G E U S

GEOTHERM

Reservoir egenskaber

Diagenese og geokemisk modellering

De Nationale Geologiske Undersøgelser for Danmark og Grønland
Energi-, Forsynings- og Klimaministeriet

I samarbejde med BRGM, LU, GFZ

Thisted Varmeforsyning, Sønderborg Fjernvarme, HOFOR Fjernvarme

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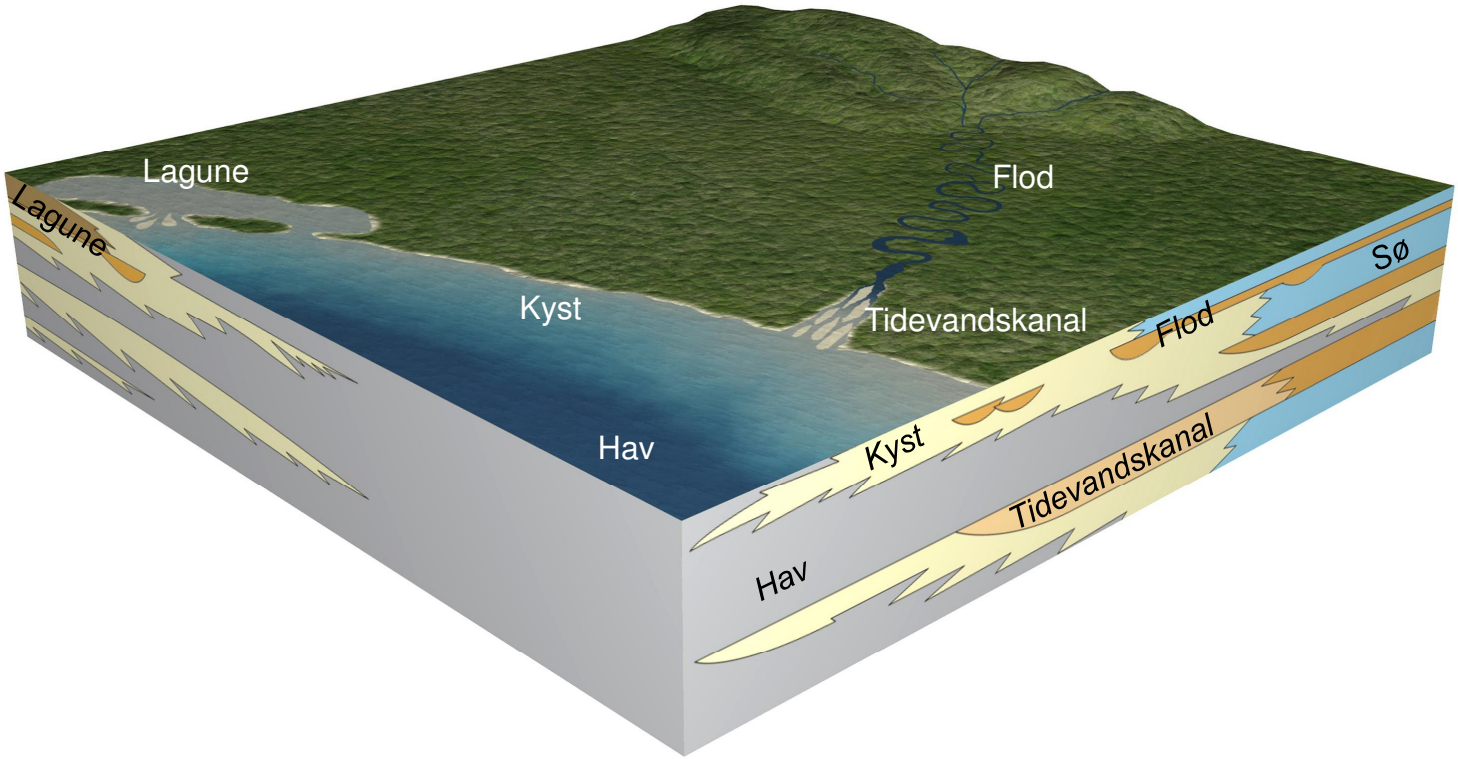
Geotermisk reservoir

- Hvordan dannes et geotermisk reservoir?
  - Sand aflejres f.eks. ved kysten
  - Aflejringsmiljøet er afgørende for sandets egenskaber
  - Sandet begraves fordi andre sand- og lerlag aflejres ovenpå
  - Temperaturen stiger ved begravelsen (→ varmt vand)
  - Imellem sandkornene afsættes cement
  - Cement-type og mængde har stor betydning for sandstens kvalitet som geotermisk reservoir



Aflejringsmiljøet beskriver de fysiske, kemiske og biologiske processer, der er aktive i forbindelse med aflejringen af sedimentet

Aflejringsmiljøet har indflydelse på:

- Lateral udbredelse og tykkelse
- Kornstørrelse og lerindhold
- Mineralogi (herunder fossil fragmenter)

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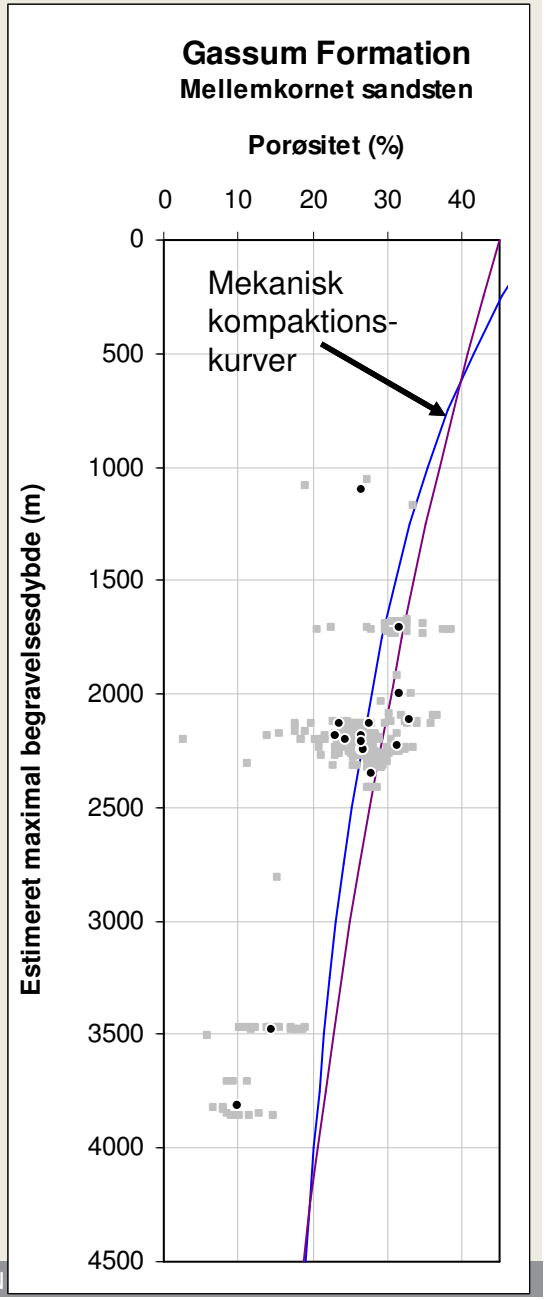
Reservoir egenskaber

- Reservoir egenskaberne påvirkes af:
  - Aflejringsmiljø
    - Lateral udbredelse of tykkelse
    - Kornstørrelsen og indhold af ler
    - Mineralogisk sammensætning
  - Ændringer i forbindelse med forøget begravelsesdybde
    - Mekanisk kompaktion
    - Mineralogiske ændringer
- Geotermiske reservoirers egenskaber kan beskrives ved:
  - Udbredelse og tykkelse af sandstenslag
  - Porøsitet (evne til at rumme vand)
  - Permeabilitet (evne til at transportere vand)



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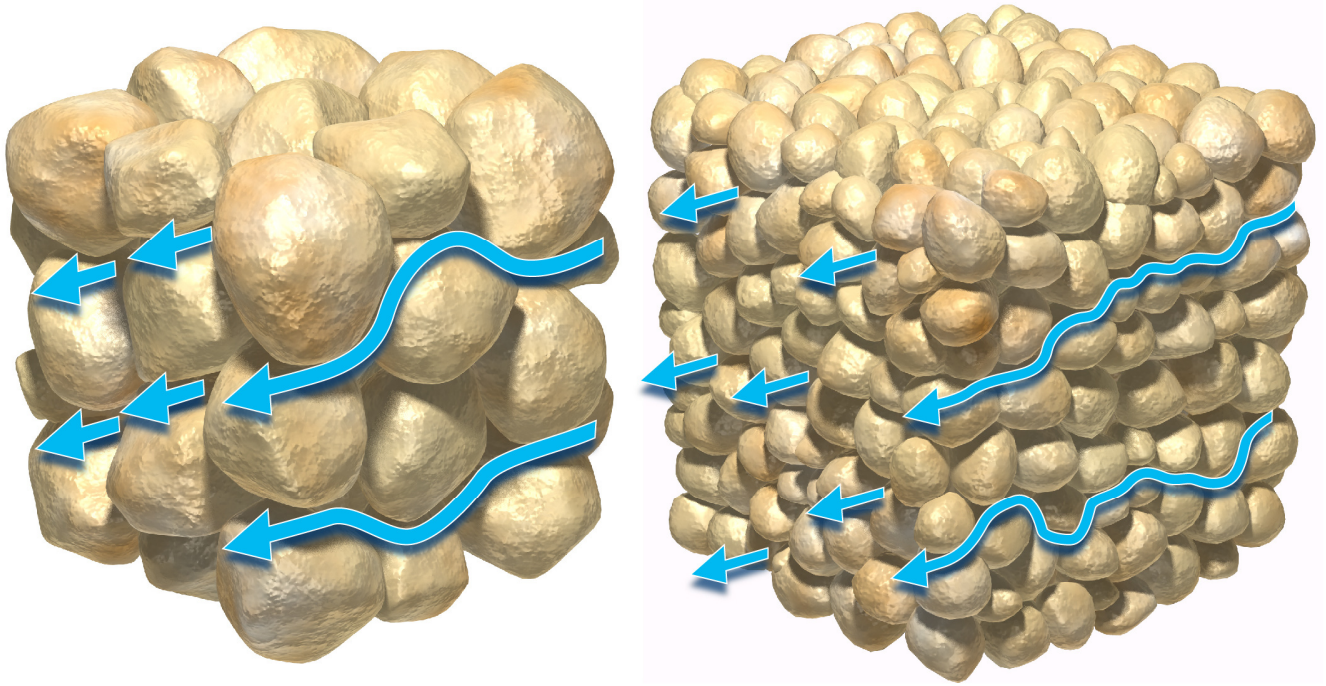
Reservoir kvalitet er påvirket af kornstørrelse

Groft sand:

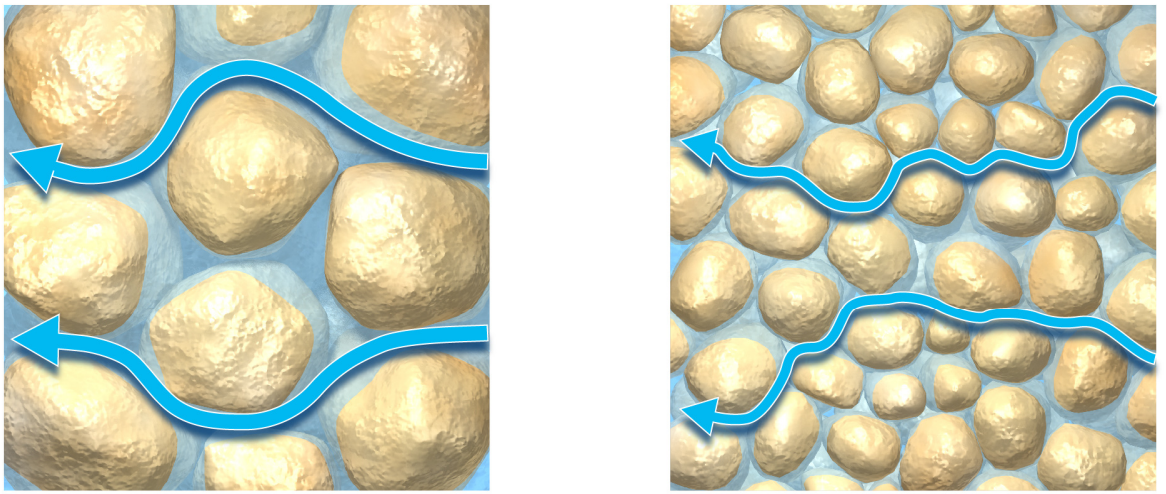
Højeste porøsitet og højeste permeabilitet

Fint sand:

Høj porøsitet og medium permeabilitet



3D



2D

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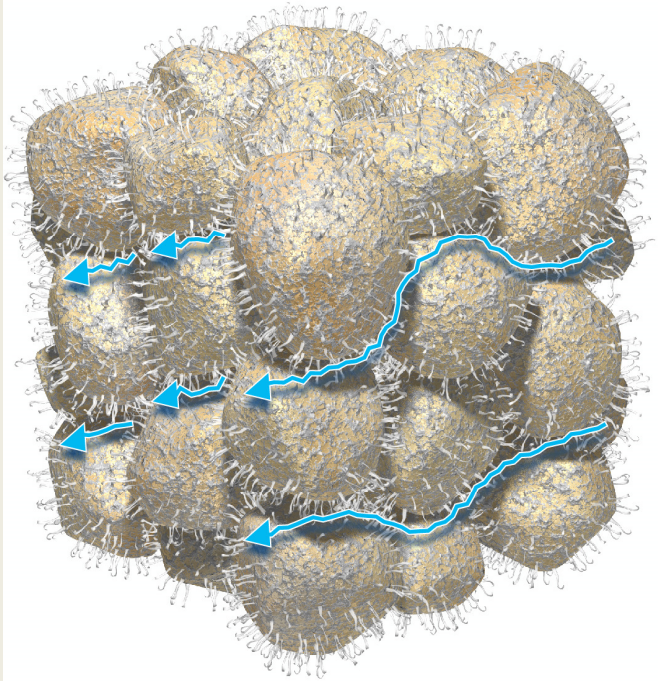
Reservoir kvalitet er påvirket af dybdemæssige mineralogiske ændringer

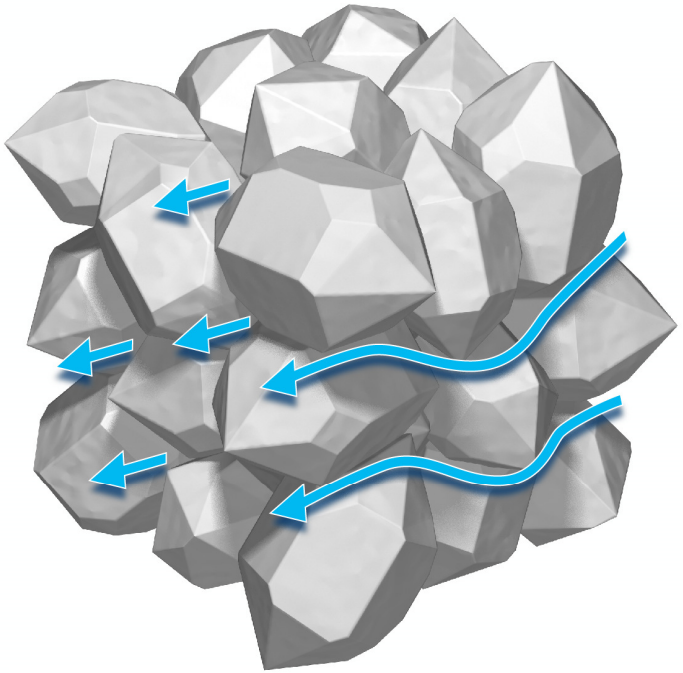
Kvarts cement

Nogen porøsitets og permeabilitets reduktion

Illit cement

Lav porøsitets og høj permeabilitets reduktion





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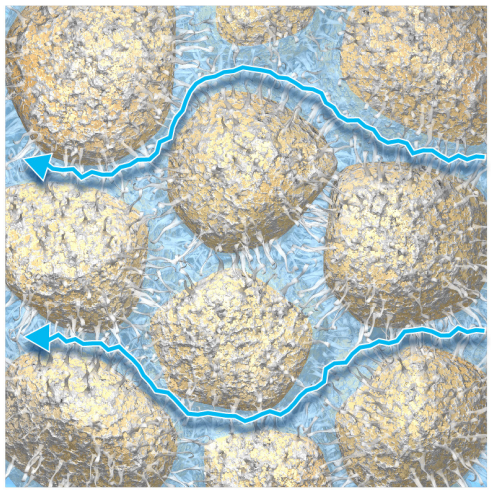

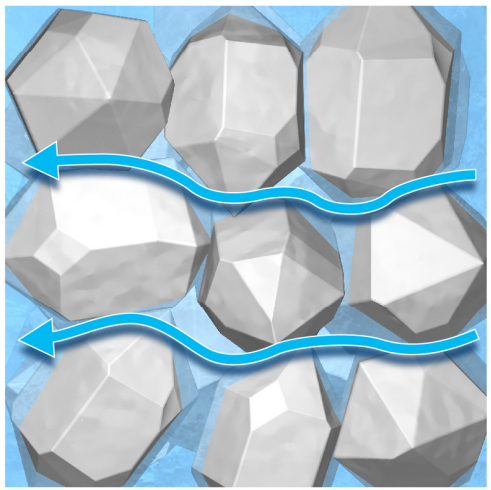

2D

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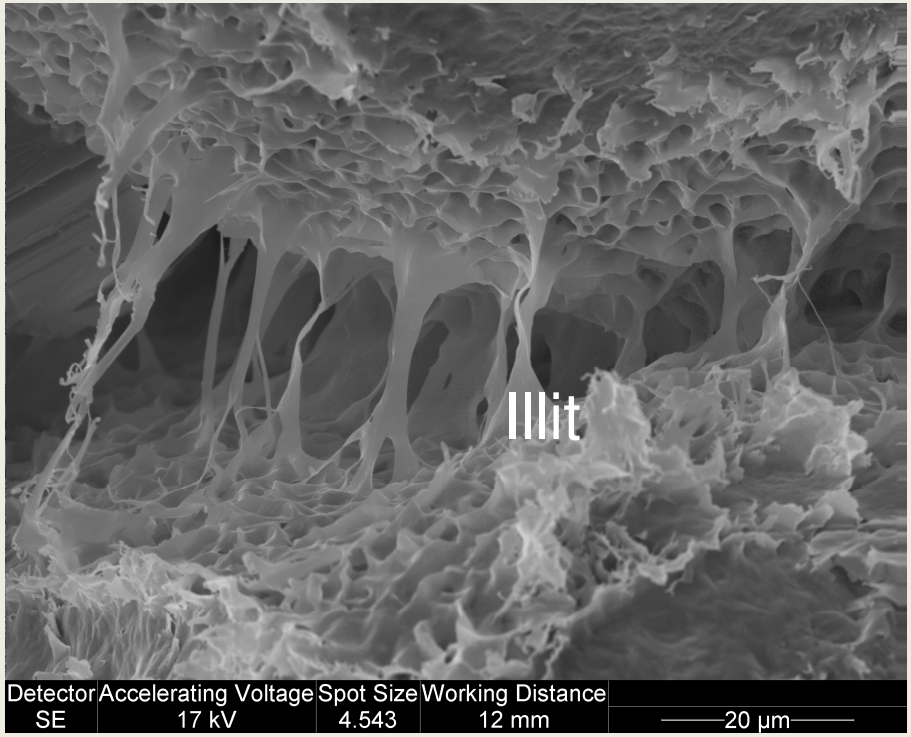
Reservoir kvalitet

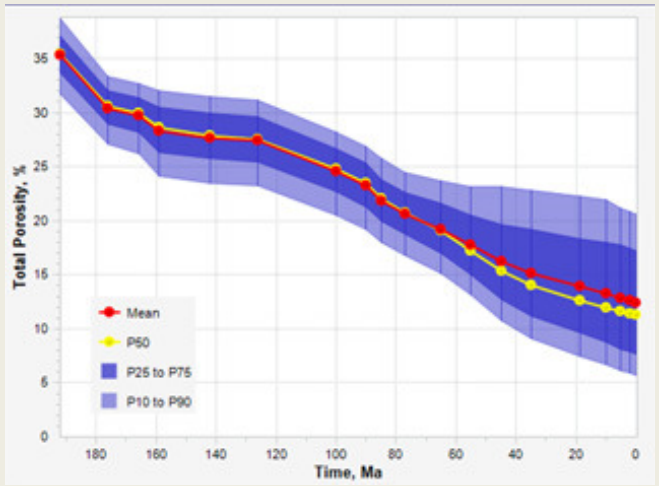


Skanning elektron mikroskopi (SEM)

Anvendes til undersøgelser af cement-typer og mængder

Diagenese modellering

- Formål:
  - Forudsigelse af reservoir egenskaber under hensynstagen til eksisternde kendskab til aflejringsmiljø, begravelsedybde, kornstørrelse, mineralogi, petrografi og fluid sammmensætning
  - Mere præcis prediction af maksimal begravelsesdybde kan øge antallet af brugbare reservoirer
  - Hurtigt kalibrering af model efterhånden som nye data kommer til
- Software: Touchstone
- Input:
  - Mineral sammensætning (opdelt efter korn, cement, korn-replacerende cement, porøsitet)
  - Kontinuitet af kornbelægninger
  - Kornstørrelse
  - Porøsitet og gas-permeabilitet ved stue temperatur
  - Porøsitet og permeabilitet ved reservoir tryk
  - Temperatur indikatorer



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Geothermal Energy

RESEARCH Open Access

Pre-drilling assessments of average porosity and permeability in the geothermal reservoirs of the Danish area

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Diagenetic effects on porosity–permeability relationships in red beds of the Lower Triassic Bunter Sandstone Formation in the North German Basin

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Porosity
Permeability

ABSTRACT

Carbonate and anhydrite cement, clay clasts and i
voir quality in the studied Bunter Sandstone Form
ability are determined by combining petrograph
samples from the Danish part of the North Germa
they largely control the distribution of cements, c
ronments is defined by the position in the basin a
tion of depositional environments is related b
promoted aeolian deposition.
The Bunter Sandstone Formation has high poros
northern North German Basin. The reservoir qual
fined bodies that leave the remaining pore spaces
cementation hinder virtually all flow through the
rosity and permeability of 20.3% and 810 mD, res
sandstones, excluding the unconsolidated ae
permeability.
The aeolian sandstones of the Volpriehausen Me
ness of about 25 m, are laterally continuous, are
sandstones of the Solling Member consist mainly
ervoir quality. However, some intervals have high
drite or halite cement and these components redu
ephemeral fluvial sandstones is variable and ther
tion well. Thus, the Volpriehausen Member is the

1. Introduction

Factors controlling porosity–permeability relationships in sandstones are readily studied in continental facies deposited under arid conditions. The diagenetic alterations are limited to a few major phases so the relative effects of the individual cement types and clay types on

controlled by
Sandstone Form
ern North Germ
thus representi
reservoir qualit
Iron oxide coat

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Predicting permeability of low-enthalpy geothermal reservoirs: A case study from the Upper Triassic – Lower Jurassic Gassum Formation, Norwegian–Danish Basin

Rikke Weibel [a,*], Mette Olivarius [a,b], Lars Kristensen [a], Henrik Friis [b], Morten Leth Hjuler [a], Claus Kjøller [a], Anders Mathiesen [a], Lars Henrik Nielsen [a]

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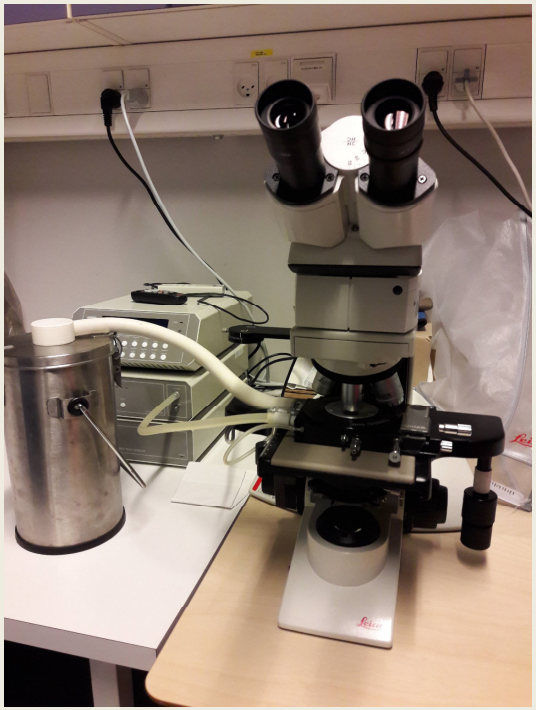
ABSTRACT

This paper aims at improving the predictability of permeability in low enthalpy geothermal reservoirs by investigating the effect of diagenesis on sandstone permeability. Applying the best fitted porosity–permeability trend lines, obtained from conventional core analysis, to log-interpreted porosity, is crucial in estimating reservoir permeability from logs. Petrographical analysis of sandstones from the Gassum Formation reveals lithological and diagenetic controls on plug permeability and porosity. Porosity–permeability trend lines vary with grain size for the shallowly buried sandstones (<2500 m). Deeply buried sandstones (>2500 m) from a steeply sloping porosity–permeability trend line since the

Temperatur indikatorer

- Formål
  - Bestemmelse af temperature fixpunkter til den diagenetiske modeling
  - Bestemme maksimal begravelsesdybde, hvorved flere potentielle reservoirer muligvis kan identificeres
- Metode
  - Fluid inklusionsanalyse af kvarts cement
  - Oxygenisotop-sammensætning af karbonat cement
  - Vitref (vitrinit reflektans) af organisk materiale



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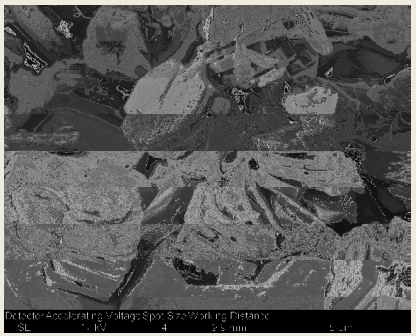
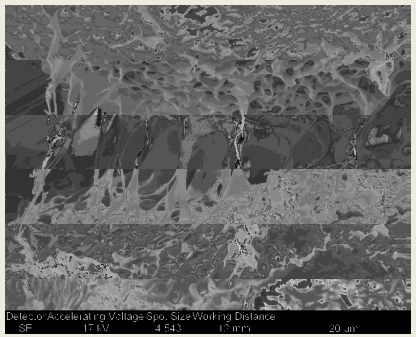
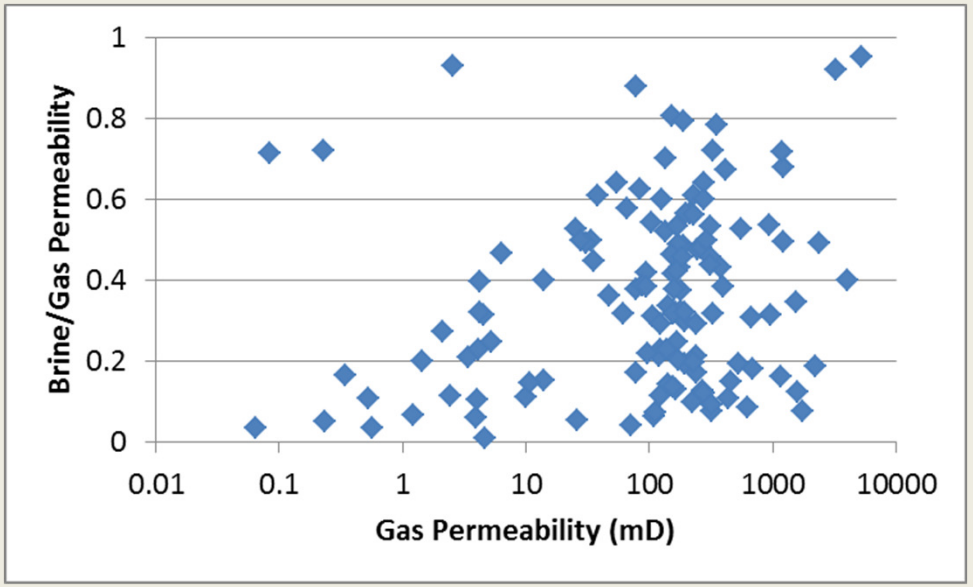
Gas- og væske-permeabilitet

- Formål
  - Forbedret forståelse af relationen mellem gas-permeabilitet og væske-peremabilitet
  - Nødvendig for opskalering af laboratorianalyser (gas-permeabilitet) til reservoir skala (strømningshastigheder)

- Prøveudvælgelse
  - Samme kornstørrelse
  - Forskellige mængde af ler
  - Forskellige typer af ler







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Geokemisk modellering

- Formål:
  - Bestemmelse af minerals faser, som forventes at kunne udfældes ved afkløling eller afgasning af formationsvandet
  - Bedre forståelse af scaling problemernes opståen for at kunne forebygge det i fremtiden
- Software: PHREEQ C
- Input:
  - Kemisk sammensætning af formationsvand fra geotermiske værker
  - Sammenligning med sandstenens mineralogiske sammensætning
  - Sammenligning med observationer fra andre geotermiske anlæg

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Konklusion

- Diagenese modellering
  - Prædiktion af reservoir egenskaberne ud fra kendskab til aflejringsmiljø, begravelsedybde, kornstørrelse, mineralogi, petrografi og fluid sammmensætning
  - Hurtig kalibrering af model ved input af nye data
  - Kendskab til præcis maksimal begravelsesdybde kan bringe flere marginale reservoirer i spil
- Geokemisk modellering
  - Bidrager med viden om mineral faser, der kan risikere at udfælde i det geotermiske anlæg eller boringerne
  - Sammenligning af det mineralogiske udgangsmateriale med formationsvandssammensætningen