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Late Cretaceous sedimentation and tectonic inversion, southern Netherlands

R. Gras
Schlumberger GeoQuest, PO Box 2988, Benghazi, Libya. Present address: Schlumberger GeoQuest, 50, Avenue Jean Jaurès, Bâtiment H, BP 362, 92541 Montrouge cedex, France

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Abstract

The Late Cretaceous in northwest Europe is characterised by general sealevel rise, leading to extensive platform carbonate sedimentation of the Chalk Group, and by tectonic inversion, as witnessed by uplift and erosion of the Late Jurassic to Early Cretaceous basins.

The Roer Valley Graben in the southern Netherlands was uplifted and eroded in the Late Cretaceous. The inversion was accomplished by the reverse rejuvenation of the graben-bounding faults. On the adjacent horst blocks northeast of the graben, the Maasbommel High and the Peel Horst, a section of the Late Cretaceous Chalk Group has been preserved. Analysis of the Late Cretaceous chronostratigraphy and facies of well Maasbommel-1 on the Maasbommel High shows that the high occupied a marginal position in the basin in Cenomanian times, and a basinal position during the Turonian to Early Santonian. A pulse of clastic influx in the Late Santonian to Early Campanian marks the onset of the reverse rejuvenation of the graben-bounding Peel Boundary Fault and the uplift of the Roer Valley Graben relative to the Peel Horst and Maasbommel High. The inversion ceased in the Late Maastrichtian, when large parts of the graben were flooded and a condensed sequence of post-inversion Chalk Group sediments was deposited regionally.

Introduction

Tectonic inversion was recognised by geologists in the former coal-mining area of South Limburg (southern Netherlands), based on fault analysis and detailed mapping of the Cretaceous and Tertiary overburden (De Sitter 1942, Kuyl 1983). However, the scale of the Late Cretaceous tectonic inversion in the Netherlands subsurface and its relevance to petroleum geology have only been recognised since the advent of modern seismic data.

The large-scale tectonic framework of the Netherlands has been discussed in Heybroek (1974), and more recently in Burgers & Mulder (1991). The Late Cretaceous stratigraphy in northern Belgium and the south of the Netherlands province of Limburg, based on outcrop and coal exploration wells, has been reviewed in Bless et al. (1987) and Felder et al. (1985). The Late Cretaceous tectonic inversion in northern Belgium and Germany, as observed on seismic data, has been discussed in Rossa (1987) and Kockel (1987) respectively. A review on the inversion of the Jurassic–Early Cretaceous basins in the Netherlands (the West Netherlands Basin, Broad Fourteens Basin and Central Graben) was published by Dronkers & Mrozek (1991).

The Late Cretaceous tectonic inversion is of great significance in the field of petroleum geology; the inversion caused widespread uplift and erosion of the Late Jurassic–Early Cretaceous basin fills. The depth of burial attained prior to the uplift controls both the hydrocarbon generation and migration, and reservoir preservation in these basins (Dronkers & Mrozek 1991).

The present article reviews the basin development during the Late Cretaceous in the southern Netherlands, addressing in particular the interaction of the tectonic inversion of the Roer Valley Graben with the sedimentation and erosion on the northeastern graben shoulder blocks. A seismic section over the Peel Horst and the adjacent Roer Valley Graben enables to assess

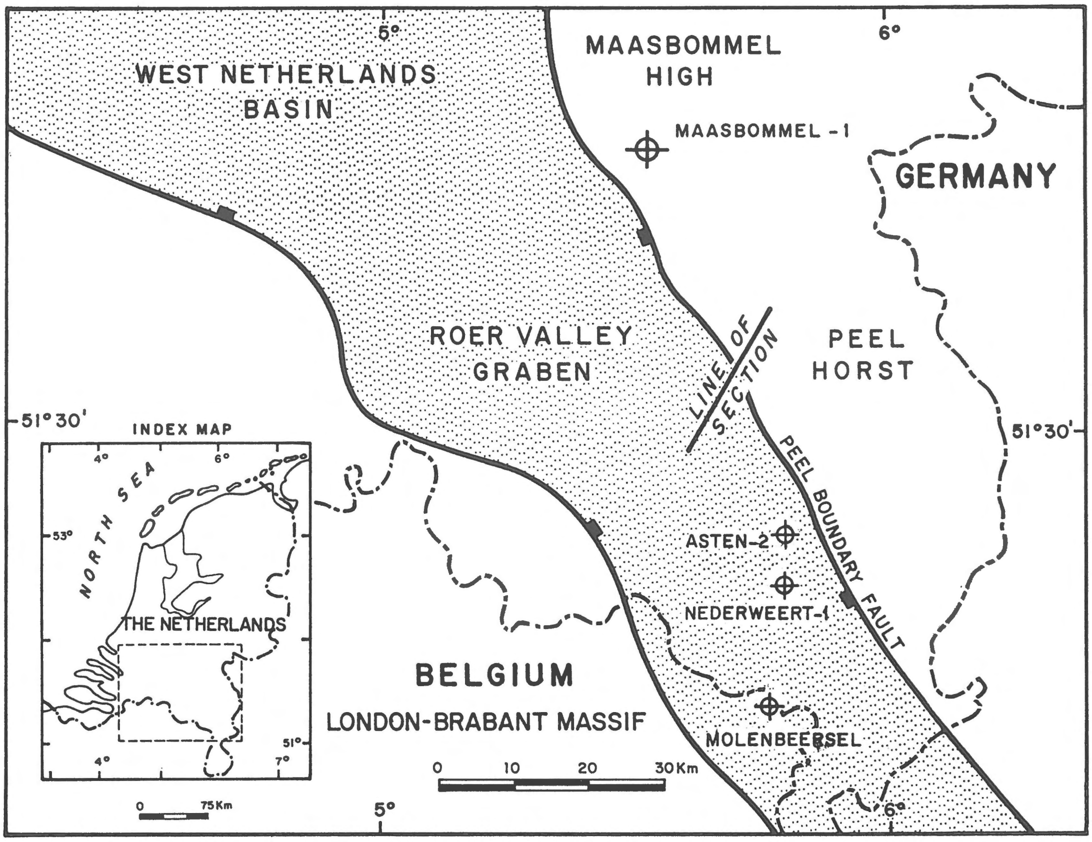

Fig. 1. Location map of study area. Asten-2 is a geothermal research well.

the general tectonic and subsidence history. The basin development in the Late Cretaceous is investigated by means of stratigraphic analysis of the Chalk Group interval from the well Maasbommel-1, situated on the Maasbommel High (Fig. 1). Maasbommel-1 was drilled by Nederlandse Aardolie Maatschappij (NAM) in 1950–1951. A synthesis of published data with the stratigraphy observed in Maasbommel-1 allows to define pre-, syn-, and post-inversion sequences and provides an estimate of the timing of inversion in the southern Netherlands.

Late Cretaceous regional setting and stratigraphy

The Late Cretaceous and Early Cenozoic evolution of northwest Europe was influenced by the opening of the North Atlantic, and by the onset of the Alpine plate collision (Ziegler 1981).

In the Late Cretaceous a large part of northwest Europe and the present North Sea formed a marine platform area bordering the passive Atlantic continental margin. The Late Cretaceous basin was bounded to the north by the Fennoscandia continent, to the west by the 'British Islands' and to the south by the Brabant Massif and Rhenish Massif (the 'Mid-European Islands'). The Late Cretaceous platform sea was connected with the Arctic Ocean, the North Atlantic and, across the Paris Basin, with the Tethys. The sediments on this platform area were predominantly finegrained bioclastic limestones. In the North Sea region these relatively uniform sediments are named the Chalk Group.

The opening of the North Atlantic Ocean in the Cretaceous corresponds in the North Sea region with the cessation of rift tectonics and the onset of regional subsidence. The Late Cretaceous acceleration of the global sea floor spreading rates, as well as climatic changes, are thought to have induced the Late Cretaceous 'first-order', global sea-level rise. This caused worldwide transgressions and consequently a progres-

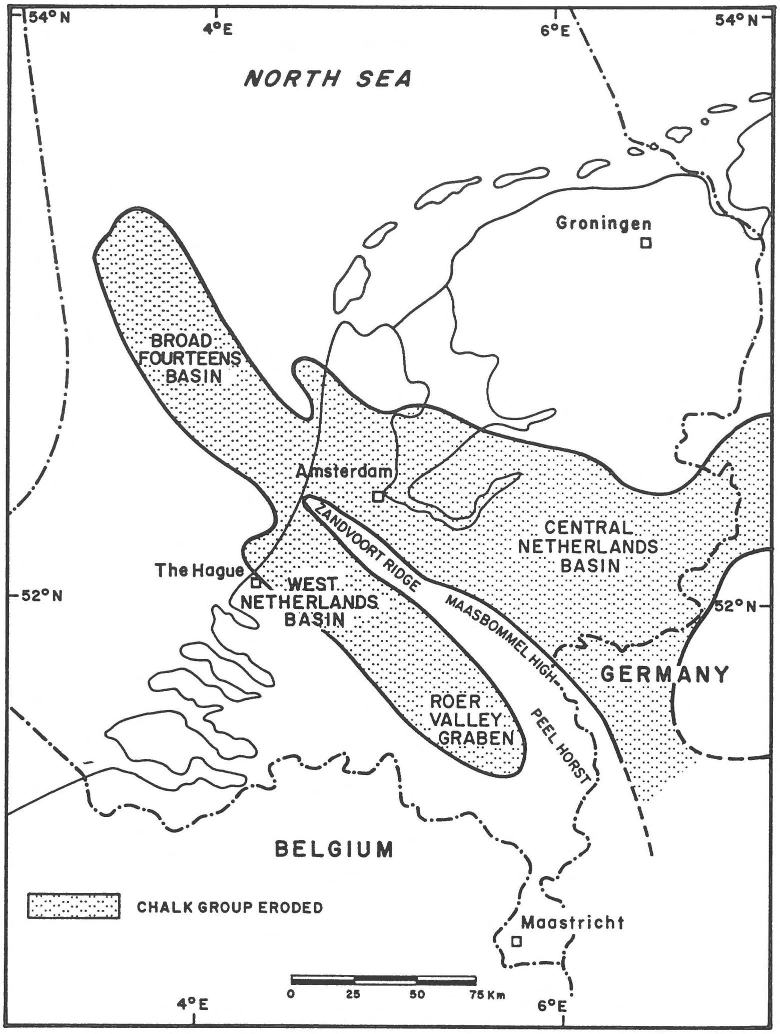

Fig. 2. Inversion and erosion of Late Cretaceous Chalk Group, the Netherlands; modified after Heybroek (1974). In the southern part of the Roer Valley Graben the post-inversion part of the Chalk Group (Late Maastrichtian–Danian) is present. The Chalk Group distribution to the north of the study area is controlled by Late Cretaceous and Cenozoic inversion phases.

sive overstepping of the margins of the Late Jurassic–Early Cretaceous rift basins. In northwest Europe the Late Cretaceous transgression inundated the land areas that existed during the Early Cretaceous, leading to immobilisation of the clastic sources and giving rise to deposition of predominantly bioclastic sediments.

In the Tethyan realm, plate collision commenced during the Coniacian–Santonian as a result of the convergence between Eurasia and Africa. The resultant compressional stresses are thought to have been transmitted through the crust of the northwest European platform, giving rise to compressional deformation, as witnessed by the widespread Late Cretaceous inversion tectonics (Ziegler 1981). In the Netherlands the extent of the inversion of the Late Jurassic to Early Cretaceous grabens is evident from the present-day distribution of the Chalk Group (Fig. 2).

In the southern Netherlands the Late Cretaceous transgression progressively oversteps the London–Brabant Massif south of the study area from the basin in the north. In the Late Maastrichtian the London–Brabant Massif is flooded, and a connection with the southern region across the Paris Basin is established, as demonstrated by the mixing of Tethyan faunas with the northern, Boreal faunas (Bless et al. 1993).

In the Netherlands, separate stratigraphic subdivisions exist for the basinal Chalk Group, applicable mainly to the Netherlands offshore, and for the basin

		LIMBURG	SOUTHERN NORTH SEA	
DANIAN		HOUTHEM FM	OMMELANDEN CHALK FORMATION	UPPER OMMELANDEN CHALK MB
MAASTRICHTIAN	LATE	MAASTRICHT FM		
	EARLY	GULPEN FM		
CAMPANIAN	LATE			MIDDLE OMMELANDEN MARL MB
	EARLY	VAALS FM		
SANTONIAN		AKEN FM		
CONIACIAN				LOWER OMMELANDEN CHALK MB
TURONIAN				
CENOMANIAN			TEXEL CHALK FM	

Fig. 3. Stratigraphic nomenclature of the Late Cretaceous Chalk Group; Limburg area after Felder et al. (1985), southern North Sea based on NAM & RGD (1980). Subdivision of the Ommelanden Chalk Formation is informal.

margin stratigraphy of South Limburg, i.e. the area around Maastricht (NAM & RGD 1980, Kuyl 1983, Felder et al. 1985). The stratigraphic nomenclature of the Chalk Group in both regions is correlated in Fig. 3. The subdivision of the Ommelanden Chalk Formation into members is informal.

Roer Valley Graben

The Roer Valley Graben is a Cenozoic graben which overlies a Late Jurassic–Early Cretaceous rift basin. It is located in the southern Netherlands, north of the London–Brabant Massif (Fig. 1). The Mesozoic rift basin in turn overlies a Carboniferous depocenter. The Roer Valley Graben is trending NW–SE, and passes towards the northwest into the West Netherlands Basin. The graben is bounded to the northeast by the Peel Boundary Fault, a fault with a history of repeated activity through geological time. The Peel Boundary Fault separates the Roer Valley Graben to the northeast from a series of horst features, the Peel Horst and the Maasbommel High. Although the Peel Horst and the Maasbommel High are different fault blocks, they share a similar tectonic position relative to the Roer Valley Graben during the Late Cretaceous. The continuation of the Maasbommel High towards the northwest is named the Zandvoort Ridge (Fig. 2).

The Roer Valley Graben was affected by two major tectonic events in the Mesozoic, rifting and inversion. The stratigraphic sequences representing these events, as postulated in this paper, are respectively pre-rift, syn-rift, post-rift and pre-inversion, syn-inversion and finally post-inversion. The Tertiary post-inversion uplift and erosion phase, evident in well Maasbommel-1, is not analysed in this article.

Seismic line 8601

Figure 4 shows a window (CDP-range 4000–5500) from a migrated stack of seismic line 8601 of the 1986–1987 non-exclusive onshore survey of the Geological Survey of the Netherlands (RGD) and Delft Geophysical (now Geco-Prakla). The section shows the Peel Boundary Fault, with the Roer Valley Graben and the Peel Horst to the southwest and northeast of the fault respectively (Fig. 1).

Within the Roer Valley Graben the pre-rift sequence is represented by strata of Carboniferous, Permian, Triassic and Jurassic age. The Jurassic Altena Group consists of the Aalburg Shale Formation, the Werkendam Formation including the Posidonia Shale Member, and the Brabant Formation. On the seismic section the pre-rift sequence is represented by the 'Top Carboniferous' unconformity, the 'Top Triassic' and the 'Posidonia Shale'. The pre-rift sequence within the graben has been truncated by the erosion caused by the Late Cretaceous inversion, which stripped off most of the Jurassic strata. As a result the incomplete pre-rift sequence is unconformably overlain by the 'Tertiary'.

The syn-rift sequence within the graben is absent on the seismic section due to the erosion caused by the inversion. In the western part of the graben, where the inversion movements were less severe, the syn-rift sequence is represented by the Late Jurassic to Early Cretaceous Delfland Formation, consisting of interbedded paralic sandstones, shales and coal. The structural relief filled in by the syn-rift Delfland Formation in the Roer Valley Graben is in the range of 1000–1500 m.

On the seismic section over the Peel Horst a strong angular unconformity marked 'Base Chalk' constitutes the top of the pre-rift sequence. The Carboniferous and the Triassic are known to subcrop at the base of the Cretaceous on the Peel Horst and Maasbommel High (Thiadens 1963, Heybroek 1974). The seismic line shows evidence for a buried topography below the 'Base Chalk' on the fault-block between CDP 5200 and CDP 5400. This topography appears to be related to pre-rift faulting of the Peel Horst, and it is thought to represent the erosional surface on the graben shoulder during the syn-rift phase. The post-rift sequence observed on the Peel Horst consists of the Late Cretaceous Chalk Group. The seismic section shows an

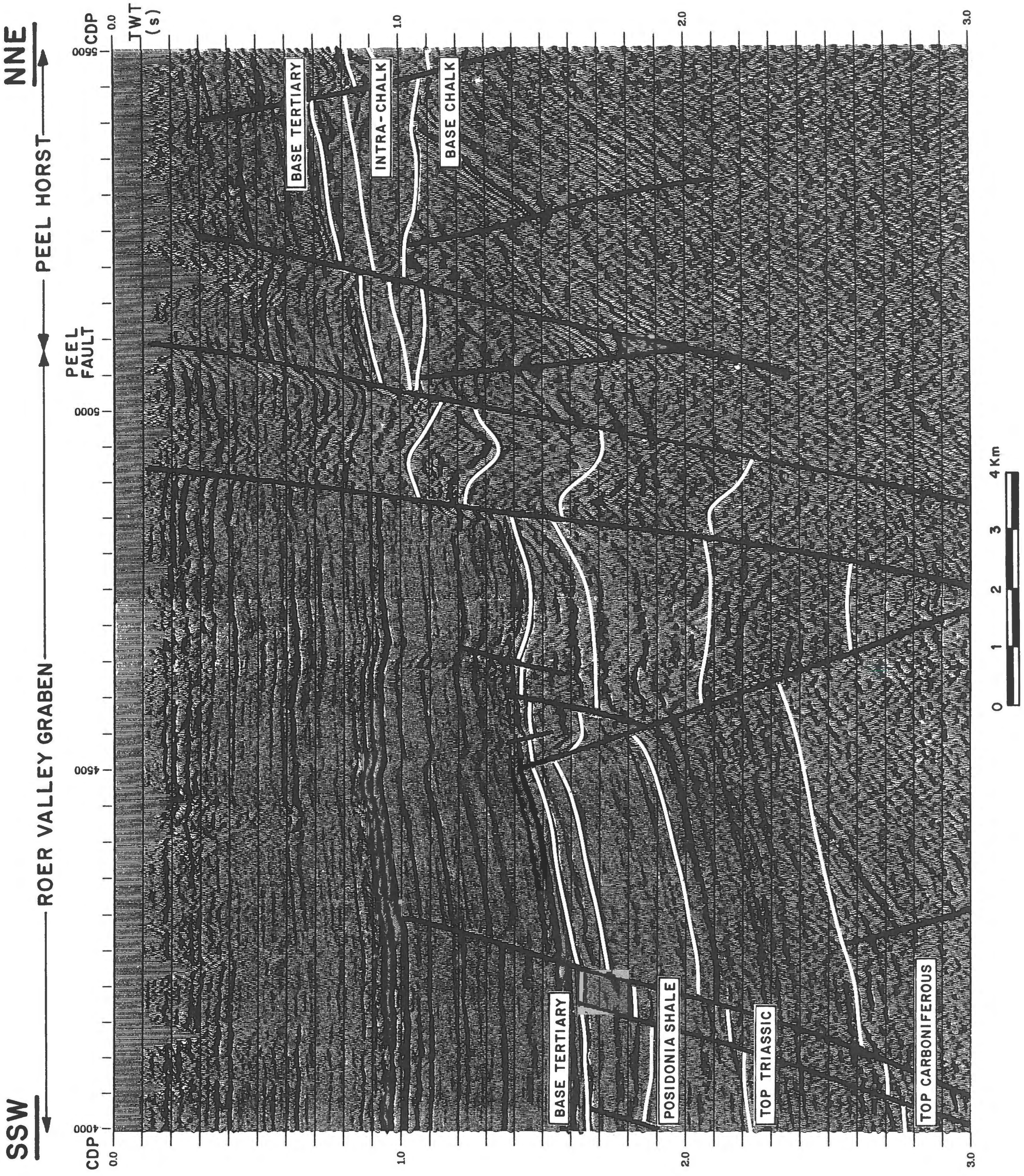

Fig. 4. Window from RGD and Geco-Prakla non-exclusive seismic line 8601, CDP-range 4000–5500, migrated stack, showing part of the Roer Valley Graben and adjacent Peel Horst. For line location see Fig. 1.

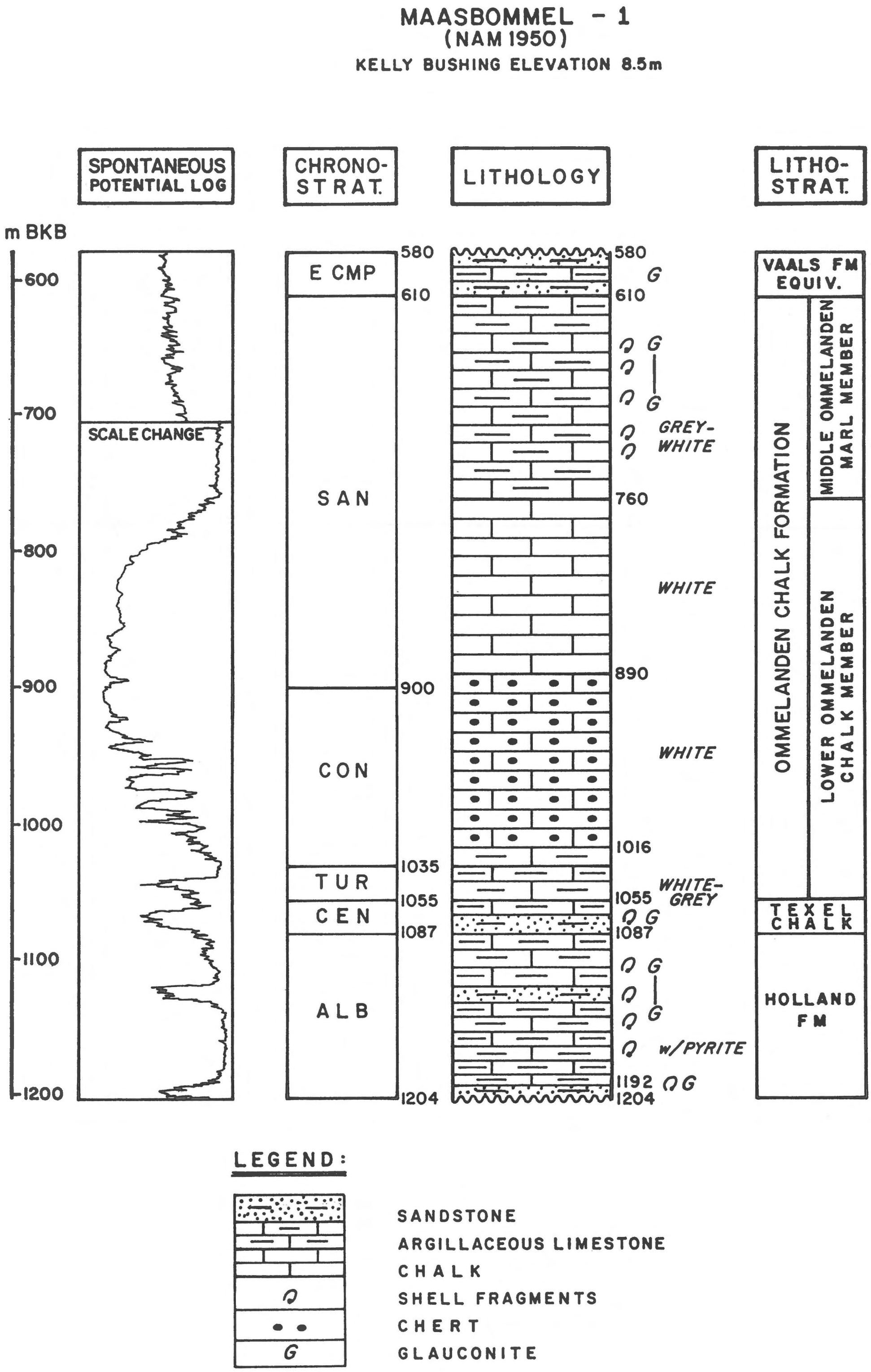

Fig. 5. Summarised stratigraphic column of the Cretaceous interval in well Maasbommel-1. Scale of the spontaneous potential log is relative.

intra-Chalk angular unconformity, indicating tilting of the Peel Horst in the Late Cretaceous. The Late Cretaceous Chalk Group on the northeastern graben shoulder blocks, both the Peel Horst and the Maasbommel High, is discussed below.

The post-inversion sequence consists of the latest Maastrichtian and the Tertiary, and is present both in the Roer Valley Graben and on the Peel Horst. From the Oligocene up to the present day the Peel Boundary Fault was active as an extensional fault (Zagwijn 1989). The Mesozoic and Cenozoic Roer Valley Graben therefore represents two extensional phases, a Late Jurassic to Early Cretaceous and an Oligocene to recent phase. The present-day activity of the Peel Boundary Fault was demonstrated on April 13, 1992, when an earthquake with a Richter-scale magnitude of 5.8 shook the Netherlands and adjacent parts of Belgium and Germany.

Maasbommel-1 Cretaceous stratigraphy

The stratigraphic breakdown of the Cretaceous in well Maasbommel-1, drilled in 1950–1951 to a total depth of 1713 m below the kelly bushing datum, is shown in Fig. 5. This division is based on microfossil and nannofossil analyses of cutting samples over the Late Cretaceous interval performed by BP Exploration in 1986, as well as on lithologic descriptions of cutting samples with a 10 m sampling interval, as supplied by NAM. A best-fit approach was adopted to the microfossil and nannofossil zonations, to derive the age dating as presented. The data were complemented by the spontaneous potential log shown in Fig. 5 and lithologic descriptions from the operator's composite log. The stratigraphic breakdown adopted follows the nomenclature for the Chalk Group in NAM & RGD (1980).

The lower part of the Cretaceous sequence in Maasbommel-1 overlies the Triassic and consists of a series of argillaceous limestones and glauconitic sandstones with abundant shell fragments and pyrite (1087–1204 m). The age of this section is Albian according to the NAM composite log and was not reassessed. Based on this age dating the section is assigned to the Holland Formation. The spontaneous potential log over the section 1087–1204 m shows generally low readings, representing impermeable argillaceous limestones, with few permeable peaks, interpreted as bioclastic grainstones and sandstones. This section is interpreted to have been deposited in a transgressive shallow marine

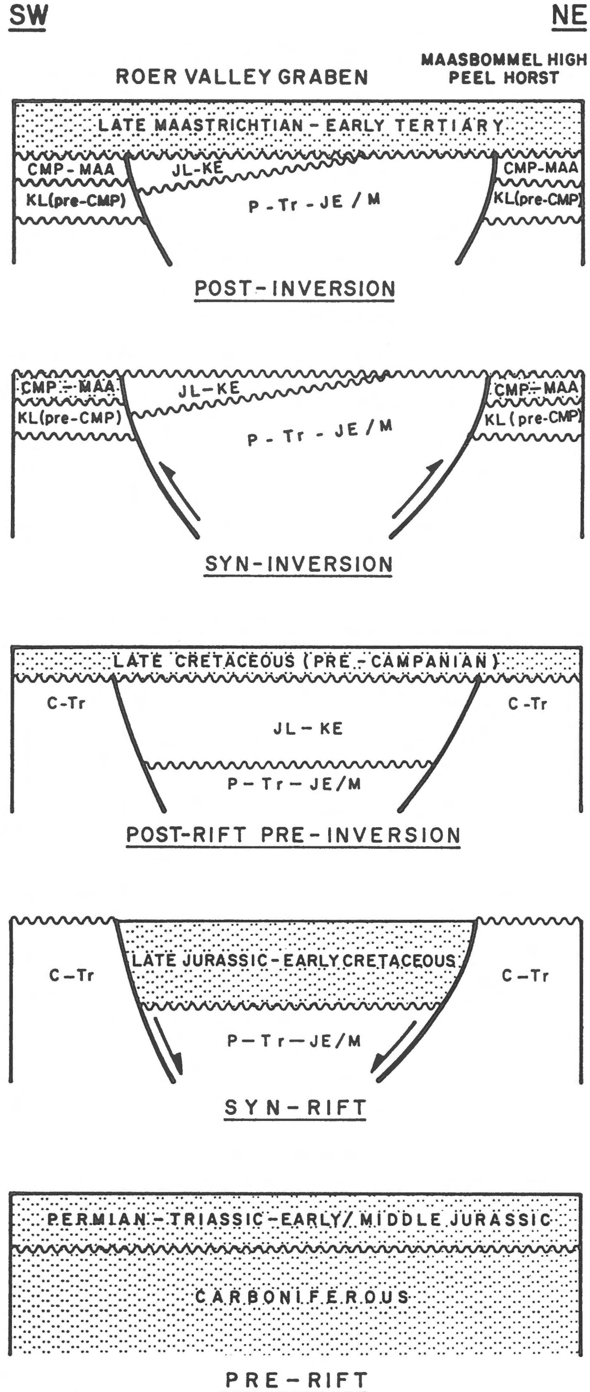

Fig. 6. Schematic Permian–Early Tertiary tectonic evolution of the Roer Valley Graben, showing rift- and inversion-related sequences.

environment in a marginal part of the latest Early Cretaceous basin. The more clastic interbeds indicate that at least part of the section is developed in the facies of the Holland Greensand Member.

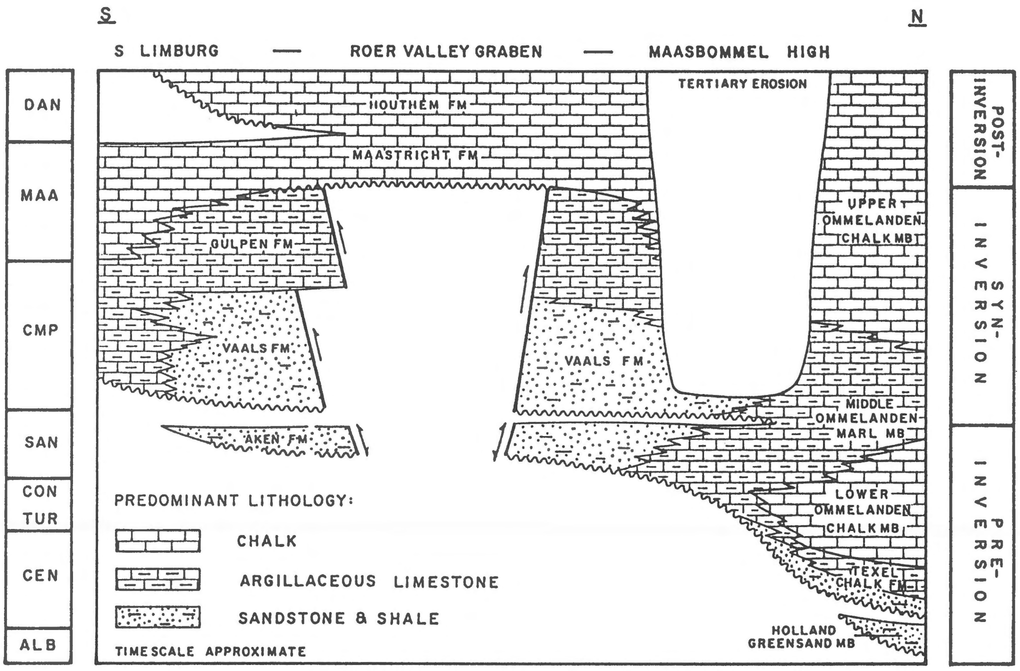

Fig. 7. Conceptual chrono-stratigraphic diagram of the Late Cretaceous in the southern Netherlands. Timescale is approximately linear.

The base of the Late Cretaceous in well Maasbommel-1 has been picked at 1087 m, where the Holland Formation is overlain by a section of grey and greenish argillaceous limestones and glauconitic sandstones (1055–1087 m). This section has been dated as Cenomanian, and it is assigned to the Texel Chalk Formation. The spontaneous potential log shows relatively high readings, attributed to the permeable nature of the interval. The interval is developed in the facies of the Texel Greensand Member, representing shallow marine basin margin deposits.

The Texel Chalk Formation is overlain by a section of predominantly chalk (760–1055 m). The age of this section is Turonian to Early Santonian and it corresponds with the lower part of the Ommelanden Chalk Formation, informally named the Lower Ommelanden Chalk member. The bottom part of this section (1016–1055 m), consisting of white to grey argillaceous, slightly glauconitic limestones, is of Turonian (1035–1055 m) and Coniacian age (1016–1035 m). The section from 890–1016 m consists of white chalk with abundant chert, coinciding largely with Coniacian ages. The spontaneous potential log shows the highest readings over the latest Coniacian and Early Santonian interval, indicating a clean and relatively permeable lithology, which corresponds with the white chalk.

The Lower Ommelanden Chalk member shows a gradual transition to argillaceous and glauconitic sediments of Santonian age (610–760 m). These sediments are assigned to the Middle Ommelanden Marl member (informal name) of the Ommelanden Chalk Formation. In the German nomenclature these sediments are named Emscher Marl. The spontaneous potential log drops to low relative values over this interval, indicating the shaliness of the formation. A slight trend towards higher readings is observed near the top.

The upper part of the Late Cretaceous sequence grades into a sandstone-bearing interval (580–610 m) of Early Campanian age. Whereas the cuttings description for this interval mentions the presence of sandstones, the spontaneous potential log does not support a clean permeable formation. The interpreted lithology is argillaceous, calcarenitic and glauconitic sandstone, supporting a nearshore, shallow marine environment of deposition for this section. The section 580–610 m is tentatively correlated as the lateral equivalent of the Vaals Formation of the southern Netherlands. This section is truncated by the unconformity at base Tertiary at 580 m.

Late Cretaceous tectonic inversion

The Late Cretaceous transgression is evident in well Maasbommel-1 by the presence of shallow marine sediments representing the basin margin during Cenomanian and Turonian times, and subsequent deposition of deeper marine platform-type sediments during Coniacian to Early Santonian times. In the latest Coniacian the sea had risen to a highstand level resulting in cessation of clastic supply. The maximum extent of the transgression is interpreted to have occurred in the Early Santonian.

Regressive conditions are observed approximately from the Late Santonian onwards, culminating in the Early Campanian with the deposition of shallow marine bioclastic and glauconitic sandstones in well Maasbommel-1. These sandstones are the time-equivalent of the Vaals Formation in the southern Netherlands. The Vaals Formation is interpreted to represent the syn-inversion sequence resulting from the uplifting Roer Valley Graben.

The inversion and erosion of the Roer Valley Graben progressively stripped off the post-rift and pre-inversion Chalk Group, the syn-rift paralic and sandy Delfland Formation, and locally the pre-rift Jurassic Altena Group. The thickness of the eroded section is estimated to be in the range of 1000–2000 m. As a consequence of the inversion, sands originating from the Delfland Formation were reworked and deposited in the new structural lows formed by the reverse faulting of the Peel Boundary Fault.

In the Late Maastrichtian the inverted Roer Valley Graben was again overstepped by the Late Cretaceous transgression. Chalk Group sediments have been observed within the graben, e.g. in a geothermal research well near Asten (Van Heederik 1988) and in Nederweert-1 (NAM & RGD 1980; for well locations see Fig. 1). These Chalk Group sections have been correlated with the Late Maastrichtian Maastricht Formation and Danian Houthem Formation on the basis of log-correlation and proprietary age dating. Bless et al. (1993) demonstrate that the Roer Valley Graben was inundated from the 'early Late Maastrichtian' onwards, based on detailed stratigraphic analysis of the well Molenbeersel in northeastern Belgium. This implies that from the Late Maastrichtian onwards (approximately 70 Ma) the relative sea-level rise exceeded the rate of inversion, resulting in net subsidence. However, the frequent occurrence of karst horizons and paleosols in the postulated post-inversion sequence indicates a close balance between subsidence and uplift.

The Permian–Early Tertiary tectonic evolution of the Roer Valley Graben and the Maasbommel High and Peel Horst, based on the data presented in this paper, is shown schematically in Fig. 6. In Fig. 7 the lithostratigraphic units used for the southern Netherlands are correlated in a conceptual chronostratigraphic diagram, based on published data in combination with the Maasbommel-1 analysis.

Discussion

The onset of tectonic inversion of the Roer Valley Graben has been estimated by indirect evidence from the sedimentary record on the adjacent Maasbommel High. The observed clastics on the northeastern graben shoulder within the overall transgressive Late Cretaceous sequence are interpreted to have been caused by the tectonic uplift of the adjacent graben, exceeding the generally rising sea level. The base of the Early Campanian clastics in Maasbommel-1, approximately timed at 84 Ma (Haq et al. 1988), is tentatively picked to mark the beginning of the tectonic inversion of the Roer Valley Graben. It is interpreted to represent the Intra-Chalk unconformity on the seismic section (Fig. 4).

During the uplift of the Roer Valley Graben the erosion is envisaged to have taken place by tidal currents, waves and storm waves on a shallow shoal or island on the margin of the Late Cretaceous platform sea. The eroded section consists of the pre-inversion Chalk Group, the Delfland Formation and older Jurassic sediments. The clastics originating from the inverting Roer Valley Graben are interpreted to have been reworked and deposited on the graben shoulder. The shallow marine sandstones of the Vaals Formation in the province of Limburg, southeastern Netherlands, constitute the syn-inversion sequence. More detailed stratigraphic analysis of the Vaals Formation and lateral equivalents is required to validate the proposed model. In addition, the position of the Santonian Aken Formation within the tectonic framework (see Fig. 7) requires further study.

The post-inversion sequence, consisting of the widespread latest Maastrichtian and Danian part of the Chalk Group, was deposited in shallow marine, nearshore conditions. The frequent karstified intervals in this sequence indicate a near balance between erosive and depositional conditions.

The data presented has important implications for the reconstruction of the burial history of the Roer

Valley Graben. The maximum depth of burial of the Roer Valley Graben prior to inversion was attained during the peak of the transgression in Turonian to Early Santonian times. The paleodepth of burial of the graben prior to the inversion should include both the extrapolated thickness of the post-rift and pre-inversion sequence (Late Cretaceous pre-Campanian) present on the graben shoulders, and the eroded fractions of the syn-rift and pre-rift sequences within the graben.

Hydrocarbon generation from the Carboniferous coals or the Jurassic Posidonia Shale Member within the graben may have taken place during the period of pre-inversion burial. The onset of inversion would have stopped any hydrocarbon generation in the graben, as a result of the uplift and cooling.

Conclusion

The stratigraphic analysis of well Maasbommel-1 shows that on the Maasbommel High transgressive marine sediments of the Chalk Group were deposited during Cenomanian to Early Santonian times. In the Late Santonian to Early Campanian an increase of clastics sedimentation is observed. This increase is correlated with the start of the uplift of the Roer Valley Graben, where Cretaceous and Jurassic sediments were progressively stripped off. Well data indicate that in the latest Maastrichtian the inverted Roer Valley Graben was flooded by the Late Cretaceous transgression, demonstrating that by that time net subsidence took place.

The timing of inversion has important implications for the reconstruction of the burial history of the Roer Valley Graben. The post-rift and pre-inversion sequence is expected to have been deposited within the graben. This sequence, and locally parts of the syn-rift and pre-rift sequences in the Roer Valley Graben have been progressively reworked and redeposited in the syn-inversion sequence in the adjacent, relatively subsiding northeastern graben shoulder blocks, the Peel Horst and the Maasbommel High.

This article demonstrates the importance of chronostratigraphic control on the analysis of tectonic history. In the case of graben inversion detailed assessment of the stratigraphy of the graben shoulders is necessary, as the erosional timespan within the graben may be represented in the stratigraphic record of the adjacent horst blocks.

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References

Bless, M.J.M., P.J. Felder & J.P.M.T. Meessen 1987 Late Cretaceous sea level rise and inversion: their influence on the depositional environment between Aachen and Antwerp – Ann. Soc. Géol. Belgique 109: 333–355

Bless, M.J.M., M. Dusar, P.J. Felder & R. Swennen 1993 Lithology and biostratigraphy of Upper Cretaceous-Paleocene carbonates in the Molenbeersel borehole (NE Belgium) – Geol. Mijnbouw 71: 239–257

Burgers, W.F.J. & G.G. Mulder 1991 Aspects of the Late Jurassic and Cretaceous history of the Netherlands – Geol. Mijnbouw 70: 347–354

De Sitter, L.U. 1942 The Alpine geological history of the Northern Border of the South Limburg coal district, Holland – Meededelingen behoorende bij Jaarverslag over 1940–1941, Geologisch Bureau v.h. Mijngebied, Geologische Stichting Heerlen: 5–25

Dronkers, A.J. & F.J. Mrozek 1991 Inverted basins of the Netherlands – First Break 9: 409–425

Felder, P.J., M.J.M. Bless, R. Demyttenaere, M. Dusar, J.P.M.T. Meessen & F. Robaszynski 1985 Upper Cretaceous to Early Tertiary deposits (Santonian-Paleocene) in Northeastern Belgium and South Limburg (the Netherlands) with reference to the Campanian-Maastrichtian – Belgium Geol. Survey Prof. Paper 1985/4 Nr 214: 151 pp

Haq, B.U., J. Hardenbol & P.R. Vail 1988 Mesozoic and Cenozoic chronostratigraphy and cycles of sea-level change. In: C.K. Wilgus, H. Posamentier, C.A. Ross & C.G.S.C. Kendall (eds.): Sea-level changes: an integrated approach – Soc. Econ. Paleont. Mineral., Spec. Publ. 42: 73–108

Heybroek, P. 1974 Explanation to tectonic maps of the Netherlands – Geol. Mijnbouw 53: 43–50

Kockel, F. 1987 Upper Cretaceous biostratigraphy, the key to the understanding of inversion tectonics in NW-Germany – Ann. Soc. Géol. Belgique 109: 357–361

Kuyl, O.S. 1983 The inversion of part of the southern border of the Central Graben in Southern Limburg during the Late Cretaceous – Geol. Mijnbouw 62: 401–408

NAM & RGD (Nederlandse Aardolie Maatschappij & Rijks Geologische Dienst) 1980 Stratigraphic nomenclature of the Netherlands – Verh. Kon. Ned. Geol. Mijnb. Gen. 32: 1–77

Rossa, H.G. 1987 Upper Cretaceous and Tertiary inversion tectonics of the Western part of the Rhenish-Westphalian coal district and in the Campine area (North Belgium) – Ann. Soc. Géol. Belgique 109: 367–410

Thiadens, A.A. 1963 The Palaeozoic of the Netherlands – Verh. Kon. Ned. Geol. Mijnb. Gen. 21: 9–28

Van Heederik, J.P. 1988 Geothermisch onderzoek in de Centrale Slenk (Noord Brabant): resultaten van de geothermische proefboring Asten – Energiespectrum, maart 1988: 38–47

Zagwijn, W.H. 1989 The Netherlands during the Tertiary and Quaternary: A case history of Coastal Lowland evolution – Geol. Mijnbouw 68: 107–120

Ziegler, P.A. 1981 Evolution of sedimentary basin in North-West Europe. In: L.V. Illing & G.D. Hobson (eds.): Petroleum geology of the continental shelf of Northwest Europe, Institute of Petroleum, London: 3–39