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ROTLIEGEND AND MAIN BUNTSANDSTEIN GAS FIELDS IN BLOCK K/13 – A CASE HISTORY[1]

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ABSTRACT

Roos, B. M. & B. J. Smits 1983 Rotliegend and Main Buntsandstein gas fields in block K/13 – A case history. In: J. P. H. Kaasschieter & T. J. A. Reijers (eds.): Petroleum geology of the southeastern North Sea and the adjacent onshore areas (The Hague, 1982) – Geol. Mijnbouw 62: 075-082.

In the Dutch offshore Block K/13, two Lower Permian Rotliegend and two Triassic Main Buntsandstein gas fields were discovered between 1972 and 1976. The coincidence of these gas accumulations is the result of a combination of several factors: – excellent reservoir sands sourced by Carboniferous gas, – gas trapped in salt-sealed Rotliegend structures flanking the Broad Fourteens Basin prior to inversion. Some gas re-migrated into Main Buntsandstein traps during and after Late Cretaceous inversion movements.

INTRODUCTION

After discovery of the large Groningen gas field in 1959 the producing Early Permian Rotliegend trend was followed westward over West Netherlands to the various fields discovered in the U.K. sector between 1965 and 1967. This triggered exploration in the Dutch sector of the North Sea and the Noordwinning Group was formed in January 1968. Current partners are Pennzoil Nederland Company – Operator (20.90%), Amax Petroleum Corporation (20.90%), Delfzee B.V. (20.90%), Billiton Exploratie Maatschappij B.V. (10.25%), Noordzee Selection (9.25%), Hoogovens Delfstoffen B.V. (9.20%), Falcon Seaboard, Inc. (6.80%) and Caland Exploratie B.V. (1.80%). DSM Aardgas B.V., on behalf of the Dutch Government, has a 40% interest in block K/13.

Exploration Licence 373/6704:EM – Blocks K/5, K/13 and P/10 was awarded to the Noordwinning Group on March 4, 1968, and accepted on March 26, 1968. A Production Licence for Block K/13 was granted on September 17, 1973.

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HISTORY OF DISCOVERIES

Exploration in Block K/13, which is located in the western part of the K quadrant along the Dutch-U.K. border (Fig. 1) started with seismic surveys in 1968 and 1969, followed by drilling a Rotliegend prospect early 1972. Although at the time of drilling well K/13-1, the possibility of gas in the Triassic Main Buntsandstein was well known through the 1966 Hewett discovery in the U.K., the formation was not considered a potential target. The rather weak hydrocarbon indicator, on seismic line K-13A (Fig. 2), was therefore not recognized as such. Fortunately, the Main Buntsandstein structure overlies the Rotliegend structure which was the objective of the well (Figs. 3 and 4). The Rotliegend was waterbearing, but the Triassic tested $.45 \times 10^6$ m^3/d (16.8 MMCFD) of gas. Interpretation of electrical logs, test results and a reinterpretation of seismic data led to the application for a Production Licence for Block K/13, which was granted on September 17, 1973. The field was named K/13-A. Based on the results from well K/13-1 and the recognized strong hydrocarbon-indicator in the Main Buntsandstein on seismic line K-13C (Fig. 5), both Buntsandstein and Rotliegend were primary objectives for well K/13-2 which was spudded in August 1973. As in well K/13-1, the Main Buntsandstein was gas bearing, testing $.78 \times 10^6$ m^3/d (29 MMCFD) of gas whereas the Rotliegend was water saturated. This field was named K/13-B.

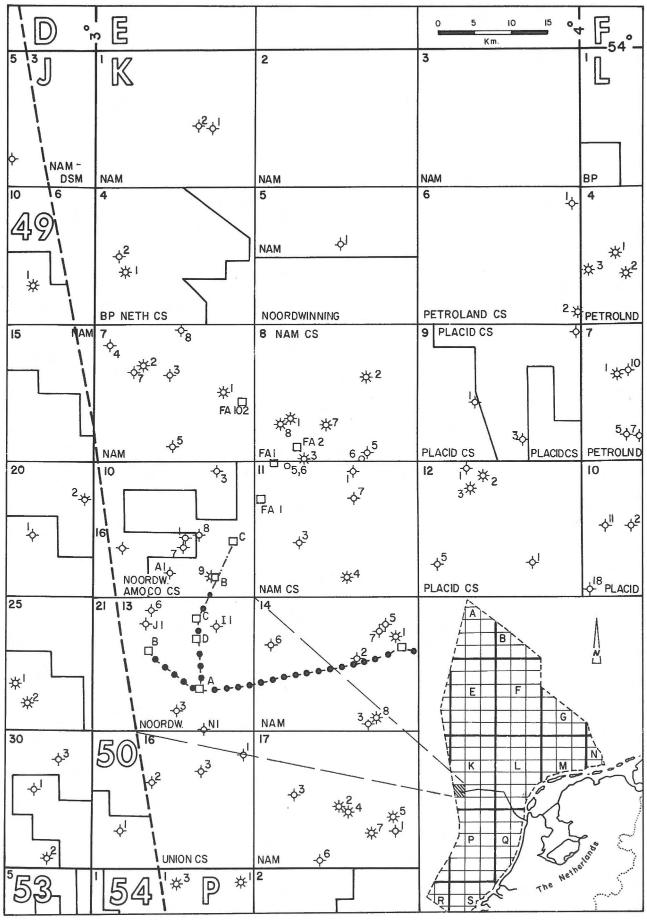

Fig. 1
Situation map with K/13 Block.

In 1973 and 1975 a total of 800 km of seismic was shot over the block. Partial reprocessing and subsequent reinterpretation resulted in the delineation of several prospects.

Based on the 1975 Rotliegend depth map (Fig. 6) well K/13-4 was drilled in July 1976. It tested 1.21 × 10^6 m^3/d (45 MMCFD) of gas from a Rotliegend reservoir and was the discovery well for the K/13-E field. Well K/13-5, reaching TD December 1976 and testing 1.10 × 10^6 m^3/d (40.8 MMCFD) of gas from the Rotliegend, proved the K/13-F field.

GENERAL STRATIGRAPHY OF ROTLIEGEND AND MAIN BUNTSANDSTEIN

The thickness of the Rotliegend in Block K/13 ranges from less than 100 m along the western side to more than 200 m in the southeast (Fig. 7). The variation in thickness reflects the palaeogeography at the time of deposition: Block K/13 is bordered on the western side by the relatively stable Winterton and Indefatigable Highs, which also influence the thickness of the Rotliegend regionally. The stable areas related to the Indefatigable High, locally control Rotliegend sediment thickness in K/13 in the northwest and along the southern boundary.

The Rotliegend in K/13 is developed as a massive, predominantly aeolian sandstone with few shale intercalations which are correlative with the Ten Boer and Ameland claystones. Details on the deposition of the Rotliegend are described in GLENNIE (1972), VAN WIJHE ET AL. (1980), VAN ADRICHEM BOOGAERT (1976), NAGTEGAAL (1979), NAM & RGD (1980), etc.

The Main Buntsandstein, also consisting of continental redbeds, is very uniform and the individual members can easily be recognized (Fig. 8). In general, thicknesses increase from zero in the west to 200 m in the southeast, but unlike the Rotliegend, the thickness of the Main Buntsandstein is influenced by erosion. The Hardegsen unconformity gradually truncates the section going in a westerly direction, toward the Indefatigable High, and removes the Hardegsen Sandstone. The blocks, stable during Rotliegend time, were uplifted during the Kimmerian phase, resulting in deep erosion by the Late Kimmerian unconformity, during the Late Jurassic. This removed the Upper Buntsandstein Röt Salt seal from the northwestern part of the 'B' field (Fig. 13). Locally, the Main Buntsandstein is absent due to Zechstein salt piercement. An overview of Permo-Triassic stratigraphy is given in figure 9.

TECTONIC HISTORY

By Late Jurassic, the Rotliegend in Block K/13 was covered by approximately 2500 to 3000 m of Zechstein, Triassic and Jurassic sediments. At the end of the Jurassic areas like the Winterton and Indefatigable Highs and the 'J' structure (Figs. 10 and 11) were uplifted and deeply truncated. In K/13, the Jurassic has been eroded, even in the basin area, except for a small area on the eastern side where a rim-synclinal wedge of Jurassic sediments was preserved owing to salt migration.

During Early Cretaceous a new period of transgression started and by the end of the Late Cretaceous the Rotliegend sands in the basin were buried by a sedimentary sequence of shale, marl and chalk 3500 to 4000 m thick. The rather quiet Cretaceous period of sedimentation was succeeded by a phase of strong tectonic movement at the transition of the Cretaceous into the Early Tertiary. This compressional phase resulted in inversion of the Broad Fourteens basin, uplifting the basin floor approximately 1500 m. On the southwestern side of the basin the Mesozoic sedimentary wedge was folded and thrusted out of the basin; on the northeastern side minor reverse movements along older fault planes can be detected (Figs. 11 and 12). Erosion, following the inversion, truncated most of the Upper Cretaceous sediments in the basin area, whereas a thick sequence of Upper Cretaceous Chalk still is present over the Indefatigable High and the 'J' structure.

During the Cenozoic, the area was buried under 900 to 1200 m of sands and clays as a result of regional subsidence.

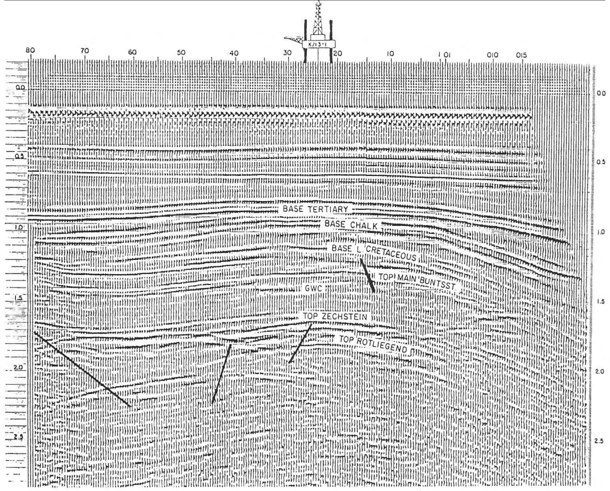

Fig. 2
Seismic line K-13A. For location see figure 3.

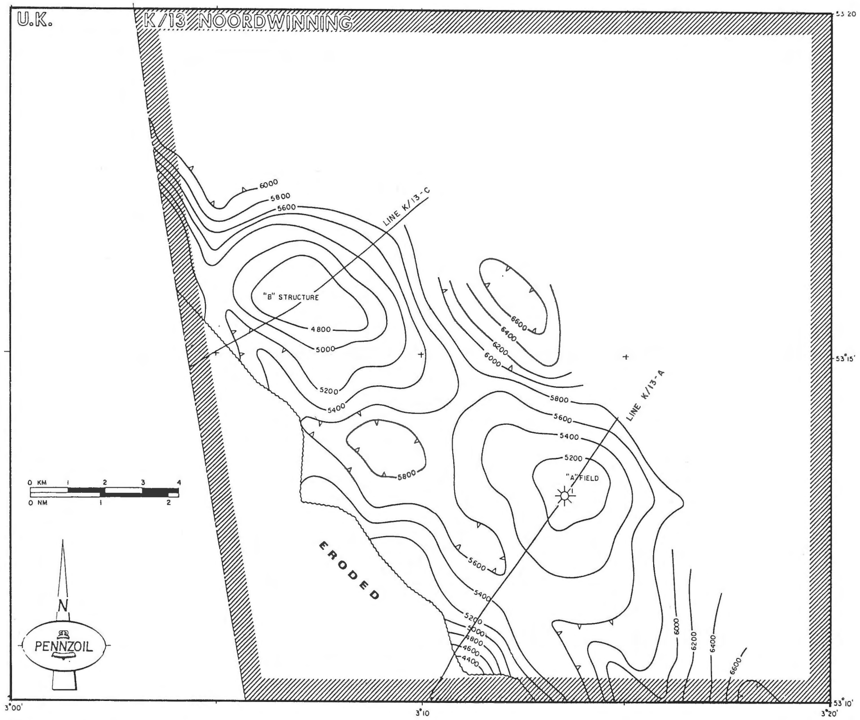

Fig. 3
Top Main Buntsandstein depth map – 1972. Contour interval 200 ft.

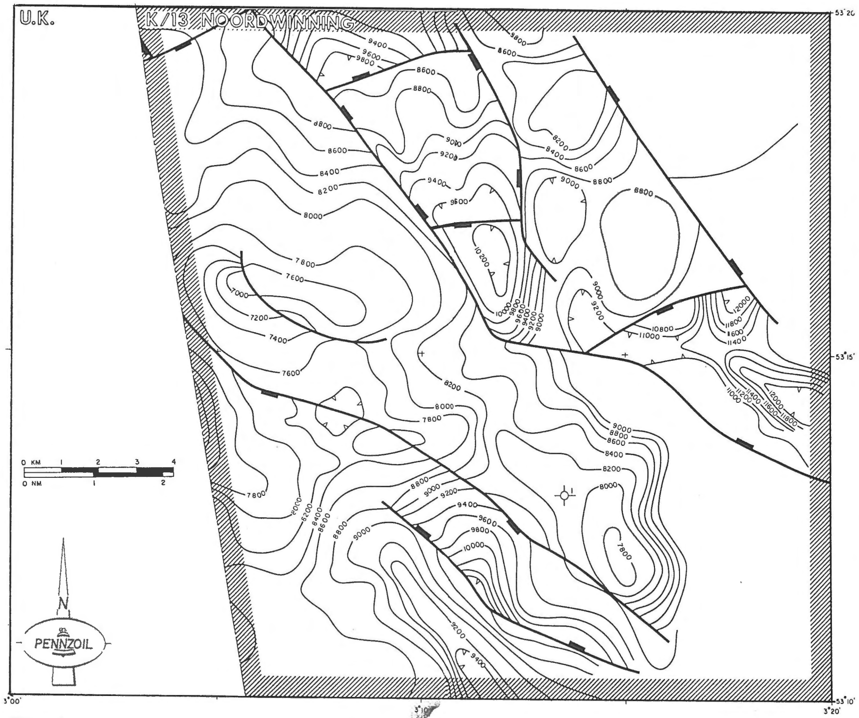

Fig. 4
Base Zechstein depth map – 1972. Contour interval 200 ft.

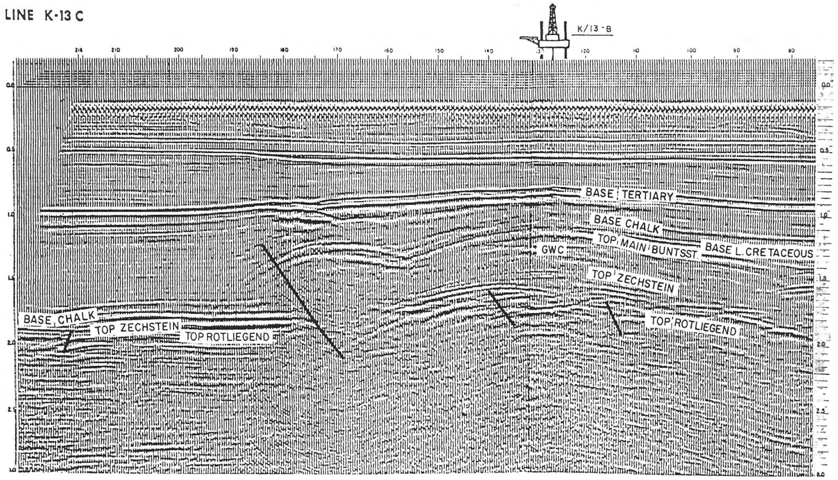

Fig. 5
Seismic line K-13C. For location see figure 3.

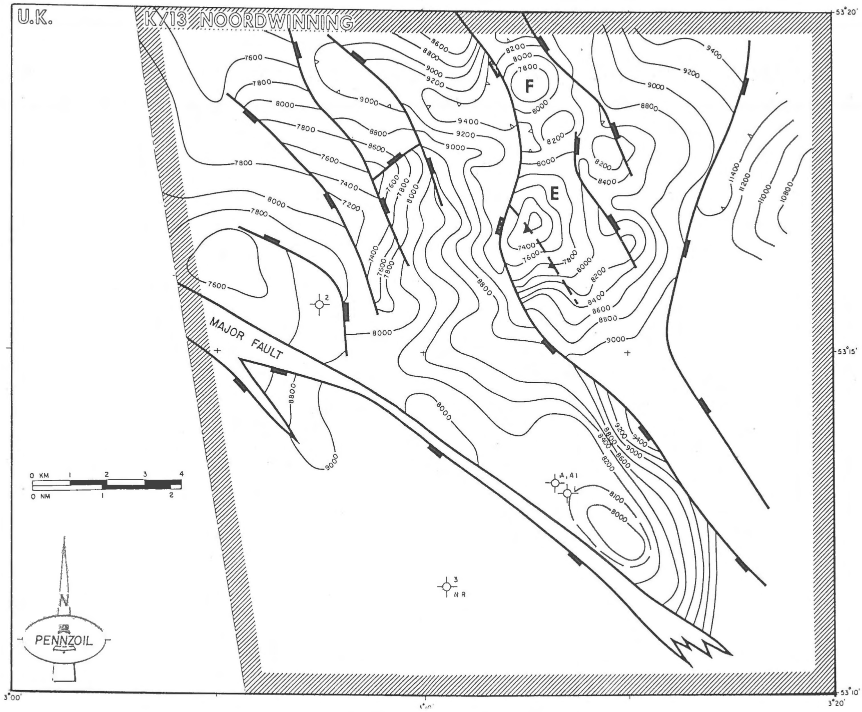

Fig. 6
Base Zechstein depth map – 1975. Contour interval 200 ft.

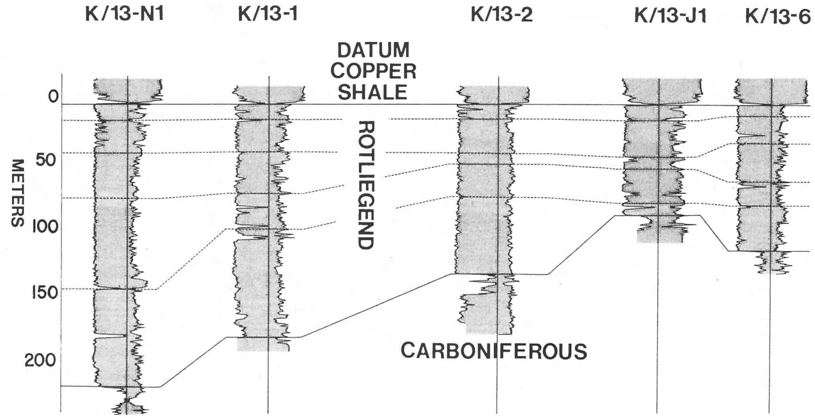

Fig. 7
Rotliegend well correlation.

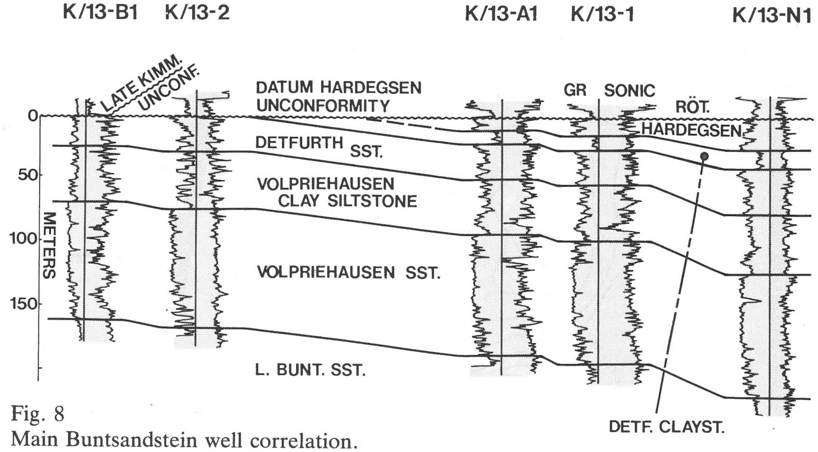

Fig. 8
Main Buntsandstein well correlation.

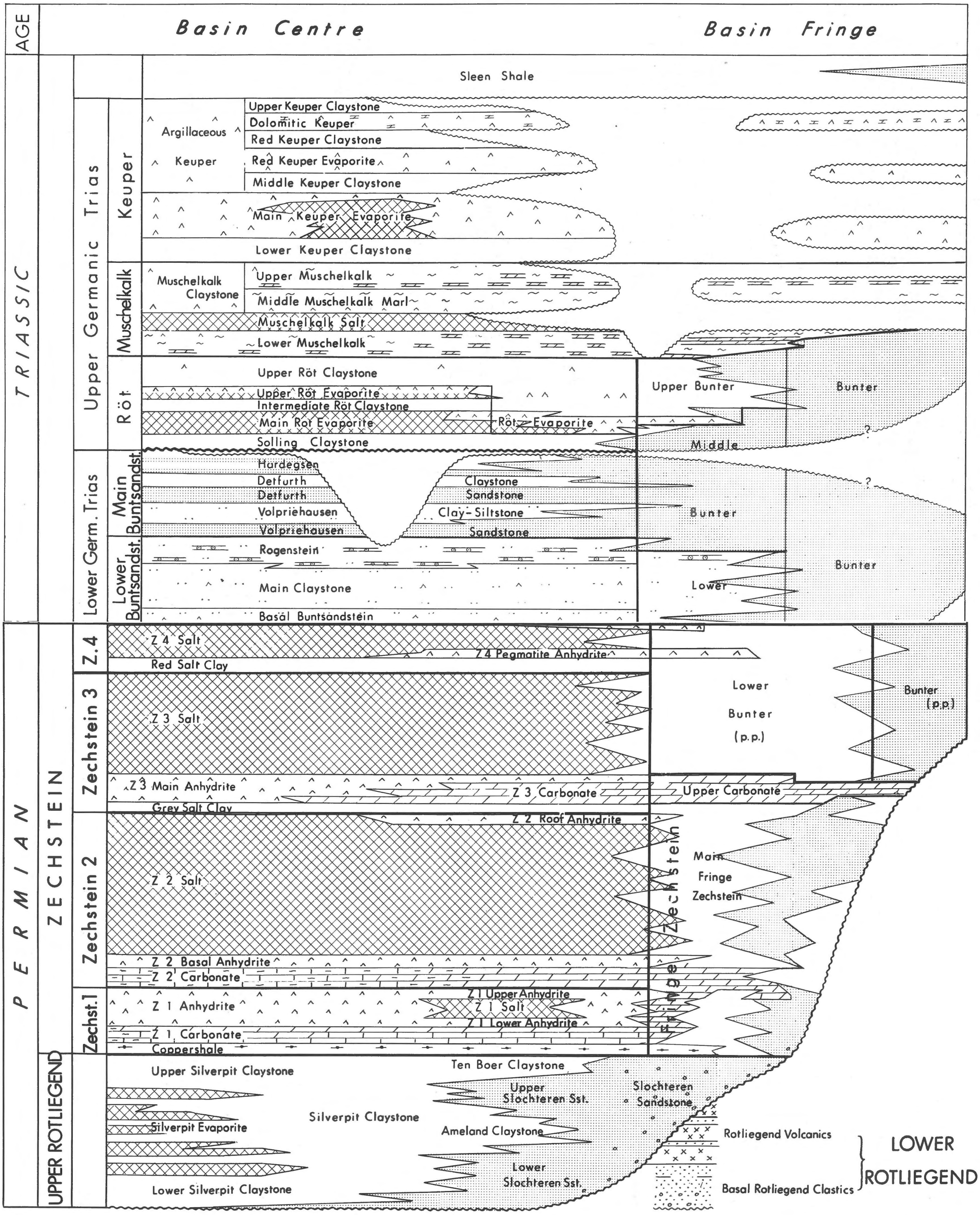

Fig. 9
Permo-Triassic Stratigraphy of The Netherlands (Ned. Aardolie Mij. & Rijks Geol. Dienst, 1980).

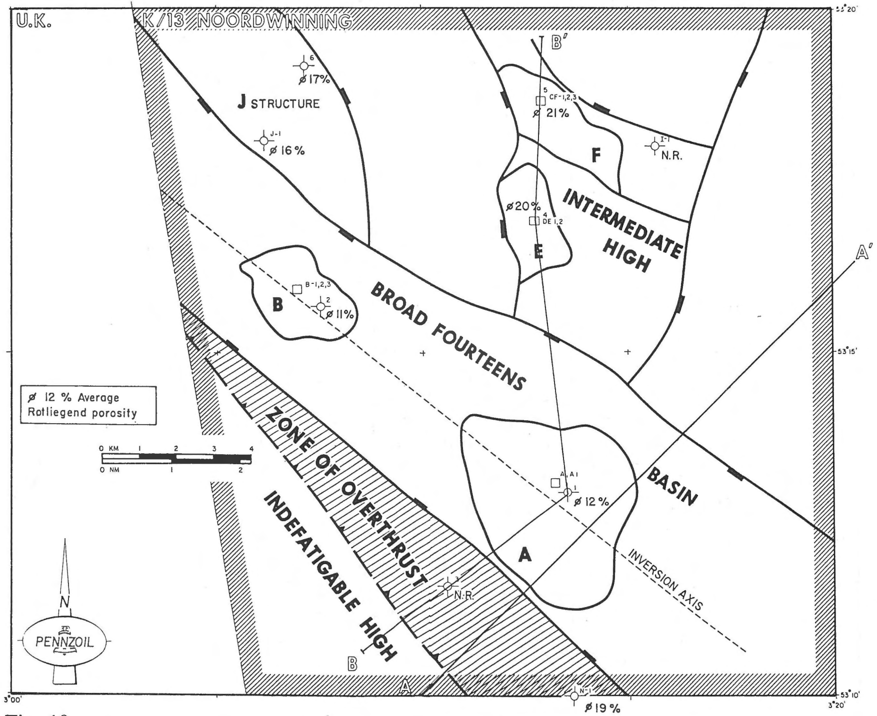

Fig. 10
Structural framework K/13.

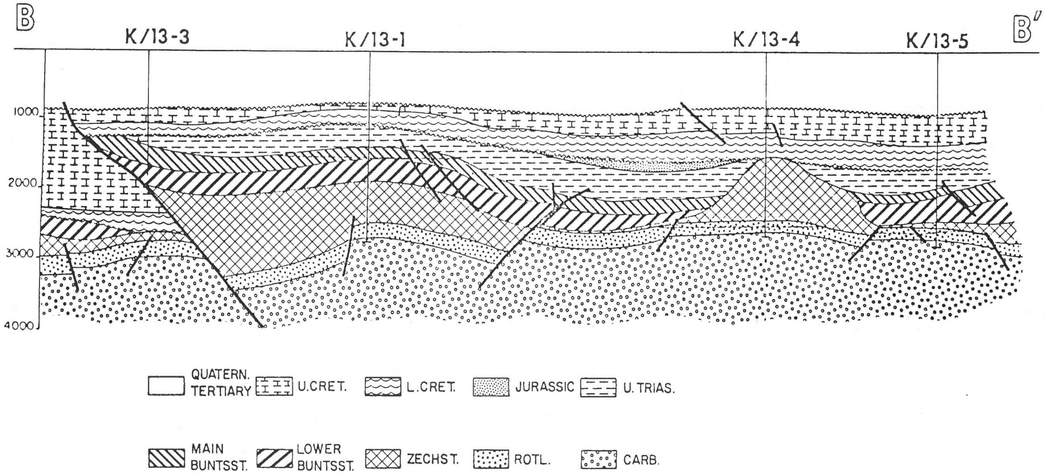

Fig. 12
Structural cross-section. For location see figure 10.

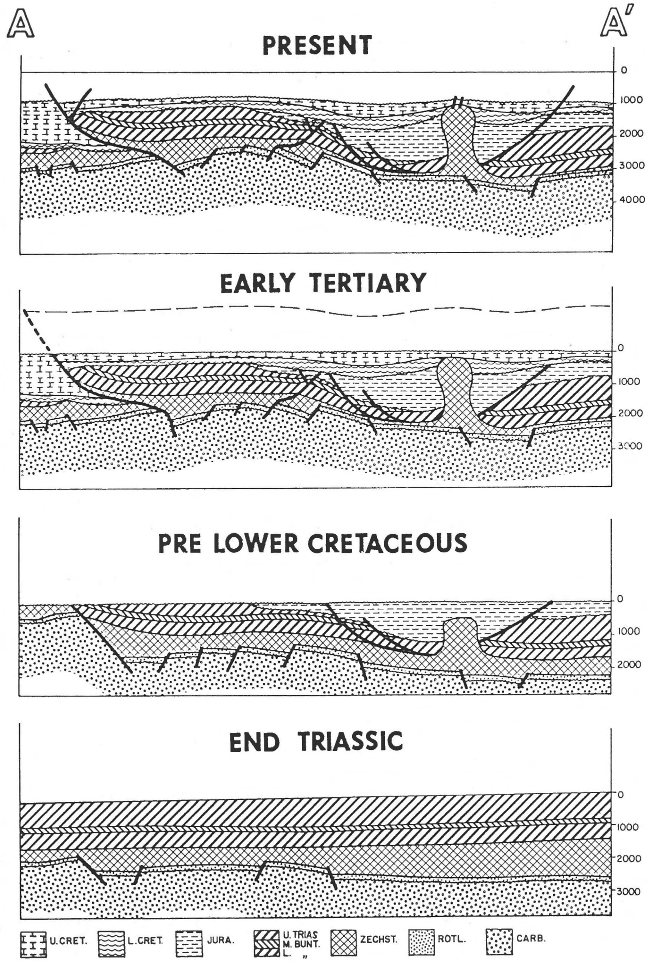

Fig. 11
Palaeo reconstruction K/13. For location see figure 10.

RESERVOIR PROPERTIES

Porosity in the aeolian and fluviatile Rotliegend sandstones shows a great variation in K/13. Palaeo-reconstructions indicate a relationship between porosity and depth of burial. Based on this, K/13 can be divided into three main structural areas (Fig. 10).

These are:

1. Stable areas – Indefatigable High, 'J' structure;
2. Inverted Graben Areas – Broad Fourteens Basin;
3. Intermediate Areas – 'E' and 'F' field area.

The average porosities in the stable areas range from 16 to 19% compared to 11 to 12% average porosity as found in the inverted graben. Average porosities in 'E' and 'F' fields range from 20 to 22 percent. The higher than expected porosity could occur because of early gas migration which preserved the original porosity at the time of migration, by inhibiting secondary pore-filling growth and illitisation.

Main Buntsandstein porosity, ranging from 18 to 24%, has the same distribution as found in the Rotliegend reservoir rocks.

HYDROCARBON GENERATION AND MIGRATION

The occurrence of hydrocarbons in Main Buntsandstein reservoirs in the North Sea is a rare phenomenon, and in the Dutch sector limited to areas of strong tectonic movement during Late Cretaceous-Early Tertiary time. The burial history of the Late Carboniferous (Westphalian) coalbearing source rocks in the Broad Fourteens Basin indicates that high maturity levels were reached prior to the Late Cretaceous-Early Tertiary inversion period (OELE ET AL., 1981). Gas generation probably started as early as Middle Jurassic (VAN WIJHE ET AL., 1980). The 'E' and 'F' structures, located on the intermediate block in the basin, trapped gas migrating out of the basin prior to the inversion period. The thick Zechstein evaporites overlying the Rotliegend sandstones prevented hydrocarbons from migrating into the Main Buntsandstein.

Comparison of the gas signatures from Rotliegend and Main Buntsandstein reservoirs, (Table I) shows that the gas found in both reservoirs has a common source. The minor differences in the N_2 and CO_2 indicate a longer migration route for gas found in Triassic reservoirs. Based on palaeo-reconstructions, it is demonstrated that the Main Buntsandstein 'A' and 'B' structures in Block K/13 were formed by the inversion during the Late Cretaceous-Early Tertiary. Therefore, gas migration into these structures has occurred during of after these tectonic movements. During the inversion, through tilting of gas filled Rotliegend traps, gas spilled out of those structures. Prior to reaching its present position, the eastern limb of the 'A' structure was in juxtaposition with the Rotliegend, allowing hydrocarbon migration into the Main Buntsandstein. The geographical relationship and the very similar gas signatures indicate that the gas found in the Main Buntsandstein 'A' and 'B' structures could have spilled out of the Rotliegend 'E' and 'F' structures. LEYTHAEUSER ET AL. (1982) discussed gas diffusion as a mechanism for primary migration and stated that shale cap rock can be a semi-permeable seal, which results in destruction of gas accumulations in a few million years. They postulate a dynamic system of very late gas migration or recent replenishment of gas structures. This model is rejected for the Main Buntsandstein gas fields, since the Zechstein salt forms a barrier to such migration.

Table I, K/13 gas compositions

	Rotliegend gas Vol. %	Main Buntsandstein gas Vol. %
HE	.079	.090
N_2	5.446	7.12
CO_2	1.695	.13
CH_4	85.382	85.21
C_2H_6	5.462	5.45
C_3H_8	1.136	1.20
C_4H_{10}	.406	0.447
C_5H_{12}	.147	0.148
C_6H_{14}	.080	.086

DEVELOPMENT OF FIELDS AND PRODUCTION FACILITIES

After discovery of the 'A' field in March 1972, a fourpile wellhead platform was installed in September 1974 and six production wells were drilled into the Main Buntsandstein reservoir. A 36-inch pipeline was laid by Pennzoil to the processing plant near Den Helder. The pipeline and plant are owned by Noordwinning, NAM/CLOMS and DSM. An eight-pile production platform was installed adjacent to the well head platform and production started in February 1976.

The 'B' field was discovered in September 1973 and was developed by three production wells drilled from a four-pile satellite platform installed in February 1976. Gas is transported by a 10-inch line to the 'A' platform for processing before entering the 36-inch line. Production commenced in July 1977.

Well K/13-5 discovered the 'F' field in December 1976. Four development wells were drilled from a four-pile well head platform. A six-pile production platform ('C' platform) was installed adjacent to the well head platform. A 20-inch pipeline connects the field with the 'A' platform, which is the riser platform for the main pipeline to shore. Production started in October 1978, 22 months after discovery.

Finally, the 'E' field, discovered by the K/13-4 well in July 1976, was developed by three wells from a four-pile satellite platform ('D'). The gas is transported through a 10-inch line to the 'C' production platform for processing and further transfer to the main line at 'A'. Production started in February 1979. In figure 15 the lay-out of fields and pipelines is illustrated.

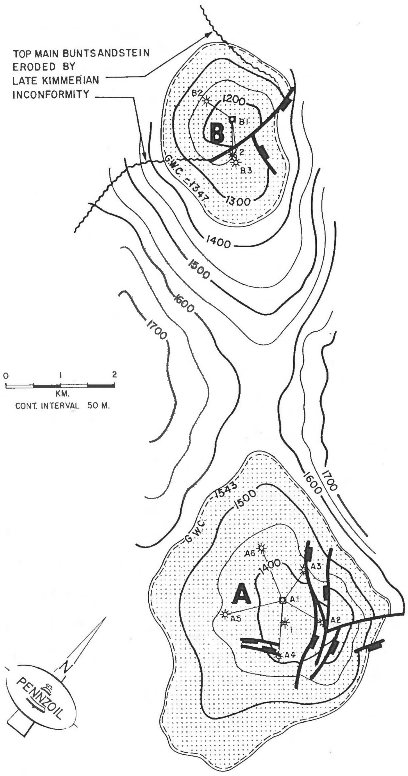

Fig. 13
Structure map K/13-A and B fields.

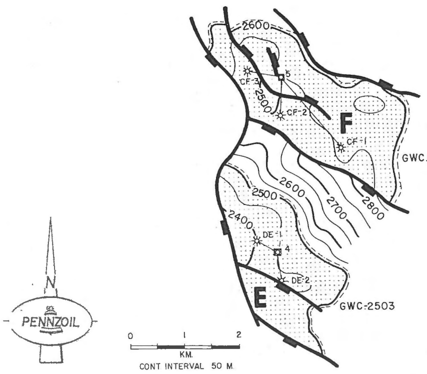

Fig. 14
Structure map K/13-E and F fields.

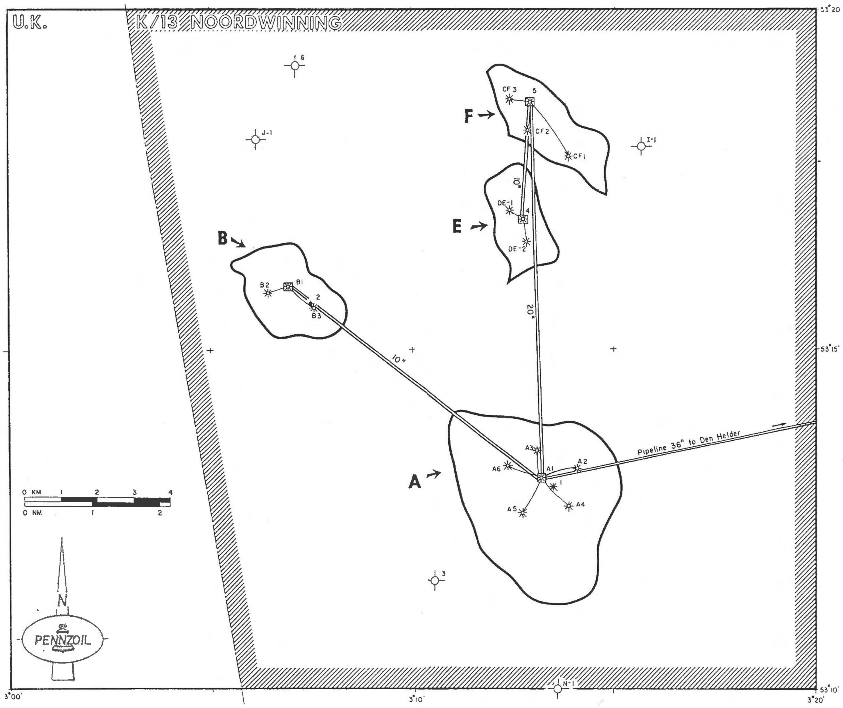

Fig. 15
K/13 fields and pipelines.

CONCLUSIONS

The joint occurrence of Rotliegend and Main Buntsandstein gas fields in Block K/13 is the result of a combination of several favourable factors of which the most important are:

1. Excellent reservoir properties in well developed, thick Rotliegend and Buntsandstein sands;
2. Abundant gas generation from Carboniferous coal beds during Jurassic time in the Broad Fourteens Basin;
3. Entrapment of gas in salt sealed Rotliegend structures flanking the Broad Fourteens Basin prior to inversion;
4. Remigration of gas into Main Buntsandstein traps formed in the late Cretaceous during and after inversion movements along large reverse faults.

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