Exploring Dinantian carbonates in the Dutch subsurface – from tombstone to cave

EBN - B. Jaarsma
PGK meeting, 18th September 2013
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Prof. Jan de Jager and Prof. John Reijmer (VU Amsterdam)

Prof. Edouard Poty (University of Liege)

Dana Petroleum Netherlands B.V. and NAM are thanked for kindly providing seismic and core data used in the review
• Introduction / background of the review
• Geology of the Dinantian carbonates play in the SNS area
• Review of the reservoir quality of the Dinantian carbonates
• The Californie platform – explaining the cave
• Prospectivity of the Dinantian carbonates in the Dutch SNS
• Conclusions
EBN – who we are and what we do

• EBN B.V. is an independent firm, Dutch state is sole shareholder, all EBN profits transferred to the Dutch government
• Payments 2012: €6.9 billion
• Production 2012: 30 BCM gas, 1.9 million barrels oil

roles
• EBN is the non-operating partner for E&P companies in the NL
• We invest in exploration, production and storage of oil & gas
• We advise the government
• We are involved in the sale of Dutch natural gas through GasTerra
• We develop and share knowledge

Download “Focus on Dutch Oil & Gas 2013” from www.ebn.nl
Strategic objective of these studies

*Promote under-explored petroleum plays and stimulate industry exploration activity, contributing to the Dutch 30-30 ambition*

Exploration projects
1. Dinantian carbonate play review
2. DEFAB prospectivity review (Dutch Northern Offshore)
3. Zechstein carbonate play review
Dinantian Carbonate Play Review NL

Review (2012 – 2013)
- Wells, literature*, fieldtrip
- Focus area 1 – with PanTerra
- Focus area 2 – MSc. N. Hoornveld
- Focus area 3 – CAL / RVG

* important references:
- Kombrink (2008)
- Total (2007)
- Wong, Batjes & de Jager (2007)

Follow-up (2013 - 2014)
Dinantian Carbonate prospectivity review
Summary and conclusions

- Dinantian carbonates in the Dutch subsurface have varying geometries and show a large range of reservoir quality
- These differences reflect differences in tectonic setting, sealevel, burial / diagenesis history between different areas
- Primary reservoir quality is low, fractures and karst required for productivity
- Well CAL-GT-01 proves possibility of very productive Dinantian carbonates
- Observed karst features can be explained by proximity of geological hiatus
- Deep-seated faults might contribute to development of karst
- The Dinantian Carbonate Play in the Dutch SNS is high risk, high reward; cluster of leads with sizable volumes ~10’s BCM, close to infrastructure
- The play extends into the UK sector with similar leads
- Further work required to de-risk reservoir quality North of LBM
- Relevant for geothermal and shale gas activities
• Introduction / background of the review

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• Conclusions
• 21 wells drilled in the NL, 25 just across the border
• Geothermal, mineral water / spa, UGS, HC exploration (only shows)
• Outcrops in Belgium, Germany, UK and Spain
• Analogues in Caspian Sea and UK

• New well data: 2 wells released and 3 drilled (2012) – reservoir rock ranging from tombstone to cave...
• New mapping (next slide)
Isolated Visean (rimmed) platforms and mounds on Devonian clastics
Tournaissian ramp possibly present downflank on highs
Deeper marine “Kulm” facies in basins
Thick Namurian section on top of Dinantian
Devonian granite root?
Extensive Tournaisian ramp while Visean shelf is limited to the South
Truncation by (much) younger section towards South
Faults increase to the North – extension of Roer Valley Graben - Tertiary activity
Fault blocks develop as a result of extension – carbonate build-ups
Transition into clastics dominated Farne Group, towards Mid North Sea High (NL E-Quads)
Brown dots indicate wells that drilled the Dinantian carbonates.

mapping EBN evaluations (2012-2013)
• Northern onshore – Nynke Hoornveld
• Southern offshore – PanTerra Geoconsultants

TNO map by Ed Duin
Dinantian Carbonate build-ups in the Northern Onshore
MSc research by N. Hoornveld (2013)

Elevation depth [m]

-4500
-5000
-5500
-6000
-6500
-7000
-7500
-8000

Fryslân, Blija

Uithuizermeeden

Muntendam

Bedum

Muntendam

Meeden

Fryslân, Tytsjerk

Luttelgeest
Dinantian Carbonate build-ups in the Dutch Northern Onshore - Uithuizermeeden

- Zechstein salt
- Rotliegend
- Westphalian
- Namurian
- Dinantian carbonates
- Devonian

Slope: +/- 15°

- Upper Visean Carbonates
- Lower Visean Dolomite
- Devonian (reef ?)
- ? Clastics
Dinantian Carbonate build-ups in the Caspian - Tengiz

Images from Kalzhekov (2012)

<table>
<thead>
<tr>
<th>key elements of the Dinantian carbonate play - Caspian</th>
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<tbody>
<tr>
<td><strong>structure</strong></td>
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<td><strong>source</strong></td>
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<td><strong>reservoir</strong></td>
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<tr>
<td><strong>seal</strong></td>
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Dinantian Carbonate build-ups in the Dutch Northern Onshore - Luttelgeest and Fryslân

Examples mapped and described in detail in Hoornveld, 2013
• Introduction / background of the review

• Geology of the Dinantian carbonates play in the SNS area

• **Review of the reservoir quality of the Dinantian carbonates**

• The Californie platform – explaining the cave

• Prospectivity of the Dinantian carbonates in the Dutch SNS

• Conclusions
- Small biodiversity after “Kellwasser” extinction events
- Carbonate mud mounds, non-framework buildups
- 6 sedimentary sequences, each representing 3rd order sequence
- Primary reservoir quality low (few %) – karst / fractures required

References: Bridges et al. (1995), Total (2007)
Chart is downloadable from Cambridge Carbonates website: http://www.cambridgecarbonates.com/downloads/crib_cards.php
carbonate dissolution – influence of temperature, pH, salinity, pressure

Types of karst:
- Meteoric karst (intra-platform / post-deposition)
- Hydrothermal karst (post-deposition)
- Mixing zone

Cueva de la Mina de Europa, from Valsero & Ardila (2009)
Kashagan – example of intra-platform karst

1) Thick fresh water lens (affecting several 4th order cycles)

- Dissolution caves and pipes
- Flank margin caves and fractures

2) Burial and compaction phase

- PLATFORM INTERIOR: Collapse breccia with argillite matrix
- PLATFORM MARGIN: Partial preservation of flank margin caves and fracture system

- Near-surface diagenesis processes have different impact on reservoir in inner platform and in platform margin
- More than 1 well or HiRes seismic required to understand heterogeneity...
Prediction of reservoir quality
Northern onshore – isolated (rimmed) Visean platforms

- analogues: Caspian Sea, Spain
- reservoir:
  - progradational facies platform slope
  - fractures / breccia in slope
  - intraplatform karst and slope karst
- tight reservoir in wells
Prediction of reservoir quality
Southern offshore - Tournaisian ramp and Visean ramp to shelf

- analogues: UK, Ardennes
- reservoir
  - Visean shelf margin (grainstone, sandbodies)
  - Tournaisian dolomitized
  - fractures in slope and fault zones
  - karst: intraplatform, meteoric (hiatus), hydrothermal
- karst encountered in wells

Seismic section flattened on base Dinantian to mimic ramp
Regional well correlation South

- **Devonian clastics**
  - O18-01
  - S02-02
  - S05-01
  - BHG-01
  - KTG-01

- **Westphalian**
  - Goeree Mb

- **Cretaceous**
  - Namurian
  - Schouwen Mb
  - Beveland Mb

- **Dinantian Carbonates (Zeeland Fm)**
Karst in the Dinantian carbonates
examples from subsurface and outcrop (1)

From Yang et al. (2010)
Karst in the Dinantian carbonates examples from subsurface and outcrop (2)

Hastenrath Quarry – cave with Cret. infill

Well KTG-01 – karst with Cret. infill

Well BHG-01 – vugs and minerals

Picture by Harmen Mijntjeff
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The Californie platform – a new well (1)

• Geothermal well (2012): with extra EBN data gathering and analysis

• 750 m Dinantian carbonates (mainly dolomite) – age largely unknown

• Fractured / karstified Tegelen FZ - losses
  Cavity > 30 m - total losses

• Very different from all other Dinantian wells
  • cave scale karst – hydrothermal and/or meteoric karst
  • massive hydrothermal diagenesis below cavity level
  • high productivity (240 m³/hr)
What’s the cause of the cavity? Meteoric or hydrothermal karst, or both
Reservoir quality of Dinantian carbonates
summary of observations and conclusions

large range of reservoir quality possible – from tombstone to cave
karst and/or fractures are required for producing reservoir
understanding diagenesis and fracturing is the key to predicting reservoir quality

• Large Karst features (in wells, seismic and outcrops) explained by a geological hiatus – karstification below exposed platform surface

• Intra-platform karst probably present as well

• Impact of faults / fractures on reservoir quality can be positive and negative; (de-)dolomitization, mineralization, hydrothermal karstification

• Lack of karst features (in Northern wells) explained by lack of hiatus and (thick) Namurian section on top of platform and lack of faults

• These conclusions are relevant for geothermal world as well
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Reservoir quality of Dinantian carbonates in the Dutch SNS

- Seismic suggests extensive Tournaisian ramp while Visean shelf is limited to the South
- Seismic indications / well observations karst in South
- (Re-activated) deep faults allow for hydrothermal diagenesis in Tertiary (poor timing wrt HC charge)?
Prospectivity of Dinantian Carbonates in the Dutch SNS – reservoir quality elements

- Distribution of Tournaisian - Visean
- Indications for karst in seismic or wells
- Presence of faults

Volumetrics ~ 1-10 BCM GIIP per lead
Key elements of the Dinantian carbonates play

<table>
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<tr>
<th>Structure</th>
<th>(faulted) carbonate platform</th>
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<tr>
<td>Source</td>
<td>Namurian / Dinantian shales (lateral migration)</td>
</tr>
<tr>
<td>Reservoir</td>
<td>karstified / fractured (Visean) limestone</td>
</tr>
<tr>
<td>Seal</td>
<td>Namurian shales (top / side seal)</td>
</tr>
</tbody>
</table>

Cartoon from Total (2007)
Prospect example area II

- SW
- NE
- P10

- Chalk
- Lwr. Cretaceous
- Permian
- Westphalian
- Top seal – Namurian shale
- Dinantian carbonates
- Devonian / basement
- Lateral HC charge from Namurian shales

5 km
Results for study area from Petroplay project (Schroot et al., 2006):

- SR potential from Devonian to Namurian source rocks is “fair” to “good” but potential could be higher in (un-drilled) intra-platform basins
- Most generation at the end of the Carboniferous, later pulses of generation and expulsion until present
- Timing of last re-activation of faults compared to charge important
Prospectivity of Dinantian Carbonates in the Dutch SNS – High risk, high reward

volumetrics ~ 1-10 BCM GIIP per lead
Way forward

Industry

• cooperation of parties to test high risk play, high reward - JIP, consortium
• cross-border
• combine with shale gas and geothermal studies and activities

G&G - focus on good understanding of geometries and reservoir distribution of the carbonate build-ups North of LBM

• facies and diagenesis evaluation of the Southern wells – compare with examples from Northern Belgium and UK (literature)
• reconstruction of sea levels, temperature, tectonics
• study examples of mineralization of the Dinantian carbonate platforms
• seismic re-processing for higher resolution imaging of the carbonate build-ups
• basin modeling using more scenarios for source rock and burial history
• potential field methods (gravimetry, magneto-telluric) to improve basement mapping; especially in areas with sparse seismic coverage
• evaluate Namurian sands as secondary target
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- The play extends into the UK sector with similar leads
- Further work primarily to de-risk reservoir quality North of LBM
- Relevant for geothermal and shale gas activities
Thanks for your interest and attention!
The presentation will be made available via [www.ebn.nl](http://www.ebn.nl)
or e-mail [bastiaan.jaarsma@ebn.nl](mailto:bastiaan.jaarsma@ebn.nl)
Relevant references

- Bridges, Gutteridge & Pickard (1995) – the environmental setting of E. Carboniferous mud-mounds
- Hoornveld (2013) - Dinantian carbonate development and related prospectivity of the onshore Northern Netherlands (MSc thesis)
- Jaarsma et al. (2013) - Exploring Dinantian Carbonates in the SNS - New Data Offering New Insights (EAGE abstract)
- Kombrink (2008) - The Carboniferous of the Netherlands and surrounding areas; a basin analysis
- Schroot et al. (2006) - Hydrocarbon potential of the Pre-Westphalian in the Netherlands on- and offshore - PETROPLAY project report (on www.nlog.nl)
- Vandenberghhe et al. (2000) – the Merksplas-Beerse geothermal well and the Dinantian reservoir
- Van Hulten (2012) - Devonian-carboniferous carbonate platform systems of the Netherlands
- Wong, Batjes & de Jager (eds.) (2007) - Geology of the Netherlands
Observations in core slabs Dinantian – coin for scale

- **breccia**
- **“coral”**
- **vuggy porosity / mineralization**
- **karst, Cret. greensand infill**
- **stylolithe**
- **formation bounded (and cemented) fractures**
- **breccia / vuggy porosity**