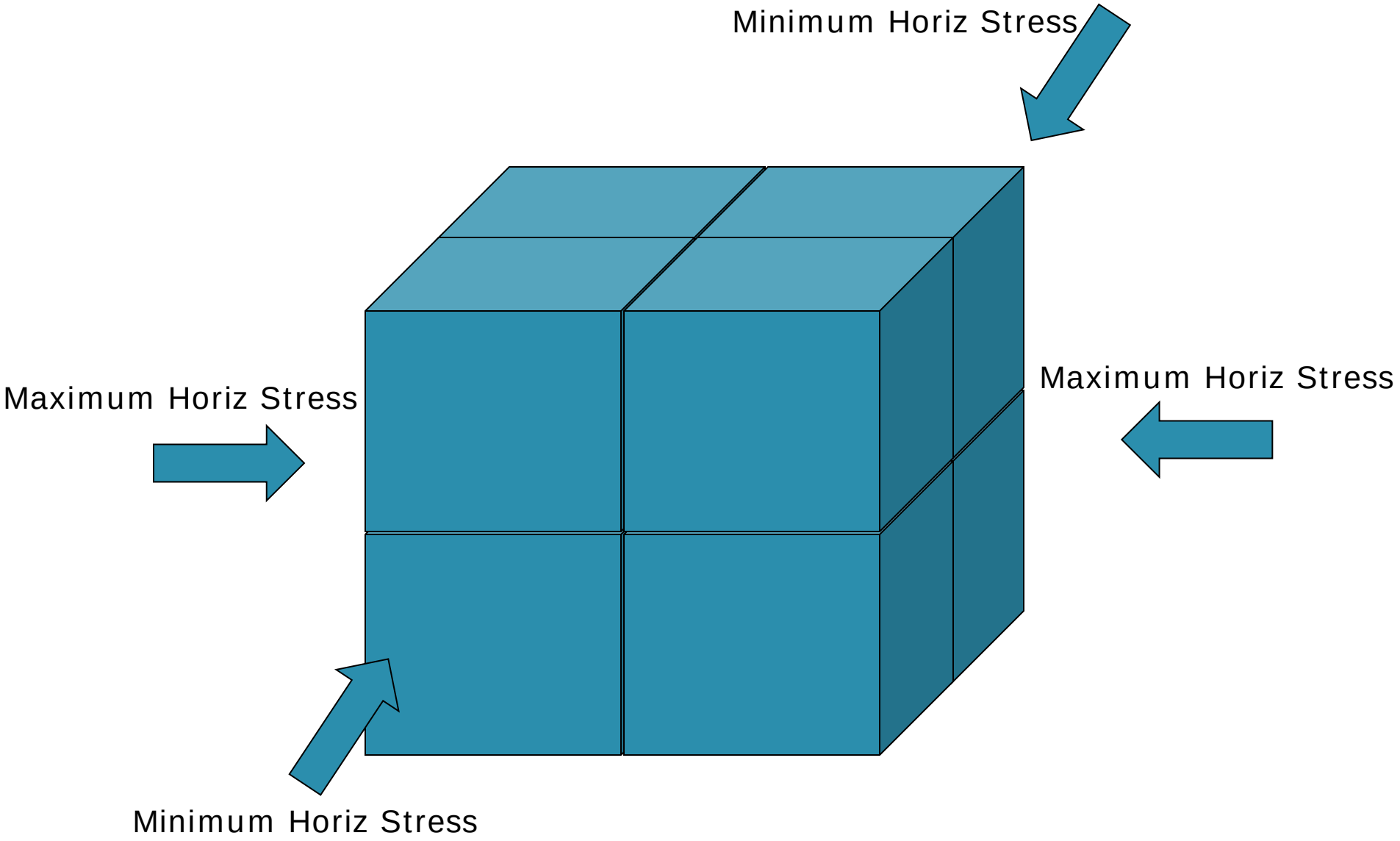
Hydraulic Fracturing

Unlocking Danish North Sea Chalks

Dansk Geologisk Forenings Årsmøde 2016

March 12 2016, Mike Mulrooney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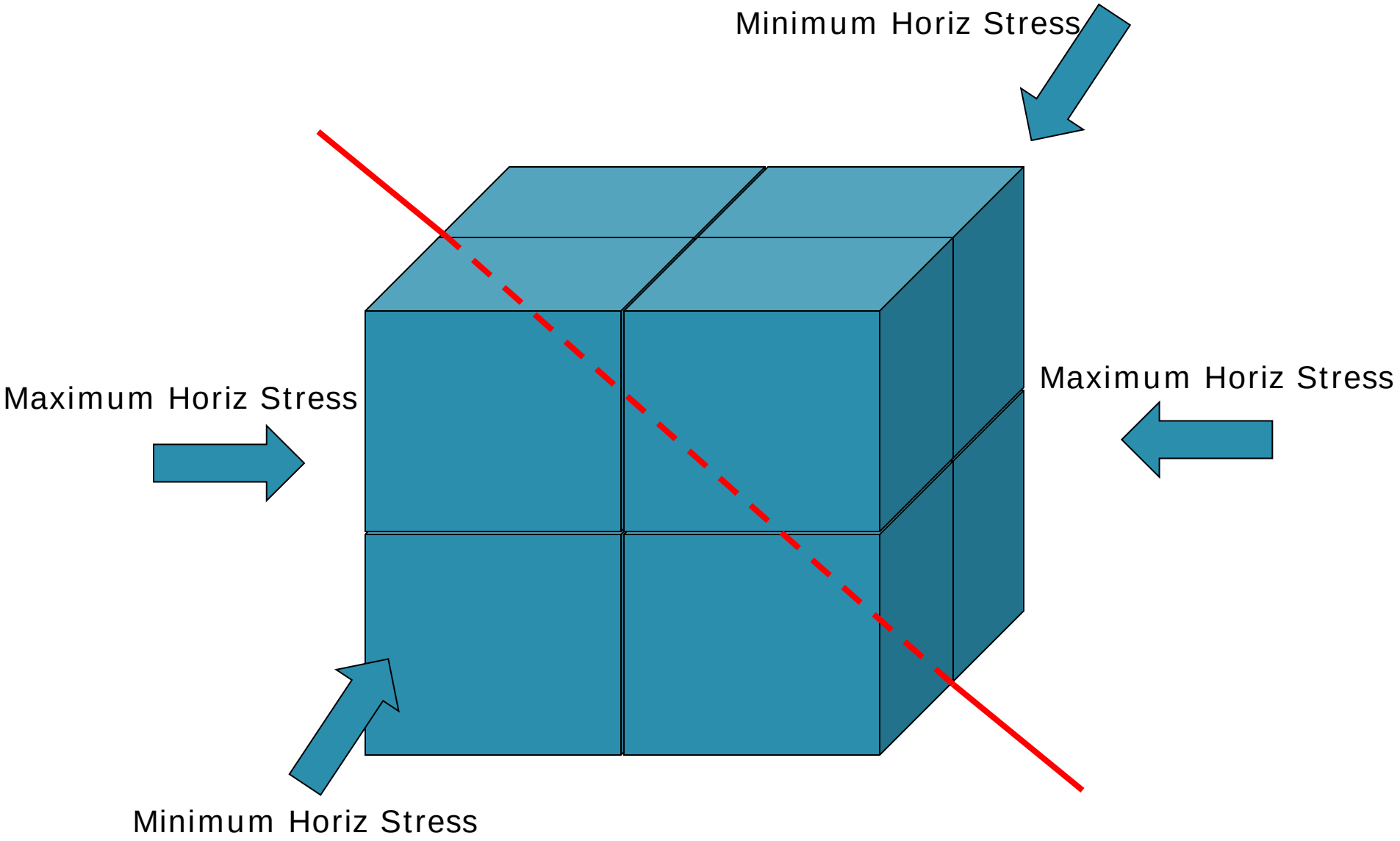
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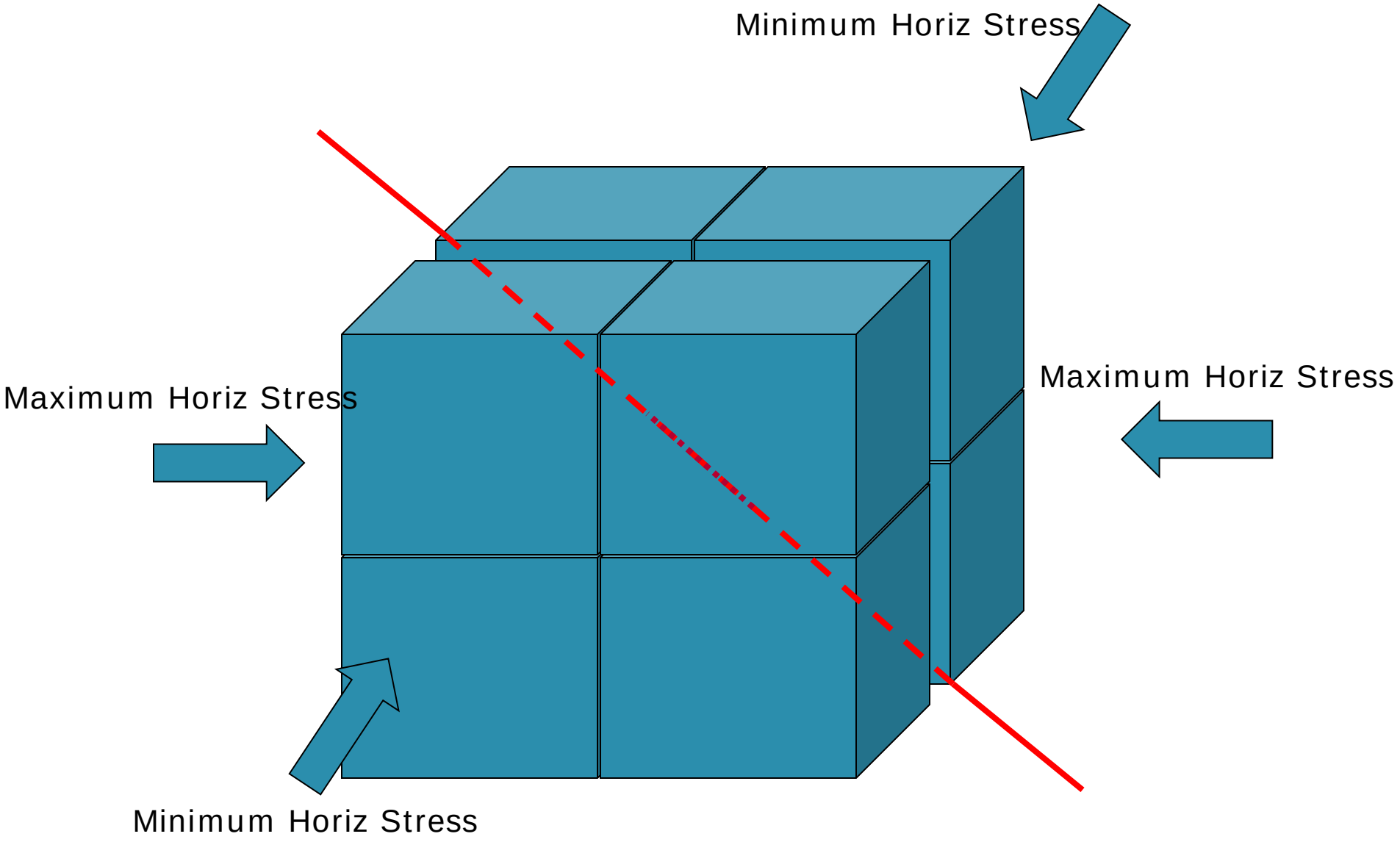
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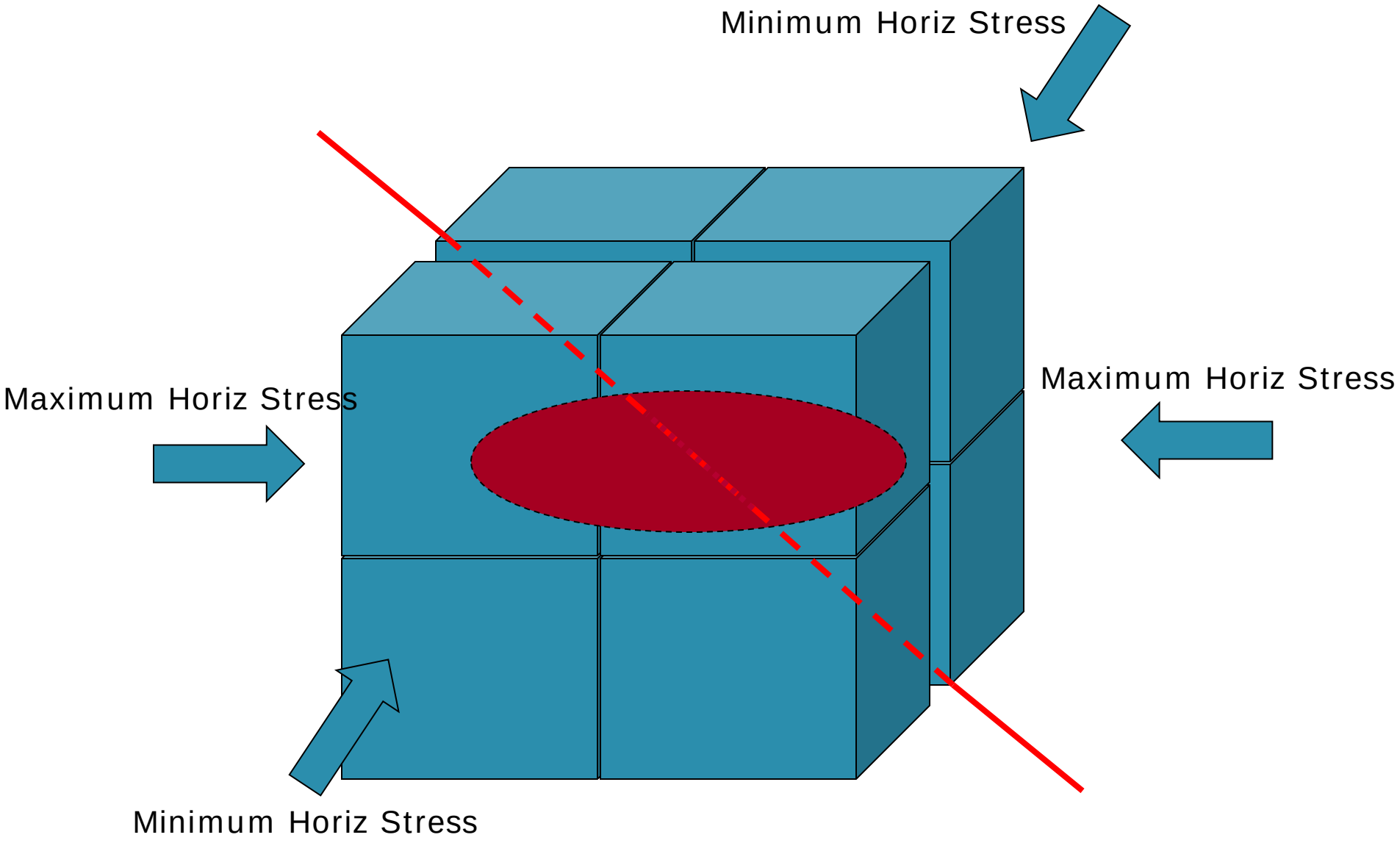
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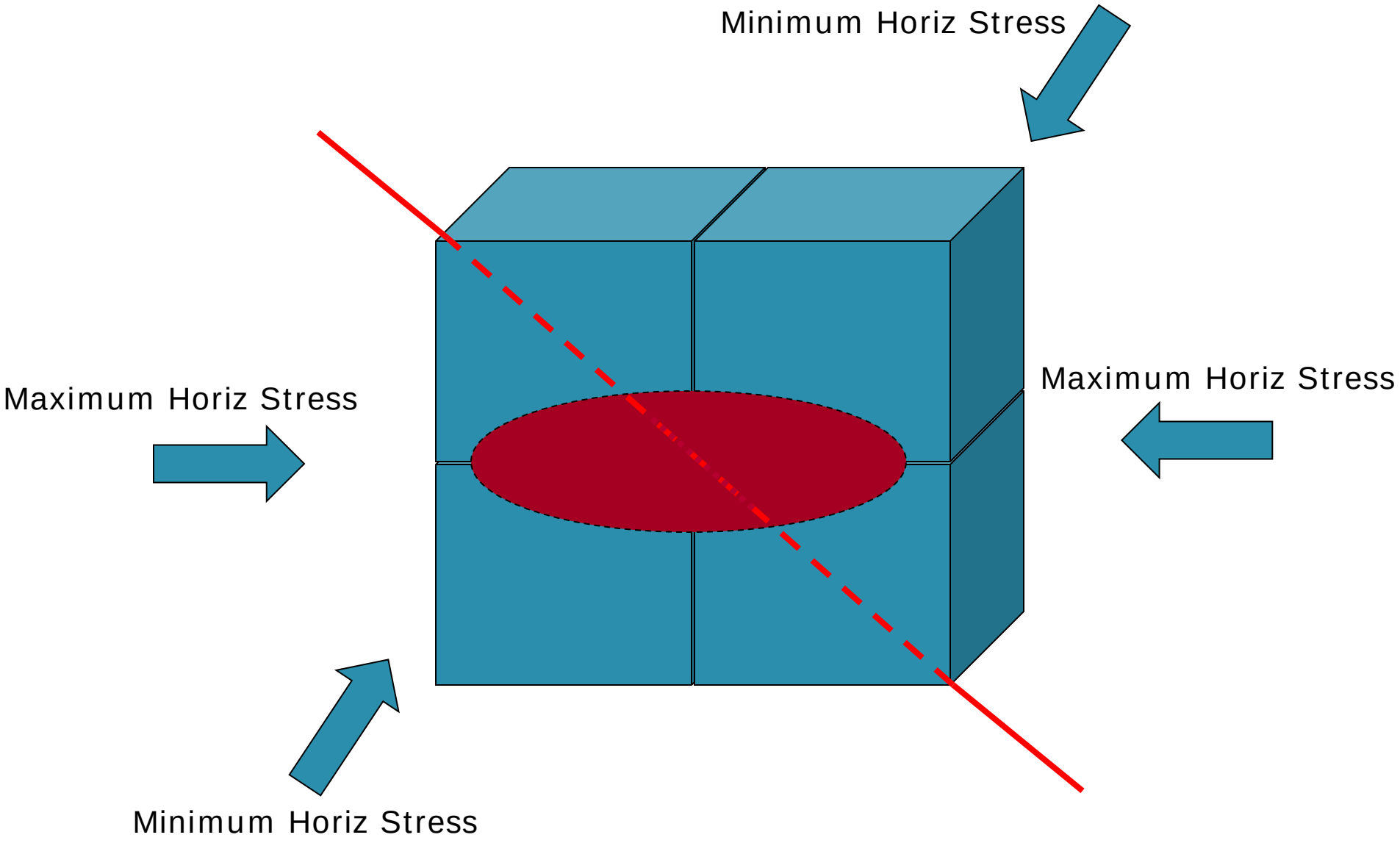
Minimum Horiz Stress
Maximum Horiz Stress
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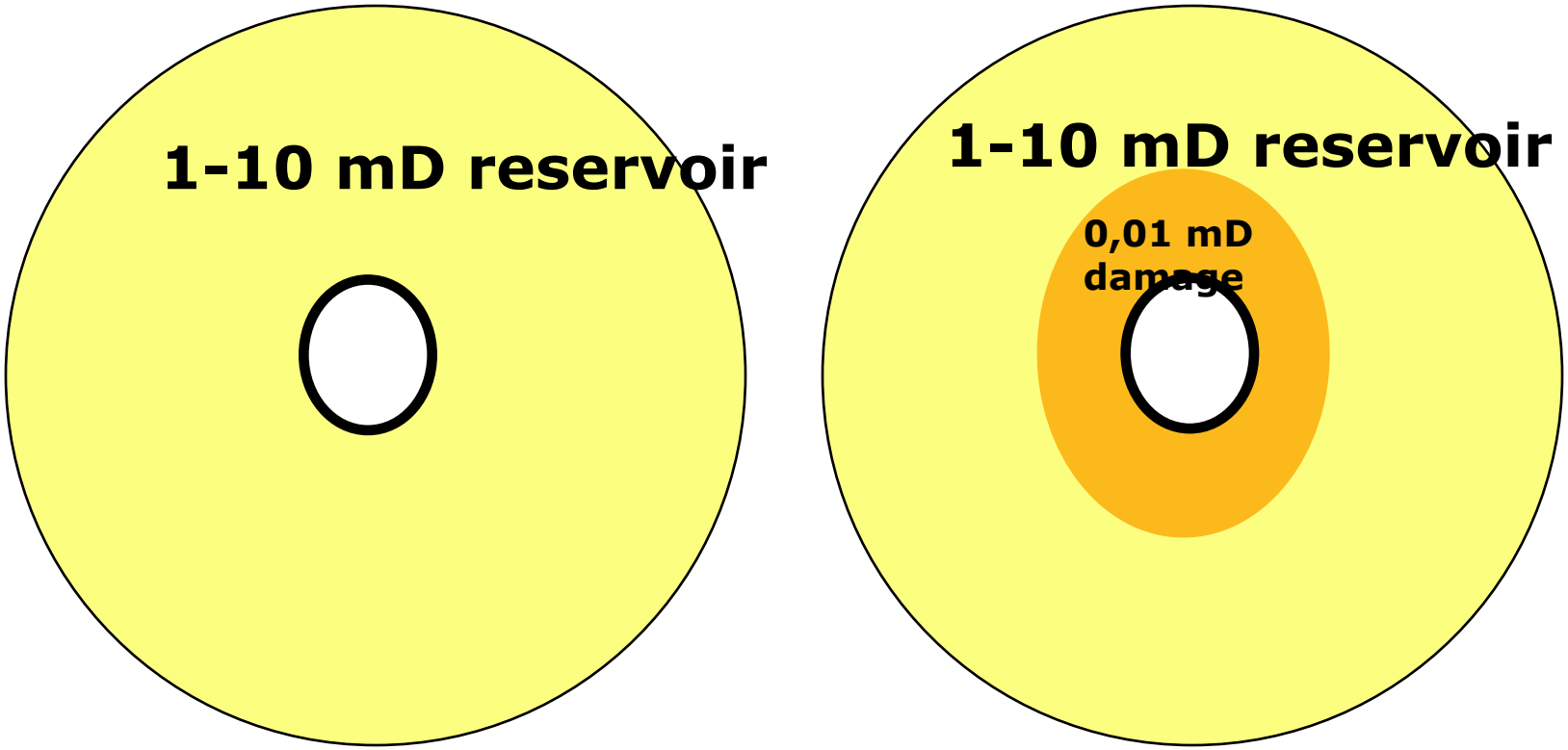
Stimulation - why and where?

- **Danish North Sea Chalks:**
  - Low permeability affect the drainage.
  - Depleted reservoir pressures affect the drainage.
  - Near wellbore formation damage incurred during drilling, perforating and completion.
  - In some fields the drainage height is too large for a single horizontal wellbore.
  - In other areas, the zone of interest is so thin or faulted, that remaining in zone while drilling is challenging.

- **One thing is certain:**
  - Wells do not produce optimally (or at all) without some sort of stimulation or attempt to remove damage that would otherwise impair flow of hydrocarbons.

Stimulation - why and where?

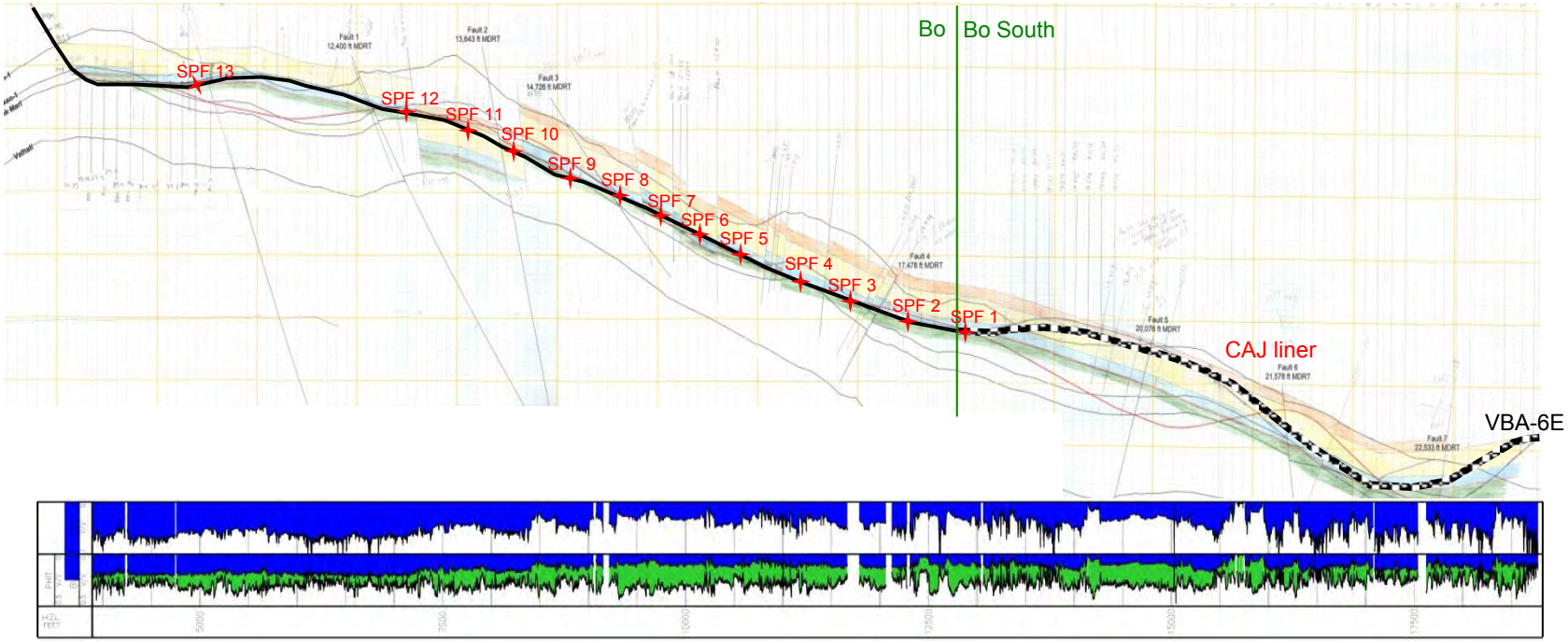
- Formation Damage: Ideal case vs. What we get



Stimulation - why and where?

- Gross reservoir height too large for a single horizontal wellbore.

- Valdemar Lower Cretaceous
  - 0.1-0.4 mD, oil reservoir, up to 300 ft gross
  - Very heterogeneous, variable clay content
  - Long horizontal wells +/- 19,500 ft MD
  - Typically 9-14 propped fracs per well



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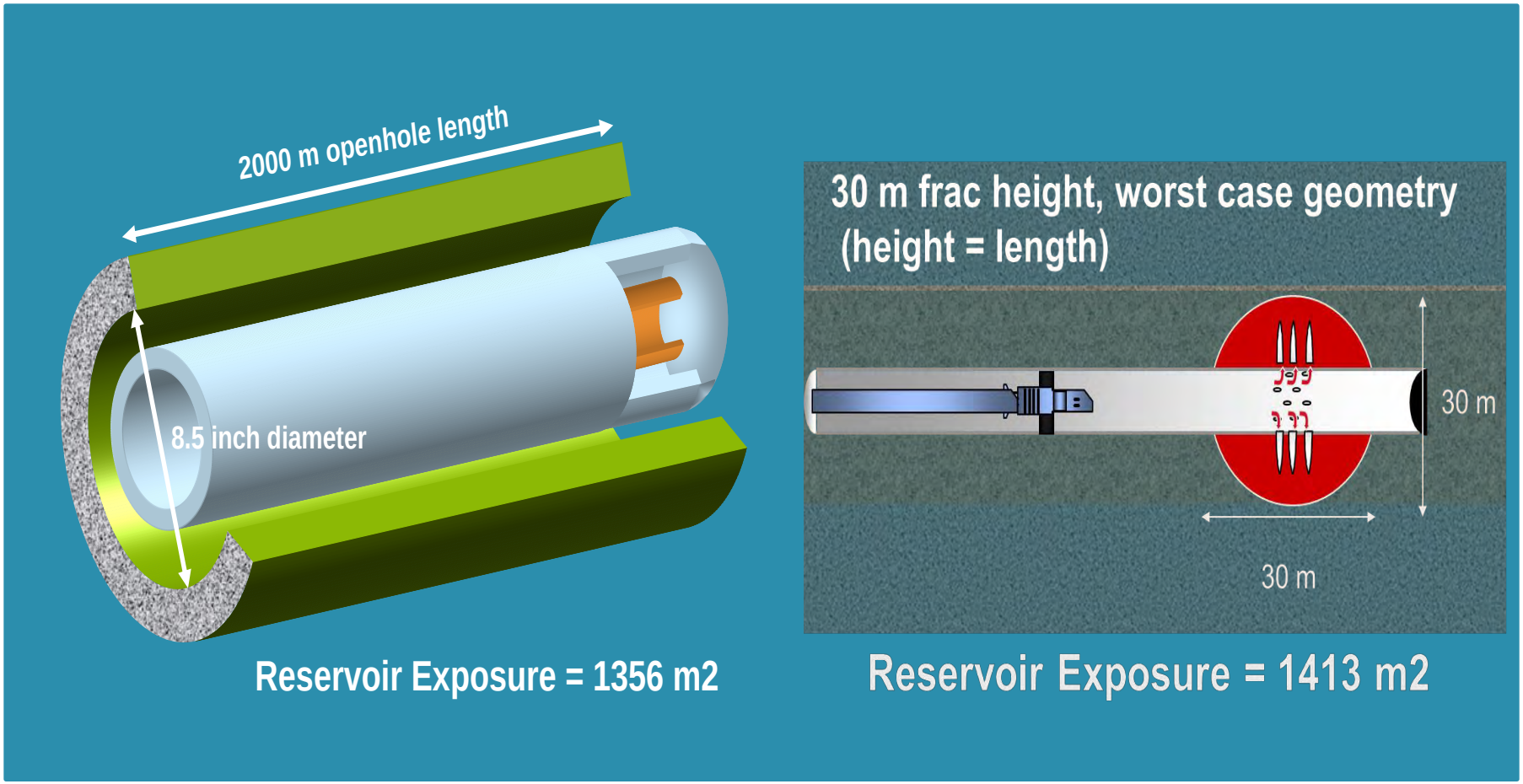
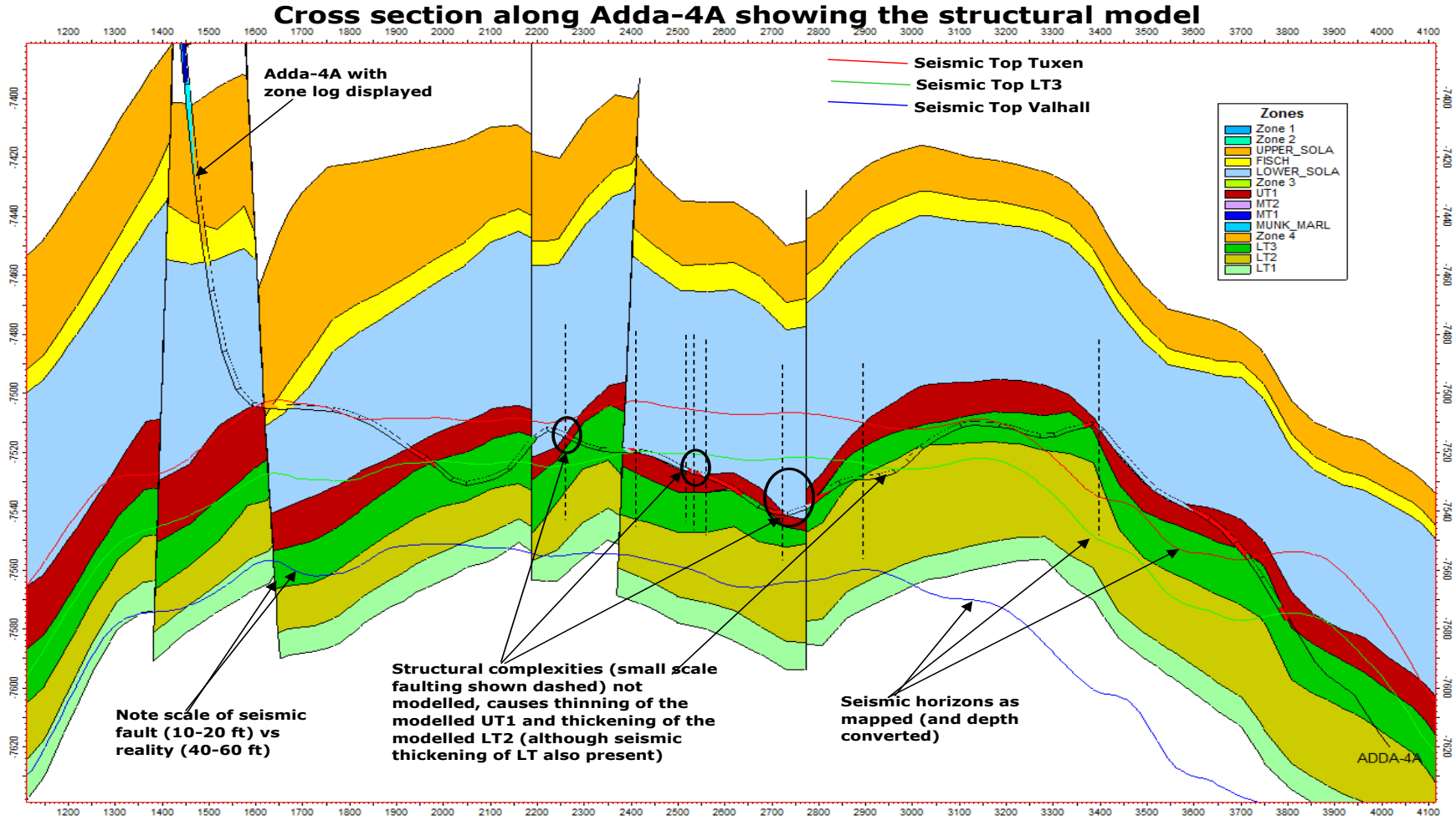


Stimulation - why and where?

- Zone of interest is so thin or faulted, that remaining in zone is challenging.



Stimulation - Methods

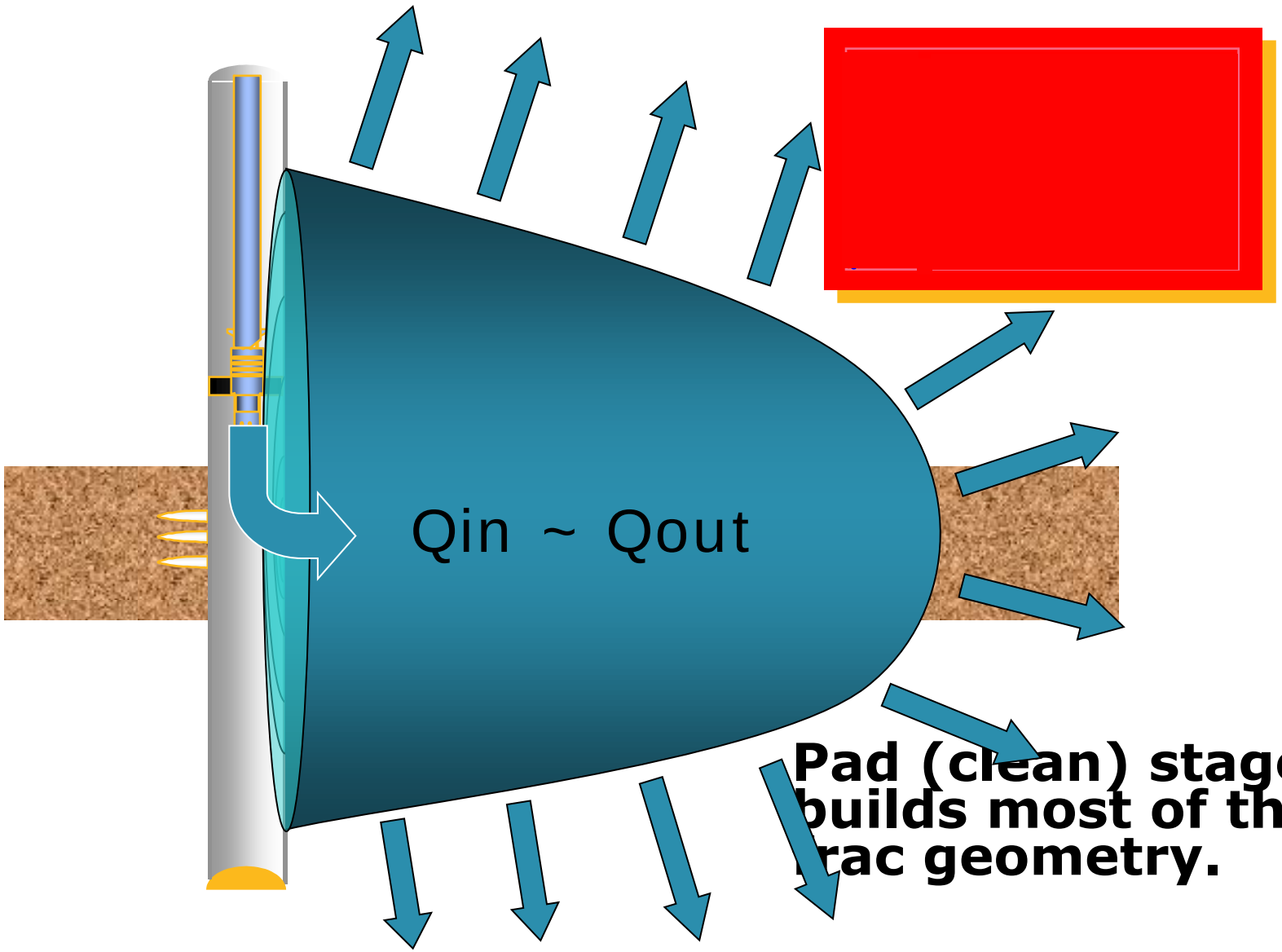
- In general, 3 types of stimulation are employed in the DUC.

  - **Matrix Acidizing**: Injecting HCl into the matrix at pressures below fracture pressure.

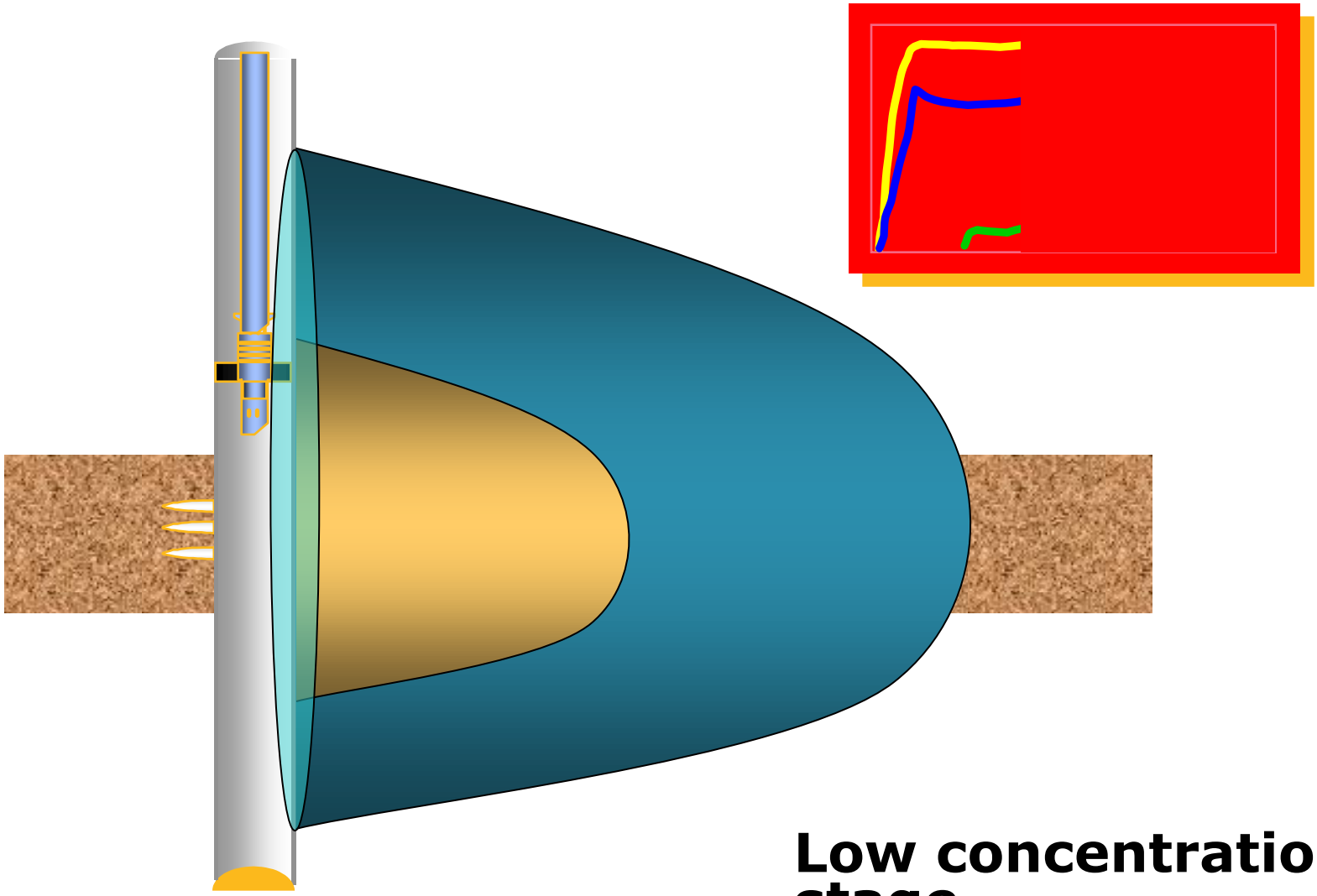
  - **Hydraulic Fracturing with Proppant**: Intentionally fracturing the reservoir layer(s) in order to create large, highly conductive fractures. Substantial increase in reservoir contact and drainage area.

  - **Hydraulic Fracturing with Acid**: Similar to proppant fracturing, but rather than filling the fractures with highly conductive proppant, creating conductivity by acid etching the walls of the fractures.

Pumping Sequence and Fracture Growth

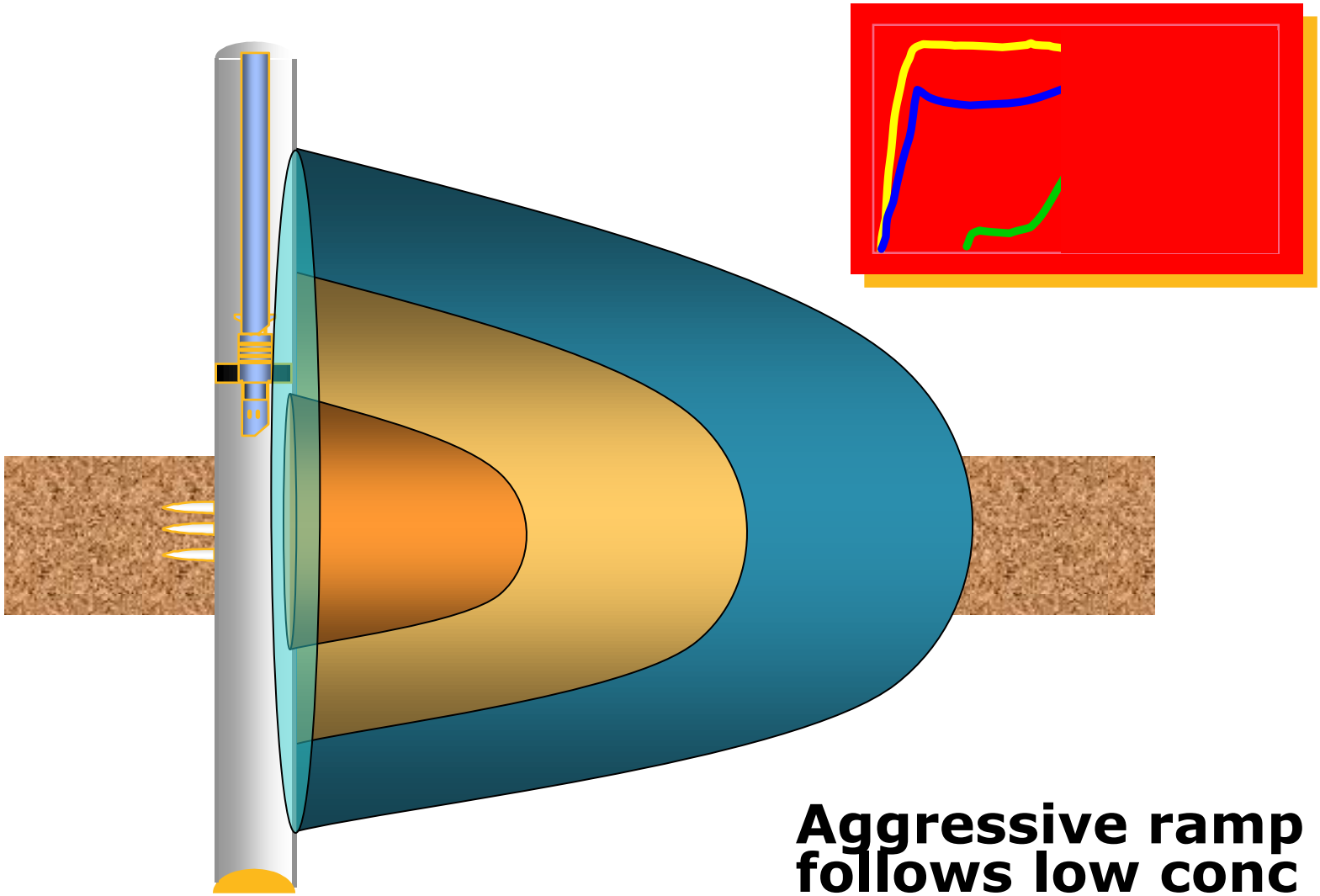


Pumping Sequence and Fracture Growth



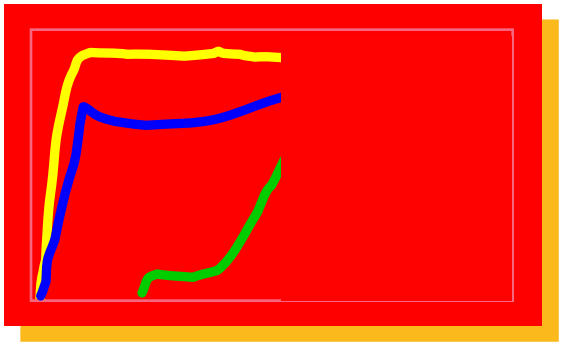
Low concentration stage

Pumping Sequence and Fracture Growth



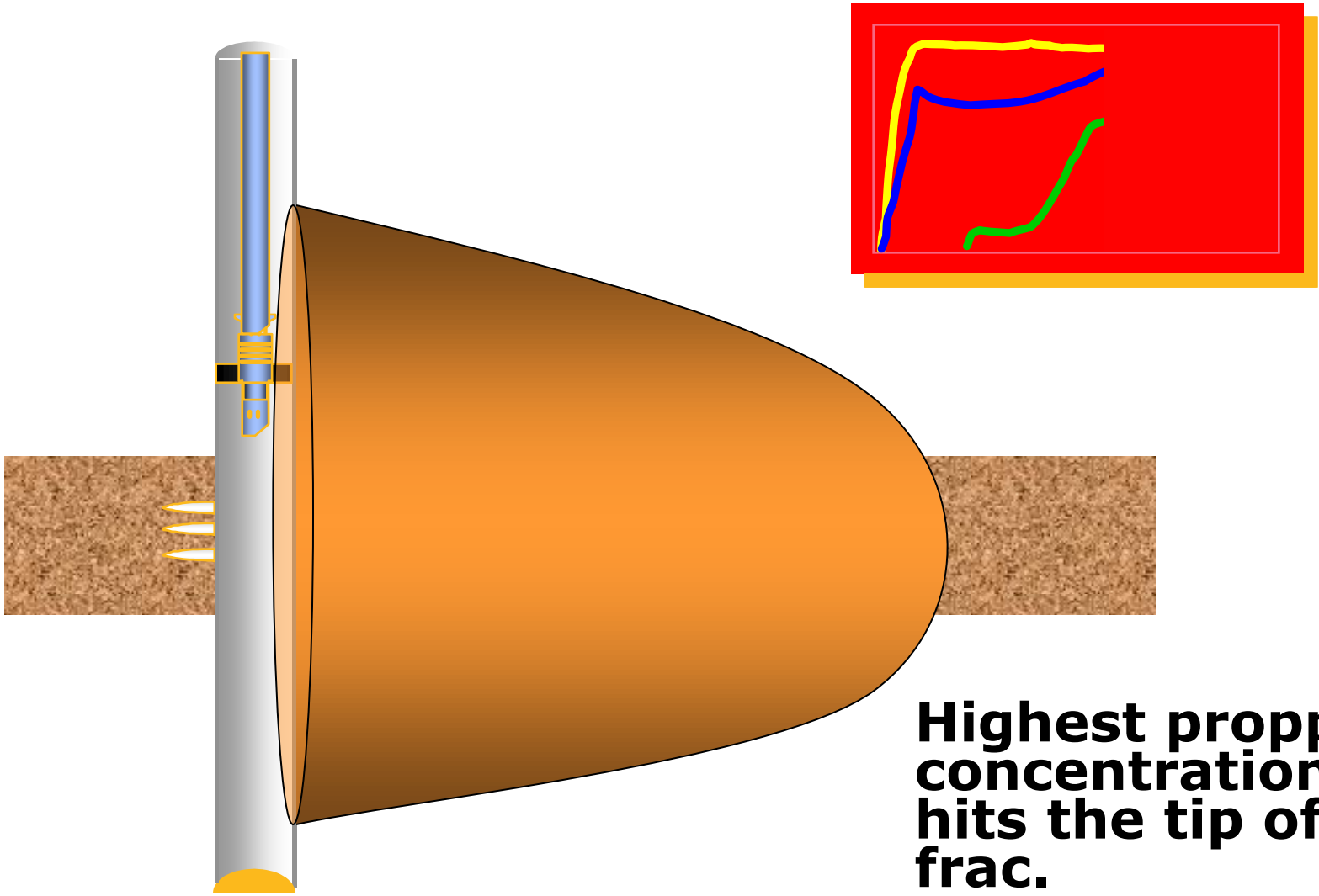
Aggressive ramp follows low conc stage

Pumping Sequence and Fracture Growth



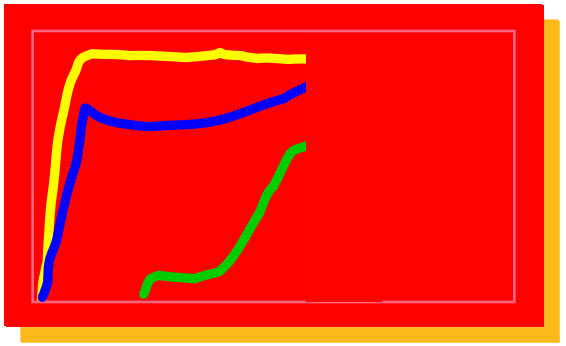
Low conc stage bridges, causing increase in width, allows placing of high concentrations

Pumping Sequence and Fracture Growth



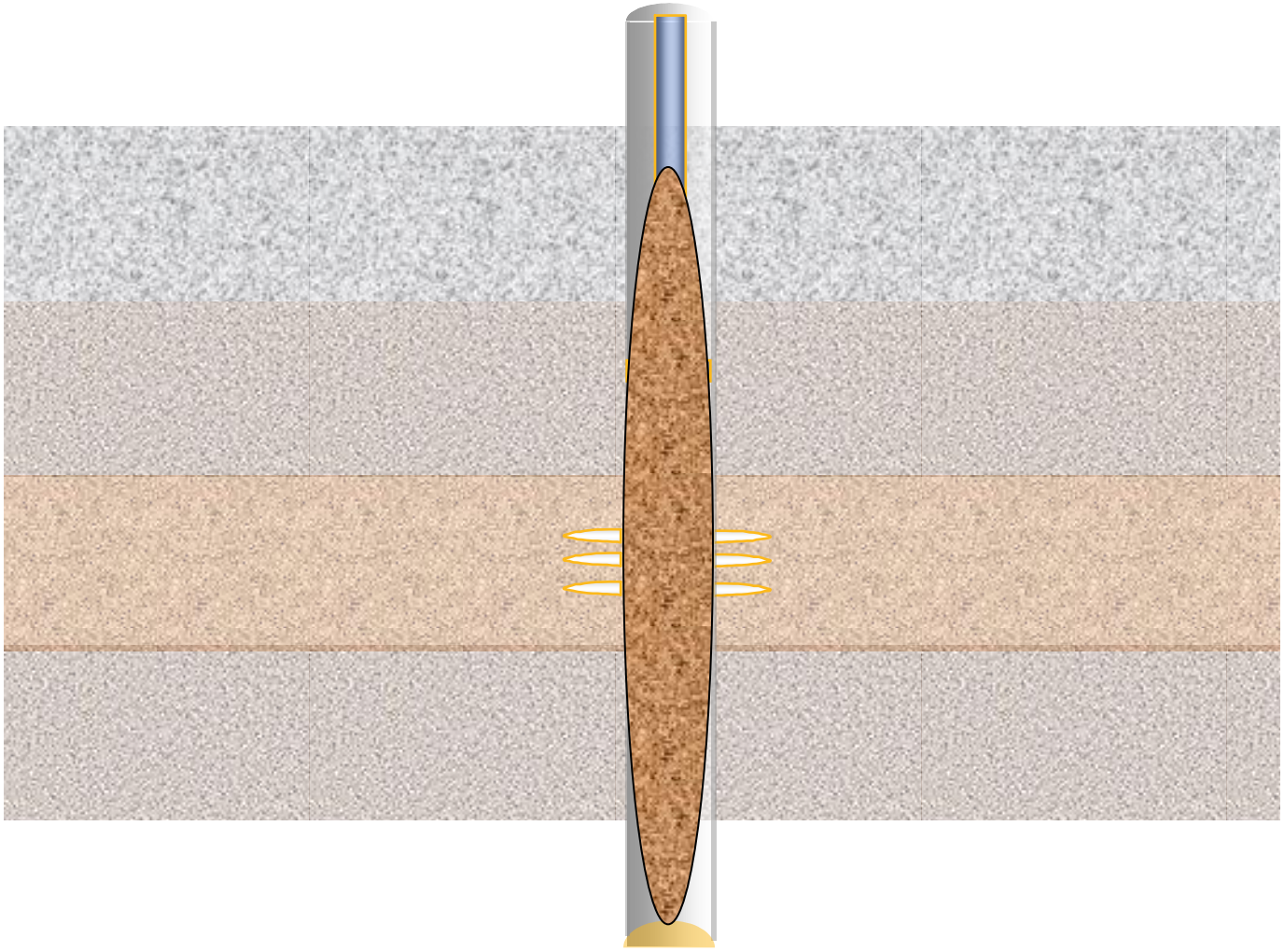
Highest proppant concentration hits the tip of the frac.

Pumping Sequence and Fracture Growth



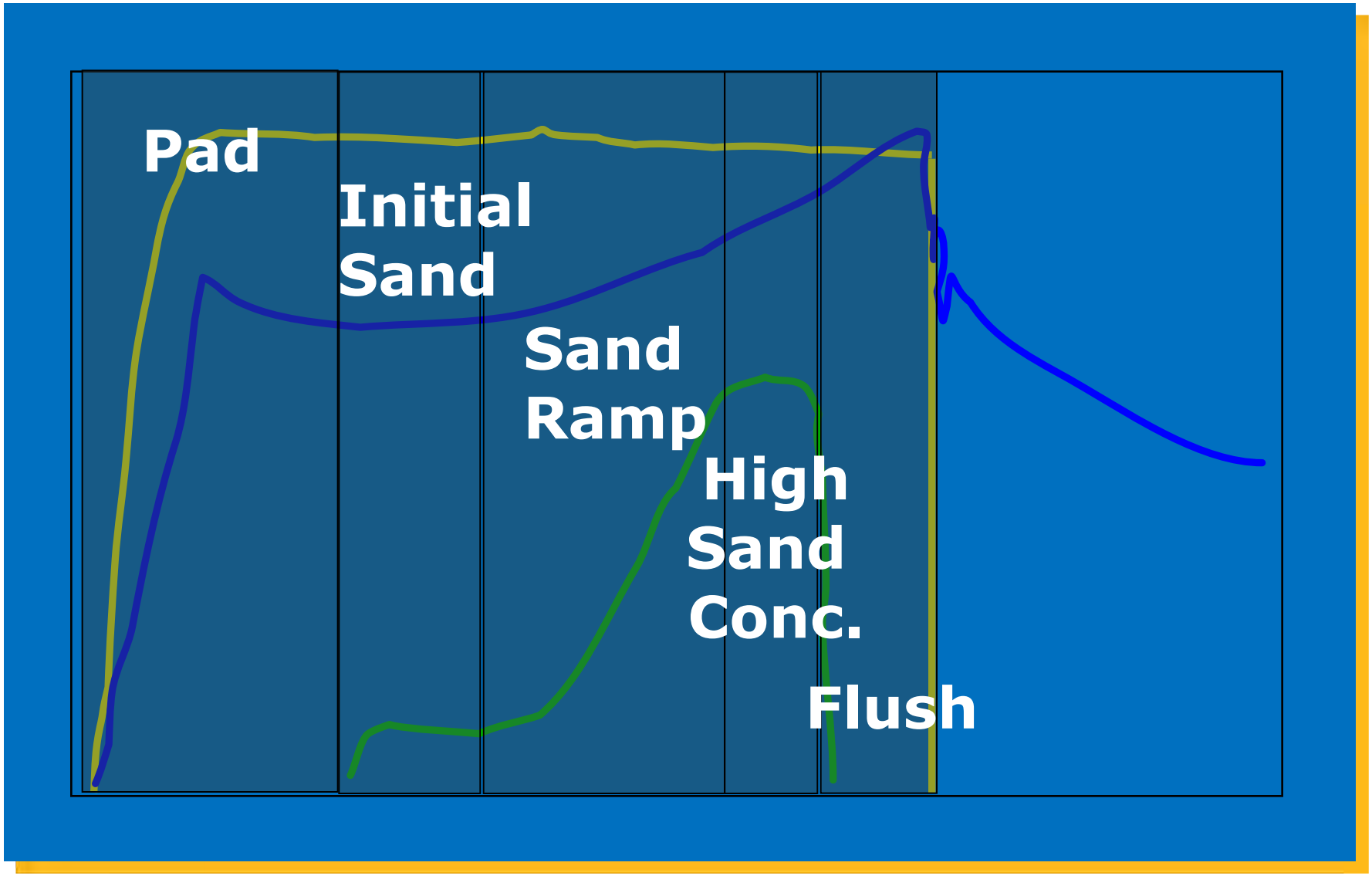
Proppant stacks back from the tip to the wellbore creating conductivity.

Along the Fracture – Side View



Fracture is packed with proppant, creating a conductive pathway or wick to the wellbore.

Simple Analysis and Design



Stimulation – Proppant Fracturing

What is important?

Lithology

Stress barriers and contrast

Sonic logs, cores, triple combo logs

Purity and more importantly clay content

Poro-perm

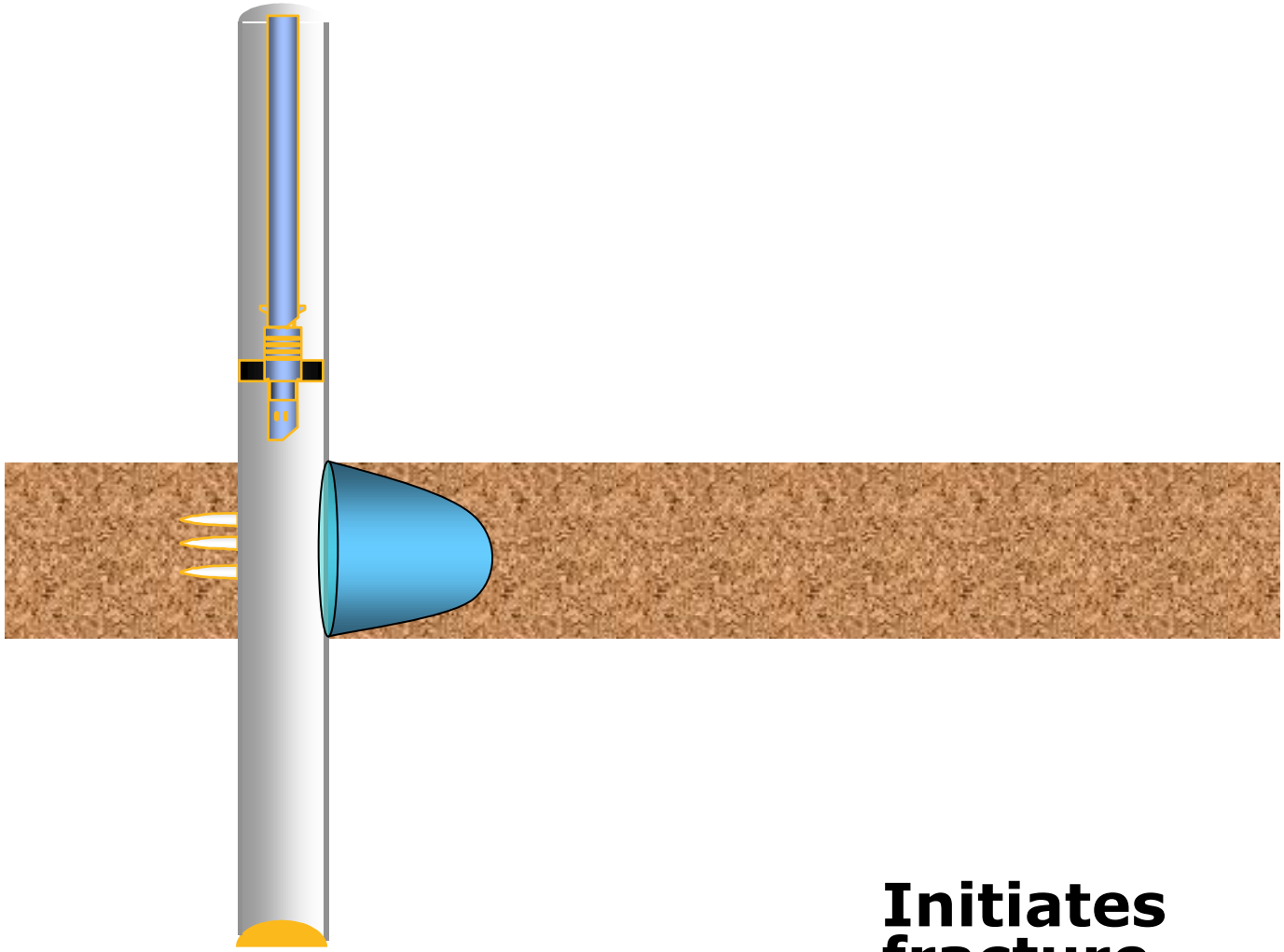
Reservoir pressure

Fracture pressure

Stimulation – Acid Fracturing

- **Hydraulic Fracturing with Acid**: Similar to proppant fracturing, but rather than filling the fractures with highly conductive proppant, creating conductivity by acid etching the walls of the fractures.

Pad



Initiates fracture

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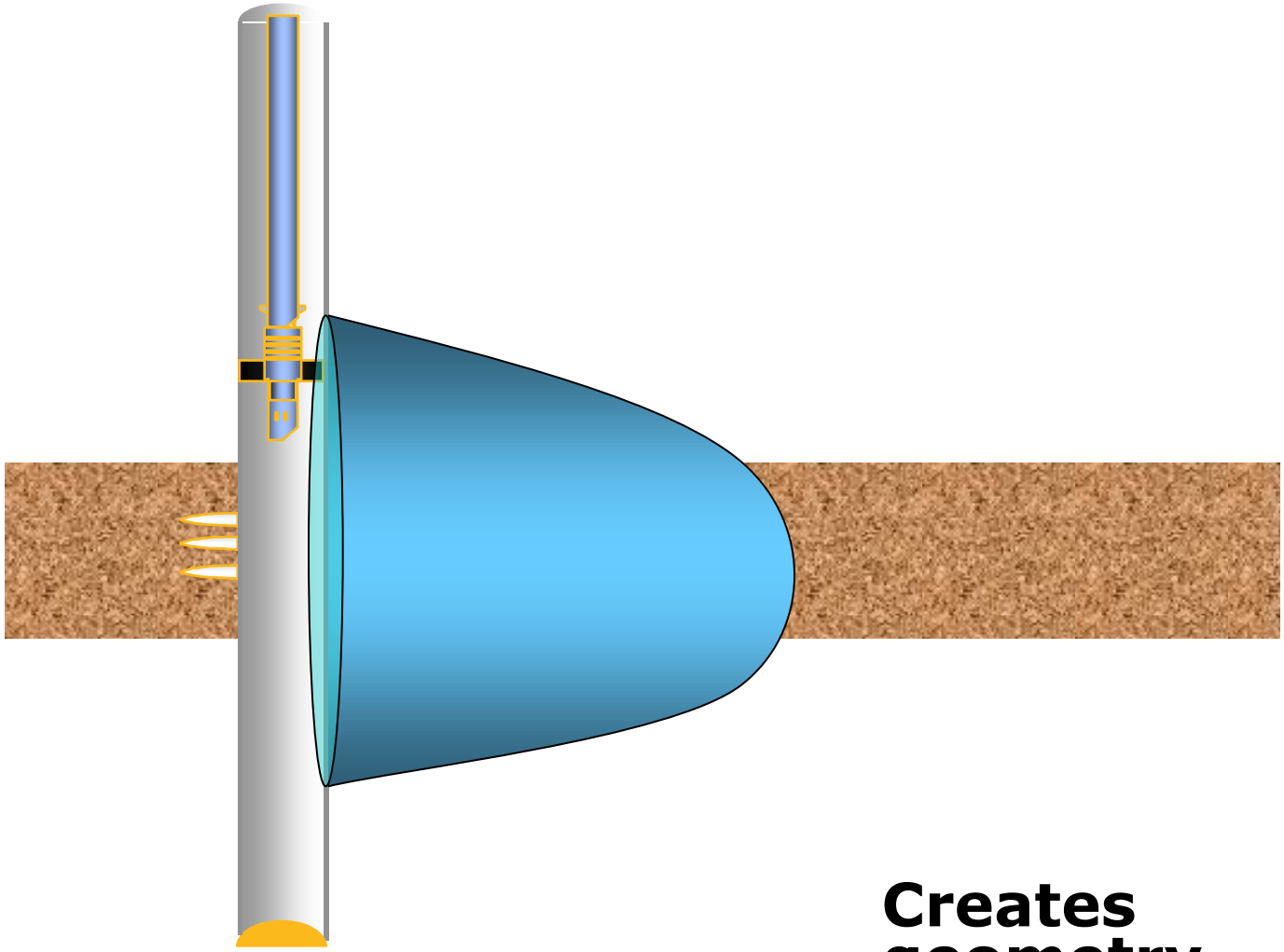

Creates geometry

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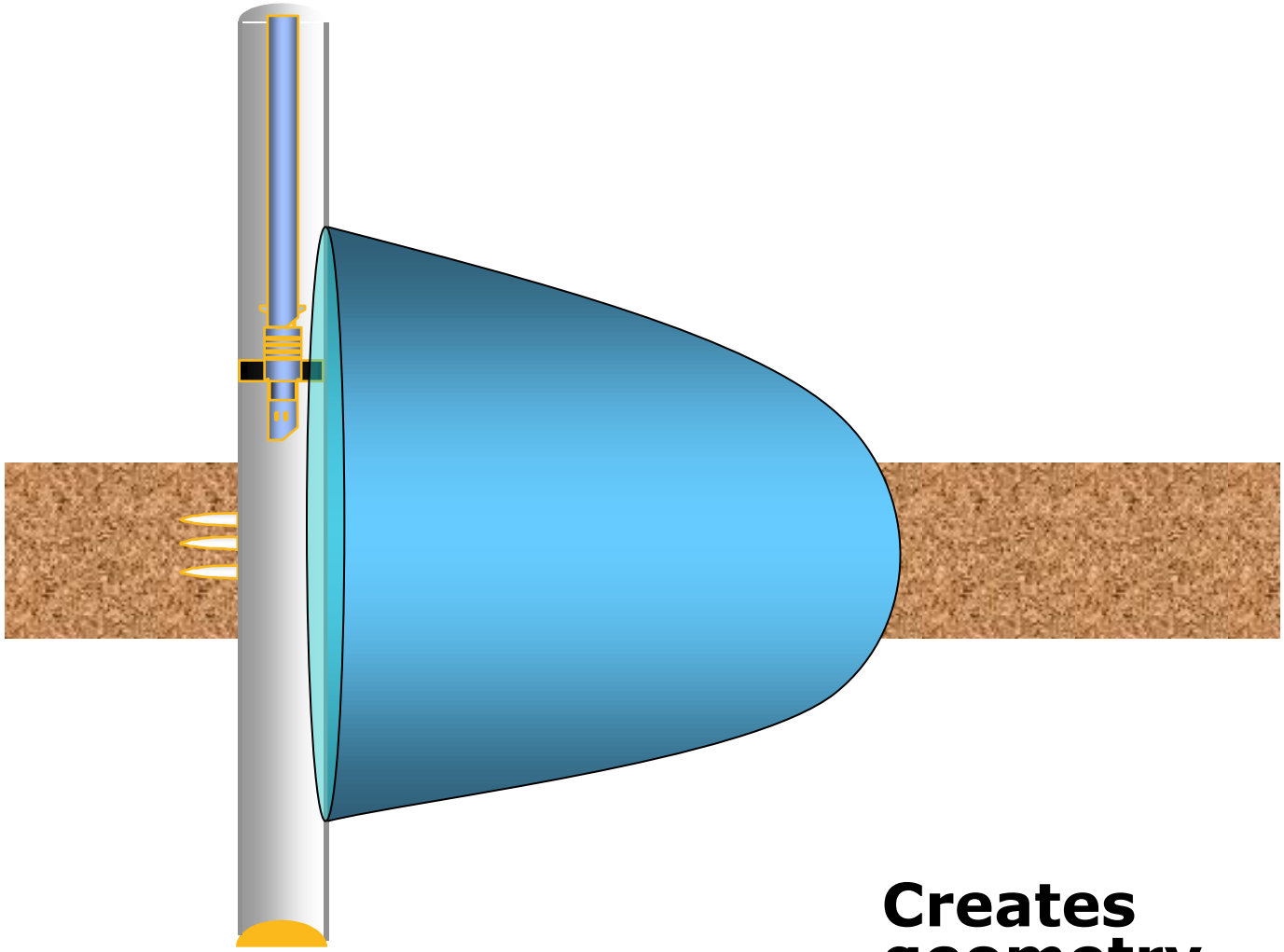
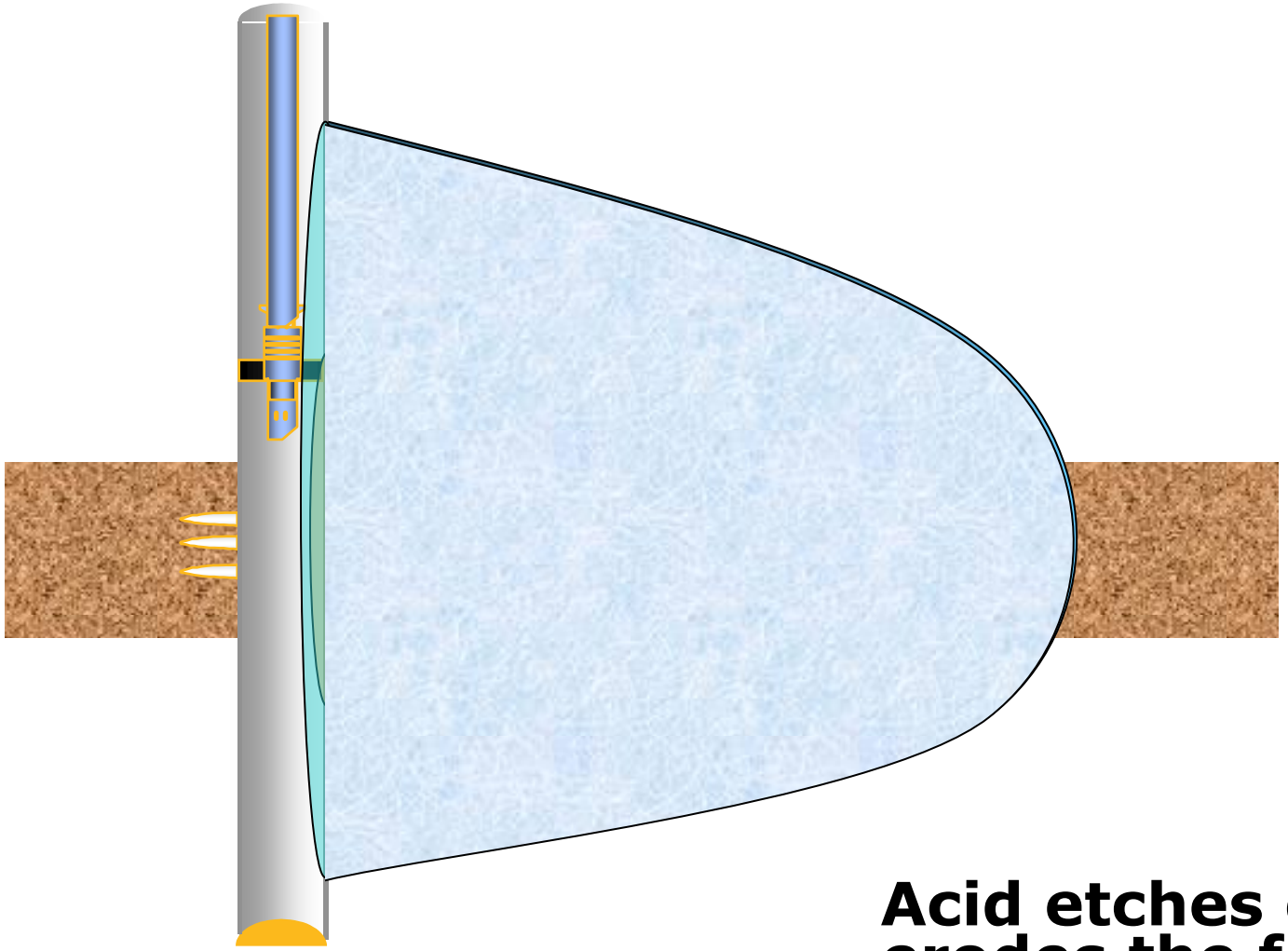


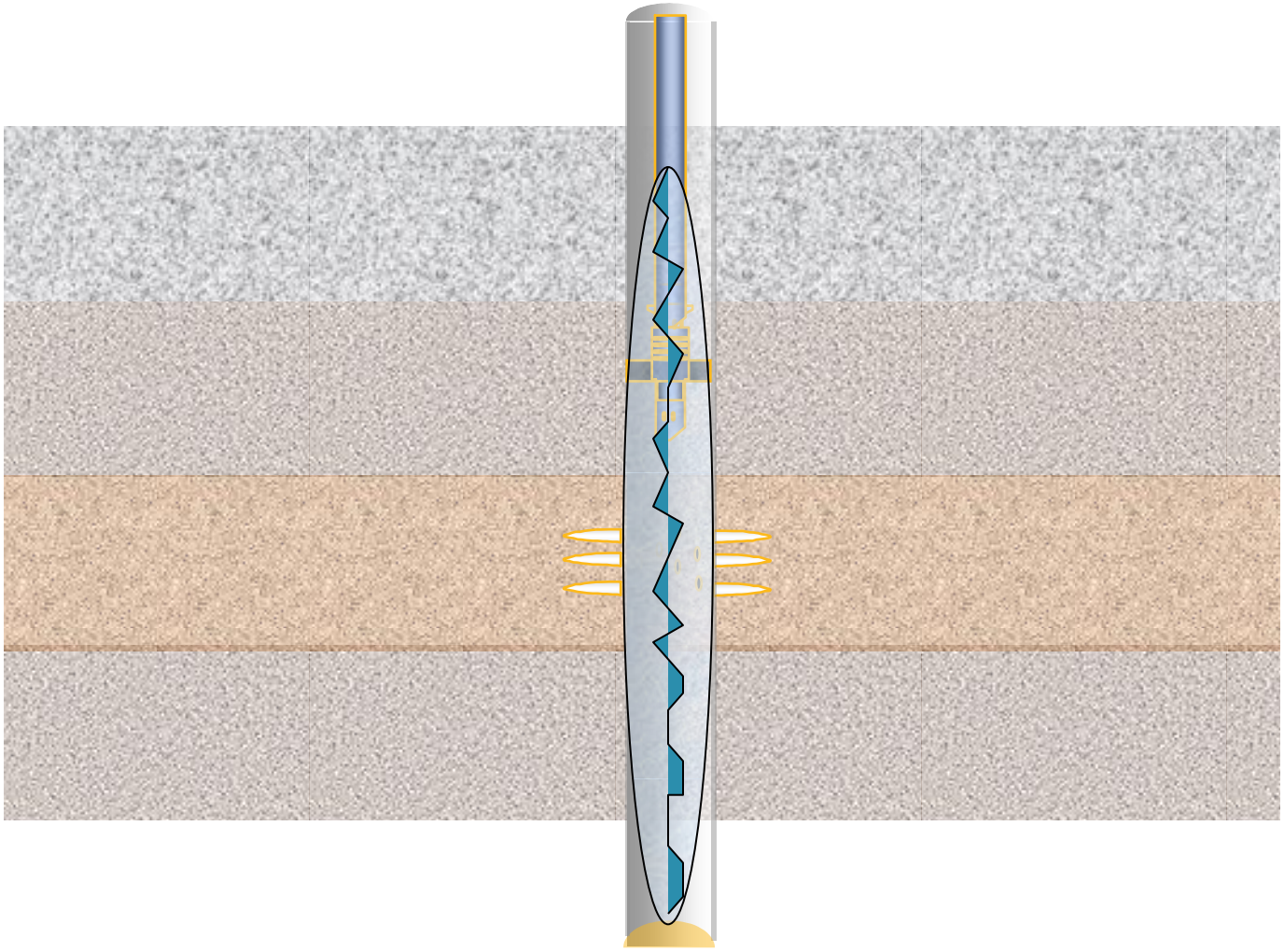
Creates geometry

Acid Stages



Acid etches or erodes the faces of the fracture

Allong the Fracture – Side View



Etched faces of the fracture walls come together unevenly, creating an open pathway to the wellbore.

Stimulation – Acid Fracturing

What is important?

Lithology

Stress barriers and contrast

Sonic logs, cores, triple combo logs

Purity and more importantly clay content

Poro-perm

Reservoir pressure

Fracture pressure

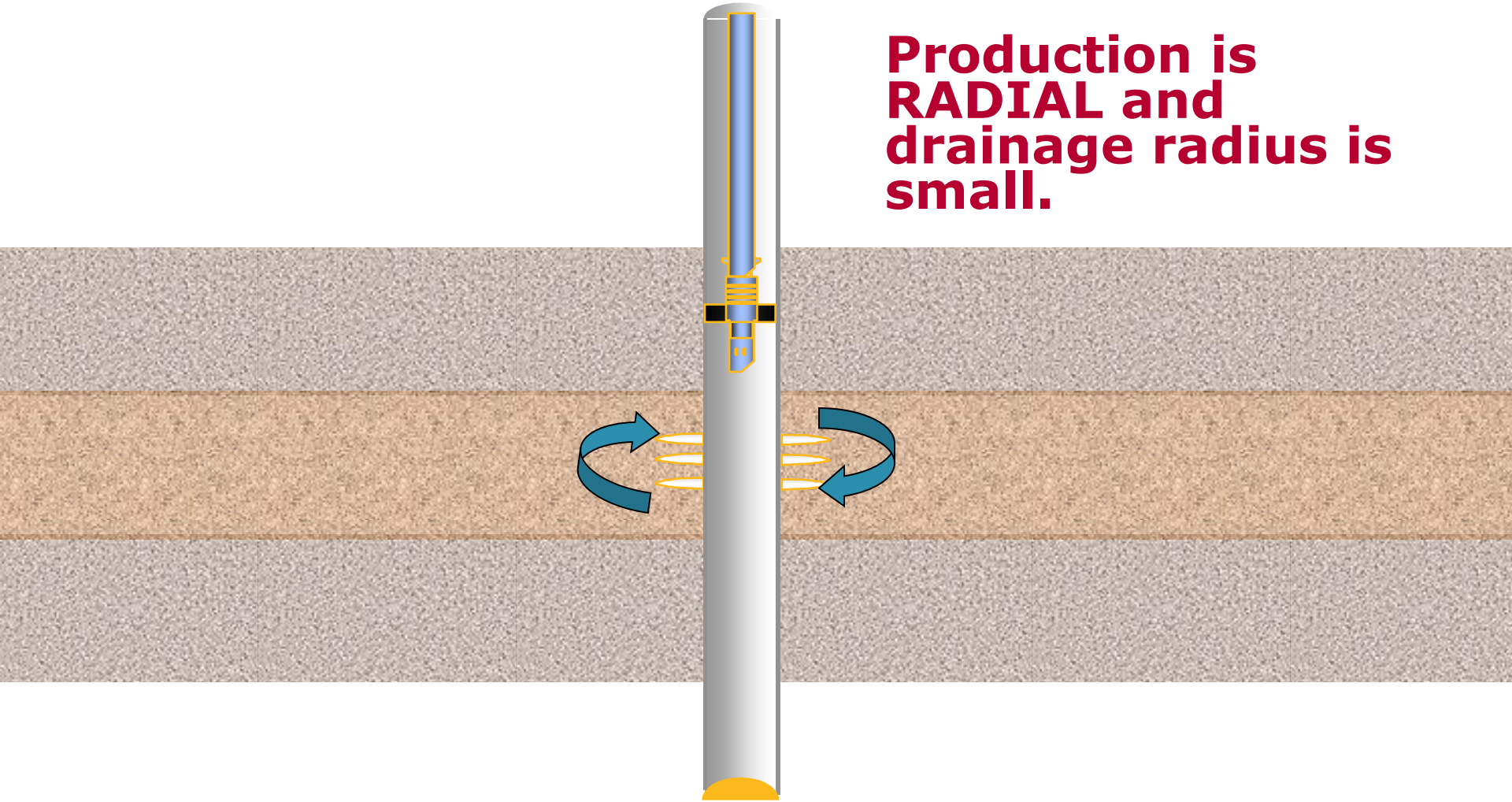
Core testing for hardness, etching, undissolved solids and retained conductivity.

Why We Do What We Do.

- Increase production
- Increase drainage radius, contacting more of the reservoir
- Increase the injection rate for injector wells
- INCREASE AREA AVAILABLE TO FLOW

- Bypass damage
- Mitigate scale effects
- Sand control

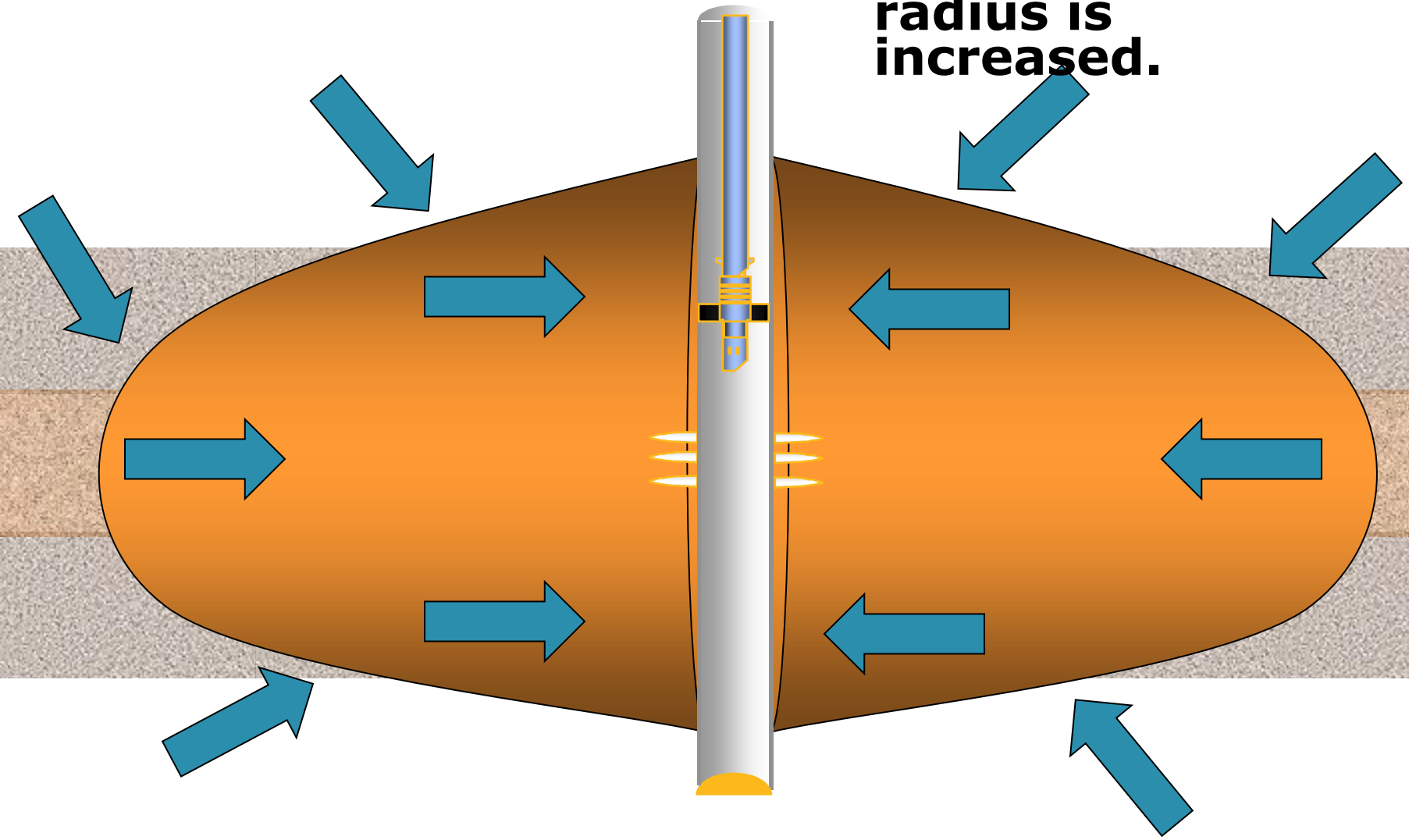
Un-Fractured Well



Production is RADIAL and drainage radius is small.

Fractured Well

Production becomes LINEAR along the fracture, and drainage radius is increased.

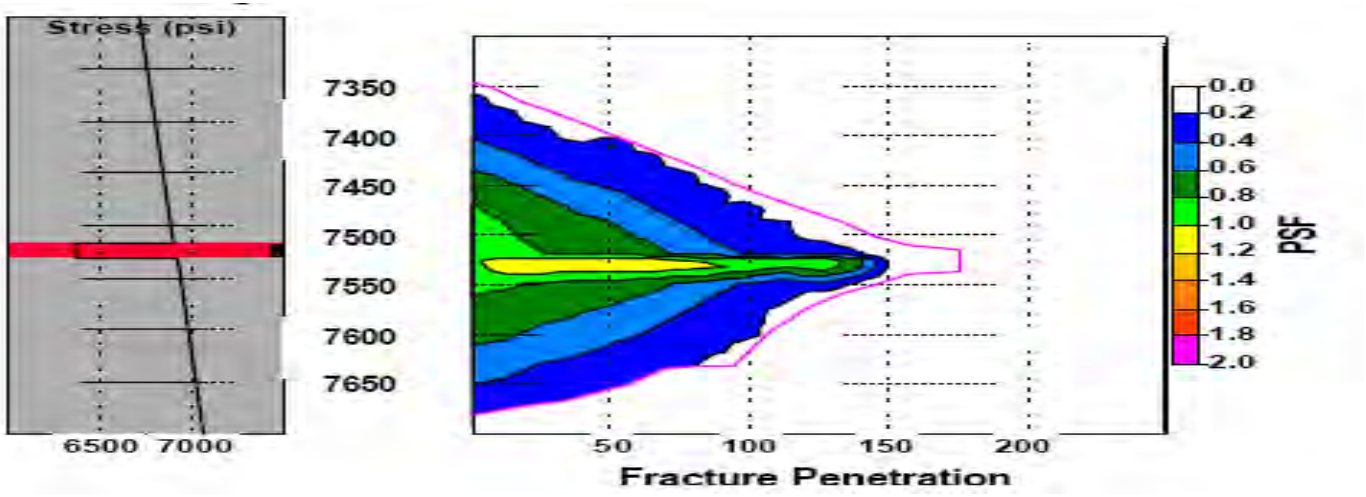


Fluid Systems and Design

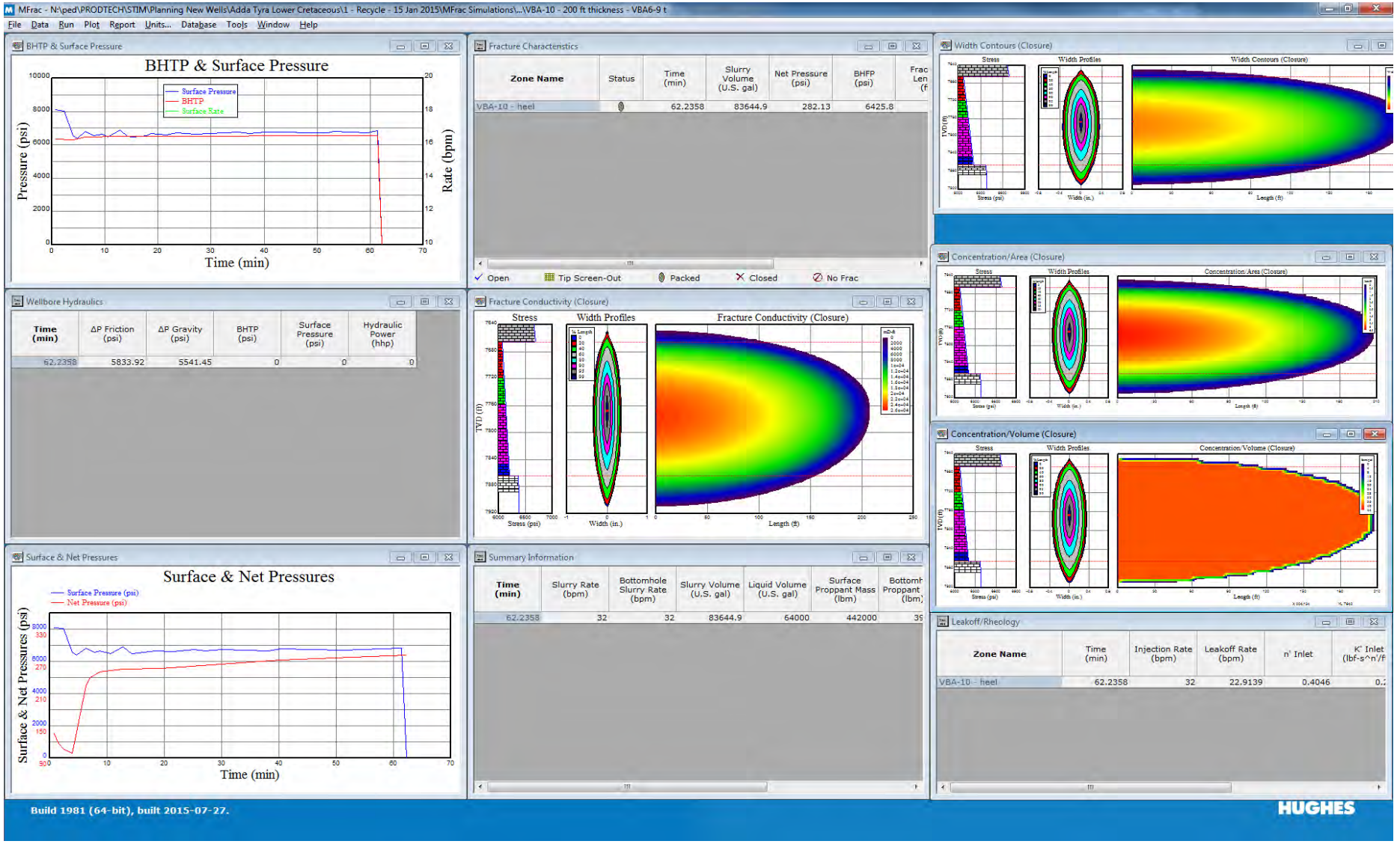
- Environmental ratings of Yellow or PLONOR for all components of the fracturing treatment.
- Tailored breaker packages to ensure highest regained perm and lowest polymer residue in the proppant pack.
- Efficient fluid deign for optimal proppant placement.

Fluid Systems and Design

- Fracture design and analysis in a variety of fracture simulation software packages.
- On sight fracturing engineer and fluid quality assurance.
- Analysis of minifrac and steprate diagnostic pumping to determine rock properties for fracturing applications. (this can be done prior to large scale fracturing operation)

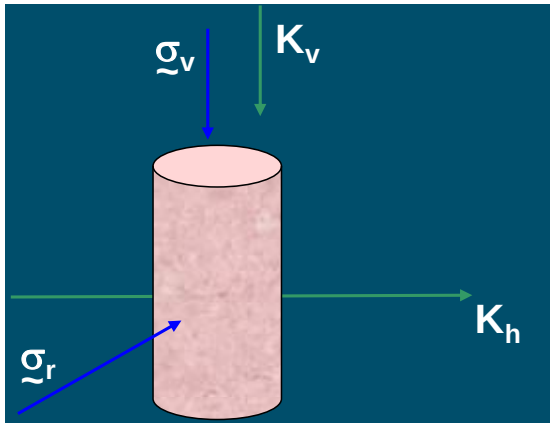


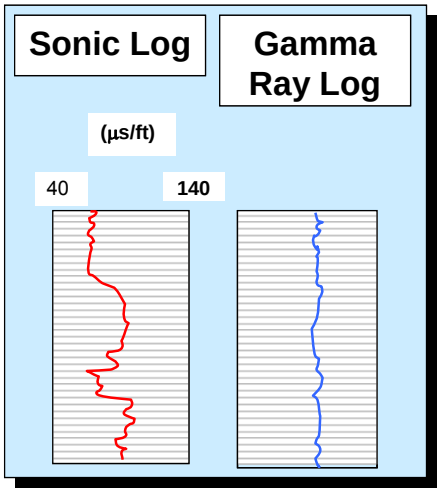
Fluid Systems and Design



Core Testing

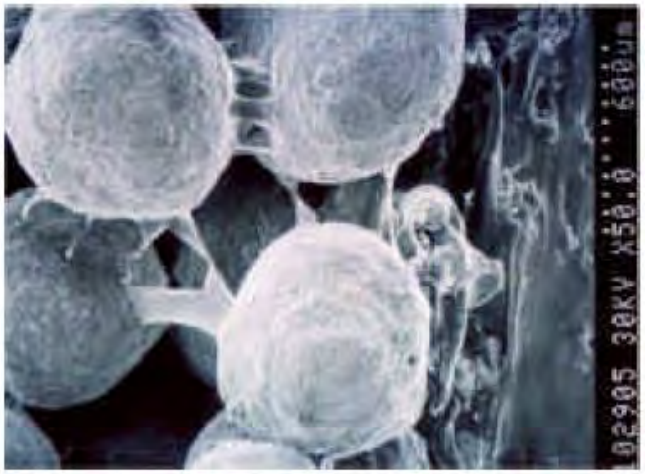
- Log Calibration:
  - Process log using sonic, gamma ray and density to give log derived modulus/Poisson's. Calibrate by selecting ~6-10 horizontal plugs and measuring static elastic properties in lab.
- Leak Off:
  - Select high and intermediate permeability ranges. Determine Cw/spurt losses under reservoir simulated conditions with clean up. Include clean up as a function of drawdown to dead crude to simulate flow dynamics correctly.





Core Testing

- Compatibility Testing:
  - Selected higher clay content intervals from XRD to determine minimum chloride ions to avoid swelling/migration of clays and/or need for commercial clay stabiliser.
- Proppant/Fluid regained conductivity
  - Using reservoir core, realistic temperature and stress, selected proppant and clean up fluids, obtain effective fracture conductivity data. Compare to model, input for proppant sizing etc.



Use and discharge of offshore chemicals

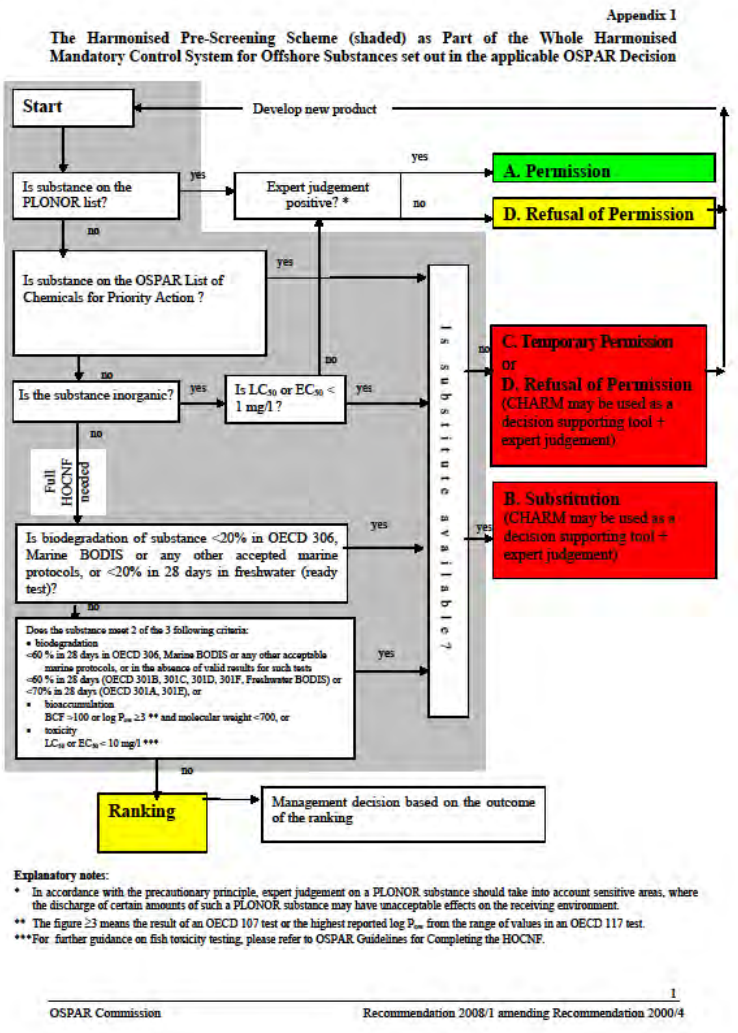
Maersk Oil strives only to use chemicals classified as Plonor (Green) or Ranking (Yellow), if it's technical possible.

Use of chemicals classified as substitution (Red), will only be accepted after separate assessment and only in a limited period.

Red chemicals: Contains substances or groups of substances that are toxic, persistent and liable to bio accumulate.

Yellow chemicals: Chemicals neither red nor green are called Ranking. The Ranking gives an indication of the relative environmental risk and is used for choosing the least environmentally hazardous chemical.

Green chemicals: Contains substances form the PLONOR list, or is inorganic non toxic. ("Substances that Pose Little or NO Risk to the environment").



Appendix 1

The Harmonised Pre-Screening Scheme (shaded) as Part of the Whole Harmonised Mandatory Control System for Offshore Substances set out in the applicable OSPAR Decision

Explanatory notes:

* In accordance with the precautionary principle, expert judgement on a PLONOR substance should take into account sensitive areas, where the discharge of certain amounts of such a PLONOR substance may have unacceptable effects on the receiving environment.

** The figure ≥3 means the result of an OECD 107 test or the highest reported log P_{ow} from the range of values in an OECD 117 test.

***For further guidance on fish toxicity testing, please refer to OSPAR Guidelines for Completing the HOCNF.

If one substance is red the product is rated as red.

For inorganic substance

Toxicity LC50 < 1mg/l

For organic substance

If biodegradation of the substance <20%

If the substance meet 2 of 3

1. Biodegradation <60 % in 28 days
2. Bioaccumulation log Pow ≥3 and MW <700
3. Toxicity LC50 < 10mg/l

Useful links:

OSPAR Commission: http://www.ospar.org/welcome.asp?menu=0

CEFAS Guide to chemical registration:
http://www.cefas.defra.gov.uk/industry-information/offshore-chemical-notification-scheme/guide-to-chemical-registration.aspx

Danish Energy Agency, Oil and Gas:
http://www.ens.dk/en-US/OilAndGas/Sider/Oilandgas.aspx

European Chemicals Agency: http://echa.europa.eu/web/guest

EUROPEAN UNION: http://europa.eu/publications/index_en.htm

REACH: http://echa.europa.eu/web/guest/regulations/reach/

CLP: http://echa.europa.eu/web/guest/regulations/clp

Biocidal Products Regulation:
http://echa.europa.eu/regulations/biocidal-products-regulation