The life cycle of the Netherlands' natural gas exploration: 40 years after Groningen, where are we now?

J. BREUNESE, H. MIJNLIEFF and J. LUTGERT

Netherlands Institute of Applied Geoscience TNO – National Geological Survey, PO Box 80015, 3508 TA Utrecht, the Netherlands (e-mail: jaap.breunese@tno.nl)

Abstract: The discovery of the giant Permian Groningen Field in 1959 triggered the main phase of gas exploration in NW Europe. This paper deals with the history and future of natural gas exploration in the Netherlands. The aim is to explain the historical exploration process and use the results to predict the remaining part of the exploration life cycle. Data from over 40 years of continuous exploration and production are presented and analysed for relationships between exploration and production (E&P) activity levels (licence area coverage, seismic surveying and drilling rates) and reserves growth. The E&P data are further investigated in terms of the exploration efficiency. After more than 1000 exploration wells drilled, the cumulative reserves growth curve still shows little sign of creaming off. At first sight, this observation would appear to indicate a not very efficient historical exploration process. The paper will try to explain the impact of the underlying dynamic factors such as added information through time, technology development and infrastructure extensions.

Past exploration has revealed part of the total natural distribution of gas accumulations present in the Netherlands subsurface. The best known, i.e. least uncertain, part of the distribution consists of discovered accumulations (although changes in the assessment of this part of the portfolio still occur). Next comes the presently known portfolio of mapped prospects, identified and assessed according to proven play concepts. There is already some of uncertainty as to their actual subsurface volumes. Finally, from the observation that new prospects have been identified even in recent years, it is proposed that the perceived prospect portfolio will also behave dynamically in the future. Indicators of the maturity level and the estimated ultimate potential of the main play areas are derived. Today's remaining potential is the source of future exploration. However, the actual outcome of future exploration is not determined by geology alone: business activity levels and exploration efficiency will be shown to be at least as important in the prediction of discovery and production rates.

Keywords: the Netherlands, exploration, maturity, natural gas, production forecast

The exploration and production of natural gas in the Netherlands was triggered by the discovery of the giant Groningen gas field in 1959, more than 40 years ago. Breunese & Rispens (1996) presented an analysis of the maturity of the natural gas plays in the Netherlands as perceived at that time. The current paper may be considered as an update; it includes some new ways of looking at maturity.

Because of its extraordinary size, the 'parent' Groningen Field is not included in the analysis in this paper. The focus is on the future of the 'children', collectively called the 'non-Groningen' gas fields. Wherever appropriate, the onshore Netherlands Territory (NT) and the offshore Netherlands Continental Shelf (NCS) are treated separately, for example, when economic factors and infrastructure come into play. In other cases, the analysis refers to the Netherlands as a whole (NL).

The question 'Where are we now?' refers to the stage of maturity in the exploration and production (E&P) life cycle. In this paper, this question is addressed by analysing successive performance indicators in the E&P process:

- data density and quality (number of wells, 3D seismic coverage);
- activity levels (active licences, exploration drilling rates);
- efficiency (exploration success rate and discovered volume per well);
- results (creaming curves, field size distribution);
- portfolios (prospects, undeveloped fields);
- the field development rate;
- production forecasts.

The first section of the paper deals with the indicators in the exploration domain. Here, maturity is a reflection of what is known of the plays or, rather, of what one thinks is known.

In the next section, indicators in the development and production domains are examined. Here, maturity has a more physical nature, namely the stage and rate of exhaustion of the natural resources. In the final section, conclusions are drawn from the analysis regarding the stage of maturity and the possibilities for extended exploration and production of non-Groningen natural gas in the Netherlands.

Exploration

Licences and 3D seismic coverage

The area covered by production and exploration licences determines the actual 'hunting ground' for exploration (Fig. 1). In addition, the geographical coverage of 3D seismic data marks the area where modern data have been acquired in order to look for prospectivity. Figure 2 shows that there is no 3D seismic coverage of old structural highs such as the London–Brabant Massif in the south and the Texel–Ysselmeer High in the central onshore.

Over the last ten years, the area of onshore exploration licences has gradually decreased (Fig. 3a). The presently remaining exploration licences are mostly in environmentally sensitive areas, such as the Ysselmeer and the Biesbosch (Fig. 1). Hence, drilling activities are difficult and 3D seismic coverage has been restricted to the areas under production.

On the NCS, the area of exploration licences has also gradually decreased over the last ten years (Fig. 3b). Note that until 1993 a

BREUNESE, J., MIJNLIEFF, H. & LUTGERT, J. 2005. The life cycle of the Netherlands' natural gas exploration: 40 years after Groningen, where are we now? In: DORÉ, A. G. & VINING, B. A. (eds) Petroleum Geology: North-West Europe and Global Perspectives—Proceedings of the 6th Petroleum Geology Conference, 69–75.

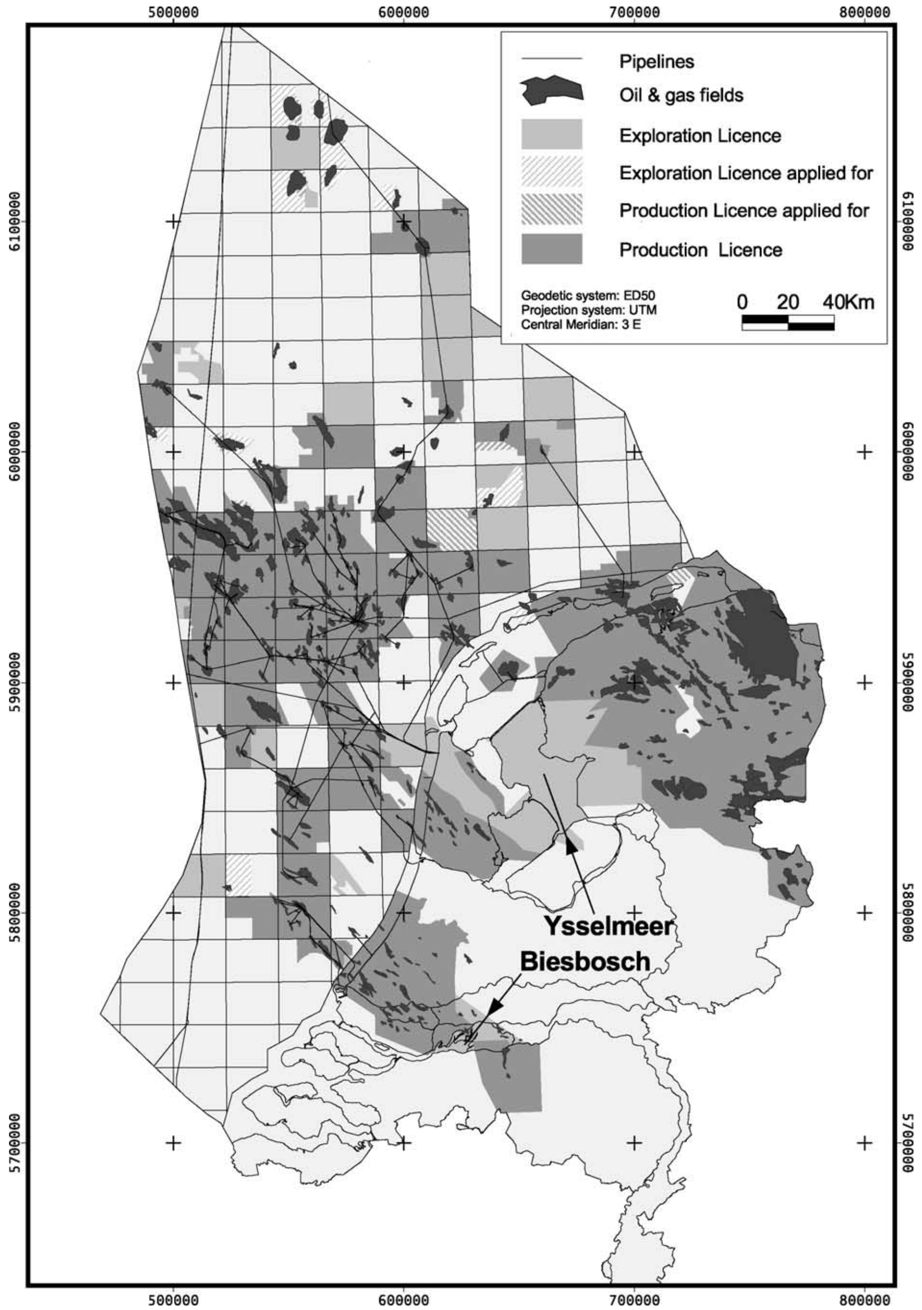

Fig. 1. Licenses and gas fields in the Netherlands.

system of offshore rounds existed. The peak in 1993 marks the eighth round of applications for exploration licences. Subsequently, an open-round system was introduced, the so-called ninth round. As Figure 3b shows, 3D seismic acquisition is still proceeding, particularly in the northern offshore area (Fig. 2). Around 50% of the existing 3D data now stretches over open acreage.

Exploration drilling

The historical exploration drilling rate onshore has been at a fairly constant level of close to ten wells per year (Fig. 4a). Only in recent years has the drilling rate dropped to less than half of that. The historical offshore exploration drilling rate (Fig. 4b) can be subdivided into three phases:

(1) 1968 – 1982: 18 wells per year;
(2) 1982 – 1992: 29 wells per year;
(3) 1992 to the present: 15 wells per year.

Since the late 1980s, virtually all exploration wells have been drilled based on 3D seismic data.

Success rate

The technical success rate has gradually improved from 0.30 to close to 0.40 (Fig. 4). Note that in Figure 4 the technical success rate has been plotted cumulatively. This implies that in recent years the technical success rate has been significantly higher than 0.40; fewer wells are needed to discover a given number of accumulations.

Exploration efficiency

The exploration efficiency here is defined as the average of the recoverable volume discovered per exploration well, taking both successful and dry wells into account.

In the very early stages of exploration for natural gas in the Netherlands relatively large volumes were discovered per well, but

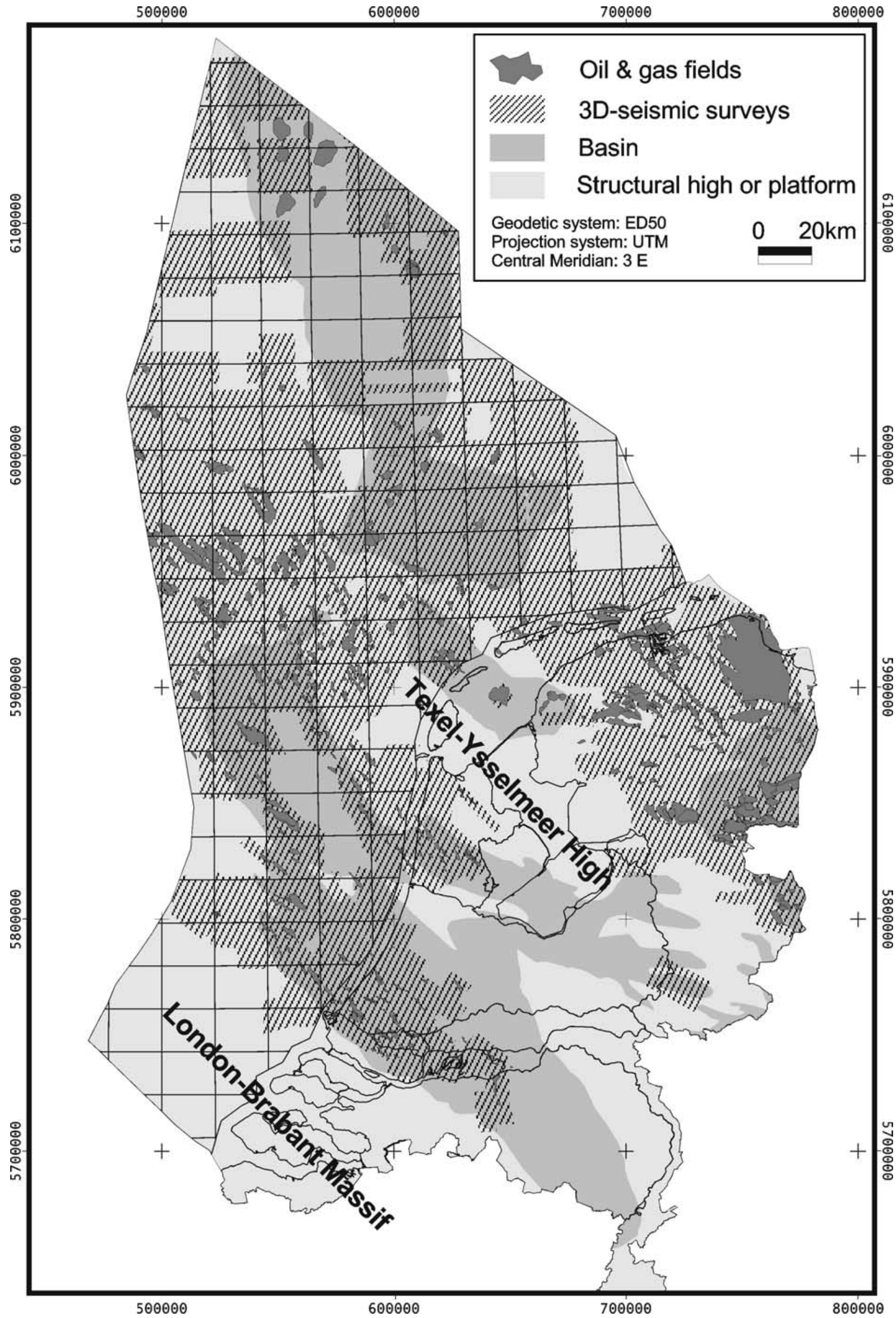

Fig. 2. Structural elements and 3D seismic coverage in the Netherlands.

these values cannot be considered representative for the future. Figure 5 displays the exploration efficiency obtained during the main stage of exploration, starting in 1980. It is observed that the average recoverable volume per exploration well has stabilized at $1.3 \times 10^9\,Sm^3$ over the last 15 years and shows no sign of further decline. This is due to new technical developments, in particular 3D seismic surveying.

Creaming curves

Creaming curves are the traditional indicators of the maturity of a play or area. In Figure 6 four (groups of) plays are distinguished according to their reservoir age: (i) Rotliegend; (ii) Zechstein & Carboniferous; (iii) Triassic; and (iv) post-Triassic.

From 1970 to 1980, an apparent creaming effect is observed. However, from the early 1980s a clear upswing in discovered GIIP is visible. Note that the discovered volume in the Rotliegend play has maintained its pace well over the last 30+ years. The apparent creaming and subsequent upturn mentioned above are attributed to the other plays, notably the Triassic reservoir play.

Only in very recent years can an overall creaming effect be observed. It is noted, however, that the exploration drilling rate has decreased markedly during that time (cf. Fig. 4a, b), which explains most of the apparent creaming.

Field size distribution

The size distribution of discovered accumulations through time is an indicator of the exploration efficiency and maturity of a given play area. According to theory, random exploration would lead to a field size distribution of fixed shape. Efficient exploration would lead to creaming, i.e. a gradual decrease of the mean field size. This hypothesis has been tested against field size distributions over a 20-year period from 1983 to the present (see Fig. 7) as taken from the Ministry of Economic Affairs (MEA 1975–2002). Five size classes have been used, as indicated.

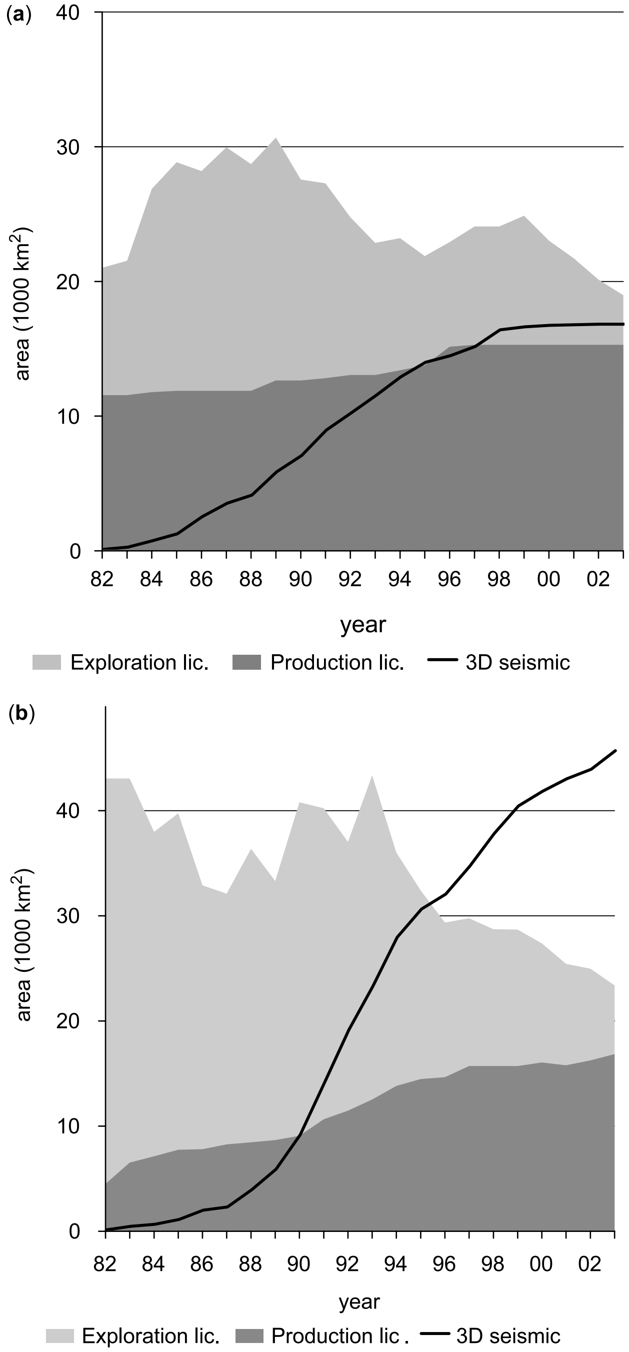

Fig. 3. Licenses and 3D seismic coverage: (**a**) onshore Netherlands Territory; (**b**) offshore Netherlands Continental Shelf.

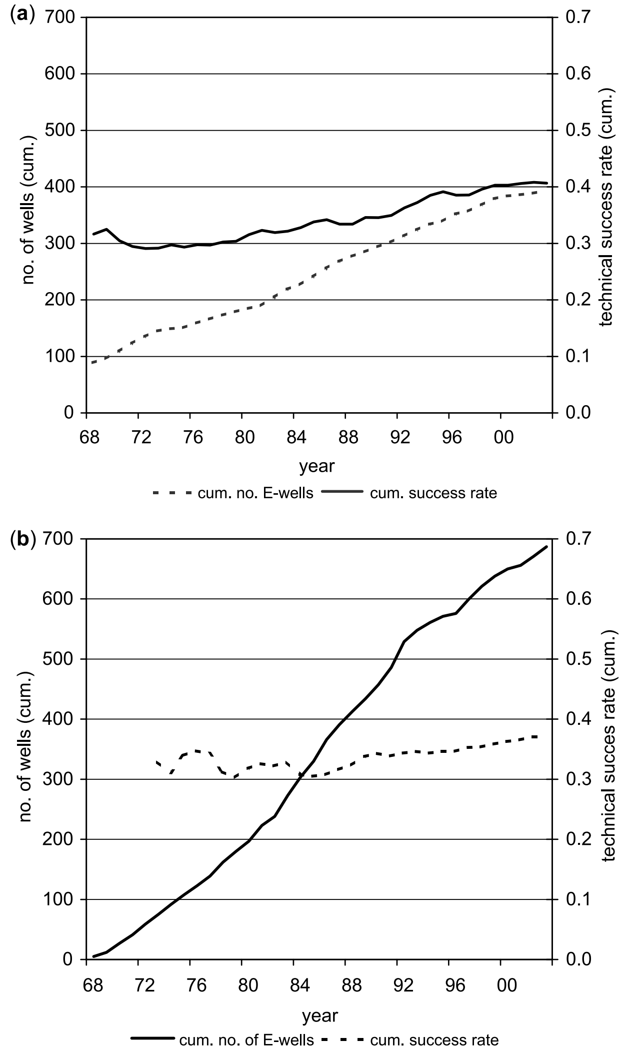

Fig. 4. Drilling rate and success rate: (**a**) onshore Netherlands Territory; (**b**) offshore Netherlands Continental Shelf.

It is observed that the size class $2-5 \times 10^9\,Sm^3$ dominates the distribution by a share that has gradually increased from 35% to close to 40%. The adjacent size classes ($1-2 \times 10^9\,Sm^3$ at the lower end and $5-10 \times 10^9\,Sm^3$ at the higher end) each represent about 23% of the distribution. In the period 1984 to 1998, a shift towards the smaller field sizes has been observed, class $5-10 \times 10^9\,Sm^3$ losing ground to class $1-2 \times 10^9\,Sm^3$. However, since 1998 this shift has vanished. The relative importance of the largest size classes ($10-20 \times 10^9\,Sm^3$ and $20-50 \times 10^9\,Sm^3$) has remained fairly constant over time.

The above analysis of the field size distribution over time can be summarized as follows: the net effect of creaming on the field size distribution has been at most very small, if not almost negligible, over the 20-year period from 1983 to the present; this is in spite of the fact that the total number of fields in the size classes analysed has more than doubled from 107 in 1983 to 227 at present.

Remaining exploration potential

The remaining exploration potential is an important indicator of the maturity of a given play or area. Assessments of the remaining exploration potential, made from 1992 onwards, have been published (MEA 1975–2002). The results have been expressed in terms of ranges (P90 to P10), as presented in Fig. 8. Note that the assessments have been restricted to identified prospects under play concepts proven in the Netherlands and, thus, do not include as yet unidentified prospects and/or unproven play concepts.

From Figure 8, it is observed that the range of assessed exploration potential has remained fairly constant over the last ten years, ranging from $200 \times 10^9\,Sm^3$ (P90) to $500 \times 10^9\,Sm^3$ (P10), with a mean of some $330 \times 10^9\,Sm^3$. This is in spite of the fact that during that same period close to $300 \times 10^9\,Sm^3$ of new reserves were discovered. In other words, the prospect portfolio has been replenished, which is the result of new data, technology and petroleum geological knowledge gained over that period.

Development

Netherlands Onshore (NT) (Fig. 9a)

Prior to the discovery of the Groningen Field in 1959, a volume of around $50 \times 10^9\,Sm^3$ had already been discovered and developed, mainly consisting of natural gas reserves in Zechstein,

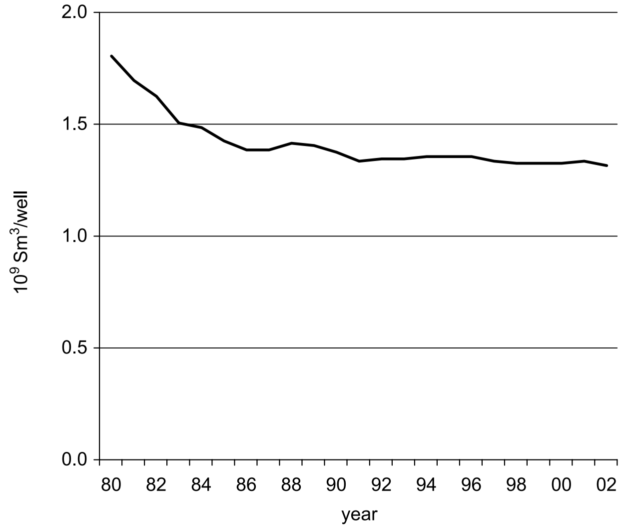

Fig. 5. Exploration efficiency (NL), recoverable cumulative volume discovered per exploration well.

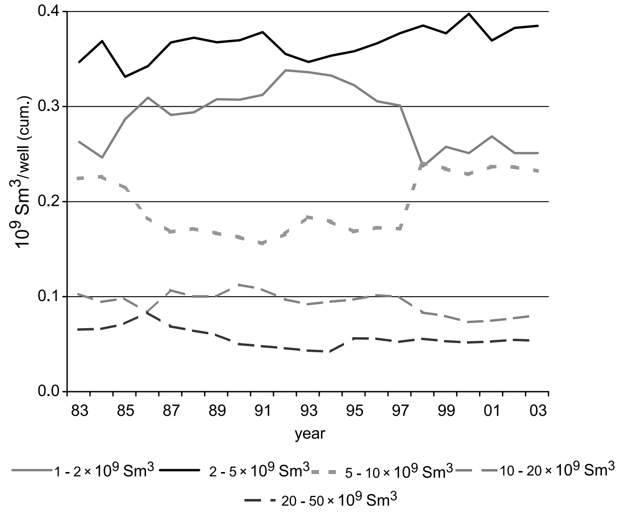

Fig. 7. Size distribution of discovered gas fields (NL).

Carboniferous and Triassic reservoirs in the eastern part of the Netherlands.

Following the Groningen discovery, a volume of 400×10^9 Sm^3 was discovered during the 1960s. Production from these discoveries started in the early 1970s. From 1973 to 1998, the development rate onshore averaged an almost constant rate of 16×10^9 Sm^3 a^{-1}. However, from 1998 a significant decline in the onshore gas development rate is observed. This is largely explained by the decreasing exploration drilling rate, which lowered the supply to the portfolio of commercial, undeveloped fields. A volume of around 40×10^9 Sm^3, discovered in the 1990s on the coast of the Wadden Sea, cannot be developed because of environmental restrictions and further exploration in this area is similarly restricted.

The portfolio of onshore non-commercial accumulations contains dozens of separate, small discoveries, but the total technically recoverable volume is relatively modest (Fig. 9a). Indeed, the onshore development cut-off is 0.5×10^9 Sm^3 or less.

Netherlands Offshore (NCS) (Fig. 9b)

After the opening of the NCS for exploration in 1968, a recoverable volume of around 200×10^9 Sm^3 was discovered before offshore production actually started in 1975. Since then, the offshore development rate has averaged an almost constant 22×10^9 Sm^3 a^{-1}. Over this period, the portfolio of undeveloped reserves has been between 150×10^9 Sm^3 and 200×10^9 Sm^3. However, from Figure 9b it is clear that the undeveloped volume has decreased over the last ten years and, moreover, is now dominated by volumes that are considered non-commercial by the current operators. Distance to infrastructure is the cause of non-commerciality in a number of cases, which emphasizes the importance of extending and maintaining infrastructure wherever feasible.

Production

In Figure 10, a series of three historical production forecasts (1975, 1980 and 1989) for the Netherlands' non-Groningen gas is

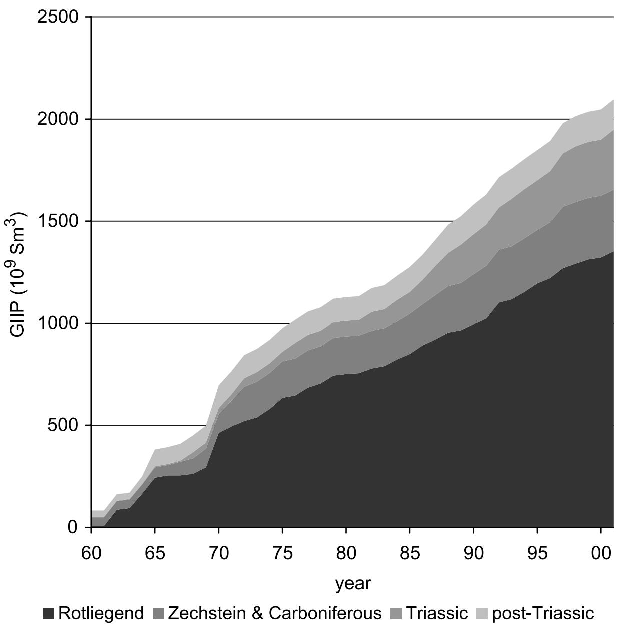

Fig. 6. Creaming curves for (aggregated) plays (NL).

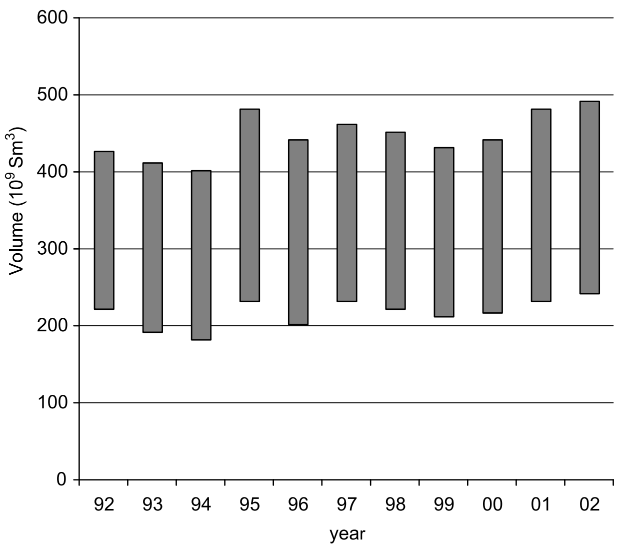

Fig. 8. Exploration potential for natural gas, historical yearly assessments (NL).

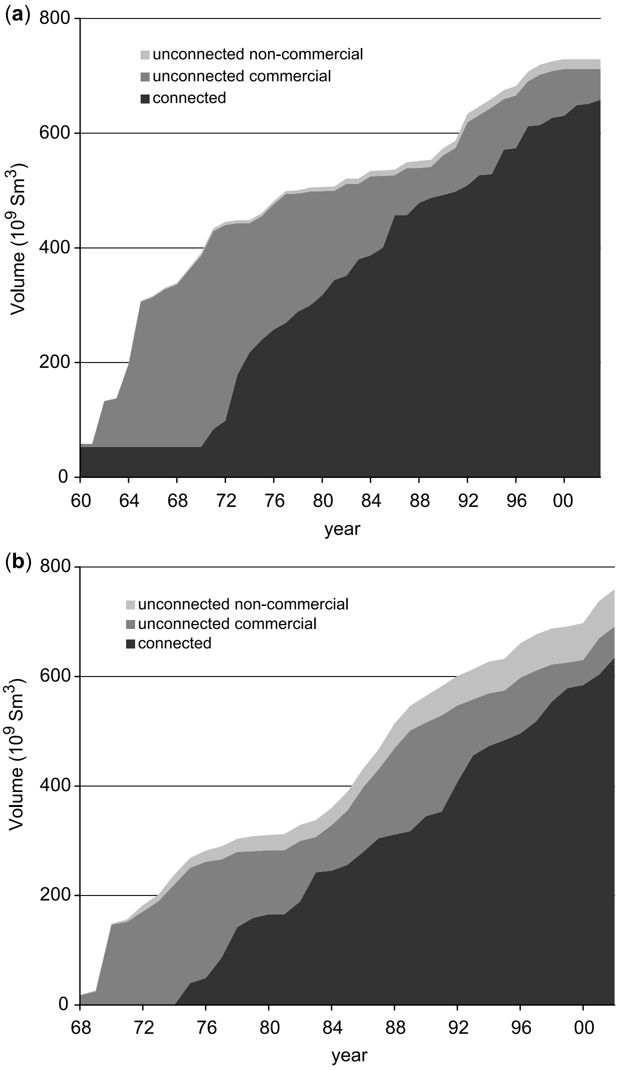

Fig. 9. Development rate: (**a**) onshore Netherlands Territory; (**b**) offshore Netherlands Continental Shelf.

presented. These historical forecasts include discovered volumes at those points in time only. With hindsight, it can be concluded that these forecasts were quite correct but only up to the point in time at which a peak production was predicted, five to seven

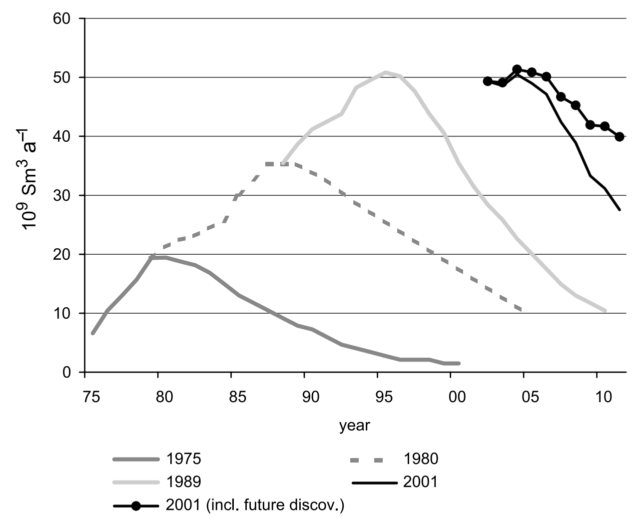

Fig. 10. Production forecasts for natural gas (NL), excluding the Groningen Field.

years after the date of forecasting. New developed discoveries (cf. Figs 9a, b) caused the moment of peak production to be postponed. In fact, the annual non-Groningen production rate continued to increase almost linearly over time to a level of over $40 \times 10^9\,Sm^3\,a^{-1}$ in the early 1990s; only then did this trend start to level off to the current production level of around $50 \times 10^9\,Sm^3\,a^{-1}$.

From Figure 10, it can be seen that the decline slope of the successive forecasts steepens. This is a reflection of the 'ageing' of the producing fields as they gradually approach their decline phase and the increase in the allowed net depletion rate of new, developed fields through pooling contracts and higher load factors. The most recent ten-year forecast presented here (2001) predicts a decline starting only three years after the date of forecast (MEA 2001), with a steep decline towards $27 \times 10^9\,Sm^3$ in 2011. In the 2001 forecast, the additional contribution from expected future discoveries is also assessed. The technique employed is described in Lutgert et al. (2005). Taking this additional production potential into account, the decline in slope is significantly reduced, leading to an expected non-Groningen production rate for the Netherlands in 2011 of close to $40 \times 10^9\,Sm^3$.

Conclusions

From the above analysis of the historical data on the E&P process regarding natural gas in the Netherlands, a number of conclusions can be drawn.

(1) Exploration
- The industry has focused on a smaller exploration 'hunting ground'.
- This focus is supported by a vast amount of 3D seismic data.
- Exploration drilling rates have decreased over the last ten years.
- This trend has been partially compensated for by increasing success rates.
- Exploration well efficiency has remained stable.
- Creaming effects in the curve of discovered GIIP are not yet significant.
- The field size distribution shows no significant signs of creaming.
- The remaining exploration potential is stable.

(2) Development
- In general the development of new discoveries has been quite fast.
- The remaining undeveloped portfolio offshore for a large part consists of (sub)marginal accumulations.
- The remaining undeveloped portfolio onshore consists mainly of reserves currently 'locked' for environmental reasons.

(3) Production
- The increasing steepness of the decline part of the production forecasts clearly indicates the 'ageing' of the portfolio of producing fields.
- In spite of historical forecasts being proven to be conservative, the non-Groningen contribution to the total Netherlands gas production now seems to have reached a ceiling.

(4) General
- After more than 40 years of 'post-Groningen' exploration for natural gas in the Netherlands, the geological exploration indicators are not unfavourable for future exploration.

- However, decreasing exploration drilling rates are leading to a supply of new gas that is insufficient to sustain the present production level.

References

Breunese, J. N. & Rispens, F. B. 1996. Natural gas in the Netherlands: exploration and development in historic and future perspective. Geologie en Mijnbouw, **74**, 353–364.

Lutgert, J. L., Mijnlieff, H. F. & Breunese, J. 2005. Predicting gas production from future gas discoveries in the Netherlands: quantity, location, timing, quality. In: Doré, A. G. & Vining, B. A. (eds) Petroleum Geology: North–West Europe and Global Perspectives–Proceedings of the 6th Petroleum Geology Conference. Geological Society, London, 77–84.

Ministry of Economic Affairs (MEA). 1975–2002. Oil and Gas in the Netherlands, Exploration and Production. Yearly reports. The Hague, the Netherlands. World Wide Web Address: http://www.nitg.tno.nl/oil&gas/downloads/jb2002eng.pdf.

Ministry of Economic Affairs (MEA). 2001. Aardgasstromen. Report NITG 02-039-A. The Hague, the Netherlands. World Wide Web Address: http://www.nitg.tno.nl/oil&gas/downloads/gasstrEZ.pdf.