by a relatively thin anhydrite.

The *Intermediate Röt Claystone Member* is a reddish brown, silty, anhydritic claystone sequence separating the evaporites of the Main Röt Evaporite Member from the Upper Röt Evaporite Member.

The *Upper Röt Evaporite Member* consists of a rapid alternation of rock salt and anhydrite. From well-to-well correla-

tion it is evident that both this member and the Main Röt Evaporite Member thin and disappear towards the basin margin. It seems reasonable to assume that the Main Röt Evaporite Member extends beyond the area of the Upper Röt Evaporite as a thin halite-anhydrite sequence which passes into an anhydritic bed before total disappearance towards the basin edge. It is then described as the *Röt Evaporite Member.*

The *Upper Röt Claystone Member* is a redbrown, silty, anhydritic, sometimes slightly dolomitic claystone succession, distinguishable from the overlying Muschelkalk Formation by an often pronounced increase of carbonate content in the basal part of the latter (expressed on wire-line logs by a decrease in gamma ray response and an increase of sonic velocity readings).

MUSCHELKALK FORMATION (RNMU)

Name – Name derived from the German stratigraphic nomenclature where it is applied to the middle unit of the Germanic Trias.

Definition – Sequence of grey and variegated marls, argillaceous dolomites and limestones, anhydritic claystones as well as an intercalated rock salt series. In the eastern and central parts of The Netherlands the lower and upper limits of the Formation are marked by a relatively high carbonate content compared to the under- and overlying formations. Towards the northern and western parts of The Netherlands, especially in the offshore section, this carbonate content gradually diminishes but the boundaries are still discernible on wire-line logs.

Age – ?Anisian – Ladinian.

Reference section – Well Sleen – 4: 1376-1601 m, coord. N 52°48′30.5″, E 06°50′15″ (encl. 10).

Additional reference section – Well L 2-1 : 3368-3650 m, coord. N 53°57′14.2″, E 04°30′46.6″ (encl. 10).

Subdivision – In The Netherlands, the Formation can be subdivided into Lower, Middle and Upper Muschelkalk, following German usage (encl. 11, acc. to WOLBURG, 1969). Over large parts of the basin a rock salt layer in the Middle Muschelkalk enables a twofold subdivision of this part of the sequence. Consequently, the following nomenclature is proposed:

		Sleen-4
Upper Muschelkalk Member	(RNMUU)	1376-1420 m
Middle Muschelkalk Marl Mbr.	(RNMUA)	1420-1468 m
Muschelkalk Salt Member	(RNMUH)	1468-1480 m
Lower Muschelkalk Member	(RNMUL)	1480-1601 m

This sequence is locally incomplete due to gentle disconformities across regional swells (WOLBURG, 1969). Furthermore, in some places, the salt bed is not present, e.g., dissolved by leaching.

In the western and northern offshore areas the boundary between the Middle Muschelkalk Marl Member and the Upper Muschelkalk Member tends to become obscure, due to the diminishing carbonate content of the latter unit. For such areas, the following subdivision can be applied:

		L2-1
Muschelkalk Claystone Member	(RNMUC)	3368-3443 m
Muschelkalk Salt Member	(RNMUH)	3443-3550 m
Lower Muschelkalk Member	(RNMUL)	3550-3650 m

The *Lower Muschelkalk Member* is characterized by an appreciable carbonate content throughout The Netherlands, although it passes from marls with intercalated argillaceous dolomites and limestones (in the onshore part of the country) into calcareous claystones towards the northern and western offshore.

The *Muschelkalk Salt Member* is widely distributed throughout the basin, but it thins and disappears towards the basin margin.

The *Middle Muschelkalk Marl Member* has a relatively low carbonate content compared with that of the Lower and Upper Muschelkalk Members and normally demonstrates an appreciable anhydritic content in its basal part. Where, for practical purposes, the Muschelkalk Salt is not distinguished separately as a member, the combination is called the *Middle Muschelkalk Member* ((RNMUM) (e.g., well Sleen-4, 1420-1480 m, encl. 10).

The *Upper Muschelkalk Member* is, in the central and eastern part of The Netherlands, developed as a dolomite-limestone-marl sequence with a distinct dolomitic interval at the base. Towards the west and north the carbonate content of the Member decreases markedly, obscuring the distinction between the Middle Muschelkalk Marl Member and the Upper Muschelkalk and, in such cases, the two units are combined into the *Muschelkalk Claystone Member.*

Towards the basin margin, the equivalent of the described Muschelkalk sequence is still discernible, but a subdivision into separate members is no longer possible. Here, the Muschelkalk Formation is developed as a sequence of marls, dolomitic marls and dolomites, limited at the base by the lowest marl or carbonate bed on top of the clastics of the Bunter Group and at the top by the uppermost marl or carbonate below the claystones of the Keuper Formation. Along the basin margin regional unconformities play an important role, and render the Muschelkalk Formation a rather incomplete sequence.

KEUPER FORMATION (RNKP)

Name – Name derived from the German stratigraphic no-

menclature where it is applied to the highest unit of the Germanic Trias.

Definition – Sequence of redbrown to variegated, silty, anhydritic claystones, with intercalated anhydrite and rock salt beds. It is situated between the top of the dolomitic claysmarls of the Upper Muschelkalk Member, or the Muschelkalk Claystone Member, and the base of the marine shales of the Sleen Shale Formation. As the above lithological criteria for boundary recognition are sometimes subtle, wire-line log characteristics play an important additional role.

Age – Ladinian – Norian.

Reference section – Well L 2-1 : 2808-3368 m, coord. N 53°57′14.2″, E 04°30′46.6″ (encl. 12).

Additional reference sections – Well Emmen-7 : 1610-1740 m, coord. N 52°46′56.7″, E 06°50′37.5″ (encl. 14),

Well K 14-1 : 1623-1810 m, coord. N 53°17′15.2″, E 03°37′07.3″ (encl. 14).

Subdivision – The full Keuper sequence consists essentially of four claystone zones alternating with three anhydritic intervals (with or without rock salt beds). The boundaries between these seven members are mainly based on those wire-line log criteria that supposedly reflect lithological changes. The proposed subdivision follows broadly the one in use in Germany (encl. 13; WOLBURG, 1969).

At many places the succession is incomplete due to the presence of some gentle disconformities on regional swells. Of these, the one at the boundary between the Keuper Formation and the Sleen Shale Formation is the most important, causing absence of part, or all, of the Keuper Formation. In these areas, the Sleen Shale Formation rests unconformably on the Muschelkalk or even on the Röt Formation.

	L 2-1	*K 14-1*
Upper Keuper Claystone Member (RNKPU)	2808-2845 m	1623-1628 m
Dolomitic Keuper Member (RNKPD)	2845-2917 m	1628-1663 m
Red Keuper Claystone Member (RNKPR)	2917-2947 m	1663-1674 m
Red Keuper Evaporite Member (RNKPE)	2947-3030 m	1674-1677 m
Middle Keuper Claystone Member (RNKPM)	3030-3076 m	1677-1703 m
Main Keuper Evaporite Member (RNKPS)	3076-3247 m	1703-1738 m
Lower Keuper Claystone Member (RNKPL)	3247-3368 m	1738-1810 m

The identification of the seven units requires a careful wire-line log correlation exercise. However, for regional purposes, a more simplified subdivision may be advisable, i.e.

	L 2-1	*Emmen-7*
Argillaceous Keuper Member (RNKPC)	2808-3076 m	1610-1614 m
Main Keuper Evaporite Member (RNKPS)	3076-3247 m	1641-1670 m
Lower Keuper Claystone Member (RNKPL	3247-3368 m	1670-1740 m

The *Lower Keuper Claystone Member* is frequently an anhydritic shale with some anhydrite stringers.

The *Main Keuper Evaporite Member* consists mainly of halite alternating with anhydrite and anhydritic shales and is capped by a unit of anhydrite and anhydritic shale. Towards the basin margin it passes into an alternation of anhydrite and anhydritic shales.

The *Middle Keuper Claystone Member* consists of silty and/or anhydritic shales.

The *Red Keuper Evaporite Member* is a unit of siltstones and anhydritic shales with intercalated anhydrite beds.

The *Red Keuper Claystone Member* consists of silty shales.

The *Dolomitic Keuper Member* is a sequence of anhydritic, partly dolomitic, partly marly shales with anhydrite beds. In the eastern part of The Netherlands dolomite stringers are common, but towards the north and west the dolomitic components decrease markedly in importance.

The *Upper Keuper Claystone Member* consists of silty shales.

The presence of local unconformities within the Keuper may result in incomplete sequences in which especially the Red Keuper Evaporite Member and the Dolomitic Keuper Member may be strongly reduced or absent. Probably the depositional area of the Keuper was somewhat reduced during the sedimentation of these evaporitic members, with, on higher blocks, a tendency to non-deposition or erosion, e.g., K 14-1.

Towards the basin margin the Keuper Formation is represented by a sequence of variegated anhydritic claystones and some intercalated anhydrite beds. In this situation, a formal subdivision of the Formation is not warranted.

6.4. BUNTER GROUP (BS)

General – The Hardegsen Unconformity, which separates the Lower and Upper Germanic Trias Groups in the basin centre, cannot be recognized within the increasingly coarse clastic sequence found along the basin margin. Here, the lithostratigraphically equivalent sediments consist of a lower sand-clay alternation, or a massive sand sequence along the basin margin proper, overlain by dolomitic and anhydritic shales and marls. The lower clastic succession is described as

the *Bunter Group,* whilst the shales and marls fall under the basin margin facies of the Keuper and Muschelkalk Formations within the Upper Germanic Trias Group.

The above concept of the Bunter Group follows closely the one in use in the stratigraphic nomenclature for the British onshore, where a predominantly coarse clastic Bunter is encountered between the Zechstein evaporites-carbonates and the so-called Keuper anhydritic shales.

Name – Name derived from the British stratigraphic nomenclature where it is applied in the same manner as proposed in this paper.

Definition (text figs. 7, 8) – Sequence of coarse and fine variegated sandstones, siltstones and shales, the latter often being anhydritic and occasionally dolomitic. It is bounded at the base by the top of the uppermost carbonate of the Fringe Zechstein Formation (or, locally, by the erosion surface on top of the Limburg Group). Its top is marked by the contact with the overlying marls or carbonates of the Muschelkalk Formation.

Age – Skythian – ? Anisian.

Reference section – Well Nederweert 1 : 1870-2583 m, coord. N 51°18′41.9″, E 05°46′14.7″ (encl. 15).

Additional reference section – Well Buurmalsen-1 : 1239-1972 m, coord. N 51°54′18.8″, E 05°18′49.2″ (encl. 16).

Subdivision – In the area of the Bunter Group two belts of lithological development can be recognized : an exterior one along the basin margin proper where, in a predominantly massive sandstone succession, objective criteria for a subdivision are lacking; and an interior one where a threefold subdivision is possible into Lower, Middle and Upper Bunter Formations (approximately equivalent to the basin-centre sequence of Lower Buntsandstein, Main Buntsandstein and Röt Formations, respectively).

LOWER BUNTER FORMATION (BSLB)

Definition – Sequence of redbrown, anhydritic, silty claystones, alternating with sandstone beds. Oolite beds are common in the top part of the Formation. The Formation is situated between the top of the Upper Carbonate Member of the Fringe Zechstein Formation and the base of the sandstone sequence of the Middle Bunter Formation.

Age – Skythian.

Reference section – Well Buurmalsen-1 : 1576-1972 m, coord. N 51°54′18.8″, E 05°18′49.2″ (encl. 16).

MIDDLE BUNTER FORMATION (BSMB)

Definition – Sequence of redbrown sandstones, massive or interbedded with silty claystone beds. The Formation lies on top of the clayey beds of the Lower Bunter Formation, whilst the top is marked by the contact with the clayey and/or anhydritic beds of the Upper Bunter Formation.

Age – Skythian.

Reference section – Well Buurmalsen-1 : 1378-1576 m, coord. N 51°54′18.8″, E 05°18′49.2″ (encl. 16).

UPPER BUNTER FORMATION (BSUB)

Definition – Sequence of redbrown, anhydritic, silty claystones, often with sandstone intercalations, especially towards the top of the Formation. It is situated between the predominantly sandy beds of the Middle Bunter Formation and the marls/carbonates of the Muschelkalk Formation.

Age – Skythian – ? Anisian.

Reference section – Well Buurmalsen-1 : 1239-1378 m, coord. N 51°54′18.8″, E 05°18′49.2″ (encl. 16).

Remarks – The Upper Bunter Formation resembles, rather closely, the Röt Formation. This latter Formation is defined as the clayey-evaporitic unit that occurs directly above the so-called Hardegsen Unconformity which, as stated earlier, cannot be recognized along the basin margin. It is therefore suggested that the name Upper Bunter Formation be maintained for this situation.

7. ALTENA GROUP (AT)

General – The Triassic was brought to a close when, during the Rhaetian, a major marine incursion took place in northwestern Europe. It was the onset of a period of distinctly open-marine sedimentary conditions which persisted during the Early Jurassic and, in some areas, continued well into the Middle Jurassic. Towards the end of the Early Jurassic regressive conditions set in and a progressively shallowing basin is envisaged in which shoals and islands developed.

The sediments corresponding to this marine sequence, which in its most complete development extends in age from Rhaetian to Oxfordian, are described as the *Altena Group*. Over the whole of The Netherlands the Group is topped by an erosion surface commonly called the Mid-Kimmerian Unconformity. This unconformity is connected with Middle Jurassic, intermittent tectonic movements coupled with halokinesis of the underlying Zechstein salt. Uplift had little effect on the elongated depressions which developed adjacent to growing salt walls and most of the sedimentary sequence was here preserved.

It should be realized that the Mid-Kimmerian movements consisted of several pulses : in the northern offshore area the Bathonian-Early Callovian phase was the most important, whereas in the southern Netherlands marine sedimentation of the Altena Group continued into the Oxfordian before it was halted by Late Oxfordian movements.

The present-day distribution of the Altena Group is presented on NAM's geological map of Pre-Cretaceous (+ Upper Jurassic) formations under the heading of Lower and Middle Jurassic (HEYBROEK, 1974).

Name – The Altena Group is named after 'Het Land van Altena', which is the northern part of the Dutch province of Noord-Brabant, and where the most complete sequence of the Group has been encountered in wells.

Definition (text figs. 9, 10) – Group consisting of, in the lower part, mainly argillaceous formations with some calcareous intercalations and, in the upper part, alternating carbonates and clastic sediments. It is defined as those units occurring between the redbrown variegated, anhydritic beds of the Keuper Formation, and the regional unconformity separating this Group from the variegated clastic beds of the Niedersachsen Group (eastern Netherlands), the coarse clastics of the Delfland Group (southwestern Netherlands) or the paralic sandstones and shales of the Central Graben Group (northern Netherlands).

Age – Rhaetian-Oxfordian.

Reference section – Well Werkendam-2 : 1507-2838 m, coord. N 51°47'29.8", E 04°50'22.1" (encl. 17, 18).

Subdivision – The Altena Group comprises four formations which are, from top to bottom:

Brabant Formation	(ATBR),
Werkendam Shale Formation	(ATWD),
Aalburg Shale Formation	(ATAL),
Sleen Shale Formation	(ATRT).

SLEEN SHALE FORMATION (ATRT)

Name – Named after the municipality of Sleen which is situated in the southeastern part of the Dutch province of Drenthe.

Definition – Sequence of grey, marine, fossiliferous shales followed by brown shales (often with a considerable content of megaspores). It is situated between the reddish, anhydritic beds of the Keuper Formation and the argillaceous limestone at the base of the Aalburg Shale Formation. Generally, the Sleen Shale Formation is easily recognizable on wire-line logs by its relatively high gamma ray and low sonic velocity readings.

Age – Rhaetian.

Reference section – Well K 14-1: 1604-1623 m, coord. N 53°17'15.2", E 03°37'07.3" (encl. 14).

Subdivision – No formal subdivision of the Sleen Shale Formation is proposed, although, locally, a distinct sandstone bed within the shale sequence as described above would allow a tripartite subdivision to be made.

AALBURG SHALE FORMATION (ATAL)

Name – Named after the municipality of Aalburg in 'Het Land van Altena' (northern part of the Dutch province of Noord-Brabant).

Definition – Sequence of dark grey, calcareous, locally silty shales with occasional thin limestones. At the base is a distinct argillaceous limestone bed which marks the contact with the silty shales of the Sleen Shale Formation below. The top of the Formation is marked by the basal bituminous shales (Posidonia Shale) of the Werkendam Shale Formation.

Age – Hettangian-Pliensbachian.

Reference section – Well Werkendam-2 : 2228-2803 m, coord. N 51°47′29.8″, E 04°50′22.1″ (encl. 17).

Subdivision – On wire-line log characteristics a subdivision would be possible in some areas, but, lithologically, there are hardly any grounds available for a formal subdivision of this monotonous shale sequence. Furthermore, the regional correlation of log markers in the Aalburg Shale Formation is considered unreliable and, therefore, not to be recommended.

A lithostratigraphic subdivision may be introduced for the southern offshore of The Netherlands based on the presence of an oolite-bearing, calcareous, silty to sandy interval in the upper part of the Aalburg Shale Formation. It is probably a lateral equivalent of the sandy 'Middle Lias' (Late Pliensbachian in age) which is present in southern England. Lack of sufficient data prevents a formal name from being assigned to this unit.

Biostratigraphically, the Aalburg Shale Formation can be subdivided into Lias α, β, γ and δ. Correlation based upon these foraminiferal-ostracodal units has proved to be satisfactory for regional studies, both in Germany and The Netherlands (KLINGLER, 1962).

WERKENDAM SHALE FORMATION (ATWD)

Name – Named after the municipality of Werkendam in 'Het Land van Altena' (northern Noord-Brabant).

Definition – Sequence of grey, slightly marly shales, with a dark grey to black bituminous shale unit at the base. Towards the middle of the section a more calcareous, silty to sandy interval occurs, developed occasionally into silt- or sandstone beds. The Formation is limited at its base by the lower limit of the afore mentioned bituminous shale and at the top by the base of the marl-limestone sequence of the Brabant Formation.

Age – Toarcian-Bajocian.

Reference section – Well Werkendam-2 : 1746-2228 m, coord. N 51°47′29.8″, E 04°50′22.1″ (encl. 18).

Subdivision – Four units of member status are recognized in the Werkendam Shale Formation, which are from top to bottom :

		Werkendam-2
Upper Werkendam Shale Mbr.	(ATWDU)	1746-1953 m
Middle Werkendam Member	(ATWDM)	1953-2007 m
Lower Werkendam Shale Mbr.	(ATWDL)	2007-2205 m
Posidonia Shale Member	(ATWDP)	2205-2228 m

The *Posidonia Shale Member* is a dark grey to black bituminous shale unit, which on wire-line logs is recognized by its high gamma ray and resistivity readings. Minor bituminous beds occur above this Member, but are included in the succeeding unit. The Posidonia Shale Member is a very marked layer occurring throughout The Netherlands and is generally recognizable as a good reflection horizon on seismic profiles.

The *Lower Werkendam Shale Member* is a grey, occasionally silty shale sequence, often with characteristic clay-ironstone concretions and/or iron-ooliths. Its top is marked by the base of the more calcareous, silty to sandy beds of the overlying member.

The *Middle Werkendam Member* consists of a marly, silty shale/calcareous siltstone-sandstone alteration, which is recognizable on wire-line logs by a marked increase in sonic velocity and resistivity values compared to those of the Upper and Lower Werkendam Shale units.

The *Upper Werkendam Shale Member* is a grey, homogeneous, somewhat marly shale, with a uniformly low sonic velocity and resistivity expression on wire-line logs.

BRABANT FORMATION (ATBR)

Name – Named after the Dutch province of Noord-Brabant, where this formation is found in its most complete development.

Definition – Sequence of limestones, marls and shales, which are often sandy, and with an increasing sand content towards the top where some calcareous sandstone beds occur. Its base is marked by the contact of marl or limestone with the shales of the Upper Werkendam Member, whilst the top is a regional unconformity, followed by the sand-shale sequence of the Delfland Group.

Age – Bajocian-Oxfordian.

Reference section – Well Oisterwijk-1 : 1787-2154 m, coord. N 51°35′32.7″, E 05°10′56.2″ (encl. 18).

Additional reference section – Well Werkendam-2 : 1507-1746 m, coord. N 51°47′29.8″, E 04°50′22.1″ (encl. 18).

Subdivision – The Brabant Formation is recognized as an erosional remnant and occupies a small area of the Roer Valley Graben in a belt from 'Het Land van Altena' to approximately the well Veldhoven-1 in the southeastern part of Noord-Brabant. The marly, sandy, fossiliferous and sometimes oolitic limestones together with the intervening shales were laid down in a shallow open-marine environment with, locally, shoals above surf base. Throughout the small area of the Brabant Formation, local facies changes and varying thicknesses of the units within the succession are indicative of

such a shallow marine environment. Despite this, the Brabant Formation can be subdivided into seven members. These are based upon the presence of four intervals consisting of sandy limestone/calcareous sandstone beds which are separated by three units of predominantly sandy marl. From top to bottom they are :

	Oisterwijk-1	*Werkendam-2*
Oisterwijk Limestone Member (ATBRØ)	1787-1808 m	(absent)
Upper Brabant Marl Member (ATBRU)	1808-1898 m	1507-1542 m
Upper Brabant Limestone Mbr. (ATBR3)	1898-1929 m	1542-1577 m
Middle Brabant Marl Member (ATBRM)	1929-1995 m	1577-1593 m
Middle Brabant Limestone Mbr. (ATBR2)	1995-2035 m	1593-1622 m
Lower Brabant Marl Member (ATBRL)	2035-2095 m	1622-1665 m
Lower Brabant Limestone Mbr. (ATBR1)	2095-2154 m	1665-1746 m

The boundaries between the various members are based on differences in carbonate/sand content as expressed on wireline logs, especially in sonic velocity and resistivity. Due to local facies changes these boundaries are certainly not synchronous.

The *Lower Brabant Limestone Member* often begins with a marl interval.

The *Lower Brabant Marl Member* is developed as a sandy marl, which is often ferruginous at the top.

The *Middle Brabant Limestone Member* is a very sandy fossiliferous limestone, with some intercalated sandy marls.

The *Middle Brabant Marl Member* is a sandy marl unit, often ferruginous towards the base. This member is sometimes strongly reduced in thickness, thus hampering the distinction between the Middle and Upper Brabant Limestone Members.

The *Upper Brabant Limestone Member* is a calcareous unit characterized by a very high sand content.

The *Upper Brabant Marl Member* is a unit of sandy marls with, especially in the lower part, a relatively high sand content or even intercalated sandstones.

The *Oisterwijk Limestone Member* consists of rather massive, oolitic algal limestones.

8. CENTRAL GRABEN, SCRUFF, NIEDERSACHSEN AND DELFLAND GROUPS

8.1. INTRODUCTION

During the Middle Jurassic much of The Netherlands was subjected to strong but intermittent tectonic movements. As a consequence an unstable system of basins and swells developed across the area with the result that uplift and erosion in some areas took place as early as the Bathonian and continued sporadically until the Kimmeridgian, whereas in the southern part of the country sedimentation of the Altena Group continued until as late as the Oxfordian. In the northern offshore sedimentation had already resumed during the Callovian.

The sedimentary basins recognizable from the later Jurassic period are :

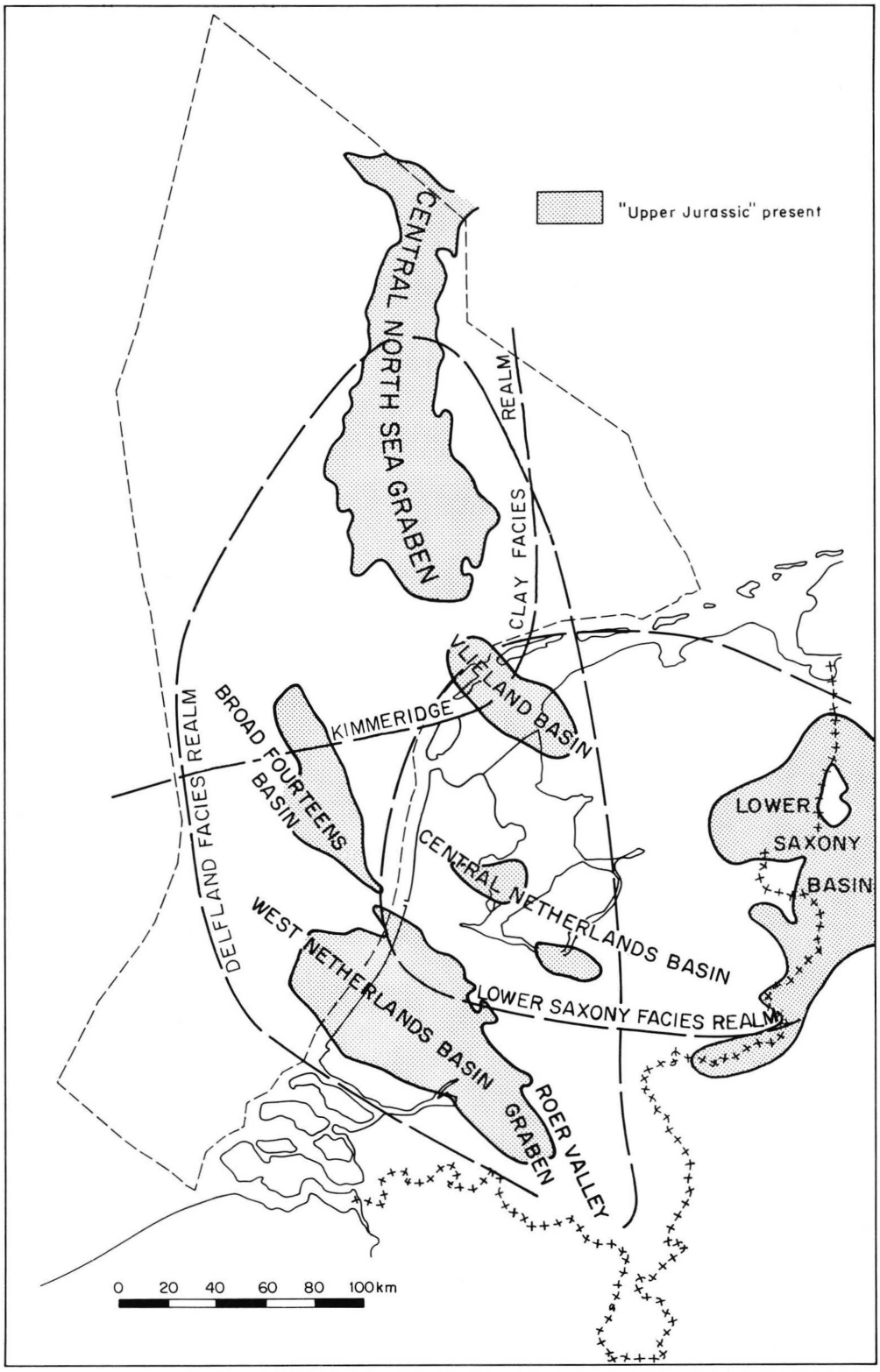
the Lower Saxony Basin,
the Roer Valley Graben – West Netherlands Basin,
the Central Netherlands Basin,
the Broad Fourteens Basin,
the Vlieland Basin,
the Central North Sea Graben (text fig. 3).

In each basin deposition was strongly influenced by local tectonic movements, often related to halokinesis of the underlying Zechstein salts.

In the Dutch area three depositional sequences are distinguished in the 'Upper Jurassic' succession, each differing basically from the others, i.e.

1. the Central Graben Group – Scruff Group of the Central North Sea Graben,
2. the Niedersachsen Group from the Lower Saxony Basin,
3. the Delfland Group in the southwestern basins.

These three sequences, although lithologically rather dissimilar, correspond in their delimitation, i.e. between the unconformities at the top of the Altena Group and at the base of the Rijnland Group. Regionally these successions cannot be delimited distinctly as they interfinger and overlap in broad transition zones (see text fig. 3). For example, the depositional pattern in the Vlieland and the Central Netherlands Basins followed initially that of the Niedersachsen



Text Figure 3. Geographic distribution of the "Upper Jurassic"

Group and later that of the Delfland Group. Consequently, the nomenclature of these transitional sequences, especially for those of the Vlieland and the Central Netherlands Basins, will be a mixture of the standard successions described in this chapter. An exception has been made for the nomenclature of the Broad Fourteens Basin and the Central North Sea Graben, since the stratigraphic relationships between the successions in both basins are at present not well understood, although interfingering relationships are seemingly evident. The nomenclatures for both these basins are therefore separate ones.

8.2. CENTRAL GRABEN GROUP (CG)

General – In the Dutch part of the Central North Sea Graben sedimentation resumed, after the period of uplift and erosion of the Mid-Kimmerian movements, with the deposition of a paralic sequence: the *Central Graben Group.*

The structure and sedimentary sequence of the Central North Sea Graben were described in 1975 by HEYBROEK. Subsequent drilling activities have yielded much new data which justify a revision, especially on the dating of the Middle and Late Jurassic events.

Name – Name derived from the Central North Sea Graben to which the Group is confined.

Definition (text figs. 9, 10) – Group of formations deposited in a predominantly paralic environment and consisting of shales, sandstone beds and some coal seams. This succession overlies unconformably the Altena Group and is limited at its top by the marine shales of the Scruff Group.

Age – Callovian-Oxfordian.

Reference section – Well F 3-3: thickness 1105 m (along hole), coord. N 54°50'45.5'', E 04°42'29.3'' (encl. 21).

Subdivision – In the type area three formations are distinguished, which are from top to bottom:

Upper Graben Sand Formation	(CGUS),
Middle Graben Shale Formation	(CGMS),
Lower Graben Sand Formation	(CGLS).

LOWER GRABEN SAND FORMATION (CGLS)

Name – Named after the Central North Sea Graben.

Definition – Sequence of pale greyish brown, very fine-grained, well sorted sandstones, occurring in beds of generally less than 10 m thickness, with intercalations of greybrown silty and variably sandy shales. Lignite particles are abundant and coal seams are occasionally present.

The Formation rests unconformably on the shaly sequence of the Aalburg Shale Formation or the Werkendam Shale Formation, both of which are formations in the Altena Group. It is conformably overlain by the silty shales of the Middle Graben Shale Formation.

Age – Callovian-Early Oxfordian.

Reference section – Well F 3-3: thickness 562 m (along hole), coord. N 54°50'45.5'', E 04°42'29.3'' (encl. 21).

MIDDLE GRABEN SHALE FORMATION (CGMS)

Name – Named after the Central North Sea Graben.

Definition – Sequence of dark grey, locally very silty shales, with common detrital carbonaceous material and some coal seams, of which 2 or 3 in the lowermost part of the Formation are seemingly persistent on a regional scale. The Formation is very variable in thickness but is found in most of the Central North Sea Graben. It is situated between the very fine-grained, mainly lignitic sands of the Lower and Upper Graben Sand Formations, respectively.

Age – Early Oxfordian.

Reference section – Well F 3-3: thickness 420 m (along hole), coord. N 54°50'45.5'', E 04°42'29.3'' (encl. 21).

UPPER GRABEN SAND FORMATION (CGUS)

Name – Named after the Central North Sea Graben.

Definition – Sequence of two coarsely clastic intervals separated by a silty-sandy shale sequence. The sandstones are greyish brown, very fine-grained, well sorted and contain abundant lignite particles. The sequence succeeds the silty shales of the Middle Graben Shale Formation and is followed by the marine shales of the Kimmeridge Clay Formation. The Formation is known only from the area adjacent to the reference section.

Age – Late Oxfordian.

Reference section – Well F 3-3: thickness 123 m (along hole), coord. N 54°50'45.5'', E 04°42'29.3'' (encl. 21).

8.3. SCRUFF GROUP (SG)

General – During the Late Oxfordian the deposition of the Central Graben Group was halted when marine conditions spread southwards and the holomarine shales of the Kimmeridge Clay Formation were laid down. Throughout this Late Oxfordian-Berriasian period paralic conditions prevailed directly to the south of the Central North Sea Graben and occasionally extended northwards into the depositional area of the Kimmeridge Clay Formation. The corresponding sediments are here described as the *Scruff Group.*

Name – Named after the offshore Upper Scruff bank, which lies adjacent to the reference well F 3-3.

Definition (text figs. 9, 10) – Group of formations situated between the carbonaceous, very fine sandstones and shales of the Central Graben Group and the basal, generally glauconitic sediments of the Rijnland Group.

Age – Late Oxfordian-Berriasian.

Reference section – Well F 3-3: thickness 767 m (along hole), coord. N 54°50′45.5″, E 04°42′29.3″ (encl. 22).

Subdivision – Within the Scruff Group two formations are distinguished, viz.

Puzzle Hole Formation (SGDF),
Kimmeridge Clay Formation (SGKI).

KIMMERIDGE CLAY FORMATION (SGKI)

Name – Name derived from the British stratigraphic nomenclature where it is applied to similar clayey deposits which are widespread in the general North Sea region.

Definition – In the northern part of the Central North Sea Graben, the Formation is a sequence of medium to dark olive-grey, generally silty shales with numerous thin dolomite streaks (expressed on wire-line logs with a characteristic peaked appearance). Fossil fragments are common in lenses; lignitic particles occur frequently. Towards the south, the carbonate streaks and the olive hue gradually disappear. Furthermore, the shales become increasingly silty to sandy which probably reflects deposition nearer to the coast. Its base is characterized by holomarine shales on top of the paralic, predominantly carbonaceous shales and/or sandstones of the Central Graben Group. At its top the Formation is unconformably overlain by the basal, generally glauconitic deposits of the Rijnland Group. Laterally, towards the south, the Formation interfingers with the Puzzle Hole Formation.

Age – Late Oxfordian-Berriasian.

Reference section – Well F 3-3: thickness 767 m (along hole), coord. N 54°50′45.5″, E 04°42′29.3″ (encl. 22).

Subdivision – In the southern part of the Central North Sea Graben, a major tongue of the Puzzle Hole Formation divides the Kimmeridge Clay Formation into two parts, as exemplified by the well F 11-2 (coord. N 54°24′54.6″, E 04°27′38.8″ (encl. 23)).

	F 11-2
Upper Kimmeridge Clay Member (SGKIU)	2035-2149 m
Lower Kimmeridge Clay Member (SGKIL)	2397-2520 m

The *Lower Kimmeridge Clay Member* is of Late Oxfordian age.

The *Upper Kimmeridge Clay Member* is of Kimmeridgian-Berriasian age and is, at least in part, probably the lateral equivalent of the Fourteens Clay Formation of the Broad Fourteens Basin.

PUZZLE HOLE FORMATION (SGDF)

Name – Named after the Puzzle Hole bank in the Dutch northern offshore.

Definition – Sequence of light brownish grey silty claystones and argillaceous siltstones with common lignitic material. Throughout the Formation thin sandstone beds and argillaceous lignite layers occur although the amounts vary from well to well. North of the reference section the Formation shows a decreasing silt content and an increasing amount of lignite.

The Puzzle Hole Formation forms a silty-sandy tongue within the Kimmeridge Clay Formation and, consequently, its lower and upper limits are marked by the contact of these silty beds with the shales of the Kimmeridge Clay Formation. Furthermore, northwards it gradually passes laterally into the Kimmeridge Clay Formation. In the extreme southern part of the Central North Sea Graben it overlies directly the Altena Group. At many places within the Graben the Upper Kimmeridge Clay is absent due to erosion, and the Puzzle Hole Formation is covered unconformably by the basal beds of the Rijnland Group.

Age – Early Kimmeridgian.

Reference section – Well F 11-2: 2149-2397 m, coord. N 54°24′54.6″, E 04°27′38.8″ (encl. 23).

8.4. NIEDERSACHSEN GROUP (ND)

General – Late Jurassic-earliest Cretaceous sedimentation occurred in the so-called Lower Saxony Basin which extended from the eastern part of The Netherlands eastwards over approximately the whole of Western Germany (where it is known as the 'Niedersächsisches Becken'). The formations which correspond to the sedimentary regime of the western fringes of the Lower Saxony Basin are assembled in the *Niedersachsen Group.*

Up till now Dutch geologists working on the eastern Netherlands have applied the nomenclature as established in Germany by authors such as KLINGLER, MALZ & MARTIN (1962) and BISCHOFF & WOLBURG (1963). It is felt, however, that this German nomenclature refers more to the basin centre sequence than to the Dutch development, which is one of a basin margin with its corresponding extreme reductions of the succession, especially in the lower part. The subdivision, as presented here, follows basically the one published by 'T HART (1969) who attempted to combine lithological, palaeontological and wire-line log characteristics. In the present scheme lithology and correlated log expressions are stressed.

The approximate chronostratigraphic parallelisation of the Dutch and German subdivisions reads as follows:

In the Central Netherlands and Vlieland Basins the rock sequences are in the lower part similar to the lower portion of the Niedersachsen Group, but the upper sections resemble the Delfland Group more closely (text fig. 3). In the Vlieland Basin volcanic rocks of similar age are treated as the Zuidwal Volcanic Formation.

Name – Named after the German area of Niedersachsen.

Definition (text figs. 9, 10) – Group of formations with a predominant clayey lithology, but also including limestones and evaporites in the lower part. The Group rests unconformably on the Altena Group (or older sediments) and is unconformably overlain by the sands or clays of the Rijnland Group. It is completely developed only in the eastern Netherlands (western margin of the Lower Saxony Basin). It also occurs in the Central Netherlands and Vlieland Basins, where it is conformably overlain by the Delfland Group.

Age – Middle Kimmeridgian-Berriasian/? Early Valanginian.

Reference section – Well Schoonebeek-197: 944-1590 m, coord. N 52°38′58″, E 07°02′34.4″ (encl. 19).

THE NETHERLANDS		*GERMANY*	
Coevorden Fm.	Upper Coevorden Clay Member Middle Coevorden Clay Member Lower Coevorden Clay Member		*Wealden* (= Bückeberg Fm.)
Weiteveen Fm.	Serpulite Member	Serpulite	*Obermalm* (= Münder Fm.)
	Upper Weiteveen Marl Member Upper Weiteveen Evap. Member Lower Weiteveen Marl Member	Obere Münder Mergel	
	Lower Weiteveen Evap. Member	Mittlere Münder Mergel Untere Münder Mergel Eimbeckhauser Plattenkalk	
	Basal Weiteveen Clastic Member	Gigas Schichten	
		Oberes Kimmeridge	

Subdivision – In the Lower Saxony Basin, two formations are recognized which are, from top to bottom:

Coevorden Formation (NDCF),
Weiteveen Formation (NDWF).

The volcanic rocks which occur in the Vlieland Basin within the Niedersachsen Group are distinguished as the

Zuidwal Volcanic Formation (NDVØ).

WEITEVEEN FORMATION (NDWF)

Name – Named after the village Weiteveen, municipality of Schoonebeek, in southeastern part of the province of Drenthe.

Definition – This sequence has a variable thickness, and was laid down in subembayments along the western margin of the Lower Saxony Basin. When in reduced thickness, i.e. laid down on swells, it consists of basal, generally coarse to conglomeratic clastics, followed by anhydritic, marly shales with limestone intercalations. In the depocentres intercalated anhydrite and other evaporite beds also occur.

It overlies unconformably the Altena Group or older sediments. Its upper boundary with the Coevorden Formation is marked by a characteristic wire-line log marker, corresponding to a conspicuous shale break in a clayey-marly interval with limestones (see encl. 19).

Age – Kimmeridgian-Late Portlandian/? Berriasian ('T HART, 1969; KEMPER, 1976).

Reference section – Well Schoonebeek-197: 1230-1590 m, coord. N 52°38'58'', E 07°02'34.4'' (encl. 19).

Subdivision – The subdivision, as presented here, applies in essence only to the Schoonebeek area, where a thick sequence of this Formation was laid down in a subembayment of the Lower Saxony Basin known as the 'Meppener Bucht' (MEYER, 1969). Correlations of these members to units in other areas, where the Formation is generally reduced in thickness, is hazardous and not recommended.

The proposed scheme reads as follows (from top to bottom):

		Schoonebeek-197
Serpulite Member	(NDWFF)	1230-1330 m
Upper Weiteveen Marl Member	(NDWFE)	1330-1358 m
Upper Weiteveen Evaporite Member	(NDWFD)	1358-1428 m
Lower Weiteveen Marl Member	(NDWFC)	1428-1470 m
Lower Weiteveen Evaporite Member	(NDWFB)	1470-1567 m
Basal Weiteveen Clastic Member	(NDWFA)	1567-1590 m

The *Basal Weiteveen Clastic Member* is a sequence of conglomerates, sandstones and shales, transgressively overlying the Altena Group or older sediments. Its top is marked by the lowest distinct occurrence of anhydrite or limestone beds within the sequence of the Weiteveen Formation, which also coincides with the disappearance of the variegated colours that distinguish this Member. Usually the Member is barren of fossils, but occasionally some fossils typical for the Middle Malm (in the German sense, i.e. approximately Kimmeridgian) are found. It is assumed that the unit is time-transgressive, marking the onset of Late Jurassic sedimentation in the eastern Netherlands.

The *Lower Weiteveen Evaporite Member* consists of an alternation of dolomitic anhydritic shales, anhydrites, halites and limestones. Over contemporaneous highs the halite layers thin and disappear, accompanied by a marked decrease of the anhydrite content. The lower limit of the Member is taken at the base of the lowest limestone or anhydrite bed on top of the Basal Weiteveen Clastic Member.

The *Lower Weiteveen Marl Member* is a predominantly marl sequence, characterized on wire-line logs by relatively low resistivity and high gamma ray readings, in comparison with the under- and overlying units.

The *Upper Weiteveen Evaporite Member* is characterized by a high anhydrite and halite content, with the corresponding relatively low gamma ray response on wire-line logs.

The *Upper Weiteveen Marl Member* is a marly shale unit with some limestone intercalations and anhydrite beds. These interbeds increase towards the top and mark the transition into the next higher unit.

The *Serpulite Member* is a limestone-rich shale interval. Its top is marked by a conspicuous shale break at the base of the Coevorden Formation. In German literature this shale is taken as coinciding with the palaeontologically marked base of the so-called Germanic Wealden.

COEVORDEN FORMATION (NDCF)

Name – Named after the town of Coevorden in the southeastern part of the Dutch province of Drenthe.

Definition – Sequence of marly claystones with occasional limestone beds, notably in its basal part. It is located between the shale-marl-evaporite-limestone succession of the Weiteveen Formation and the basal, generally glauconitic beds of the Rijnland Group.

Age – Berriasian-? earliest Valanginian. (The described sequence corresponds to the so-called Germanic Wealden for which the age attribution is controversial in literature. Latest publications suggest an age range as above; KEMPER, 1973, 1976).

Reference section – Well Schoonebeek-197: 944-1230 m, coord. N 52°38'58'', E 07°02'34.4'' (encl. 19).

Subdivision – On palaeontological evidence the corresponding sequence in NW Germany has been subdivided into Wealden-1 to -6 (WICK & WOLBURG, 1962). This subdivision is, however, not recognizable in the lithological expression of the Coevorden Formation.

On account of the differences in lime content of this Formation a tripartite subdivision is possible, viz.

	Schoonebeek-197
Upper Coevorden Clay Member	(NDCFU) 944-1041 m
Middle Coevorden Clay Member	(NDCFM)1041-1126 m
Lower Coevorden Clay Member	(NDCFL) 1126-1230 m

The *Lower Coevorden Clay Member* is characterized by a very calcareous basal part (with limestone intercalations), while its upper part has a relatively low calcareous content. Its base, on top of the Serpulite Member of the Weiteveen Formation, is marked by a distinctive shale break in a marly-limestone sequence. The top is taken at the base of an interval with a distinct increase in lime content (with a corresponding increased resistivity reading on wire-line logs).

The *Middle Coevorden Clay Member* is an interval of calcareous claystones.

The *Upper Coevorden Clay Member* is a section of only slightly calcareous claystones. On wire-line logs it can be distinguished from the Middle Coevorden Clay Member by its relatively low resistivity expression.

ZUIDWAL VOLCANIC FORMATION (NDVØ)

Name – Named after the Zuidwal gas discovery in the Dutch Waddenzee.

Definition – In the Vlieland Basin, notably in the area of Petroland's Zuidwal gas discovery, eroded Upper Germanic Trias sediments are unconformably overlain by volcanic rocks of the Zuidwal Volcanic Formation. This unit is succeeded by the clays of the Coevorden Formation, or by the basal sandy beds of the Rijnland Group. These rocks consist of basaltic breccias and tuffs (COTTENÇON ET AL., 1975).

Age – Probably Berriasian (reported as probably Purbeckian by COTTENÇON ET AL., 1975).

Reference section – Well Zuidwal-1 : 1944-3002 m, coord. N 53°11'14.7'', E 05°09'19.5'' (see COTTENÇON ET AL., figs. 1, 4).

8.5. DELFLAND GROUP (DF)

General – After the erosion period which was brought about by the Mid-Kimmerian movements, fluviatile to deltaic sedimentation prevailed over the western and central Netherlands. The corresponding sediments are assembled in the *Delfland Group*, which is approximately time-equivalent to the Niedersachsen and Scruff Groups.

In the Roer Valley Graben, the West Netherlands Basin and the main part of the Broad Fourteens Basin the Delfland Group lies between the marine sediments of the Altena and Rijnland Groups, respectively. However, in the Central Netherlands and Vlieland Basins the Group overlaps sediments assigned to the Niedersachsen Group, whilst in parts of the Central North Sea Graben and the Broad Fourteens Basin it appears to interfinger with the marine Kimmeridge Clay Formation of the Scruff Group. In the latter case too few data are available to understand fully the stratigraphic relationships of these sequences, and, therefore, a separate nomenclature is maintained for these two areas:

a. the deltaic-fluviatile sediments in the Central North Sea Graben are described as the Puzzle Hole Formation of the Scruff Group,

b. the marine clays, intercalated in the Delfland Group in the northern part of the Broad Fourteens Basin, are included as the Fourteens Clay Formation (fig. 9).

Name – Named after the polder authority of Delfland in the province of Zuid-Holland.

Definition (text figs. 9, 10) – Sequence of rapidly alternating paralic sands and shales, with some coal beds and with common lignitic matter. Towards the basin centre there is a major intercalation of marine clays. In the type area, the Delfland Group is unconformable over the Altena Group, whereas in the Central Netherlands and Vlieland Basins it rests conformably upon the restricted-marine sediments of the Niedersachsen Group. In all areas, it is followed unconformably by the Rijnland Group, which usually has a glauconitic sandy basal unit.

Age – Kimmeridgian-Berriasian (-? Early Valanginian). The age of the Delfland Group is controversial due to the extreme paucity of age-diagnostic fossils. It rests unconformably upon Oxfordian deposits in the Roer Valley Graben. It is followed, again unconformably, by the Late Valanginian beds of the Rijnland Group so that the top part might be as young as Middle Valanginian. However, some authors maintain that in a basin-margin position the Delfland Group might be as young as Barremian, when its upper part would represent the fluviatile equivalent of the marine beds of the Rijnland Group which are in a more basinal position (e.g., HAANSTRA, 1963).

Reference section – Well Nieuwerkerk-1 : 968-1942 m, coord. N 51°57'00.2'', E 04°37'32.4'' (encl. 20).

Additional reference section – Well K 15-1: 1559-2270 m, coord. N 53°13'28.2'', E 03°53'47.6'' (encl. 20).

Subdivision – In the whole of the Roer Valley Graben, the West Netherlands Basin and the southern part of the Broad Fourteens Basin the Delfland Group consists of a monotonous sequence of rapidly alternating sands and clays which, for practical purposes, have not been subdivided into units of formational rank, although the introduction of a *Roer Valley Graben Formation* can be considered. In the northern part of the Broad Fourteens Basin, a tripartite subdivision is possible into (from top to bottom):

Upper Delfland Formation (DFUP),
Fourteens Clay Formation (DFFC),
Lower Delfland Formation (DFLØ).

LOWER DELFLAND FORMATION (DFLØ)

Name – As for Delfland Group.

Definition – Sequence of rapidly alternating sands and clays, with common lignitic matter, contained between the erosional surface on top of the Altena Group and the base of the marine clays of the Fourteens Clay Formation.

Age – Early Kimmeridgian.

Reference section – Well K 15-1: 2110-2270 m, coord. N 53°13'28.2'', E 03°53'47.6'' (encl. 20).

FOURTEENS CLAY FORMATION (DFFC)

Name – Named after the Broad Fourteens, an offshore shoal west of the Dutch province of Noord-Holland.

Definition – Sequence of predominantly greenish grey, silty, slightly marly clays, with some intercalated thin fossiliferous limestones. The Formation is contained between the sand-clay sequences of the Lower and Upper Delfland Formations.

Age – Late Kimmeridgian.

Reference section – Well K 15-1: 1833-2110 m, coord. N 53°13'28.2'', E 03°53'47.6'' (encl. 20).

UPPER DELFLAND FORMATION (DFUP)

Name – As for Delfland Group.

Definition – Sequence of rapidly alternating clays and sands, with common lignitic matter. Its base overlies the marine clays of the Fourteens Clay Formation, whilst its top is marked by the base of the glauconitic sands of the Rijnland Group.

Age – Latest Kimmeridgian-Berriasian(-? Early Valanginian).

Reference section – Well K 15-1: 1559-1833 m, coord. N 53°13'28.2'', E 03°53'47.6'' (encl. 20).

9. RIJNLAND AND CHALK GROUPS

9.1. INTRODUCTION

At the beginning of the Cretaceous (Berriasian) paralic conditions prevailed over most of The Netherlands, e.g., Delfland Group of the Roer Valley Graben, the West Netherlands Basin, Central Netherlands Basin and Broad Fourteens Basin, and the Coevorden Formation of the Lower Saxony Basin. It is assumed that a general uplift of the region, which began in the latest Jurassic, reached its maximum during the late Berriasian-early Valanginian, causing the removal of much of the paralic Delfland-Coevorden sediments from the highs and basin edges, whilst leaving the sedimentary sequences in the basins proper intact.

During the Valanginian sedimentation resumed over most of the area, but now under a fully marine regime. This major Cretaceous transgression followed the pre-existing pattern of basins and highs by ingressing first into the basin centres and gradually engulfing the highs. The oldest of these transgressive beds can be dated as Middle Valanginian.

Marine sedimentation continued during the whole Cretaceous, although within the sedimentary succession several local and some regional hiatuses are recognized, being the

result of the interplay of sealevel oscillations and continuing tectonic movements in the basins and highs (HEYBROEK, 1974).

The corresponding sedimentary sequence is clearly subdividable into two groups, viz.

the *Rijnland Group,* mainly of argillaceous nature and essentially of an Early Cretaceous age, and

the *Chalk Group,* composed in the main of a monotonous chalk succession and essentially of Late Cretaceous age but locally extending into the Early Paleocene (Danian).

Over much of the country, these two groups demonstrate great thicknesses (up to several thousands of metres) whilst some of the units of lower rank are equally characterized by thick, monotonous lithologies. To gain a finer subdivision, micropalaeontologically defined intervals, supplemented locally by wire-line log correlations, are successfully applied.

9.2. RIJNLAND GROUP (KN)

Name – Named after the polder authority Rijnland in the Dutch province of Zuid-Holland.

Definition (text figs. 11, 12) – Group of argillaceous formations which may contain sandstone beds at the base and, locally, similar coarse clastic intercalations at higher levels contiguous with the basin margin. It follows the Delfland-Scruff-Niedersachsen sequences when encountered in succession, but is often located between older formations and the base of the chalky carbonates of the Chalk Group. Along the southern margin of the West Netherlands Basin its top is marked by the base of greensands interpreted as the basal beds of the Chalk Group.

Age – Middle Valanginian-Albian (locally earliest Cenomanian).

Reference section – Well Vlieland Oost-1: 1522-2246 m, coord. N 53°17′22.3″, E 05°04′17.7″ (encl. 24).

Subdivision – Two formations are distinguished: the (lower) Vlieland Formation, which is of an argillaceous-sandy nature, and the (upper), essentially marly Holland Formation.

VLIELAND FORMATION (KNNC)

Name – Named after the Dutch Wadden island of Vlieland, where the reference well is located.

Definition – Sequence of marine, grey to brownish grey, slightly marly shales, with, locally, basal sandstone beds as well as higher sandstone intercalations along the basin margin. The Formation is limited at the base by the top of the Niedersachsen-Delfland-Scruff Groups when encountered in succession but it often rests on older formations, whilst its top is formed by the base of the marls or marly, bituminous clays of the Holland Formation. This upper boundary is usually characterized on wire-line logs by a change to a lower gamma ray response and increased resistivity and velocity readings. It often marks a disconformity within the sequence.

Age – Middle Valanginian-Barremian.

Reference section – Well Vlieland Oost-1 : 1650-2246 m, coord. N 53°17′22.3″, E 05°04′17.7″ (encl. 24).

Additional reference sections (for the Vlieland Shale Member) – Well Ruinen-1 : 848-956 m, coord. N 52°44′10.0″, E 06°27′12.8″ (encl. 26).
Well Berkel Schiebroek-2 : 1115-1483 m, coord. N 51°57′54.1″, E 04°28′03.0″ (encl. 25).

Subdivision – In many parts of The Netherlands a twofold subdivision is applicable, viz.

		Vlieland Oost-1
Vlieland Shale Member	(KNNCM)	1650-2200 m
Vlieland Sandstone Member	(KNNCZ)	2200-2246 m

The *Vlieland Sandstone Member* forms the transgressive basal section of the Vlieland Formation and, consequently, its age may vary according to the emplacement of sedimentation. Most frequently, it consists of fine- to medium-grained argillaceous, glauconitic sandstones although locally it can grade into conglomeratic sandstones. Bioturbation is a common feature, shell fragments and lignite particles are often present. Frequently it shows a coarsening-upward sequence, or a succession of such sequences (COTTENÇON ET AL., 1975). These beds are interpreted as barrier sands, partly reworked into transgressive sheet sands.

The *Vlieland Shale Member* is a dark brownish grey to grey, slightly marly shale.

In the West Netherlands Basin a number of sandstone tongues penetrate the Vlieland Shale Formation from the south, resulting in a succession of alternating sand and shale beds, and distinguished as (from top to bottom):

De Lier Sand-Shale Member (KNNCL)
ref. well Eemhaven-1: 1676-1759 m, coord. N 51°53′26.2″, E 04°24′21.5″ (encl. 26)
Eemhaven Shale Member (KNNCU)
ref. well Eemhaven-1 : 1759-1778 m (encl. 26)
IJsselmonde Sandstone Member (KNNCY)
ref. well Ridderkerk-2: 1034-1216 m, coord. N 51°53′11.4″, E 04°34′17.9″ (encl. 26)
IJsselmonde Shale Member (KNNCA)
ref. well Ridderkerk-2: 1216-1234 m (encl. 26)

Berkel Sandstone Member (KNNCB)
ref. well Berkel Schiebroek-2: 1483-1586 m, coord. N 51°57′54.1″, E 04°28′03.0″ (encl. 25).
Berkel Sand-Shale Member (KNNCC)
ref. well Berkel Schiebroek-2 : 1586-1695 m (encl. 25)
Rijswijk Sandstone Member (KNNCR)
ref. well De Lier-40 : 1928-1995 m, coord. N 51°58′57.7″, E 04°13′23.3″ (encl. 25)

All of these sandstone tongues pinch out into the Vlieland Shale Member towards the north. They form E-W oriented sandstone bodies along the southern basin margin. Each younger tongue is found further towards the south compared to the previous one, thus following the gradual transgression of the Early Cretaceous sea. Consequently, hardly any well shows all sandstone tongues in one section.

Separate names are given to the shale bodies which are intercalated between these sandstone members. Where such shales are located between the base of the Holland Formation and the uppermost named sandstone tongue, the shale body is described as the Vlieland Shale Member (e.g., Berkel Schiebroek-2, encl. 25). In the West Netherlands Basin the Vlieland Shale Member as well as the other named shale tongues show a considerable sand-silt content compared to the reference section in well Vlieland Oost-1.

The *Rijswijk Sandstone Member* is a massive sandstone sequence with only a few minor shale intercalations. It is fine-to medium-, occasionally coarse-grained, frequently containing shell fragments, lignite particles and bioturbation. It is interpreted as a transgressive sheet sand. Foraminiferal data indicate an Hauterivian age.

The *Berkel Sand-Shale Member* consists of an alternation of fine -grained sandstones, siltstones and shale streaks, sometimes with a somewhat thicker shale bed at the base. Its upper boundary with the Berkel Sandstone Member is gradational but is normally taken at the base of the massive, clean and porous sandstones of this Member. Foraminiferal data suggest an age of approximately Early Barremian.

The *Berkel Sandstone Member* is a massive sequence of fine- to medium-grained sandstones with conglomeratic streaks, shell fragments and lignite particles. All sedimentological evidence points to an interpretation of the both Berkel members as a barrier sand body. The Berkel Sandstone Member is approximately Middle Barremian in age (foraminifera). At places where these two members are difficult to separate, both can be taken together as the *Berkel Clastic Member* (KNNCD).

The *IJsselmonde Shale Member* marks a transgressive phase that brought about a considerable southward extension of the marine depositional realm. Therefore, it often overlies, unconformably, the Delfland Group. Its age is approximately Middle Barremian.

The *IJsselmonde Sandstone Member* is, in typical development, a massive, well stratified sandstone unit with only a few clay intercalations. The sandstones are normally fine- to medium-grained with some coarser, conglomeratic streaks. It is interpreted as a barrier sandstone body which at its very top shows some evidence of transgressive reworking below the Eemhaven Shale Member. Micropalaeontological data suggest a Late Barremian age.

The *Eemhaven Shale Member* is a very silty-sandy shale sequence, which yields Late Barremian microfaunas.

The *De Lier Sand-Shale Member* consists of an alternation of thin sandstones and sandy shales, commonly glauconitic, and with shell fragments and frequent bioturbation. It is interpreted as the distal part of a more southerly situated delta complex. Where present, it forms the top part of the Vlieland Formation, and lies directly below the Holland Formation. Based upon foraminiferal data, a Late Barremian age is concluded.

In the Lower Saxony Basin, a similar penetration of the Vlieland Shale Formation by sandstone tongues is observed. The following subdivision is applicable (from top to bottom): (coord. N 52°46′08.1″, E 06°36′54.2″, encl. 26)

		Westerbork-1
Gildehaus Sandstone Member	(KNNCG)	1084-1091 m
Westerbork Shale Member	(KNNCW)	1091-1121 m
Ruinen Shale Member	(KNNCE)	1121-1143 m
Bentheim Sandstone Member	(KNNCP)	1143-1176 m
Bentheim Shale Member	(KNNCV)	1176-1192 m

The above subdivision of the sedimentary sequence found along the edges of the Lower Saxony Basin in The Netherlands is a simplified counterpart of the German subdivision, as applied in outcrops and subsurface in the adjacent German area (WOLBURG, 1954; BOIGK, 1960; KEMPER, 1976). These two nomenclatures relate as follows:

The Netherlands	*Germany*
	Brunsvicensis Tone
Vlieland Shale Member	Blätter Tone
	Tonmergeliges Oberhauterive
Gildehaus Sandstone Member	- Gildehaus Sandstein
	Noricum Zwischenmittel
Westerbork Shale Member	Noricum Sandstein
	Senckenbergi Tonstein
	Grenzsandstein
	Toniges Obervalendis
Ruinen Shale Member	Dichotomiten Sandstein
	Toniges Zwischenmittel
Bentheim Shale Member	- Bentheimer Sandstein
Bentheim Shale Member	- Toniges Mittelvalendis

The *Bentheim Shale Member* usually forms the basal portion of the Vlieland Formation along the edges of the Lower Saxony Basin. It overlies, unconformably, the Coevorden Formation. Microfaunal data suggest a Middle Valanginian age.

The *Bentheim Sandstone Member* usually consists of fine- to medium-grained barrier sand bodies deposited in a relatively shallow sea between land tongues and islands (KEMPER, 1976). Locally these sandstones are calcareous and contain shell fragments, in addition to lignite particles and glauconite grains. Fossil evidence suggests a Middle Valanginian age.

The *Ruinen Shale Member* in typical development is a relatively thin sequence of silty shale beds. In The Netherlands an intercalated sandstone bed observed in Germany ('Dichotomiten Sandstein') has not as yet been found. The top of this member is taken at the base of a thin siltstone or sandstone bed ('Grenzsandstein' of German terminology). On palaeontological grounds a Middle to Late Valanginian age is attributed to this Member.

The *Westerbork Shale Member* is a relatively thin shaly sequence with, frequently, a thin siltstone or sandstone at its base, which is correlatable with the 'Grenzsandstein' of German nomenclature. Both in northwestern Germany and the eastern Netherlands the base of this member usually marks a small unconformity which separates two depositional cycles, the lower one of approximately Middle to Late Valanginian age (comprising Bentheim Shale Member-Bentheim Sandstone Member-Ruinen Shale Member), and the upper one of approximately Hauterivian-Barremian age (Westerbork Shale Member-Gildehaus Sandstone Member-Vlieland Shale Member).

The above mentioned basal sandy bed ('Grenzsandstein') is recognized on wire-line logs as a band of somewhat lower gamma ray radiation. Either due to poor quality wire-line logs or minimal development of this bed, it is unrecognizable in a number of wells and, for practical purposes, the Ruinen and Westerbork Shale Members can be lumped together as the *Schoonebeek Shale Member* (KNNCS).

Nowhere in the Netherlands has an equivalent of the German 'Noricum Sandstein' been encountered.

Fossil evidence suggests an Early Hauterivian age for the Westerbork Shale Member.

The *Gildehaus Sandstone Member* consists chiefly of coarse-grained to conglomeratic sandstones with pebbles of quartz, sandstone and limestone. It frequently contains clay flakes, clay-ironstones and some coals embedded in an argillaceous, very glauconitic sandstone. Medium-grained sandstones, often with a high content of calcareous cement, occur as well and grade locally into lime-sandstones. In some localities a high content of sponge spicules is typical. Palaeontological data indicate a Late Hauterivian age for this Member.

In some areas along the edge of the Lower Saxony Basin, e.g., in Twente and western Drenthe, the various sandstone bodies merge into one, usually conglomeratic, sandstone at the base of the Vlieland Formation. Following the earlier definitions such occurrences should then be described as the Vlieland Sandstone Member, e.g., well Oldenzaal-5 (see WOLBURG, 1954). Agewise this sandstone might locally be as young as Barremian ('T HART, 1969).

HOLLAND FORMATION (KNGL)

Name – Named after the Dutch province of Zuid-Holland, where this formation is well-known from various well sections.

Definition – Sequence of grey and redbrown marls and marly shales, often with bituminous shale intercalations in the basal portion. Along the basin margin glauconitic sandstones are occasionally intercalated.

The Holland Formation overlies the Vlieland Formation, the contact being characterized by a pronounced and sudden upward increase in carbonate content, which is reflected on wire-line logs by a decrease in gamma ray readings and an increase in resistivity and sonic velocity response. This boundary marks regionally a slight but distinct unconformity.

At its top the Holland Formation is limited by the base of the carbonates of the Chalk Formation. Locally this boundary is transitional by way of a very gradual upward increase of carbonate content. Although in such cases the boundary definition is ambiguous, the base of the lowest distinct limestone is taken as the top of the Formation. Along the basin margin, e.g., along the southern basin edge of the West Netherlands Basin, the top of the Holland Formation is defined as the contact of marly deposits below glauconitic sandstones of the Chalk Formation.

Age – Aptian-Albian- (locally) earliest Cenomanian. Palaeontological data suggest a regional disconformity within the Holland Formation with the absence of the Upper Aptian and part of the Lower Albian.

Reference section – Well L 5-1: 2295-2403 m, coord. N 53°44′31.8″, E 04°31′44.6″ (encl. 27).

Additional reference section – Well De Lier-2: 1127-1580 m, coord. N 51°58′44.0″, E 04°13′39.5″ (encl. 27).

Subdivision – Over most of The Netherlands a tripartite subdivision of the marl-shale sequence of the Holland Formation is apparent. In the West Netherlands Basin, a fourth unit of glauconitic sandstone is recognized. The units are (from top to bottom):

	L 5-1	*De Lier-2*
Upper Holland Marl Member (KNGLU)	2295-2371 m	1127-1279 m
Middle Holland Shale Member (KNGLM)	2371-2384 m	1279-1358 m
Holland Greensand Member (KNGLG)	–	1358-1408 m
Lower Holland Marl Member (KNGLL)	2384-2403 m	1408-1580 m

The *Lower Holland Marl Member* is a grey and redbrown marl or calcareous shale unit, frequently with intercalated bituminous shale beds (especially in the basal portion). On wire-line logs the Member is recognizable by its relatively low gamma ray response in comparison to that of the Vlieland Shale and Middle Holland Clay Member, respectively. Microfaunal data indicate an Early Aptian age.

The *Holland Greensand Member* in the West Netherlands Basin is a green, very glauconitic, fine-grained sandstone to siltstone, present only along the southern margin of the basin and rapidly shaling out towards the north. The other parts of the Holland Formation are, in this basin, developed as greenish grey, silty to very silty, glauconitic marls and shales. An Early Albian age is concluded from the available faunal data.

Recognition of the *Middle Holland Shale Member* is based upon its distinctly lower lime content in comparison with that of the Lower and Upper Members, respectively. Faunal data evidence an Early Albian age.

The base of the Middle Holland Shale Member marks a pronounced transgression throughout The Netherlands ('Albian transgression'). In some places the transgressive base is marked by a thin basal sand or conglomerate, e.g., in southwestern Drenthe and in the Betuwe (province of Gelderland). These thin coarse clastic beds are included in this Member.

The *Upper Holland Marl Member* is characterized by its carbonate content which gradually increases towards the top of the Member. Its base, on top of the Middle Holland Shale Member, is marked by a sudden decrease in gamma ray reading and an increase of resistivity and sonic velocity character. Its top is taken at the base of the chalky limestones of the Chalk Group and this can be observed on wire-line logs as a rather pronounced decrease in gamma ray response and increase in resistivity and sonic velocity readings. In a number of cases such wire-line log characteristics indicate a very gradual change across this boundary rendering its definition rather ambiguous. Microfaunal data suggest a Middle-Late Albian- (locally) earliest Cenomanian age.

In the region of Nijmegen, an unnamed greensand is encountered as an intercalation in the Upper Holland Marl Member.

9.3. CHALK GROUP (CK)

General – The Rijnland Group is overlain by a generally thick sequence of carbonates and marls described as the *Chalk Group*. It is well-known from outcrops in the southern part of the Dutch province of Limburg, where it is developed as generally soft, porous, friable limestones (on top of glauconitic sandstones). In the subsurface it consists normally of hard, densely cemented, chalky and marly limestones.

One of the main characteristics of the chalks is its relatively low content of terrigenous material and its dominance of mainly pelagic calcareous fossils, such as coccoliths, planktonic foraminifera, etc. In most of the Dutch chalks benthonic calcareous organisms form an important constituent as well, e.g., benthonic foraminifera, sponges, bryozoa, inoceramid lamellibranchs, etc. Towards the basin edges biocalcarenites and -rudites are common.

Name – The name Chalk is the one in common use throughout northwestern Europe for these essentially Late Cretaceous rocks.

Definition (text figs. 11, 12) – Sequence of white to light grey, fine-grained bioclastic carbonates and marly carbonates. Chert concretions, usually in layers parallel to the bedding, are common. Along the basin margin sand tongues are present as well as coarser bioclastic limestones. Argillaceous material is admixed in varying proportions in parts of the section, notably in the basal portion of the Group. However, it appears that variations in clay content do not form a basis for a regional subdivision as these are too variable over longer distances.

The base of the Chalk Group is taken at the base of the limestone succession on top of the marls of the Holland Formation. On wire-line logs this boundary is usually marked by a pronounced decrease in gamma ray radiation and an increase in resistivity and sonic log response. In the West Netherlands Basin the basal portion consists locally of greensands on top of the marls of the Holland Formation. In southern Limburg the lowest formation of the Chalk Group (Aken Formation) consists of clays and sandstones covering Palaeozoic rocks.

The top of the Group is taken at the top of the carbonates below the sands, marls and clays of the Lower North Sea Group.

Age – Cenomanian-Danian.

Reference section – Well De Paauwen-1: 822-1720 m, coord. N 53°16'30.6'' E 06°45'15.6'' (encl. 29).

Subdivision – A persistent basin-wide shale bed in the lower part of the Chalk Group allows for a twofold subdivision, which is (from top to bottom):

Ommelanden Chalk Formation (CKGR),
Texel Chalk Formation (CKTX).

In the southern part of Limburg and its adjacent areas in Belgium and Germany, a more detailed subdivision has been established (FELDER, 1975). In this basin-margin development lenses of coarse bioclastic limestones, sandstones and shales occur. Here five formations are distinguished, which are (from top to bottom):

Houthem Formation (CKHM),
Maastricht Formation (CKMA),
Gulpen Formation (CKGP),
Vaals Formation (CKVA),
Aken Formation (CKAK).

For more detailed information (also on the subdivision of these formations) reference should be made to FELDER's publication.

TEXEL CHALK FORMATION (CKTX)

Name – Named after the Dutch Wadden Island Texel, south of the reference well L 12-2.

Definition – Sequence of light grey chalks and marly chalks with some marl intercalations, comprised between the base of the Chalk Group and the top of a persistent shale bed, described in England as the *Actinocamax plenus Marl.*

Age – Cenomanian.

Reference section – Well L 12-2: 2324-2405 m, coord. N 53°20′24.5″, E 04°45′42.6″ (encl. 28).

Additional reference section – Well De Lier-2 : 1084-1127 m, coord. N 51°58′44.0″, E 04°13′39.5″ (encl. 28).

Subdivision – Two members are distinguished (from top to bottom):

	L 12-2	*De Lier-2*
Texel Marlstone Member (CKTXM)	2324-2405 m	1084-1110 m
Texel Greensand Member (CKTXG)	-	1110-1127 m

The *Texel Greensand Member* occurs in the West Netherlands Basin and in the region of Nijmegen as the basal member of the Texel Chalk Formation. It is a greenish, glauconitic, fine-grained, calcareous to very calcareous sandstone, with intercalated marls.

The *Texel Marlstone Member* is the characteristic marly chalk of the Formation. Its top is marked by a black shale of a few metres thickness, which occurs throughout The Netherlands.

OMMELANDEN CHALK FORMATION (CKGR)

Name – Named after the surroundings of the town of Groningen, commonly known as the Ommelanden, in which the reference section is located.

Definition – Sequence of chalks, chalky limestones and marly chalks, with occasional marl intercalations. Along the basin edge lenses of coarse, bioclastic limestones and tongues of sandstone occur which are described as separate formations in southern Limburg and adjacent areas. The Formation is limited at its base by the top of the Texel Marlstone Member (or in absence of this Member by older formations), and at its top by the base of the sandstones, clays and marls of the Lower North Sea Group.

Age – Turonian – Early Paleocene (Danian).

Reference section – Well De Paauwen-1: 822-1654 m, coord. N 53°16′30.6″, E 06°45′15.6″ (encl. 29).

Subdivision – The monotonous lithological development of the Ommelanden Chalk Formation does not allow for a regionally recognizable formal subdivision. Various attempts at a subdivision on wire-line log characteristics proved useful for local purposes, but not acceptable over larger areas.

Micropalaeontological studies on the Ommelanden Chalk Formation have yielded a promising biostratigraphic subdivision. On nannoplankton especially work has still to be carried out along the lines suggested by SISSINGH (1977), who has stated that good results have been attained for central and northern regions of the North Sea. Although improvements can be gained by further studies, the available foraminiferal data demonstrate now already that several unconformities are present within the sequence. However, their regional extent and correlation remain as yet undefined.

10. REVIEW OF POST-CHALK SUCCESSION

The post-Chalk deposits form an almost continuous cover over the whole of The Netherlands and its offshore areas. The thicknesses of this cover vary from a few metres in the extreme southern and southeastern parts of the country to more than 2000 metres in the northern offshore.

Almost all Cenozoic sediments can be assembled in three groups, viz. the Lower, Middle and Upper North Sea Groups. In view of the similar clastic nature of the groups, these can be assembled, if required, into the North Sea Supergroup. The chalks and soft limestones of Early Paleocene (Danian) age, which are of local occurrence and restricted nature, are in sedimentary continuity with the Late Cretaceous part of the Chalk Group.

Distribution maps of the lithostratigraphic units under description were published by KEIZER & LETSCH (1963) and by ZAGWIJN & VAN STAALDUINEN (1975). In the former publication a chronostratigraphic nomenclature is applied. According to the subdivision presented in this paper KEIZER & LETSCH's Lower Montian is part of the Chalk Group, the Upper Montian-Bartonian corresponds to the Lower North Sea Group, the Tongrian-Chattian to the Middle North Sea Group and the Lower Miocene-Pliocene forms part of the Upper North Sea Group.

The ages of the different lithostratigraphic units are based on the foraminiferal biozonation as established for the North Sea region (see KEIZER & LETSCH, 1963; DOPPERT, 1975). The correlation of these zones with the worldwide chronostratigraphic frame is not always assured. The area of contention concentrates on the central and upper part of the sequence for which the subdivision of the Oligocene, the Oligocene-Miocene boundary, the Miocene subdivision, the Miocene-Pliocene and the Pliocene-Pleistocene boundaries are not generally agreed upon. For the pre-Miocene part, the chronostratigraphic subdivision of KEIZER & LETSCH is followed. For the Miocene-Recent section the views of the RGD are adhered to.

For hydrocarbon exploration purposes the post-Chalk sequence constitutes an overburden succession which is of little economic interest and, consequently, data-gathering is not of prime importance. Normally, this sequence is drilled with large hole diameters with a resulting poor quality of the wireline logs. Furthermore, the non- to poorly consolidated nature of these sediments allows for high penetration rates during drilling and, as a result of this, cutting samples are mostly of poor quality because of the high degree of contamination by caving from higher levels.

Under these circumstances, and taking into account that the succession under description consists for the major part of rather monotonous clastic sequences, micropalaeontological criteria (especially top occurrences of fossil types) play an important role in the subdivision of the post-Chalk deposits in wells. Both the RGD and NAM have studied such biostratigraphical aspects in detail.

11. LOWER NORTH SEA GROUP (NL)

General – After the deposition of the Chalk Group, clastic sedimentation prevailed during the Early Tertiary. The Paleocene-Eocene part of this succession is assembled in the *Lower North Sea Group,* which rests unconformably on the Chalk Group, except possibly in those areas where Danian chalk deposits are found. Over practically the whole of The Netherlands the boundary with the Middle North Sea Group is marked by an important sedimentary gap, corresponding approximately to the Lower Oligocene.[x])

Some names of the subdivisions of the Lower North Sea Group are taken from the Belgian stratigraphic nomenclature, where these units are exposed and have been studied in great detail (FOURMARIER, 1954; KAASSCHIETER, 1961).

Name – Named after the North Sea. The prefix 'Lower' is added to denominate the lower part of the clastic sequence lying immediately on top of the Chalk Group.

Definition (text figs. 13, 14) – Sequence of predominantly grey, sometimes calcareous clays, with sandstone intercalations along the edge of the North Sea Basin. It overlies, usually unconformably, the carbonates of the Chalk Group. Its top is marked by the erosion surface below the Middle North Sea Group.

Age – Paleocene-Eocene.

[x]) Upon completion of the present manuscript, results of calcareous nannoplankton studies on the lowermost part of the Rupel Formation in some wells in the southern Netherlands suggested an Early Oligocene age – zone NP 21 (VERBEEK, RGD, personal communication). Therefore, the absence of the Lower Oligocene in the Dutch subsoil can be seriously doubted. Based on the above, it seems more logic to assume that the Tongeren Formation represents a coastal-lagoonal-terrestrial age-equivalent of the lower part of the Rupel Formation, as present in a more basinal position.

Reference section – Well Dongen-1: 691-1063 m, coord. N 51°37′36.4″, E 04°54′48.2″ (encl. 30).

Subdivision – In the southern Netherlands a twofold subdivision is recognized based upon the occurrence of a sandy interval in the lower part of the Group. Towards the northern Netherlands and its adjacent offshore areas this sandy zone passes into a persistent tuffaceous interval, hence (from top to bottom):

Dongen Formation (NLFF),
Landen Formation (NLLF).

LANDEN FORMATION (NLLF)

Name – Named after the Belgian municipality of Landen in the province of Brabant. As early as 1839, DUMONT selected Landen as the type locality for the Paleocene clastics on top of the Chalk Group.

Definition – Formation of light grey marls and calcareous clays, with or without a sandy basal sequence. It overlies, usually unconformably, the carbonates of the Chalk Group. Its top is taken at the lower limit of the sandy or tuffaceous interval that marks the basal part of the Dongen Formation.

Age – Paleocene.

Reference section – Well Veldhoven-1: 1363-1425 m, coord. N 51°26′20.9″, E 05°21′37.2″ (encl. 30).

Additional reference section – Well K 17-2: 998-1069 m, coord. N 53°04′33.5″, E 03°30′51.4″ (encl. 30).

Subdivision – In the southern part of The Netherlands and the adjoining parts of Belgium two members are recognized, whereas over the rest of the Dutch region only the upper member is present, viz.

		Veldhoven-1	*K 17-2*
Landen Clay Member	(NLLFC)	1363-1412 m	998-1069 m
Heers Sand Member	(NLLFS)	1412-1425 m	–

The *Heers Sand Member* is a glauconitic, calcareous sand, alternating with clay beds, and characterized by *Cyprina morrisi*. In The Netherlands it is known only from a restricted area in the provinces of Noord-Brabant and Limburg. In the Peel area this sand covers a thin, non-marine clay-sand sequence with brown coal. These beds are included in the Heers Sand Member (VAN DEN TOORN, 1967).

The *Landen Clay Member* consists, in the southern Netherlands, of a yellowbrown marl overlain by a dark grey, silty clay. Towards the north these two intervals merge into a grey to greenish grey clay with local marl intercalations (especially in the basal part of the Member).

DONGEN FORMATION (NLFF)

Name – Named after the Dutch municipality of Dongen, in the province of Noord-Brabant.

Definition – Formation of greengrey and brown, slightly calcareous clays, with an intercalated sandstone sequence, occurring in most of the onshore Netherlands. In the southern part of the country a basal sandy interval is found, whereas in the northern and offshore Netherlands the lowermost part of the Formation is characterized by tuffaceous clays. The top of the Formation is marked by the unconformable contact with the sands and clays of the Middle North Sea Group.

Age – Eocene.

Reference section – Well Dongen-1: 691-993 m, coord. N 51°37′36.4″, E 04°54′48.2″ (encl. 30).

Additional reference section – Well L 2-4: 1007-1532 m, coord. N 53°51′22.2″, E 04°38′59.2″ (encl. 31).

Subdivision – The subdivision of the Dongen Formation is not uniform across The Netherlands due to some lithological variations within the sequence. In general a fourfold subdivision can be recognized, with either a sandy or tuffaceous interval forming the base, viz. (from top to bottom):

		Dongen-1	*L 2-4*
Asse Clay Member	(NLFFB)	691- 735 m	1007-1035 m
Brussels Sand Member	(NLFFS)	735- 844 m	–
Brussels Marl Member	(NLFFM)	–	1035-1099 m
Ieper Clay Member	(NLFFY)	844-985 m	1099-1524 m
Basal Dongen Sand Member	(NLFFD)	985- 993 m	–
Basal Dongen Tuffite Member	(NLFFT)	–	1524-1532 m

In the northermost offshore area the Brussels Marl Member becomes gradually less calcareous and tends to loose its identity. In this area the sediments equivalent to the Ieper Clay-Brussels Marl-Asse Clay can be combined into the

Dongen Clay Member (NLFFC)

The *Basal Dongen Sand Member* is usually a thin (max. 3 metres), glauconitic sandstone bed. However, it increases markedly in thickness in the eastern part of the province of Noord-Brabant where it also contains some clay intercalations. Towards the north it is replaced by the Basal Dongen Tuffite Member.

The *Basal Dongen Tuffite Member* is a tuffaceous se-

quence of markedly widespread distribution throughout the North Sea Basin. It consists of tuffaceous clays alternating with dark grey and redbrown clays. The volcanic beds form an excellent marker horizon throughout the area, especially in view of its characteristic wire-line log expression (JACQUÉ & THOUVENIN, 1975).

The *Ieper Clay Member* is a sequence of dark grey and greenish grey, often slightly calcareous, commonly glauconitic clays. In the southern part of the country these clays are very silty and thin sand stringers are common.

The *Brussels Sand Member* consists of calcareous, glauconitic sandstones with streaks or bands rich in *Nummulites*. This characteristic development, however, occurs mainly in the southern Netherlands. Northwards the grainsizes gradually diminish, and the Member becomes very silty to the extent that it is unrecognizable as a sandy unit. Nevertheless, the equivalent beds remain discernible over most of The Netherlands, including the offshore, by its relatively high lime and silt content, and is then called the Brussels Marl Member.

The *Brussels Marl Member* is a greenish grey to brownish grey, silty, calcareous clay to marl. On wire-line logs, it is distinguishable from the under- and overlying clays by higher resistivity and sonic velocity expressions as well as by lower gamma ray readings.

The *Asse Clay Member* is a dark greenish grey, slightly calcareous clay succession. In the southeastern Netherlands it contains thin sand intercalations which increase in number towards the top of the Member.

The *Dongen Clay Member* consists of dark grey to greenish grey, usually slightly calcareous clays, and is found only in the northern offshore area.

12. MIDDLE NORTH SEA GROUP (NM)

General – After the deposition of the Lower North Sea Group, erosion prevailed over practically the whole of The Netherlands. During this period varying amounts of the Lower North Sea Group were removed, as is evident from the maps given by KEIZER & LETSCH (1963). Sedimentation resumed again with the *Middle North Sea Group,* which represents approximately the depositional package laid down during the Oligocene. With the exception of the southern part of the province of Limburg, the Lower Oligocene is absent over the whole country[x]. At the Oligo-Miocene boundary erosion again prevailed over part of The Netherlands. This erosional level (or its lateral equivalent) is taken as the upper boundary of the Middle North Sea Group.

Name – Named after the North Sea. The prefix 'Middle' is added to designate the middle (approximately Oligocene) part of the clastic sequence on top of the Chalk Group.

Definition (text figs. 13, 14) – Sequence of dark brownish grey and greenish grey clays with varying amounts of intercalated sand beds. These sands are restricted mainly to the southeastern margin of the North Sea Basin. The succession is bounded at the base by the erosional unconformity on top of the Lower North Sea Group. Its upper limit is taken directly below the glauconitic basal beds of the Upper North Sea Group.

Age – Oligocene (– Early Miocene)

Reference section – Well Veldhoven-1: 935-1229 m, coord. N 51°26'20.9'', E 05°21'37.2'' (encl. 32).

Additional reference section – Well Doornspijk-2: 619-779 m, coord. N 52°24'36.2'', E 05°46'15.6'' (encl. 32).

Subdivision – The Middle North Sea Group is subdivided into three formations, which are (from top to bottom):

Veldhoven Formation	(NMVF),
Rupel Formation	(NMRF),
Tongeren Formation	(NMTF).

TONGEREN FORMATION (NMTF)

Name – Named after the Belgian town of Tongeren, in the province of Limburg. Tongeren was selected by DUMONT (1839) as the type locality of the Tongrian, the oldest stage of the Oligocene.

Definition – Sequence of fine-grained micaceous sands, overlain by lagoonal to terrestrial clay deposits containing some sand and brown coal beds (KUYL, 1975).

Age – Early Oligocene.

Reference section – Not designated, although KUYL (1975) selected stratotypes from the southern part of the province of Limburg for the separate members.

[x]see footnote, p. 48

Subdivision – The Tongeren Formation, known only from the southern part of the Dutch province of Limburg, has been fully described by KUYL. This author subdivided the Formation into two members, which are (from top to bottom):

Goudsberg Member (NMTFG),
Klimmen Member (NMTFK).

RUPEL FORMATION (NMRF)

Name – Named after the Belgian river Rupel. In 1849, DUMONT used this name to describe the middle part of the Belgian Oligocene sequence.

Definition – Sequence of dark browngrey clays with varying amounts of sand beds along the southern basin margin. In the southern part of Limburg it overlies the lagoonal to terrestrial clays of the upper part of the Tongeren Formation. Elsewhere it rests unconformably on the Lower North Sea Group. It is overlain by the sands and silty shales of the Veldhoven Formation.

Age – Middle Oligocene[x)].

Reference section – Well Veldhoven-1: 1098-1229 m, coord. N 51°26'20.9'', E 05°21'37.2'' (encl. 32).

Additional reference section – Well Doornspijk-2: 715-779 m, coord. N 52°24'36.2'', E 05°46'15.6'' (encl. 32).

Subdivision – In most of the Dutch subsoil the Rupel Formation consists of a monotonous clay sequence. In the southern Netherlands a sandy bed occurs at the base of the Formation, thus allowing a twofold subdivision into:

	Veldhoven-1	*Doornspijk-2*
Boom Clay Member (NMRFB)	1098-1213 m	715-779 m
Berg Sand Member (NMRFS)	1213-1229 m	

Local subdivisions are in use in the areas of southern Limburg and the Achterhoek-Twente (eastern parts of the provinces of Gelderland and Overijssel). In southern Limburg the Formation consists of a basal sand overlain by clayey sands with clay lenses and topped by silty clays, and described by KUYL (1975) as (from top to bottom):

Boom Clay Member (NMRFB),
Nucula Clay Member (NMRFN),
Berg Sand Member (NMRFS).

Locally an unnamed sand bed separates the Boom and Nucula Clay units.

For the Achterhoek-Twente area a local subdivision was proposed by VAN DEN BOSCH ET AL. (1975). This can be compared with the general Dutch nomenclature as follows:

(this paper)	(VAN DEN BOSCH ET AL.)
Boom Clay Member	Winterswijk Member (NMRFW)
	Brinkheurne Member (NMRFH)
Berg Sand Member	Ratum Member (NMRFR)

The Ratum and Brinkheurne Members compare rather closely with the Berg Sand and Boom Clay units. The Winterswijk Member is described as a sandy clay with intercalated very fine-grained sands. It is correlated with the more silty upper part of the Rupel Formation in the Lower Rhine embayment (FRG) where it is known as the Lintforter Schichten.

The *Berg Sand Member* is a thin bed of greenish grey, fine-grained sand, occasionally with a layer of gravel at the base. It is interpreted as the transgressive base of the Rupel Formation. It is known from the southern part of The Netherlands.

The *Boom Clay Member* is a dark brownish grey, slightly silty clay, commonly with septaria in which the lime content of the Formation is concentrated. In the southern Netherlands the upper part of the Boom Clay Member usually shows a relatively high silt content. In those areas where the Berg Sand Member is absent the Boom Clay rests directly on the Asse or Dongen Clay Members. The determination of the boundary can be difficult on lithological grounds; on wire-line logs the Boom Clay shows a somewhat higher gamma ray response compared to the clays of the Lower North Sea Group. Micropalaeontological criteria are commonly applied to assist in the determination of this boundary.

VELDHOVEN FORMATION (NMVF)

Name – Named after the Dutch municipality of Veldhoven, in the province of Noord-Brabant.

Definition – Sequence of sands and silty clays, located between the top of the Boom Clay Member and the glauconitic base of the Upper North Sea Group.

Age – (Middle-) Late Oligocene (-Early Miocene).

Reference section – Well Veldhoven-1: 935-1098 m, coord. N 51°56'20.9'', E 05°21'37.2'' (encl. 32).

x)see footnote, p. 48

Additional reference section – Well Doornspijk-2: 619-715 m, coord. N 52°24'36.2'', E 05°46'15.6'' (encl. 32).

Subdivision – The Veldhoven Formation can be subdivided into two members:

	Veldhoven-1	*Doornspijk-2*
Veldhoven Clay Member (NMVFØ)	935-1047 m	619-715 m
Voort Sand Member (NMVFV)	1047-1098 m	-

The *Voort Sand Member* is a brownish grey to greenish black, often clayey, fine- to medium-grained sand. It is known from the southeastern Netherlands where it overlays the Boom Clay. In the Peel-Kempen area it attains a considerable thickness (more than 50 m), but thins rapidly towards the north.

The *Veldhoven Clay Member* is a greenish grey, silty clay sequence. Where the Voort Sand Member is absent, the Veldhoven Clay Member can be distinguished from the Boom Clay by the higher silt content in the upper part of the lower member, expressed on the gamma ray by a lower reading. Furthermore, the Boom Clay shows typical brownish colouring, whereas the Veldhoven Clay exhibits greenish grey aspects.

The Veldhoven Clay Member is found in the southern and central parts of the country. Further north it is absent.

13. UPPER NORTH SEA GROUP (NU)

General – Over most of The Netherlands, an important hiatus marks the Oligo-Miocene boundary. However, in the southeastern part of the country, notably in the Peel area, Central Graben and southeasterly continuation in Germany (Lower Rhine district), sedimentation was continuous. These post-Oligocene sediments have been assembled in the *Upper North Sea Group*.

The Upper North Sea Group is subdivided into many formations, as treated in detail by ZAGWIJN & VAN STAALDUINEN (1975). The largely continental formations of Quaternary age will not be dealt with here since they have been described fully in ZAGWIJN & VAN STAALDUINEN.

Name – Named after the North Sea. The prefix 'Upper' is used to denote the upper part of the clastic sequence above the Chalk Group.

Definition (text figs. 15, 16) – Sequence of clays and fine to coarse sands of marine origin, and of clays, sands and gravels of terrestrial origin, the latter including occasional peat and brown coal seams and glacigenous beds towards the upper part. The terrestrial beds occur mainly in the eastern parts of the country whereas the marine deposits are typical for the western Netherlands. In general the presence of marine shells, an easily recognizable feature in bore hole samples, is taken as indicative of the marine origin of a bed. There is a general trend from coarse- to fine-grained sediments towards the north and west. In most places, the successsion unconformably overlies the Middle North Sea Group, or older beds. The top is formed by the Recent land surface or sea floor.

Age – Miocene-Quaternary (Holocene).

Reference section – Well Rijsbergen 50A/154 : 0-234 m, coord. N 51°30'50.5'', E 04°39'15.4'' (encl. 33).

Subdivision – The subdivision of the Upper North Sea Group is almost exclusively based on data from onshore wells (ZAGWIJN & VAN STAALDUINEN, 1975). The marine sequence is subdivided by two markers, namely (from top to bottom): the top of a sequence of clayey beds, and the top occurrence of beds rich in glauconite. This results in (from top to bottom):

Maassluis Formation (NUMS),
Oosterhout Formation (NUØT),
Breda Formation (NUBA).

The terrestrial deposits of Mio-Pliocene age are subdivided into three formations:

Scheemda Formation (NUSA),
Kieseloölite Formation (NUKØ),
Heksenberg Formation (NUHG).

The Heksenberg Formation is restricted to the southeastern Netherlands, the Kieseloölite Formation to the southeastern and eastern Netherlands, and the Scheemda Formation to the northeastern and eastern Netherlands. Their definition, which is discussed below, is by lithological criteria and by the provenance of the clastic sediments as revealed by the heavy mineral and gravel assemblages.

BREDA FORMATION (NUBA)

Name – Named after the town of Breda in the province of Noord-Brabant.

Definition – Sequence of marine, glauconitic sands, sandy clays and clays. In many places a layer rich in glauconite occurs at the base. In this respect the original definition of the Breda Formation (DOPPERT ET AL., 1975), which included strata from below the glauconitic-rich layer, has been slightly amended. The latter strata are assigned at present to the Middle North Sea Group.

In many places an unconformity is present at the base of the Breda Formation. The youngest beds beneath the Formation belong to the Veldhoven Clay Member of the Veldhoven Formation. In other places, in particular in the southeastern Peel region and part of southern Limburg, the lower limit of the Formation is difficult to establish, as a gradual transition from the slightly glauconitic beds of the Veldhoven Formation into the greensands of the Breda Formation occurs.

The upper limit of the Breda Formation is taken at the uppermost occurrence of greensands or clays rich in glauconite.

Age – Miocene, locally also earliest Pliocene.

Reference section – Well Rijsbergen 50A/154: 174-234 m, coord. N 51°30'50.5'', E 04°39'15.4'' (encl. 33).

Additional reference section – Well Klundert 43H/63: 281-318 m, coord. N 51°39'17.3'', E 04°33'07.1'' (encl. 33)

Subdivision – No general subdivision into sand and clay members can be made. Some members of local importance, however, are mentioned. In southern Limburg, continental deposits of the Heksenberg Formation (see below) intertongue with the Breda Formation. This continental tongue divides the Breda Formation into a lower *Kakert Member* and an upper *Vrijherenberg Member* (KUYL, 1975). These members consist of loamy, glauconitic sands.

In the central Peel region, two local members have been named in the upper part of the Formation (ZAGWIJN, 1967): *Oploo Sand Member* (shelly, glauconitic sands) overlain by the *Haps Sand Member* (glauconitic sands which are poor in fossils and contain ironstone horizons and a gravelly bed at the base). The last mentioned Member is related to an ancient shoreline in this area.

In the eastern Netherlands, in the region of the Achterhoek and Twente, a detailed subdivision has been proposed by VAN DEN BOSCH ET AL. (1976). From top to bottom the following members have been named:

Delden Member,
Zenderen Member,
Eibergen Member,
Aalten Member.

The subdivision is based on variations in clay and sand content. All deposits are more or less rich in glauconite.

In the northeastern Netherlands, notably in the eastern parts of the provinces of Groningen and Drenthe, the topmost beds of the Breda Formation have been described as the *Nieuweschans Member* (DOPPERT ET AL., 1975). They are, generally, greenish, liver-coloured, clayey sands, containing a heavy mineral assemblage, rich in hornblende, which is characteristic for this Member in this area. The deposits lack remains of marine shells, but palynological data point to a marine origin.

Remarks – The Breda Formation is rarely exposed. In the subsurface it is generally present, except in small areas in the south and east of the country.

In the southeast the Formation consists mainly of sand, but towards the north and west it is gradually replaced by clay with a variable sand content.

The Formation overlies either the Veldhoven Clay Member or the Boom Clay Member. When the basal part of the Formation is clay, the lower boundary is in many places marked by a bed with high gamma ray radiation, probably due to an enrichment in glauconite. Where this marker-bed is missing designation of the boundary has to rely on palaeontological data.

In the southeastern Netherlands the lower and middle parts of the Breda Formation intertongue with continental beds of the Heksenberg Formation. The upper part of the Formation, however, intertongues with the continental beds of the Scheemda Formation in the northeastern Netherlands and with the Kieseloölite Formation in the southeastern Netherlands.

OOSTERHOUT FORMATION (NUØT)

Name – Named after the municipality of Oosterhout in the province of Noord-Brabant.

Definition – Sequence of marine sands, grey and greenish clays and sandy clays. The glauconite content is moderate to low. In the southern and northeastern parts of The Netherlands the lower part of the Formation consists of sands extremely rich in shell debris and shell beds ('Crag facies'). In most areas the latter deposits are overlain by clays.

The Formation overlies beds, rich in glauconite but poor in shells, belonging to the Breda Formation. The upper boundary of the Formation is, in most places, taken at the top of a series of clay beds which are overlain by shelly, fine to coarse sands with sparse clay intercalations and forming part of the Maassluis Formation. In other places the Formation intertongues with and is overlain by continental deposits of the Kieseloölite and Scheemda Formations.

Age – Pliocene, locally possibly latest Miocene. The topmost beds are in some places of earliest Pleistocene age.

Reference section – Well Klundert 43H/63, 105-281 m, coord. N 51°39′17.3″, E 04°33′07.1″ (encl. 33).

Additional reference section – Well Hellevoetsluis-1, 217-337 m, coord. N 51°51′28.4″, E 04°10′20.2″ (encl. 33).

Subdivision – No formal subdivision of the Formation is in use. The *Lievelde Member* in the Achterhoek region (VAN DEN BOSCH ET AL., 1976) is considered to be a continental deposit.

Remarks – The Formation is exposed at a locality close to Nieuwnamen in the southern part of the province of Zeeland. It is present in the subsurface over the greater part of The Netherlands, but passes laterally into continental deposits of the Scheemda Formation and Kieseloölite Formation in the northeastern, eastern and southeastern parts of the country. In the southern part of the country the continental upper clay member of the Kieseloölite Formation (*Reuver Clay Member*) grades laterally into the marine clay beds at the top of the Oosterhout Formation.

MAASSLUIS FORMATION (NUMS)

Name – Named after the municipality of Maassluis in the province of Zuid-Holland.

Definition – Sequence of marine coarse- and fine-grained sands containing shells and shell fragments, and with some intercalated sandy clays and clay lenses. Glauconite is sparse or absent. The Formation overlies the clays or sandy clays of the Oosterhout Formation, and is overlain by continental beds of Quaternary age.

Age – Early Pleistocene.

Reference section – Well Gaag-1, 113-231 m, coord. N 51°57′15.4″, E 04°14′15.5″ (encl. 33).

Additional reference section – Well Rijsbergen 50A/154, 60-77 m, coord. N 51°30′50.5″, E 04°39′15.4″ (encl. 33).

Remarks – The Formation is present in the subsurface over most of The Netherlands, but is absent in the eastern, southeastern and extreme southwestern parts of the country. The lower boundary is taken at the base of sands overlying the clays of the Oosterhout Formation. The top of the Formation is taken at the uppermost occurrence of sands, or locally clays, containing marine shells, and which are overlain by continental beds of Early Pleistocene age.

HEKSENBERG FORMATION (NUHG)

Name – Named after Heksenberg, a village near Heerlen in the province of Limburg.

Definition – Sequence of continental quartz sands (with brown coal seams), over- and underlain by marine beds of the Breda Formation (KUYL, 1975).

Age – Early Miocene.

Reference section – Well Asten-1, 722-800 m, coord. N 51°23′47.8″, E 05°47′27.4″ (encl. 33). (intertonguing with Breda Formation).

Remarks – The Formation has a restricted distribution in the southeastern Netherlands, notably in southern Limburg. It consists of sands, which in some places are very pure white quartz sands, but locally they can be very humic. Several brown coal seams occur which continue eastwards into Germany where they form part of the Niederrheinische Braunkohlen Formation. This Formation has, however, a wider stratigraphic age range than the Heksenberg Formation, namely from Middle Oligocene to Late Miocene. The most prominent seams are the Morken and Frimmersdorf seams.

According to their sedimentary structures in some places the lower sands of the Formation were deposited in a beach or tidal flat environment. Marine fossils are, however, absent.

KIESELOÖLITE FORMATION (NUKØ)

Name - The name is well established in Dutch stratigraphy and is based on the presence of oölitic chert pebbles in gravels.

Definition - Sequence of continental gravels, sands and clays which overlie the marine beds of the Breda Formation and underlie non-marine Quaternary deposits. They were deposited by an ancient River Rhine system.

Age - Late Miocene and Pliocene, locally earliest Pleistocene.

Reference section - Exposures east of Reuver in Germany and near Schinveld and Brunssum in southern Limburg.

Subdivision - The Formation is subdivided into several sand, gravel or clay members. The most complete sequence (from southern Limburg) is from top to bottom : *Meinweg-Reuver Clay Member, Schinveld Sand Member, Brunssum Clay Member, Waubach Sand Member, Waubach Gravel Member* (ZAGWIJN & VAN STAALDUINEN, 1975).

Remarks - The Formation is restricted to the surface and subsurface of the southeastern Netherlands and the adjoining area in Germany (Lower Rhine Embayment). The sands and gravels are rich in quartz and, according to their heavy mineral and gravel assemblages, were deposited by an ancient River Rhine system. The clays are very compact and often very organic. Thin brown coal seams may be intercalated in the clay members.

The Formation intertongues with the upper part of the Breda Formation and with the Oosterhout Formation. The Reuver Clay Member grades laterally into marine upper clay beds of the Oosterhout Formation of the southern and southwestern Netherlands.

SCHEEMDA FORMATION (NUSA)

Name - Named after the municipality of Scheemda in the province of Groningen.

Definition - Sequence of continental sands with occasional gravel and clay beds. The Formation lies between the marine beds of the Breda Formation and non-marine Quaternary deposits, and was deposited by ancient rivers flowing out of northern Germany.

Age - Pliocene, perhaps in parts also Late Miocene.

Reference section - Well Zuidlaren 12E/84, 91.60-151.10 m, coord. N 53°05'28.5'', E 06°42'11.5'' (ZAGWIJN & VAN STAALDUINEN, 1975).

Additional reference section - Well Onnerpolder 12E/16, 114.50-165.00 m, coord. N 53°08'28.6'', E 06°39'52.8'' (op. cit.).

Remarks - The Formation is restricted to the subsurface of the northeastern Netherlands, notably to the provinces of Groningen, Drenthe and the northern part of Overijssel. The sands and gravels are extremely rich in white quartz, and some clay beds and thin brown coal seams occur. The Formation intertongues with the uppermost party of the Breda Formation and with the Oosterhout Formation.

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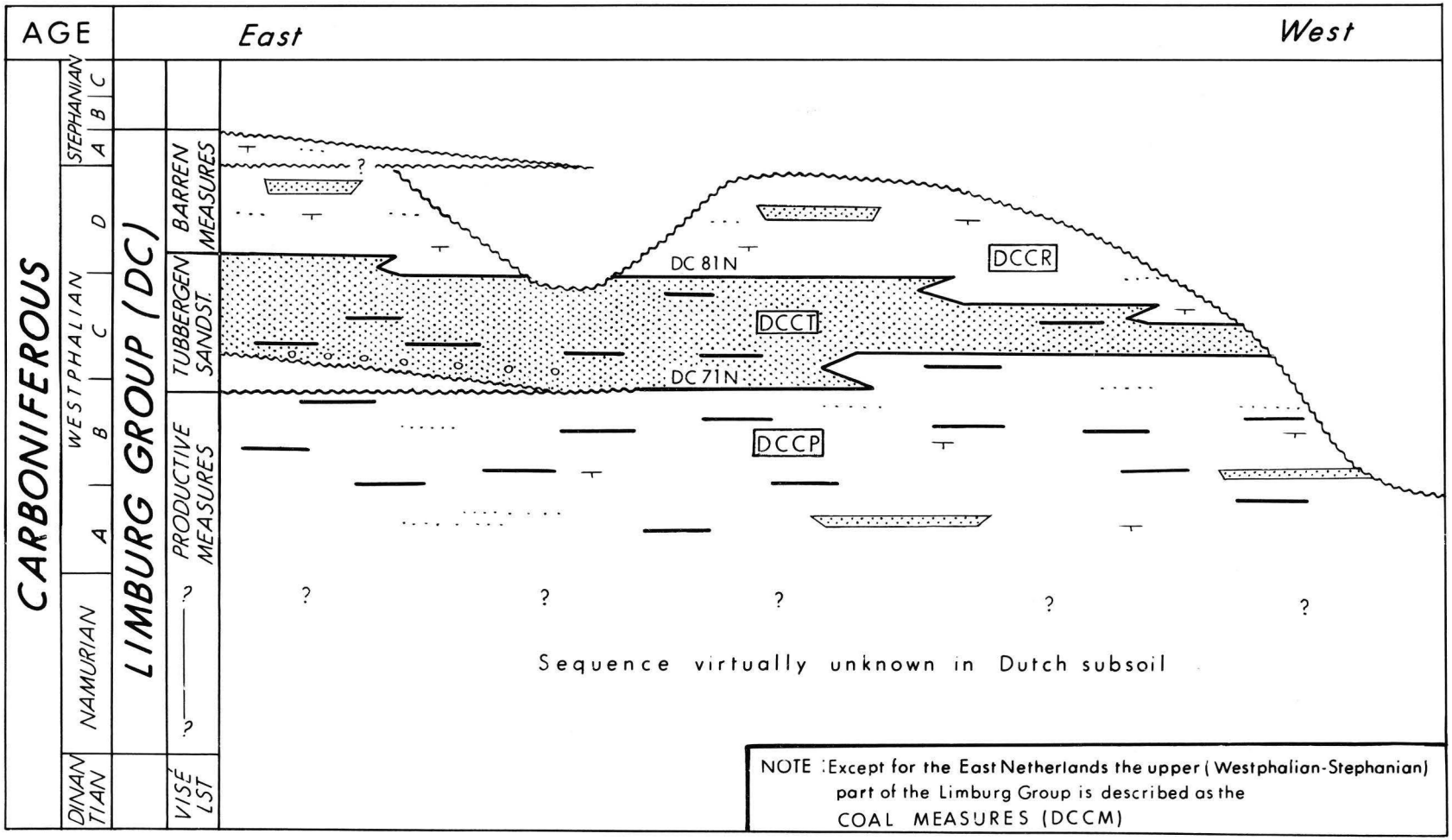
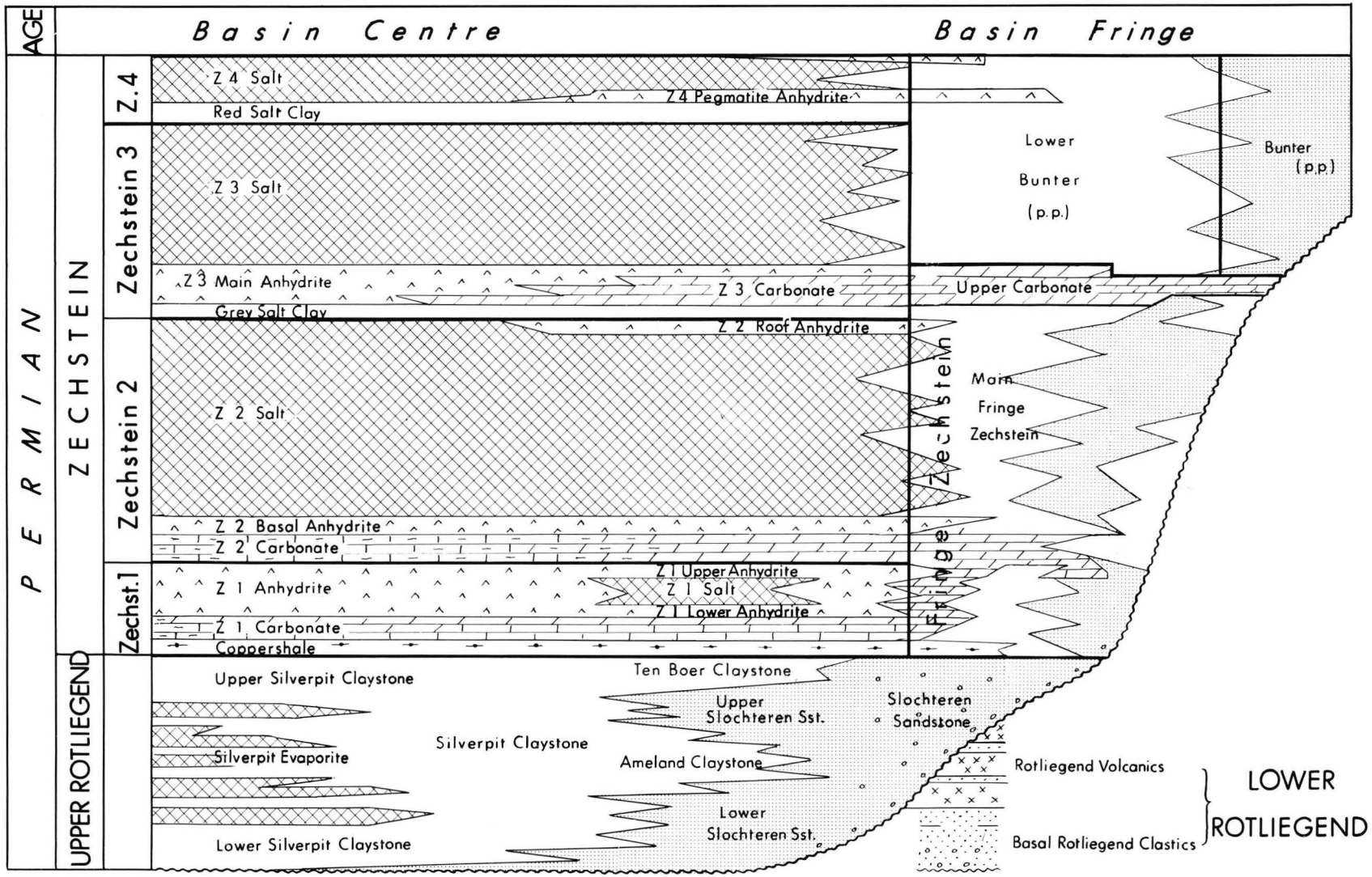
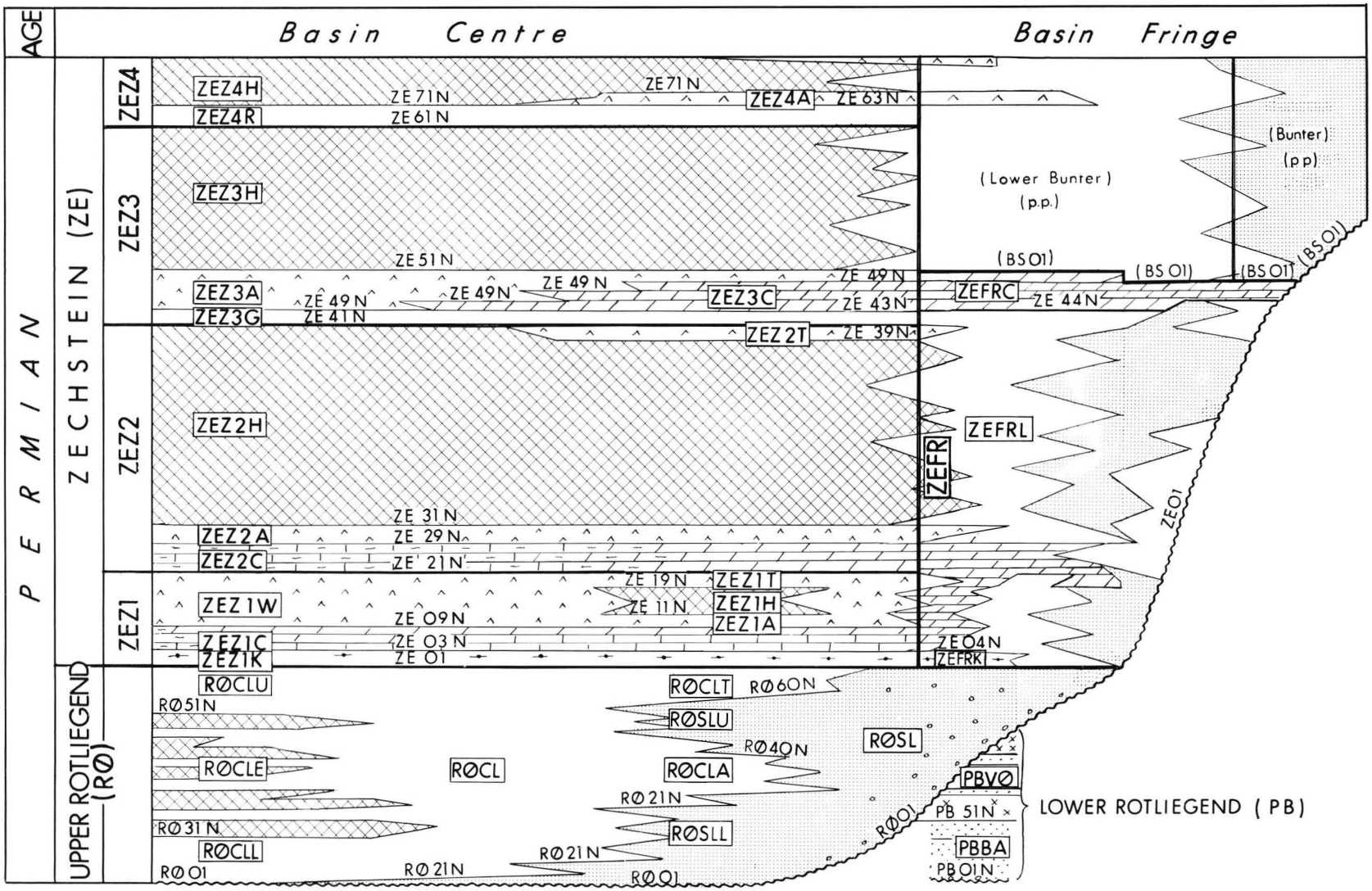


Text figure 4 Rock stratigraphic diagram Limburg Group in the eastern Netherlands (easternmost Overijssel, south-eastern Drenthe)



Text figure 5. Rock stratigraphic diagram of the Rotliegend and Zechstein Groups



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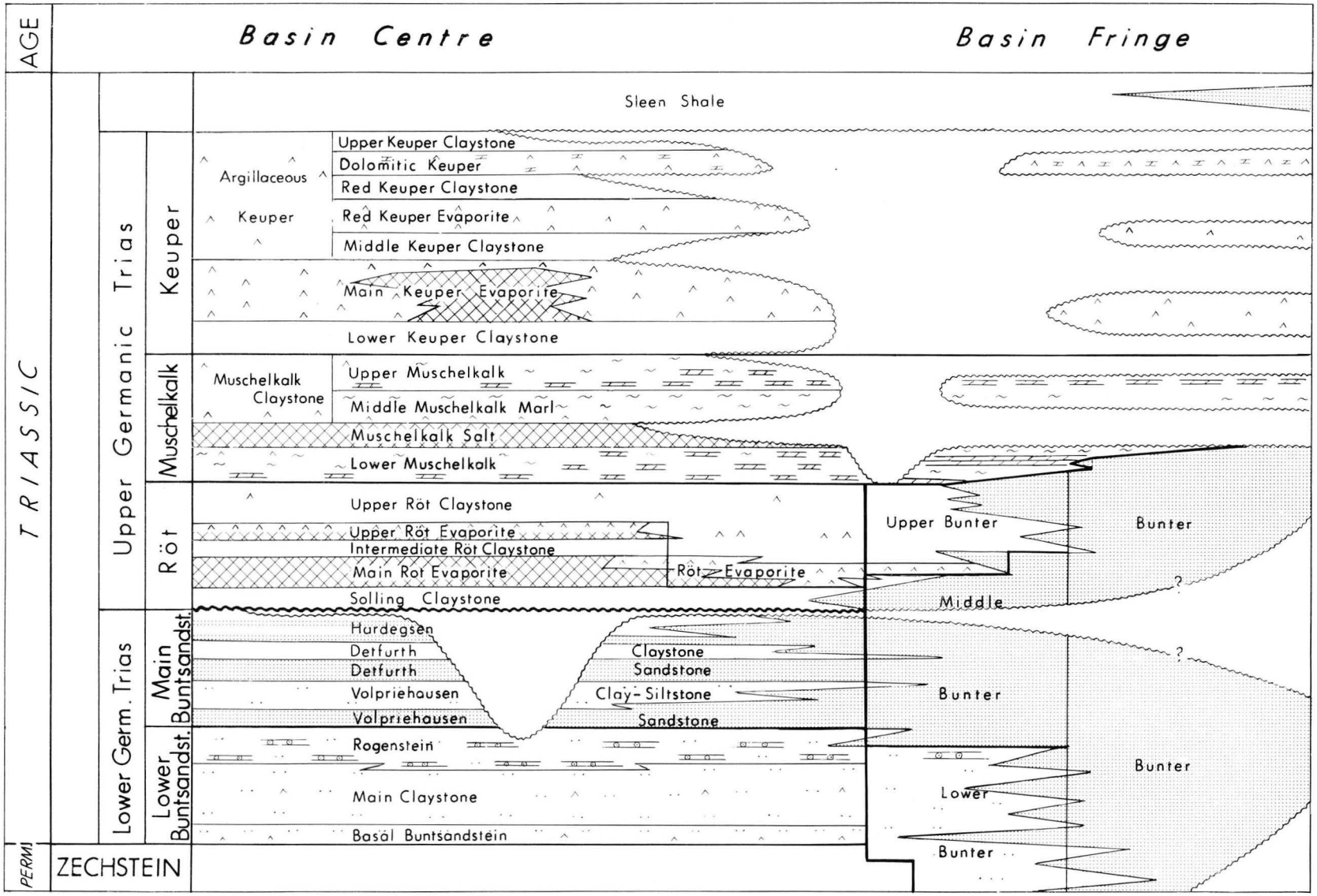
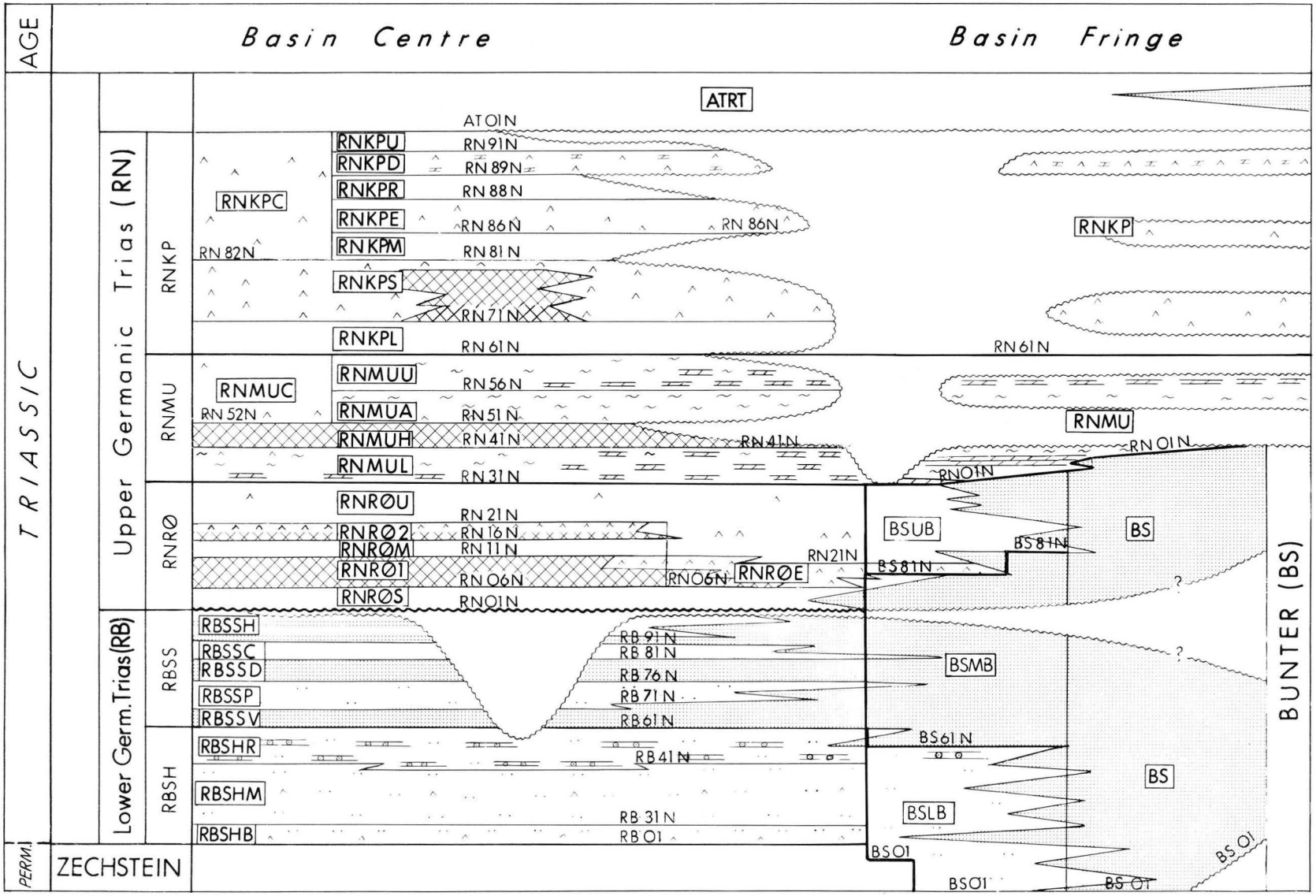
Text figure 6. Codes for the Rotliegend and Zechstein Groups



Text figure 7. Rock stratigraphic diagram of the Bunter, Lower and Upper Germanic Trias Groups



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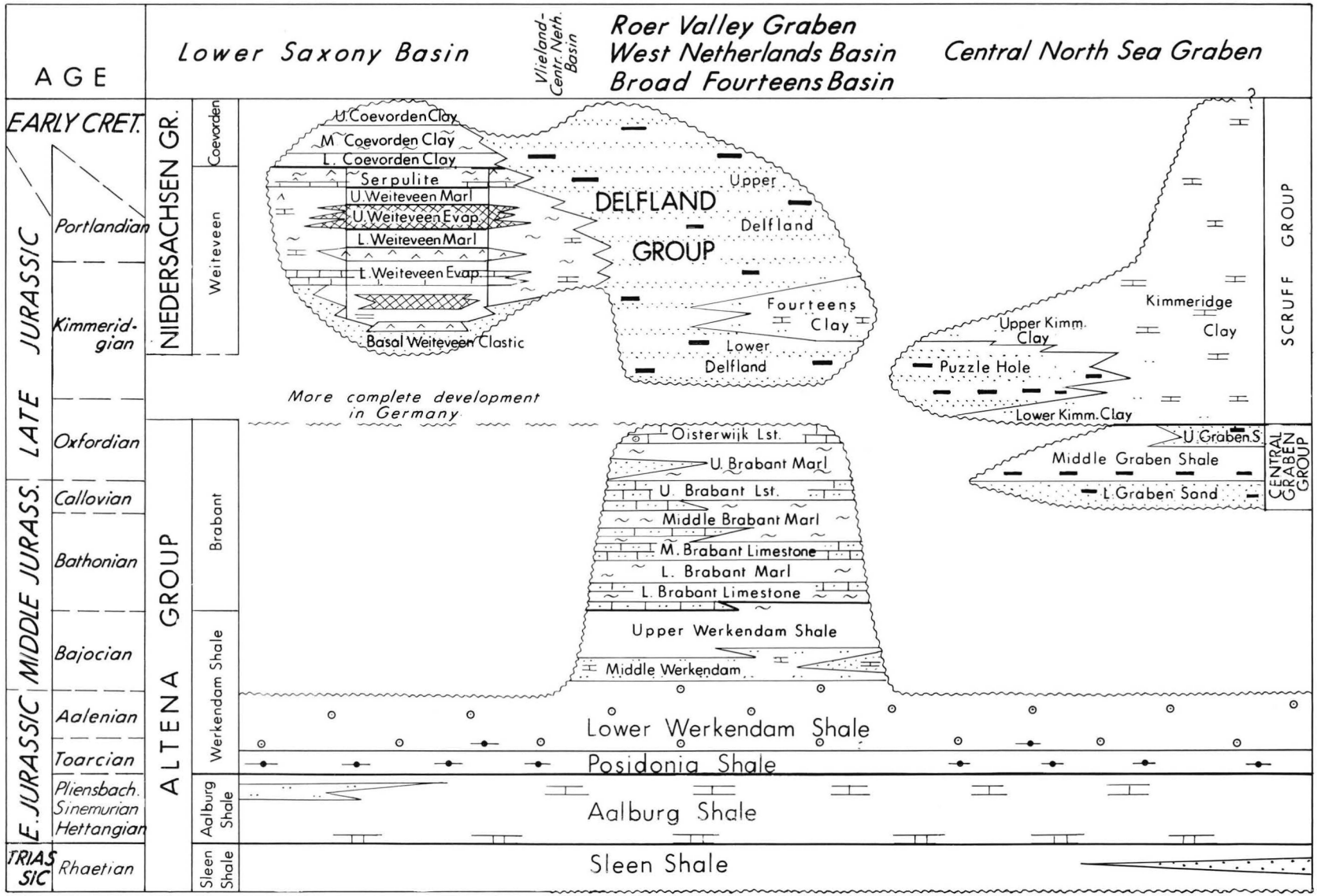

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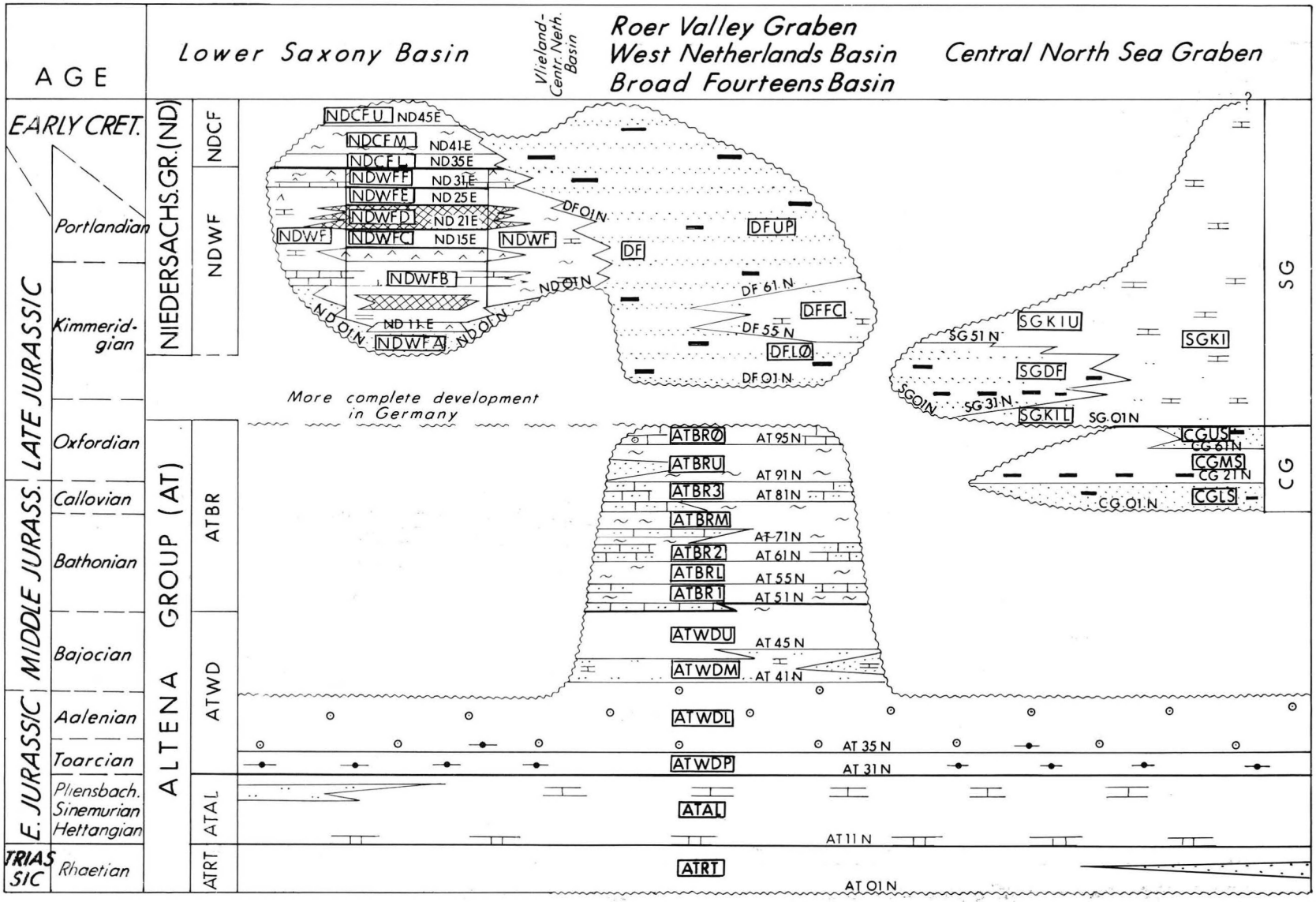

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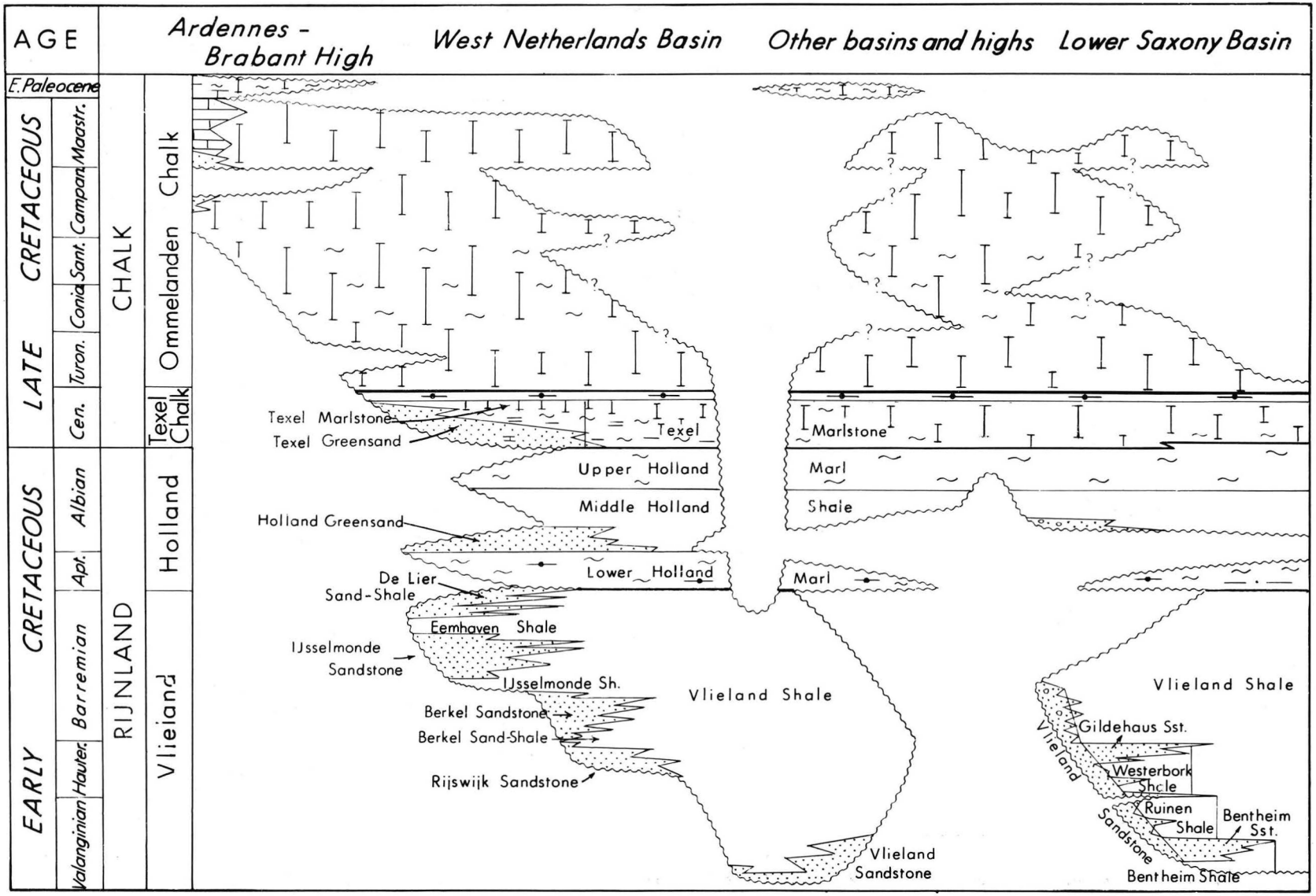
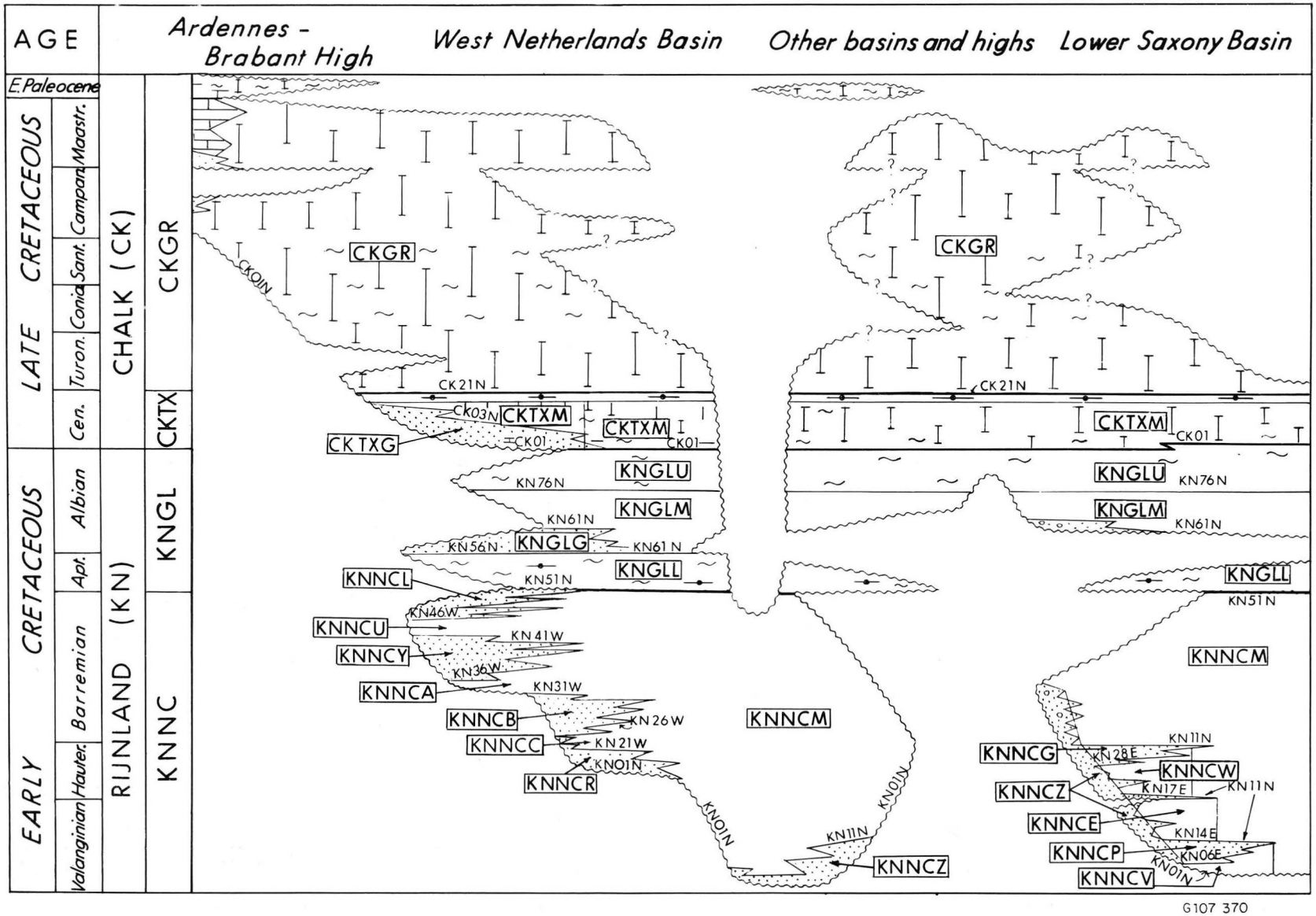


Text figure 11 . Rock stratigraphic diagram of the Rijnland and Chalk Groups



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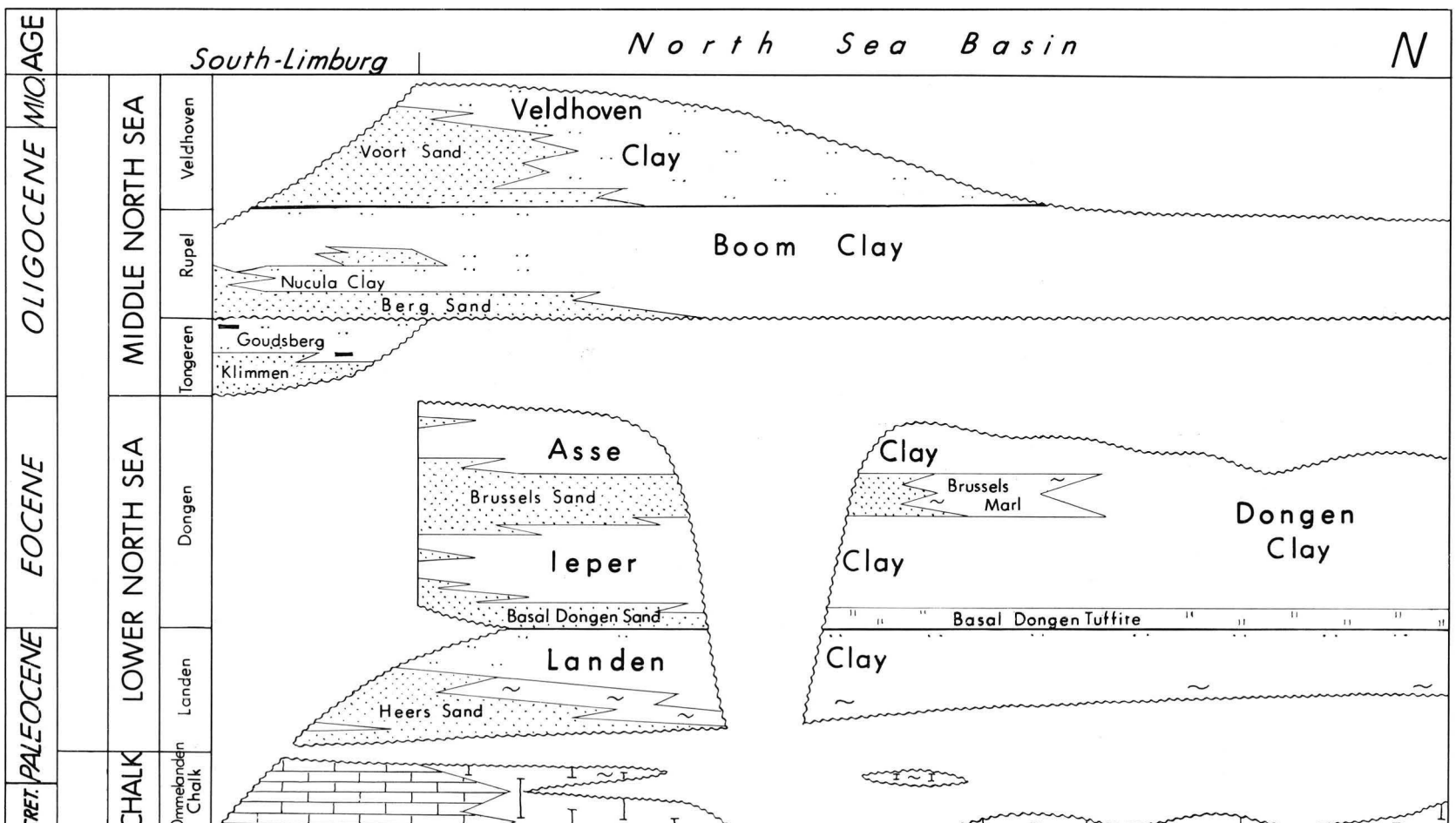
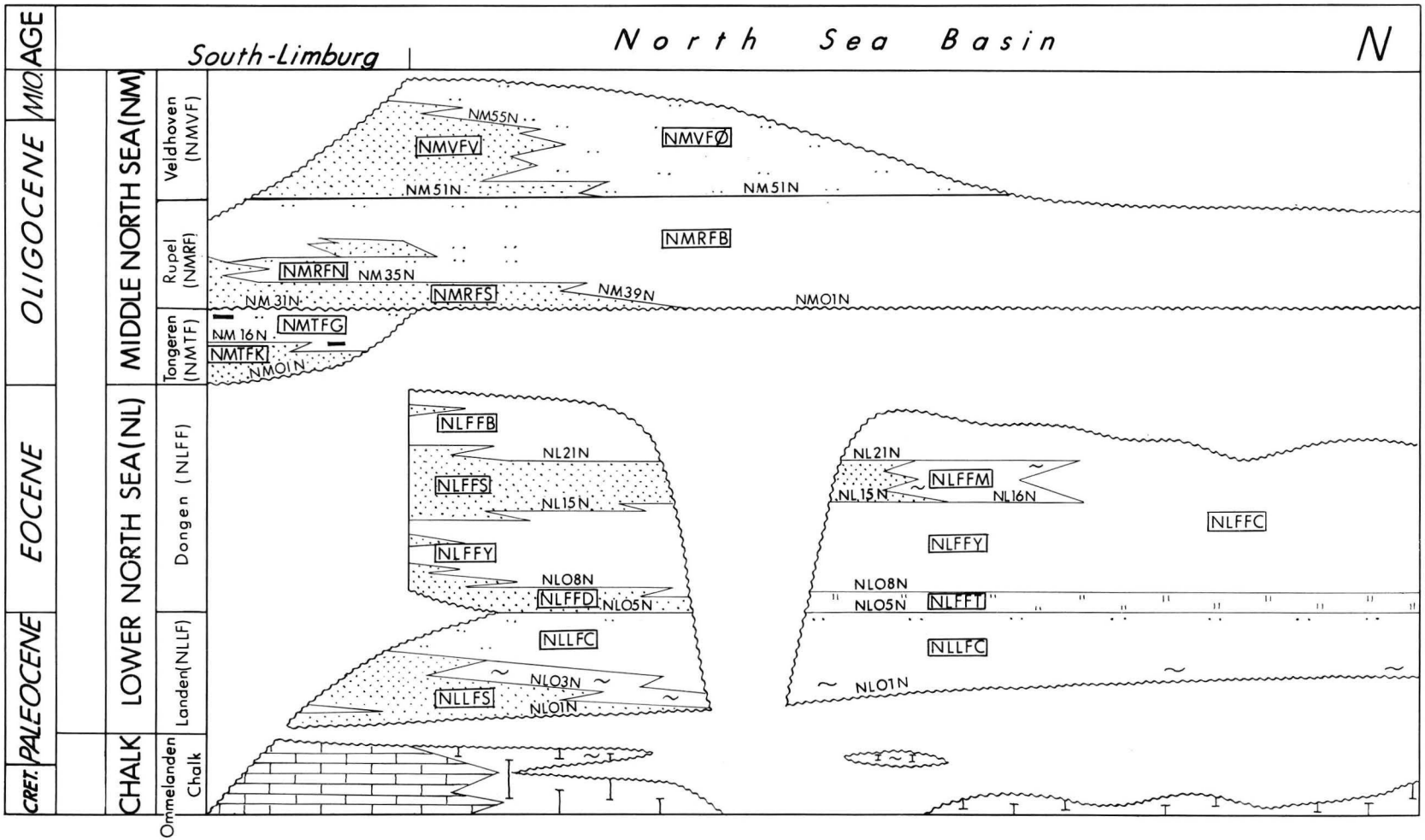
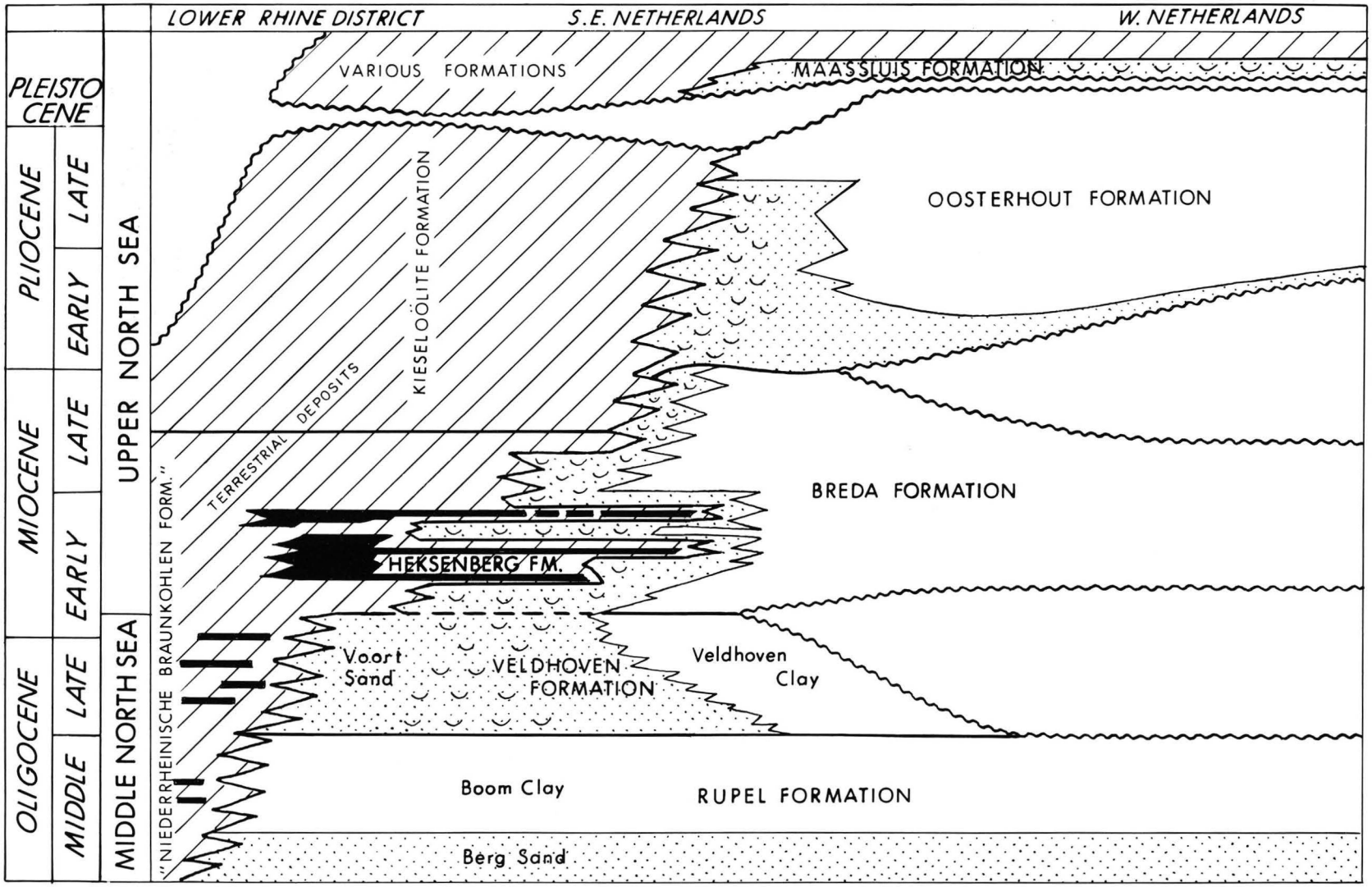


Text figure 13. Rock stratigraphic diagram Lower- and Middle North Sea Groups



Text figure 14. Codes for Lower and Middle North Sea Groups



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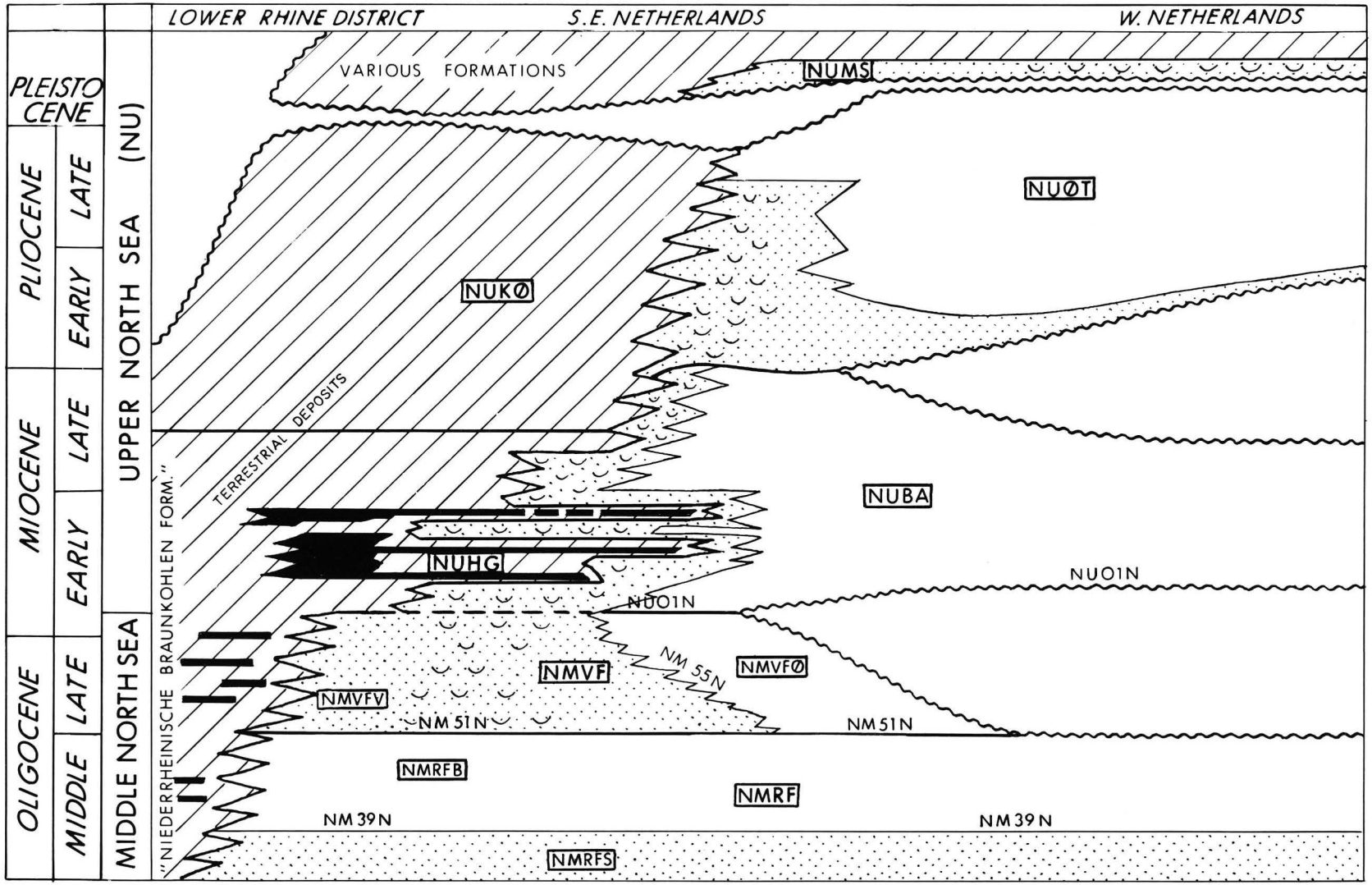

Text figure 16 . Codes for Upper North Sea Group

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INDEX OF LITHOSTRATIGRAPHIC CODES

STRATIGRAPHIC NOMENCLATURE OF THE NETHERLANDS

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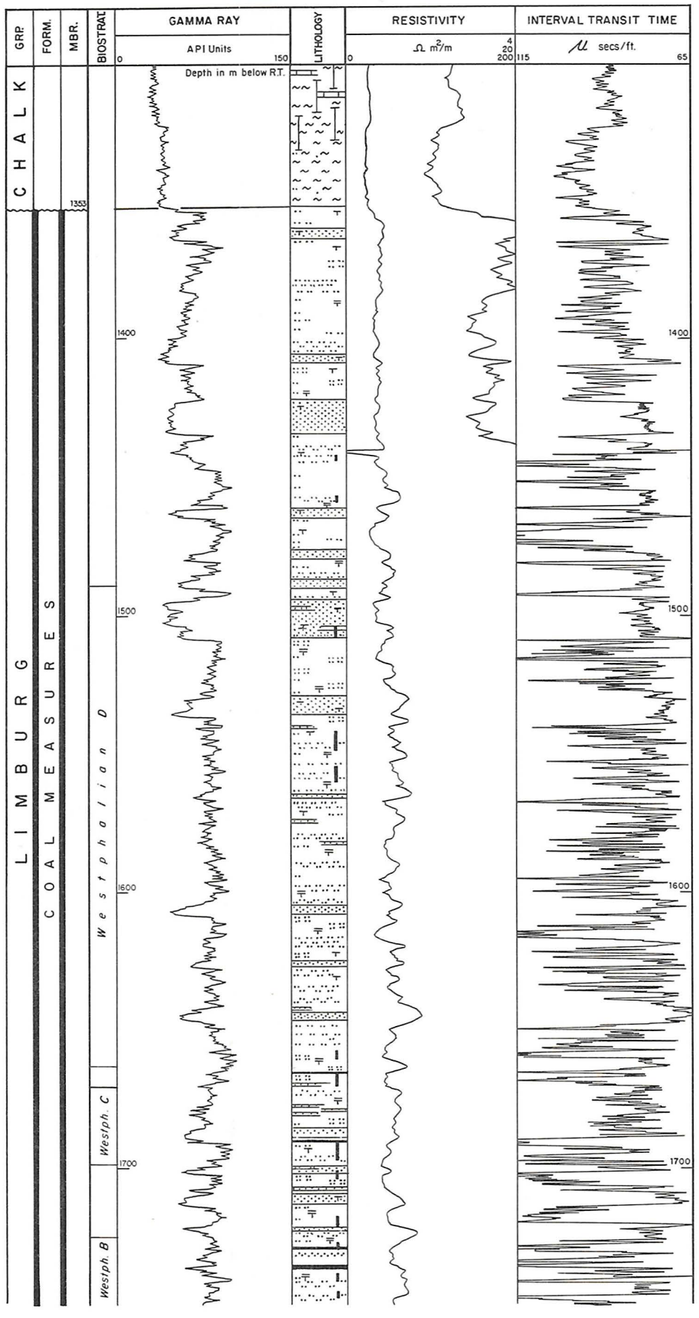

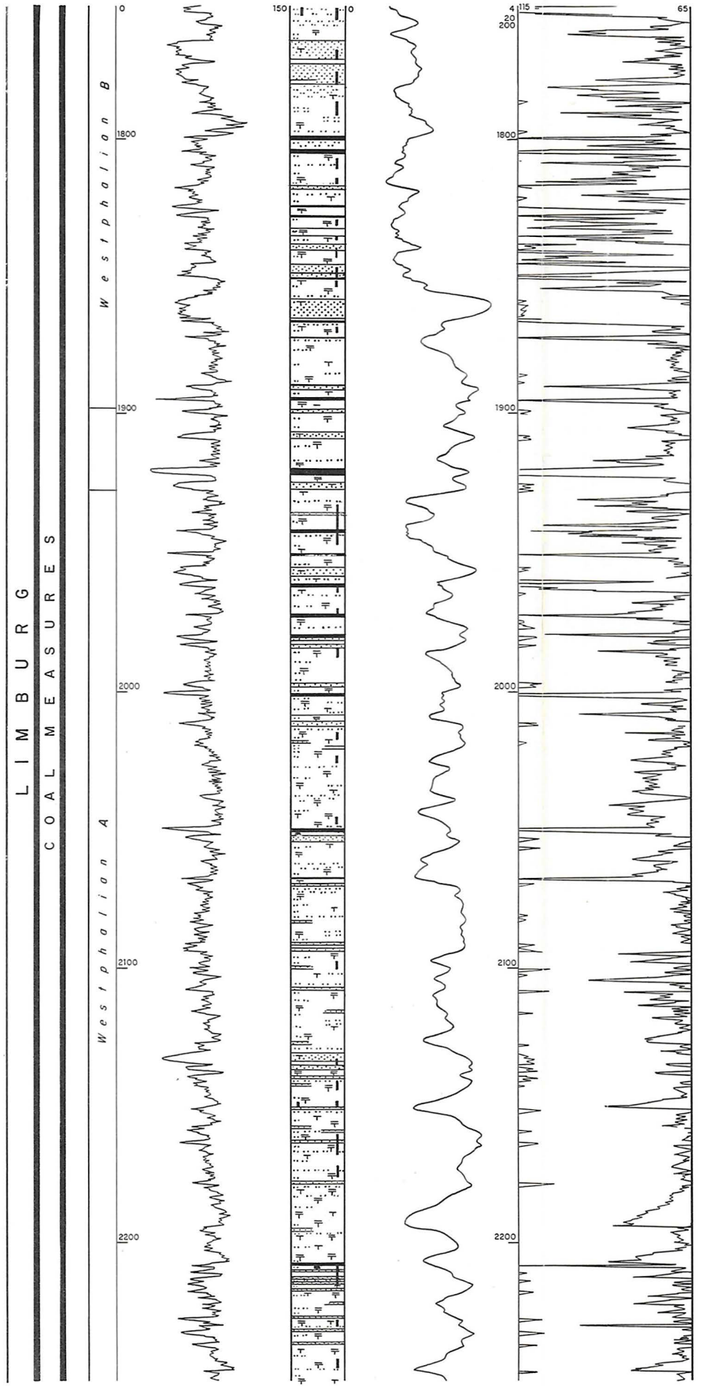

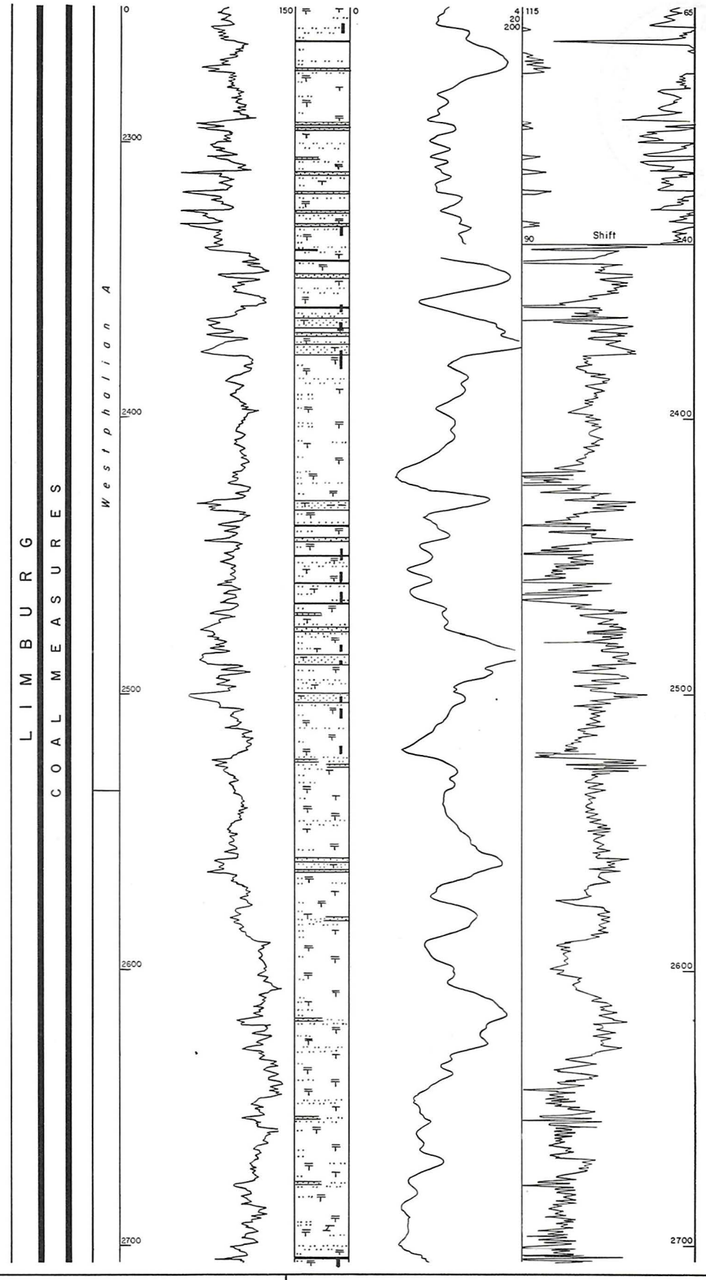

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G.103.544-

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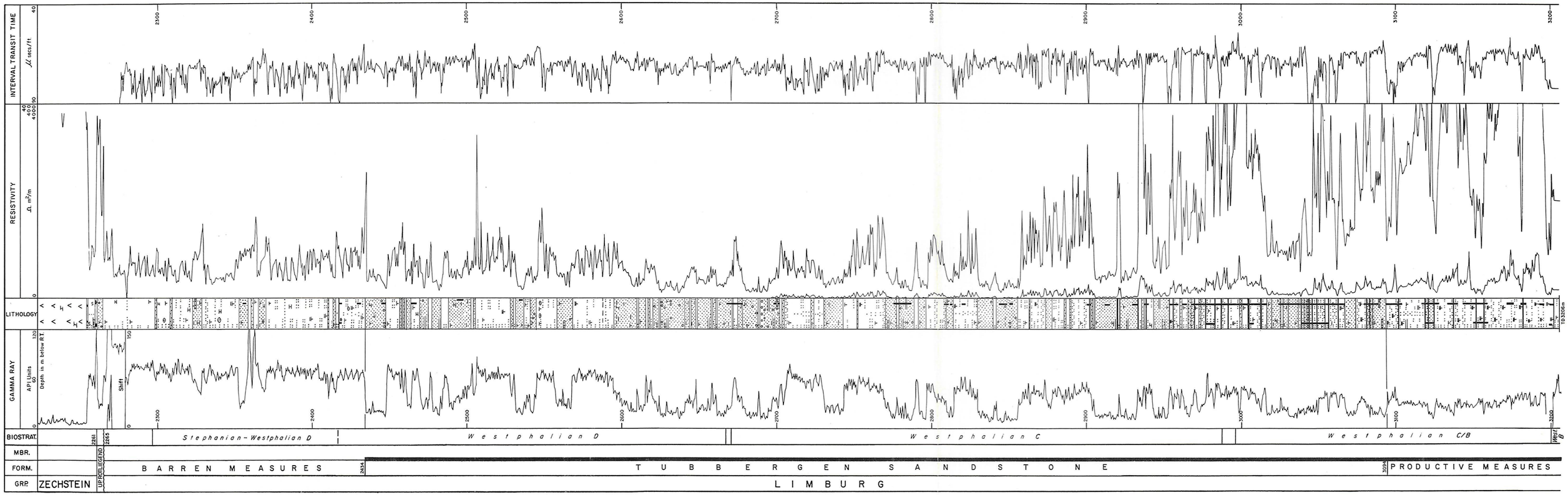

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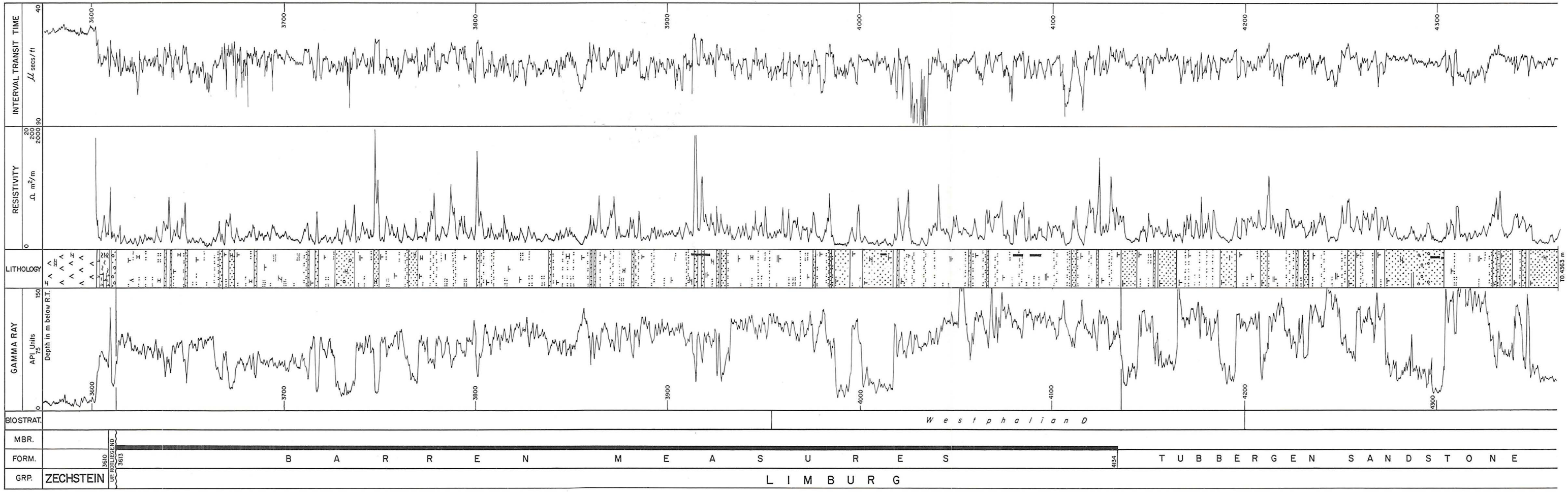

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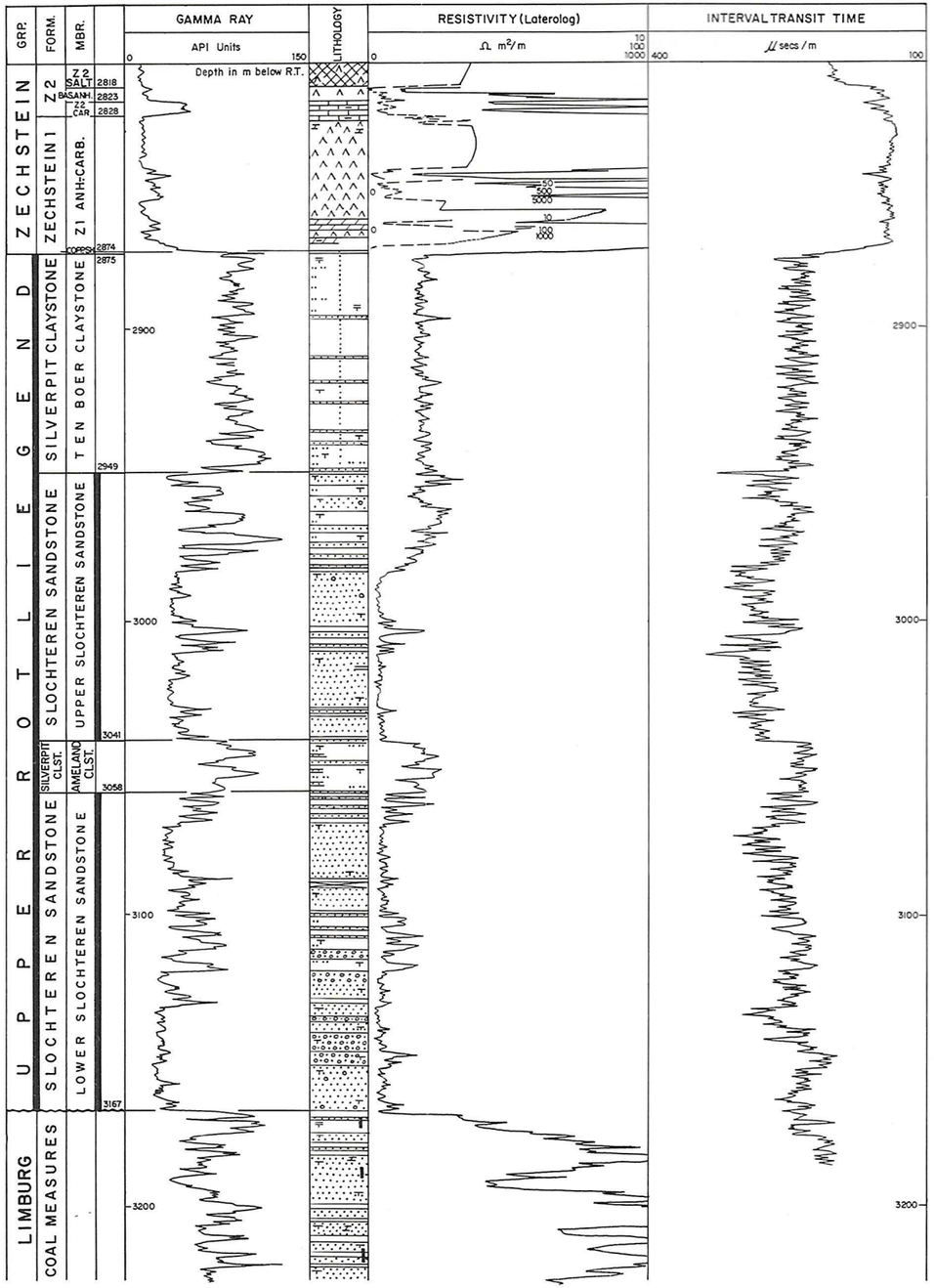

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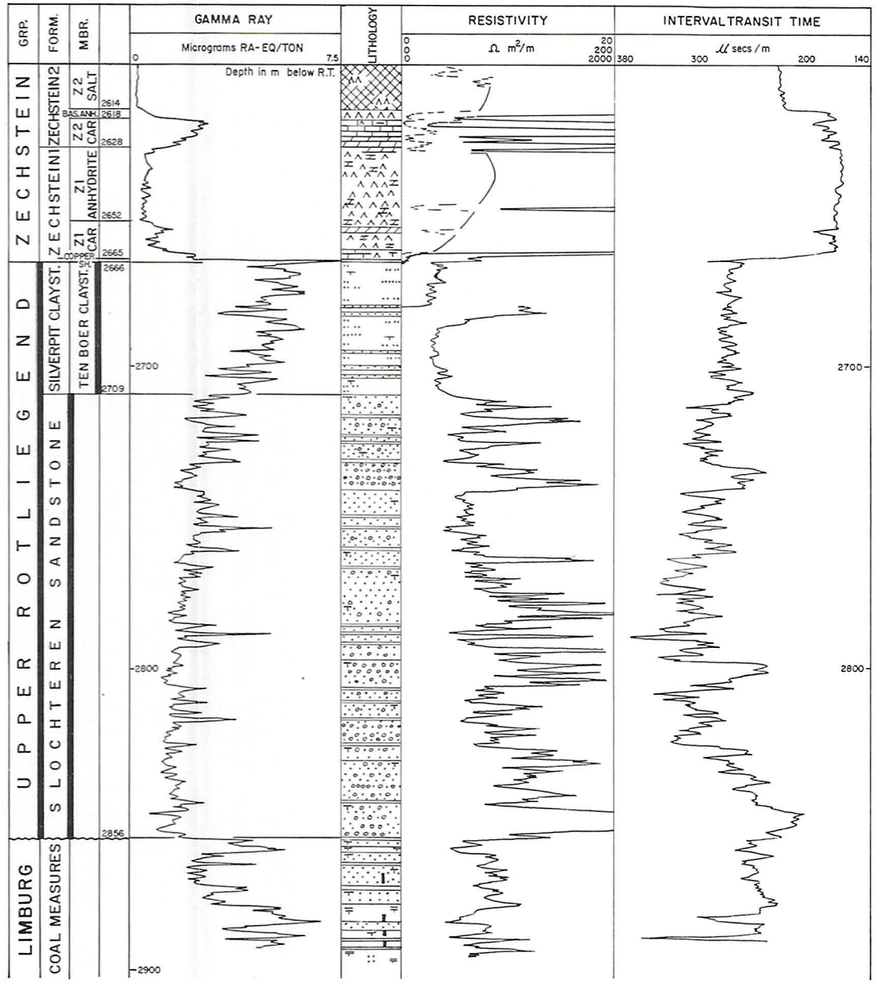

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UPPER ROTLIEGEND

ENCL. 4

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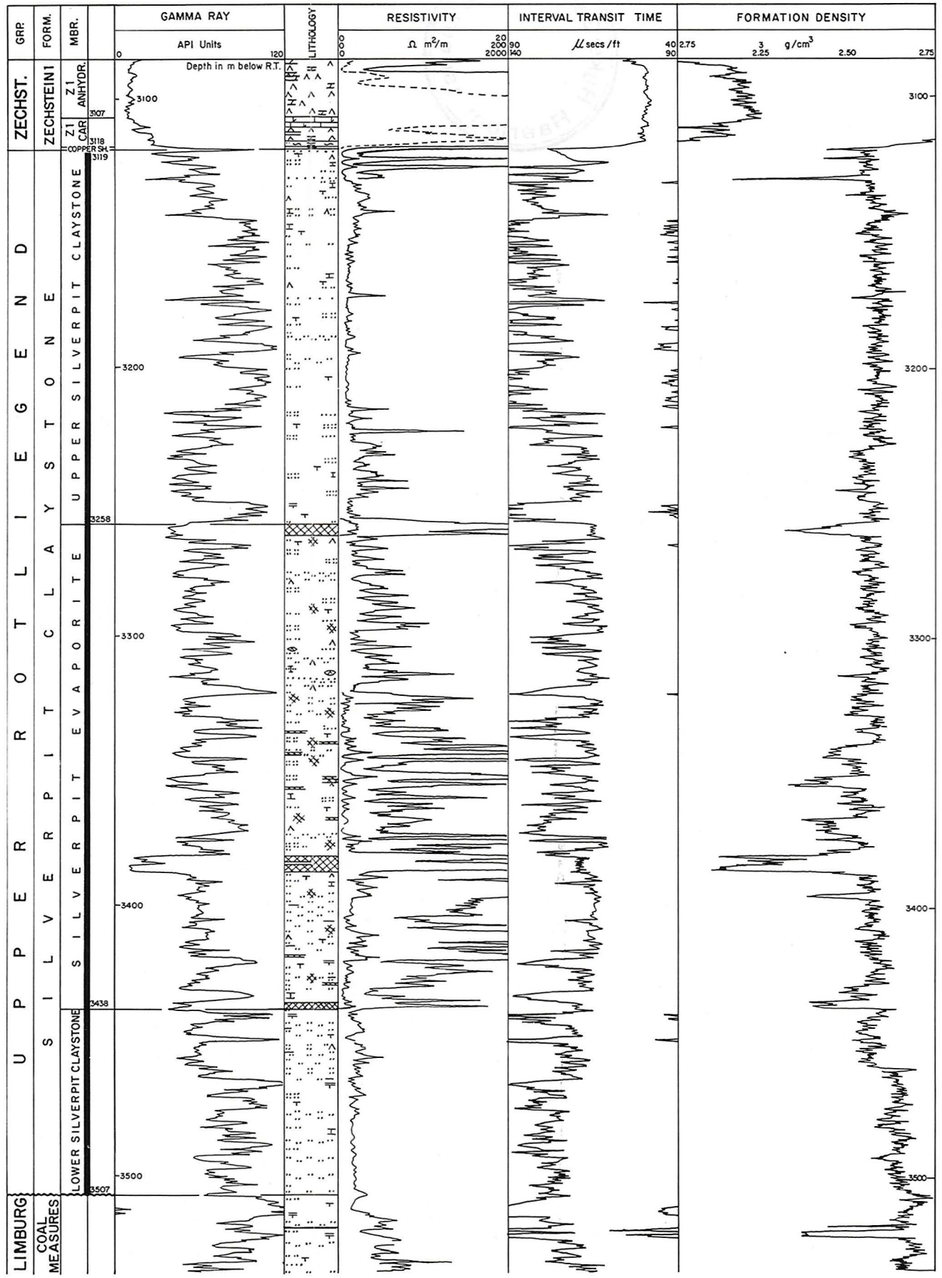

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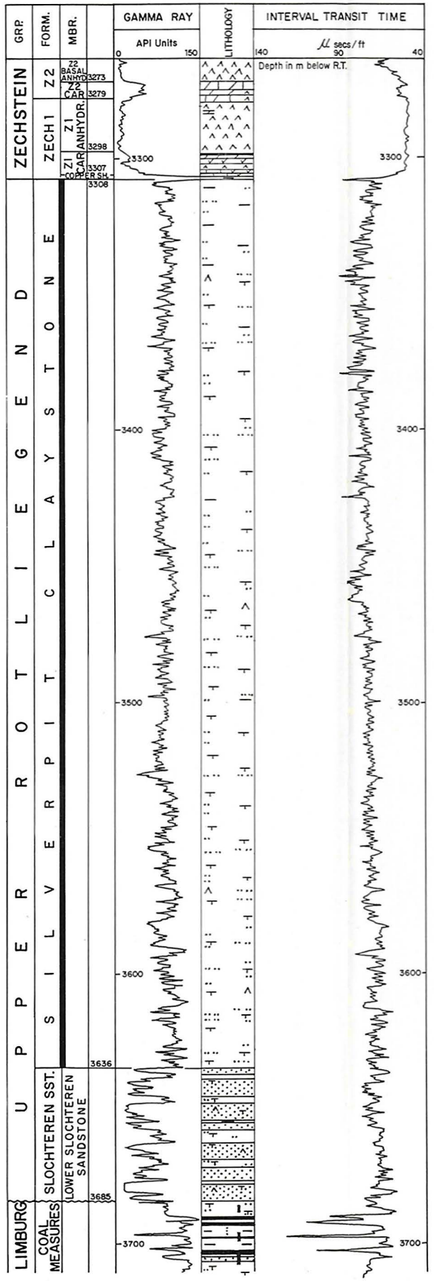

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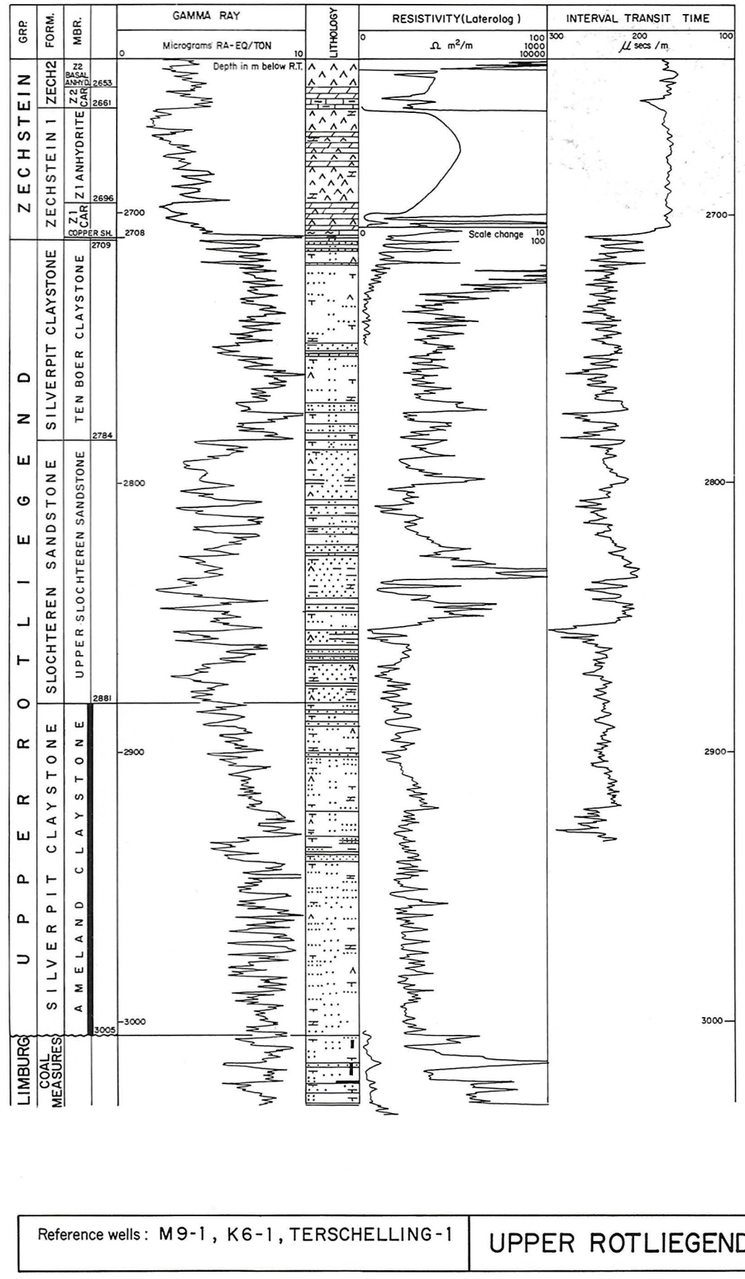

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G. 103.544 –

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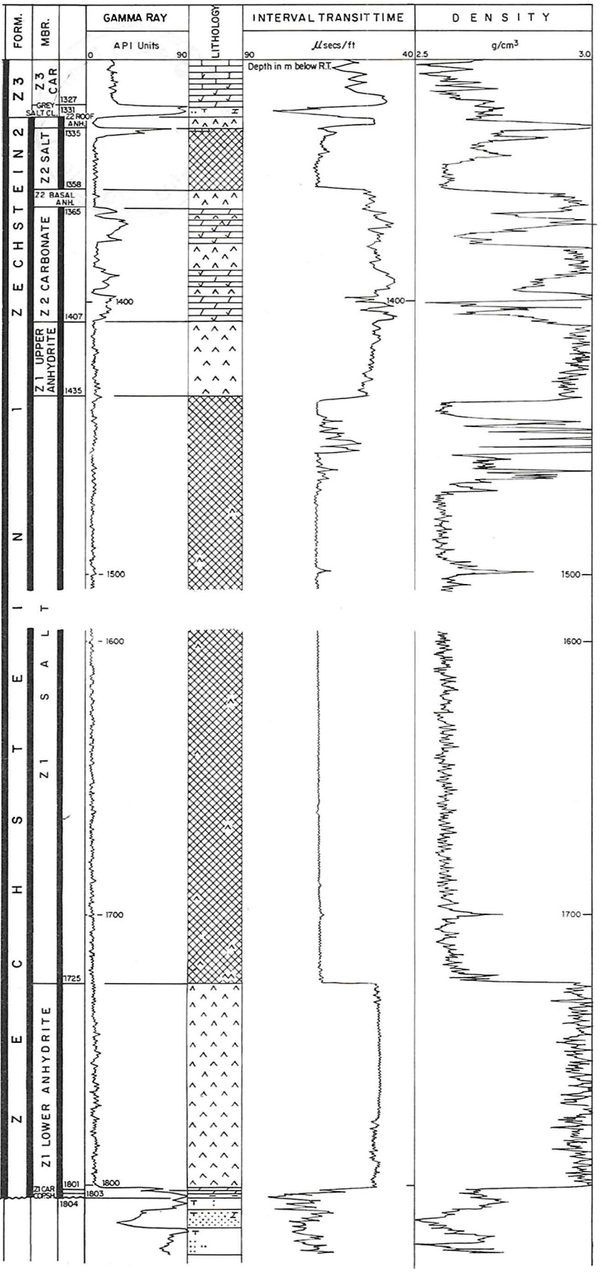

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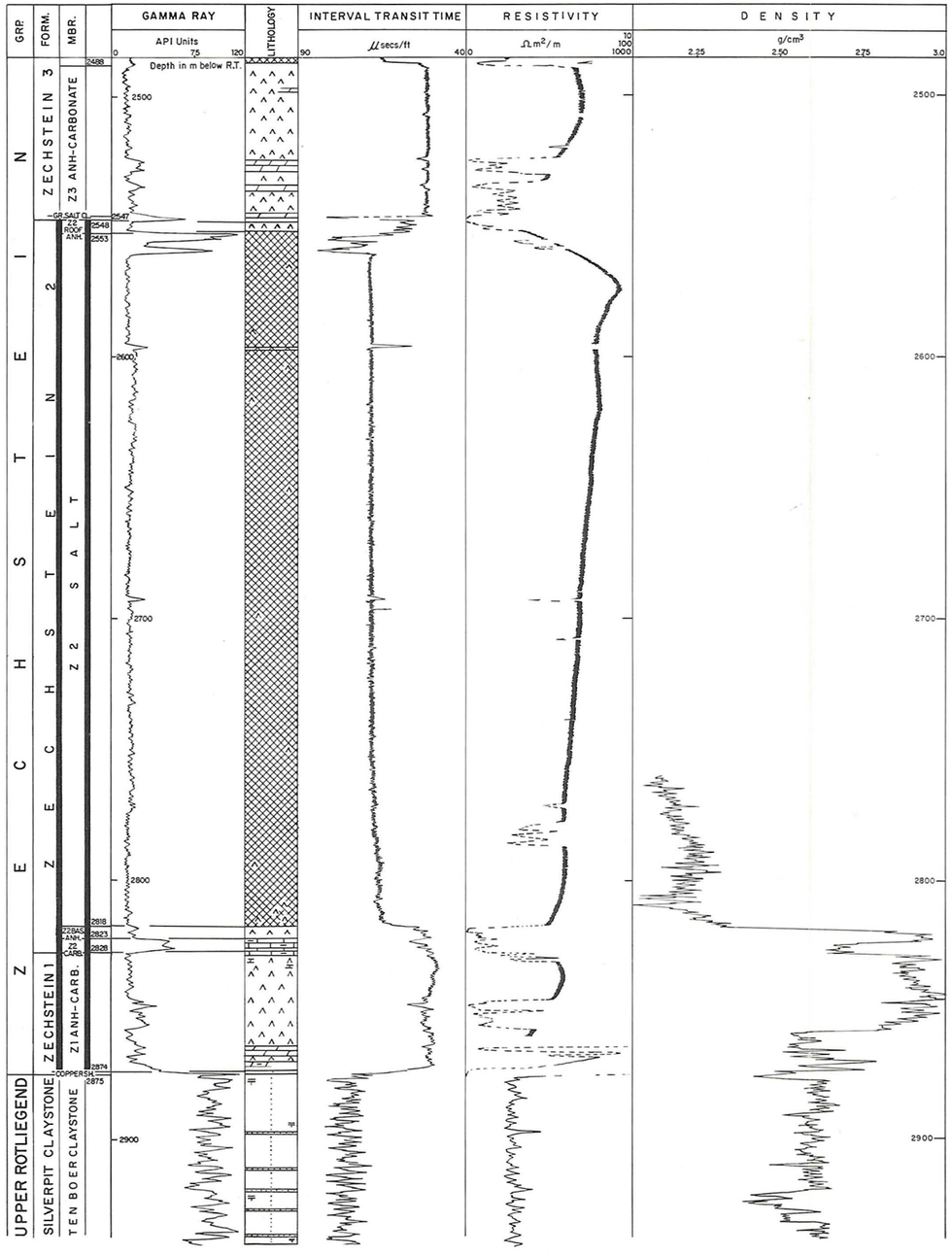

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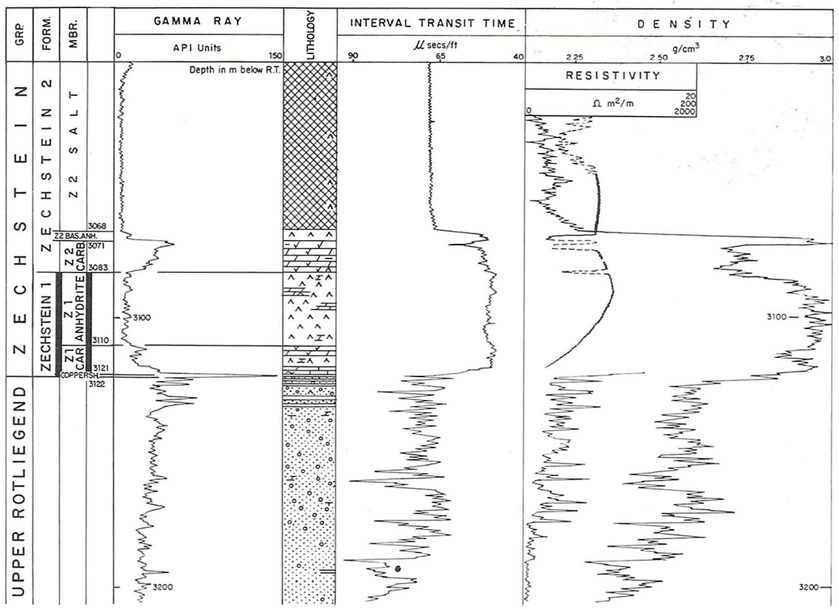

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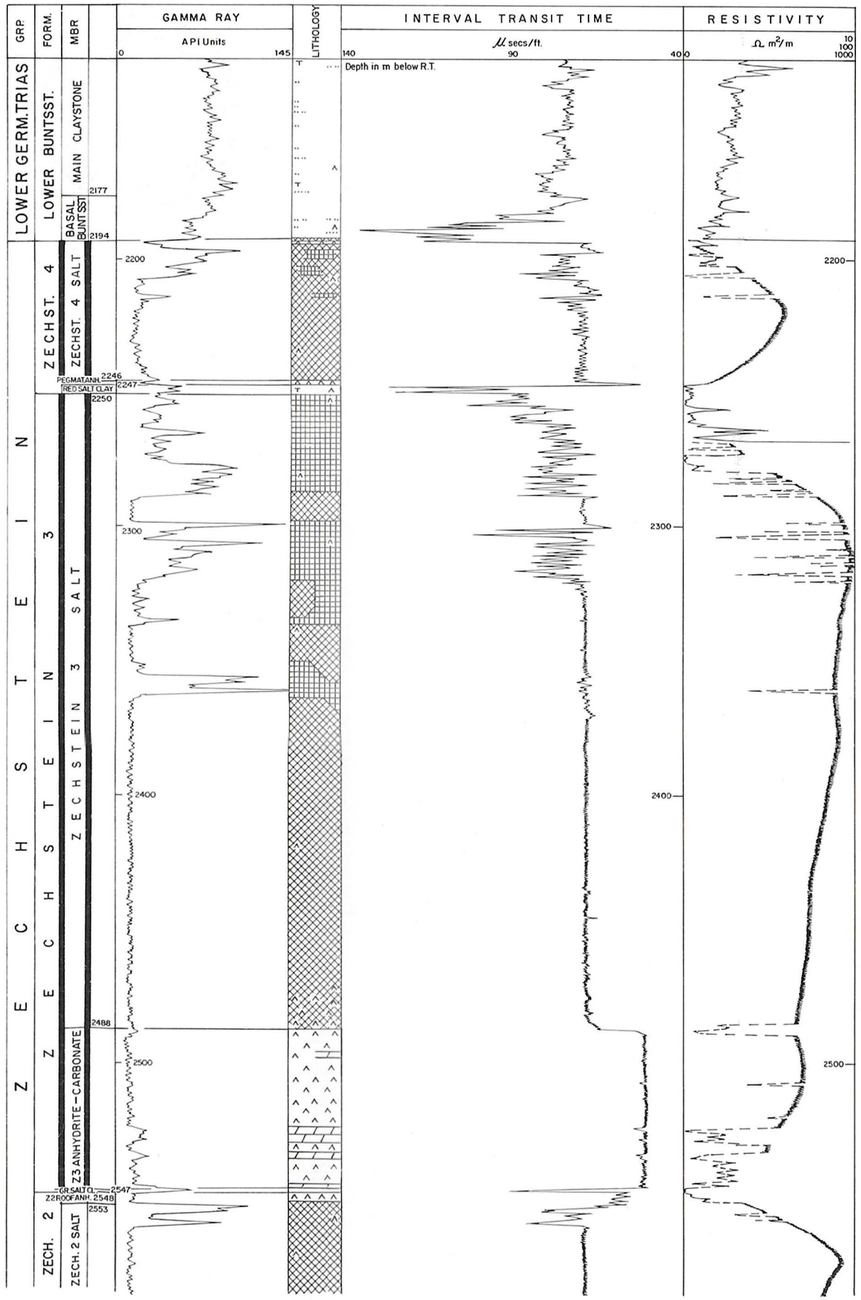
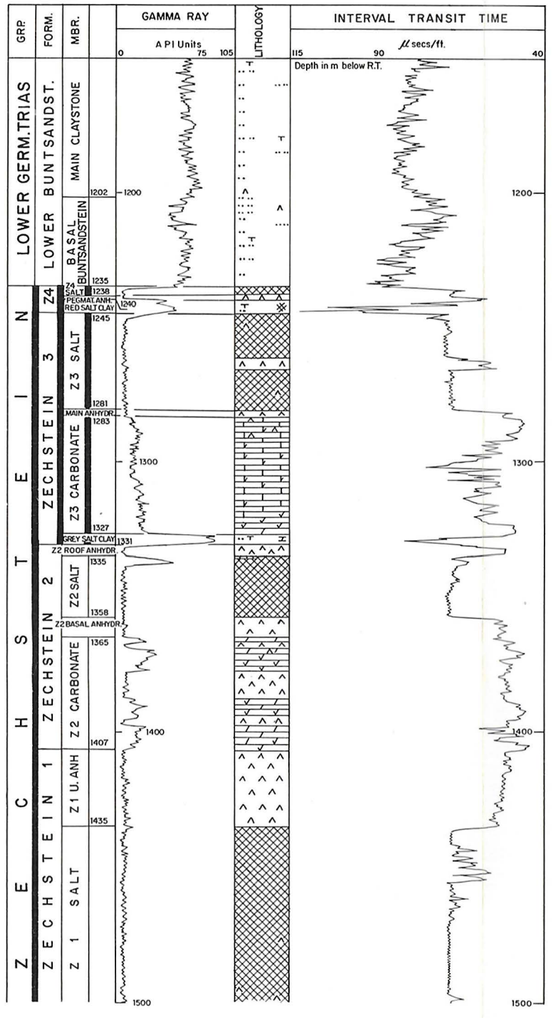
G. 103.544 –

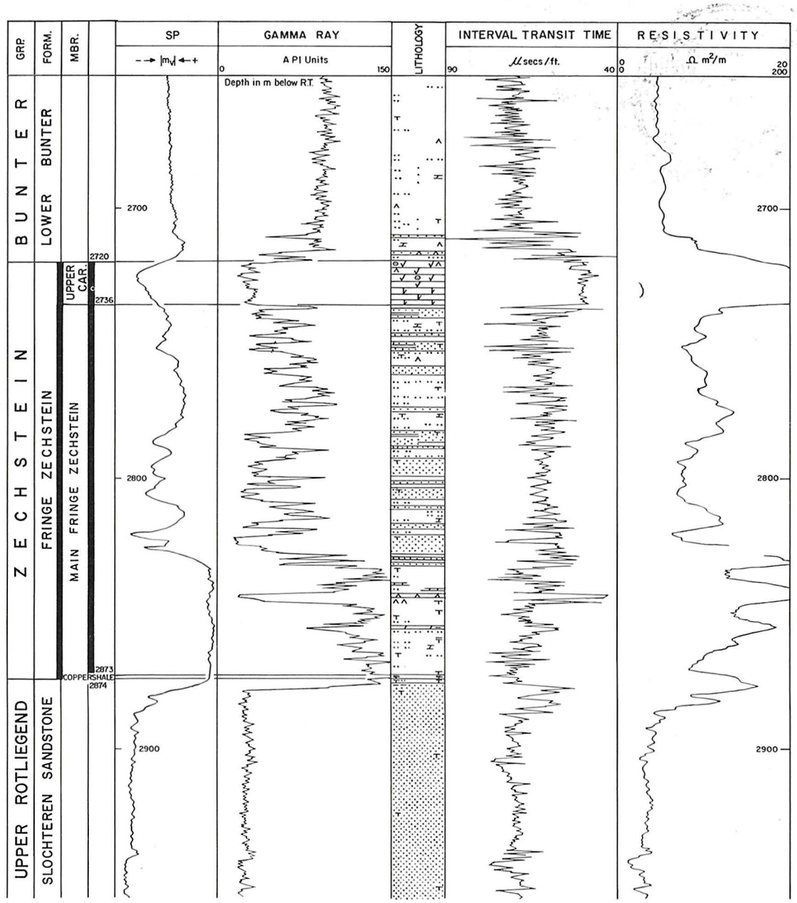
UITHUIZERMEEDEN-1 (NAM)



ROSSUM-WEERSELO-3 (NAM)

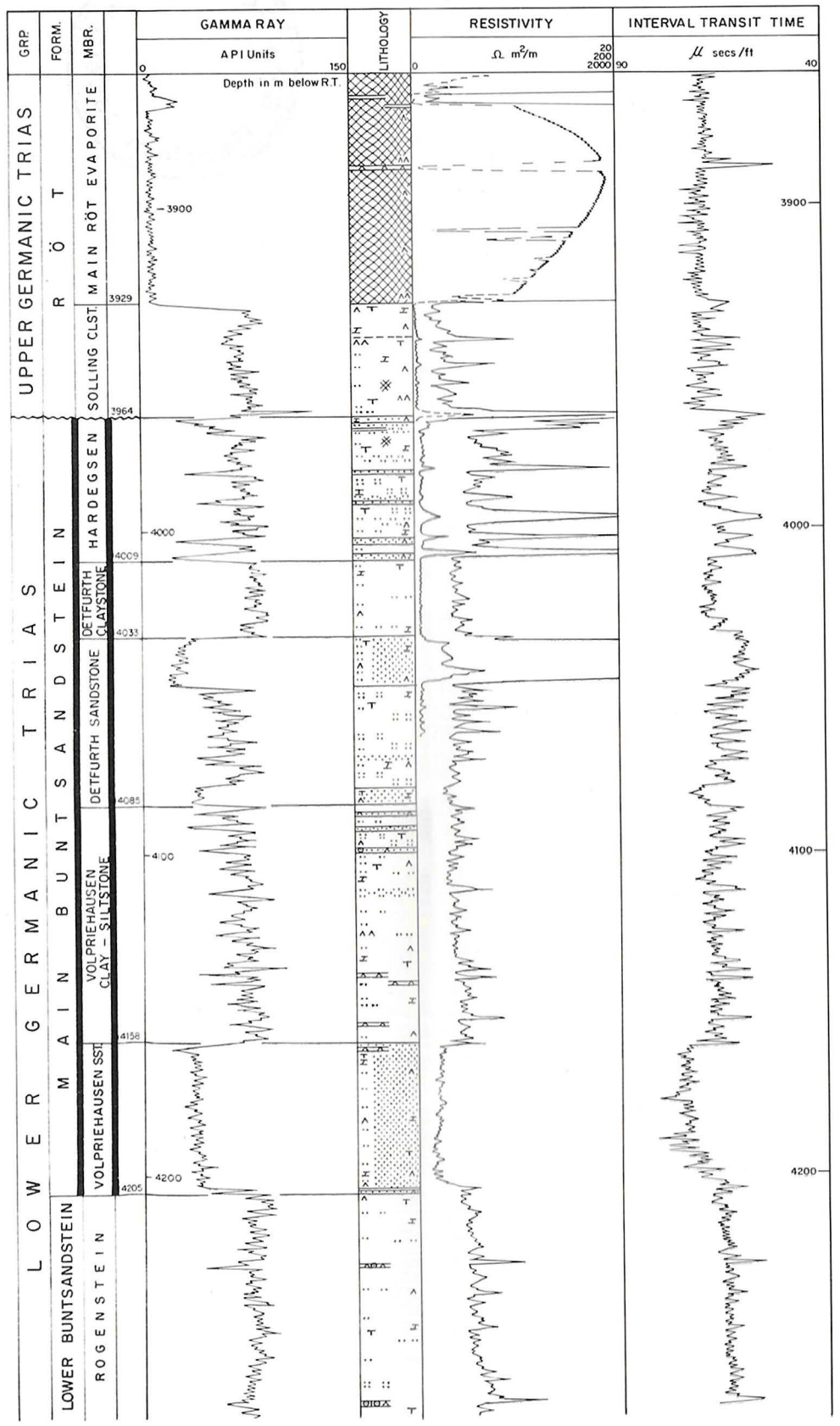


Q 11-1 (3d hole) (NAM- BOW VALLEY)

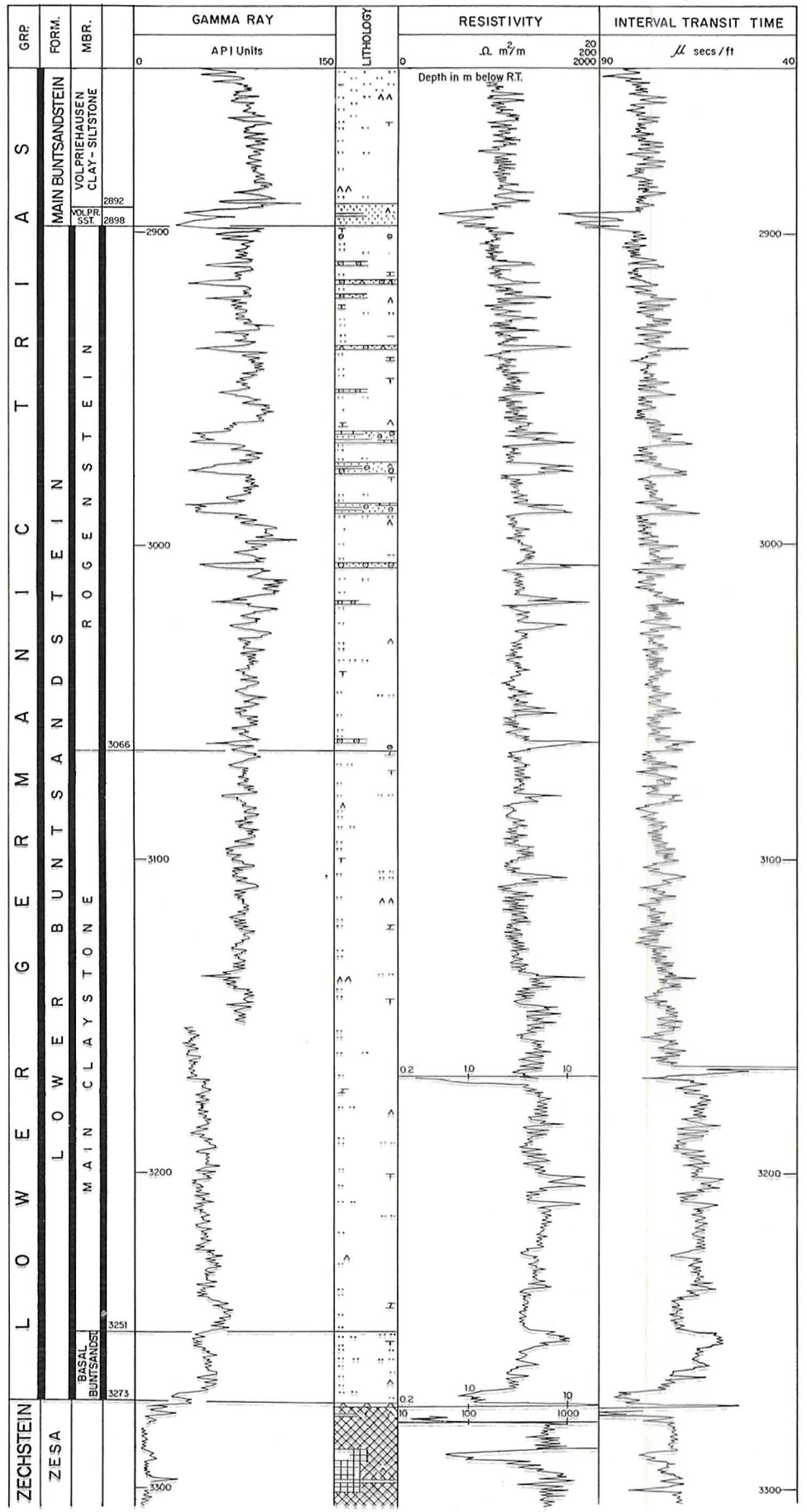


Reference wells : UITHUIZERMEDEN-1 ROSSUM-WEERSELO-3 / Q11-1 (3d hole)	ZECHSTEIN	ENCL. 7

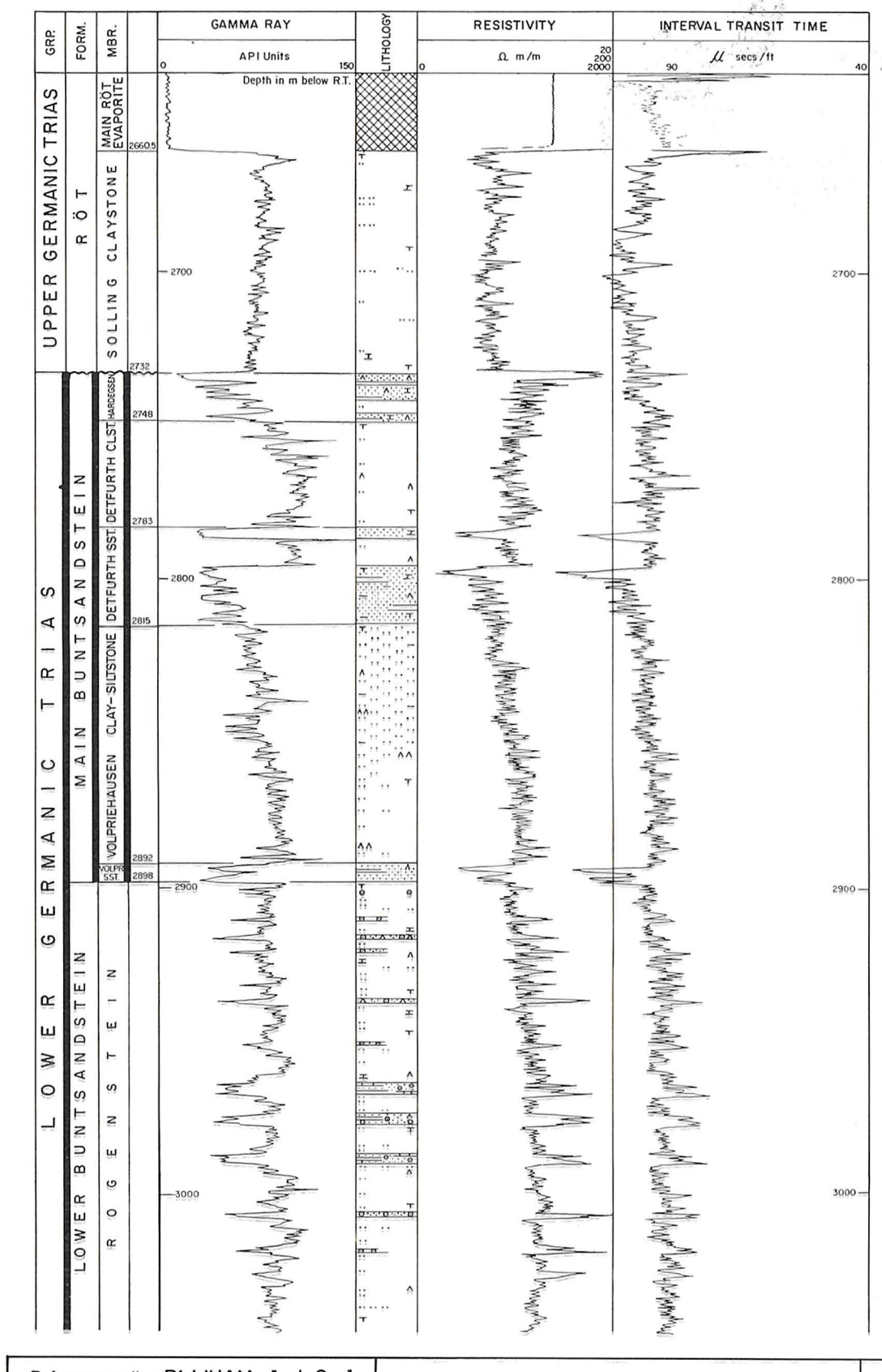
L 2-1 (NAM)



BLIJHAM-1 (NAM)



BLIJHAM-1 (NAM)

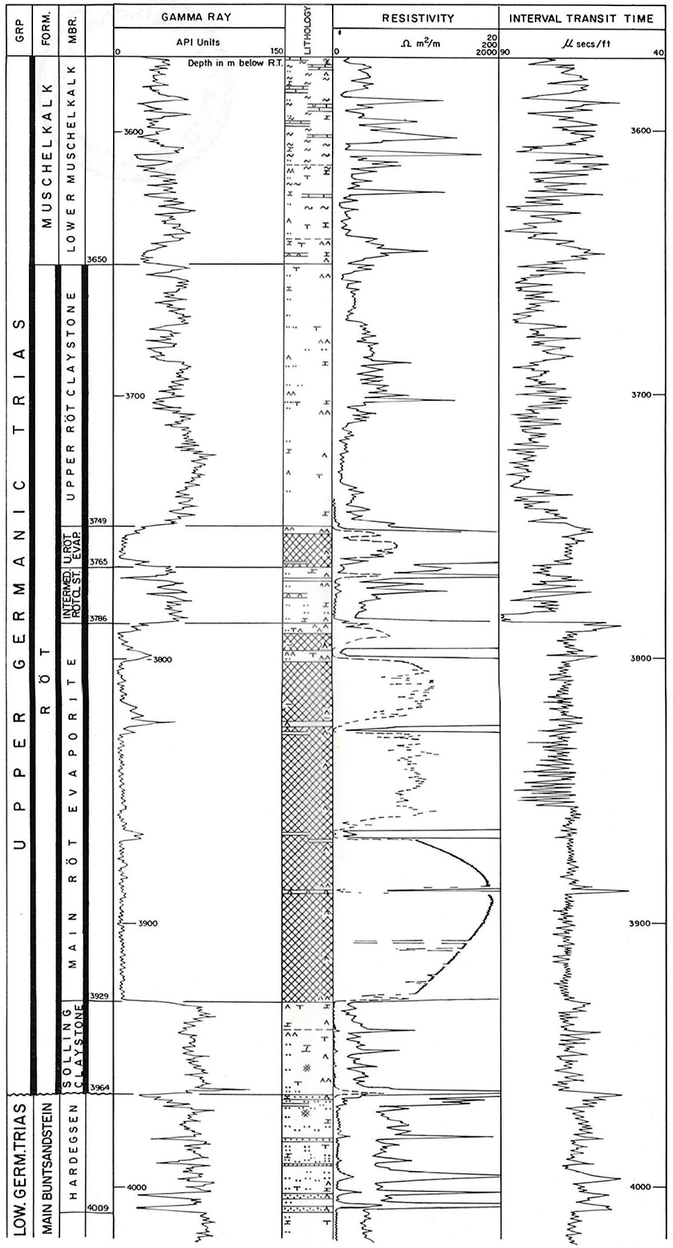


Reference wells : BLIJHAM-1, L 2-1

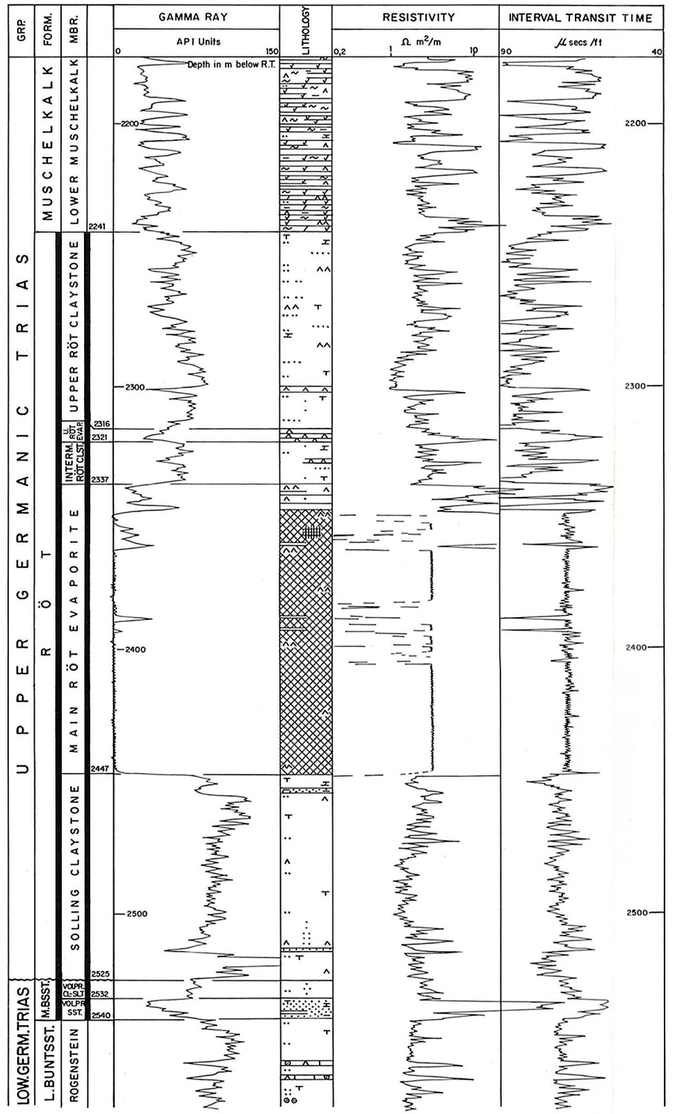
LOWER GERMANIC TRIAS

ENCL. 8

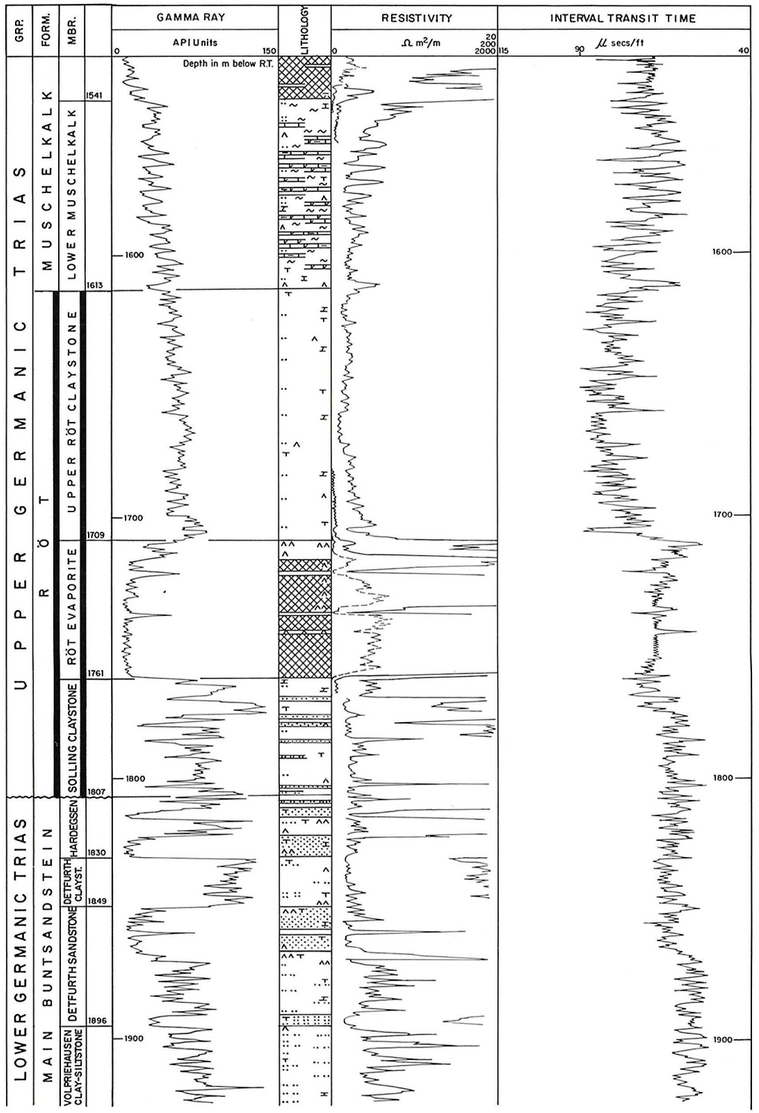
L2-1 (NAM)



ELEVELD-101 (NAM)



K17-1 (NAM)



Reference wells : L2-1, ELEVELD-101 K17-1	LOWER-UPPER GERMANIC TRIAS	ENCL. 9

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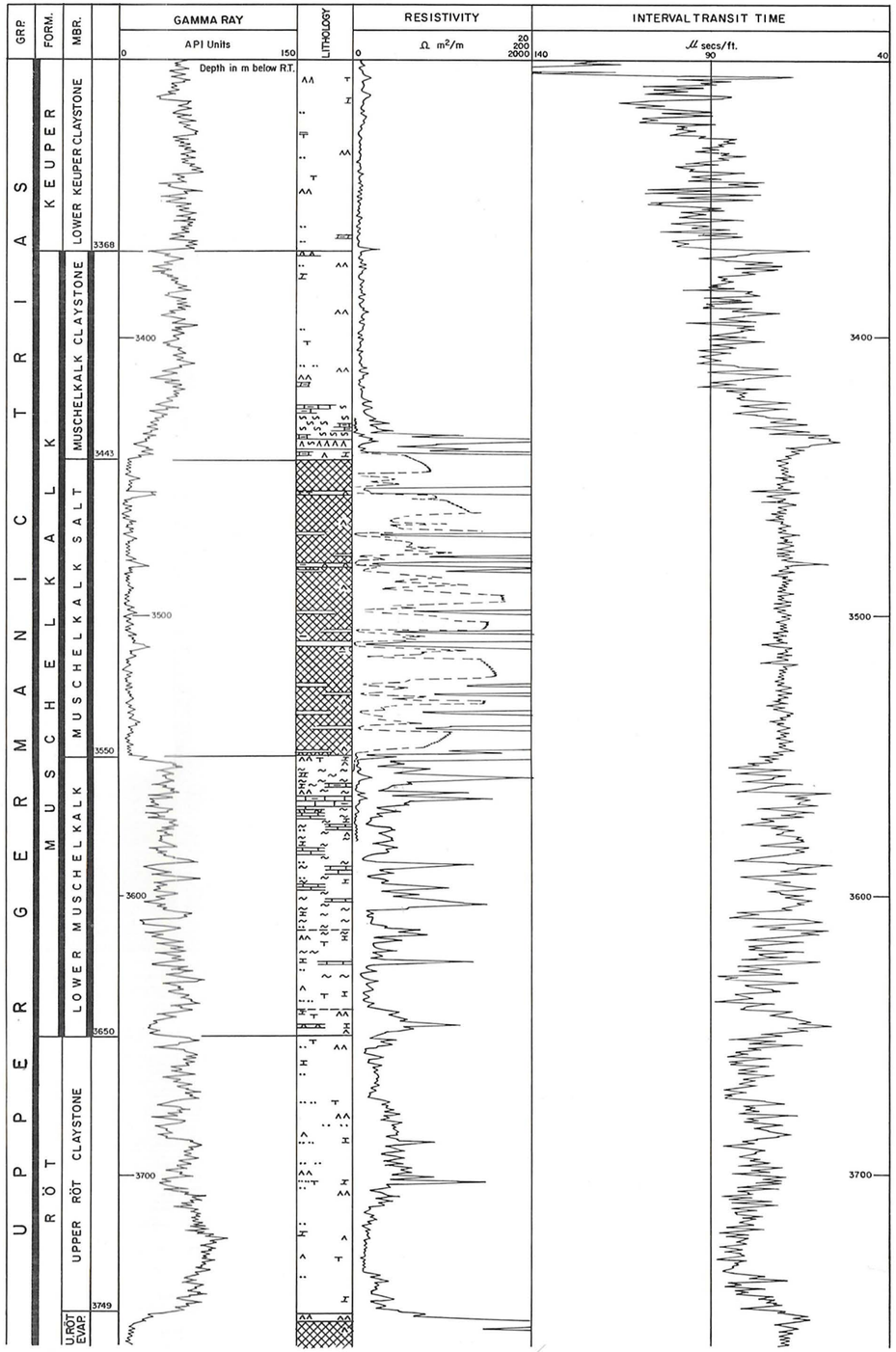
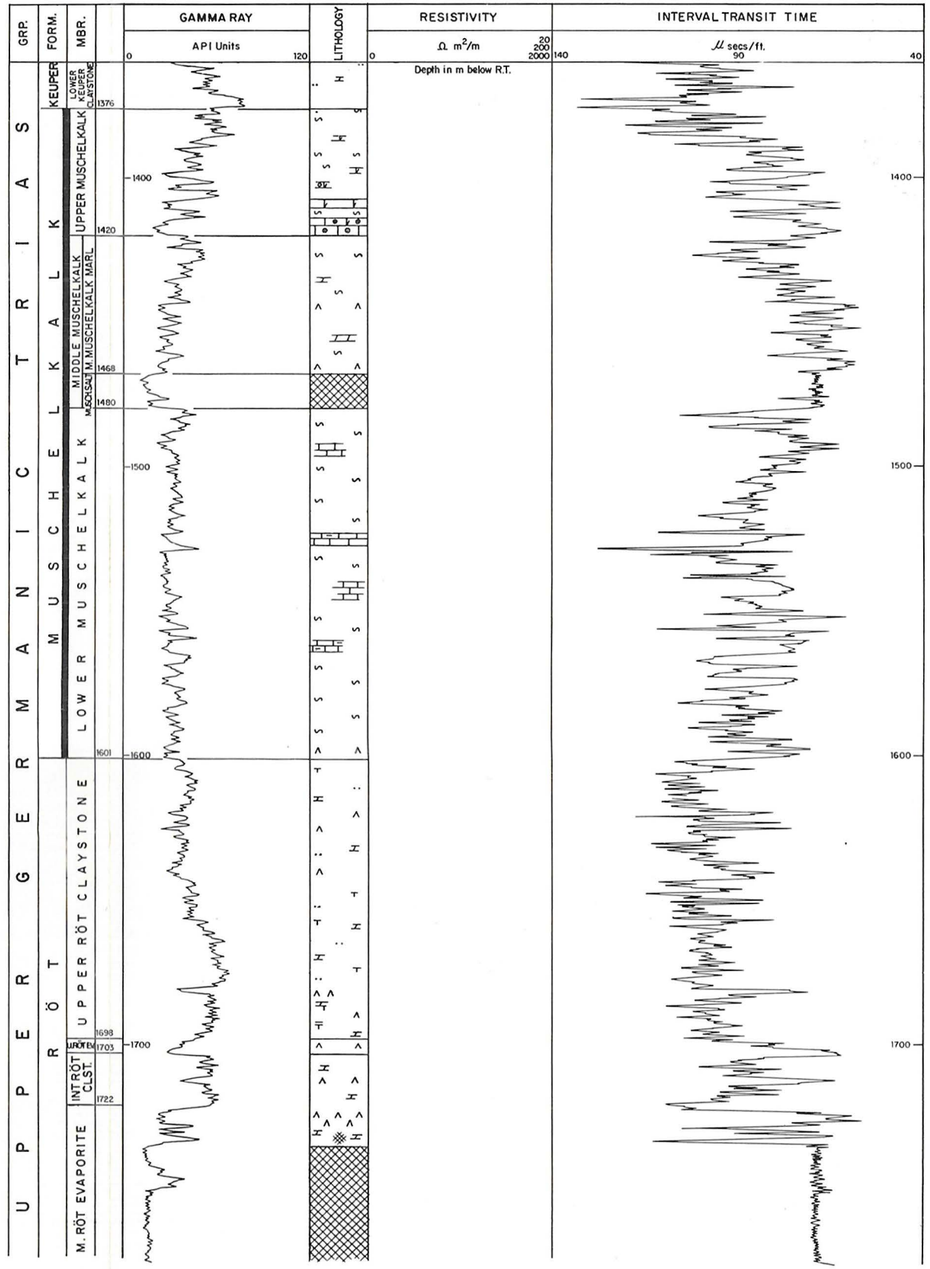
L2-1 (NAM)



SLEEN-4 (NAM)



Reference wells: L 2-1, SLEEN-4	UPPER GERMANIC TRIAS	ENCL. 10

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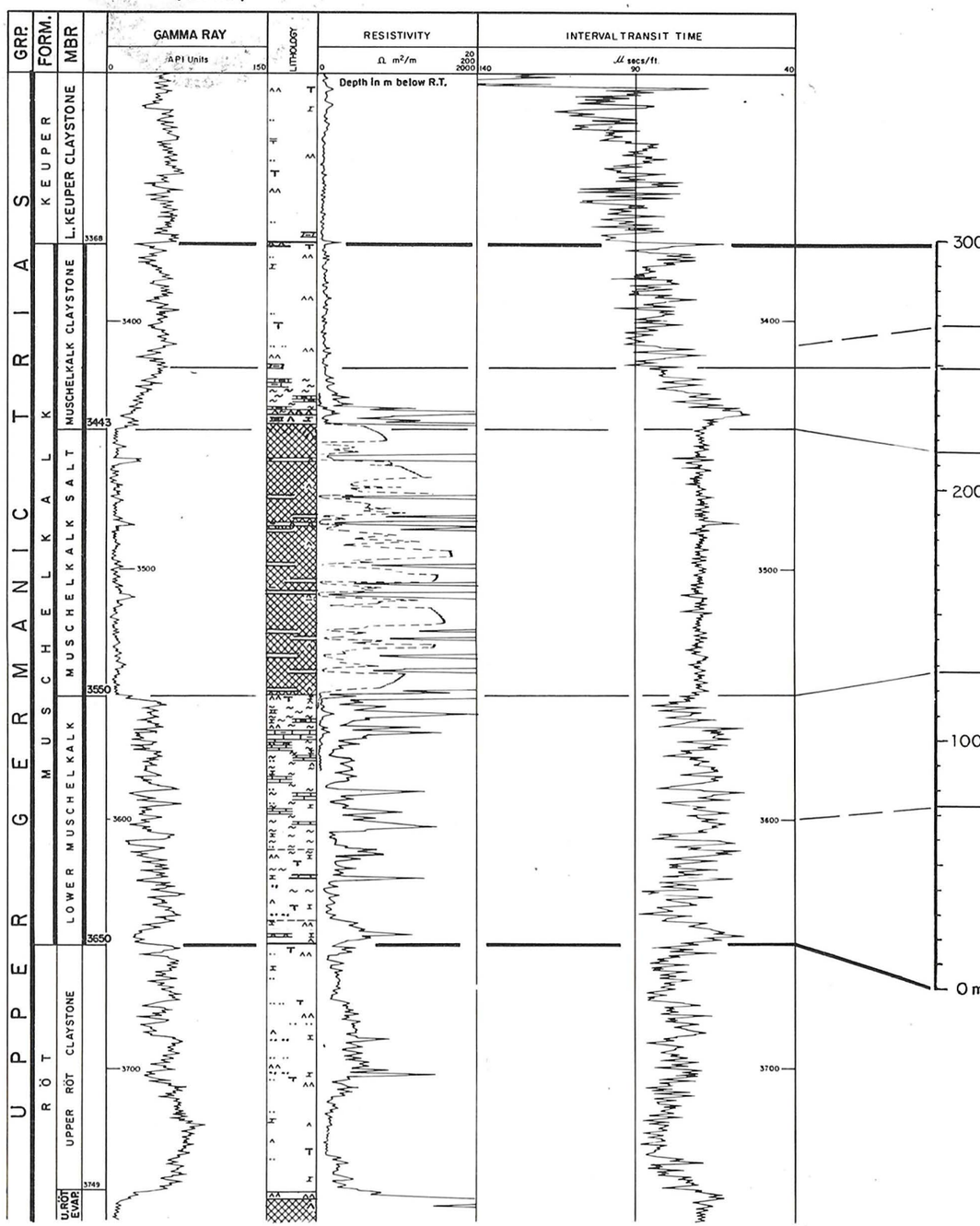
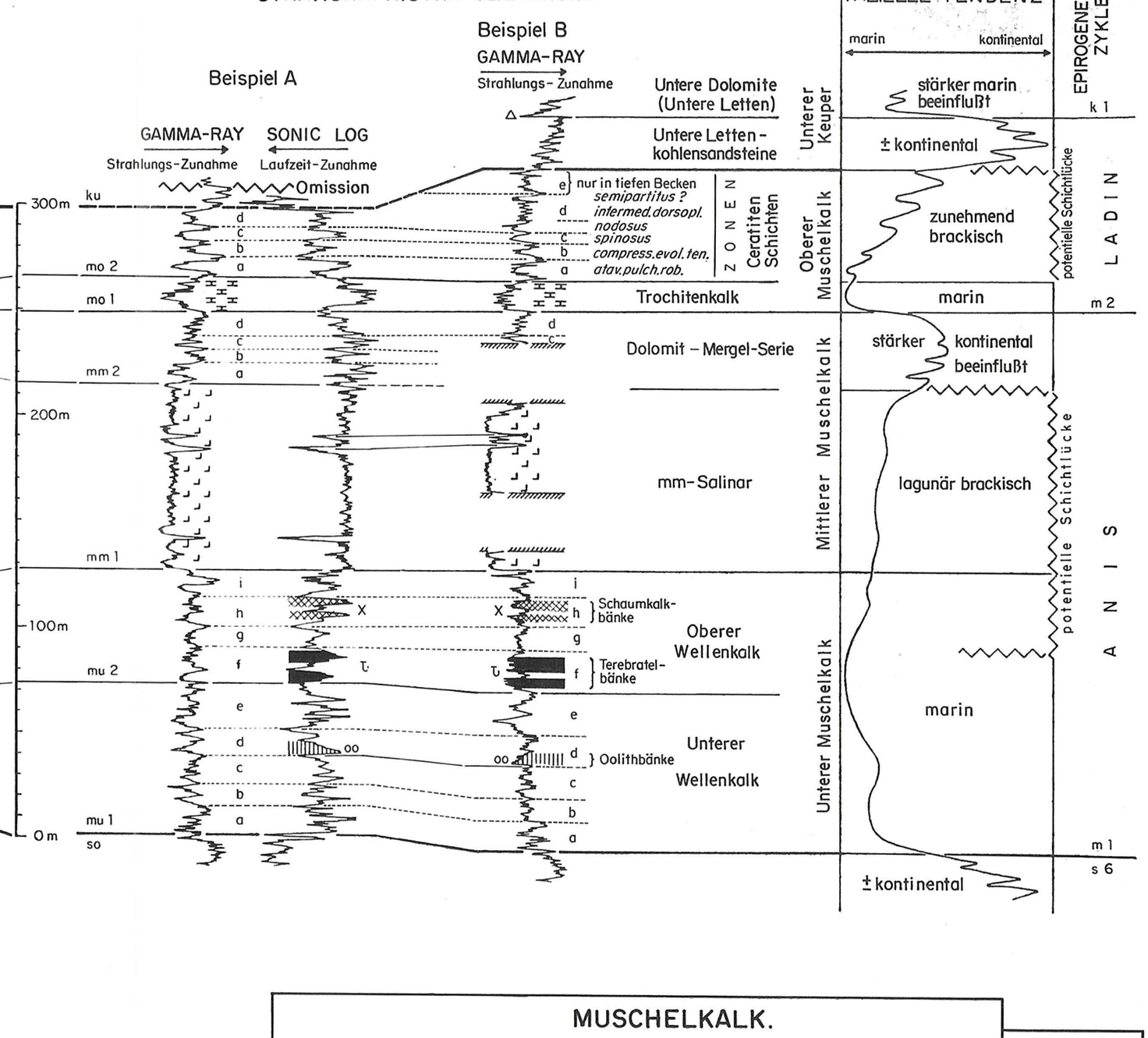
THE NETHERLANDS

L2-1 (NAM)



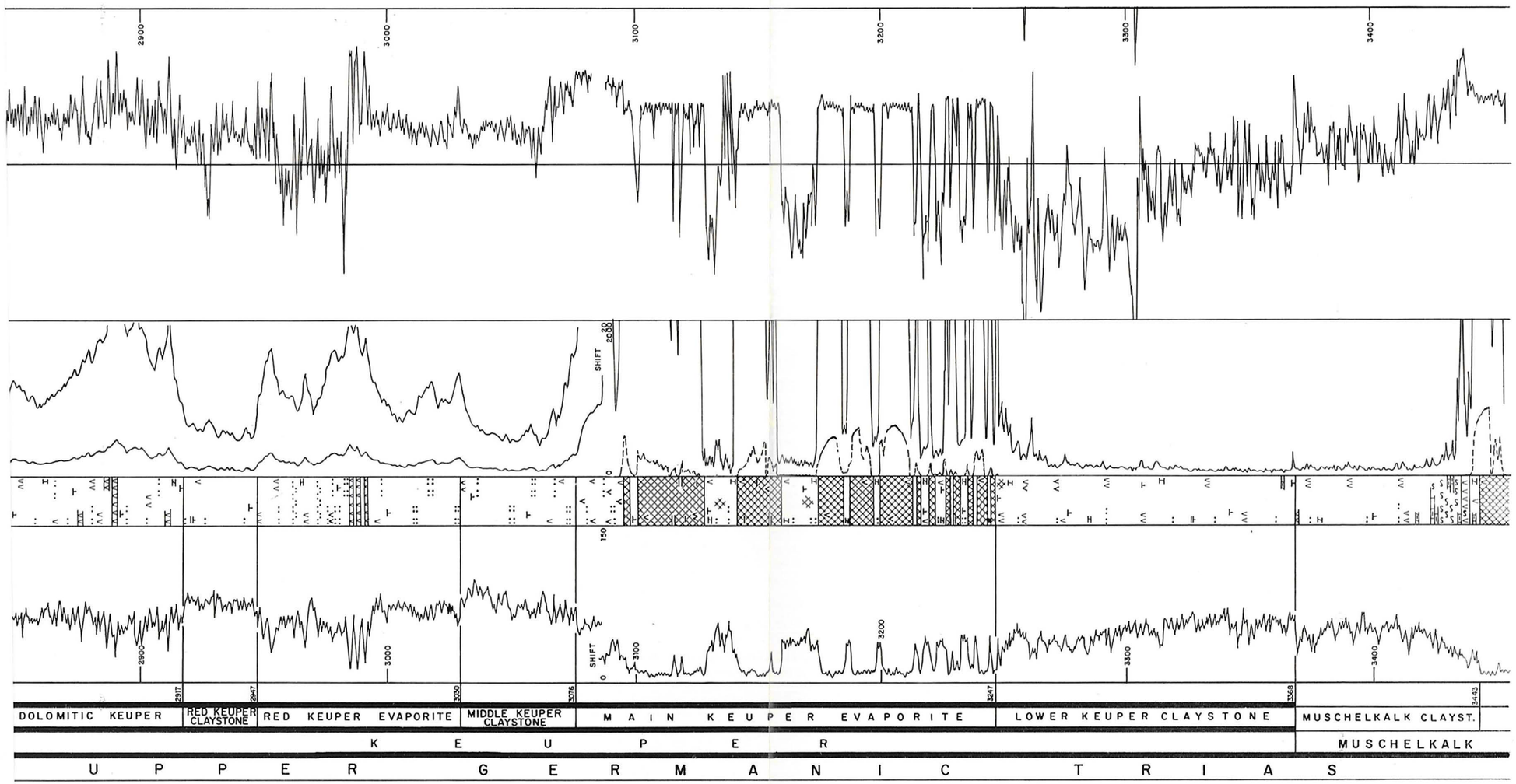
N.W. GERMANY (AFTER WOLBURG 1969)



MUSCHELKALK.

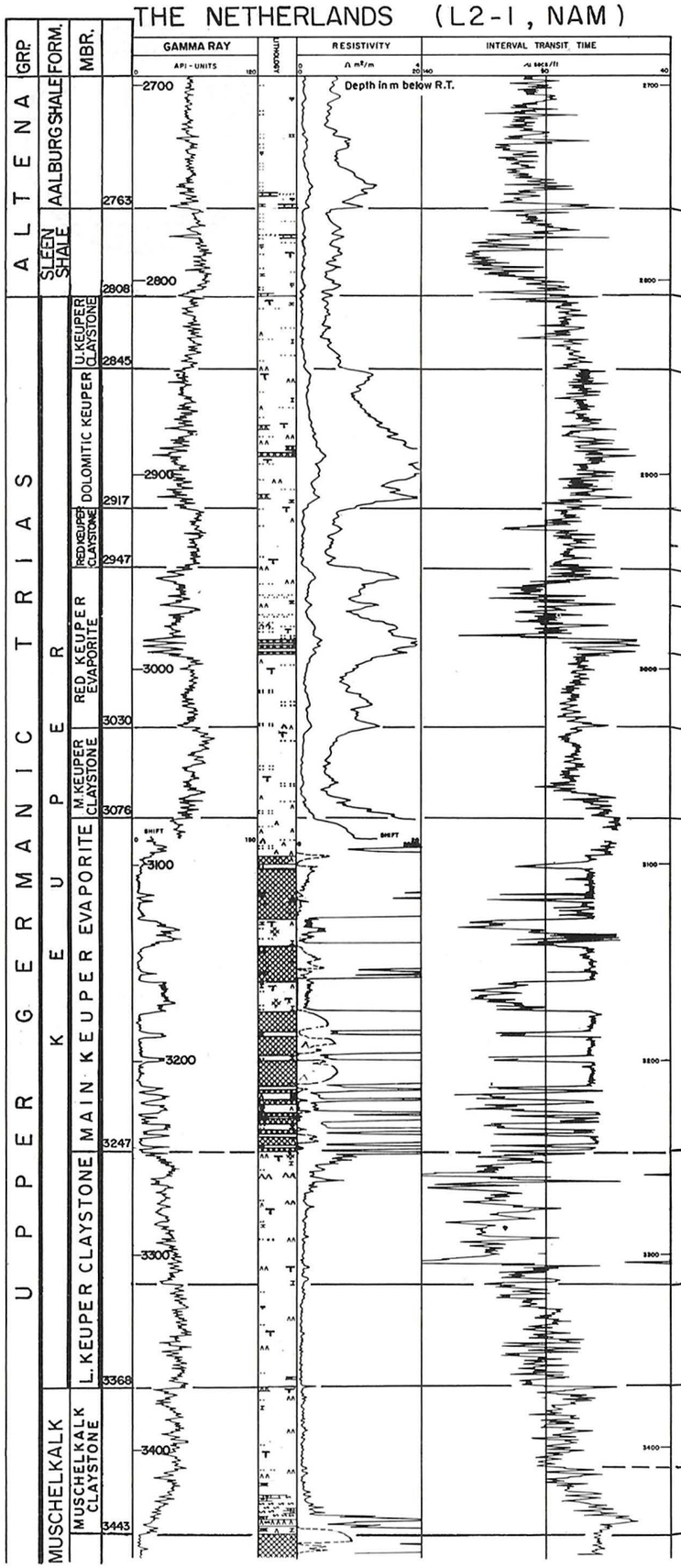
NOMENCLATURE IN THE NETHERLANDS AND N.W. GERMANY.

ENCL. 11



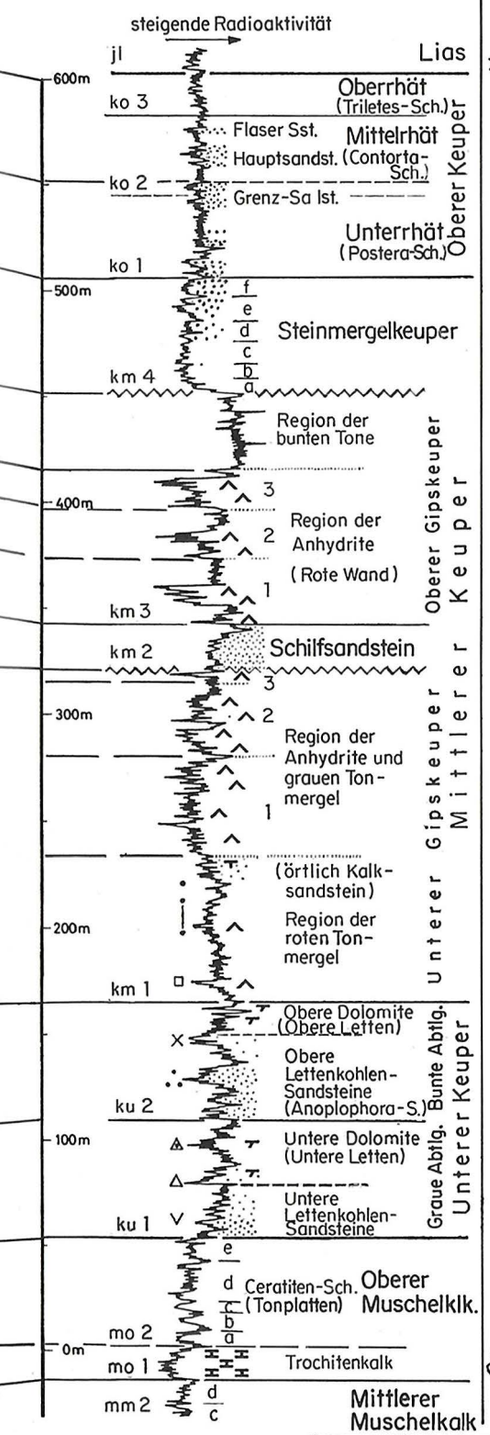
Reference well : L 2-1	UPPER GERMANIC TRIAS	ENCL. 12

THE NETHERLANDS (L2-1, NAM)

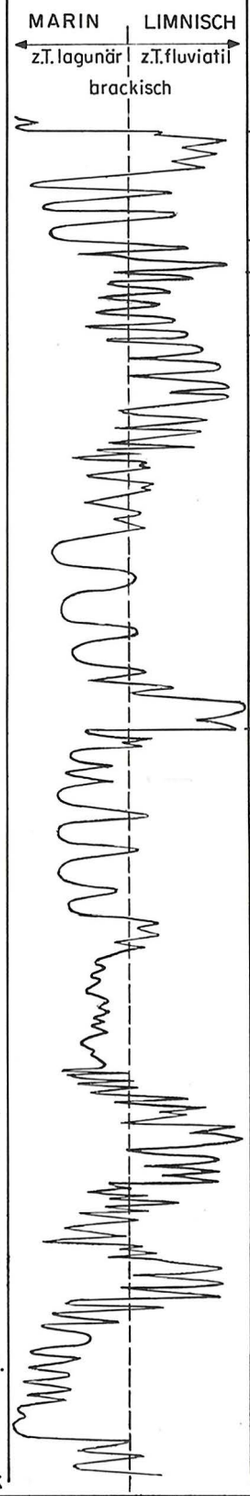


N.W. GERMANY (After Wolburg 1969)

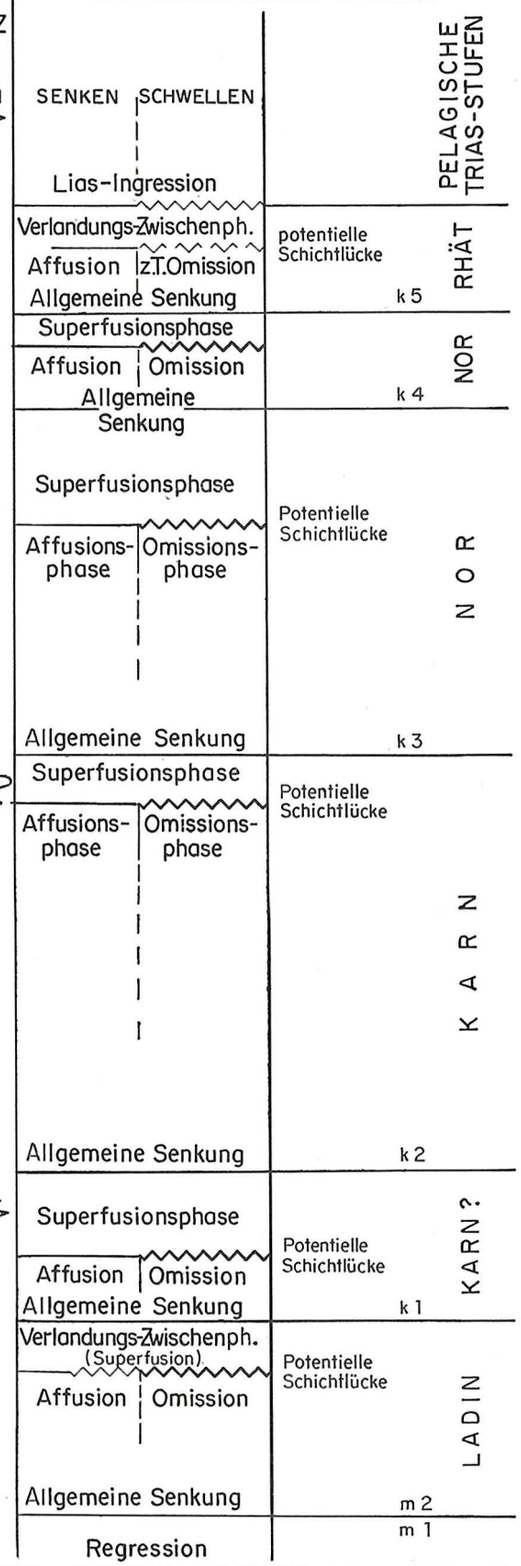
STRATIGRAPHISCHE GLIEDERUNG



SCHEMA DER FAZIELLEN TENDENZ



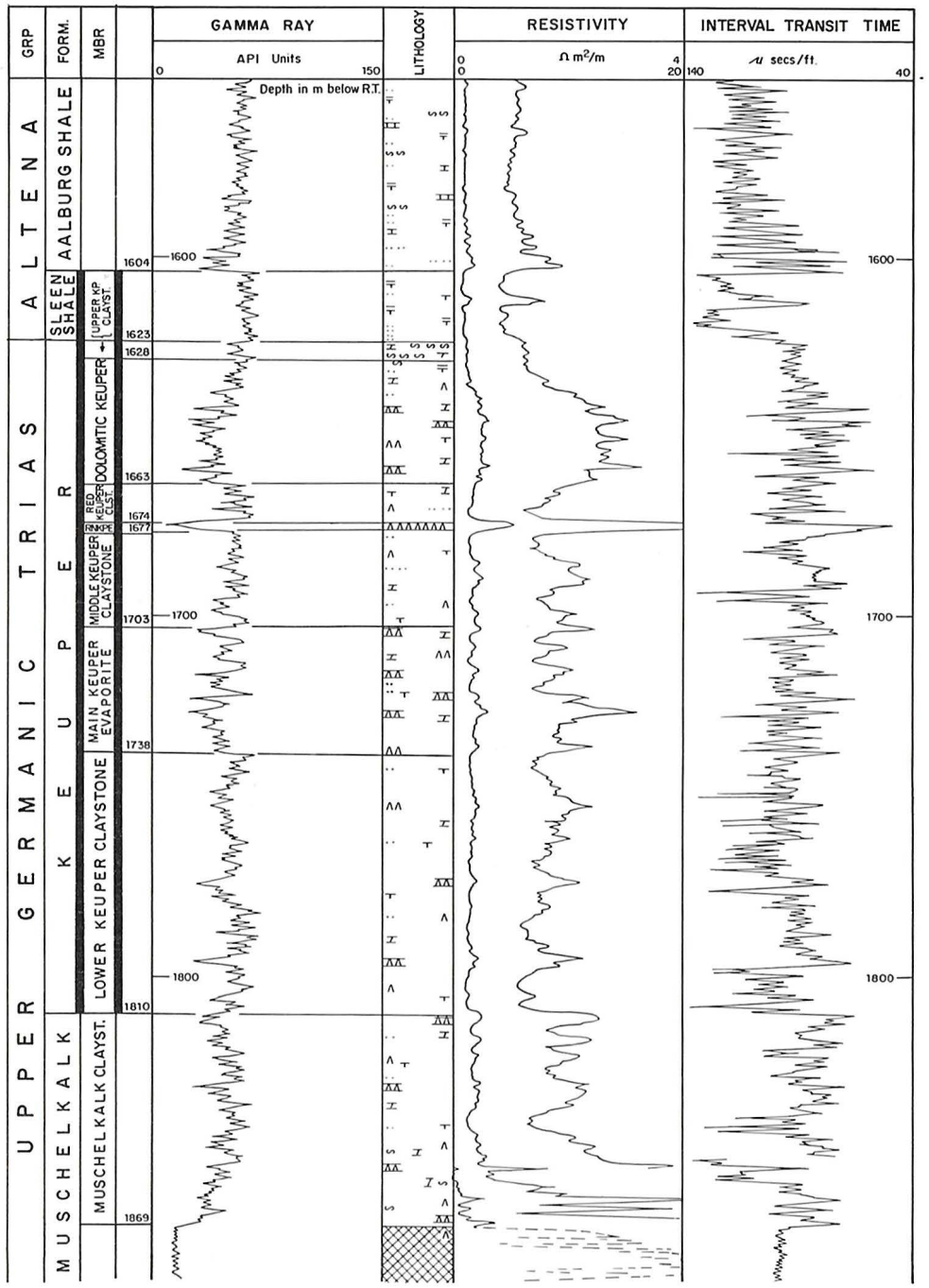
EPIROGENETISCHE ZYKLEN



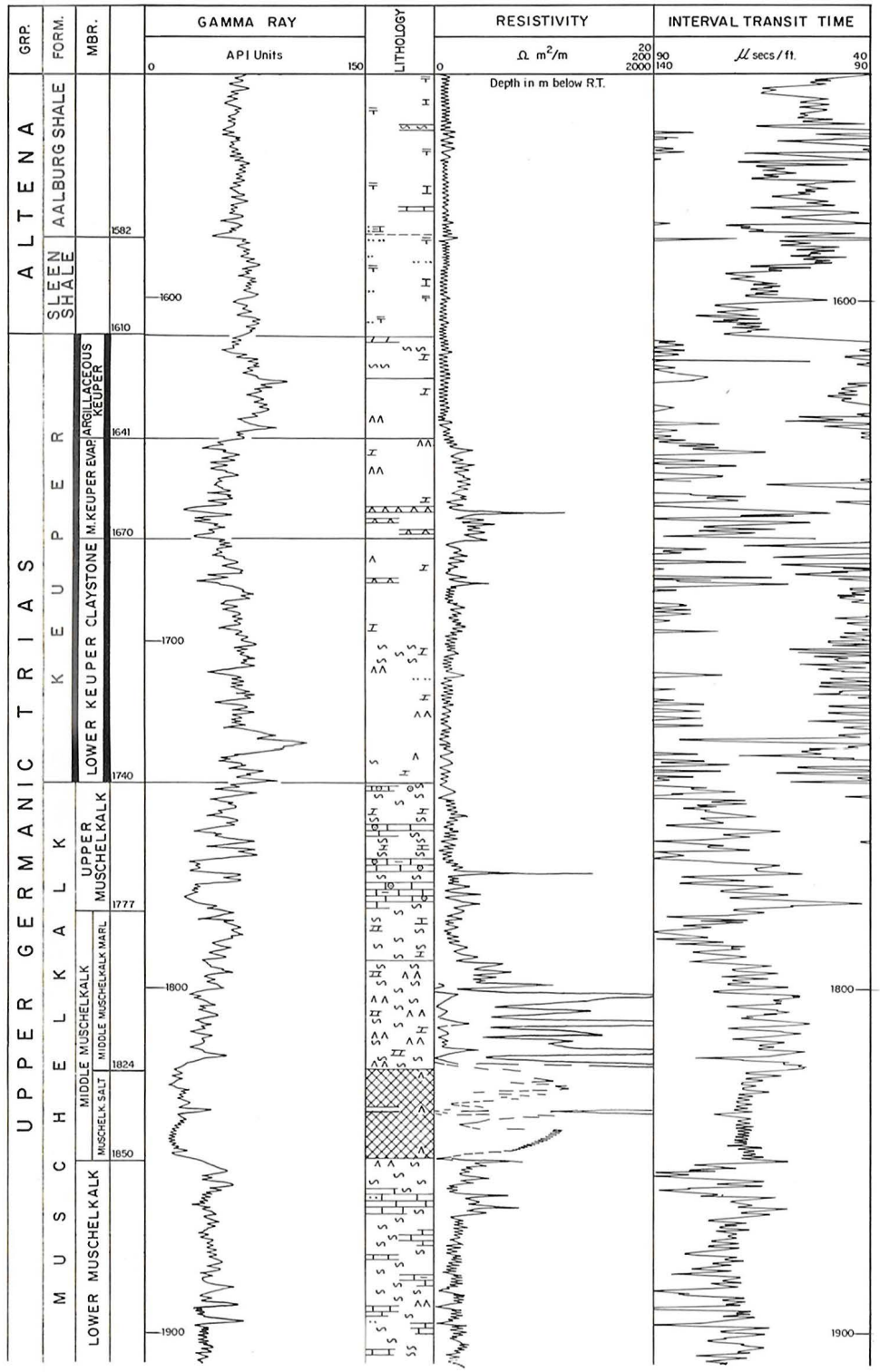
KEUPER
NOMENCLATURE IN THE NETHERLANDS AND N.W. GERMANY.

ENCL. 13

K 14-1 (NAM)



EMMEN-7 (NAM)



Reference wells : K 14-1 EMMEN-7	U.GERMANIC TRIAS - ALTENA	ENCL. 14

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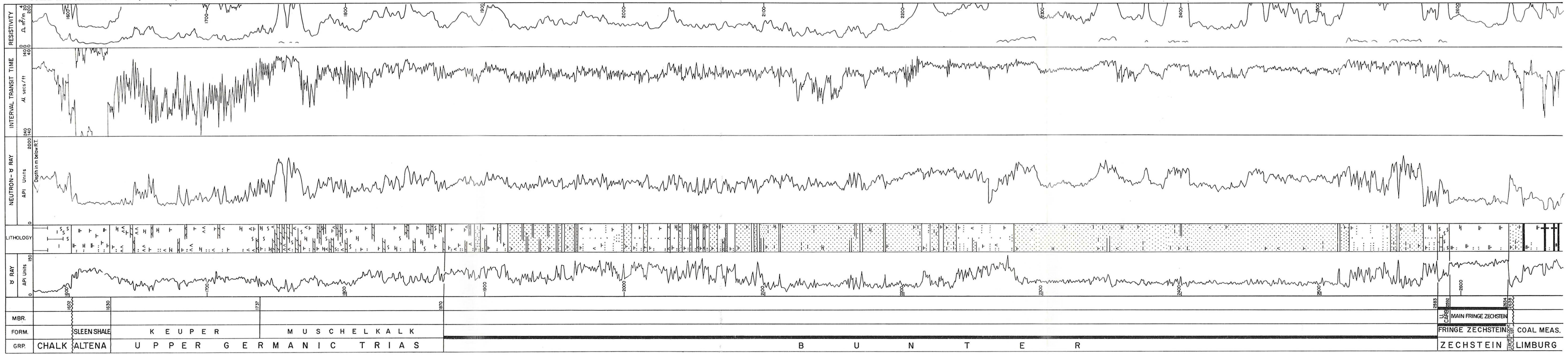
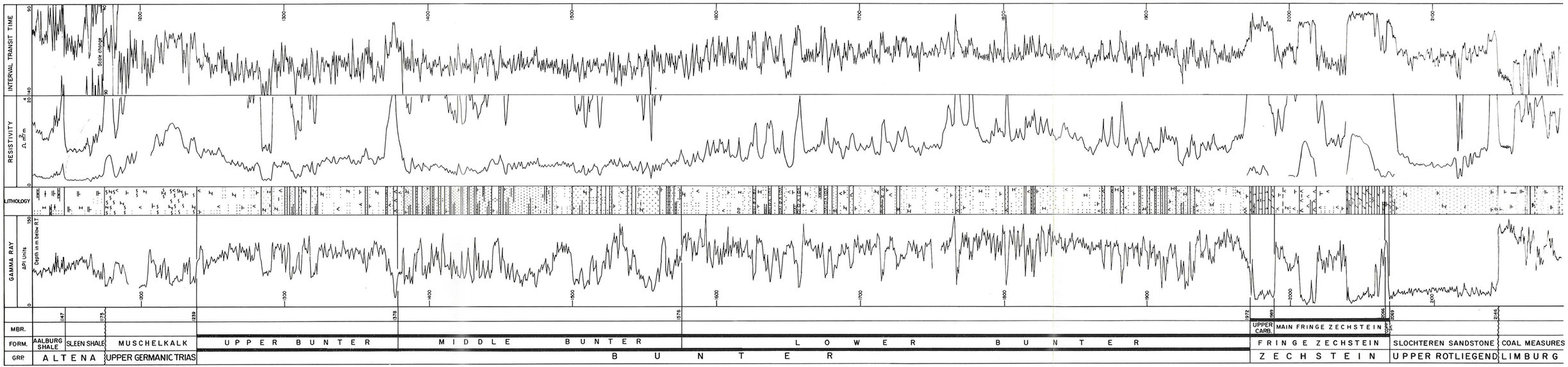
NEDERWEERT-1 (FINA)



Reference well : NEDERWEERT-1	ZECHSTEIN-BUNTER	ENCL. 15

6.103.544

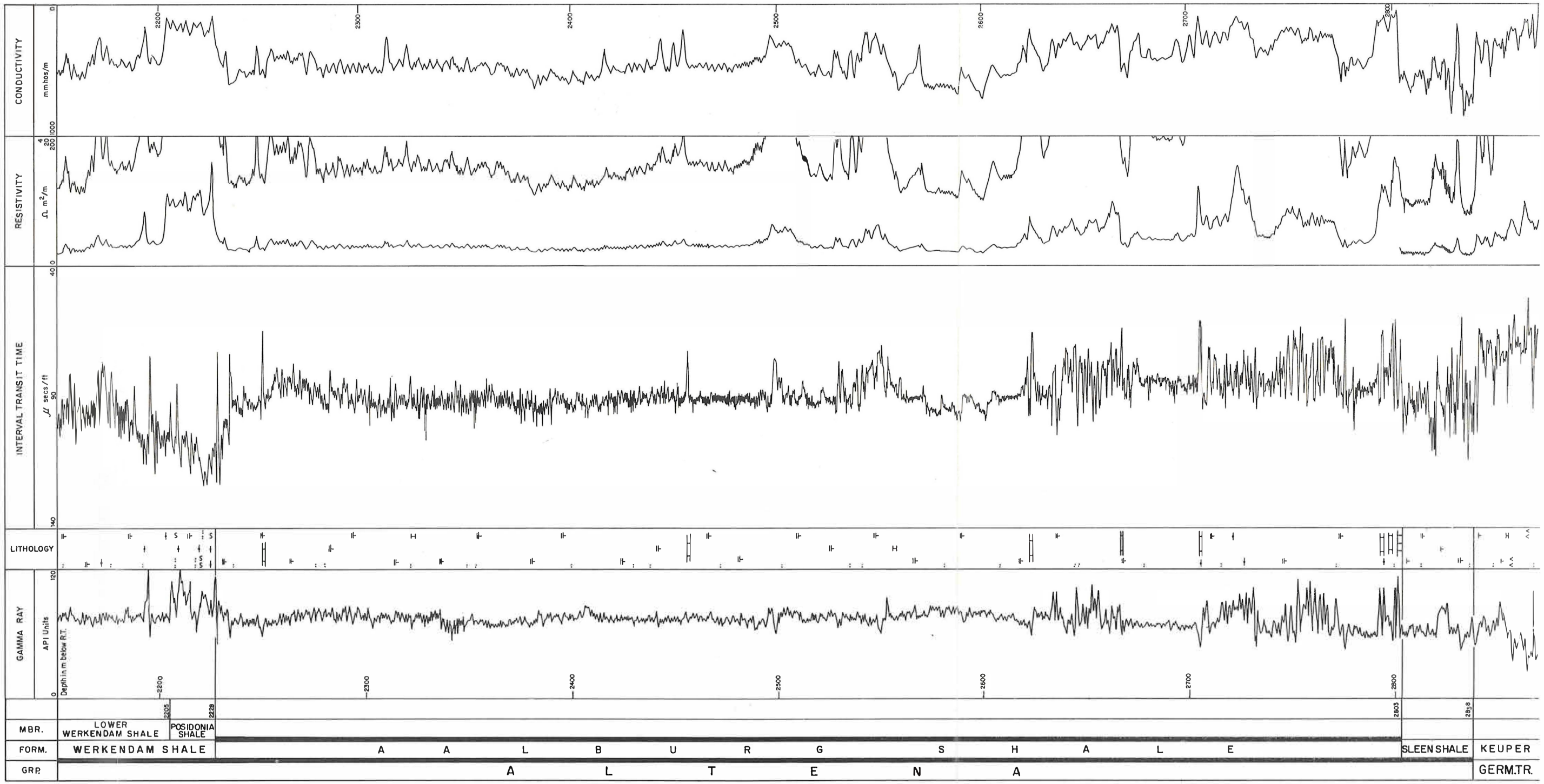
BUURMALSEN-1 (NAM)



Reference well : BUURMALSEN-1	ZECHSTEIN-BUNTER	ENCL. 16

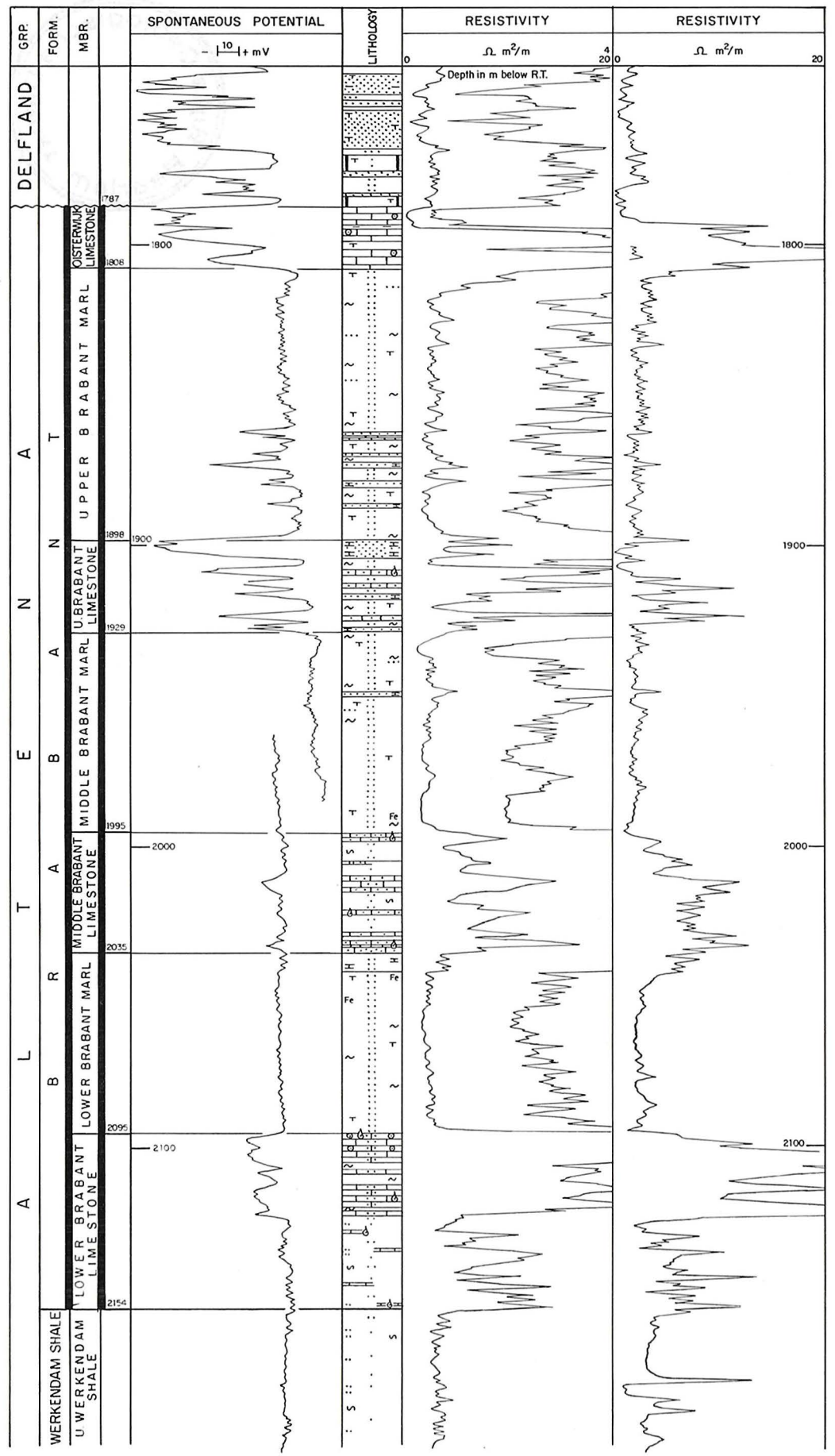
G 107 544 –

WERKENDAM-2 (NAM)

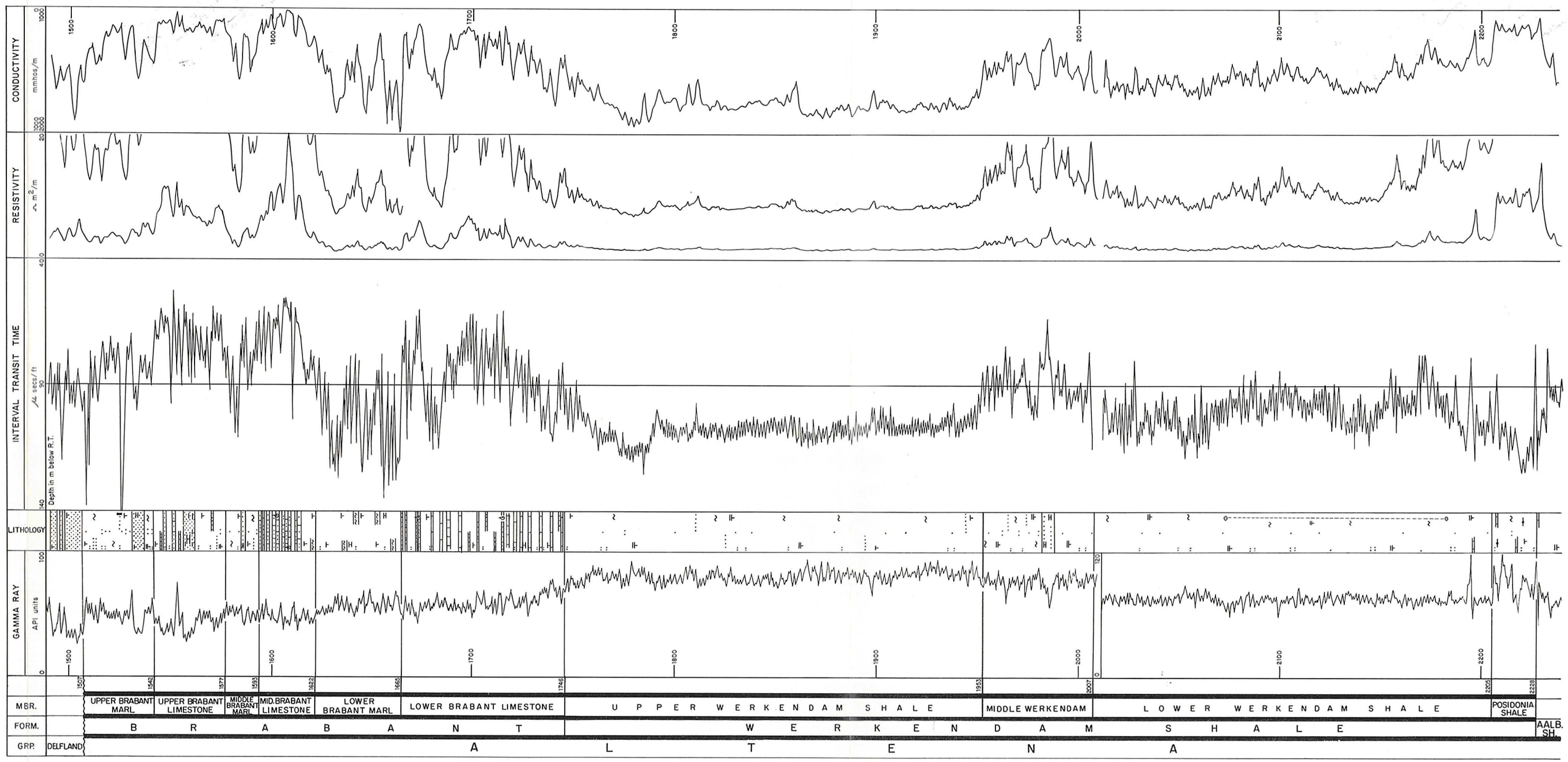


Reference well : WERKENDAM-2	A L T E N A	ENCL. 17

OISTERWIJK-1 (NAM)



WERKENDAM-2 (NAM)

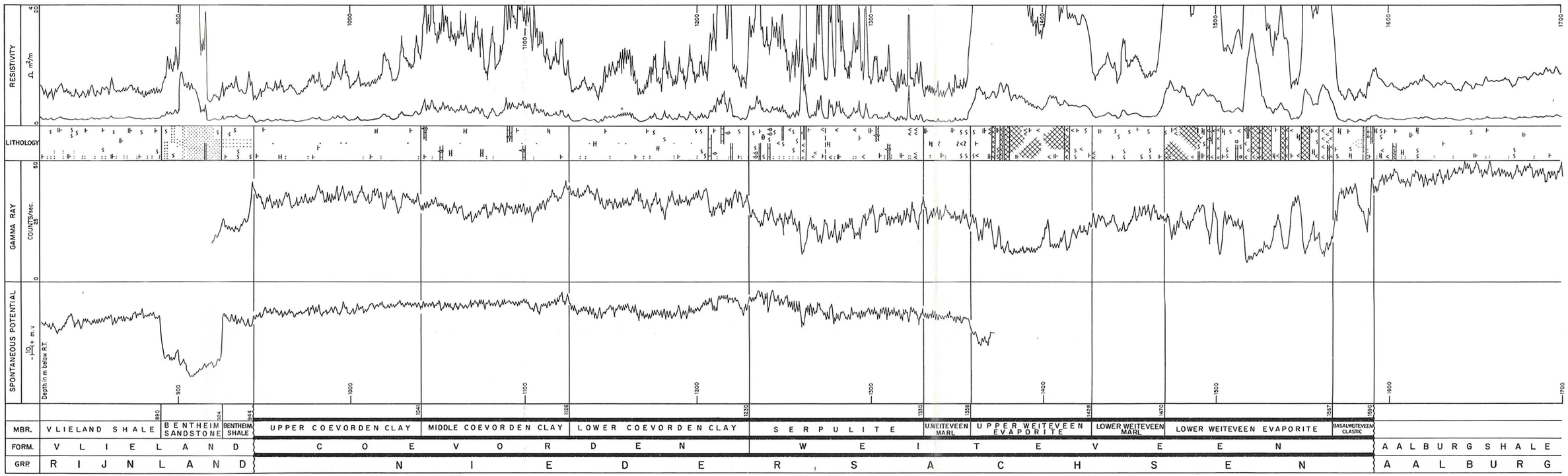


Reference wells: OISTERWIJK-1
WERKENDAM-2

ALTENA

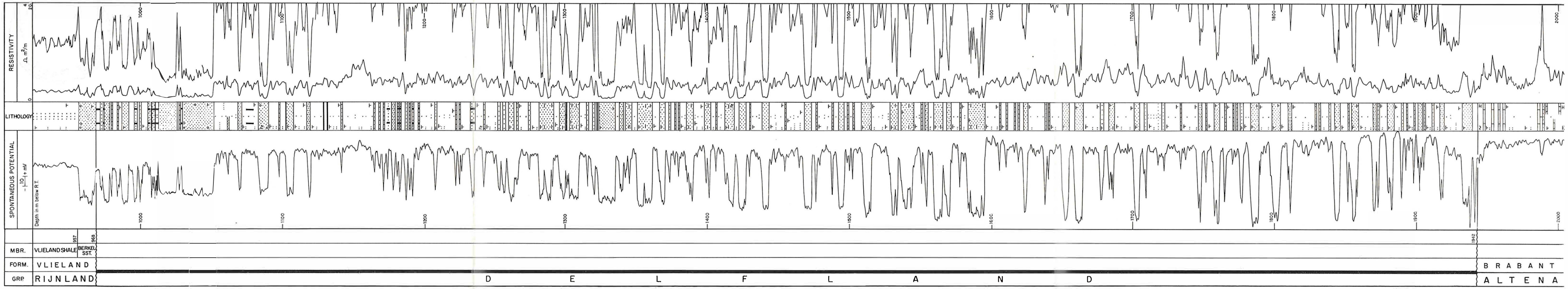
ENCL. 18

SCHOONEBEEK-197 (NAM)

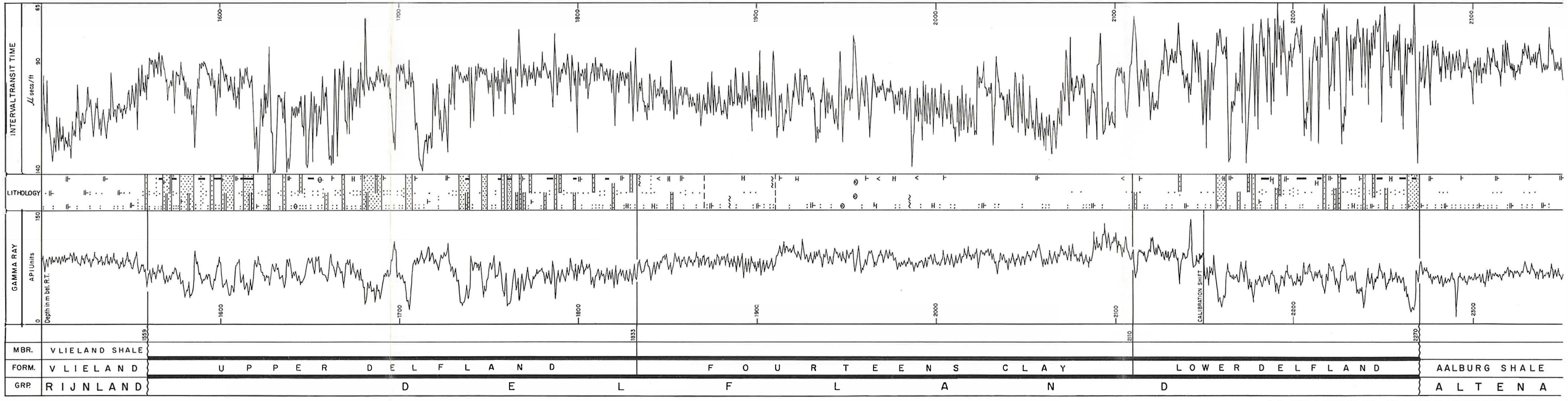


Reference well : SCHOONEBEEK-197	NIEDERSACHSEN	ENCL. 19

NIEUWERKERK-1 (NAM)



K 15-1 (NAM)

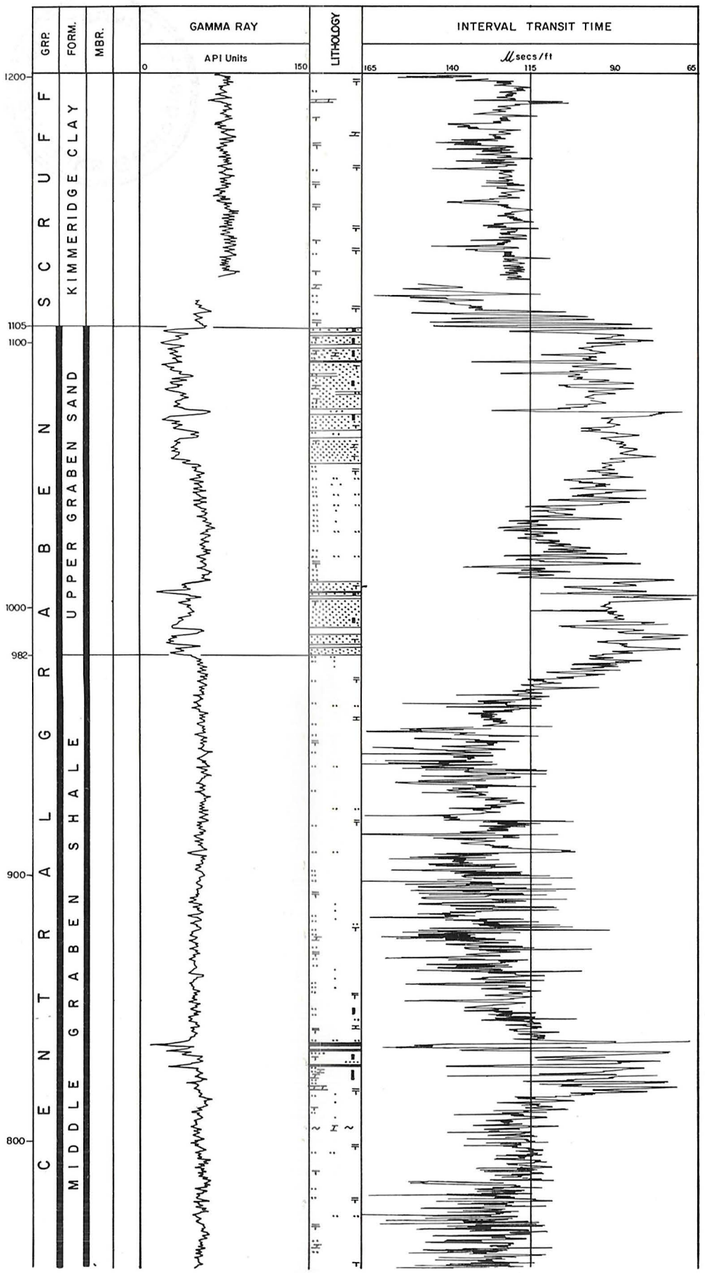


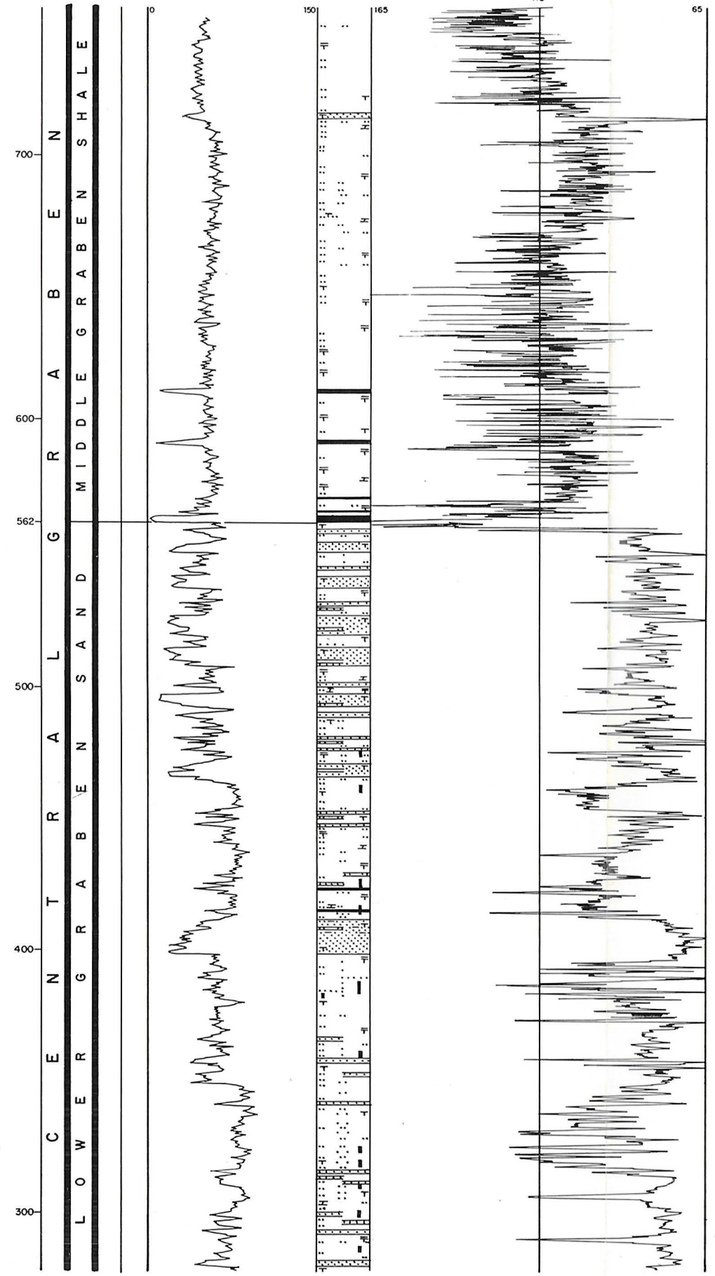
Reference wells : NIEUWERKERK-1 K15-1

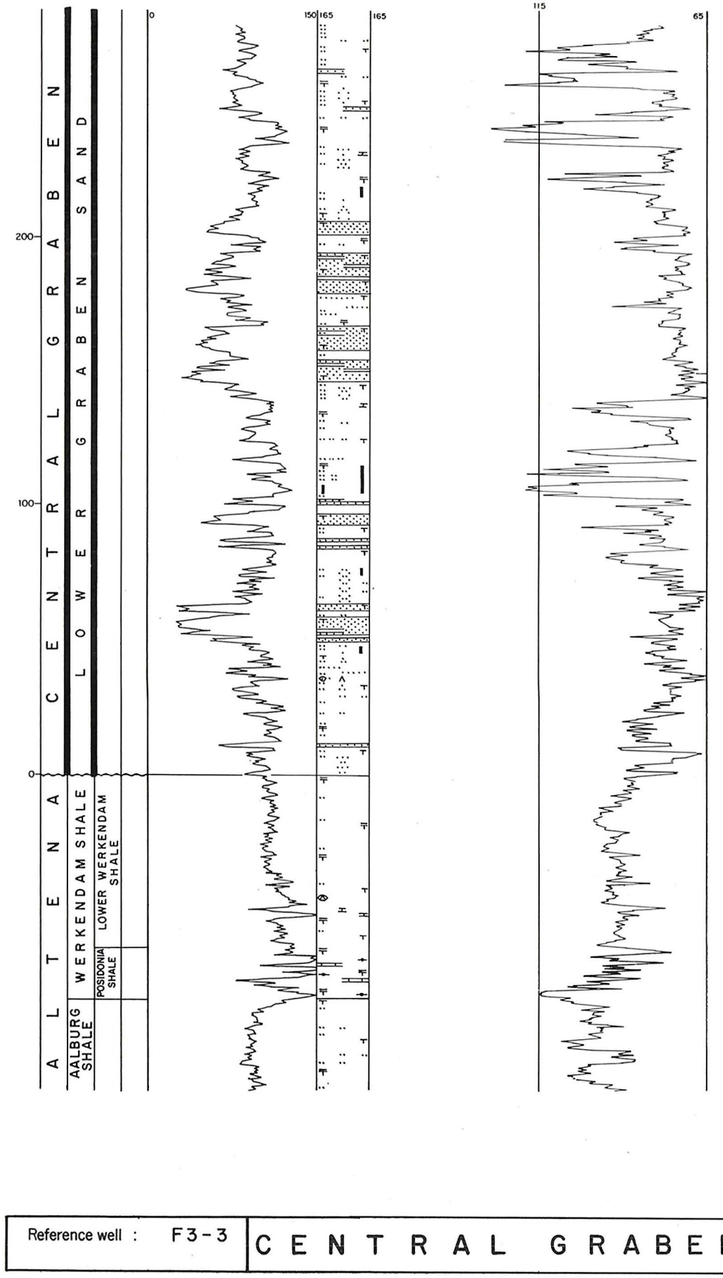
D E L F L A N D

ENCL. 20

F3-3 (NAM, UNION, PETROLAND, TENNECO)







Reference well : F3-3	CENTRAL GRABEN	ENCL. 21

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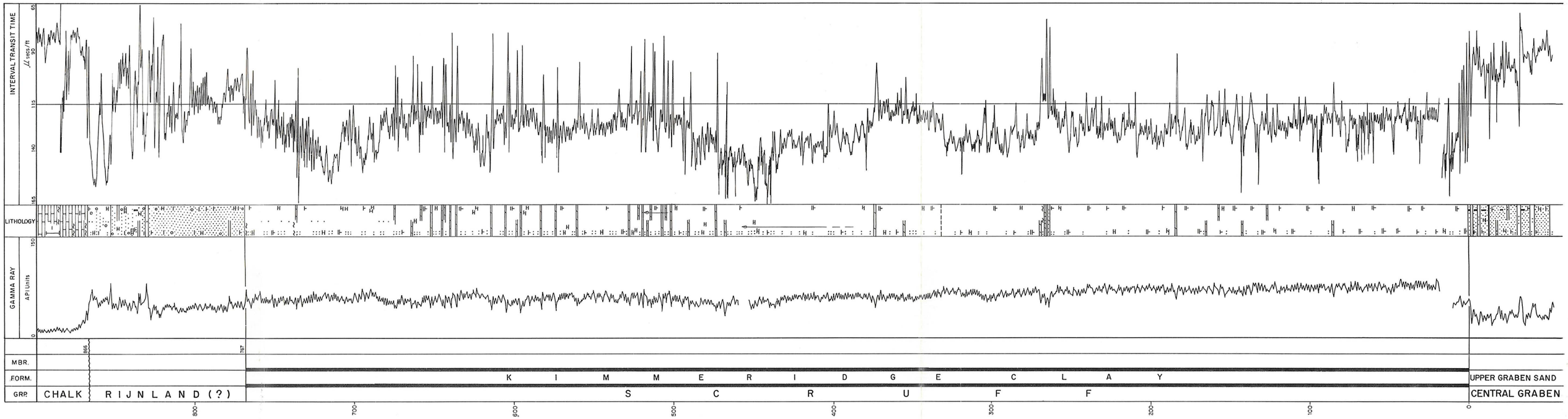
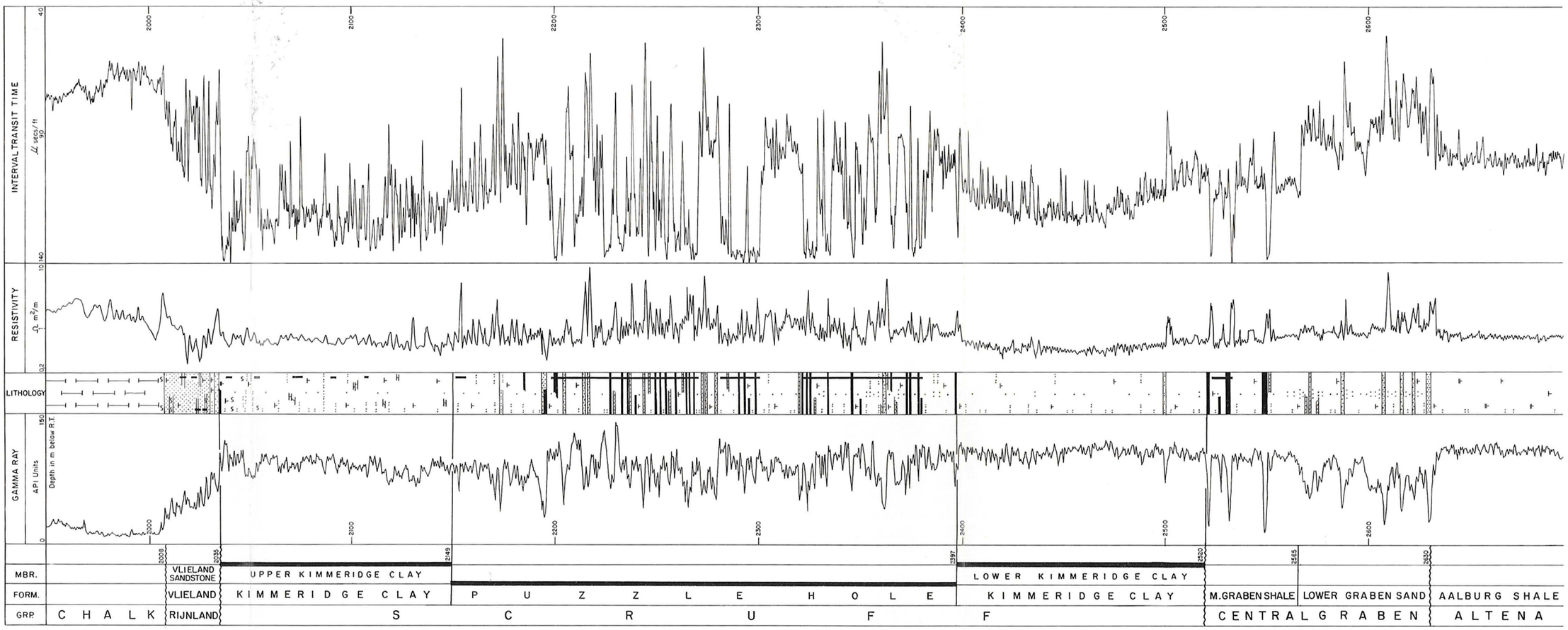
F 3-3 (NAM, UNION, PETROLAND, TENNECO)



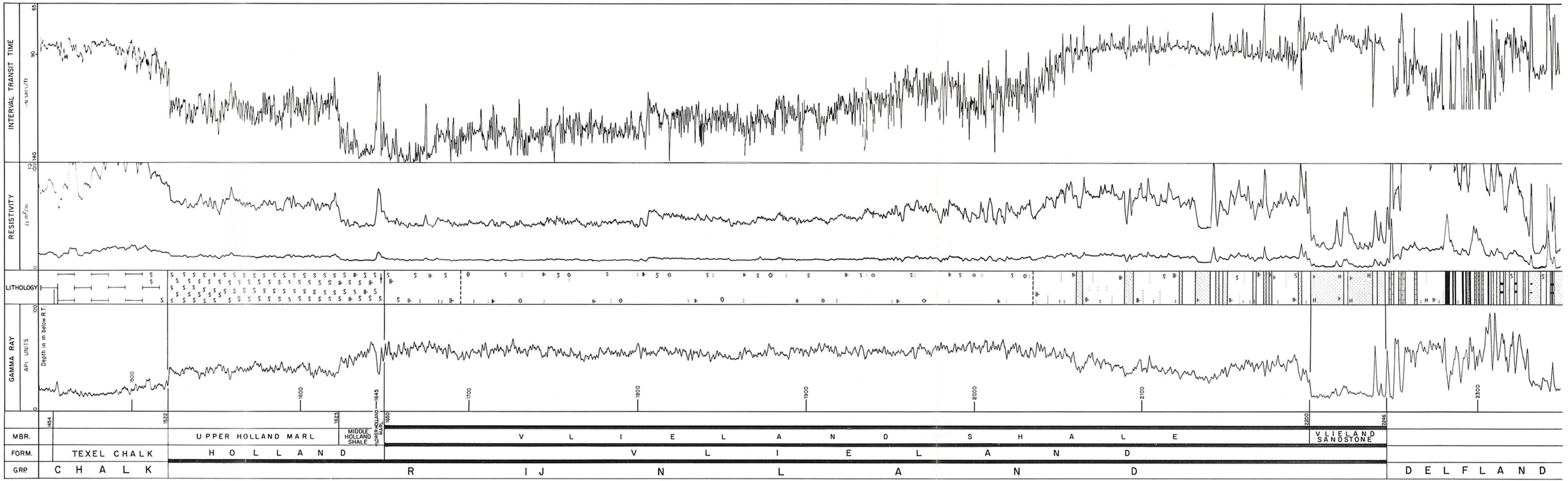
Reference well : F3-3	SCRUFF	ENCL.22

F 11-2 (NAM)



Reference well : F 11-2	S C R U F F	ENCL. 23

VLIELAND OOST-1 (NAM)



Reference wells : VLIELAND OOST-1	RIJNLAND	ENCL. 24

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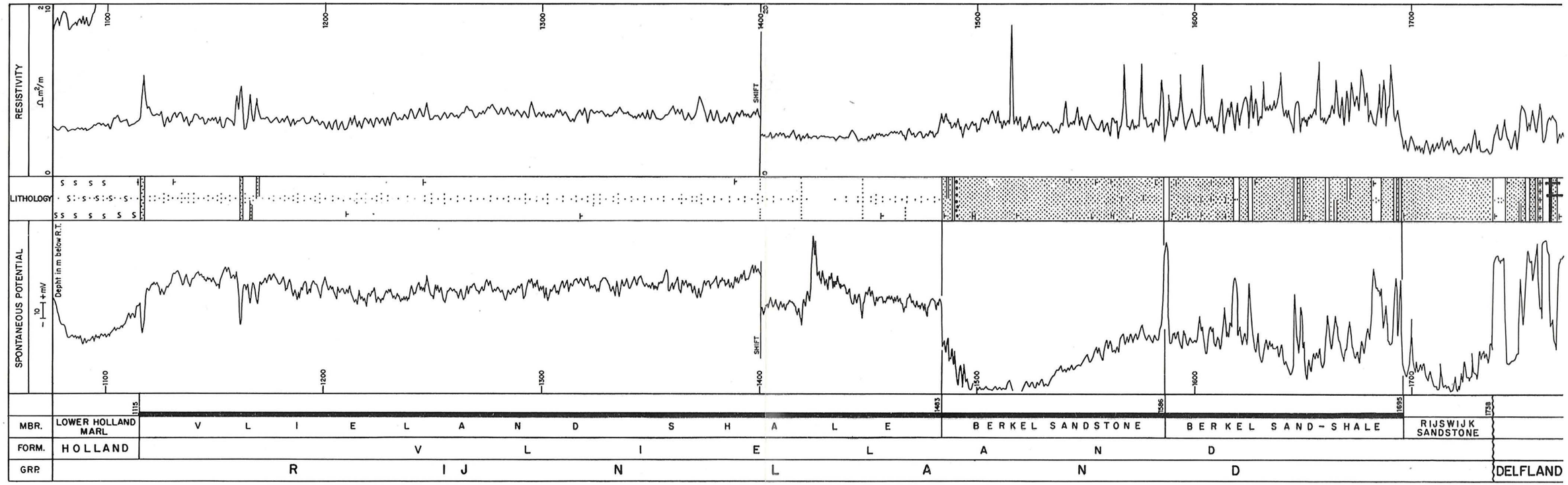
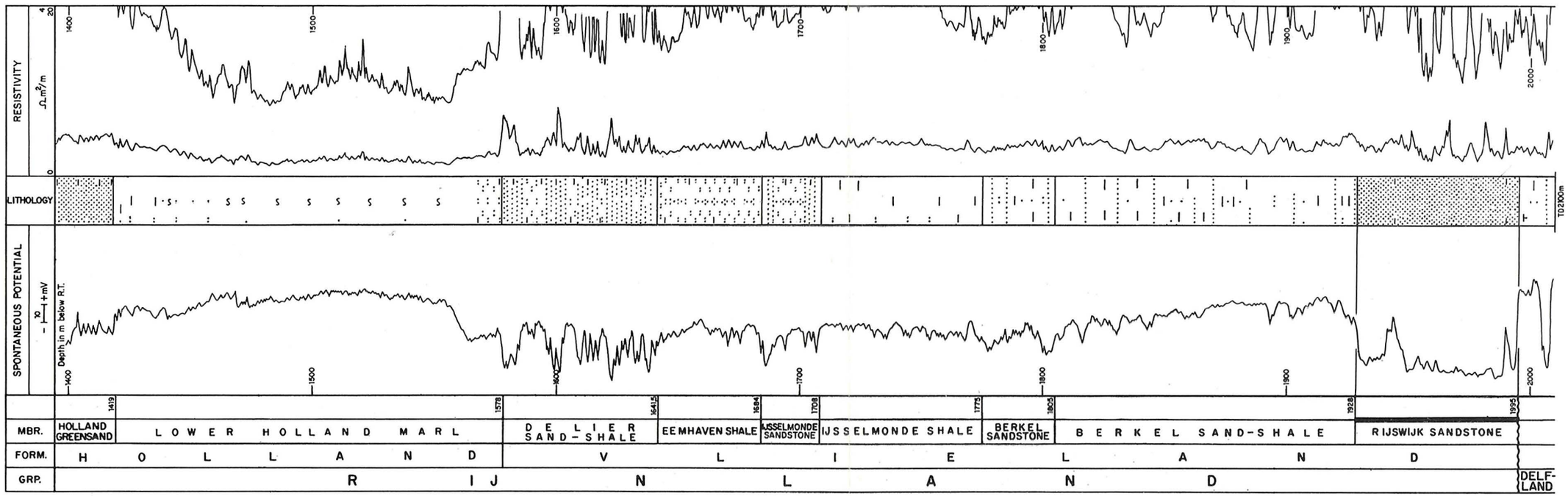
BERKEL SCHIEBROEK-2 (NAM)



DE LIER-40(NAM)



Reference wells : BERKEL SCHIEBROEK-2, DE LIER-40

RIJNLAND

ENCL. 25

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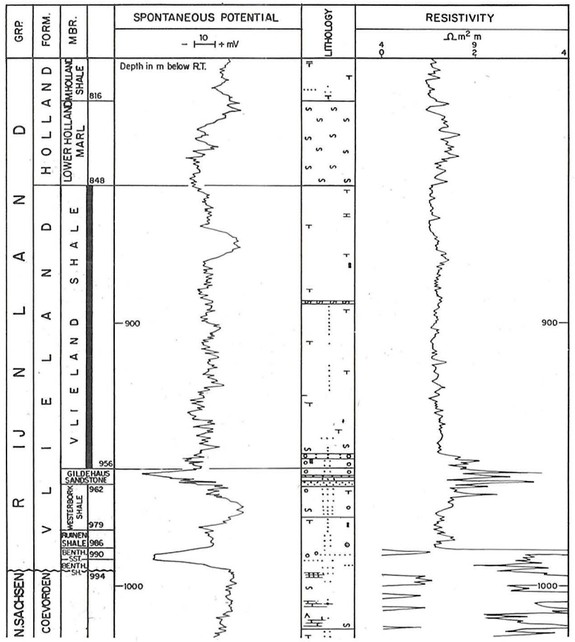
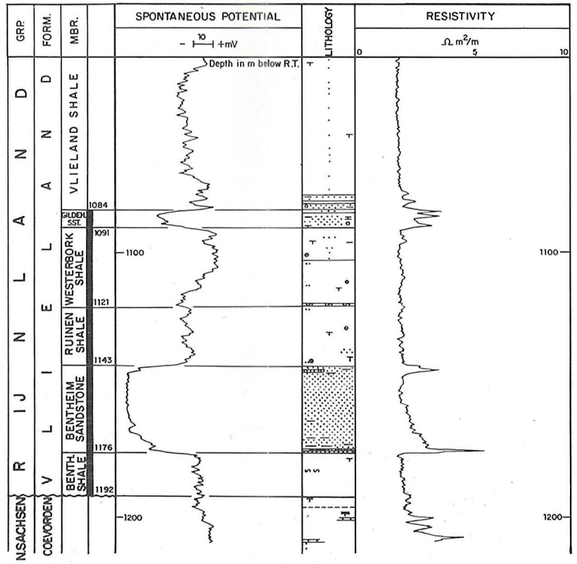
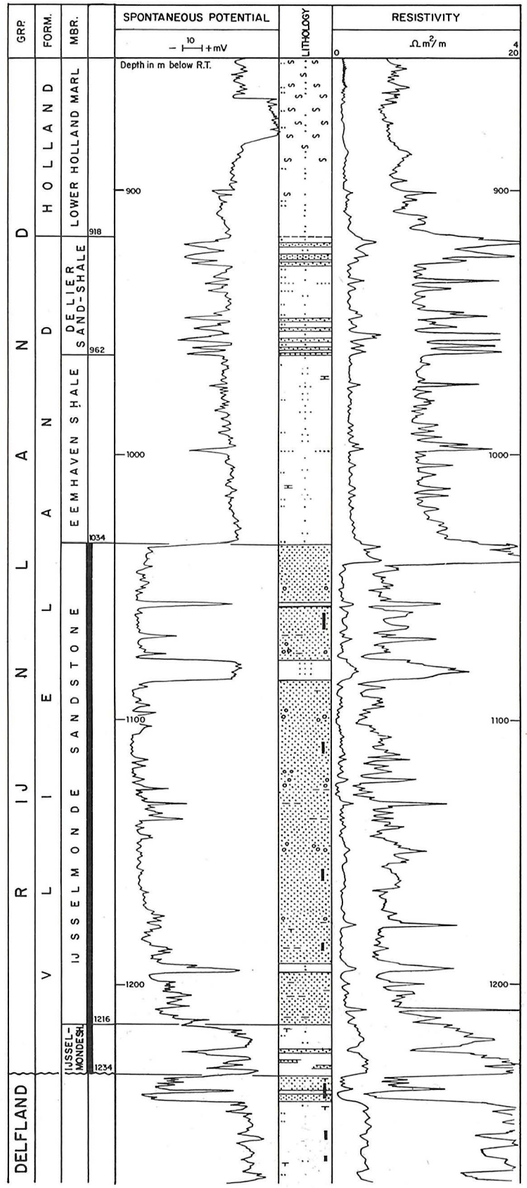
RUINEN-1 (NAM)



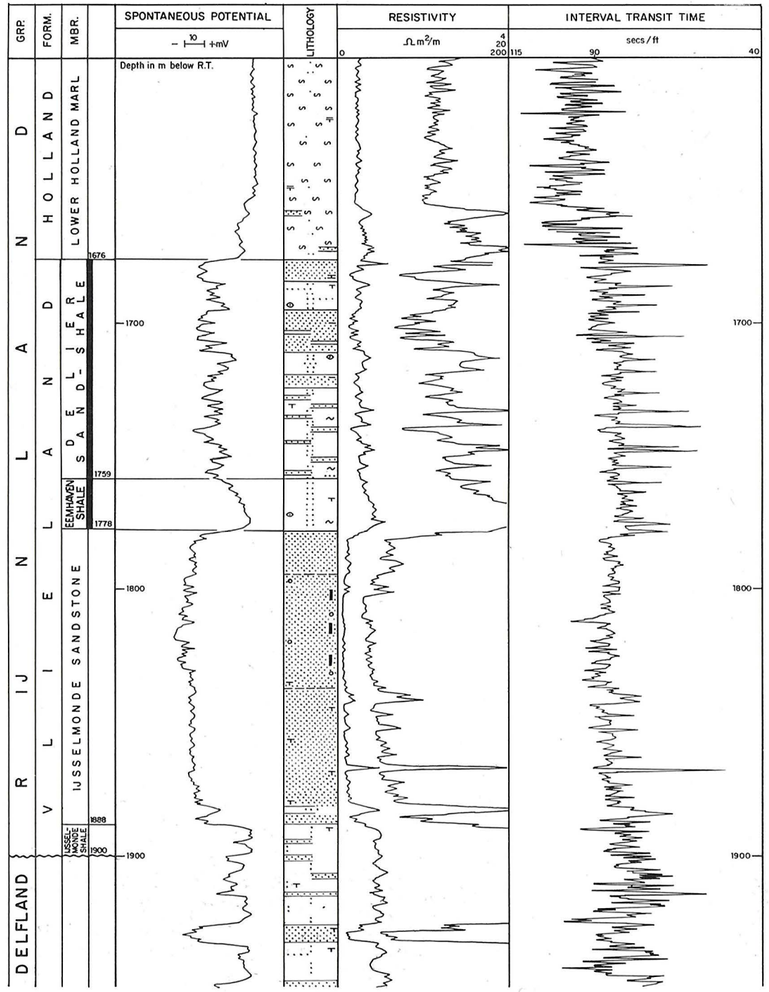
WESTERBORK-1 (NAM)



RIDDERKERK-2 (NAM)

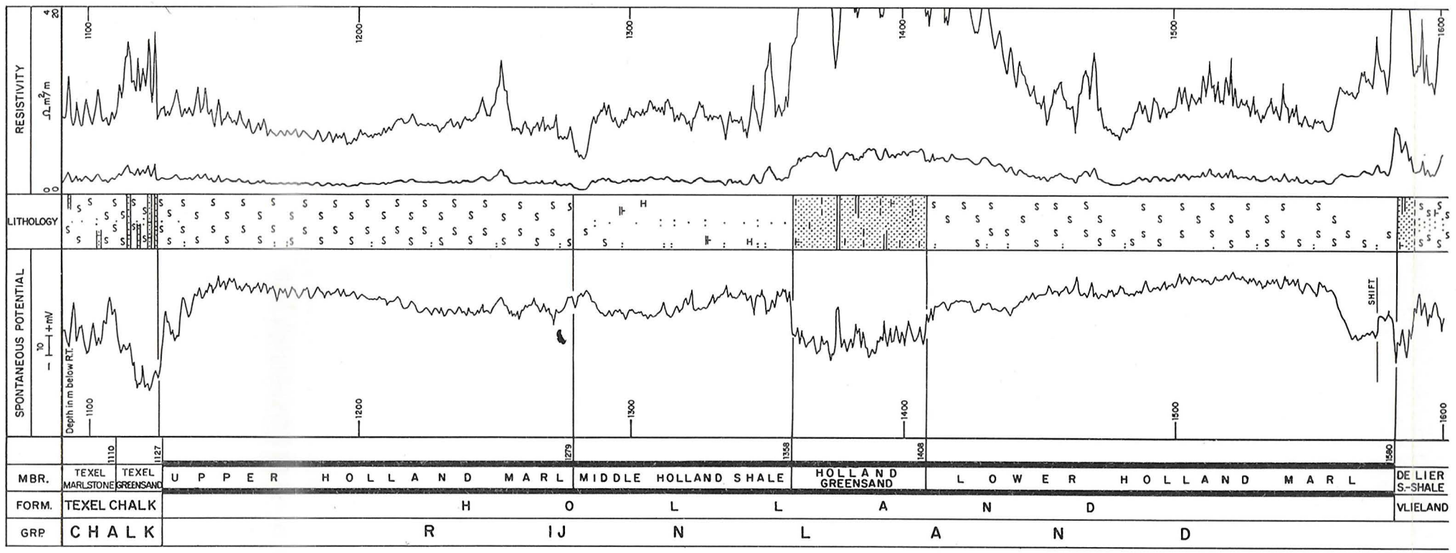


EEMHAVEN-1 (NAM)

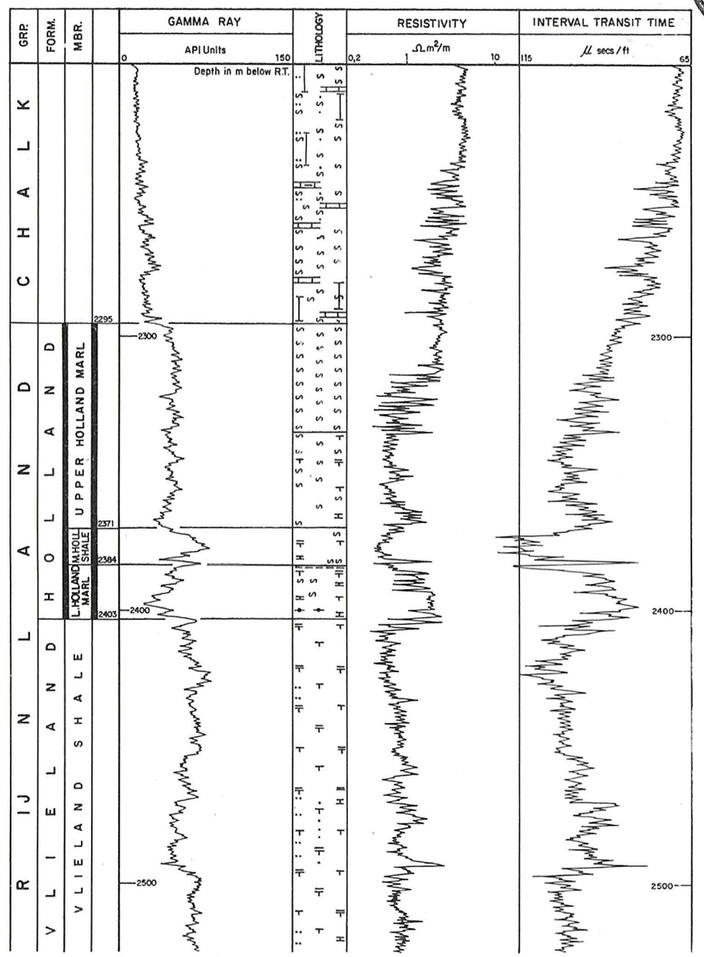


Reference wells : RUINEN-1, WESTERBORK-1 RIDDERKERK-2, EEMHAVEN-1	RIJNLAND	ENCL.26

DE LIER - 2 (NAM)



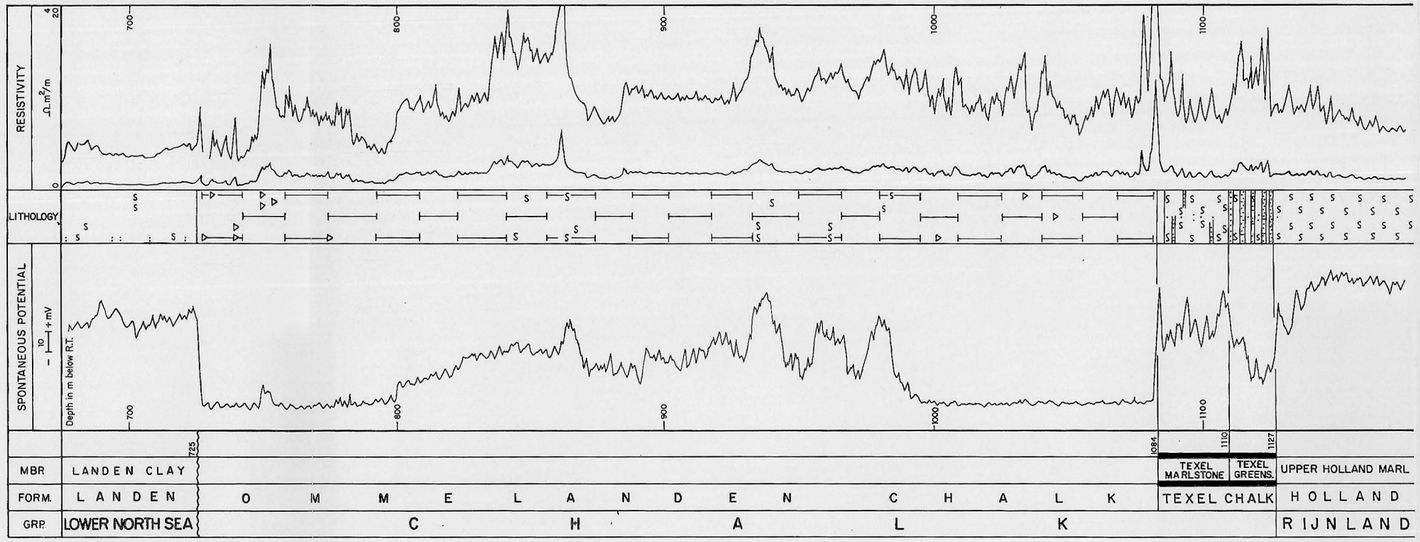
L5-1 (NAM)



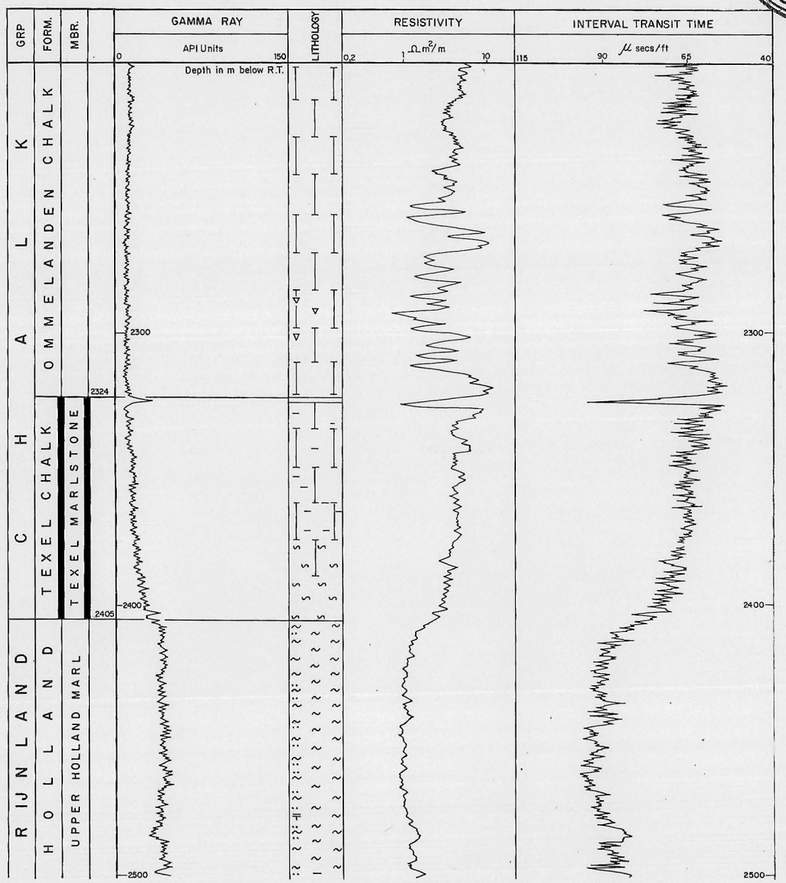
Reference wells : DE LIER - 2, L5 - 1	R I J N L A N D	ENCL. 27

G. 103.544 -

DE LIER-2 (NAM)

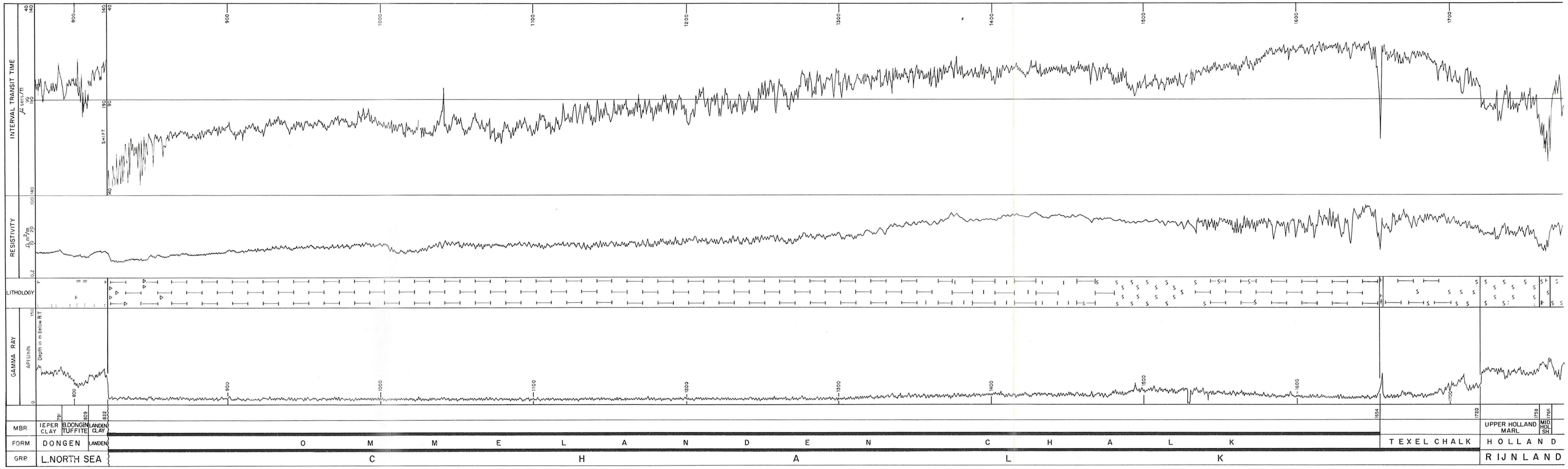


L12-2 (NAM-CLMS)



Reference wells : DE LIER-2, L12-2	C H A L K	ENCL. 28

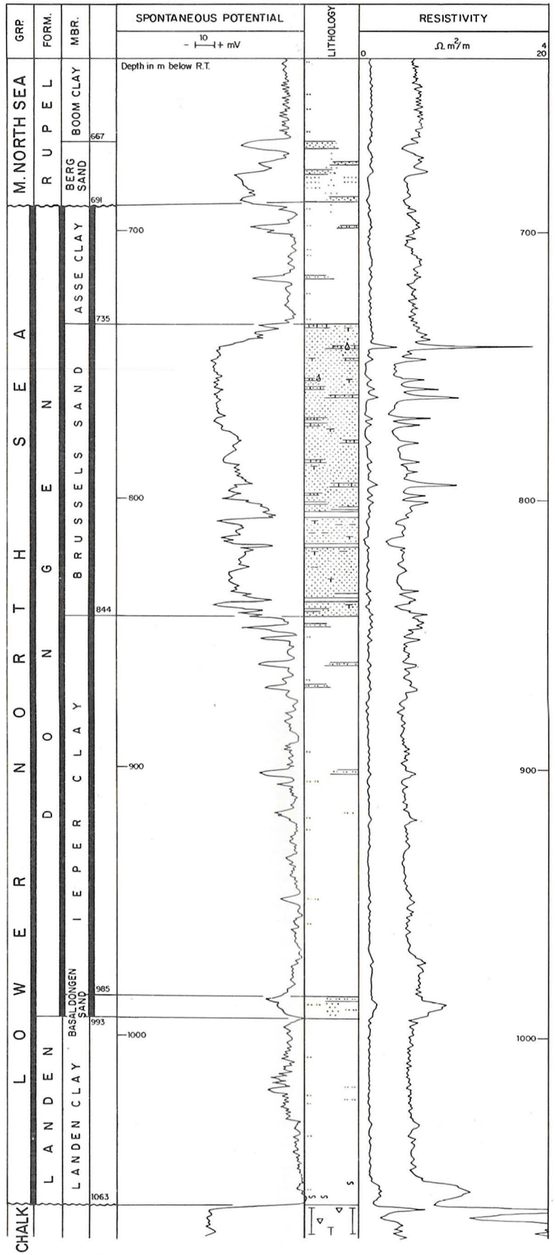
DE PAAUWEN-1 (NAM)



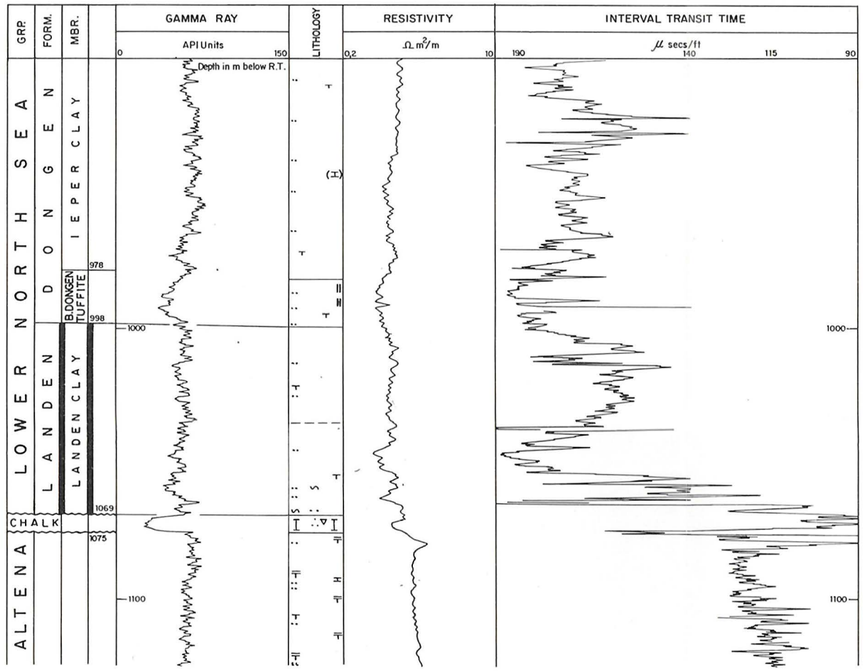
Reference wells : DE PAAUWEN-1	C H A L K	ENCL. 29

G.103.544 -

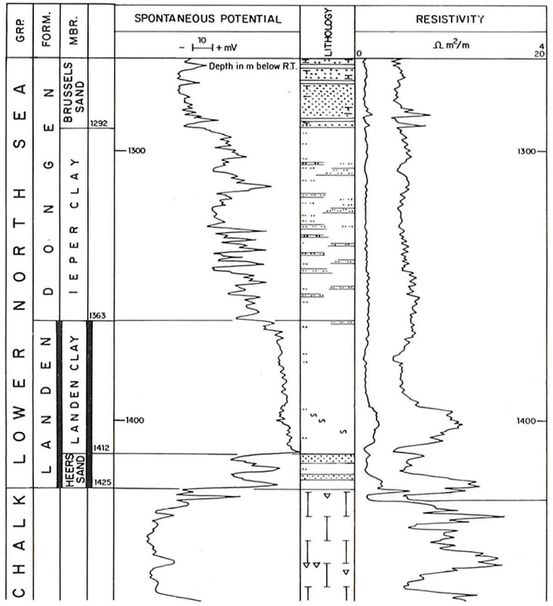
DONGEN-1 (NAM)



K17-2 (NAM)

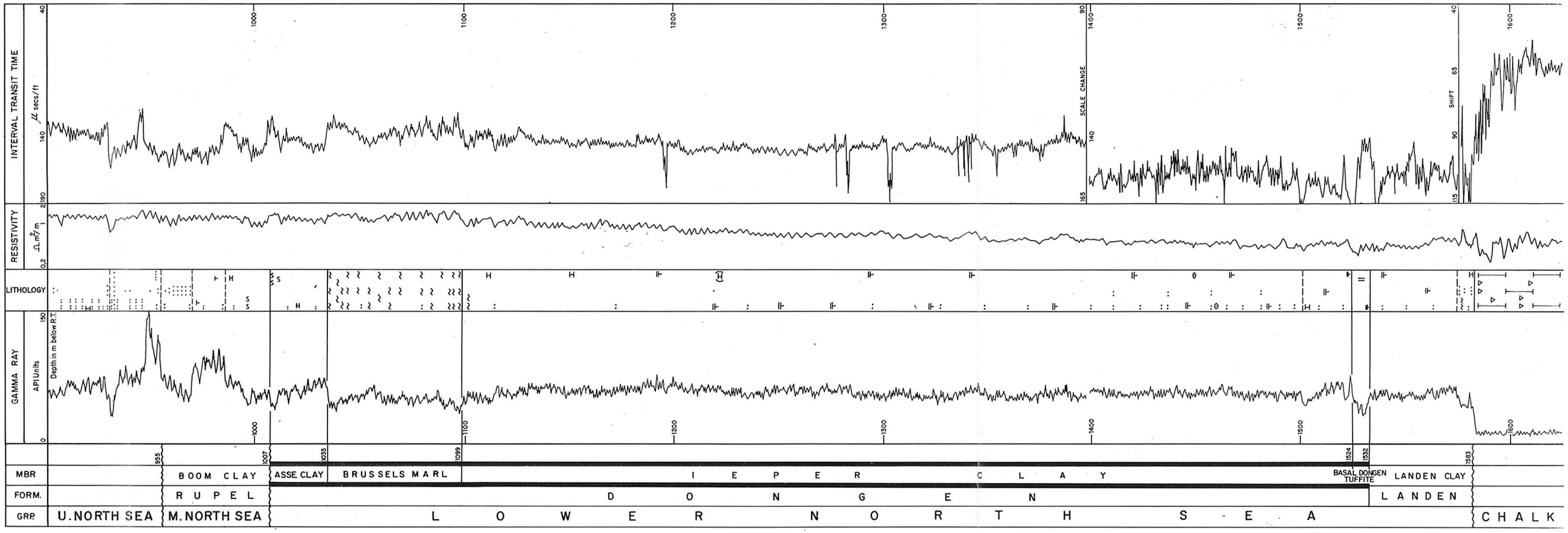


VELDHOVEN-1 (NAM)



Reference wells : DONGEN-1 , K17-2 VELDHOVEN-1	LOWER NORTH SEA	ENCL. 30

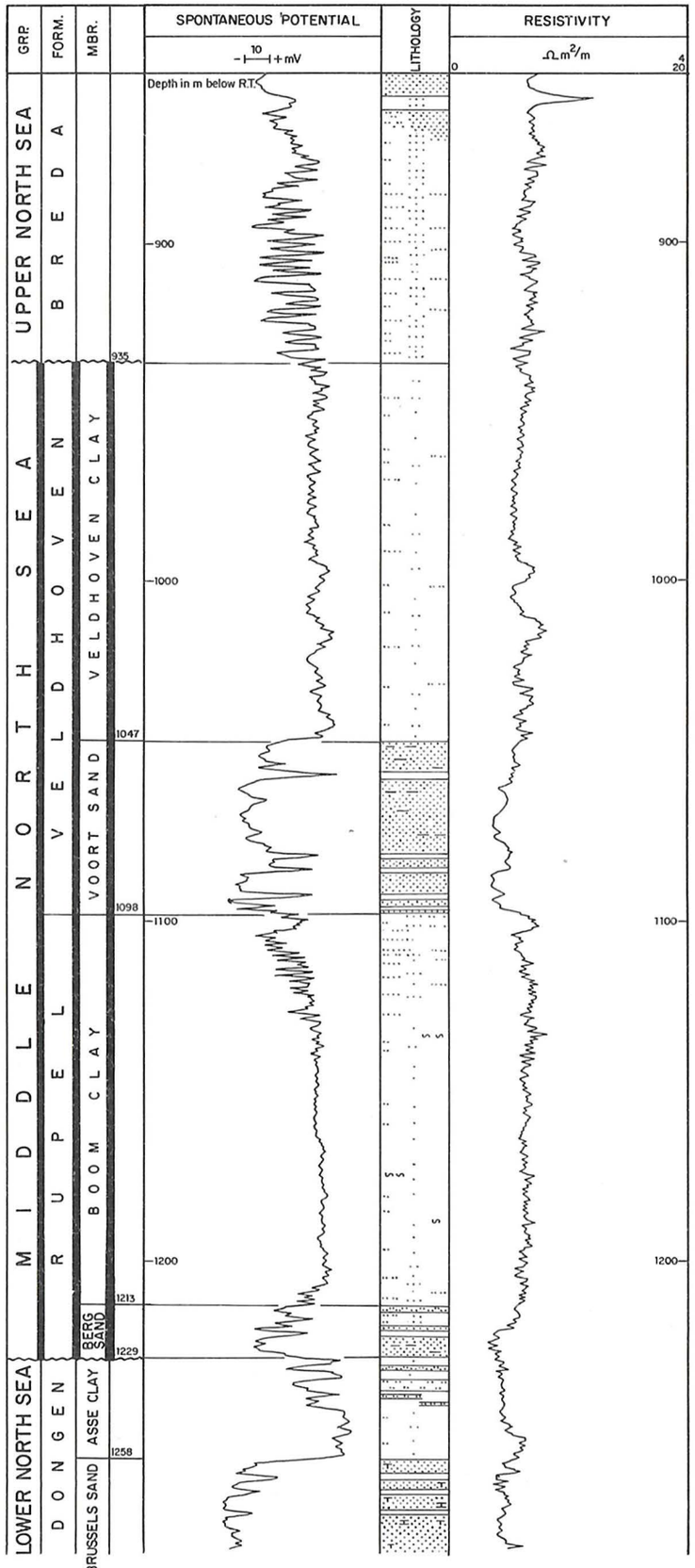
L2-4 (NAM)



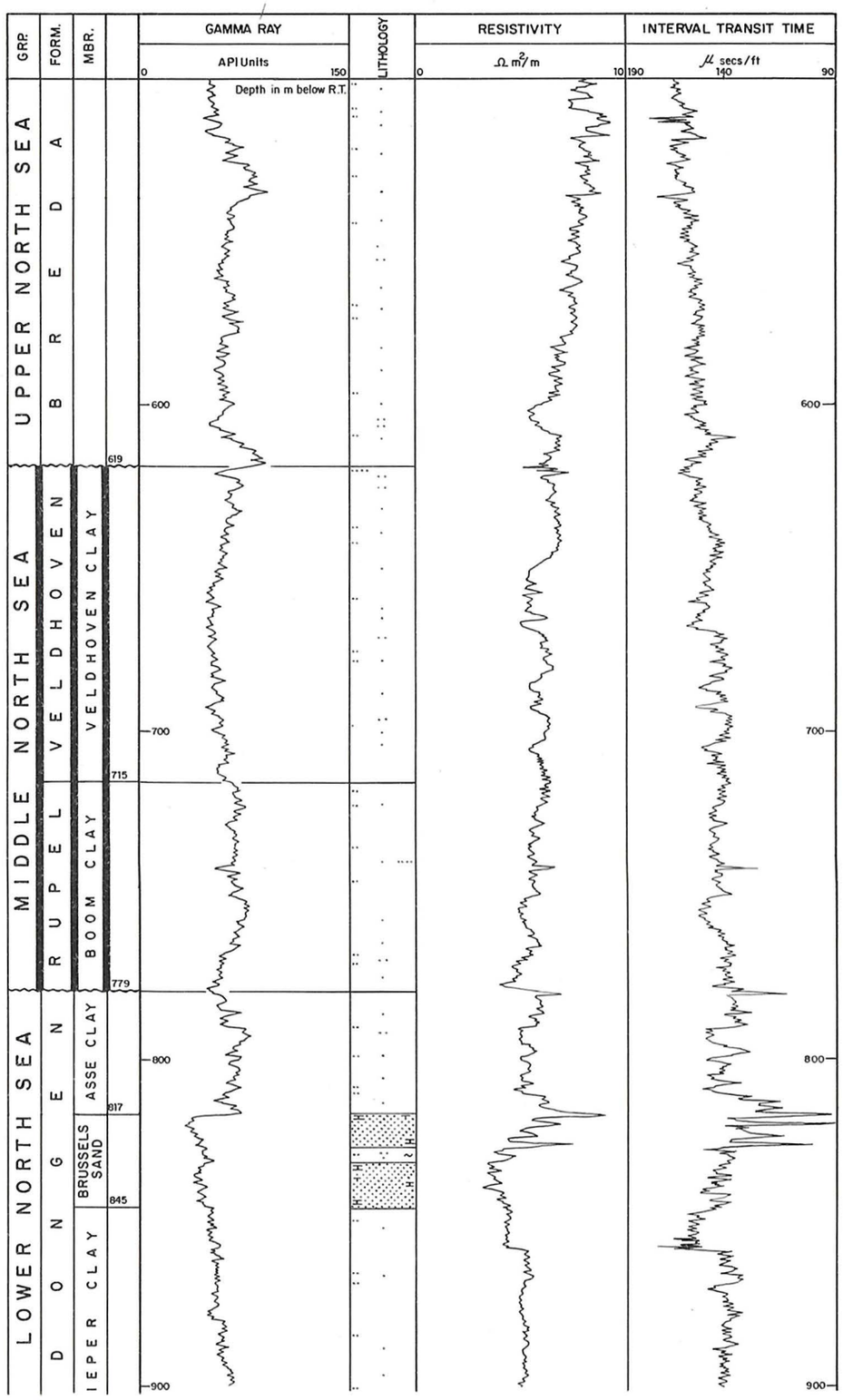
Reference wells : L2-4	LOWER NORTH SEA	ENCL. 31

G. 103.544 –

VELDHOVEN-1 (NAM)

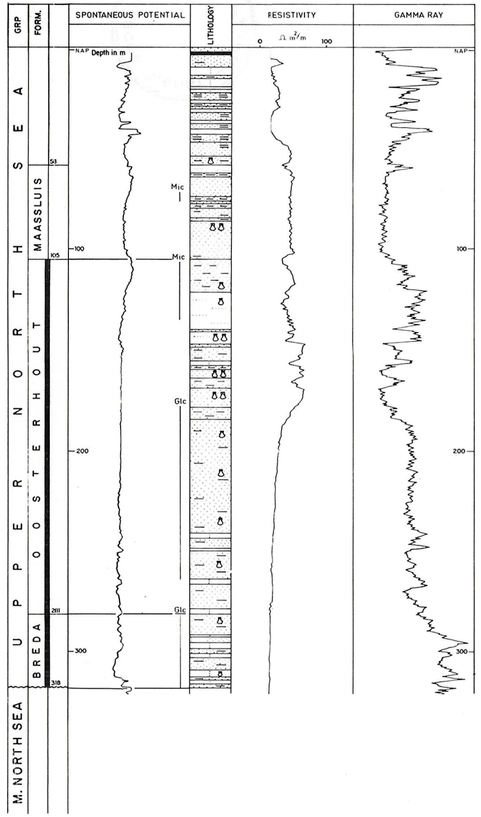


DOORNSPIJK-2 (NAM)

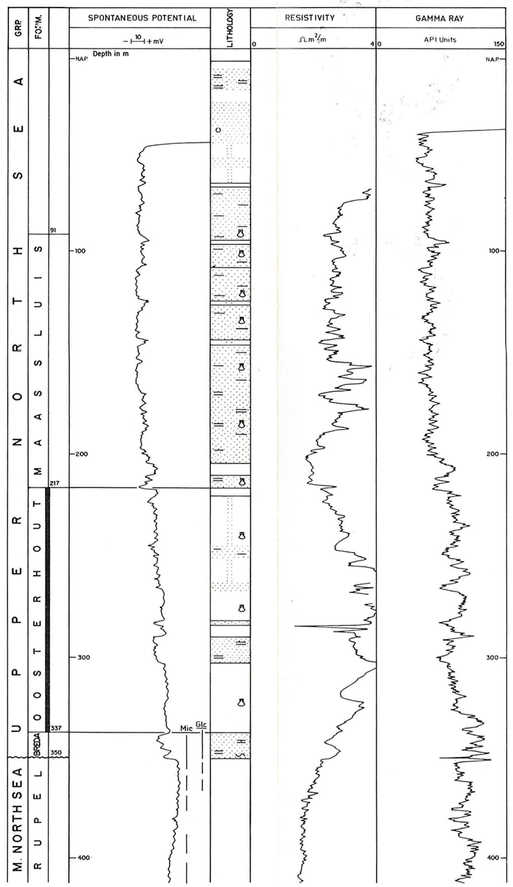


Reference wells : VELDHOVEN-1, DOORNSPIJK-2	MIDDLE NORTH SEA	ENCL. 32

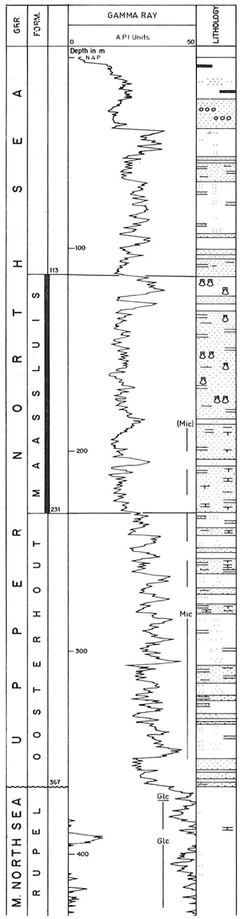
KLUNDERT 43 H-63



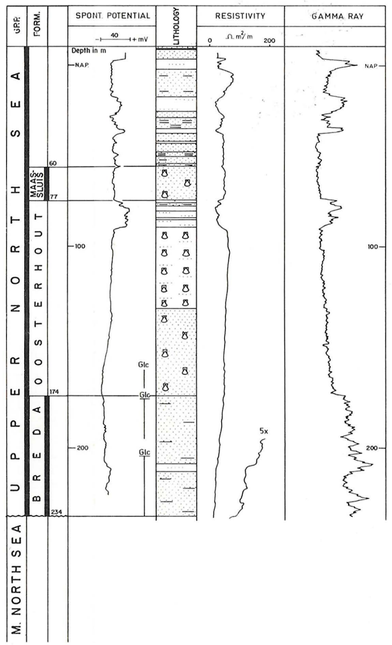
HELLEVOETSLUIS - 1 (NAM) 37 D - 178



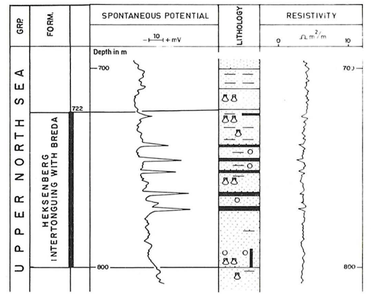
GAAG - 1 (NAM) 37 B-185



RIJSBERGEN 50 A-154



ASTEN - 1 (NAM) 52 C-142

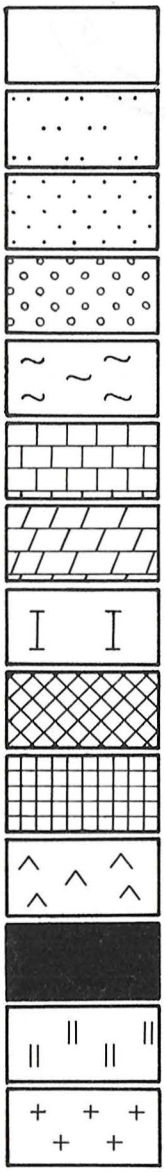


Reference wells : KLUNDERT 43H-63
HELLEVOETSLUIS -1, GAAG -1
RIJSBERGEN 50A-154, ASTEN -1

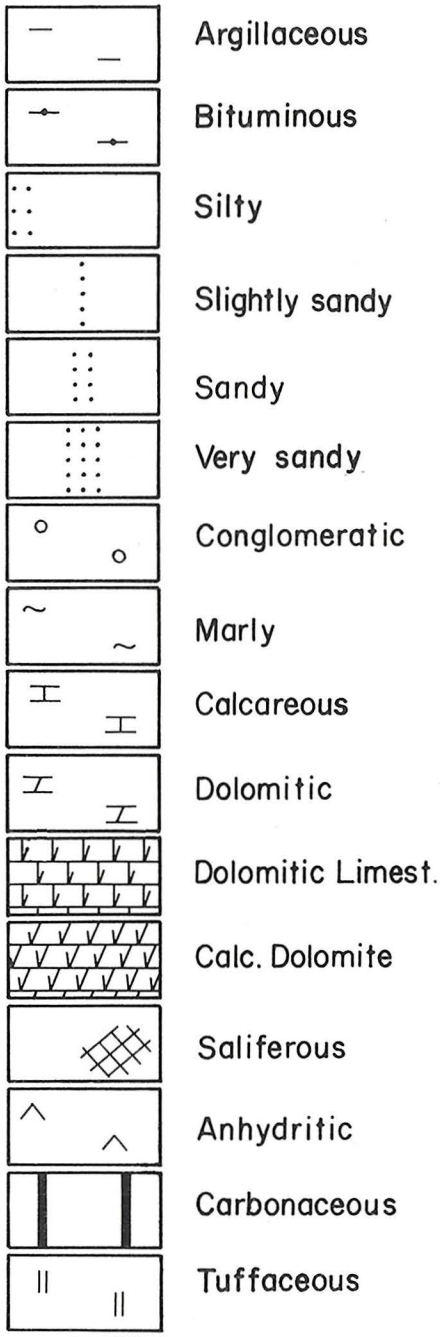
UPPER NORTH SEA

ENCL. 33

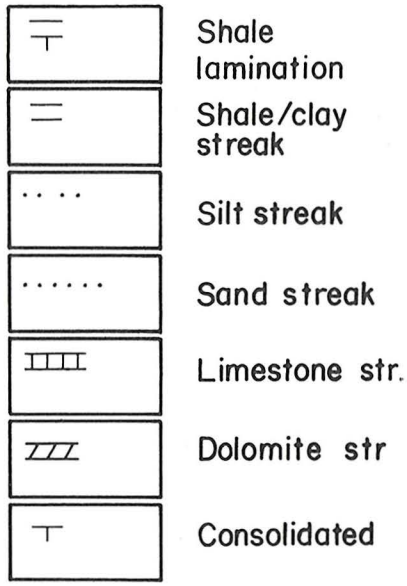
MAIN ROCK TYPES



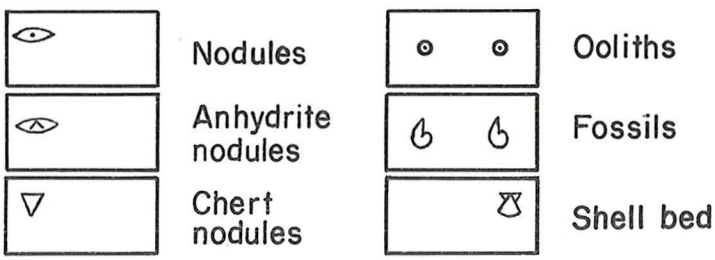
MIXTURES



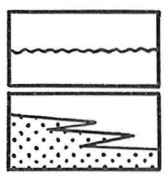
TEXTURES



INCLUSIONS



SUPERPOSITION



LOCATION MAP REFERENCE SECTIONS ENCL. 35

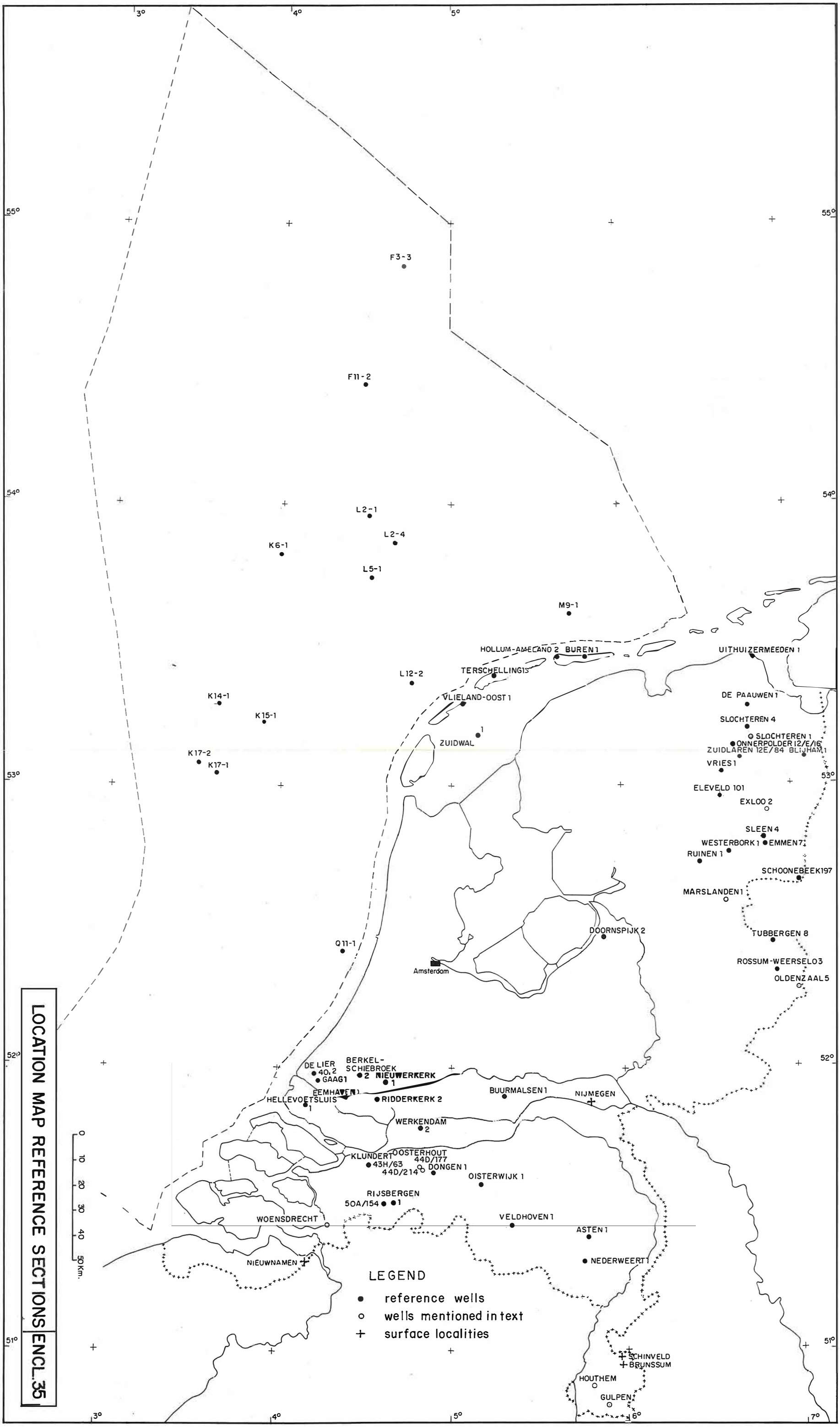


TABLE OF THE STRATIGRAPHIC NOMENCLATURE OF THE NETHERLANDS

System	Group	Code	Area	Formation	Code	Member	Code
MIOCENE–RECENT	UPPER NORTH SEA	NU		Various Pleistocene and Holocene formations and members (see ZAGWIJN and VAN STAALDUINEN 1975)			
			Continental	SCHEEMDA	NUSA	Several local members (see text)	
			Continental	KIESELOÖLITE	NUKØ		
			Continental	HEKSENBERG	NUHG		
			Marine	MAASSLUIS	NUMS	Several local members (see text)	
			Marine	OOSTERHOUT	NUØT		
			Marine	BREDA	NUBA		
OLIGOCENE	MIDDLE NORTH SEA	NM		VELDHOVEN	NMVF	Veldhoven Clay	NMVFØ
						Voort Sand	NMVFV
				RUPEL	NMRF	Boom Clay	NMRFB
						Winterswijk	NMRFW
						Brinkheurne	NMRFH
						Nucula Clay	NMRFN
						Ratum	NMRFR
						Berg Sand	NMRFS
				TONGEREN	NMTF	Goudsberg	NMTFG
						Klimmen	NMTFK
PALEOCENE–EOCENE	LOWER NORTH SEA	NL		DONGEN	NLFF	Asse Clay	NLFFB
						Brussels Sand	NLFFS
						Brussels Marl	NLFFM
						Ieper Clay	NLFFY
						Basal Dongen Sand	NLFFD
						Basal Dongen Tuffite	NLFFT
						Dongen Clay	NLFFC
				LANDEN	NLLF	Landen Clay	NLLFC
						Heers Sand	NLLFS
LATE CRETACEOUS	CHALK	CK		OMMELANDEN	CKGR		
				TEXEL	CKTX	Texel Marlstone	CKTXM
						Texel Greensand	CKTXG
			South Limburg	HOUTHEM	CKHM		
			South Limburg	MAASTRICHT	CKMA		
			South Limburg	GULPEN	CKGP		
			South Limburg	VAALS	CKVA		
			South Limburg	AKEN	CKAK		
EARLY CRETACEOUS	RIJNLAND	KN		HOLLAND	KNGL	Upper Holland Marl	KNGLU
						Middle Holland Shale	KNGLM
						Holland Greensand	KNGLG
						Lower Holland Marl	KNGLL
			In general	VLIELAND	KNNC	Vlieland Shale	KNNCM
						Vlieland Sandstone	KNNCZ
			Lower Saxony Basin			Vlieland Shale	KNNCM
						Gildehaus Sandstone	KNNCG
						Westerbork Shale	KNNCW
						Ruinen Shale	KNNCE
						Schoonebeek Shale	KNNCS
						Bentheim Sandstone	KNNCP
						Bentheim Shale	KNNCV
			S.W. Netherlands Basin			Vlieland Shale	KNNCM
						De Lier Sand-Shale	KNNCL
						Eemhaven Shale	KNNCU
						IJsselmonde Sandstone	KNNCY
						IJsselmonde Shale	KNNCA
						Berkel Clastic	KNNCD
						Berkel Sandstone	KNNCB
						Berkel Sand-Shale	KNNCC
						Rijswijk Sandstone	KNNCR
?	NIEDERSACHSEN	ND	Lower Saxony Basin	COEVORDEN	NDCF	Upper Coevorden Clay	NDCFU
						Middle Coevorden Clay	NDCFM
						Lower Coevorden Clay	NDCFL
				WEITEVEEN	NDWF	Serpulite	NDWFF
						Upper Weiteveen Marl	NDWFE
						Upper Weiteveen Evaporite	NDWFD
						Lower Weiteveen Marl	NDWFC
						Lower Weiteveen Evaporite	NDWFB
						Basal Weiteveen Clastic	NDWFA
				ZUIDWAL VOLCANIC	NDVØ		
EARLY–MIDDLE–LATE JURASSIC	DELFLAND	DF	S.W. Netherlands	UPPER DELFLAND	DFUP		
				FOURTEENS CLAY	DFFC		
				LOWER DELFLAND	DFLØ		
	SCRUFF	SG	Central N. Sea Graben	KIMMERIDGE CLAY	SGKI	Upper Kimmeridge Clay	SGKIU
						Lower Kimmeridge Clay	SGKIL
				PUZZLE HOLE	SGDF		
	CENTRAL GRABEN	CG	Central N. Sea Graben	UPPER GRABEN SAND	CGUS		
				MIDDLE GRABEN SHALE	CGMS		
				LOWER GRABEN SAND	CGLS		
	ALTENA	AT		BRABANT	ATBR	Oisterwijk Limestone	ATBRØ
						Upper Brabant Marl	ATBRU
						Upper Brabant Limestone	ATBR3
						Middle Brabant Marl	ATBRM
						Middle Brabant Limestone	ATBR2
						Lower Brabant Marl	ATBRL
						Lower Brabant Limestone	ATBR1
				WERKENDAM SHALE	ATWD	Upper Werkendam Shale	ATWDU
						Middle Werkendam	ATWDM
						Lower Werkendam Shale	ATWDL
						Posidonia Shale	ATWDP
				AALBURG SHALE	ATAL		
				SLEEN SHALE	ATRT		
TRIASSIC	UPPER GERMANIC TRIAS	RN		KEUPER	RNKP	Argillaceous Keuper	RNKPC
						Upper Keuper Claystone	RNKPU
						Dolomitic Keuper	RNKPD
						Red Keuper Claystone	RNKPR
						Red Keuper Evaporite	RNKPE
						Middle Keuper Claystone	RNKPM
						Main Keuper Evaporite	RNKPS
						Lower Keuper Claystone	RNKPL
				MUSCHELKALK	RNMU	Muschelkalk Claystone	RNMUC
						Upper Muschelkalk	RNMUU
						Middle Muschelkalk	RNMUM
						Middle Muschelkalk Marl	RNMUA
						Muschelkalk Salt	RNMUH
						Lower Muschelkalk	RNMUL
				RÖT	RNRØ	Upper Röt Claystone	RNRØU
						Röt Evaporite	RNRØE
						Upper Röt Evaporite	RNRØ2
						Intermediate Röt Claystone	RNRØM
						Main Röt Evaporite	RNRØ1
						Solling Claystone	RNRØS
						Upper Solling Claystone	RNRØC
						Solling Sandstone	RNRØB
						Lower Solling Claystone	RNRØA
	BUNTER	BS		UPPER BUNTER	BSUB		
				MIDDLE BUNTER	BSMB		
				LOWER BUNTER	BSLB		
	LOWER GERMANIC TRIAS	RB		MAIN BUNTSANDSTEIN	RBSS	Hardegsen	RSSSH
						Hardegsen Claystone	RBSSA
						Hardegsen Sandstone	RBSSS
						Detfurth Claystone	RBSSC
						Detfurth Sandstone	RBSSD
						Volpriehausen Clay-Siltstone	RBSSP
						Volpriehausen Sandstone	RBSSV
				LOWER BUNTSANDSTEIN	RBSH	Rogenstein	RBSHR
						Main Claystone	RBSHM
						Basal Buntsandstein	RBSHB
PERMIAN	ZECHSTEIN	ZE		ZECHSTEIN 4	ZEZ4	Z 4 Salt	ZEZ4H
						Z 4 Pegmatite Anhydrite	ZEZ4A
						Red Salt Clay	ZEZ4R
				ZECHSTEIN 3	ZEZ3	Z3 Salt	ZEZ3H
						Z3 Main Anhydrite	ZEZ3A
						Z3 Carbonate	ZEZ3C
						Z3 Anhydrite-Carbonate	ZEZ3B
						Grey Salt Clay	ZEZ3G
				ZECHSTEIN 2	ZEZ2	Z2 Roof Anhydrite	ZEZ2T
						Z2 Salt	ZEZ2H
						Z2 Basal Anhydrite	ZEZ2A
						Z2 Carbonate	ZEZ2C
				ZECHSTEIN 1	ZEZ1		
			Basin Centre			Z1 Anhydrite	ZEZ1W
						Z1 Carbonate	ZEZ1C
						Z1 Anhydrite-Carbonate	ZEZ1B
						Coppershale	ZEZ1K
			Eastern Subbasin			Z1 Upper Anhydrite	ZEZ1T
						Z1 Salt	ZEZ1H
						Z1 Lower Anhydrite	ZEZ1A
						Z1 Carbonate	ZEZ1C
						Z1 Anhydrite-Carbonate	ZEZ1B
						Coppershale	ZEZ1K
				FRINGE ZECHSTEIN	ZEFR	Upper Carbonate	ZEFRC
						Main Fringe Zechstein	ZEFRL
						Coppershale	ZEFRK
				ZECHSTEIN CAPROCK	ZECP		
				ZECHSTEIN SALT	ZESA	Upper Zechstein Salt	ZESAU
						Lower Zechstein Salt	ZESAL
	UPPER ROTLIEGEND	RØ		SLOCHTEREN SANDSTONE	RØSL	Upper Slochteren Sandstone	RØSLU
						Lower Slochteren Sandstone	RØSLL
				SILVERPIT CLAYSTONE	RØCL	Ten Boer Claystone	RØCLT
						Ameland Claystone	RØCLA
						Hollum Claystone	RØCLH
			Basin Centre			Upper Silverpit Claystone	RØCLU
						Silverpit Evaporite	RØCLE
						Lower Silverpit Claystone	RØCLL
	LOWER ROTLIEGEND	PB		ROTLIEGEND VOLCANICS	PBVØ		
				BASAL ROTL. CLASTICS	PBBA		
CARBONIFEROUS	LIMBURG	DC	East Netherlands	BARREN MEASURES	DCCR		
			East Netherlands	TUBBERGEN SANDSTONE	DCCT		
			East Netherlands	PRODUCTIVE MEASURES	DCCP		
				COAL MEASURES	DCCM		