Role of Rock Mechanical Properties in Subsidence above Producing Gas Fields in the Wadden Sea Region

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Long-term Subsidence Study in the Wadden Sea Region
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Overview of Wadden Subsidence Problem

The key issue is to predict the subsidence that will occur above the producing gas fields in the Wadden Region

Current modelling efforts, using rock properties measured in the laboratory, have not been able to match the measured subsidence rates

Rock mechanical property data, which can only be obtained from laboratory measurements on cores, will be crucial for future subsidence modelling efforts

Therefore, rock mechanics tests performed in the next two years must be carefully designed and conducted, so as to yield meaningful and useful rock property data

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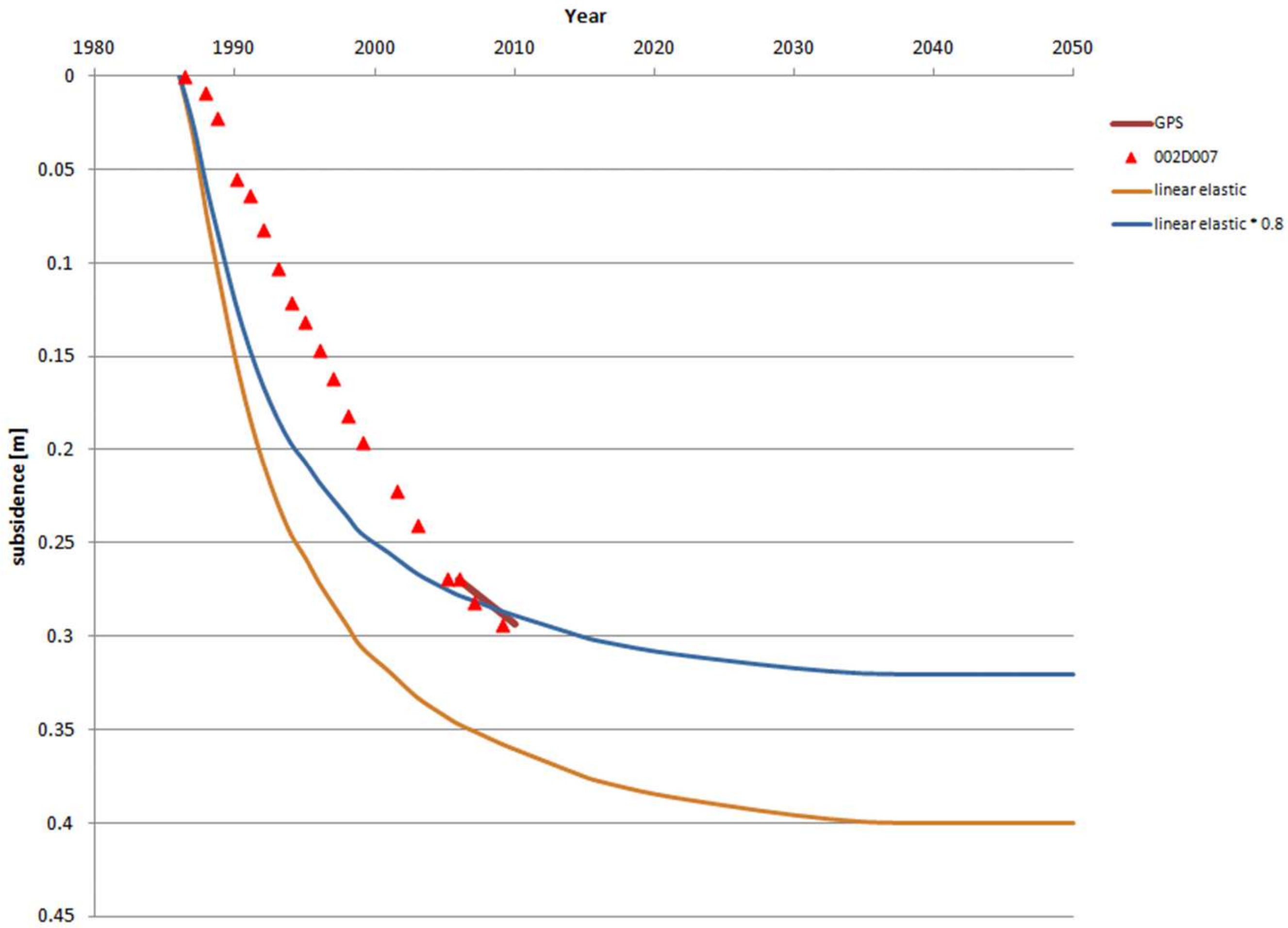
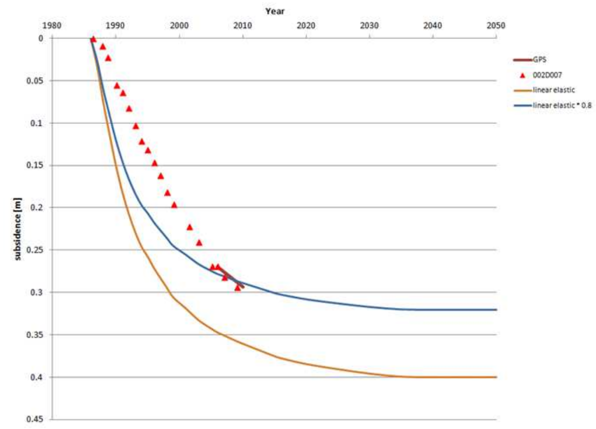
Mismatch between Predictions and Measurements



Subsidence Delay?

A recurring theme in the discussion has been the supposed existence of a “subsidence delay”, in which surface subsidence lags behind reservoir compaction

The comparison shown in graph on right shows no lag or delay, in my opinion – merely a mismatch between the predicted and observed rates



The key paper on this subject, “Subsidence Delay: Field Observations and Analysis”, M. Hettema, E. Papamichos, and P. Schutjens, *IFP Review*, 2002, also does not, in my opinion, show a subsidence *delay*.

The simplest interpretation of the data they show, from eight different fields, is that the rate of subsidence can increase dramatically if the drawdown is sufficiently large as to cause the rock to compact inelastically.

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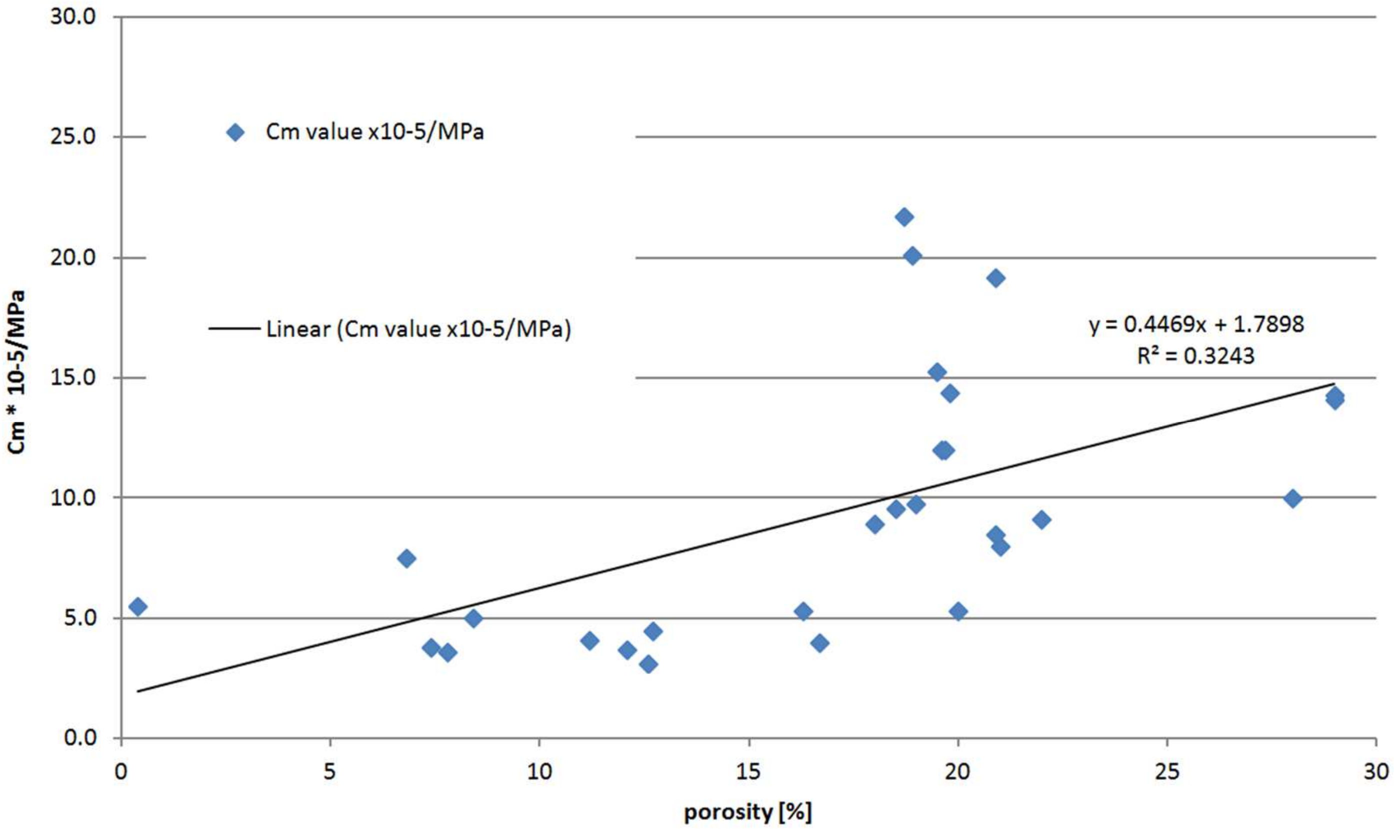
Compressibility vs Porosity



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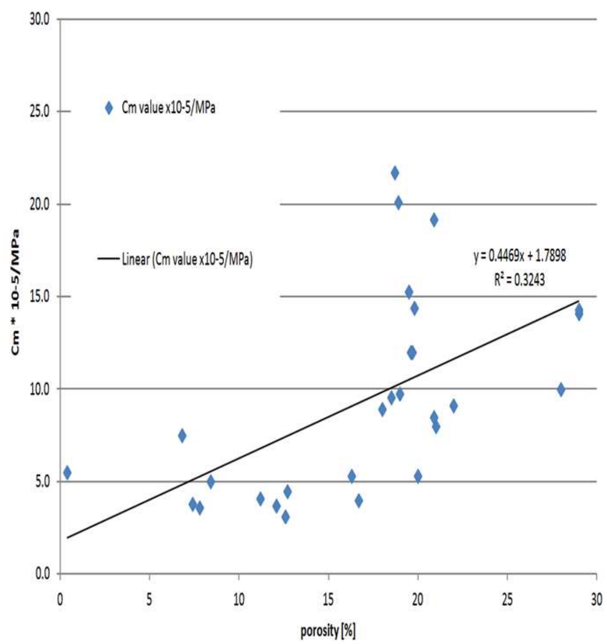
Compressibility-Porosity Correlation

• Correlation is very poor, with errors sometimes greater than a factor of 2

• The least-squares best-fit line is skewed upwards by three outlier (?) data points near $\phi = 0.2$

• Eighteen (69%) of the data lie below the fitting line, whereas only 8 (31%) lie above

• Compressibility of sandstones is typically stress-dependent, but this stress dependence is not reflected in the data or the curve fit



• Perhaps a Monte Carlo method can be used to generate stochastic compressibility distributions in the reservoir

Candidate Hypotheses (after Mossop, April 2013)

1. Artifact of geodetic data

   Obviously, accurate geodetic data is required

2. Artifact of geodetic data sparsity and salt flow

   Can simple calculations reveal whether or not salt flow is capable of somehow limiting the surface subsidence?

3. Inaccurate reservoir/aquifer modelling

   Perhaps a comparison between analytical and FEM models give some insight into this possibility

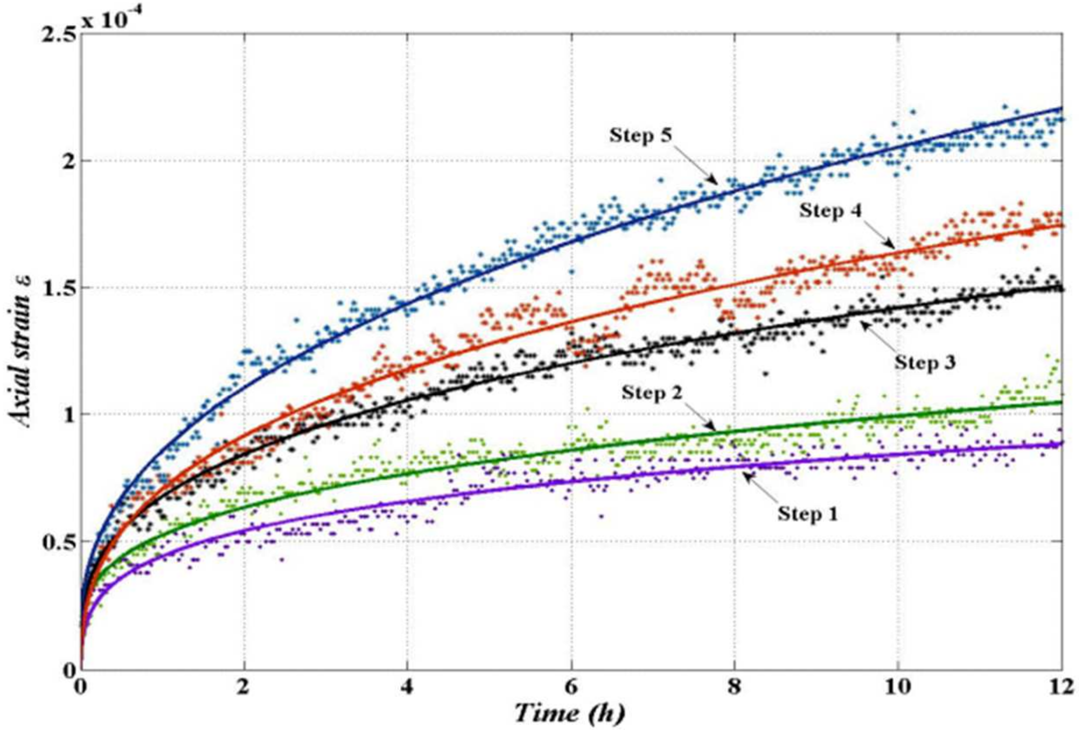
4. Visco-plastic compaction of solid component

   Accurate laboratory determination of rock mechanical properties is required

5. Pressure diffusion where permeability has a 'long tail' statistical distribution

   Not clear how this can be the case in a sandstone reservoir; this hypothesis answers a question that may not exist (i.e., "delay")

Visco-plastic compaction of solid component



A visco-plastic (time dependent) volume strain process within the solid grain structure of the rock – creep at grain contacts, damage, *etc*.

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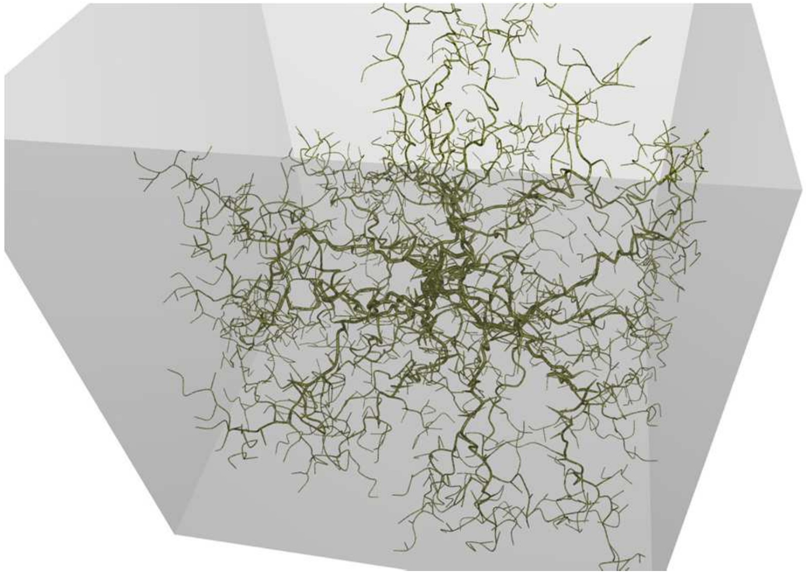
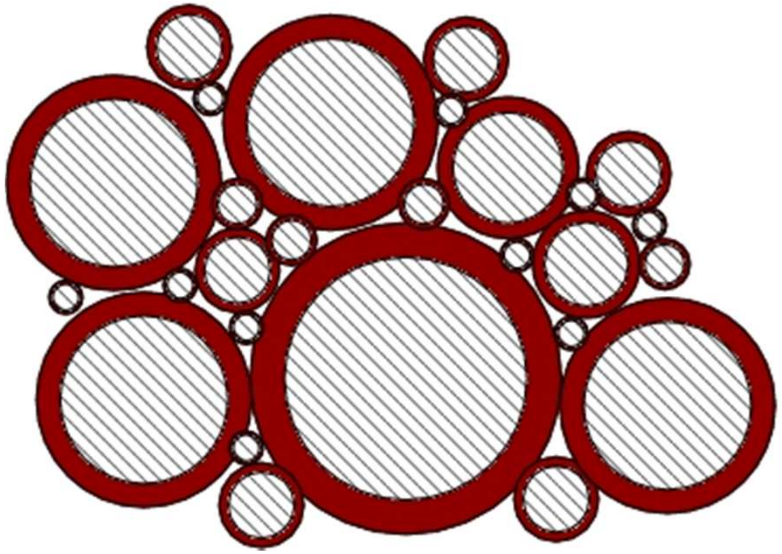
Pressure diffusion where permeability has 'long tail' statistical distribution





A 'long-tailed' permeability distribution (commonly observed), produces a complex dendritic drainage pattern which would be consistent with a seemingly high connection permeability but low poroelastic compaction permeability.

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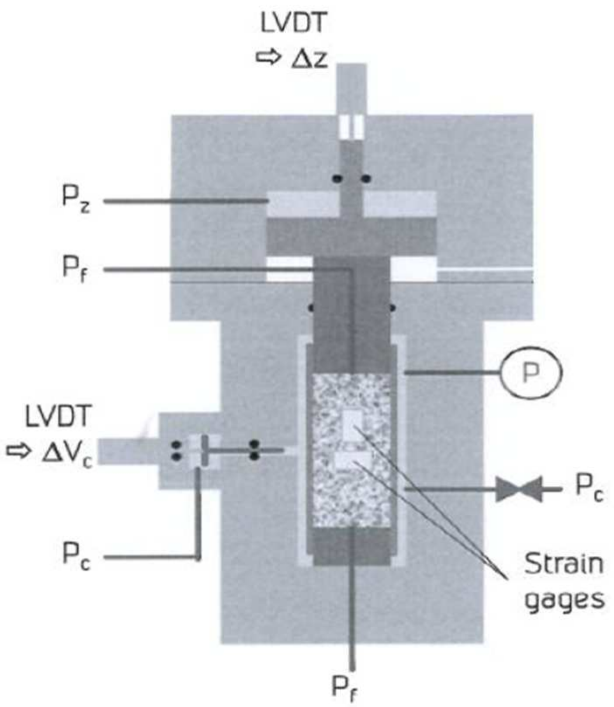
Long-Term Compaction Tests



The first tests will be executed using a non-aqueous pore fluid (hexane is the tentative candidate).

Pressure, stress and temperature taken to in-situ conditions (~3 days)

Pore fluid pressure reduced to depleted conditions with five equally space pore pressure reversals of 5 MPa (~4 days)

Hold conditions (~75 days)

The same test program will then be repeated using sibling samples and aqueous brine

Enhanced Experimentation Set-up

Enhanced experimentation setup:

- Enhanced experimentation setup consisting of 4 cells
- Pressure supply for the four cells is applied by one axial pump, one radial pump and pore pressure pump
- Stresses and pore pressure up to 25 MPa.
- Room temperature.
- Sample size 20 mm in length and 10 mm in diameter
- No radial displacement measurement so no uniaxial control mode.
- EE setup to be used for trends in pore fluid influence on compaction behaviour.

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Suggestions for Compressibility Tests

- Uniaxial strain depletion tests should be conducted with radial strain control
- Stresses should reproduce the assumed reservoir stress conditions
- Cm and Poisson's ratio should be computed as a function of pore pressure
- Brine should be used as pore fluid (and a non-aq fluid in at least one case)
- Tests should be run at room temperature and at reservoir temperature
- Not clear why stress reversal cycles are needed (?)
- Hydrostatic compression tests should be conducted as a consistency check
- Traditional triaxial stress tests should be conducted to failure
- Some tests should be conducted on horizontal core plugs to test for anisotropy

Suggestions for Creep Tests

- In uniaxial strain mode, deplete the pore pressure, starting from the initial reservoir pressure, by, say, 10 MPa

- Hold pore pressure, axial stress, and radial strain constant, while monitoring the axial strain

- A few hours should suffice to determine whether or not the rock is undergoing creep

- Long-term creep tests are probably not necessary; either:

  rock is not creeping at a given level of drawdown

  a few hours of data should suffice to fit a function to creep data

- Perhaps one long-term creep test can be done to verify this latter assertion