Solids production

ROSE

Rock Physics and Geomechanics

Course 2012

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When hydrocarbons are produced from a reservoir, solid particles sometimes follow the reservoir fluid into the well. This unintended byproduct of the hydrocarbon production is called *solids production*.

Solids production occurs not only in sand

- but sand has attracted most attention so far

Consequences of solids production

1. Erosion of the production equipment,
   leading to malfunctions and leakages.
   A safety problem!

2. Instability of the production cavities and the well;
   may result in complete filling of the hole so that the well has to be abandoned.
   An economical problem!

3. The necessity to handle large amounts of polluted solids.
   An environmental problem!

The problem may also occur in other reservoirs

- chalk

- coal

-…

Up until 1960, nobody really cared –

- then some serious accidents could be linked to sand production

- as a result, sand production was avoided at any cost.

During the 1980ies:
-Sand control equipment shall be installed only when necessary

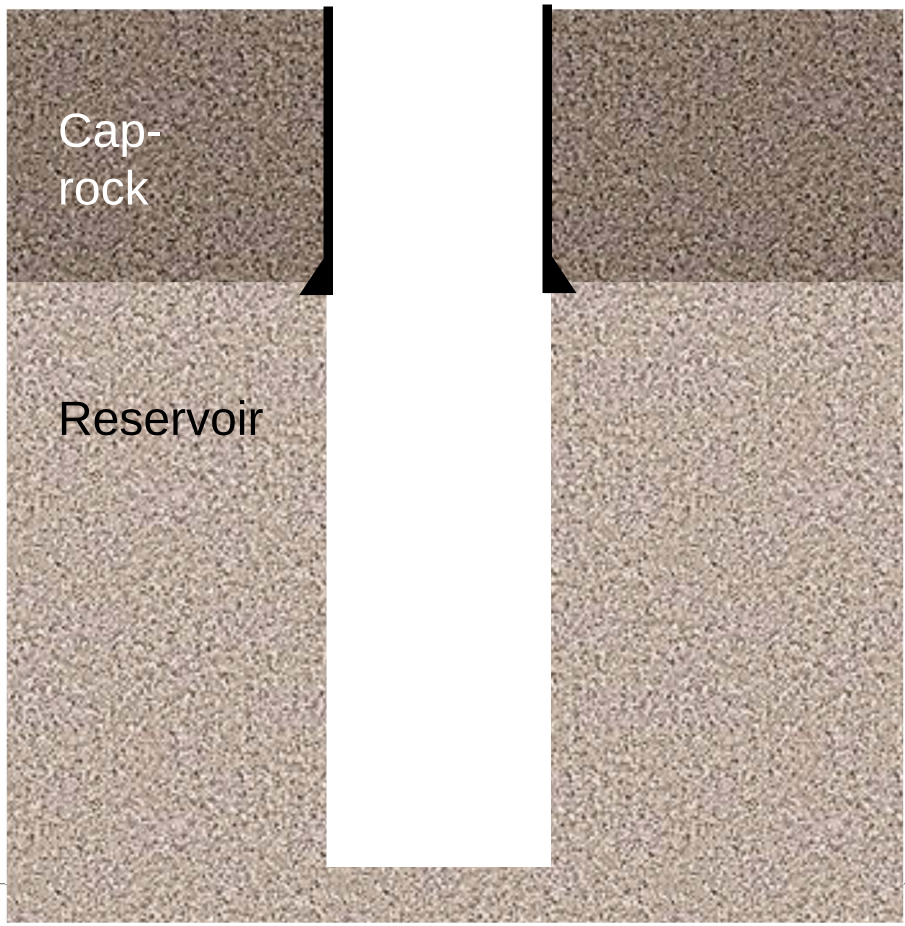
Challenge: *When is sand control necessary?*

For the last 10-15 years:
-Sand management (some sand is acceptable)

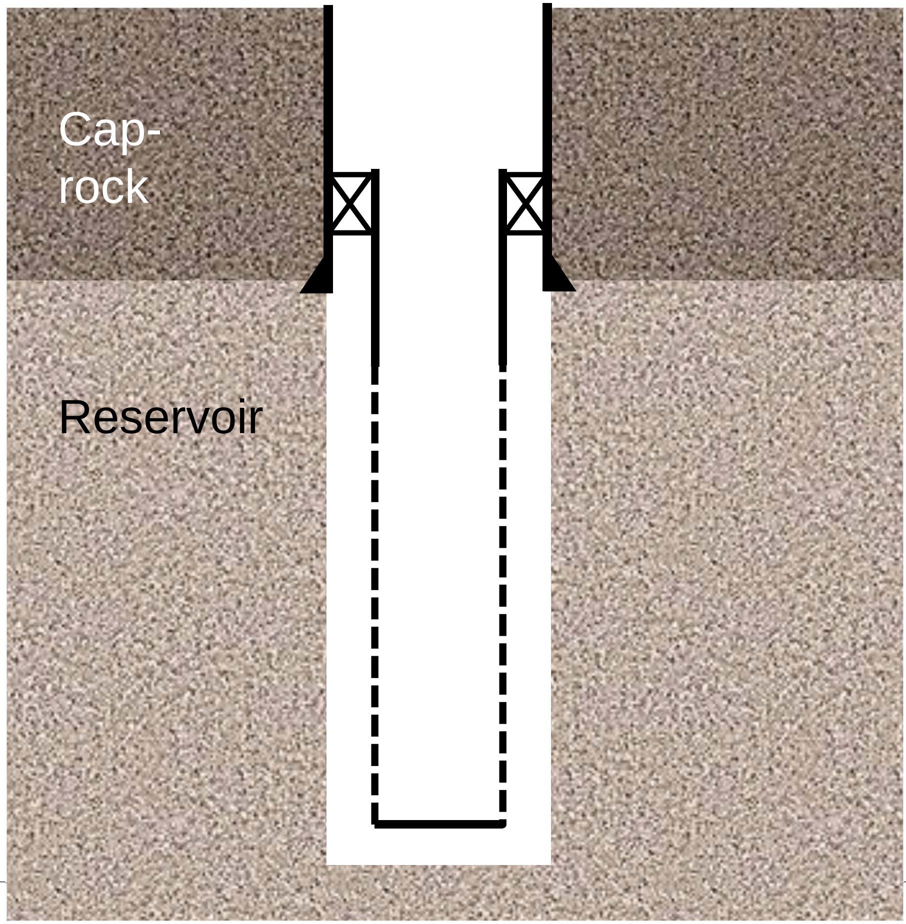
Challenge: *How much sand is going to be produced?*

Well completion and solids control

In relatively strong and stable formations, the hole may be left open



In relatively strong and stable formations,
the hole may be left <u>open</u>

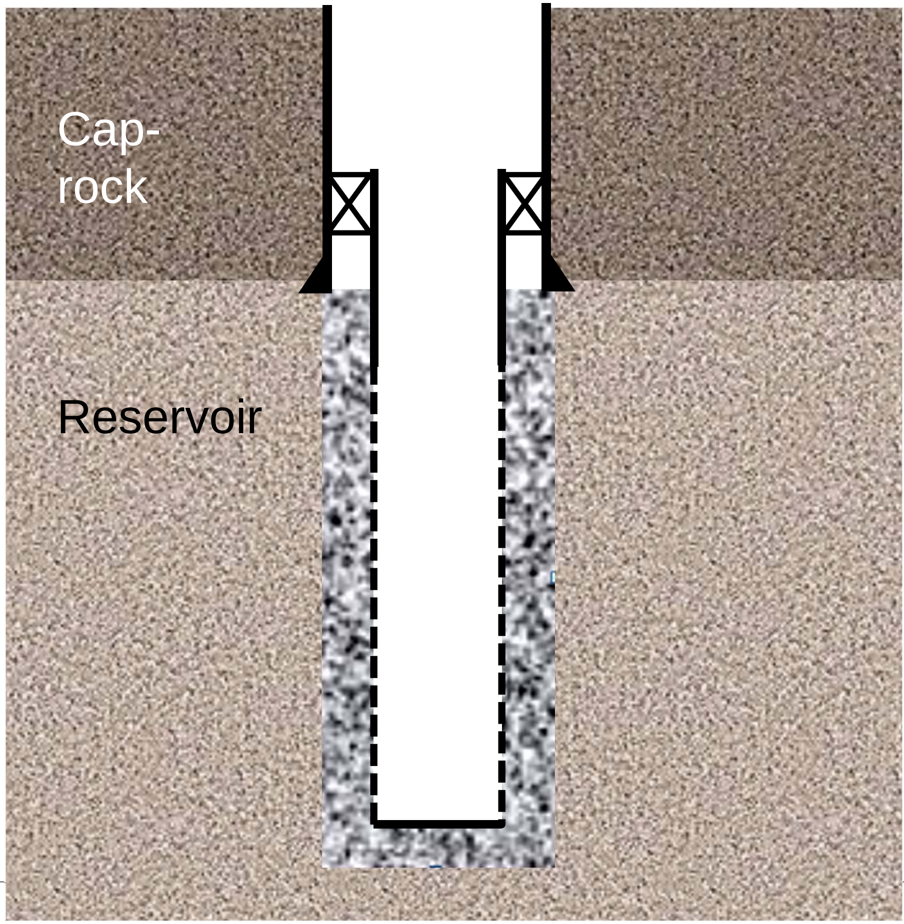


Sand control:
Slotted liner (or screen)

The slotted liner acts as a filter preventing sand grains from entering the well.

Problems:
- Clogging of the slots
- Erosion of the slots
- Formation failure
  → collapse of the liner

In relatively strong and stable formations,
the hole may be left open

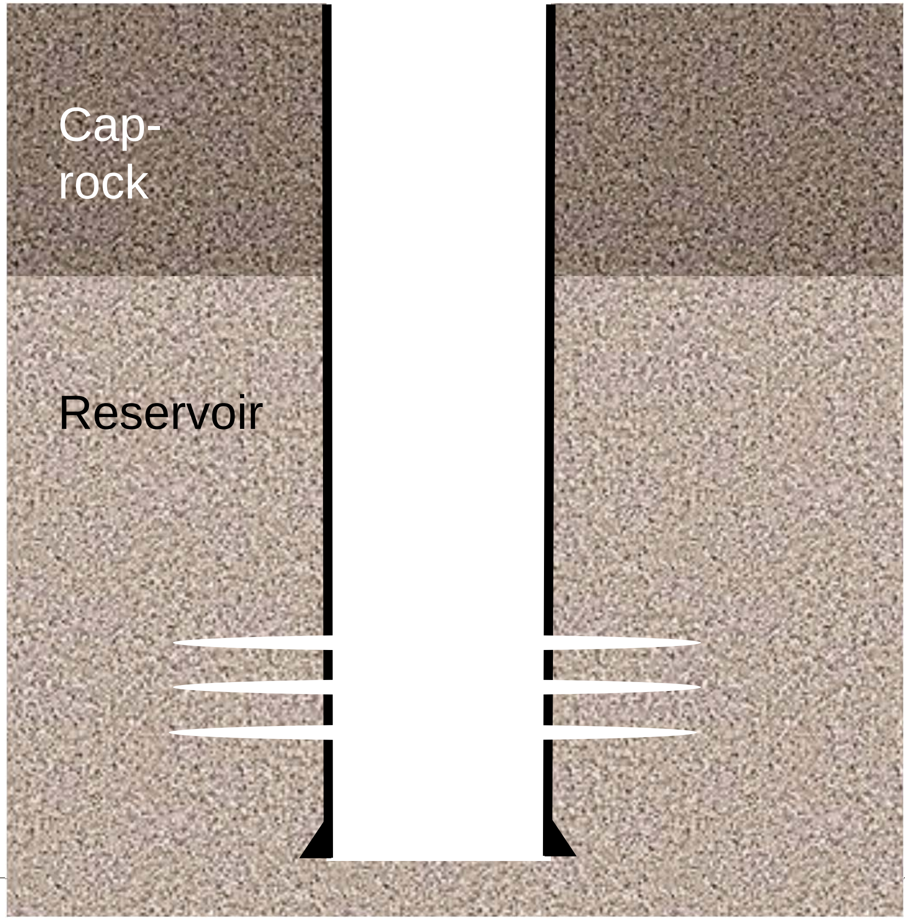


Sand control:
Gravel behind slotted liner (or screen)

The gravel provides some support for the borehole wall, and acts as a filter preventing sand grains from entering the well.

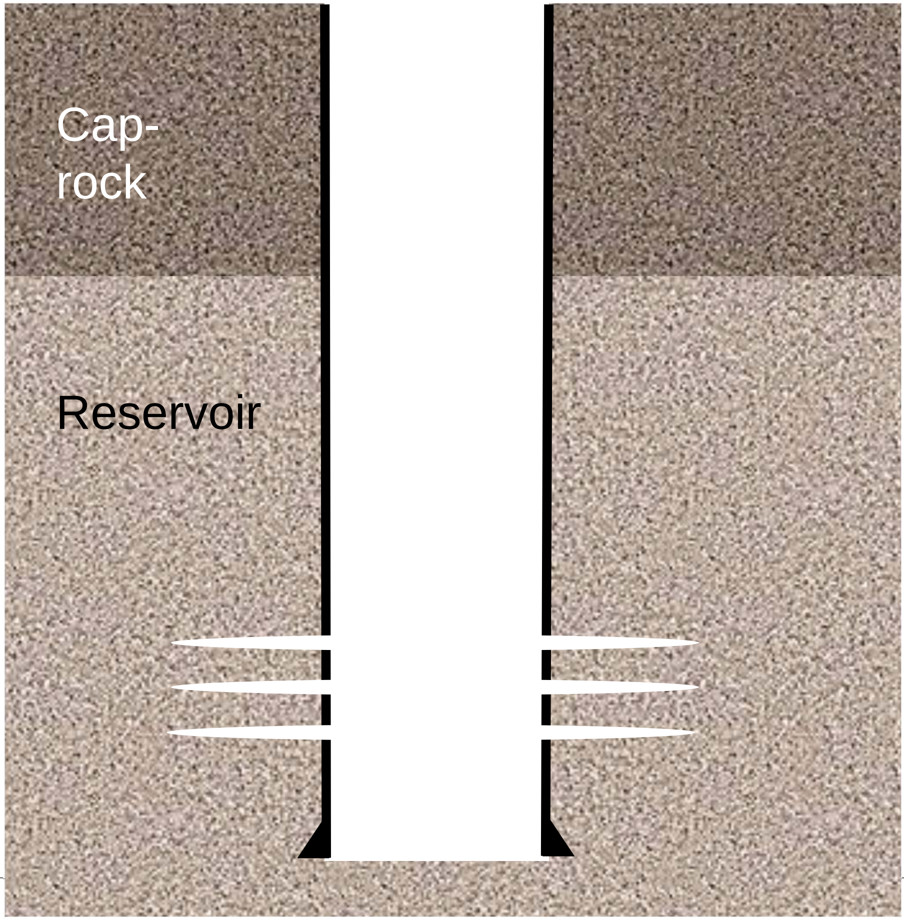
Problems:
-Reduced productivity
-Clogging

In weak formations, the hole is cased and perforated



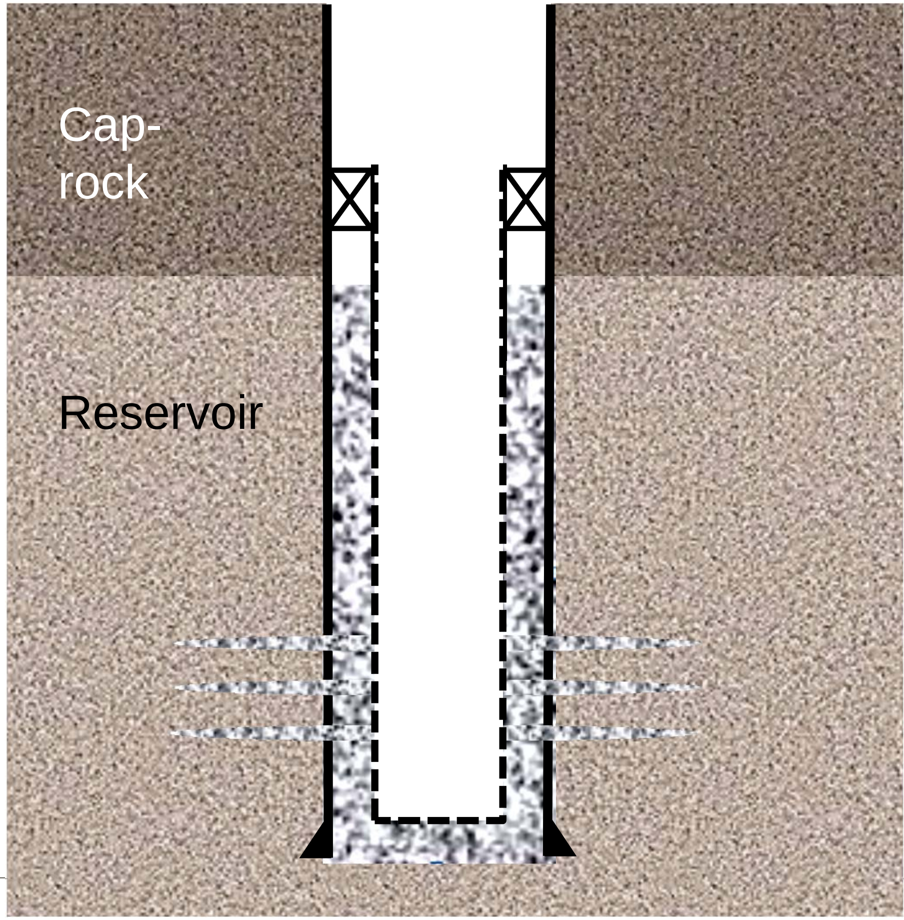
Perforations are typically cylindrical holes, 1-2 cm in diameter, 20-50 cm long. Typical perforation density: 10-40 per m.

In weak formations, the hole is <u>cased and perforated</u>



Sand control:
Small holes are more stable than large ones, hence a cased and perforated well may be more stable than an open hole.

In weak formations, the hole is <u>cased and perforated</u>

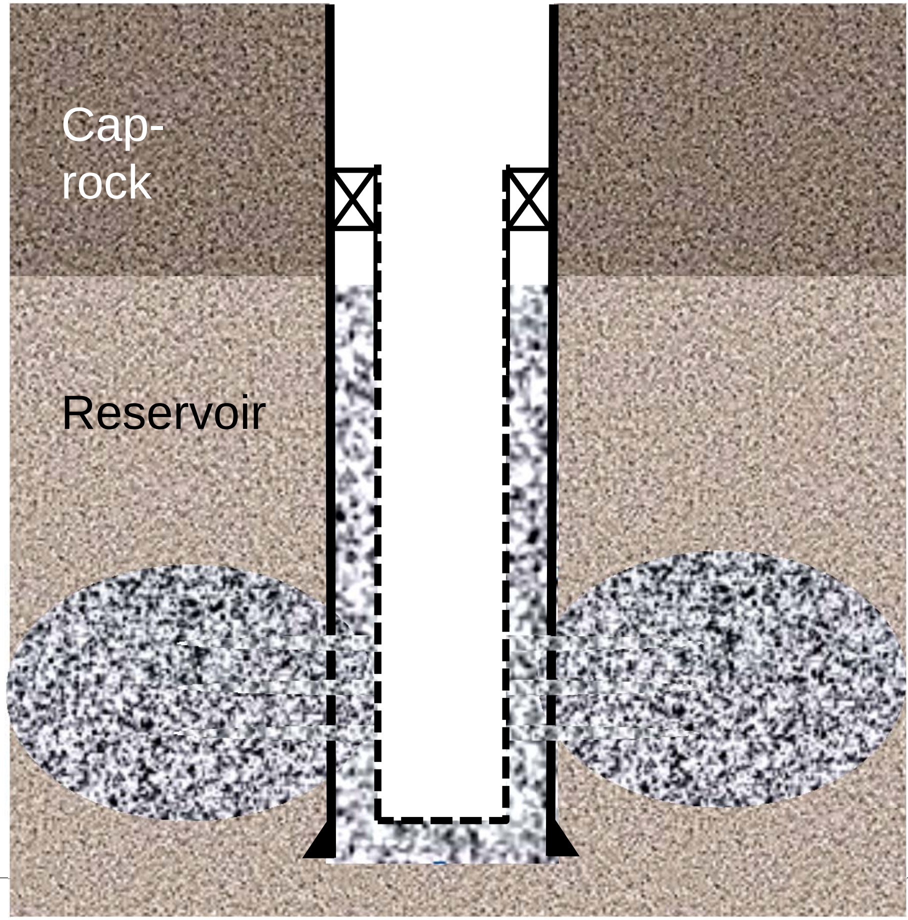


Sand control:
Gravel behind slotted liner
(or screen)

The gravel may provide some support for the perforations, and acts as a filter preventing sand grains from entering the well.

Problems:
-Reduced productivity
-Clogging

In weak formations, the hole is <u>cased and perforated</u>



Sand control: Frac and pack

As a part of the gravel pack operation, a hydraulic fracture is created.

May lead to improved productivity (negative skin) due to increased inflow area.

Problems:
-Containing fractures is always difficult

Active sand control is

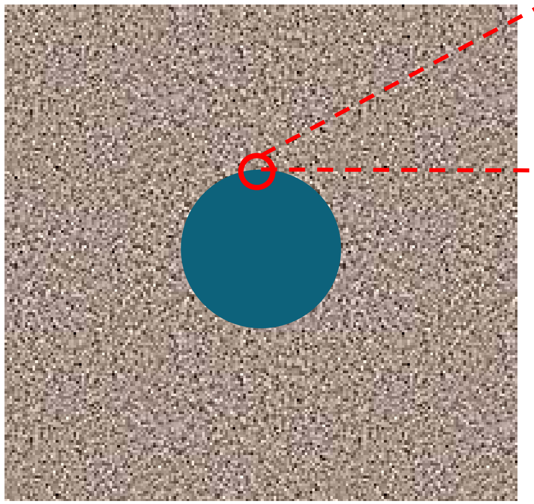
-expensive

-reduces productivity

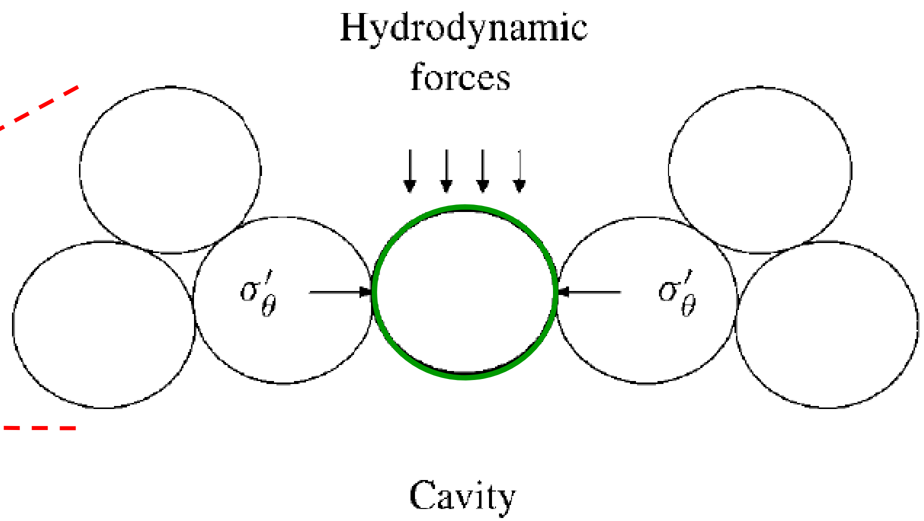
-needs maintenance

⇒It is preferable to avoid active sand control, if possible

Sand production



Consider a sand grain at
the wall of a producing cavity



The hydrodynamic forces are orders of magnitude too small – they are not able to destroy competent rock on their own.

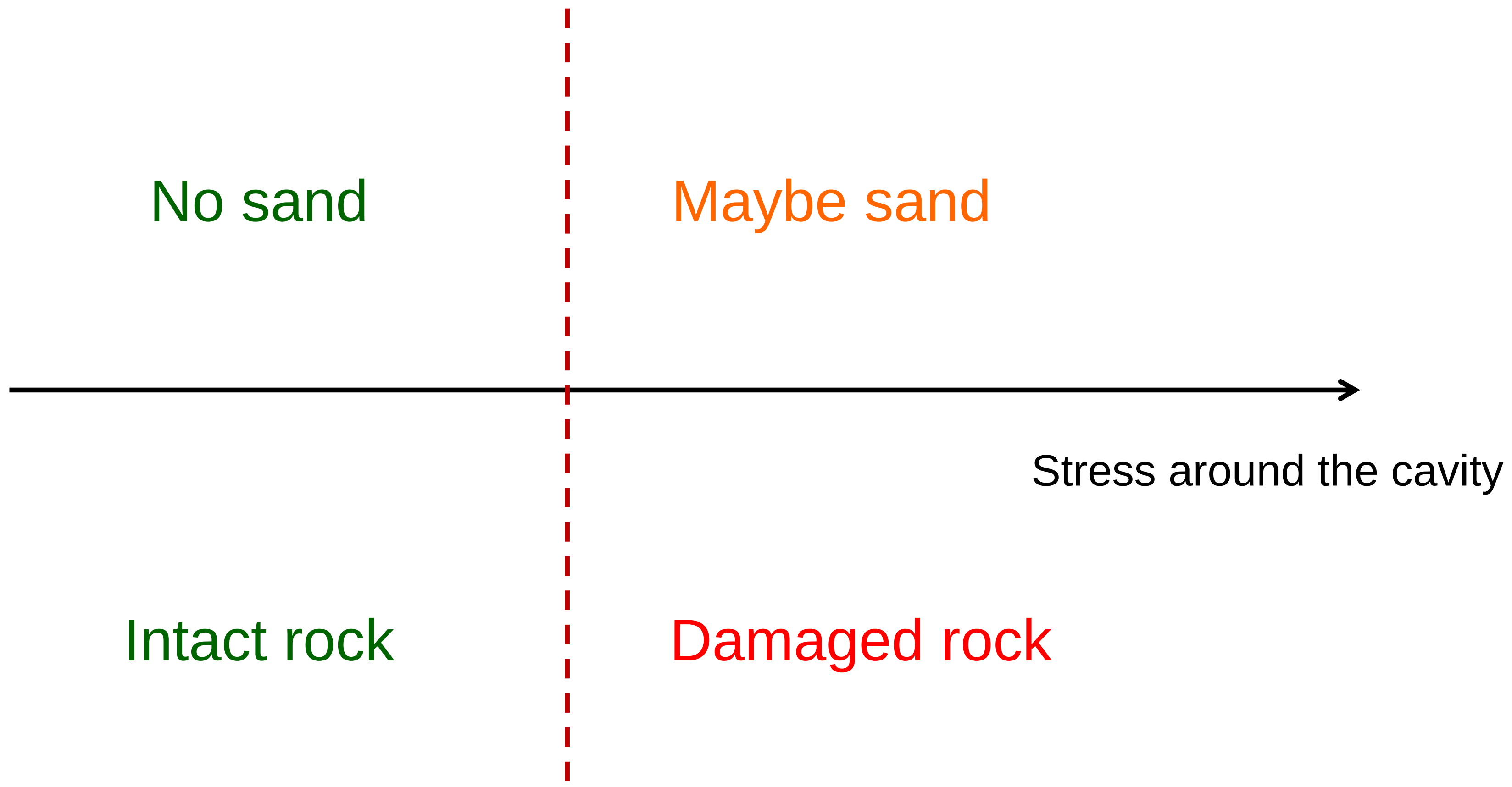
The main role of the hydrodynamic forces is to remove grains from damaged or unconsolidated rock, and transport the loose material into the well.

$\Rightarrow$
A necessary condition for sand production is that the rock in the vicinity of the producing cavity is unconsolidated, or has been damaged.

Stress concentrations in the vicinity of the cavity may cause such damage.

Criteria for stress induced damage of the rock around the producing cavities $\rightarrow$ criteria for onset of sand production

Note: Such criteria are necessary, but not necessarily sufficient for sand production.

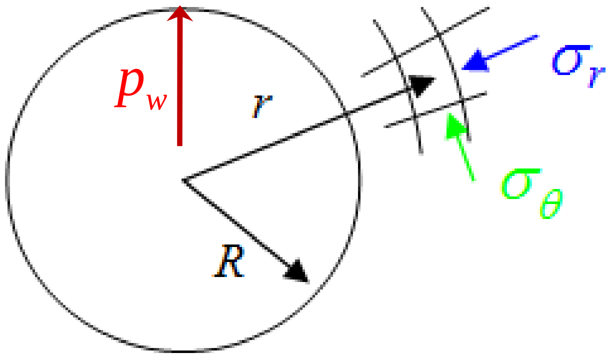

No sand
Maybe sand
Stress around the cavity
Intact rock
Damaged rock

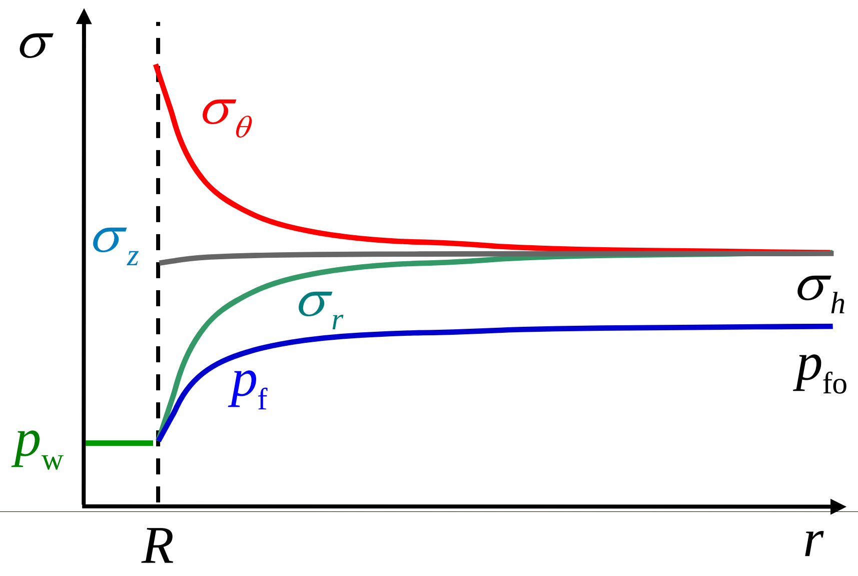
Consider sand production from a cylindrical cavity, which may represent

- an open hole

- a perforation

Stress around the cavity





Boundary conditions:

$$\sigma_r = p_w \qquad \text{for } r = R$$

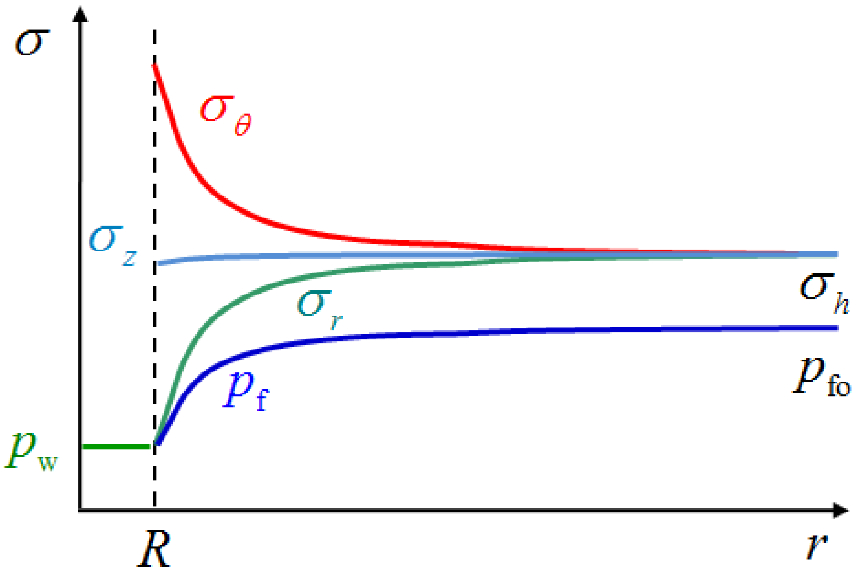
$$\sigma_r = \sigma_h \qquad \text{for } r \to \infty$$

For simplicity,
we here assume that the in situ stress state is isotropic

Stresses at the cavity wall:

$$\sigma_r = p_w$$
$$\sigma_\theta = 2\sigma_h - p_w + 2\eta\left(p_w - p_{fo}\right)$$

<u>Shear failure</u> occurs if $\sigma_1' = C_0 + \sigma_3' \tan^2\beta$
(Mohr-Coulomb criterion)



Assuming α = 1, and

$$\sigma_1' = \sigma_\theta' = 2\sigma_h - p_w + 2\eta\left(p_w - p_{fo}\right) - p_w$$
$$\sigma_3' = \sigma_r' = p_w - p_w = 0$$

(pore pressure = well pressure at the cavity wall)

$$\Rightarrow$$

$$2\sigma_h - 2p_w + 2\eta\left(p_w - p_{fo}\right) = C_0$$

$$2\sigma_{\mathrm{h}} - 2p_{\mathrm{w}} + 2\eta\left(p_{\mathrm{w}} - p_{\mathrm{fo}}\right) = C_0$$ $\leftrightarrow$ Shear failure criterion

Introducing:

1. Drawdown $D = p_{\mathrm{fo}} - p_{\mathrm{w}}$
2. Effective in situ stress $\sigma'_{\mathrm{h}} = \sigma_{\mathrm{h}} - p_{\mathrm{fo}}$

and remember that $2\eta \rightarrow \dfrac{1-2\nu_{\mathrm{fr}}}{1-\nu_{\mathrm{fr}}}$

we may solve the shear failure criterion for
$D = D_c$ (= the critical drawdown)

$$D_c = \left(1-\nu_{\mathrm{fr}}\right)\left(C_0 - 2\sigma'_{\mathrm{h}}\right)$$

Critical drawdown:

$$D_c = (1 - \nu_{\text{fr}})(C_0 - 2\sigma'_{\text{h}})$$

If $D > D_c$ the rock fails at the cavity wall, and sand <u>may</u> be produced.

If $D < D_c$ the rock does not fail, and sand will <u>not</u> be produced.

Critical drawdown:

$$D_c = (1-\nu_{\mathrm{fr}})(C_0 - 2\sigma'_{\mathrm{h}})$$

Minimum formation strength required to avoid rock failure during production

D increases with C_0

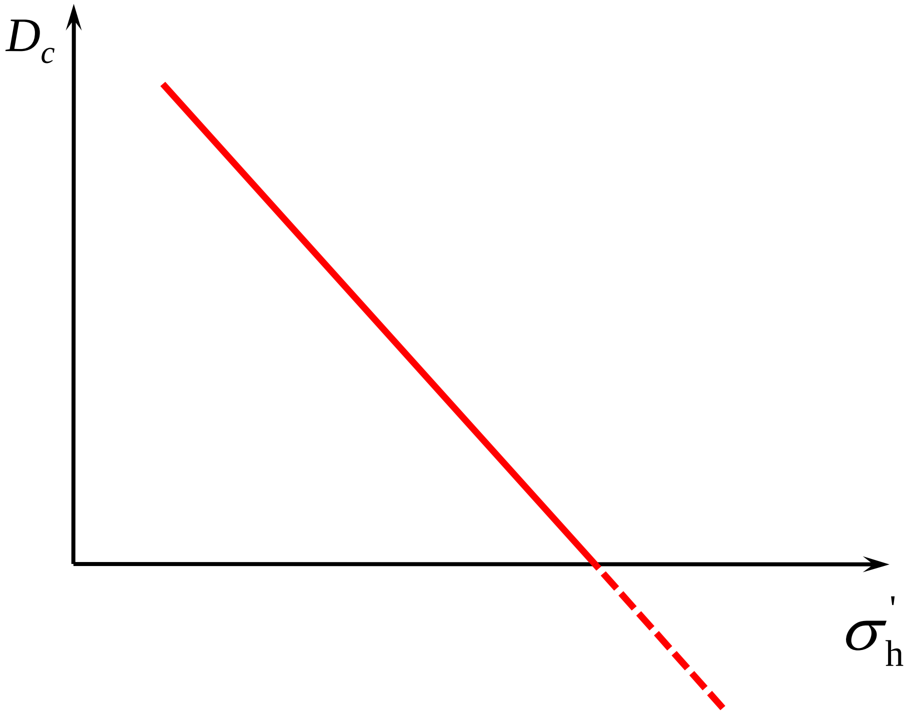
$\Rightarrow$ The stronger the rock is, the less likely it is to produce sand

Perforation strategy in order to prevent sand production:

selective perforation
= only perforate in the strongest parts of the formation

Critical drawdown:

$$D_c = (1-\nu_{fr})(C_0 - 2\sigma'_h)$$



D_c decreases with

$$\sigma'_h = \sigma_h - p_{fo}$$

$\Rightarrow$ The probability for sand production increases with falling in situ pore pressure

Sand production becomes more likely as the reservoir is being depleted

In general, the in situ stress state is not isotropic, i.e. $\sigma_\mathrm{v} \neq \sigma_\mathrm{H} \neq \sigma_\mathrm{h}$

If the cavity is parallel to one of the principal stress directions, the result may be expressed as

$$D_c = \left(1 - \nu_\mathrm{fr}\right)\left(C_0 - 2\sigma'_\mathrm{is}\right)$$

where the effective in situ stress is given by

$$2\sigma'_\mathrm{is} = 3\sigma'_{\mathrm{max}\perp} - \sigma'_{\mathrm{min}\perp}$$

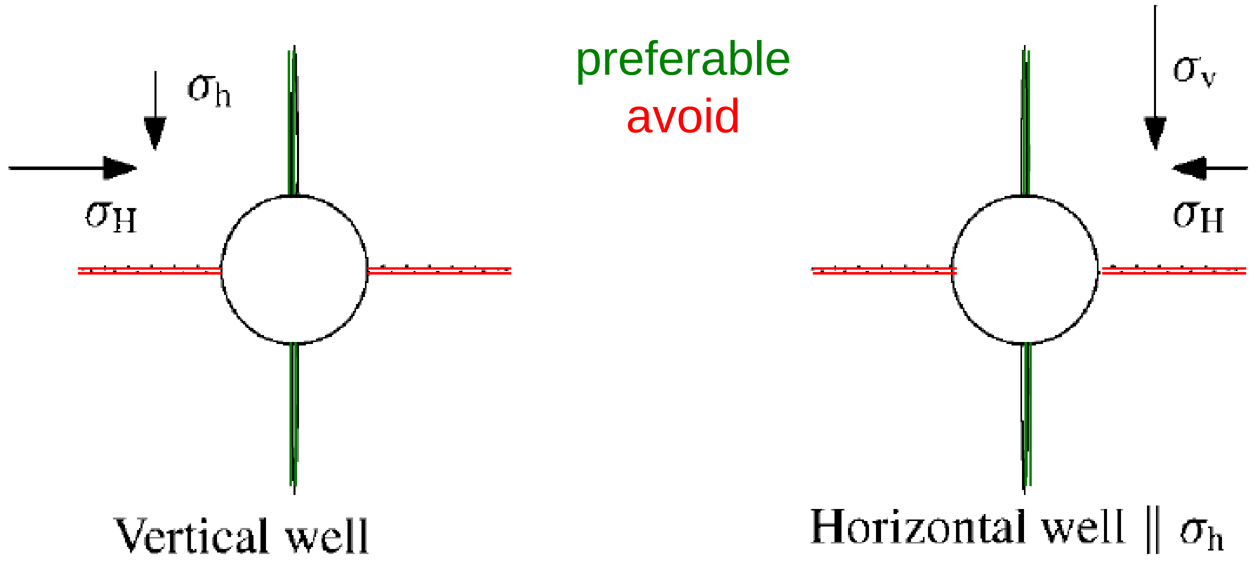
$\sigma'_{\mathrm{max}\perp}$ and $\sigma'_{\mathrm{min}\perp}$ are the maximum and minimum effective principal stresses, respectively, in the plane normal to the cavity axis

Rule of Thumb: Stress anisotropy in the plane normal to the cavity axis reduces the critical drawdown and increases the risk of sand production

Perforation strategy in order to
prevent sand production:

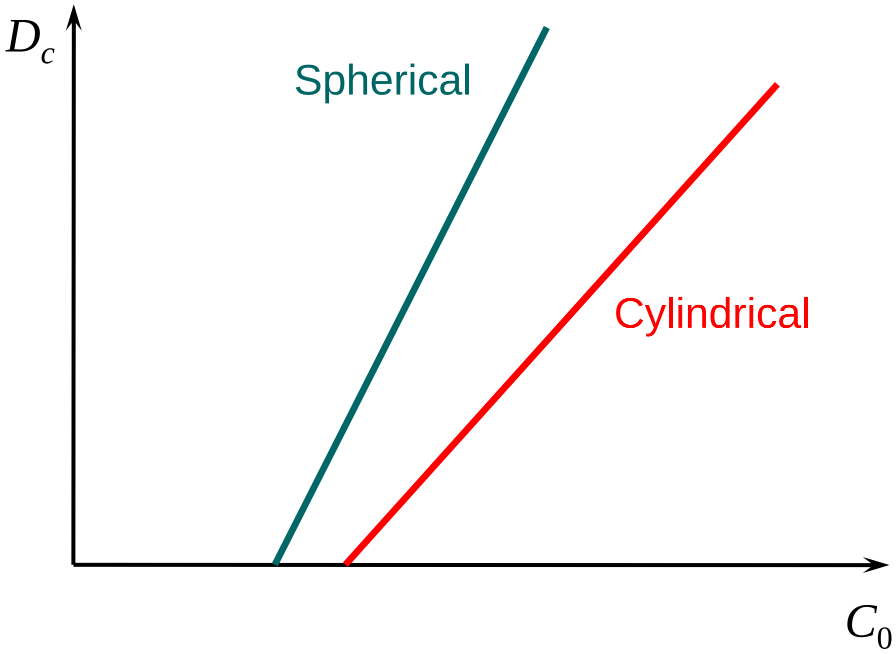
oriented perforation
= perforate in the directions where the
critical drawdown is largest

Usually:



Perforations are created like cylinders (more or less) because it is convenient.

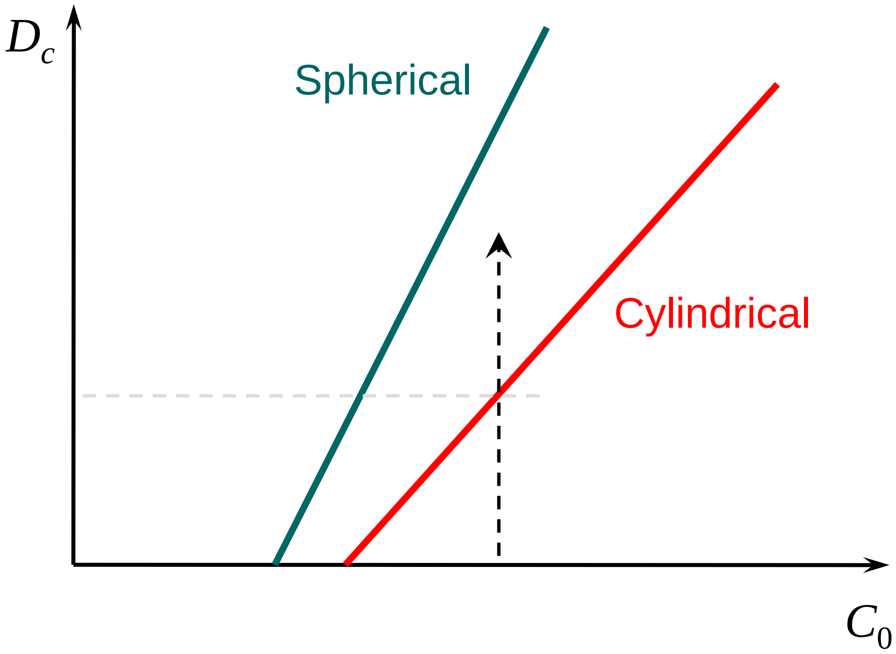
However, (semi)spherical cavities are more stable



⇒ It is possible that a cavity that starts to produce sand at a given drawdown may take a more stable shape as a consequence of the sand production, and therefore stops to produce sand after a while

Perforations are created like cylinders (more or less) because it is convenient.

However, (semi)spherical cavities are more stable



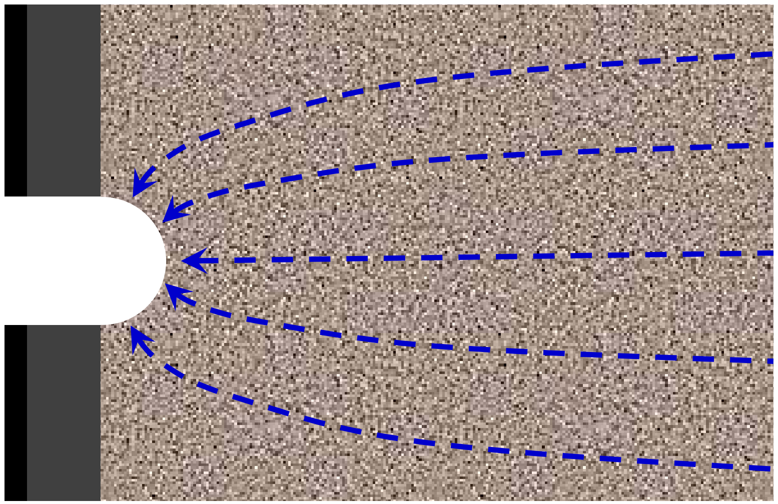
⇒ It is possible that a cavity that starts to produce sand at a given drawdown may take a more stable shape as a consequence of the sand production, and therefore stops to produce sand after a while

Sand arches –

Sand arches –

- may be formed when damaged rock or loose sand is pushed towards a small opening

- may remain stable during production



- possibly assisted by capillary forces

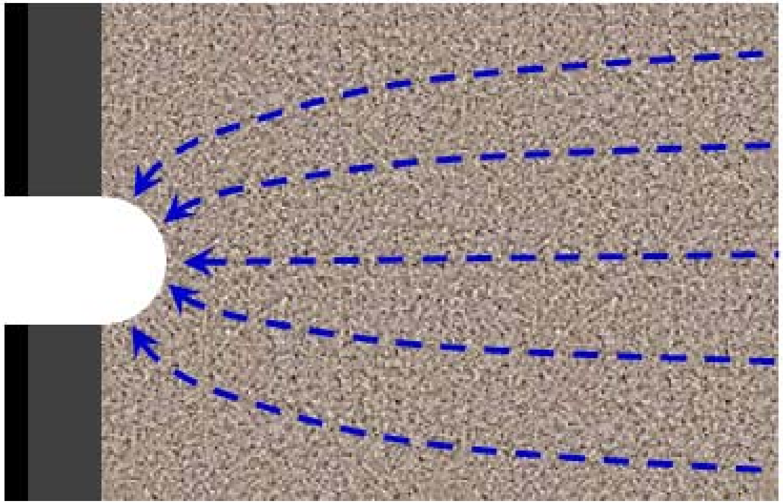
Line of arguments:

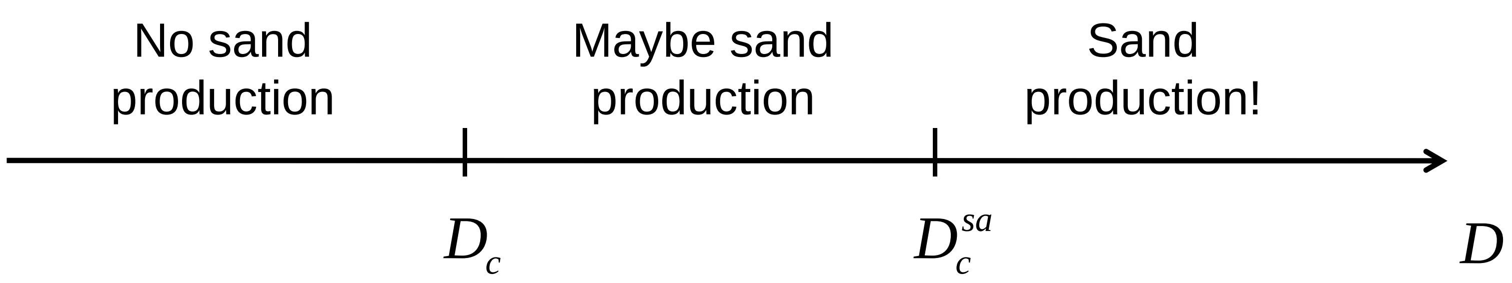
First, the rock is assumed to be in a plastified state due to shear failure.

Next, sand production is provoked by tensile failure of the plastified material at the cavity wall.

Critical drawdown for a sand arch:

$$D_c^{sa} = 2C_0$$



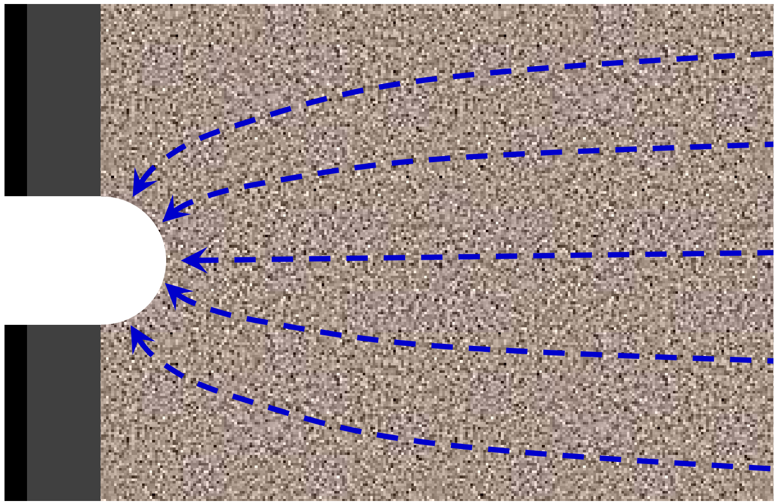

No sand production
Maybe sand production
Sand production!
D_c
D_c^{sa}
D

Effects of in situ stress

The expressions for critical drawdown for a sand arch do not involve in situ stresses.

Cause: The sand arch consist of plastified material, hence the stress state is controlled by the plastic flow criterion.

Note: The in situ stresses are still of importance for inducing plastification, but not for onset of sand production.



This is particularly important for HTHP reservoirs, where criteria based on shear failure alone are found to be overly conservative.

Common observation:

Sand comes with the water

Other observations:

Sand production following water breakthrough is a temporary phenomenon.

As the water cut increases, sand production declines towards the level it had before water breakthrough, or even below.

Common observation:

Sand comes with the water

Possible causes:

1. Water weakening

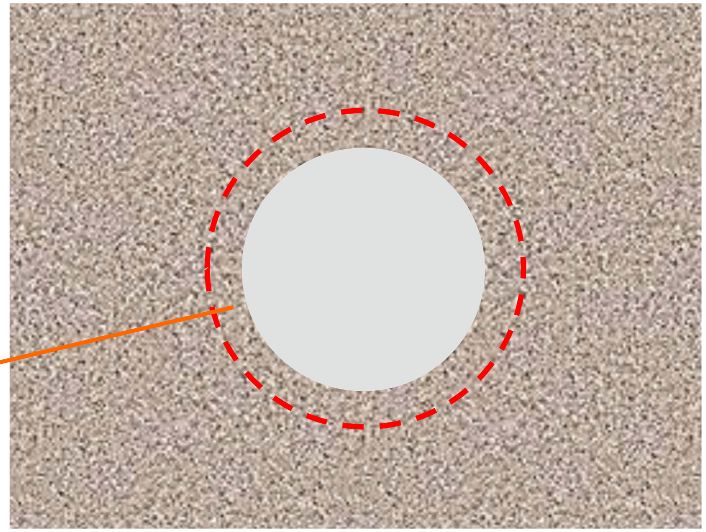
2. Loss of capillary cohesion

3. Pore pressure gradient enhancement

Possible contribution from all three effects

Sand volume

Simple sand erosion model



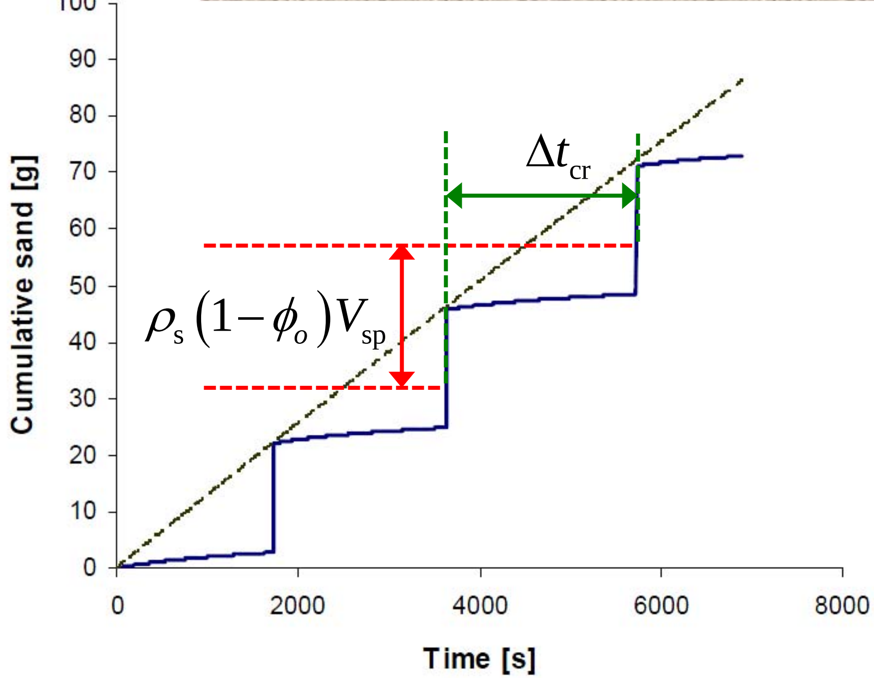
Sand erosion from
a sand producing zone

⇒ Sand production rate

$$\frac{\Delta M_s}{\Delta t} = M_s \frac{2}{\tau_s} \frac{D - D_c}{C_0} \left(\frac{Q}{A q_{fl}^{cr}} - 1 \right)$$

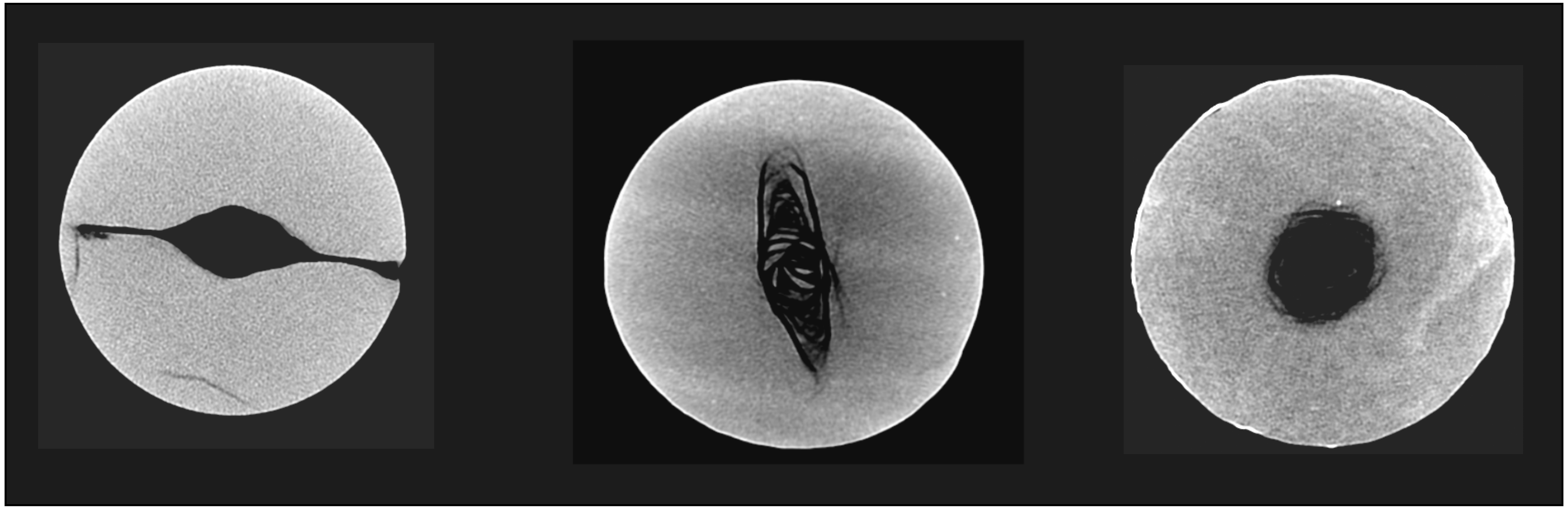
$$M_s = \pi L R_c^2 \rho_s \left(1 - \phi_o\right)$$

= total amount of sand removed from the cavity



Separate calibration for each class

Different classes of cavity failure:



Class A:
Slit-like breakouts

Class B:
Convex breakouts due to shear failure

Class C:
Uniform failure

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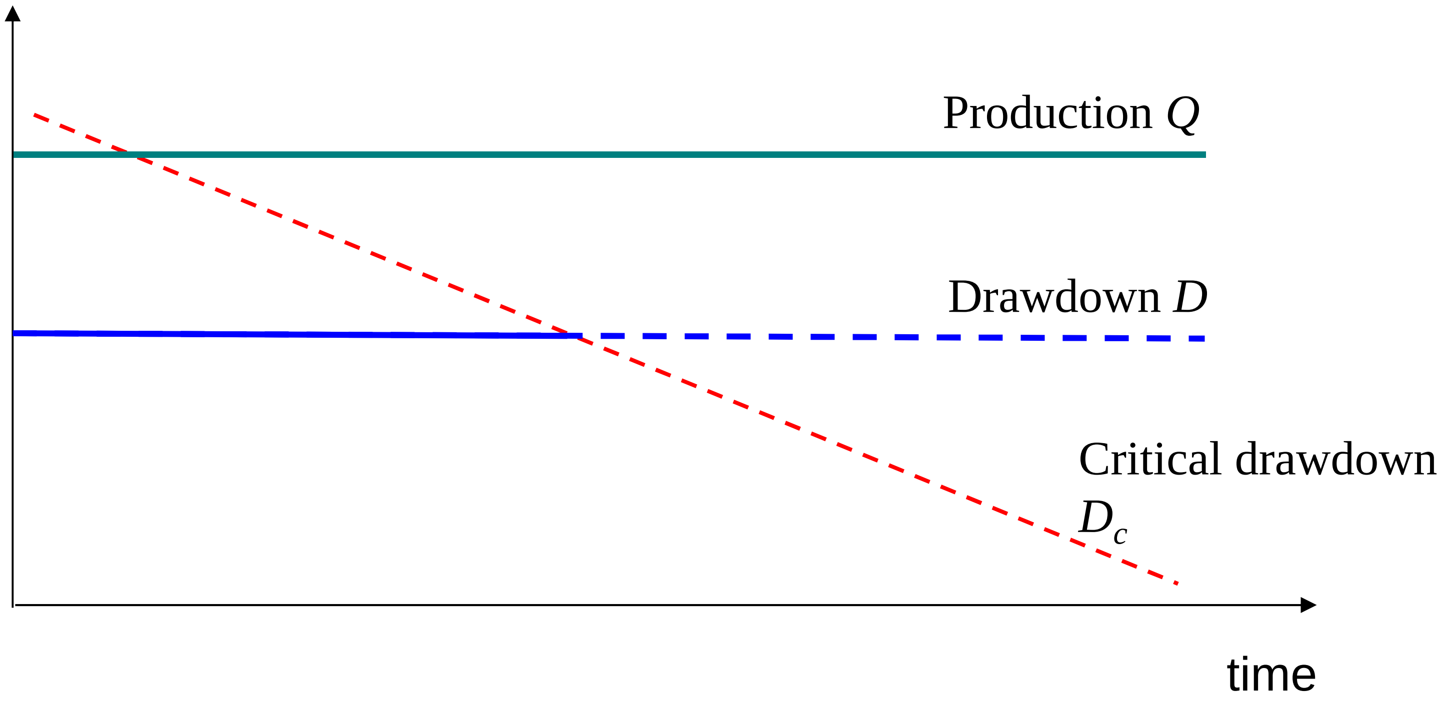
Predictions by the model
– constant production, depleting reservoir



Note:
-The dimensions are scaled from lab to field conditions
-A finite response-time is assumed for the well parameters

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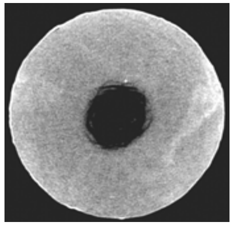
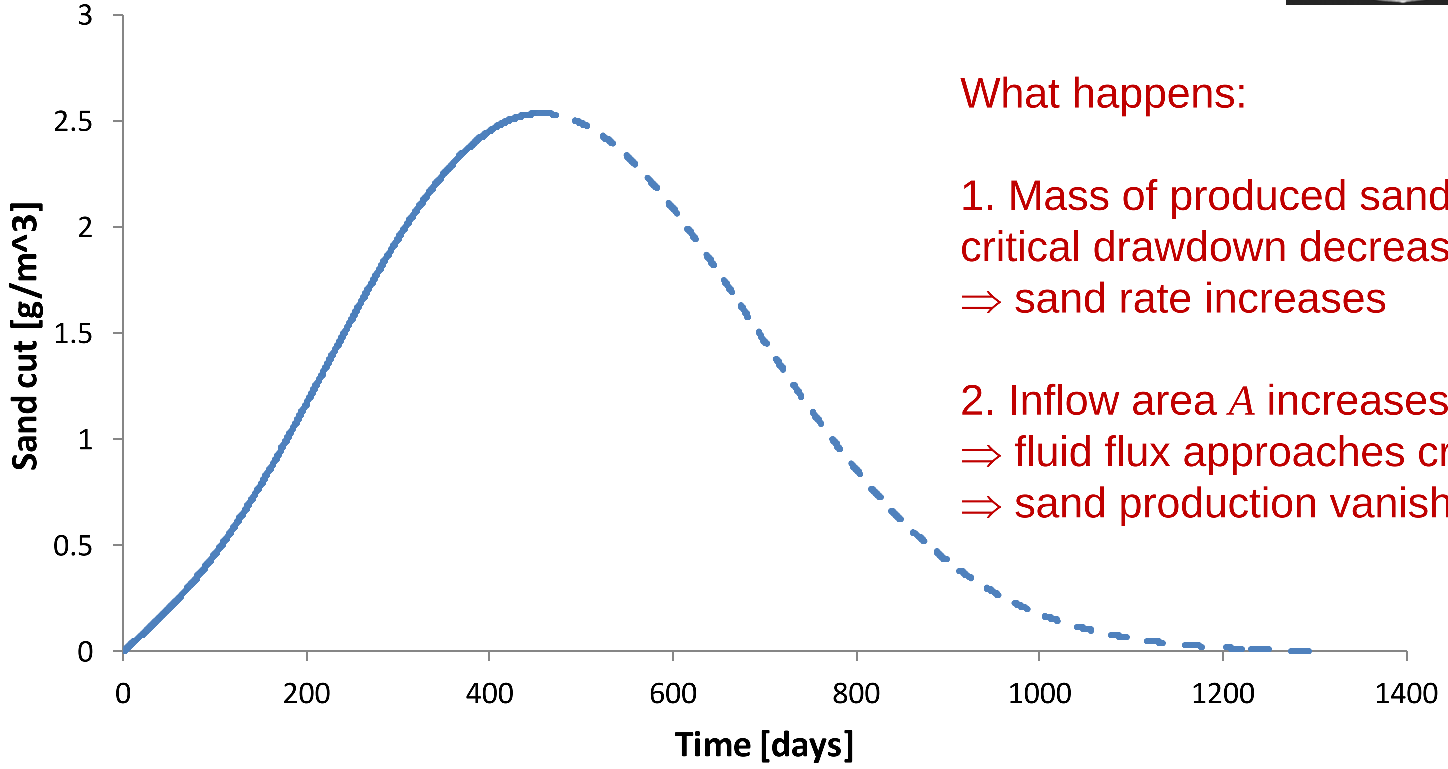
Predictions by the model
– constant production, depleting reservoir

Class C:
Synthetic sandstone





What happens:

1. Mass of produced sand increases, critical drawdown decreases
⇒ sand rate increases

2. Inflow area A increases
⇒ fluid flux approaches critical flux
⇒ sand production vanishes gradually

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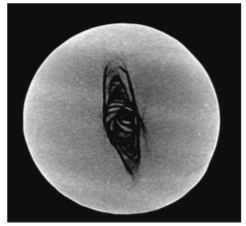
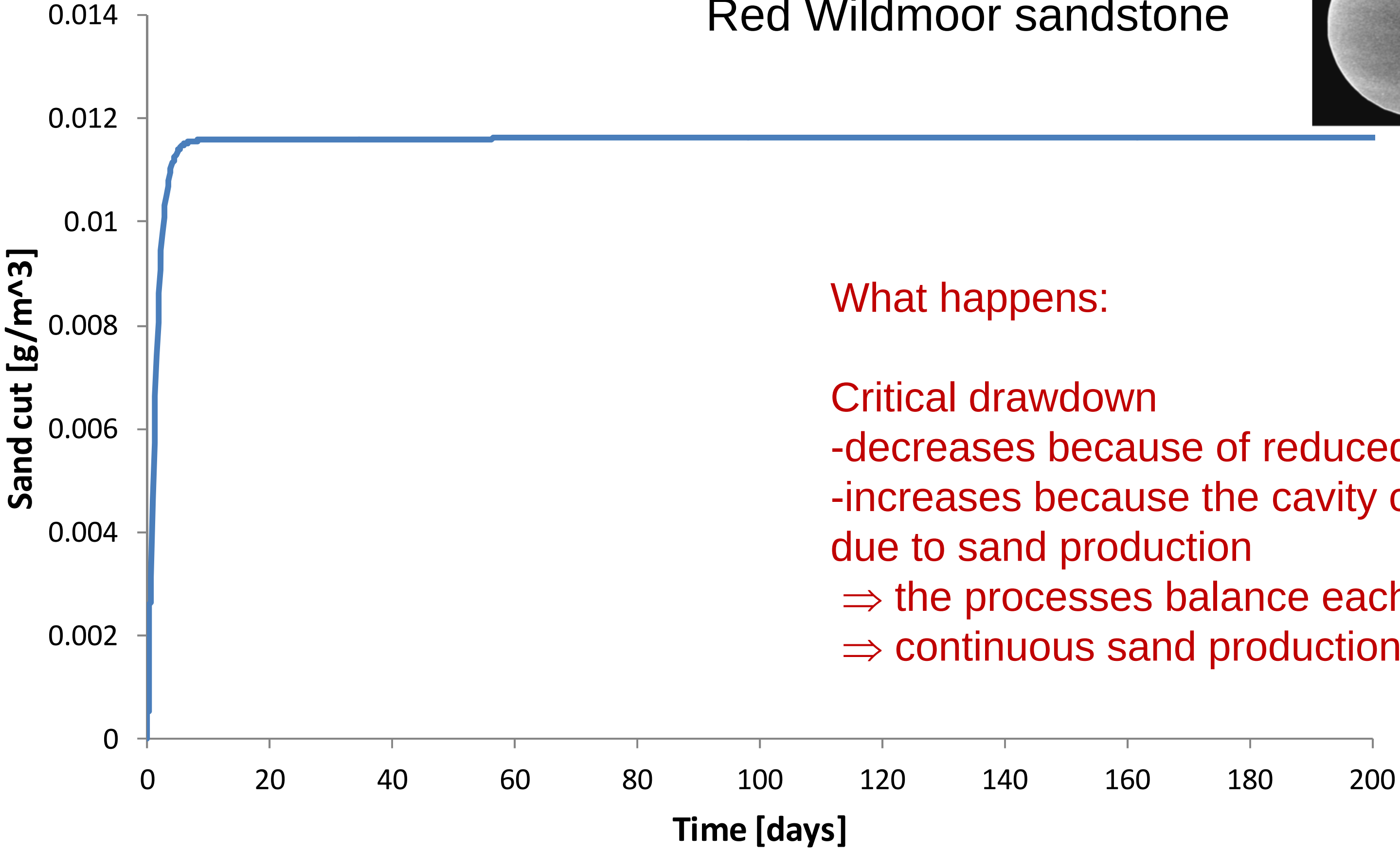
Predictions by the model
– constant production, depleting reservoir

Class B:
Red Wildmoor sandstone





What happens:

Critical drawdown
-decreases because of reduced pore pressure,
-increases because the cavity changes shape due to sand production
⇒ the processes balance each other
⇒ continuous sand production rate

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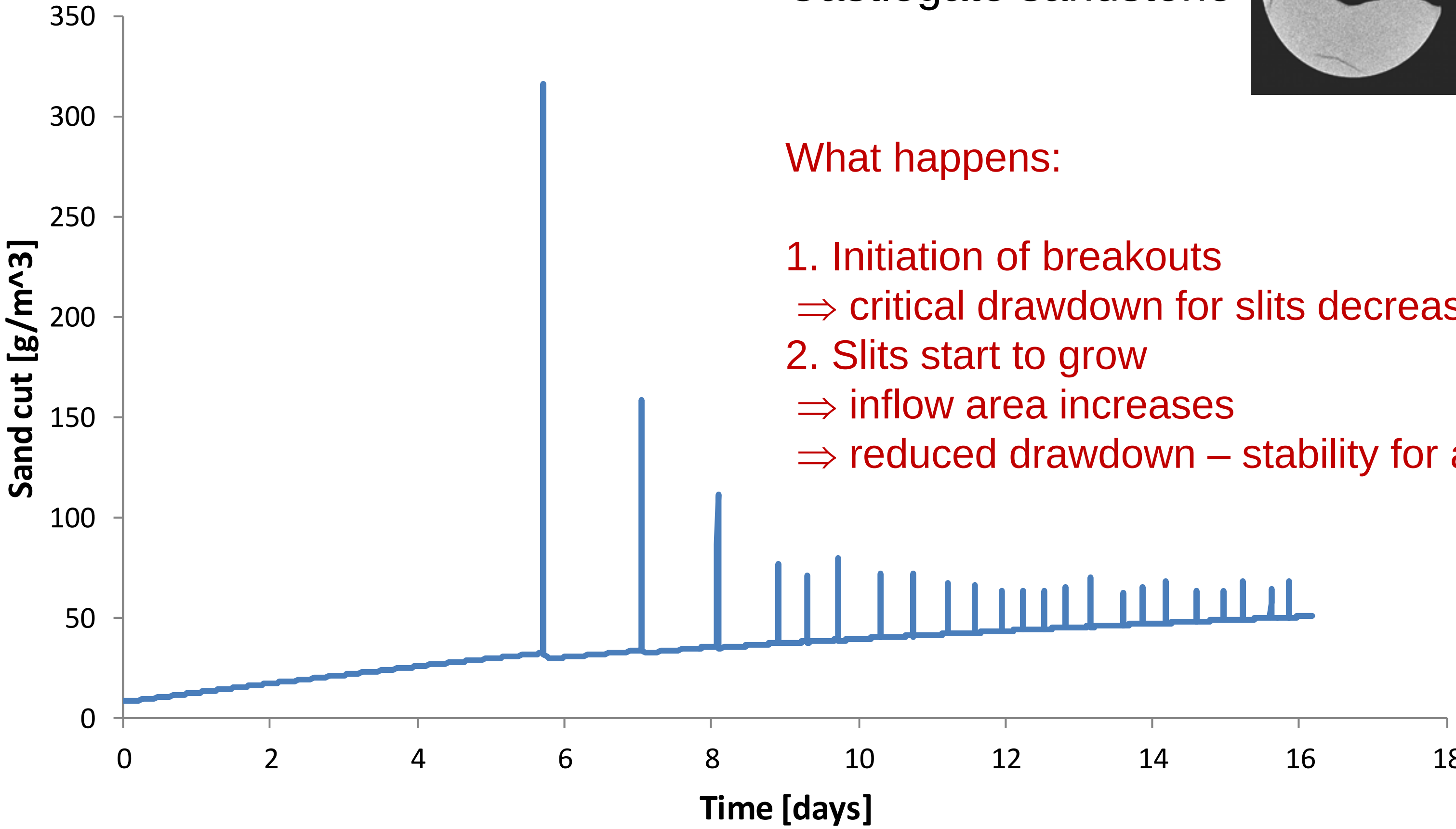
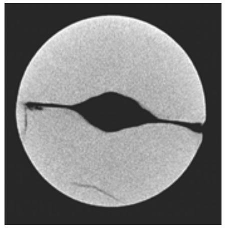
Predictions by the model
– constant production, depleting reservoir



Class A:
Castlegate sandstone



What happens:

1. Initiation of breakouts
 ⇒ critical drawdown for slits decreases
2. Slits start to grow
 ⇒ inflow area increases
 ⇒ reduced drawdown – stability for a while

Other rock types?

If solids production happens, it could be a problem if

- the rock contains significant amounts of abrasive components

- large amounts of solids are produced, so that the well may become choked or destabilized

Rock strength and effective stresses decide whether solids production may occur.

Solids production can also be a problem in chalk

The chalk is not abrasive, hence the major problem is interruption of the production and possibly loss of the well

Consequences of solids production

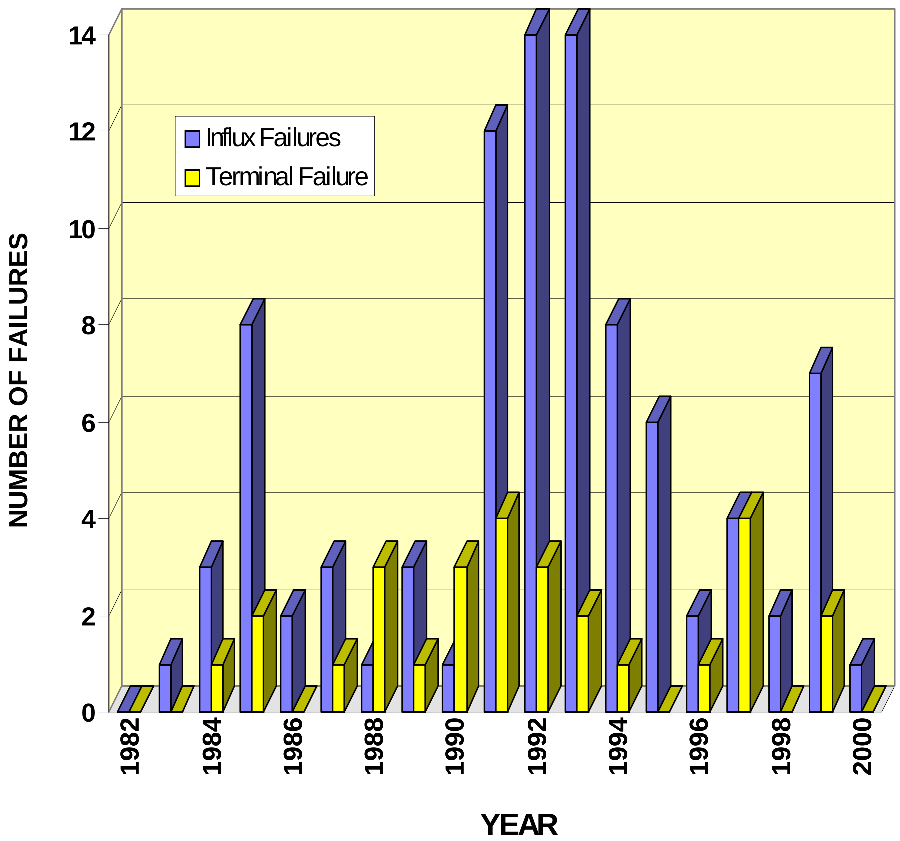
1. Erosion of the production equipment,
   leading to malfunctions and leakages.
   A safety problem!

2. Instability of the production cavities and the well;
   may result in complete filling of the hole so that the well has to be abandoned.
   An economical problem!

3. The necessity to handle large amounts of polluted solids.
   An environmental problem!

Chalk influx failures at Valhall (1982-2000)

Well Failures at Valhall



	Influx	Terminal
1982	0	0
1983	1	0
1984	3	1
1985	8	2
1986	2	0
1987	3	1
1988	1	3
1989	3	1
1990	1	3
1991	12	4
1992	14	3
1993	14	2
1994	8	1
1995	6	0
1996	2	1
1997	4	4
1998	2	0
1999	7	2
2000	1	0

Influx Failure

Well plugged with solids. Returned to production after clean out.

Terminal Failure

Casing collapsed. Well could not be returned to production.

References:

Fjær, E., Holt, R.M., Horsrud, P., Raaen, A.M. and Risnes, R. (2008) "Petroleum Related Rock Mechanics. 2nd Edition". Elsevier, Amsterdam

Barkved, O., Heavy, P., Kjeldstadli, R., Kleppan, T., and Kristiansen, T.G. (2003) "Valhall Field – Still on Plateau after 20 Years of Production", SPE 83957

Fjær, E. and Papamichos, E. (2008) "The variable rate of sand production captured by an analytical model". Proceedings of SHIRMS 2008 1st Southern Hemisphere International Rock Mechanics Symposium, Perth, Australia: CSIRO Publishing Australian Centre for Geomechanics, 355-368