EXPLANATION TO TECTONIC MAPS OF THE NETHERLANDS

by NEDERLANDSE AARDOLIE MAATSCHAPPIJ B.V., Assen

compilation and comments by P. HEYBROEK
(with two plates in cover)

SUMMARY

Three structural contour maps and three geological maps at different levels covering the Netherlands are presented and discussed. The levels depicted are the top Carboniferous, the base Cretaceous–Upper Jurassic and the base Tertiary. The maps are discussed in relation to the tectonic history of the Netherlands. The deformation is classed as intracratonic, epeirogenetic. Three successive patterns of movement are recognized: the Permo–Triassic, the Jurassic–Lower Cretaceous, and the Cenozoic. They are basically different from each other but relatively constant in themselves. The Jurassic–Lower Cretaceous pattern and its inversion in the Upper Cretaceous receives special attention.

I. INTRODUCTION

Three structural contour maps and three geological maps at different levels have been prepared as a contribution to the tectonic map sheet of "The Atlas of the Netherlands" (1963). In the present paper the structure and geology as shown on these maps is discussed (two plates and fig. 2).

The deeper geology of the Netherlands is covered by a blanket of very young sediments and its knowledge depends almost exclusively on geophysical and well data. A vast amount of these data were gathered by the Nederlandse Aardolie Maatschappij during the 25 years of its search for hydrocarbons. These data were interpreted over the years by a large number of earth scientists. The presented maps are based on this effort which is hereby acknowledged. Thanks are due to the parent companies of the Nederlandse Aardolie Maatschappij B.V. (NAM), Shell Nederland B.V. and Esso Nederland B.V. for releasing the data for publication.

The data vary considerably in quality and density according to area. New data will become available from continuing exploration activities, which will result in refinements and possibly significant changes in interpretation.

In view of the scale of the maps often a significant and sometimes extreme amount of simplification of the data has been necessary to allow the main features to emerge. This has been the responsibility of the compiler.

Published literature is used for the mapped portions of Germany, Belgium and the Dutch coalmining district.

The three levels for which the maps are drawn have been chosen for their suitability in tracing the structural evolution. However, the availability of comprehensive regional information has played a considerable role.

The deepest level depicted, the top Carboniferous, represents an erosional surface largely molded by Permian erosion (geological section on plate, fig. 1) but also in part by Cretaceous and even Tertiary erosion. The subcropping formations span the whole of the Carboniferous (fig. 2). This level has been chosen to illustrate the structural connection with the well explored mining districts in the southeast.

The base Cretaceous–Upper Jurassic level represents in essence the base of a transgressively onlapping sequence deposited on an erosional surface during a long time interval of strong differential movements (fig. 1).

The base Tertiary level represents a general transgression of uppermost Paleocene–lowermost Eocene age in large parts of the area. It should be noted that there are exceptions mainly towards the edge of the basin, where younger strata onlap.

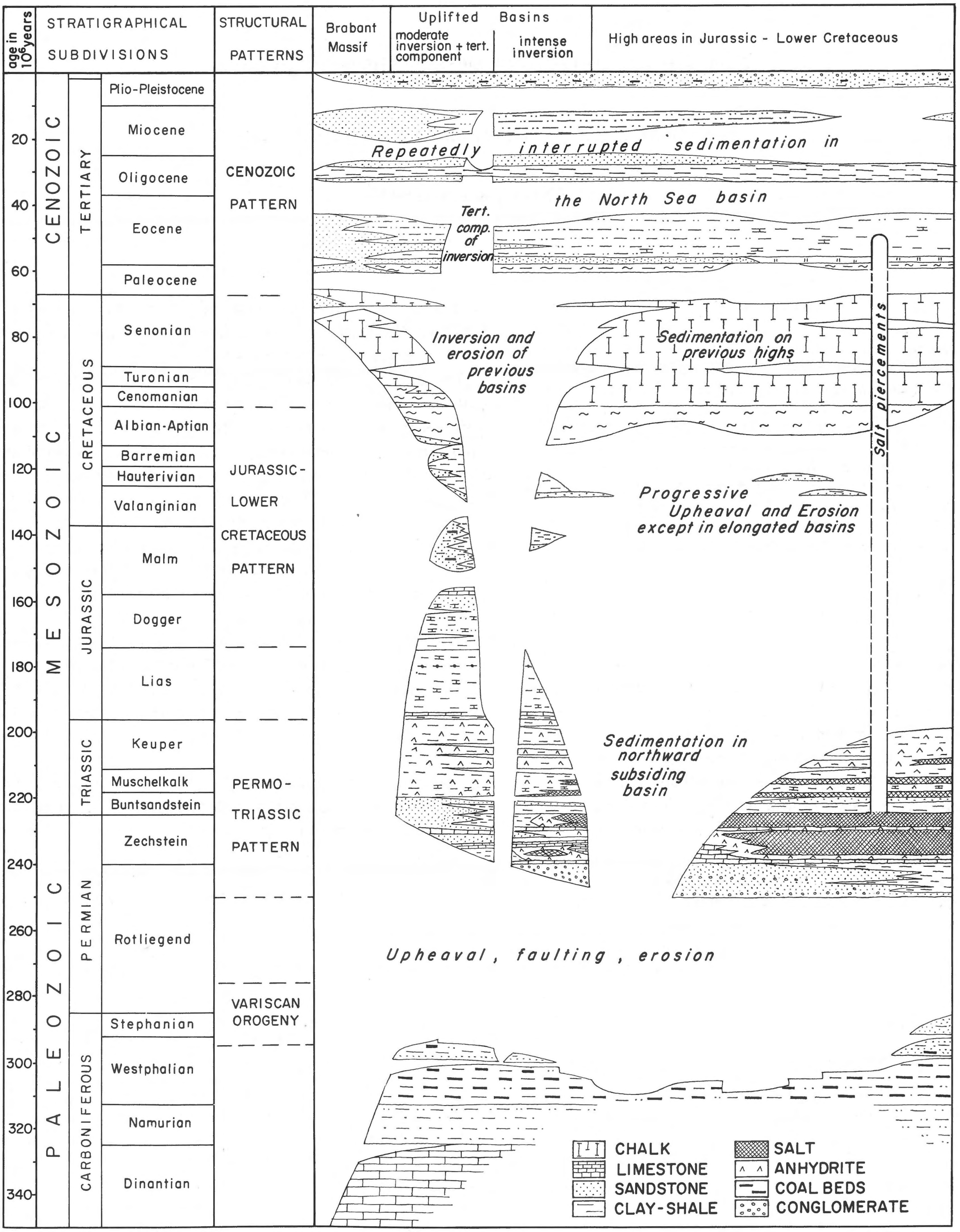
A review of the tectonic history of the Netherlands is given in the following paragraphs and diagrams. It is based on published literature and additional NAM data.

II. REVIEW OF THE TECTONIC HISTORY OF THE NETHERLANDS

The geological record of the subsurface of the Netherlands in general dates back to the Westphalian. During the Westphalian a thick sequence was deposited in a peat swamp facies in a basin extending from Great Britain into eastern Europe. This was brought to a close by the Variscan (Hercynian) orogeny which affected a region through middle and western Europe. The northern front of this belt is near the Netherlands border, southeast of Limburg province (fig. 2; Fourmarier, 1954; Hoyer, 1962). North of the mountain front, folding was slight and died out quickly to the north.

During early Permian, both the northern foreland and the mountain range were uplifted. This was accompanied by intense northwest-southeast faulting perpendicular to the

SCHEME OF GEOLOGICAL EVENTS IN THE NETHERLANDS FIG. 1



earlier fold trend. Some of these faults acted as preferential zones of weakness for displacements during subsequent tectonic movements.

Since the Carboniferous, no orogenic movements are recognized near or in the Netherlands and all later deformations are classed as intracratonic, epeirogenetic. Only vertical movements (normal and reverse faulting) are assumed, as no direct evidence is found for horizontal displacements. The vertical movements are manifest either as relatively unbroken regional warps or along faults and within fault-bounded blocks.

Associated with the general upheaval at the end of the Carboniferous, there began a long period of erosion which lasted for about 30 million years. According to conservative estimates 1500-2000 m of Carboniferous strata were removed from large regions of the country where erosion cut into the Westphalian–A (Patijn, 1964; Stäuble and Milius, 1970). The geological map of the Carboniferous (fig. 2) indicates the degree of Permian erosion, except in the south where an appreciable amount of post-Permian erosion occurred (see section on plate). Our knowledge of the structure of the Carboniferous below the erosion surface is still fragmentary as it is deduced largely from well data; traceable seismic reflections are practically non-existent. Two areas with only moderate uplift and erosion can be distinguished. One runs north-south along the eastern Netherlands border; the first indication of the *Ems low*, a Permo-Triassic element of accentuated subsidence. The other one is in the south and has a southeast-northwest alignment. Its southern edge has been modified by post-Permian erosion. The northeastern edge coincides with the eastern limit of the *Roer Valley graben* indicating an early Permian component for this structural element, which has been repeatedly re-activated during the later history of the Netherlands.

A basin was initiated in late Rotliegend time on the eroded Carboniferous surface, and continued its subsidence in essentially the same form until the end of the Triassic, with the younger formations overlapping the older ones. The basin is flanked by the London–Brabant and Rhenish massifs in the south and the Mid North Sea and Fyn-Grinsted highs in the north (fig. 3; Glennie, 1972; Heybroek et al, 1967; Bartenstein, 1968).

In this basin accumulated the coarse clastics, shales and evaporites of the Rotliegend, the evaporites and carbonates of the Zechstein and the reddish clastics and evaporites of the Trias. All these sediments were deposited in a restricted marine to continental environment. The sedimentary thickness generally increases northwards, indicating that the Netherlands occupies a position on the southern flank of that basin (Glennie, 1972; Brueren, 1957; Visser, 1963; Geiger and Hopping, 1968; Wolburg, 1961, 1969; Trusheim, 1963). The Permo-Triassic structural pattern is, moreover, characterised by swells and deeps running almost perpendicular (SSW-NNE) to the axis of the main basin. These were caused by periodically active differential subsidence. In the Netherlands the *Ems low* is found along the eastern border whilst the *Netherlands swell* occupies a large part of the land area and the *Off-Holland low* in the North Sea is parallel to the west coast (fig. 4). An accentuated subsidence occurred in the *Roer Valley graben*, especially along the western boundary fault.

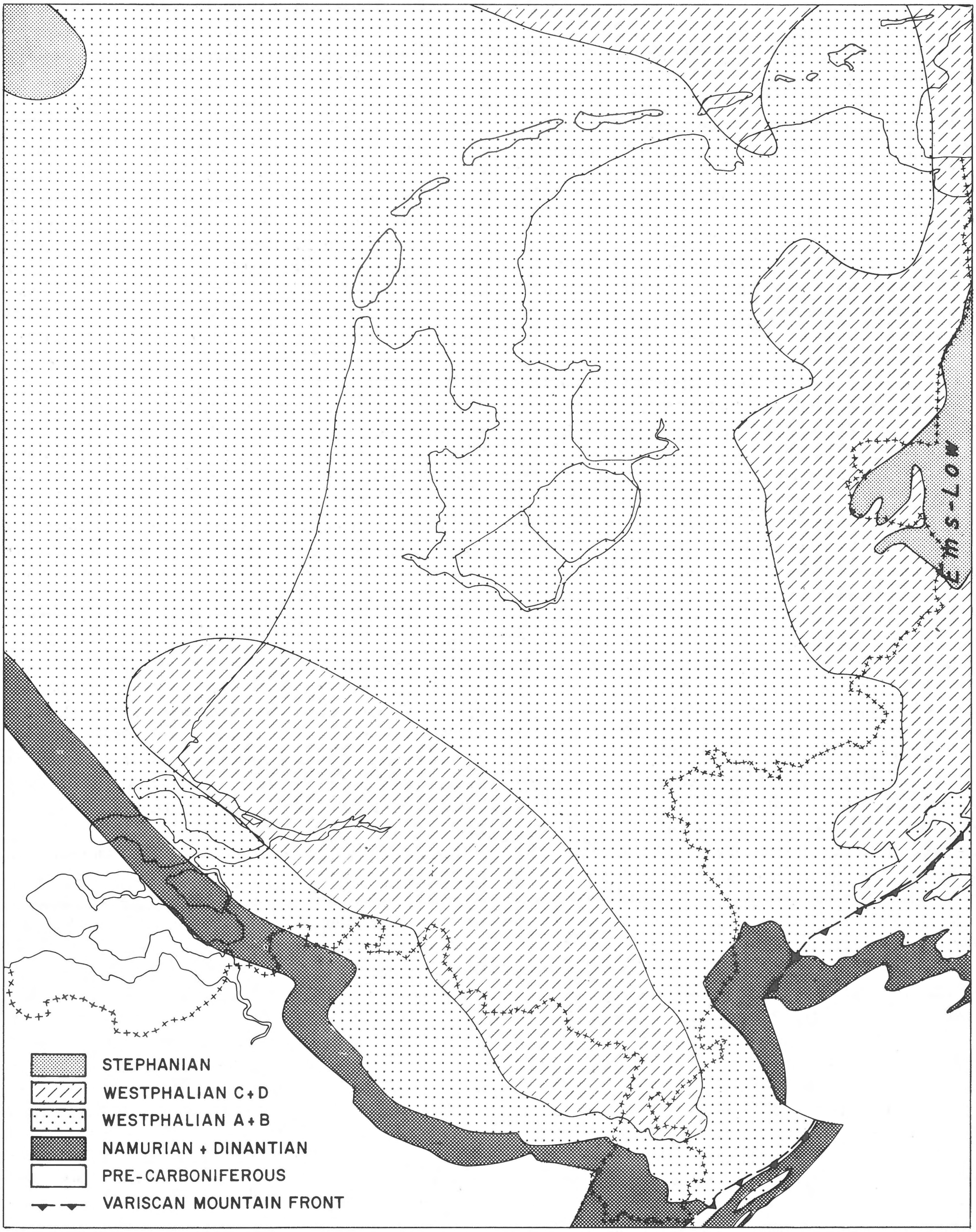
The rocksalt deposits of the Zechstein may have reached a thickness of 1500 m in the centre of the basin north of the Dutch coast. These salts became mobile when the overburden reached a sufficient thickness to trigger the intense halokinetic movements which formed salt concentrations in pillows and piercements. In the northern part of the area these movements strongly affected the configuration of the younger layers and are responsible for the pronounced local disturbances depicted on the depth contour maps at base Lower Cretaceous and base Tertiary levels (fig. 3; Trusheim, 1960; Sanneman, 1963; Mulder, 1950; Heybroek et al. 1967).

The tectonic movements during the Lower and Middle Jurassic are difficult to reconstruct because the sediments of this period have largely been removed during later periods of uplift and erosion. However, the lithology and the paleontology of the Lower Jurassic indicates the presence, for the first time since the Dinantian, of open marine conditions and a general transgression that probably drowned large Triassic land areas. A homogeneous sequence of black calcareous and sometimes bituminous shales was deposited over large parts of western Europe, indicating a period of relative tectonic quiescence. However, from the fragmentary knowledge of sedimentary thicknesses there are indications that deeps and swells existed in the Lower Jurassic basin, not caused by halokinetic movements. These differ in pattern from those of the Permo-Triassic. They herald a completely different structural style which becomes evident during the Upper Jurassic and Lower Cretaceous (Haanstra, 1963; for a compilation of northwest European data see Sorgenfrei, 1969).

The lithology of the Middle Jurassic indicates a regression; sandstones and shallow water limestones appearing in the sequence. It has been demonstrated that the clastics were derived from the north. Erosional remnants indicate that, at least locally, sedimentation proceeded until the Middle Oxfordian, after which the uplift became general and the whole area was affected by erosion (Haanstra, 1963; Brand and Hoffman, 1963).

Sedimentation resumed gradually in the Kimmeridgian and continued into the Valanginian with fresh to brackish water facies in narrow elongated and isolated basins. Meanwhile, erosion modified the surrounding highs. Generally a break in sedimentation and some erosion occurred in the basins at the end of the Upper Jurassic. Sedimentation resumed in the Lower Cretaceous in a marine environment with essentially the same pattern of basins and highs persisting. On the geological map of the pre-Cretaceous–Upper Jurassic, two complete basins and portions of two others are present in the area considered. They are character-

FIG. 2



GEOLOGICAL MAP OF THE CARBONIFEROUS

ised by the presence of Lower and Middle Jurassic sediments which were removed by erosion from the bordering highs.

Each of the two basins may be subdivided on the basis of differences in tectonic development. The southernmost basin can be split into the *Roer Valley graben* and the *West Netherland basin,* whilst the more medial basin is divided into the *Central Netherlands basin* and the *Broad Fourteens basin*.

The western termination of the *Lower Saxony basin* crosses the Dutch border from the east (B o i g k, 1968; 't H a r t, 1969). The southern extension of the *Central North Sea graben* enters the map from the north.

The basins are flanked by high areas such as the *Brabant massif* in the south and the narrow complicated ridge between the Roer Valley–West Netherlands basin and the Central Netherlands–Broad Fourteens basin. The latter is characterised by a number of local highs such as the *Krefeld high, Maasbommel high, Zandvoort ridge* and *IJmuiden high.* The *Texel–IJsselmeer high* is north of the Central Netherlands–Broad Fourteens basin. It holds a similar position to the "Pompeckscher Swelle" in Germany north of the Lower Saxony basin with which it merges in the Groningen area (B o i g k, 1968). The name North Netherlands high has been used previously for this connecting element (S t ä u b l e and M i l i u s, 1970; 't H a r t, 1969). Between the Broad Fourteens basin and the Central North Sea graben the *Cleaverbank high* is found. It may be noted that the ESE-WNW direction of all these tectonic elements is at right angles to the deeps and swells in the Permo-Triassic basin (fig. 4 and 5).

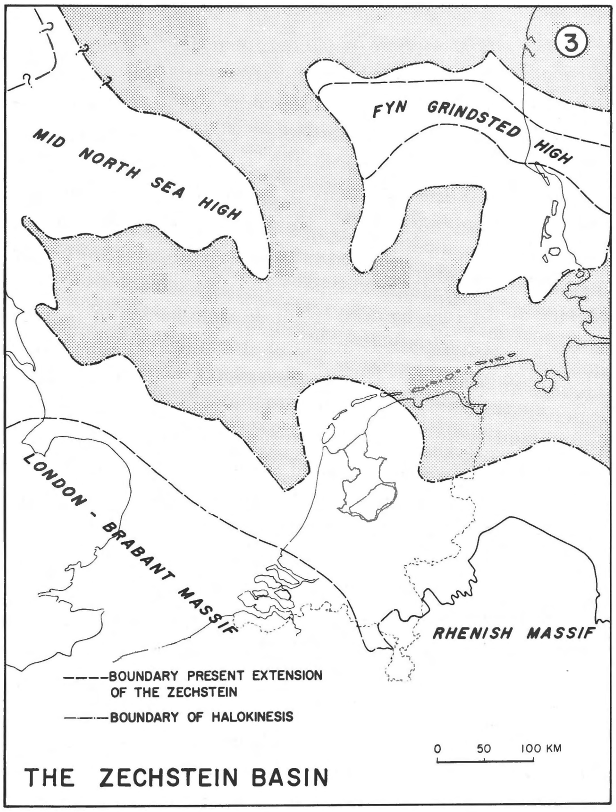
A thick complete sequence of Lower Cretaceous marine sediments was deposited in the basin centres. Thin deposition took place locally on the highs only to be partly removed during minor regressions in the Lower Cretaceous. However, in Aptian-Albian times, the transgression became gradually more general and all highs were submerged and subsequently covered by a thick sequence of homogeneous chalk of Upper Cretaceous age (V i s s e r and S u n g, 1958). The presence of a nearby landmass may only be deduced in the south where clastic intercalations occur in the chalk. This landmass also was eventually largely covered by the Maestrichtian Sea (P a n n e k o e k, 1956); L e g r a n d, 1968; A r n o l d, 1964).

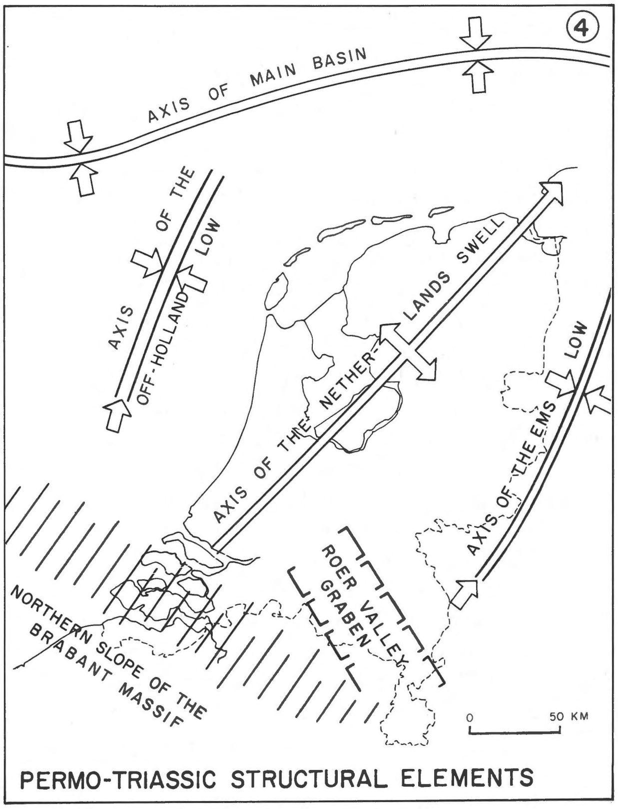
The early Upper Cretaceous must be regarded as a time of relative tectonic quiescence following the Jurassic–Lower Cretaceous movements. However, in the middle of the Upper Cretaceous the Jurassic–Lower Cretaceous structural pattern was re-activated, although in the opposite sense. The former basins became high areas and were eroded, while the former bordering highs were downwarped to a certain extent. On the geological map of the pre-Tertiary, the uplifted Upper Jurassic–Lower Cretaceous basins stand out as windows of older rocks in a general blanket of Upper Cretaceous sediments. Elsewhere in northwest Europe, other basins experienced similar retroactive movements, called "inversion" by previous authors. (V o i g t, 1962; H e y b r o e k et al, 1967).

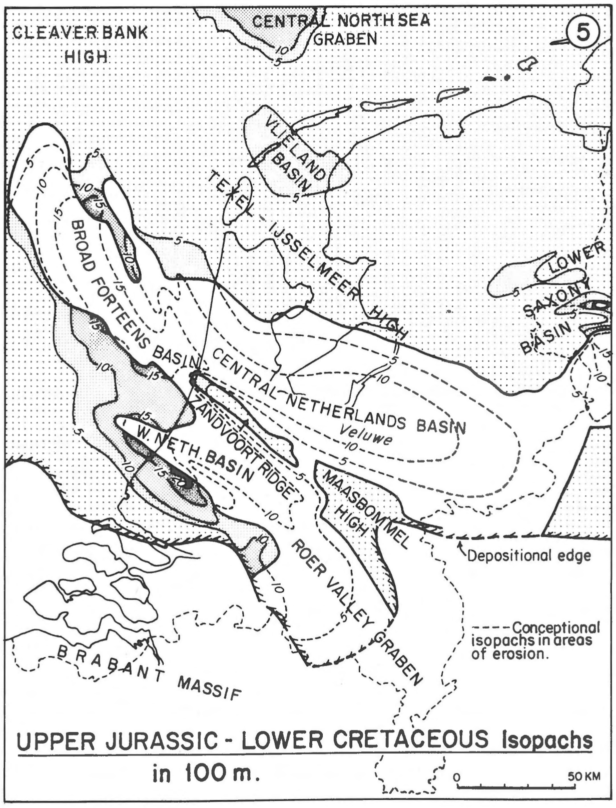
A more detailed impression of Upper Jurassic and Cretaceous tectonics may be gained form figures 5, 6 and the geological section (plate). The large variation in Upper Jurassic–Lower Cretaceous sediment thickness between the highs and the basins is indicative of differential subsidence (fig. 5). Due to later erosion, the record in the basins is incomplete, and the estimates of original thickness remain speculative. The present day thickness distribution of the Upper Cretaceous illustrates the upheaval of the Upper Jurassic–Lower Cretaceous basins and the subsidence of the bordering highs (fig. 6). The latter became basins of deposition during late Upper Cretaceous, forming troughs which encircle the uplifted Upper Jurassic–Lower Cretaceous basins. These inversion movements persisted through the Senonian but were of varying amplitudes (fig. 1). Figures 5 and 6 disclose, moreover, a small additional Upper Jurassic–Lower Cretaceous basin, the *Vlieland basin,* which was slightly uplifted in the Upper Cretaceous.

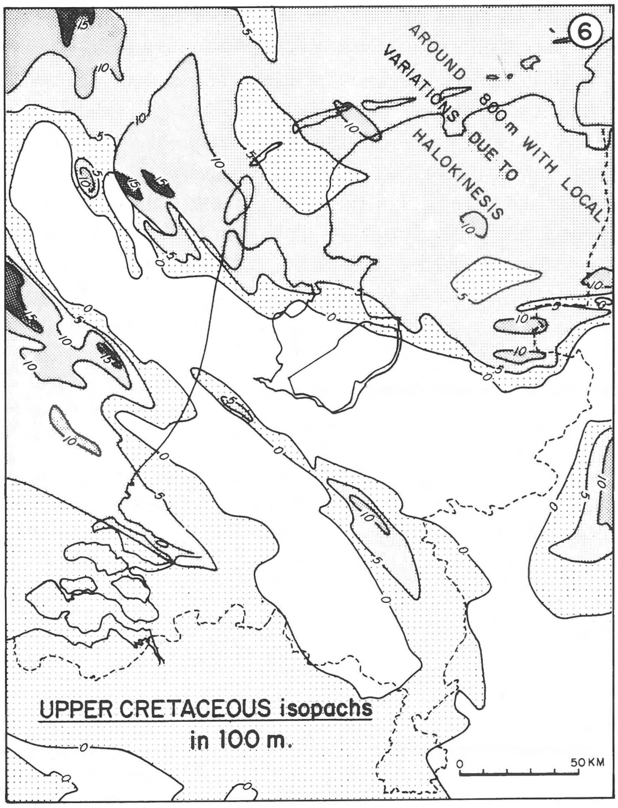
The Roer Valley graben and the Broad Fourteens basin have a slightly different direction (330°) from the Central and West Netherlands basins (300°). A reasonable explanation can be found for the Roer Valley graben in the already existing Permian boundary faults. These faults were re-activated by the Jurassic–Cretaceous stress field although their trends do not match exactly. The same explanation may be given for the trend of the Broad Fourteens basin, since it is situated in apparent continuity with the Roer Valley graben though direct evidence is lacking for the older faults. The very complex character of the dividing Maasbommel–Zandvoort–IJmuiden high trend may then be due to the interference of Permian and Jurassic–Cretaceous faults systems.

The four fully depicted Upper Jurassic–Lower Cretaceous inverted basins show marked differences in tectonic behaviour. The geological map of the pre-Tertiary shows that the West Netherlands basin is less deeply eroded than its extension, the Roer Valley graben. This indicates a stronger inversion of the latter during Upper Cretaceous times. The Central Netherlands basin appears to have undergone the most severe uplift as it is locally stripped down to the Carboniferous. However, there is evidence that the downwarp in the basin was relatively minor. The large area of Upper Malm sediments, in the Veluwe region (fig. 5), rests unconformably on deeply eroded Lower Jurassic and Triassic (H a a n s t r a, 1963) indicating a long period of erosion and late subsidence of the basin in the Upper Jurassic. Between the Upper Jurassic and the Lower Cretaceous a relatively long period of erosion also can be assumed. There is evidence, moreover, that during the Upper Triassic a swell developed in the eastern part of this basin, permitting only thin and incomplete Upper Triassic sedimentation (W o l b u r g, 1969; H a r s v e l d t, 1963). This swell may also have been responsible for a relatively reduced Lower Jurassic deposition. All these factors may have contributed to the large hiatus in the Central Netherlands uplifted basin below the Tertiary cover. In the Broad Fourteens basin, a thick and


3
FYN GRINDSTED HIGH
MID NORTH SEA HIGH
LONDON - BRABANT MASSIF
RHENISH MASSIF
----BOUNDARY PRESENT EXTENSION OF THE ZECHSTEIN
——BOUNDARY OF HALOKINESIS
0 50 100 KM
THE ZECHSTEIN BASIN


4
AXIS OF MAIN BASIN
AXIS OF THE OFF-HOLLAND LOW
AXIS OF THE NETHERLANDS SWELL
AXIS OF THE EMS LOW
ROER VALLEY GRABEN
NORTHERN SLOPE OF THE BRABANT MASSIF
0 50 KM
PERMO-TRIASSIC STRUCTURAL ELEMENTS


5
CLEAVER BANK HIGH
CENTRAL NORTH SEA GRABEN
VLIELAND BASIN
TEXEL - IJSSELMEER HIGH
BROAD FORTEENS BASIN
LOWER SAXONY BASIN
CENTRAL NETHERLANDS BASIN
Veluwe
W. NETH. BASIN
ZANDVOORT RIDGE
MAASBOMMEL HIGH
ROER VALLEY GRABEN
Depositional edge
----Conceptional isopachs in areas of erosion.
BRABANT MASSIF
UPPER JURASSIC - LOWER CRETACEOUS Isopachs
in 100 m.
0 50 KM


6
AROUND 800 m WITH LOCAL VARIATIONS DUE TO HALOKINESIS
UPPER CRETACEOUS isopachs
in 100 m.
0 50 KM

rather complete Upper Jurassic–Lower Cretaceous sequence is thought to have been deposited. In the northwestern part, the Upper Cretaceous inversion is most pronounced.

The inversion movements of the Jurassic–Lowe Cretaceous basins were the last to follow the described segmented pattern of deformation. At the onset of the Tertiary, most uplifted basin "highs" were levelled by erosion and an almost general Lower Tertiary transgression covered the area.

During the Cenozoic a large basin developed, conformable with the present day North Sea (H e y b r o e k et al, 1967). The Netherlands occupies the southernmost tip of this *North Sea basin*. The basin axis shifted with time and subsidence was not continuous, giving rise to periods of regression and partial erosion which did not, however, change the general basin form (K e i z e r and L e t s c h, 1963).

On the base Tertiary depth contour map, the axis of the North Sea basin extends southward as indicated by the 1000 and 1500 m contours and can be followed to the south in the *Lower Rhine embayment.* Southwest of this axis subsidary basins and swells exist. A high exists in the western Netherlands, the *Kijkduin high,* flanked to the south by a trough, the *Voorne trough* (L a g a a y et al, 1967). This indicates that the inversion movements in the West Netherlands basin continued well into the Miocene. In contrast, the subsidence in the Roer Valley graben has been greater than elsewhere on the map (maximum 1900 m) reflecting thick, Upper Miocene and Pliocene sedimentation. The Maasbommel high and the Peel horst appear to have undergone renewed uplift until the present time (K e i z e r and L e t s c h, 1963). No clearly established influence of the other inverted Upper Jurassic–Lower Cretaceous basins is apparent from the contour map at base Tertiary level. The behaviour of the Roer Valley graben and the Peel horst in the Cenozoic is unique among the northwest European inverted basins. A genetic connection between these late Tertiary–Quaternary movements and those in the Upper Rhine Graben has been discussed by C l o o s (1939). The West Netherlands basin is not alone in its sustained uplift during the Tertiary. The Wealden basin in England and the Pays de Bray in France show the same phenomenon.

III. ADDITIONAL REMARKS

The base Cretaceous (including Upper Jurassic) depth contour map depicts an erosion plane which differs in age from place to place. In the extreme south, the Maestrichtian covers the eroded Brabant massif whereas the covering sediments in the basin centres are locally as old as Kimmeridgian. All intermediate ages, over a time span of 75 million years, are represented somewhere in the area. On the high areas outside the Brabant massif, the base Cretaceous is essentially of Aptian to Albian age although over 500 m of older Lower Cretaceous is present in the West Netherlands basin.

The top Carboniferous depth contour map shows the net results of positive and negative movements since the Upper Rotliegend except in areas where appreciable post-Permian erosion has occurred. The present-day highs and lows generally have a very complex origin which may be partly unravelled by a comparison of the other maps presented. It is noticed that many faults, of which only the largest are shown, change direction of throw, sometimes repeatedly. This is understandable, when realized that subsequent movements in an opposite direction have occurred along the same fault plane. This explains also the fact that some of the faults are at present reverse faults, at least for some stratigraphic levels.

No direct or implied use is made of Stille's theory of orogenic phases in this review of the tectonic history of the Netherlands contrary to all previous contributions. The epeirogenic movements described above are not regarded as adhering to this theory, as it appears that they have continuously been present. However, it proves possible to recognize three successive patterns of subsidence and uplift since the Permian, which are basically different from each other, but relatively constant in themselves. These styles are labelled "Permo-Triassic", "Jurassic–Lower Cretaceous" and "Cenozoic" patterns. This does not imply that sharp time boundaries should be allocated to these styles. On the contrary, relatively long transition periods existed in which elements of both the receeding and the oncoming patterns may be recognized, while a few tectonic elements may be common to more than one of these patterns. The Lower Jurassic and Upper Cretaceous illustrate such a transition period.

REFERENCES

(1963) – Atlas of the Netherlands; The Hague.

Arnold, H. (1964) – Fazies und Machtigkeit der Kreidestufen im Munsterländer Oberkreidegebiet: Fortschr. Geol. Rheinld. u. Westf., Bd. 7, p. 566-610.

Bartenstein, H. (1968) – Present status of the Palaeozoic Paleogeography of North Germany and adjacent parts of North West Europe: Geology of Shelf Seas. Donovan, D.T. editor, London.

Boigk, H. (1968) – Gedanken zur Entwicklung des Niedersachsischen Tektogens: Geol. Jb., Vol. 85, p. 861-900.

Brand, E. and K. Hoffman (1963) – Stratigraphy and Facies of the North West German Jurassic and Genesis of its oil deposits: Proc. Sixth World Petr. Congr., Section 1, p. 223-246.

Brueren, J.W.R. (1957) – The stratigraphy of the Upper Permian "Zechstein" formation in the eastern Netherlands: Att. del conregno di Milano Sept.-Oct. 1957: I Giacimenti Gassiferi dell'Europa.

Cloos, H. (1939) – Hebung- Spaltung- Vulkanismus: Geol. Rundschau, Vol. xxx, Zwischenheft 4A, p. 401-519.

Fourmarier, P. (ed.) (1954) – Prodrome d'une description géologique de la Belgique: Soc. Géol. de Belgique, Liège.

Geiger, M.E. and C.A. Hopping (1968) – Triassic stratigraphy of the Southern North Sea basin: Phil. Trans. Royal Soc. of London, Serie B, No. 790, Vol. 254, p. 1-36.

Glennie, K.W. (1972) – Permian Rotliegendes of Northwest Europe interpreted in the light of modern desert sedimentation studies: Bull. Am. Ass. Petr. Geol., Vol. 58, No. 6, p. 1048-1071.

Haanstra, U. (1963) – A review of Mesozoic geological history in the Netherlands: Verh. Kon. Geol. Mijnb. Gen., Vol. 21-1, p. 35-57.

Harsveldt, H.M. (1963) – Older conceptions and present view regarding the Mesozoic of the Achterhoek: Verh. Kon. Ned. Geol. Mijn. Gen., Vol. 21-2, p. 109-130.

Hart, B.B. 't (1969) – Die Oberjura- und Unterkreide-Sedimentation in den nördlichen und östlichen Niederlanden: Erdöl und Kohle, Vol. 22, No. 5, Mai 1969, p. 253-261.

Heybroek, P., U. Haanstra and D. Erdman (1967) – Observations on the geology of the North Sea area: Proc. Seventh World Petr. Congr., Vol. 2, p. 905-916.

Hoyer, P. (1962) – Das Verklingen der variscischen Faltung am unteren Niederrhein: Fortschr. Geol. Rheinld. u. Westf., Vol. 6, p. 433-446.

Keizer, J. and W.J. Letsch (1963) – Geology of the Tertiary in the Netherlands. Verh. Kon. Geol. Mijnb. Gen., Vol. 21-2, p. 147-173.

Lagaay, R.A., B.J. Collette and J.A. Schouten – Seismic profiling in the North Sea basin. Geol. en Mijnb., Vol. 46, No. 10, p. 351-355.

Legrand, R. (1968) – Le massif du Brabant: Mém. Expl. Cartes Geol. et Min. Belgique, No. 9, 148 p.

Mulder, A.J. (1950) – De Zoutpijler van Schoonlo: Geol. en Mijnb., Vol. 12, No. 6, p. 169-179.

Pannekoek, A.J. (ed.) (1956) – Geological History of the Netherlands. The Hague.

Patijn, R.J.H. (1963) – La formation de gaz due a des rehouillifications dans le nord-est des Pays Bas. 5me Congrès Int. Carbonifère, Paris.

Sanneman, D. (1963) – Über Salzstock – Familien in N.W. Deutschland: Erdöl Zeitschr., Vol. 79, p. 499-506.

Sorgenfrei, Th. (1969) – Geological perspectives in the North Sea area: Bull. Geol. Soc. of Denmark, Vol. 19, Part 2, p. 160-196.

Stäuble, A.J. and G. Milius (1970) – Geology of Groningen gas field, Netherlands: Am. Ass. Pet. Geol., Memoir No. 14, Giant Petr. fields.

Trusheim, F. (1960) – Mechanism of salt migration in Northern Germany: Bull. Am. Ass. Petr. Geol., Vol. 44, No. 9, p. 1519-1540.
(1963) – Zur Gliederung des Buntsandsteins: Erdöl Zeitschr. H. 7, p. 272-292.

Visser, W.A. and G.C.L. Sung (1958) – Oil and natural gas in the northeastern Netherlands: Habitat of Oil. Am. Ass. Petr. Geol. Tulsa, p. 1067-1090.

Visser, W.A. (1963) – Upper Paleozoic Evaporites: Verh. Kon. Ned. Geol. Mijnb. Gen., Vol. 21-2, p. 61-72.

Voigt, E. (1962) – Über Randtröge vor Schollenrändern und ihre Bedeutung im Gebiet der Mitteleuropäischen Senke und angrenzender Gebiete: Zeits. Deutsch. Geol. Ges., Vol. 114, No. 2, p. 378-418.

Wolburg, J. (1961) – Sedimentations – Zyklen und Stratigraphie des Buntsandsteins in N.W. Deutschland: Geotekt. Forsch., H. 14, p. 7-74.
(1969) – Die epirogenetischen Phasen der Muschelkalk- und Keuper-Entwicklung N.W. Deutschlands, mit einem Rückblick auf den Buntsandstein. Geotekt. Forsch., H. 32, p. 1-65.

Literature used for map compilation

Arnold, H. (1964) – Die Verbreitung der Oberkreidestufen im Münsterland und besonders im Ruhrgebiet: Fortschr. Geol. Rheinld. u. Westf., Bd. 7, p. 697-690.

Bethune, P. de, – Atlas de Belgique, Planche 8, Géologie, echelle 1 : 500.000.

Braun, F.J. and H.W. Quitzow (1961) – Die erdgeschichtliche Entwicklung der niederrheinischen Landschaft: Niederrheinisches Jahrbuch Bd. V.

Delmer, A. (1963) – Commentaires sur la carte des mines du bassin houiller de la Campine: Ann. Mines de Belg., No. 6, p. 739-754.

Dübraum, H.J. and W. Wolff (1958) – Das Schwerebild des südlichen Teiles der Niederrheinischen Bucht: Fortshr. Geol. Rheinld. u. Westf., Bd. 2, p. 387-407.

Ellerman, C. (1963) – Beitrag zur Gliederung und Verbreitung des Tertiars im West Emsland: N. Jahrb. für Geol. u. Paläont., Bd. 117.

Geoph. dienst der staatsmijnen (1949) – Eindverslag van het Geophysische onderzoek in Z.O. Nederland: Med. Geol. Stichting, C-1-3 No. 1.

Harsveldt, H.M. (1963) – Older conceptions and present view regarding the Mesozoic of the Achterhoek: Verh. Kon. Ned. Geol. Mijnb. Gen., Vol. 21-2, p. 109-128.

Hedeman, H.A. and R. Teichmüller (1971) – Die palaögeographische Entwicklung des Oberkarbons: Fortschr. Geol. Rheinld. u. Westf., Vol. 19, p. 129-142.

Herbst, G. (1971) – Revier von Aachen-Erkelenz: Fortschr. Geol. Rheinld. u. Westf., Vol. 19, p. 61-68.

Hoyer, P. (1962) – Das Verklingen der variscischen Faltung am unteren Niederrhein: Fortschr. Geol. Rheinld. u. Westf., Vol. 6, p. 433-466.
(1967) – Die Tektonik des Steinkohlengebirges nordlich des Ruhrgebietes: Fortschr. Geol. Rhienld. u. Westf., Vol. 13, p. 1359-1388.

Hoyer, P., R. Teichmüller and J. Wolburg (1967) Die tektonische Entwicklung des Steinkohlengebirges im Münsterland und Ruhrgebiet: Zeits. Deutsch. Geol. Ges., Vol. 119, p. 549-552.

Jongmans, W.J. and F.H. van Rummelen (1941) – Overzicht van de gegevens over boringen in Zuid-Limburg en het Peelgebied: Geol. Stichting Meded. Jaarversl. 1940-1941, p. 123-143.

Kent, P.E. and P.J. Walmsley (1970) – North Sea Progress: Bull. Am. Ass. Petr. Geol. Vol. 54, No. 1, p. 168-181.

Legrand, R. (1968) – Le massif du Brabant: Mém. Expl. Cartes Géol. et Min. Belgique, No. 9, 148 p.

Meyer, K. von (1969) – Zur Paläogeographie der Stufen Rhät bis Alb im Emsland: Erdöl-Erdgas Zeitschr., Vol. 85, p. 484-505.

Michelau, P. (1958) – Geologische Übersichtskarte des Rheinische-Westfälischen Steinkohlgebietes 1 : 100.000: Geol. Landesamt Nordrhein-Westf.

Nodop, J. (1962) – Verweisung einer Karte des präkretarischen Untergrundes Nordwestdeutschlands: Zeit. Deut. Geol. Ges., Vol. 114, No. 2, p. 423-426.

Patijn, R.J.G. and W.F.M. Kimpe (1961) – De kaart van het Carboon oppervlak: Med. Geol. Stichting, Serie C-I-1, No. 4.

Schott, W. (ed.) (1967) – Paläogeographischer Atlas der Unterkreide von Nordwestdeutschland: Bundesamt. Bodenforsch., Hannover, Pt 1.