Diagenesis and reservoir quality of late Palaeozoic carbonates of the Barents Shelf

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Introduction

• Estimating carbonate reservoir quality is a challenge in exploration
• Reservoir quality starts with early diagenetic processes
  – Initial mineralogy of grains: potential for dissolution and cementation
  – Palaeoclimatic conditions: Availability of meteoric water and susceptibility to
dolomitisation
  – Nature of eustasy (glacio-eustatic vs. greenhouse): Duration and amplitude of
  exposure during low stands
• The late Palaeozoic is a time of major global change
  – If we understand how these changes influence diagenetic and pore systems
  – We can explain why we expect different reservoir types and quality in
different carbonate systems
  – Go some way to risking reservoir properties in carbonates and siliceous facies
Late Palaeozoic global changes

- **Palaeotectonic**
  - Closure of Urals
  - Northward drift

- **Eustatic**

- **Palaeoclimatic**

![Map showing Palaeotethys circulation and Panthalassa cool water](image1)

Montañez & Poulsen 2013

- **Siliceous**
- **Heterozoan carbonates**
- **Photozoan carbonates**

Decay of ice sheets

Post-glacial warming

Urals seaway closes
7128/6-1: carbonate microfacies

- Aragonite
- Molluscs
- Phylloid algae
- Green algae
- Palaeoaplysina
- Heterozoan
- Photozoan
7128/6-1: carbonate microfacies

- Non-skeletal grains
  - Peloids
  - Ooids
  - Coated grains

- Heterozoan
- Photozoan

Non-skeletal grains
7128/6-1: carbonate microfacies

- High Mg calcite
- Red algae
- Echinoderms
- Heterozoan
- Photozoan
7128/6-1: carbonate microfacies
7128/6-1: carbonate microfacies

- Heterozoan
- Photozoan
- Silica
7128/6-1: diagenesis overview

Core plug porosity %

0 15 30

Depth (m) 1600 1700 1800 1900 2000 2100
Chrono-stratigraphy
Top (m)
Cones
Depositional environments
GAMMA RAY
NEUTRON POROSITY
BULK DENSITY
Core plug components
Aragonite
Mouldic pores
Anhydrite nodules
Dolomite
Chert
Spiculite
Heterozoan
Photozoan

Artinskian - Sakmarian
Sakmarian - Azeolian
Gzolian - Serpukhovian
7128/6-1: diagenetic features

Core plug porosity %

Aragonite components
Mouldic pores
Anhydrite nodules
Dolomite
Phylloid algal plate,
Gipsdalen Group 2103.6m
FoV 5mm

Heterozoan
Photozoan

Core plug porosity %

Depth (m)
1600
1700
1800
1900
2000
2100
2200
2300
2400
2500
Tortonian - ? Kungurian
Artinskian - ? Sakmarian
Sakmarian - Azeolian
Gzdian - Serpukhovian

Topostratigraphy
1588.00
1925.50
1992.50
1954.00
1540.00
2022.00
2074.00
2102.00
2150.00

Chronic stratigraphy

Depth (m)

Core plug porosity %

Core plug porosity %
7128/6-1: diagenetic features

Core plug porosity %

- 0
- 15
- 30

Core plug porosity

- Chert
- Phylloid biomould, Gipsdalen Group 2075.60m FoV 5mm
- Heterozoan
- Photozoan

Depositional environments:
- Cones
- Anhydrite nodules
- Mouldic pores
- Dolomite
- Aragonite components

Depth (m): 2150.00 to 1852.00

Chrom stratigraphy:
- Topasien - ? Kungurian
- Artinskian - ? Sakmarian
- Sakmarian - Azaolian
- Czol - Serpukhovian
7128/6-1: diagenetic features

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- **Chert**
- **Dolomite**
- **Anhydrite nodules**
- **Aragonite components**
- **Mouldic pores**

Anhydrite nodules in *Palaeoaplysina* bioherm Gipsdalen Group 1968.5m
7128/6-1: diagenetic features

Chert nodules
Tempelfjorden Group
1718.5m

Core plug porosity %

Depth (m) | Chrono-stratigraphy | Tops (m) | Depositional environments |
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Aragonite components
Mouldic pores
Anhydrite nodules
Dolomite

Chert
Heterozoan
Photozoan
7128/6-1: diagenetic features

- Aragonite components
- Mouldic pores
- Anhydrite nodules
- Dolomitised subtidal fusulinid grainstone with intercrystal and mouldic porosity. Gipsdalen Group 1964.75m FoV 5mm

Core plug porosity %

0  15  30
Porosity in photozoan carbonates

Gipsdalen Group, Ørn Fm

**Dolomitised cycle**
- Intergranular and mouldic pores in oncoid packstone enhanced by dolomitisation

**Partly dolomitised cycle**
- Clastic LST/TST – porosity reduced by compaction and calcite cement

**Internal and mouldic pores in Palaeoaplysina boundstone enhanced by dolomitisation**

**Intergranular and mouldic pores in subtidal packstone; minor calcite cement**
Dolomitisation: 7128/6-1

Fusulinid moulds in dolomitised matrix. Subtidal facies Gipsdalen Group 1973.75m

NB relatively early anhydrite nodules common throughout core replacing all depositional facies

Dolomitised bioclast packstone with mouldic pores, some with saddle dolomite Gipsdalen Group 2014.5m

Intercrystal pores in dolomitised bindstone. Cycle top peritidal facies Gipsdalen Group 2017.5m

Dolomitised fusulinid grainstone with intercrystal and mouldic porosity. Subtidal facies Gipsdalen Group 1964.75m
Photozoan carbonates: cyclicity

- Good preservation of depositional porosity
  - Minimal cementation or alteration at emergent surfaces
  - High Mg calcite and aragonite allochems – early mouldic pores
  - Intensive micritisation, inhibits early cementation
  - Subtidal to emergent HST part of cycles

- Emergent surfaces/cycle boundaries
  - Microcodium, fine sandstone, deepening events
  - No karst or superficial deposits
  - Cycles 5-25m thick

- Evaporitic dolomitisation
  - Minor plugging of porosity by evaporites

- Reservoirs
  - Layered – enhanced by dolomitisation
  - Matrix porosity
Porosity in heterozoan carbonates

Bjarmeland Group, Isbjørn Fm

1745m

Overgrowth cement on crinoids; Fracture-bridging cement preserve fracture porosity

1755m

Porosity reduced by overgrowths and compaction

1765m
Karst development at sequence boundaries

Karst surface and matrix FoV 5mm
Heterozoan carbonates

• Poor preservation of depositional porosity
  – Echinoderms are dominant allochem with rare micritisation – early overgrowth cementation
  – Rare aragonite allochems - poor potential for early mouldic pores
  – Rare depositional porosity associated with LST/TST sandstone
• Emergent surfaces/cycle boundaries
  – Karst and superficial deposits associated with varying orders of low stand
  – Cycles 50+m thick
• No associated evaporites
  – Or dolomite
• Reservoir types
  – Karst systems penetrating from sequence boundaries
  – Fracturing
Late Permian biogenic silica production

- Onset of global warming after glaciation
  - Acidification of ocean
  - Carbonate production replaced by biogenic silica
  - Eustasy changes to lower frequency/amplitude greenhouse cycles

Ramp model and sequence stratigraphic context based on Svalbard outcrop

Blomeier et al. (2013)

Ehrenberg et al. (1998 2001)
Biogenic silica production

• Initial bioclasts
  – Hollow spicules with walls of opaline silica
  – Highly metastable initial mineralogy
  – Various diagenetic pathways

• Now all quartz

Demosponge spicules 7128/6-1
1629.70m FoV 5mm

Demosponge spicules 7128/4-1
1576.12m FoV 5mm

Demosponge spicules 7128/4-1
1576.21m FoV 1.25mm
Porosity in the spiculite

Dissolved sponge spicules partly infilled by hydrocarbons 1930.75m FoV 5mm 7128/6-1

Margin of chert nodule in porous spiculite 1631.75m FoV 5mm 7128/6-1

Dissolution of prismatic bivalves in porous spiculite 1929.00m FoV 5mm 7128/6-1

Post-stylolite dissolution of brown carbonate matrix in porous spiculite 1634.50m FoV 5mm 7128/6-1
Porosity preservation in spiculite

- Original opal A and CT changes to chalcedony/quartz
  - Multiple events of silica dissolution and reprecipitation

- Openness of diagenetic system
  - Poorly winnowed argillaceous facies, quartz stays in system (poor permeability or complexed by clays) resulting in local cementation
  - Clean winnowed facies, open diagenetic system quartz lost to pore fluid and no cementation

- Pore system comprises micro- very small mesopores
  - Need fracturing (compactive) or dissolution to improve permeability

Images from 7128/4-1

In situ sponge

centimetres
Conclusions

- Reservoir quality can be better understood in the context of late Palaeozoic global events that influenced carbonate and siliceous sedimentary and diagenetic systems
  - Initial mineralogy of carbonate grains: potential for early dissolution and cementation
  - Palaeoclimatic conditions: availability of meteoric water and susceptibility to dolomitisation
  - Nature of eustasy (glacio-eustatic vs. greenhouse): Duration and amplitude of exposure during low stands
- Different carbonate and siliceous systems will have different reservoir types
- Go some way to risking reservoir properties in carbonates and siliceous facies
Acknowledgments

• Thanks to Lundin Norway and PL 492 partner Aker BP
• Sarah Thompson for the microfacies analysis