Well stimulation
History, benefits and application in Peru

Gerrit Nitters
Independent consultant

Introduction

- Who am I?
  - A specialist in well stimulation operations with over 40 years' experience the oil industry
  - I was Shell's global well stimulation coordinator and Principal Technical Expert on well stimulation providing active advice
  - After retirement from Shell in 2006 I founded the Nitters Petroleum Consultancy Int. B.V.
  - Support (including on-site) on acid and fracturing treatments for a range of oil companies including RWE DEA (now INEOS), Shell and ExxonMobil
  - Involved in Geothermal Energy projects in the Netherlands and a board member of Hoekse Waard Duurzaam, a Dutch energy cooperation
  - Current activity is participation in the formulation of the Regional Energy Strategy (RES) and the Regional Heat Transition strategy together with the authorities
  - I authored and co-authored many SPE papers about well stimulation.
  - SPE's Distinguished Lecturer on Well Stimulation in 2005.
  - In addition, committee member for several SPE conferences and forums on well stimulation.
  - One of the contributors to the SPE Monograph on Acidizing (issued in 2016).
  - I wrote technical guidelines for stimulation of geothermal wells in cooperation with IF Technology for a project of the Dutch Ministry of Economic Affairs.
  - Lecturing at PetroEdge Asia and SCA
    - Well Stimulation Workshop: Practical and Applied - Leo Roodhart, PhD and Gerrit Nitters P & IH (Live Online Version Available)

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Presentation outline

- Introduction
- History of well stimulation
- Current state of the art
  - Matrix Acidizing
  - Hydraulic fracturing
- Application in Peru
  - History
  - Options
  - Issues
- Other stimulation methods
  - (Ultra)Sound
  - Shockwaves (   )
  - Fishbones

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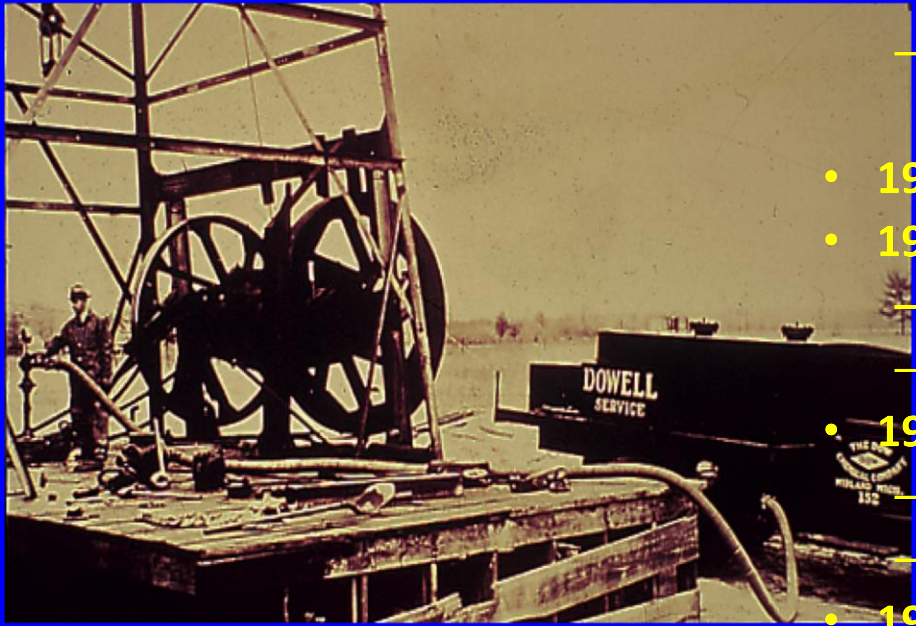
WELL STIMULATION

- What is well stimulation?
  - Any activity that enhances productivity of a well by affecting the near well bore area
    - Matrix treatments – restore natural productivity
    - Hydraulic fracturing – enhance natural productivity
    - Perforation?
    - Etc?

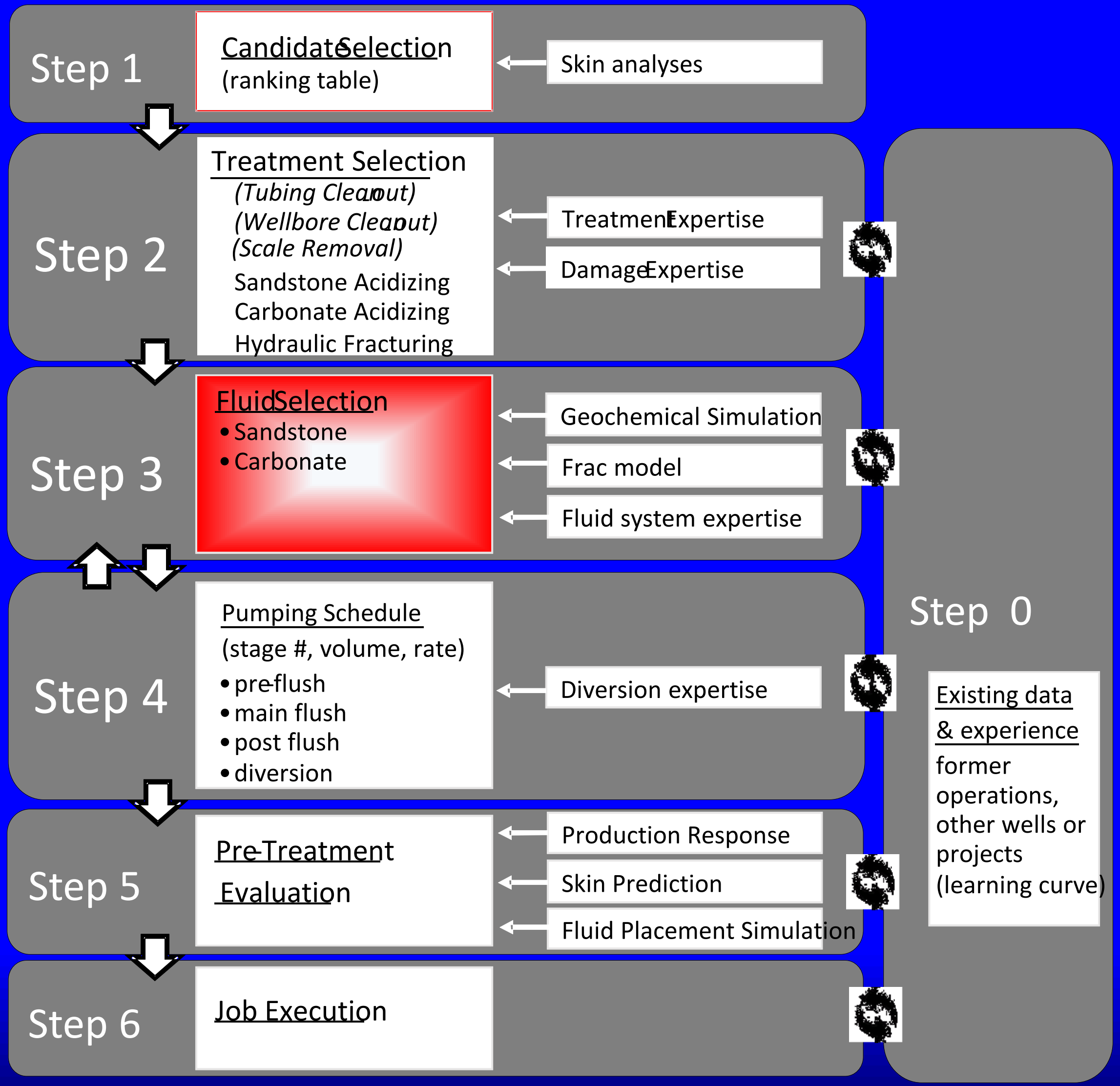
- What is it not?
  - Reservoir enhancement like steam drive or water flooding
  - Removal of scale, wax, etc. from the tubing

History
Acidising treatments

- **1895 First acid job**
  - **Successful HCl treatments by the Ohio Oil company**
  - **Corrosion problems**
- **1932 HCl with arsenic corrosion inhibitor**
- **1933 first HF treatment in sandstone**
  - **disappointing due to formation plugging – precipitates**
- **1940 First HF/HCl treatment**
- **1950/60’s Numerous treatments**
  - **Additives to combat shortcomings**
  - **Better theoretical understanding**
- **1970’s Alternative HF/HCl systems**
  - **Fluoboric acid**
  - **Self Generating mud acids, etc**
- **1980’s Diversion and placement techniques**
  - **Foams**
  - **Coiled tubing**
- **1990’s Computerised design and execution support**



Acidizing in early days



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Carbonate Treatment Selection

Type of rock / damage	Acid Wash / Soak	Matrix Treatment		CFA*	Acid Frac	MHF*	Wormholes Required
		Low Rate	High Rate				
Plugged perforations	X	X					No
Shallow damage, no vugs or fracs		X	X				No
Deep damage, no vugs or fracs		?	X				Yes
Shallow damage, vugs or fracs			X	?			Yes
Deep damage, vugs or fracs				X			Yes
Deep or shallow damage, low perm, natural fracs				X	X	?	No - N/A
Deep or shallow damage, low perm, no natural fracs					X	X	N/A

*CFA = Closed Fracture Acidizing, MHF = Massive Hydraulic Fracturing

Wormhole development

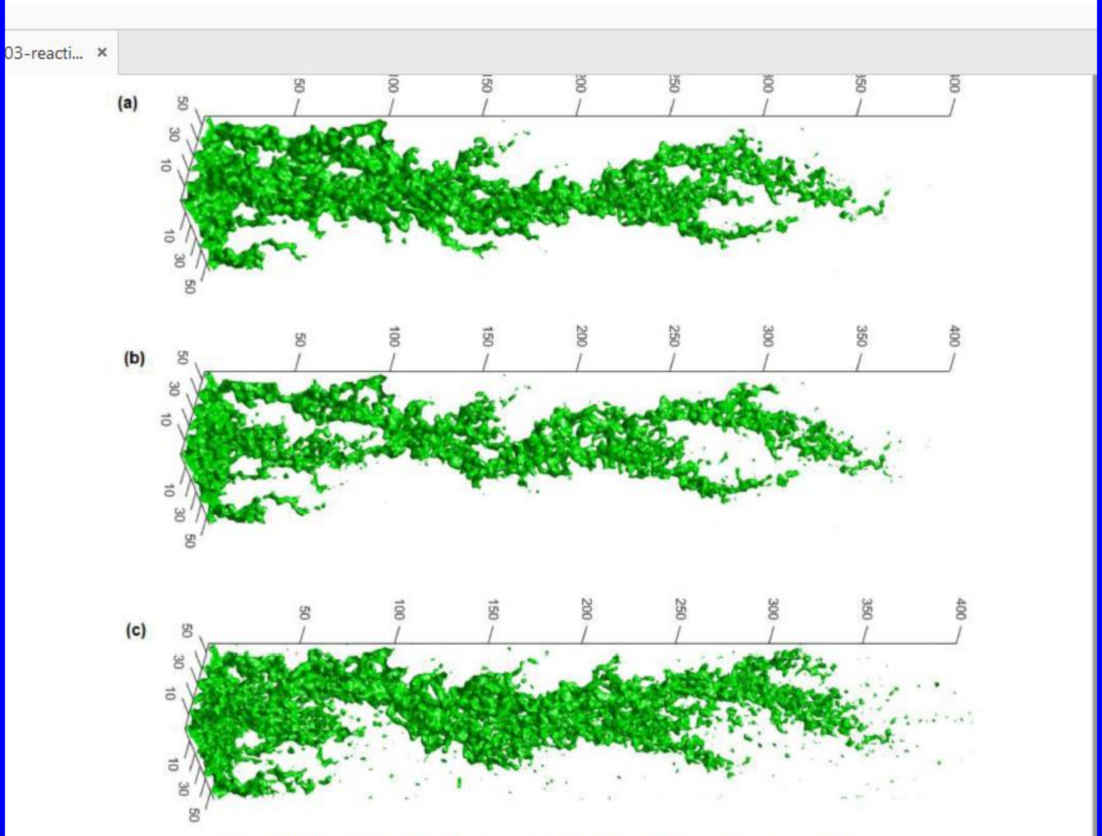
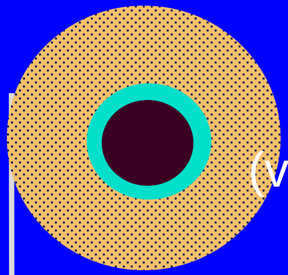
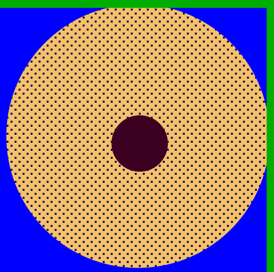
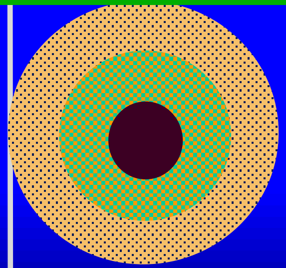


Figure 6—Dissolution patterns obtained using 3D numerical simulations at various dimensionless acid injection velocities (V/Vmin) a) at V/Vmin = 0.7; b) V/Vmin = 1.0 and c) V/Vmin = 2.0.

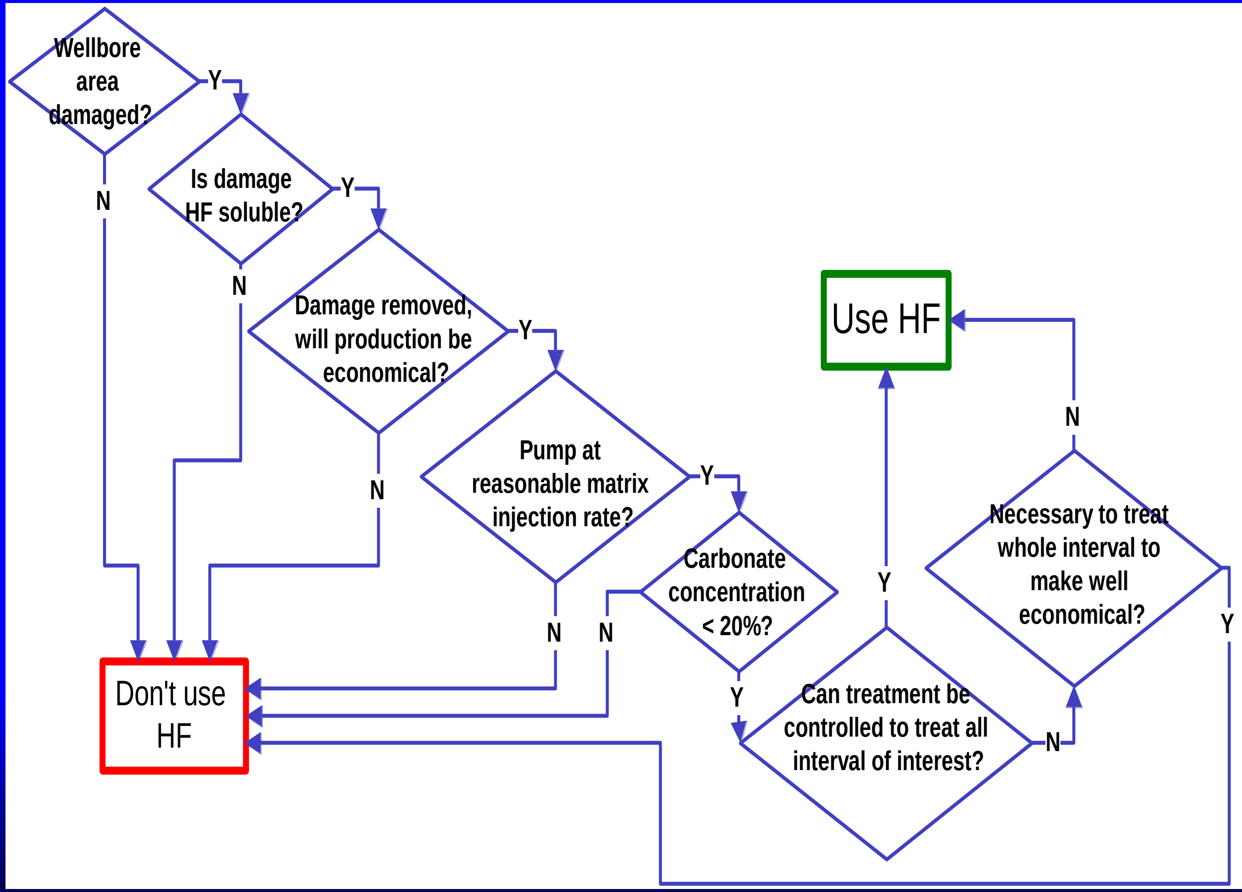
Surface Reaction Rate and Diffusion Rate

Surface Reaction Rate	Diffusion Rate	
HIGH HCl High Temperature	HIGH plain HCl	 Compact Dissolution (very inefficient)
HIGH HCl or organic acids High Temperature	LOW viscosified acid emulsified acid	Wormholing 
LOW Organic Acids Low Temp	HIGH	 Uniform Dissolution (inefficient)

Sandstone reservoirs

Sandstone Matrix Acidizing Chemistry

Flow Diagram for Use of
HF in Sandstone Acidizing



Matrix Acidizing Volume Guidelines

Permeability	Formation temperature <150 °F	150 - 250 °F	>250 °F
K < 20 mD*	100 gal/ft	50 gal/ft	50 gal/ft
K = 20 - 100 mD	150gal/ft	100 gal/ft	100 gal/ft
K >100 mD	200gal/ft	150gal/ft	100 gal/ft

* Consider fracturing for low permeabilities!

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Sandstone Matrix Acidizing Systems

- Procedures and Conditioning
- Damage Removal Systems
  - Regular Mud Acid 3% HF + 12% HCl
  - Half strength Mud acid 1.5% HF + 6% HCl
  - Specially Formulated Mud Acid
    - 0.5 – 1.5 % HF + 6 – 13.5% HCl
- Geochemical Simulation

Pumping schedule

- Paccaloni's on-site design method
- Design curves based on generalised core flushing tests
- Method based on acid response curves

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Sandstone Matrix Acidizing - Damage Removal Systems

	Halliburton	Baker/BJ	Schlumberger
HCl/HF system (including surfactant and aluminum scale inhibitor)	**Sandstone Completion Acid**	**Sandstone Acid** (phosphonic / HF acid mix)	(no product)
Retarded HF/HCl system (Including surfactants)	**Fines Control Acid**	**Sandstone Acid** (phosphonic / HF acid mix)	**Clay Acid** (HF/HCl + Boric acid)
Low concentration HCl/HF system	**K-Spar Acid**	**Sandstone Acid** (phosphonic / HF acid mix)	**Clay Acid** (HF/HCl + Boric acid)
Organic HF systems	**Volcanic Acid**	(HF with formic or acetic acid, no trade name)	**Organic Mud Acid**
High concentration HCl/HF systems	**Silica Scale Acid**	**Sandstone Acid** (phosphonic / HF acid mix)	(no trade name, sometimes referred to as Double Strength Mud Acid)

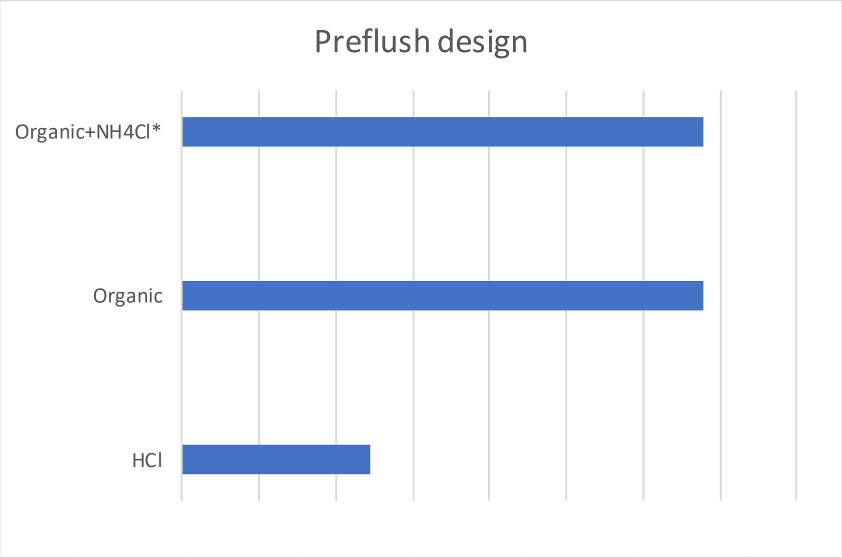
Acidising treatment selection

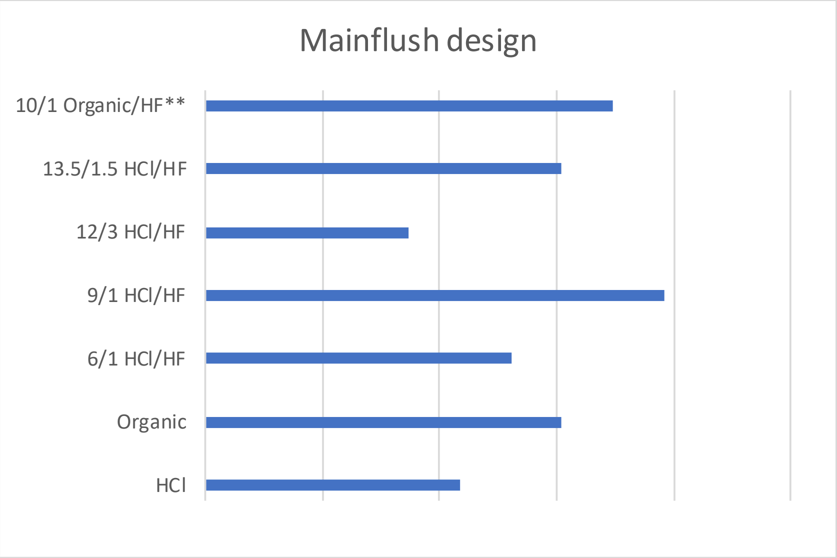
Microsoft Excel Worksheet

Pre and main flush design		Input
		%
minerals	HCl-sensitive clays	
	Zeolites	0
	Carbonate	4
	Kaolinite	3
	Illite	2
	Smectite	0
	Feldspars	7
temperature	F	275

Type '1' in the applicable boxes
Leave the rest empty

Sandstone matrix acidizing - acid selection





*) Acetic or formic acid + 3- 5 % NH4Cl
**)Acetic or formic acid + HF

Hydraulic fracturing development options

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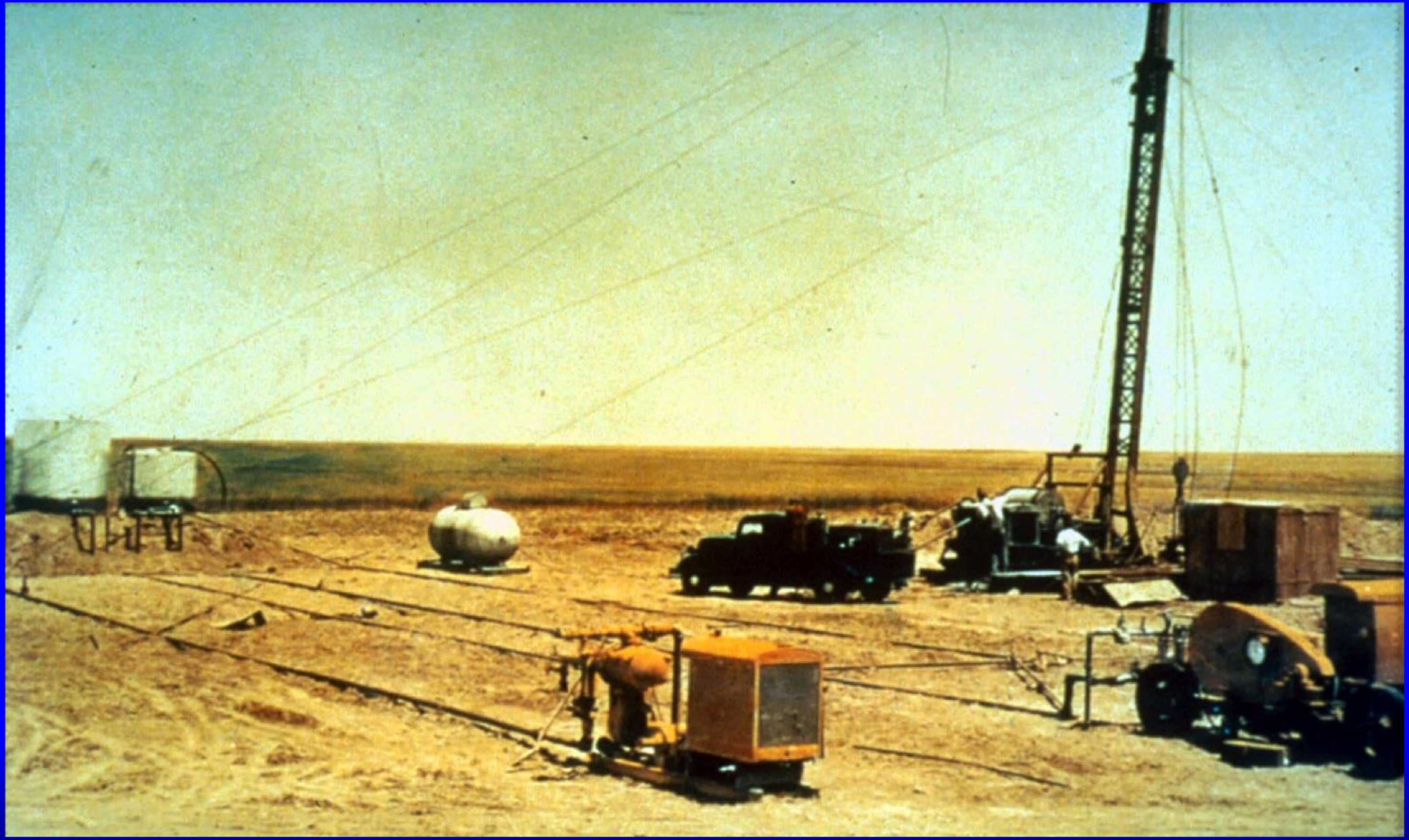
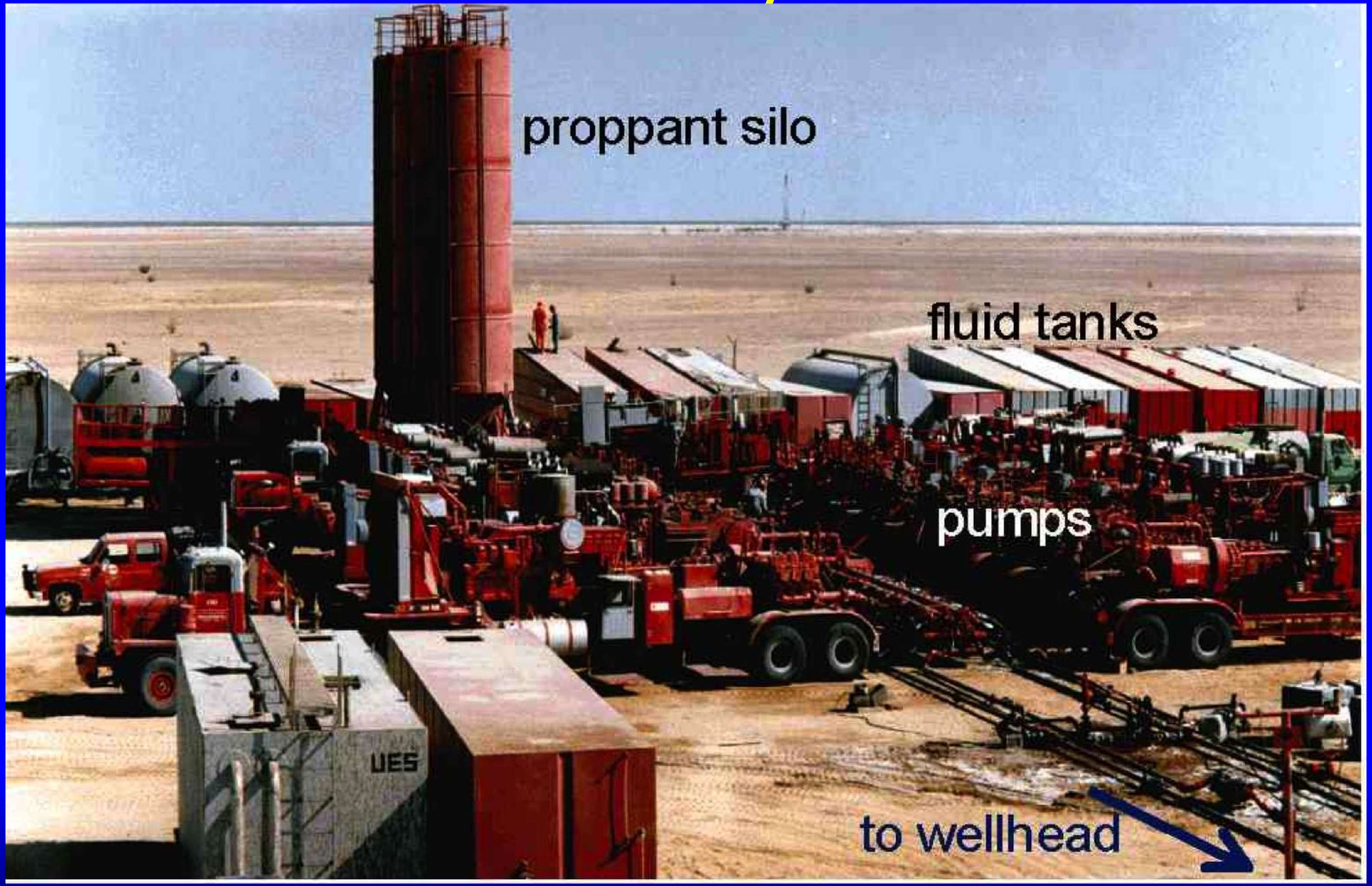
First Hydraulic Fracture Treatment - 1947



Nowadays



Why fracturing?

Well inflow equation:

$$Q = \frac{Kh(P_e - P_{wf})}{\mu . B_0 (Ln\, {}^{r_e}\!/_{r_w} + S)}$$

<u>Fracturing affects:</u>

The skin factor S

- A highly conductive fracture by-passing the skin (Skinfrac or Frac & Pack)

The formation capacity Kh;

- More formation height may be connected with the wellbore, showing up as an increase in Kh

The ratio re/rw;

- Increased effective well bore radius, i.e., r_w is replaced by $L_f/2$ (half the length of the fracture)

- ***it can provide sand control!***

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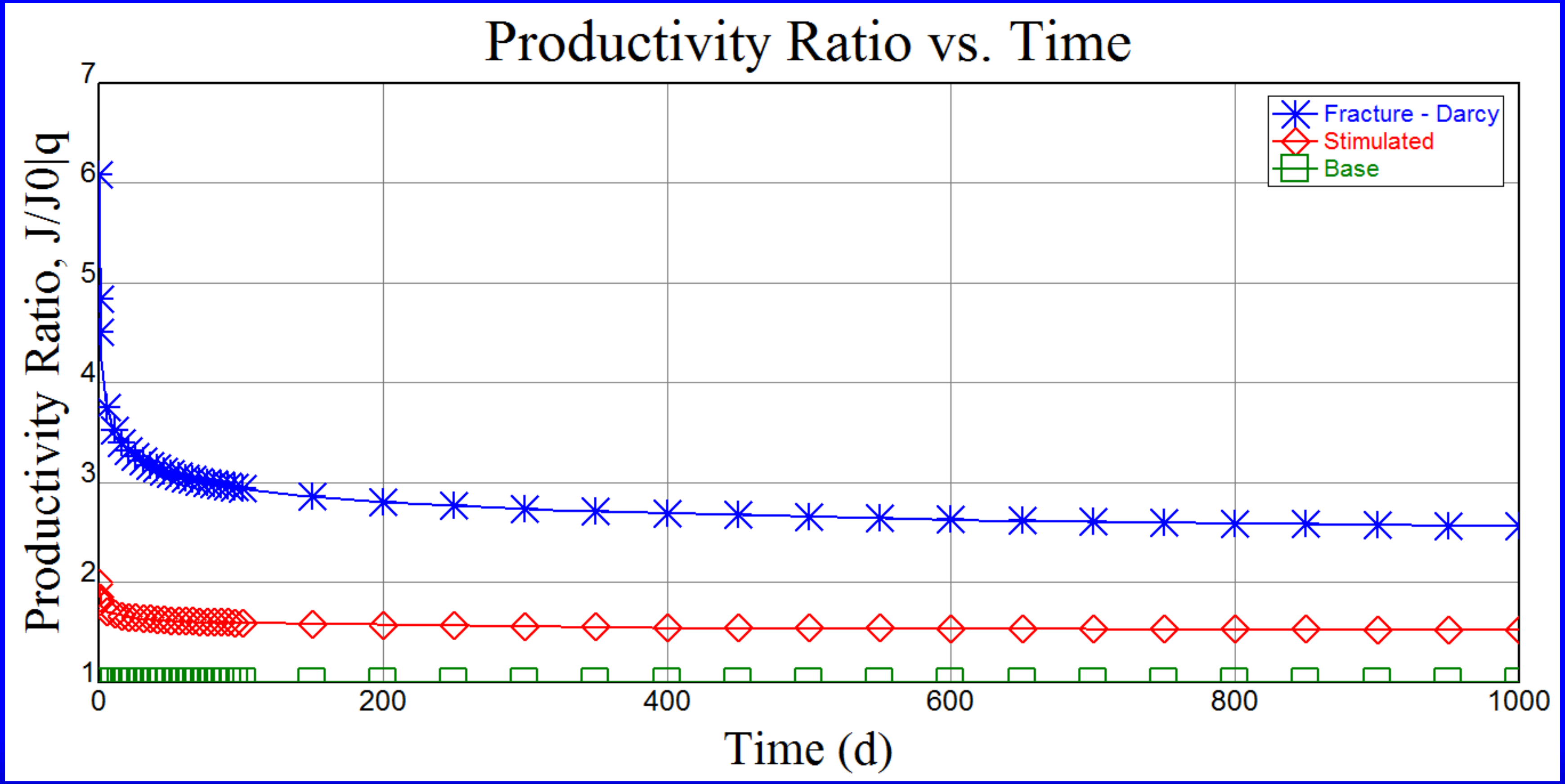
Productivity improvement



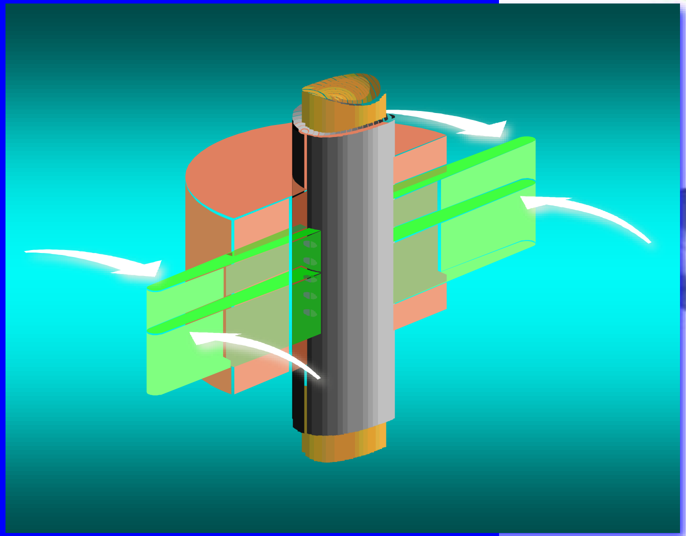
- For the injection well it means **higher injection rates** without **increasing the surface pressure**

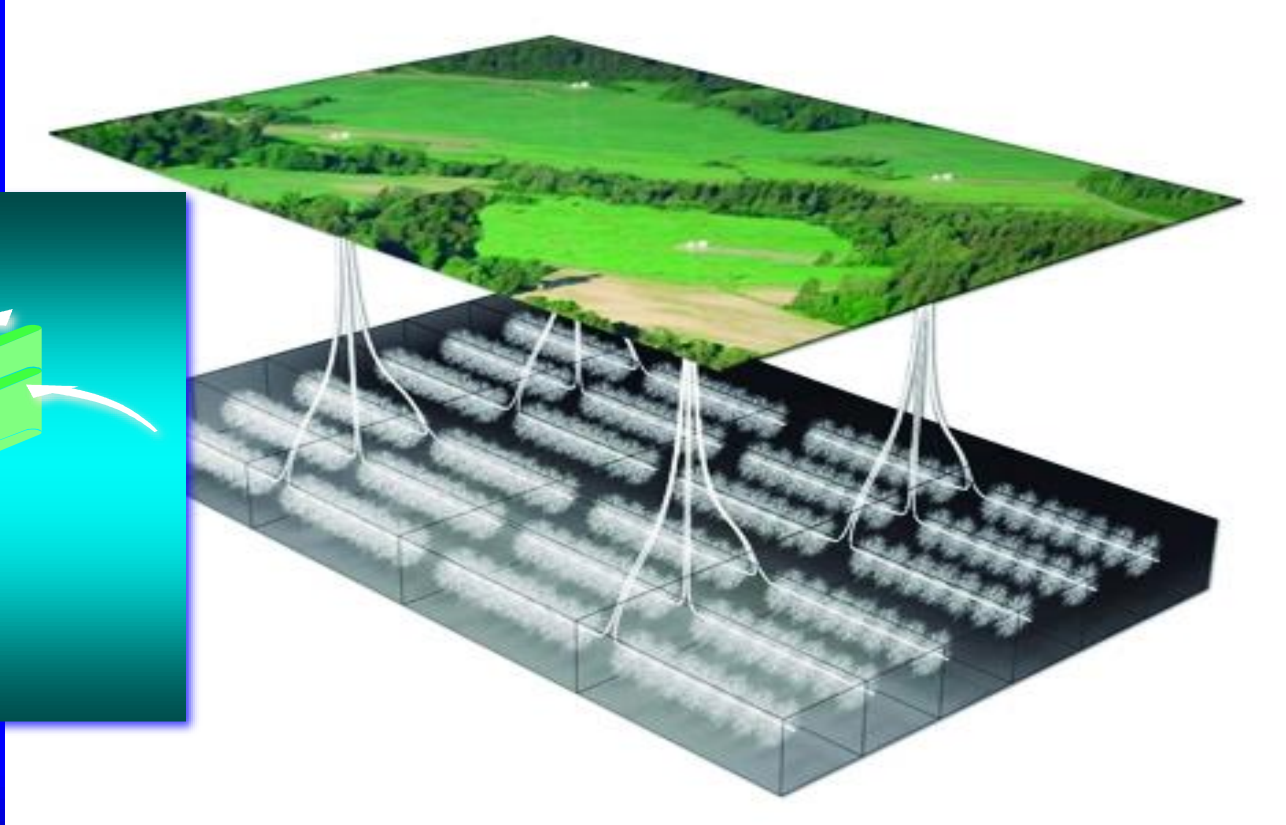
Type of Fracturing treatments

- Skin Frac
- Frac & Pack
- Massive Hydraulic Frac
- Multiple vertical fracs
- Multiple horizontal hole fracs
- Shale gas frac
- Coal Bed Methane frac
- Acid frac

From small frac & packs in high permeability sandstones

To massive multi fracs in Shalegas





What controls a fracture?

- Lots of parameters, but in the beginning, there is the…….

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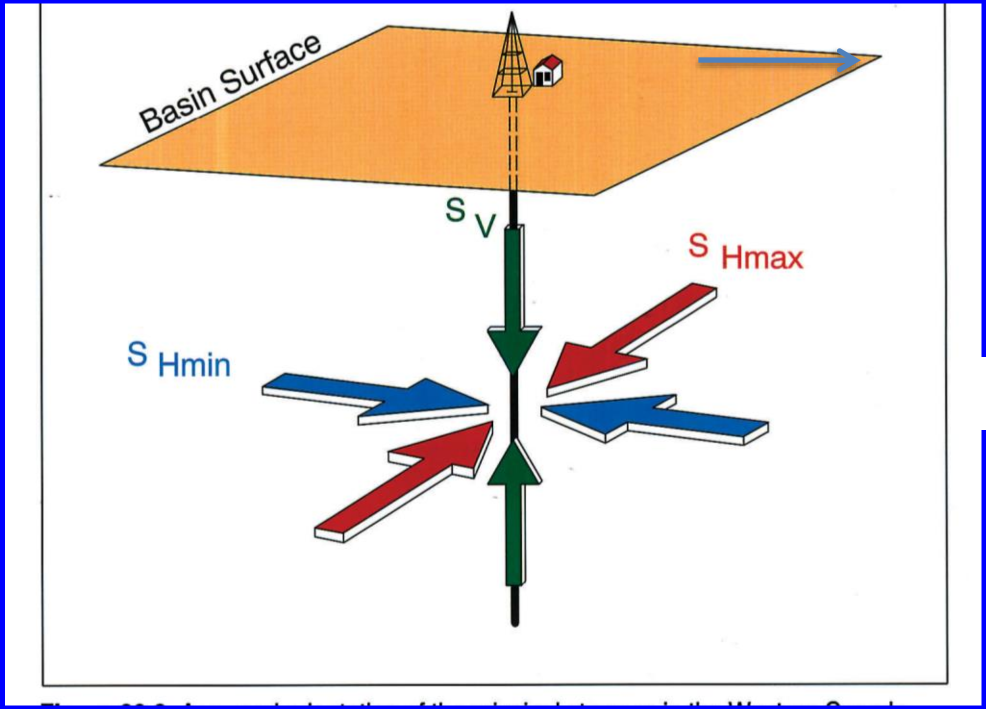
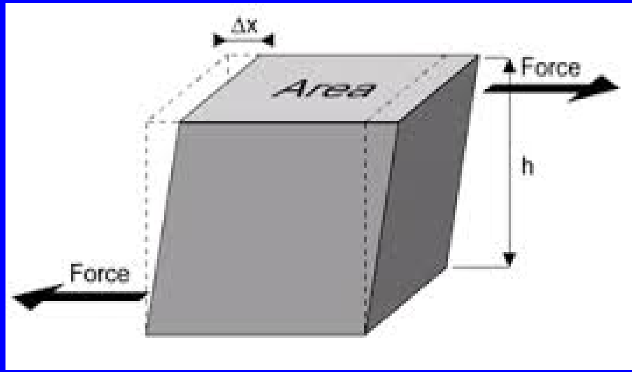
The weight of the overburden…

Horizontal and vertical stress: $\sigma_{1,2,3}$

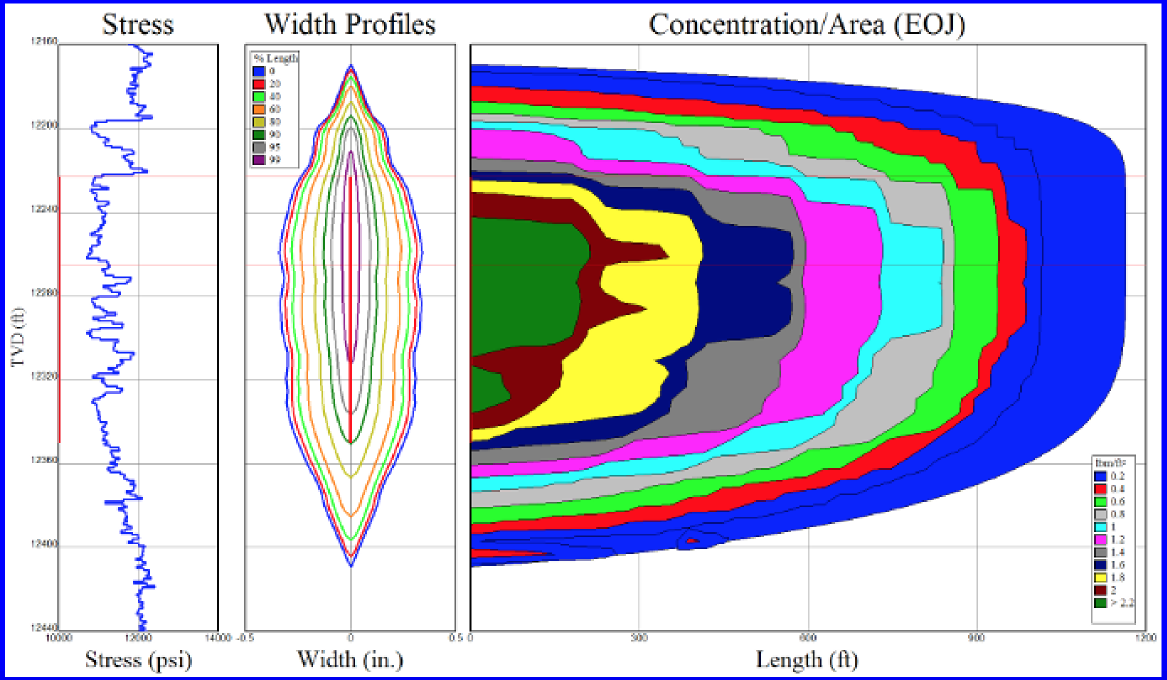


And the stiffness of the rock

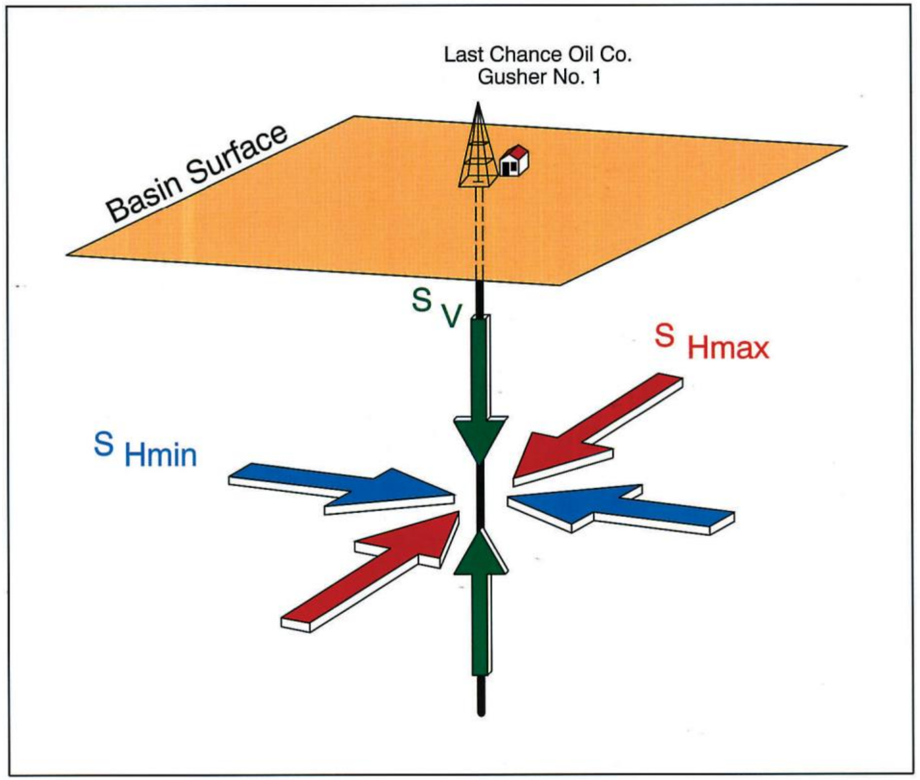
Young's Modulus: E



….Control the shape of the fracture

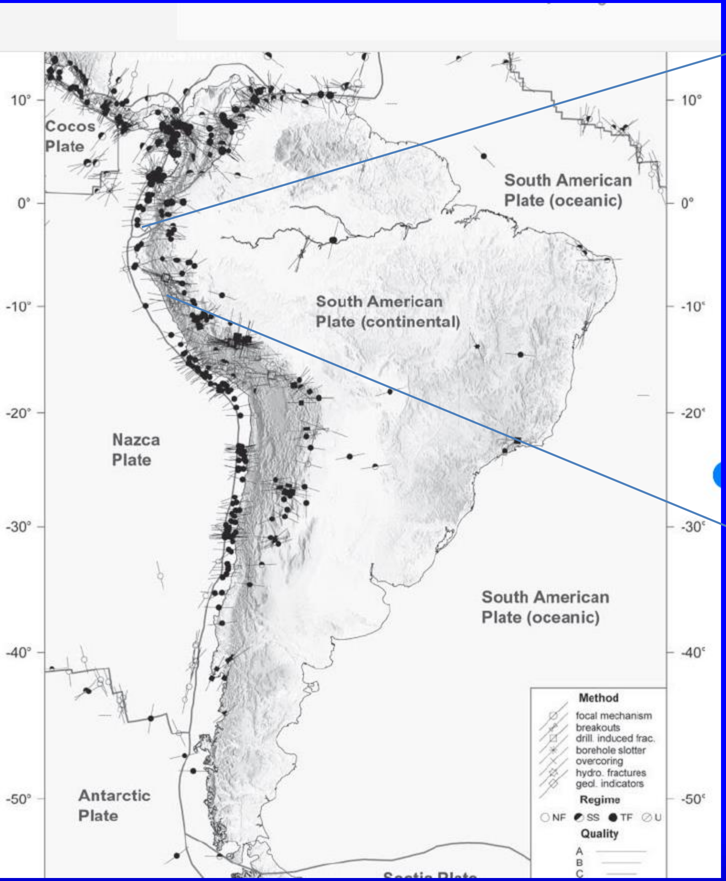


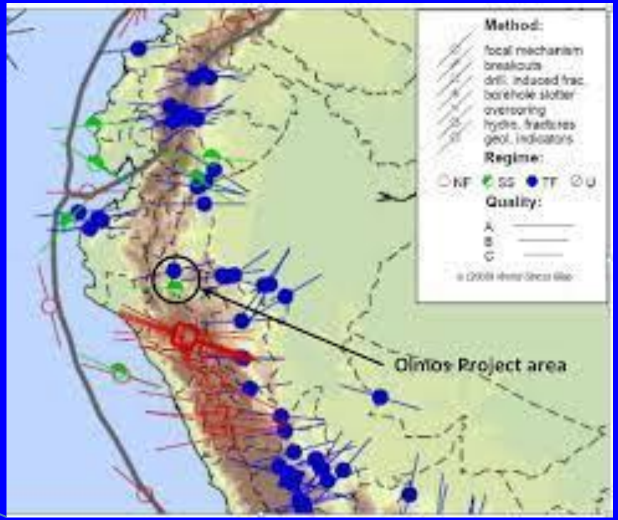
The orientation of the horizontal stresses control the azimuth of the fracture …



A growing fracture follows
the least resistance

Maximum Horizontal Stress Orientation North West Peru

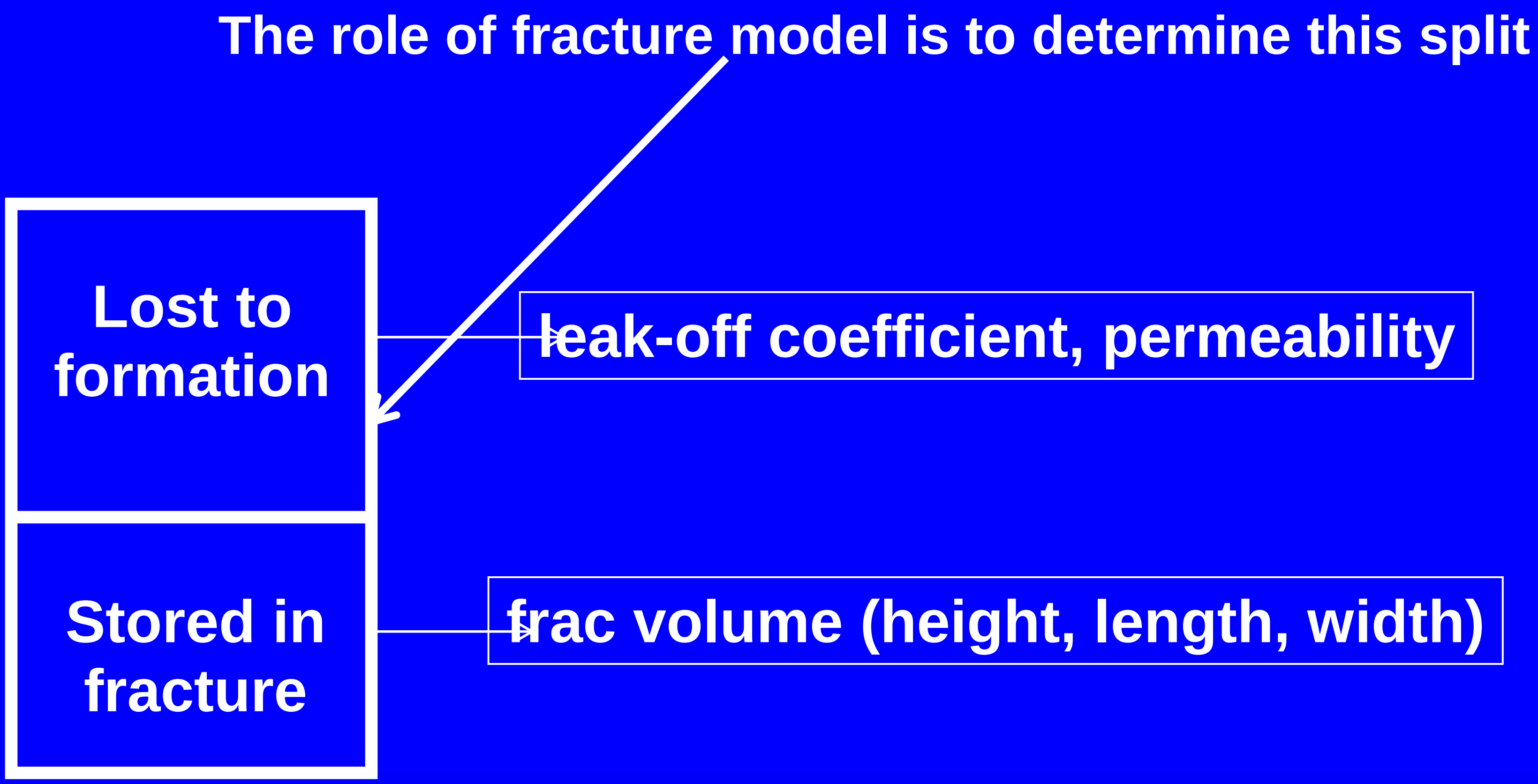




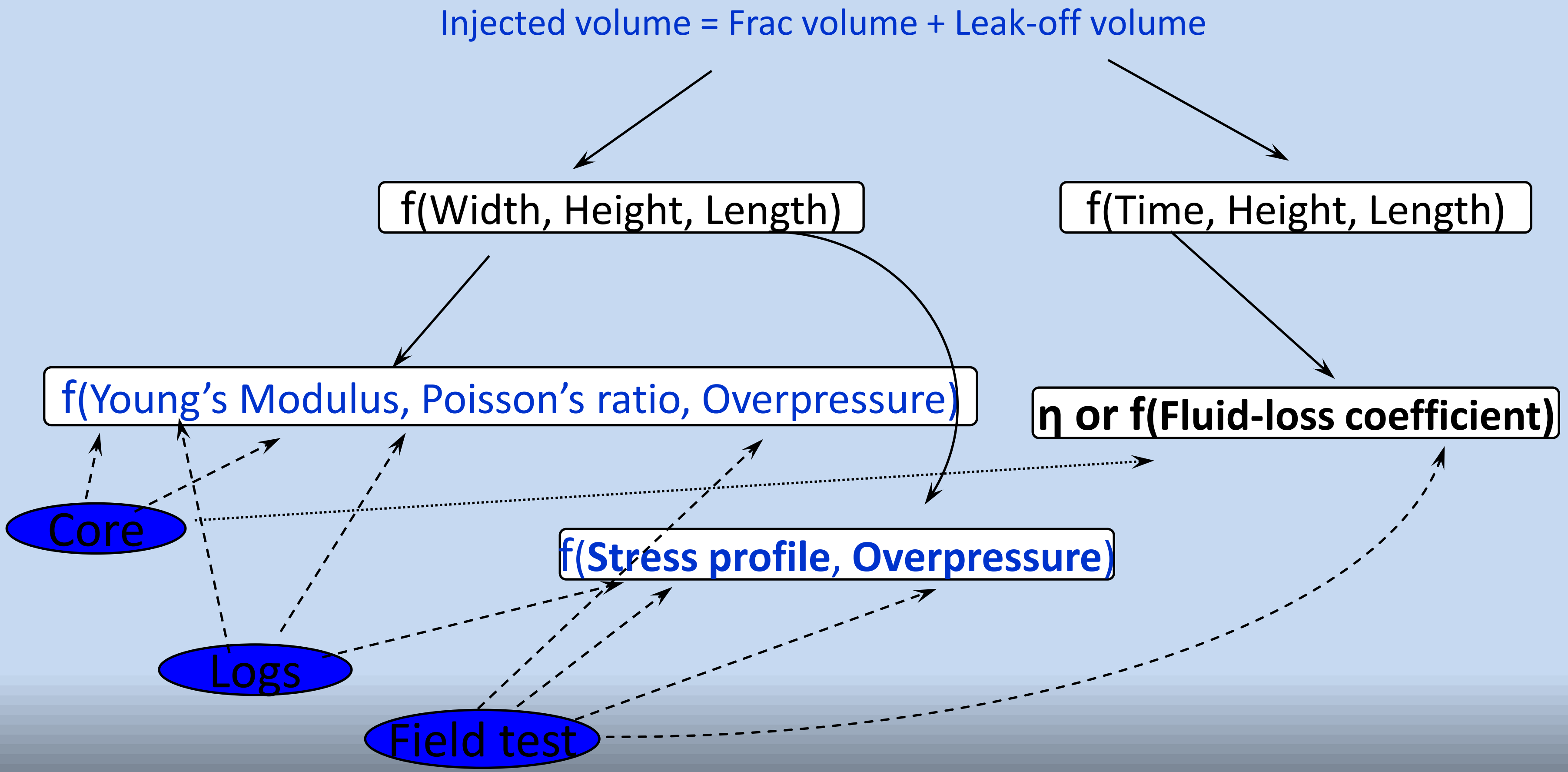
Fractures will grow roughly east west

Material Balance

Total Injected volume

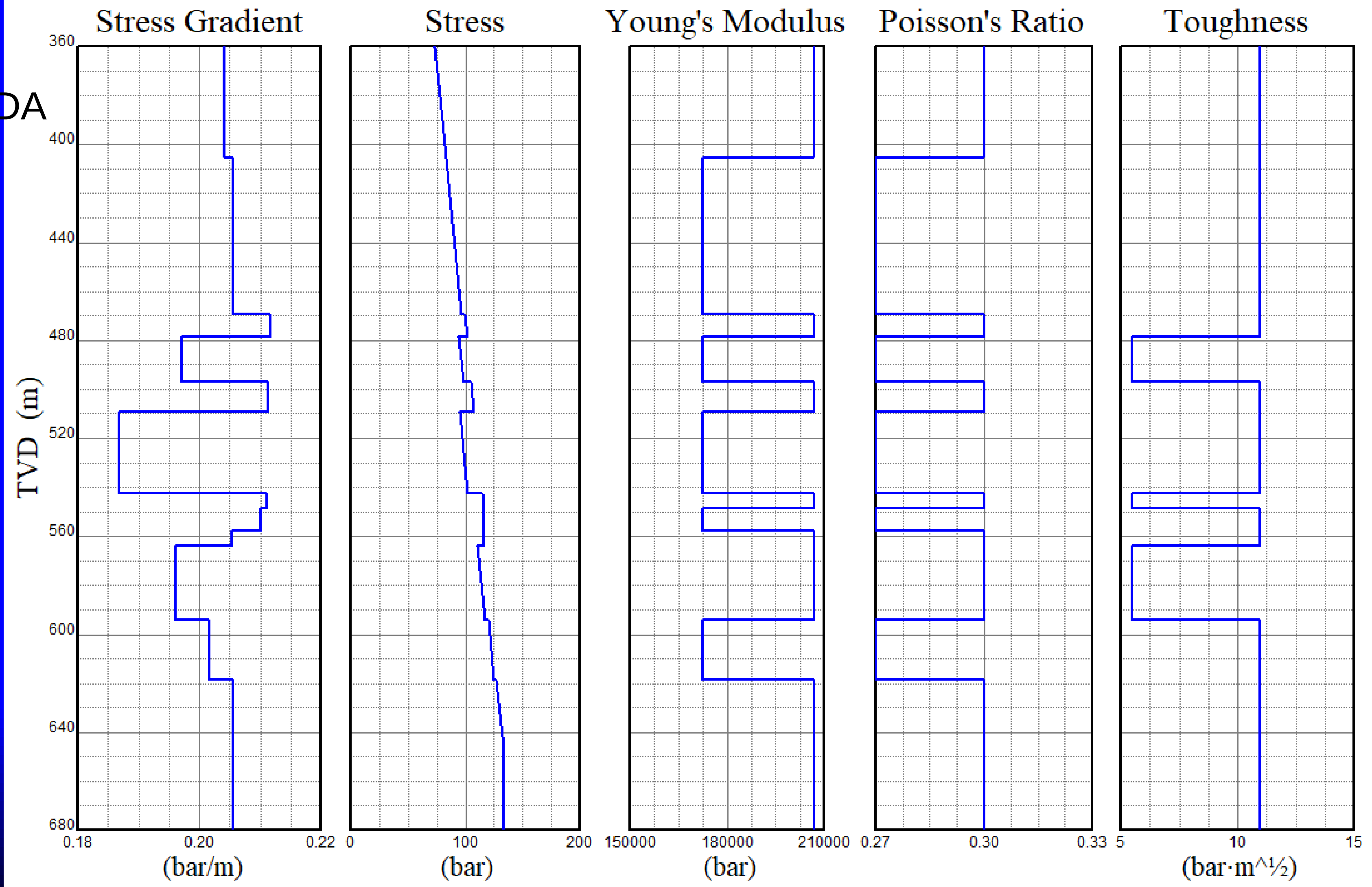


Identify Critical Parameters



Rock mechanical input data

Well Name: 12683 BR
Location: LOTE - IV
Formation: PALEGREDA



Measure (or assume) in-situ stress profile

Cost: High ↔ Low | Accuracy: High ↔ Low

- Microfracs across the interval of interest incl. under- and overlaying shales, evaporites,etc. .
- Perform two microfracs in different zones
  Run the DSI log
  Calibrate the DSI log with the microfrac data.
- Run the DSI log
  Calibrate with minifrac just prior to the main frac
- Convert core derived Poisson's ratios and Young's modulus into calculated stress data
  Calibrate with minifrac data.
- Estimate data from Gamma Ray log
  Calibrate with minifrac data.

Design programs

• Fracpro	BP, Halliburton , Mearsk, Fenix, RES*
• Gopher	CoreLab, Barree
• Stimplan	Shell, NSI consultancy
• Mfrac	ExxonMobil, Baker Hughes , NPCI
• Shellfrac	Shell
• Fraccade	Schlumberger

* Own version of Fracpro

Application of hydraulic fracturing in Peru

- Started in 1953
  - International Petroleum Co., Ltd., initiated sand-oil fracturing
  - 319 jobs
  - Average job size 300 bbl of oil with 18,900 lb of Ottawa sand
  - 271 jobs
  - Total additional oil: 1,860,633 bbl
- Since the turn of the century multiple treatments in the Talara area
  - Mostly small jobs upto 500 bbls of fluid and 50,000 lbs of sand
  - Permeabilities 10 mD or higher
  - Shallow depths
  - High stress levels: 0.9 psi/ft or more

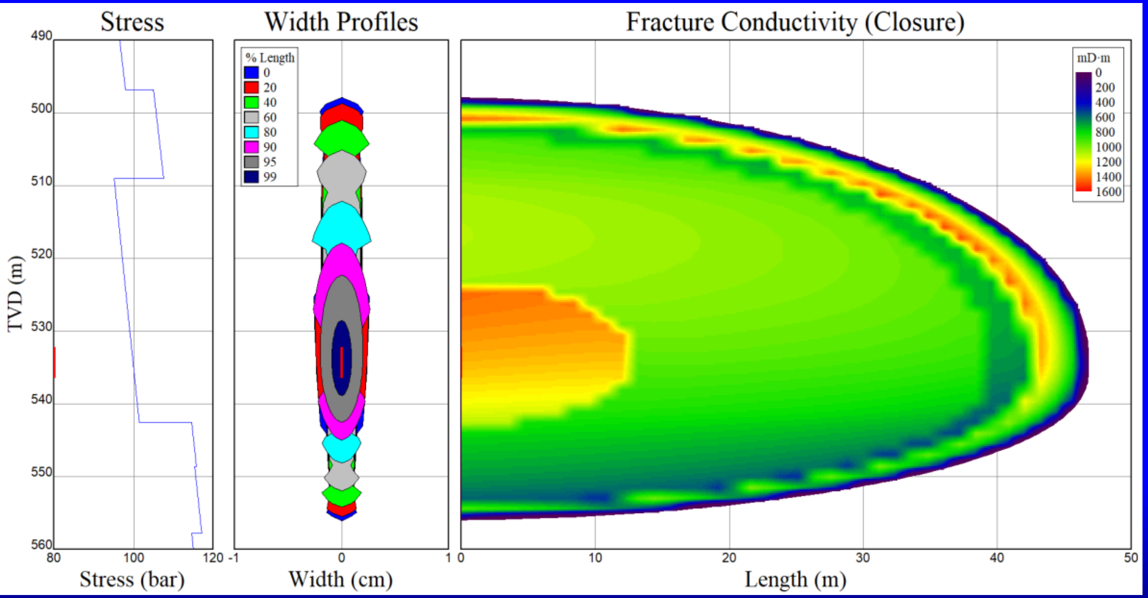
Application in Peru

1. Within the operational constraints design for about 50,000 lbs of proppant and up to 30,000 gals of fracture fluid.
2. Further optimization requires larger amounts of proppants and fluids per fracture, as a first estimated 100,000 lbs of proppant with 50,000 – 60,000 gals of frac fluids. It might also be useful to investigate alternative fluid systems and proppant sizes.
3. Check optimum for each well with a suitable software package
4. Investigate the options to get suitable equipment for larger fracs

General | Stages

Flush Fluid Type: FR01 — Well Volume: 4.70578 (m^3) — Variable Column: Total Mass

	Slurry Rate (m^3/min)	Stage Liquid Volume (m^3)	Stage Time (min)	Stage Type	Fluid Type	Prop. Type	Prop. Conc. (100 kg/m^3)	Prop. Damage Factor	Total Mass (kg)
1	3.17975	45.4249	14.2857	Pad	B028	0000	0	0	0
2	3.17975	11.3562	3.89465	Prop	B028	0005	2.39653	0.5	2721.55
3	3.17975	13.2489	4.73231	Prop	B028	0005	3.59479	0.5	7484.27
4	3.17975	26.4979	9.84172	Prop	B028	0005	4.79306	0.5	20184.9
5	3.17975	3.78541	1.5137	Prop	B028	0005	7.18959	0.5	22906.4
6									
7									
8									



Minimum requirements for successful stimulation treatments

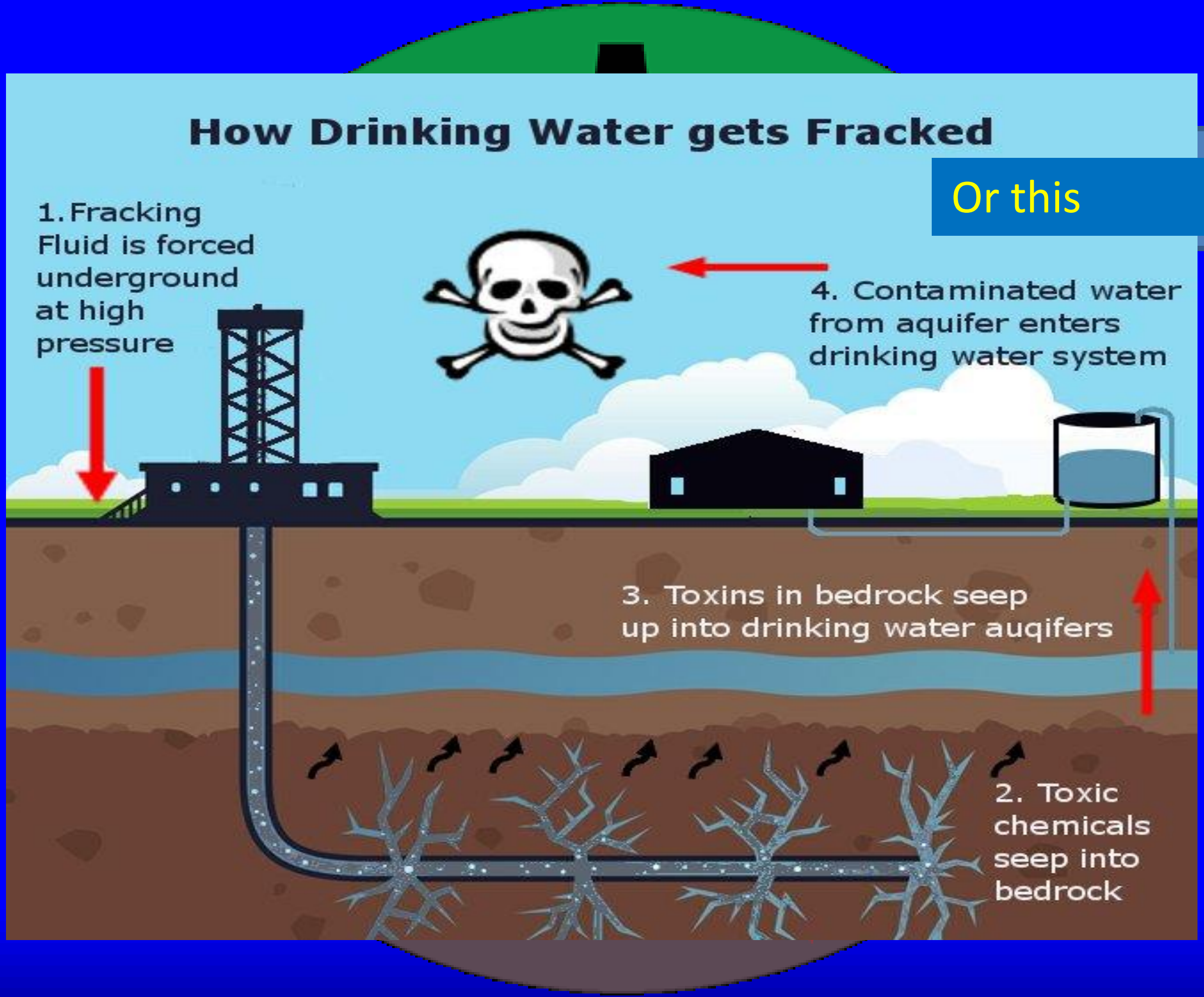
	Fracturing	Acidizing	Remarks
Production rate:	Gas > 100,000 m^3/d	Not relevant	This number is strongly field/reservoir dependent
	Oil > 10 bpd*	Not relevant	
Hydrocarbon saturation:	30 % or more	30 % or more	Highly depleted wells are poor stimulation candidates
Water cut:	50 % or less**	50 % or less**	
Distance to FWL:	> 20 m	Not relevant	
Gross reservoir height:	10 m or more	no limit, but diversion needed in longer intervals	
Permeability:	Gas 0.0001 - 1 mD, Oil 0.1 - 50 mD***	Gas > 1 mD, Oil > 10 mD	Low perm reservoirs need a frac, not acid
Reservoir pressure:	Gas: two times the abandonment pressure Oil: 80 % depletion	Gas: two times the abandonment pressure Oil : 80 % depletion	Highly depleted wells are poor stimulation candidates
Production system:	Current production not more than 80 % of maximum capacity of facilities	Current production not more than 80 % of maximum capacity of facilities	Must be able to handle increased production
Damage Skin:	S>2, Skinfrac	S>2, damage soluble in acid and/or solvent	

** Read "water> 10bpd" for water injection or water production wells (e.g. geothermy)*

** can be higher if water can be handled economically

**** Skinfraccing can also be applied at higher permeabilities*
Oil/gas-shales are fracced and produced at much lower permeabilities!

Fractures come in all shapes and sizes



Or this

Frac fluids

– <u>Main Components: Water and sand</u>
– Additives:
– <u>Guar Gum</u>
    • <u>http://www.guargum.co.in/</u>

» Borate; crosslinker to create higher viscosity

» Acetate and carbonate salts; pH buffers

» Persulfates and enzymes ; to break down viscosity after the treatment

» Citrus extracts to enhance flowback (Orange oil)

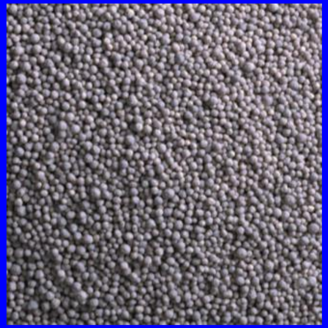
» Bactericide to prevent fluids from premature bacterial breakdown

– All materials are classified as WGK 1 (Germany)

– 100% green materials e.g CleanStim (Halliburton) OpenFrac (SLB)

Proppants

- Sand
- Sintered Bauxite
- Ceramics



Earthquakes

- **Fracs have triggered minor earthquakes, up to 3 on the Richter scale**
- **Only in tectonically active areas (Like NW Peru!)**
- **Large scale injections**