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Hydraulic Fractures:

Overview

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Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company,
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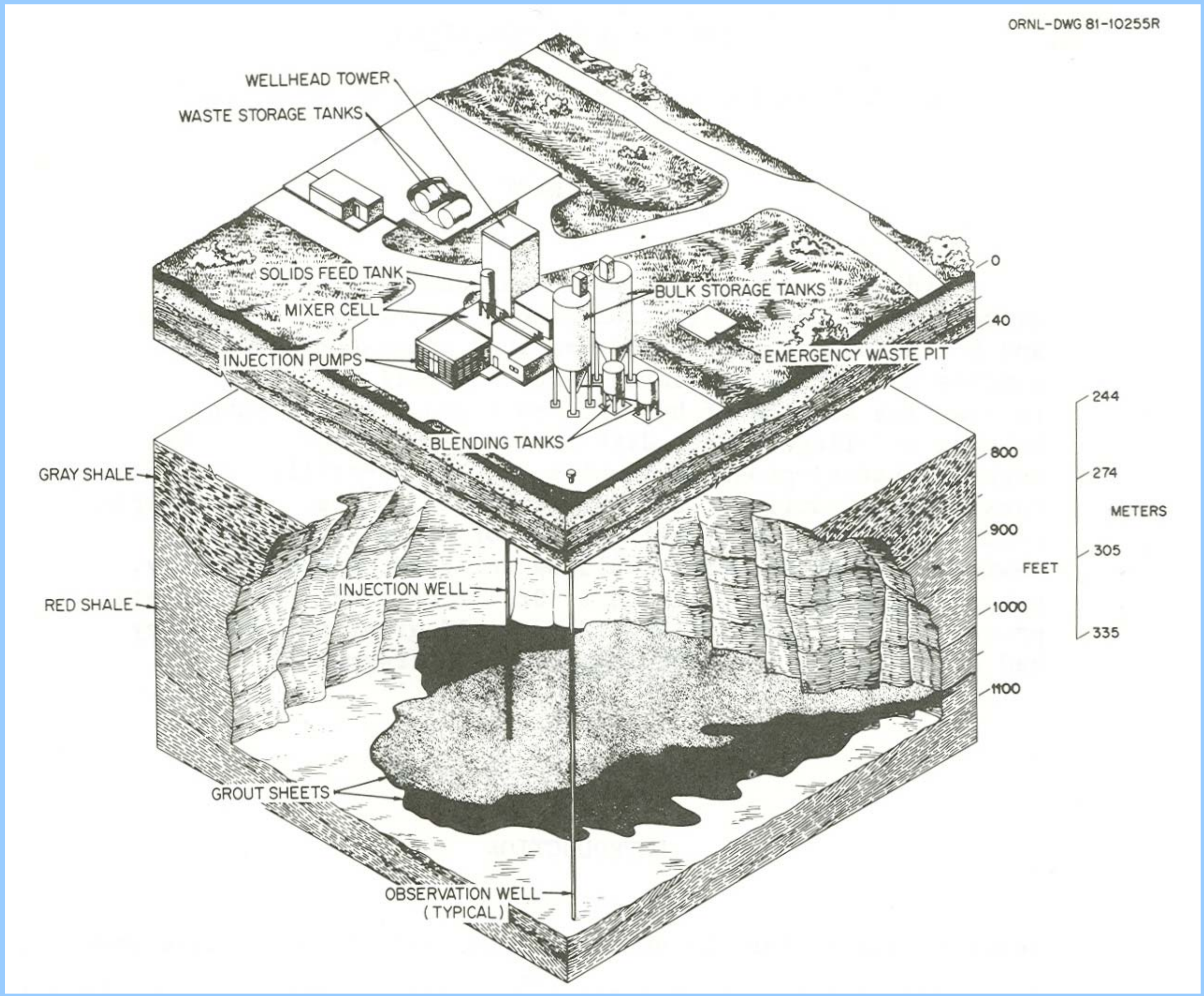
Outline of Overview

- Scale of Hydraulic Fracturing Industry and Emerging Issues
- Principles and Methods of Hydro-fracturing
- Needed Approaches
  - Site Data
  - Optimization
  - Monitoring
- Case Examples

Additional Sources of Information on Hydraulic Fracturing

- Pinnacle Technology - http://www.pinntech.com/index.html
- Schlumberger - http://www.slb.com/content/services/stimulation/fracturing/index.asp?

Oak Ridge Waste Disposal Application



Hydraulic Fracturing

- Over 50 Years of Use
- Leading Technique to Stimulate Production
  - Key to Profitability for Many Areas
  - Increasing Use in High Perm Completions
- Widely Utilized (Year 2000 Estimates)

	N. America
Frac Jobs	25,000+
Spending	~$2 billion

Uses of Hydraulic Fractures

- Increase the flow rate of oil and/or gas from low permeability reservoirs,
- Increase the flow rate of oil and/or gas from wells that have been damaged,
- Connect the natural fractures and/or cleats in a formation to the wellbore,
- Decrease the pressure drop around the well to minimize sand production,
- Decrease the pressure drop around the well to minimize problems with asphaltine and/or paraffin deposition,
- Increase the area of drainage or the amount of formation in contact with the wellbore, and
- Connect the full vertical extent of a reservoir to a slanted or horizontal well.

Emerging Issues in the US

- Groundwater impacts of hydraulic fracturing
  - Hydraulic fracturing has often been not controlled by the operators such that fractures breakout of units and contaminate groundwater
  - Such a threat to groundwater has become a major concern to agricultural areas of the US that use groundwater for irrigation
  - Major US congressional activity and legislation to address these issues

In Well Configuration

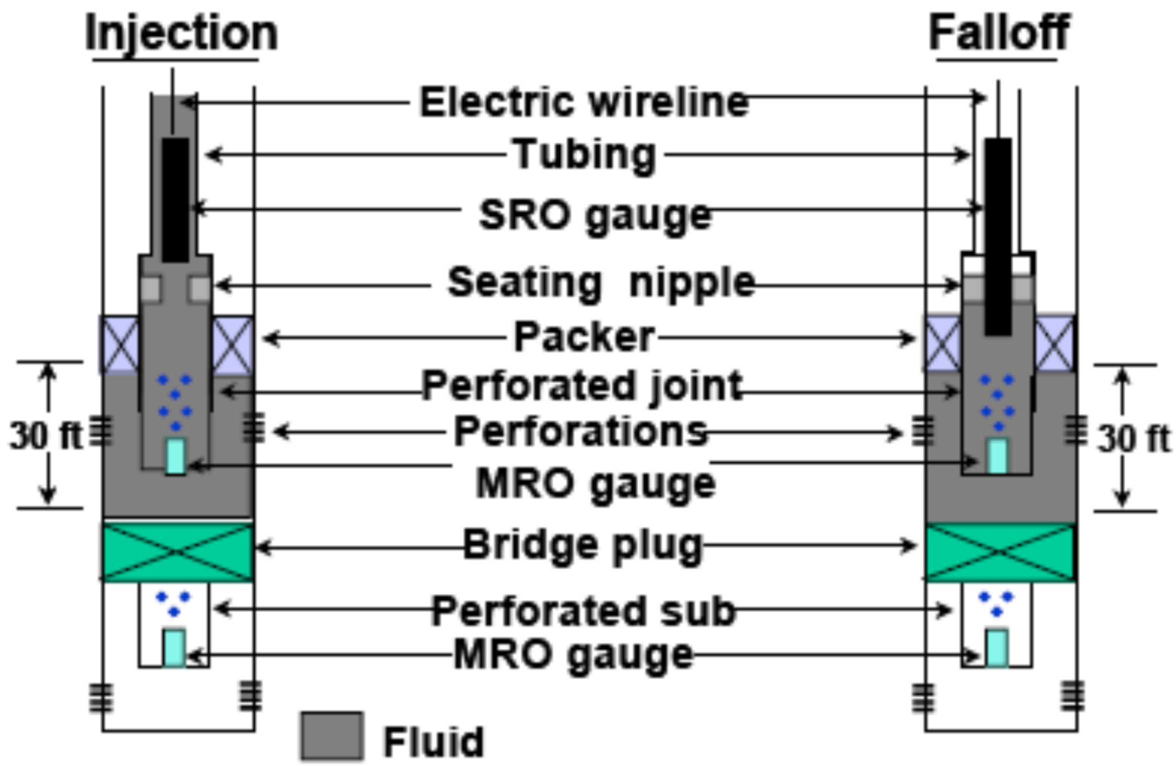


Fig. 4 – Cased hole test configuration.

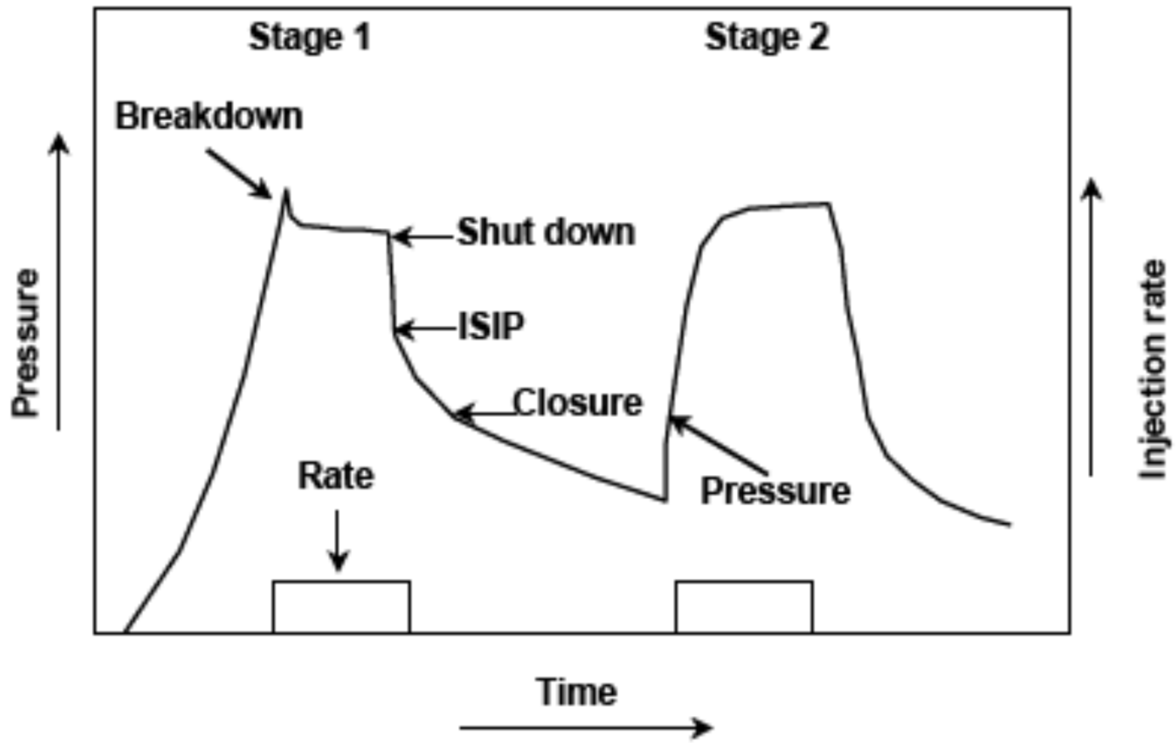
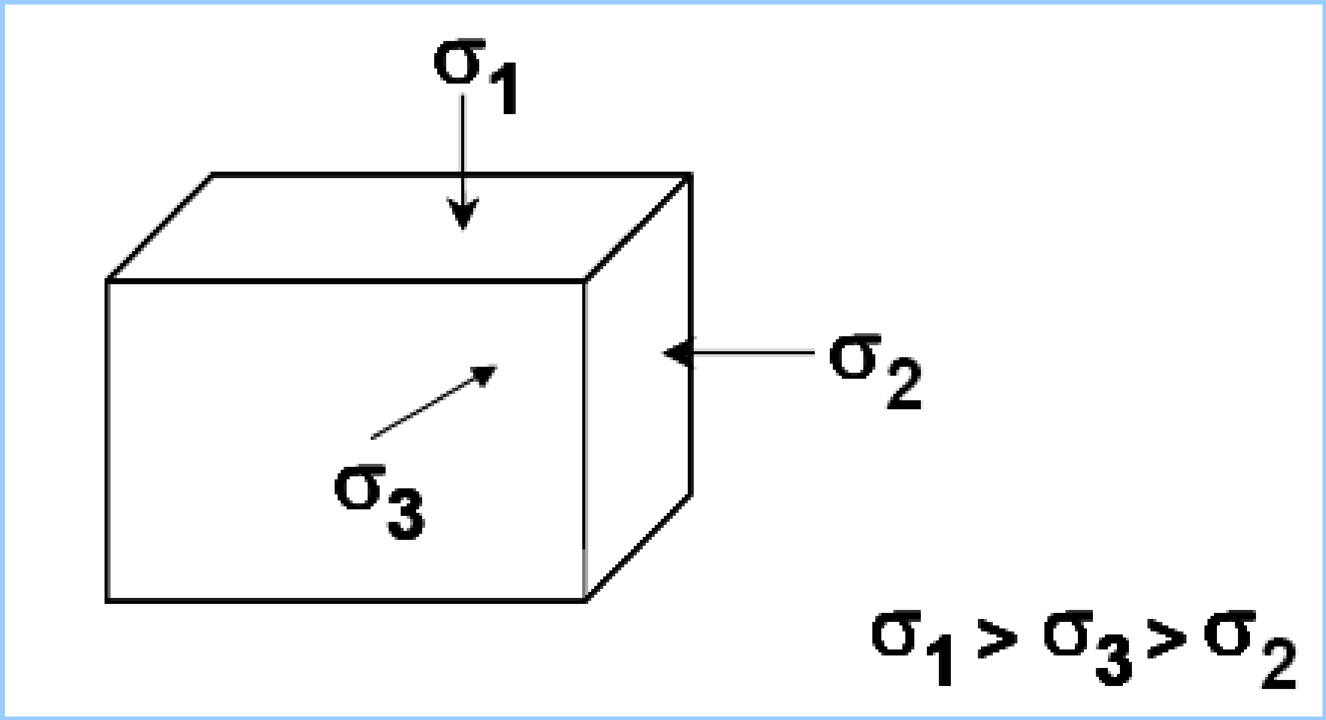


Fig. 5 – Typical stress test pump-in/shut-in.

Mechanical Principles

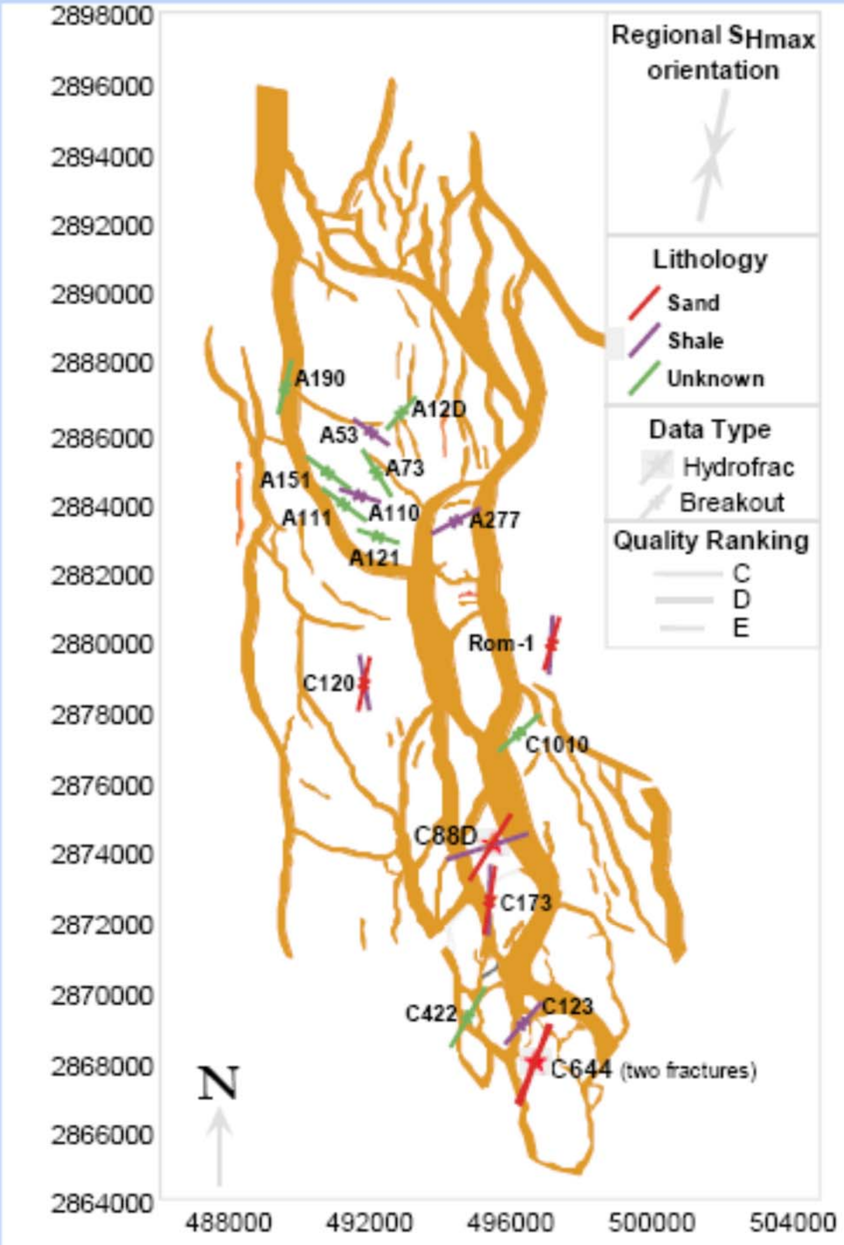


$$\sigma_{min} \cong \frac{\nu}{1-\nu}\left(\sigma_{ob} - \alpha\,\sigma_p\right) + \alpha\,\sigma_p + \sigma_{ext} \qquad \text{Eq. 1}$$

Where:

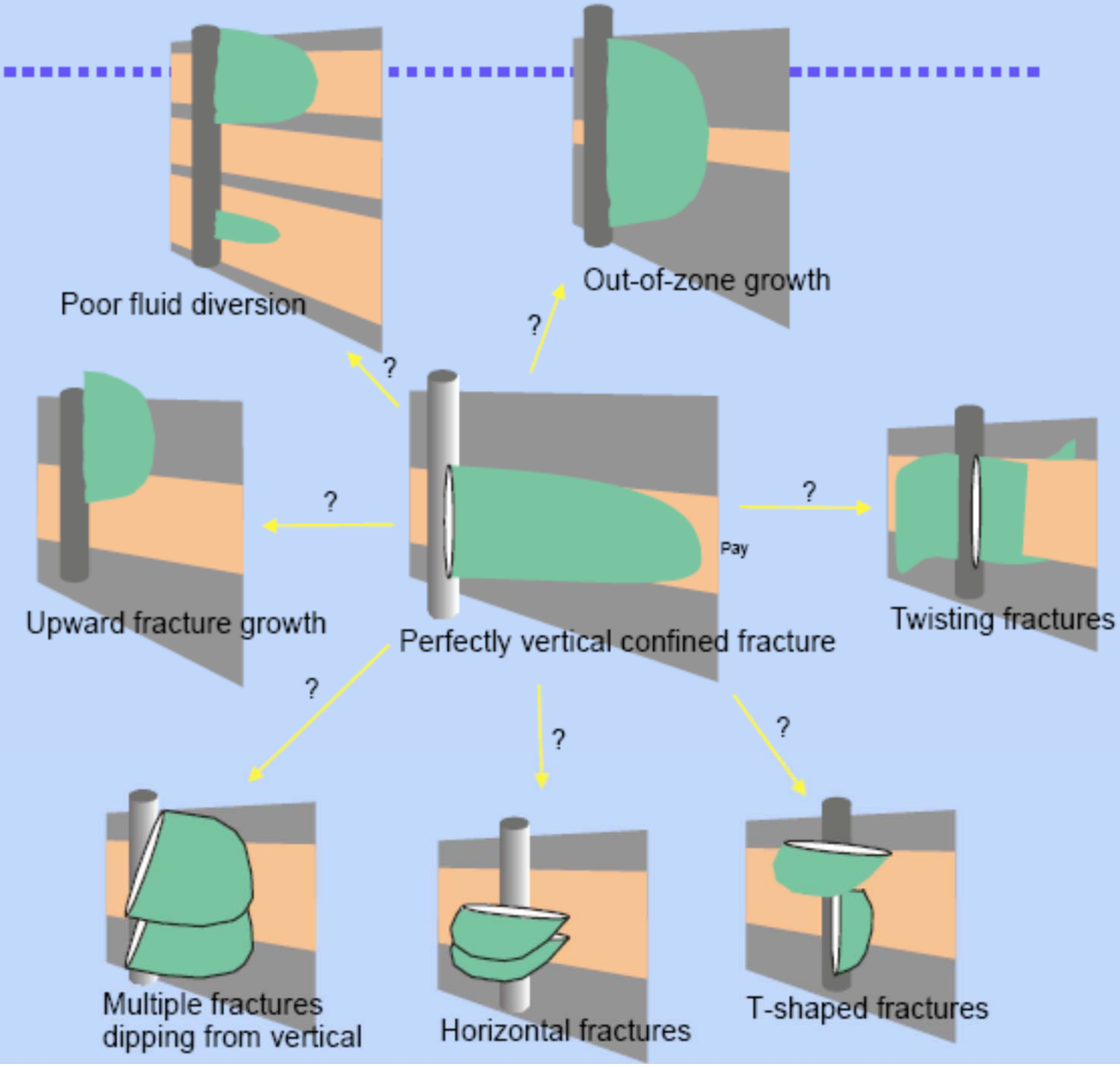
σ_{min}	=	the minimum horizontal stress (*in-situ* stress)
ν	=	Poissons' ratio
σ_{ob}	=	overburden stress
α	=	Biot's constant
σ_p	=	reservoir fluid pressure or pore pressure
σ_{ext}	=	tectonic stress

Arcabuz-Culebra Field - Fault Map



- Fracture Mapping
  - Tilts & Micros
    - Frac Height, Length & Direction
  - Calibrated Frac Model
- Frac Orientation Varies
  - Geomechanical Model & Mapping
  - Arcabuz Fracs Will Parallel Nearest Fault
  - Culebra Fracs Will Generally Follow the Regional Trend

Fracture Growth Is More Complex Than We Tend To Think



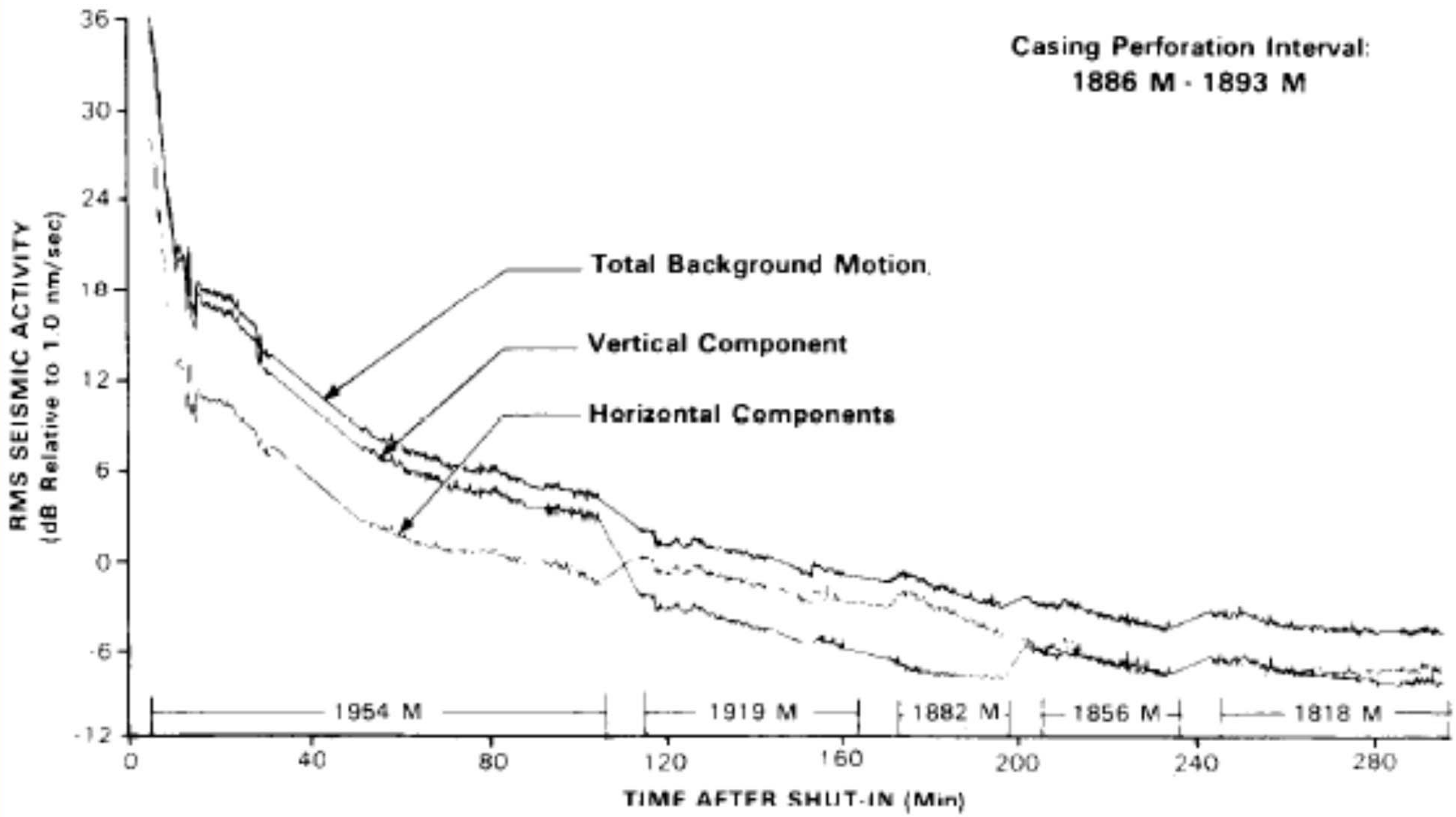
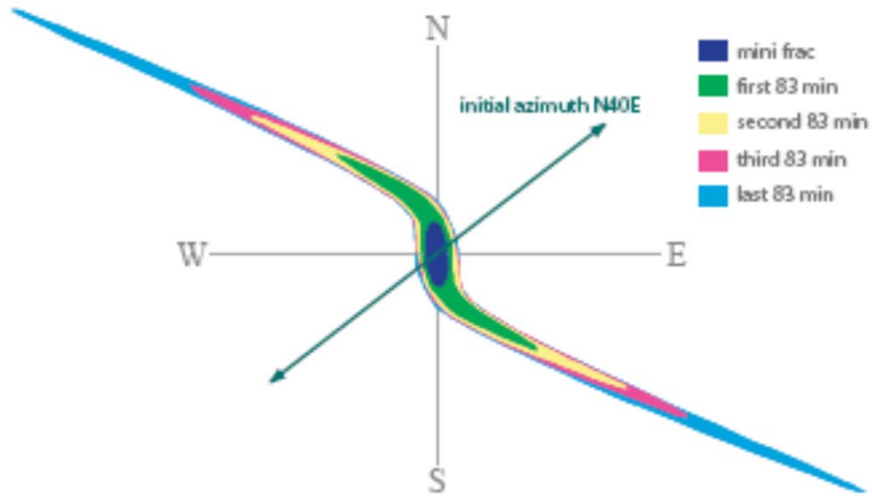
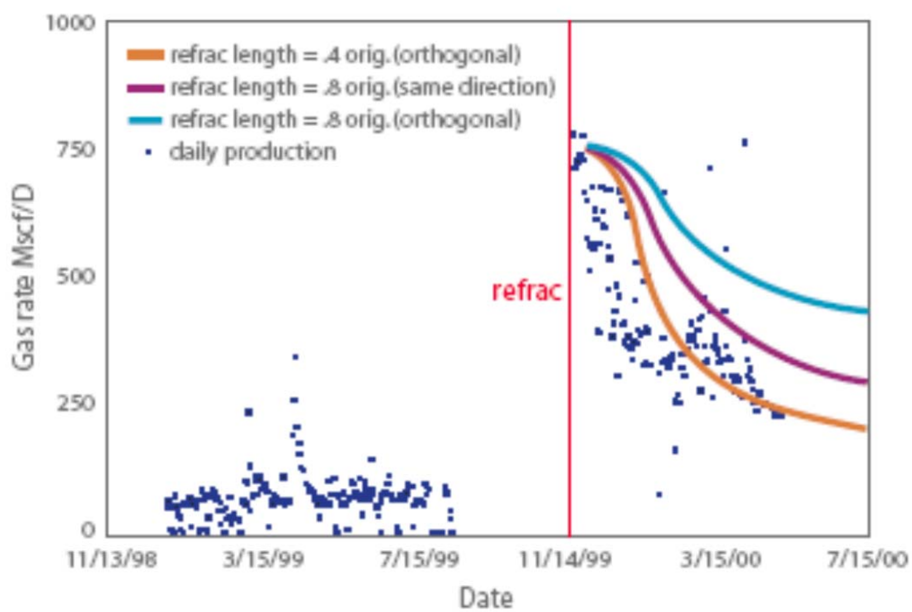


Fig. 1. RMS amplitudes of the total, the horizontal, and the vertical components of background motion at SFE 1 versus time relative to shut-in. Shown also are the five associated recording depths occupied during the specified times. Straight lines are recording hiatuses.



Plan view of refracture azimuth changing with time.



Production history match for refrac treatment showing best match is for an orthogonal fracture about 40% of the length of the original.

Needed Approaches

- Site Data
- Optimization
- Monitoring

Fundamental Site Information

By far, the most important parameters are:

- the In-situ stress profile;
- the permeability profile of the zone to be stimulated and the layers of rock above and below the target zone.

Information Required for Design Optimization

In order of importance,

1. the in-situ stress profile,
2. formation permeability,
3. fluid loss characteristics,
4. total fluid volume pumped,
5. propping agent type and amount,
6. pad volume,
7. fracture fluid viscosity,
8. injection rate, and
9. formation modulus.

Frac Diagnostics Overview

- Three Major Groups of Fracture Diagnostic Tools

- Group 1: Indirect Diagnostics
  - Net pressure analysis
  - Production data analysis
  - Well testing, etc.
- Group 2: Direct Near-Wellbore Diagnostics
  - Tracer, temperature, production logging
  - Hydraulic Impedance Testing (HIT)
- Group 3: Direct Far-Field Diagnostics
  - Tiltmeter fracture mapping
  - Microseismic imaging

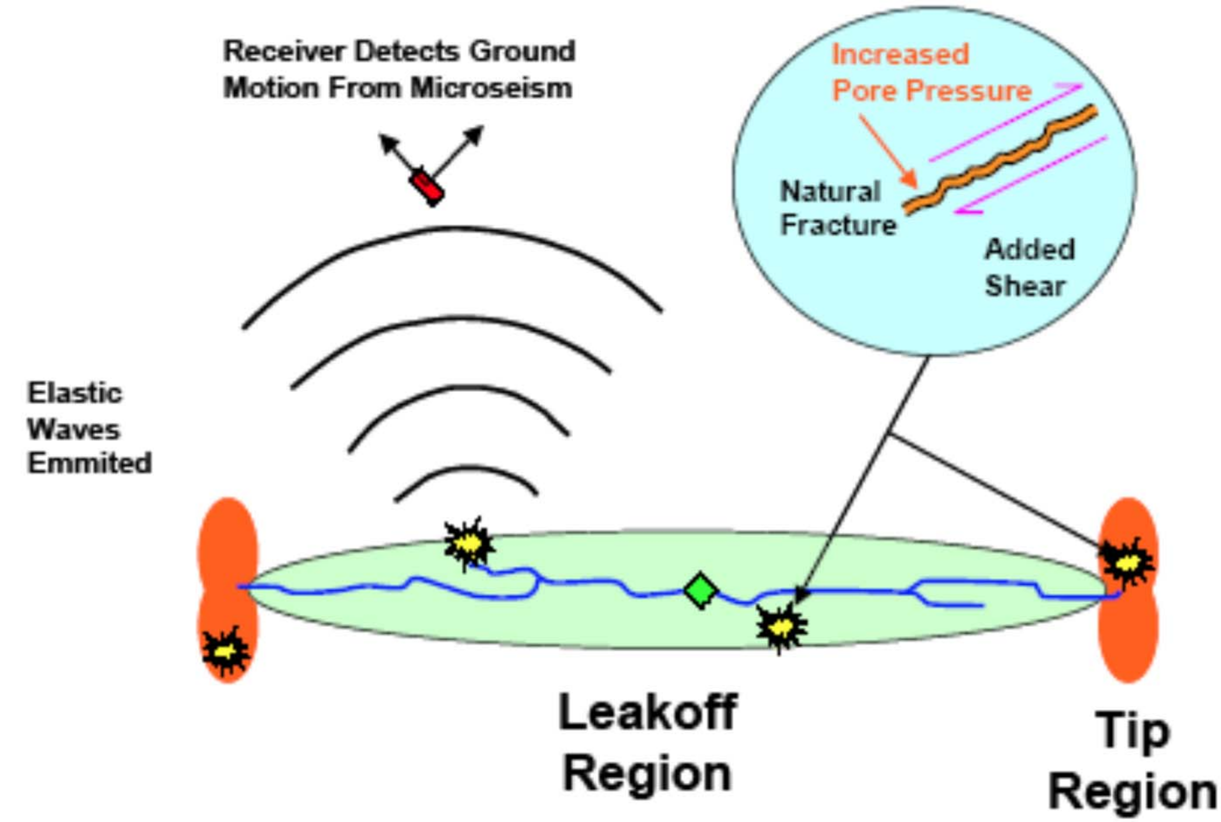


Fig. 18 – Principle of microseismic fracture mapping.

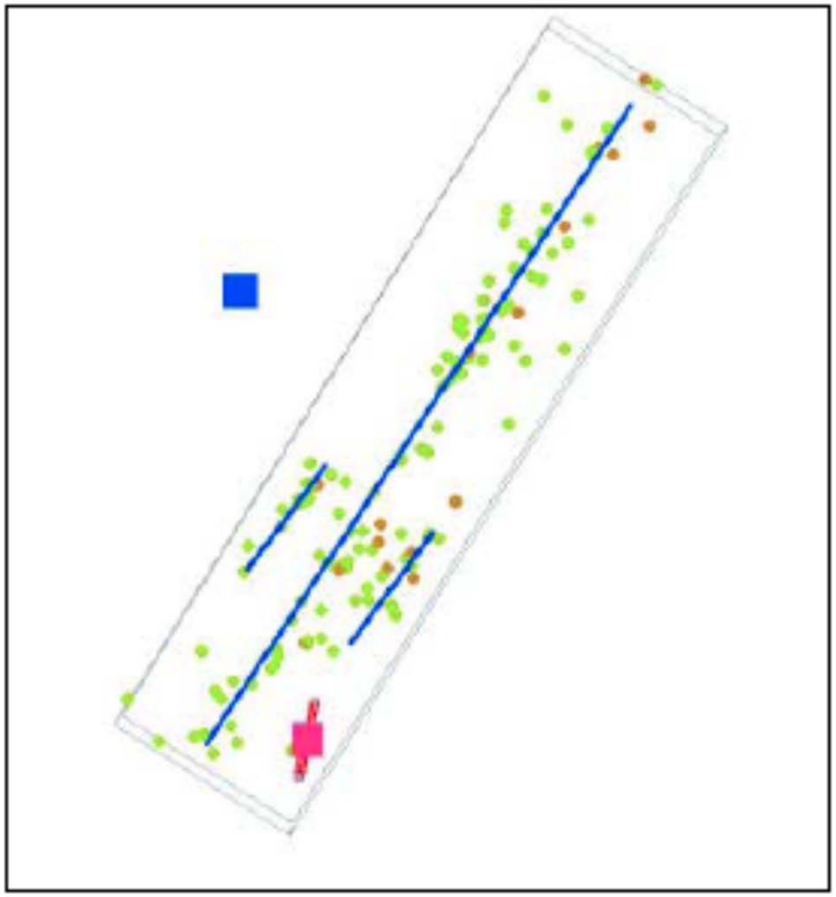


Figure 2. The frac treatment propagated to the northeast of this treatment well (red square) along three NE-SW trending orientations.

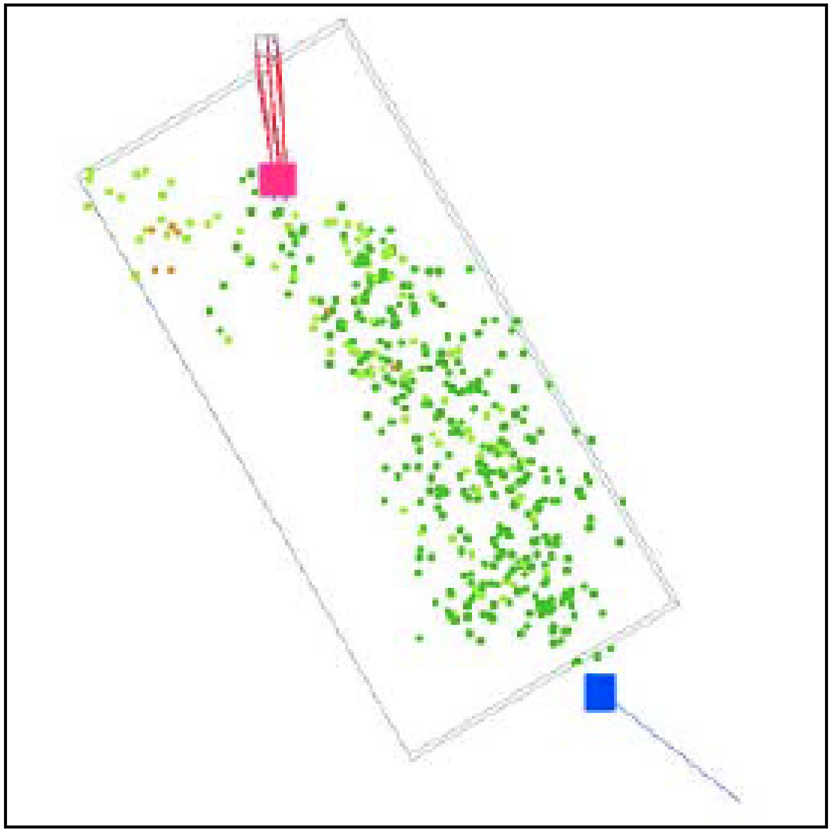
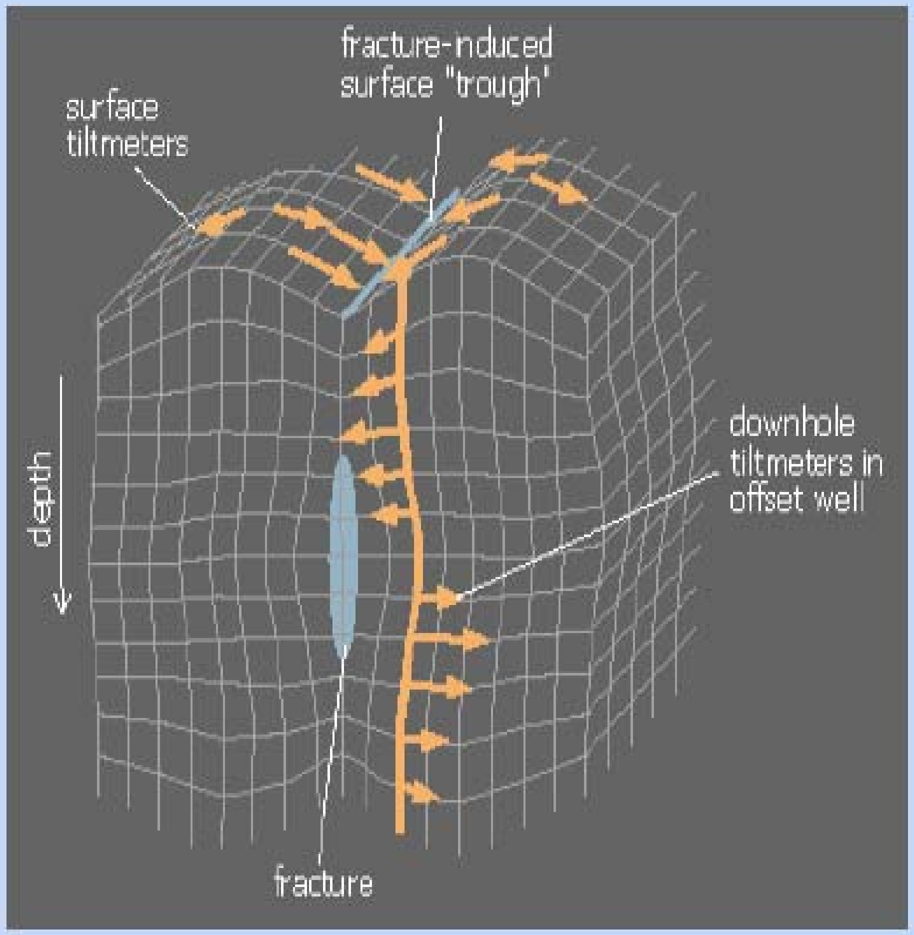


Figure 3. The diffuse cloud of events that were imaged while treating this well run perpendicular to the field's predominant NE-SW fracture orientation, indicating influence from fractures already being produced by a neighboring well.

Principle Of Tiltmeter Fracture Mapping

- **Hydraulic Fracture**
  - **Results in a characteristic deformation pattern in the rock around the fracture**
- **Measurement**
  - **Measure induced tilt (deformation) of the earth at several locations**
- **Analysis**
  - **The induced tilt from an array of tiltmeters reflects the geometry and orientation of the created hydraulic fracture**



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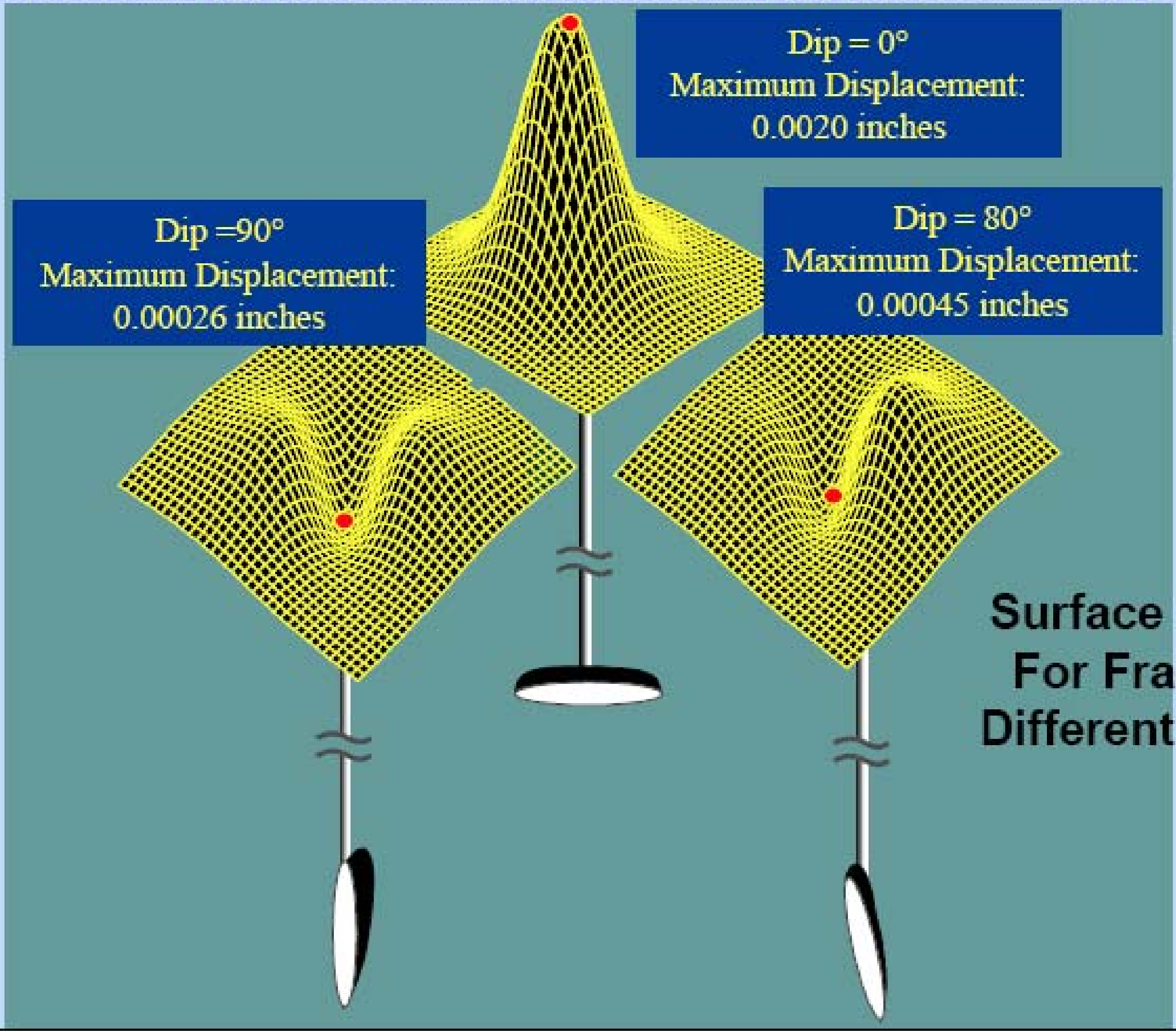
Surface Tiltmeter Mapping



Surface Deformation
For Fractures With
Different Orientations

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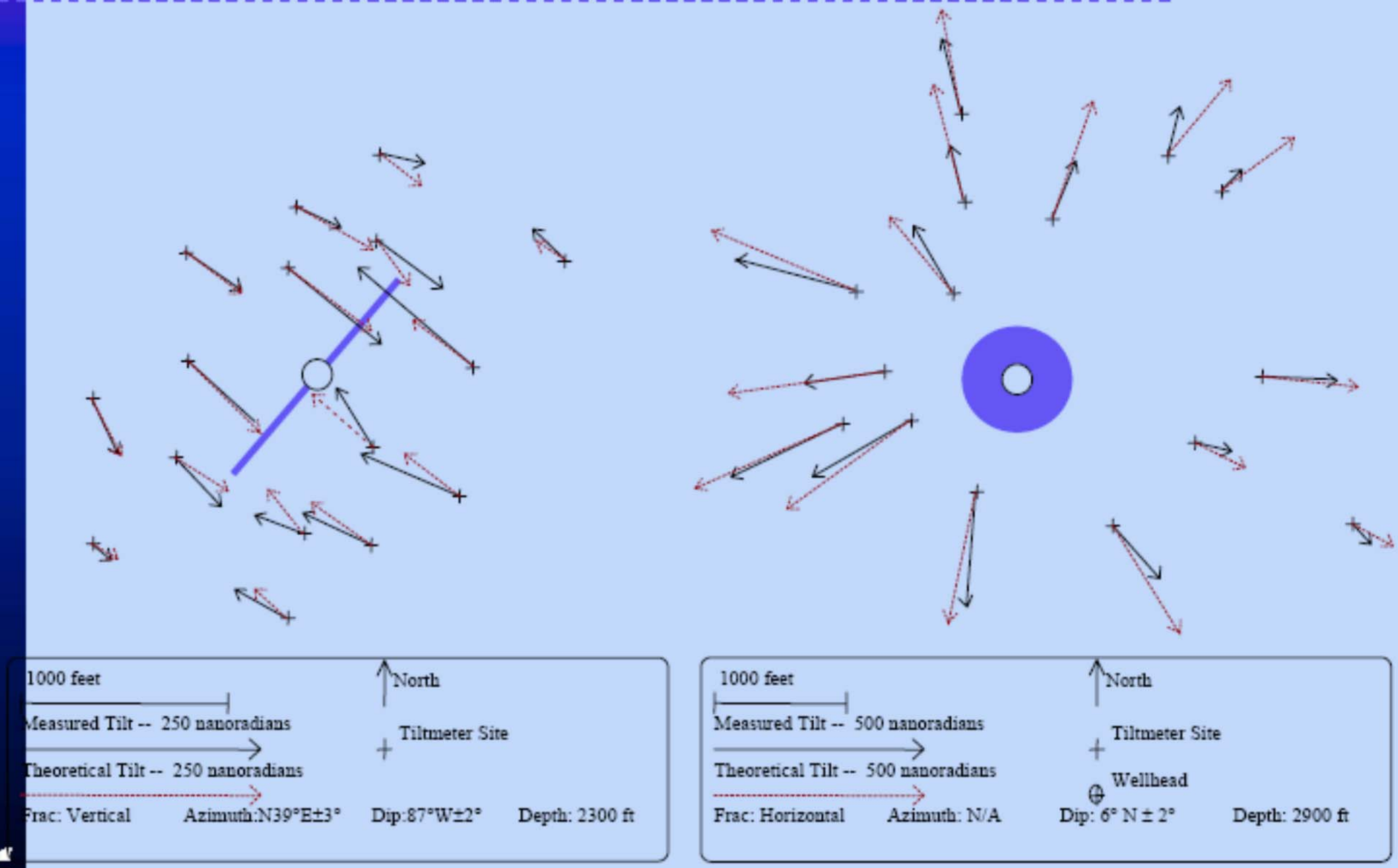
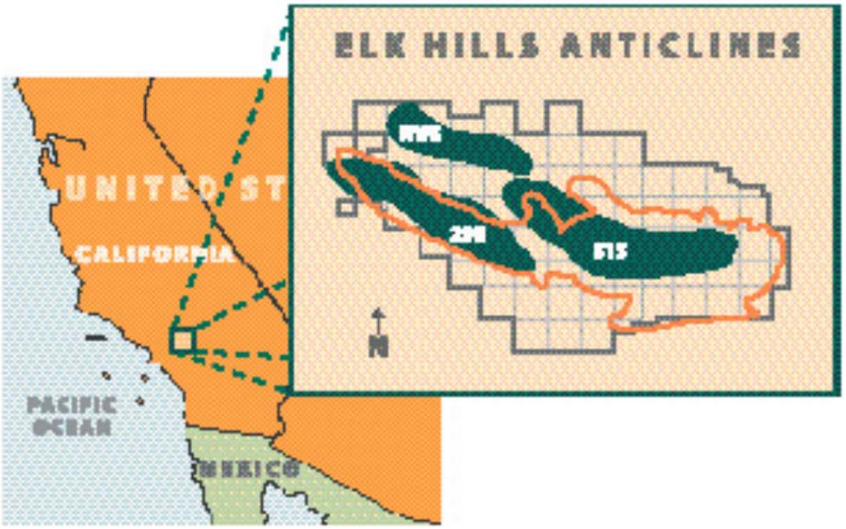
Tilt Vector Map For Vertical And Horizontal Fracture



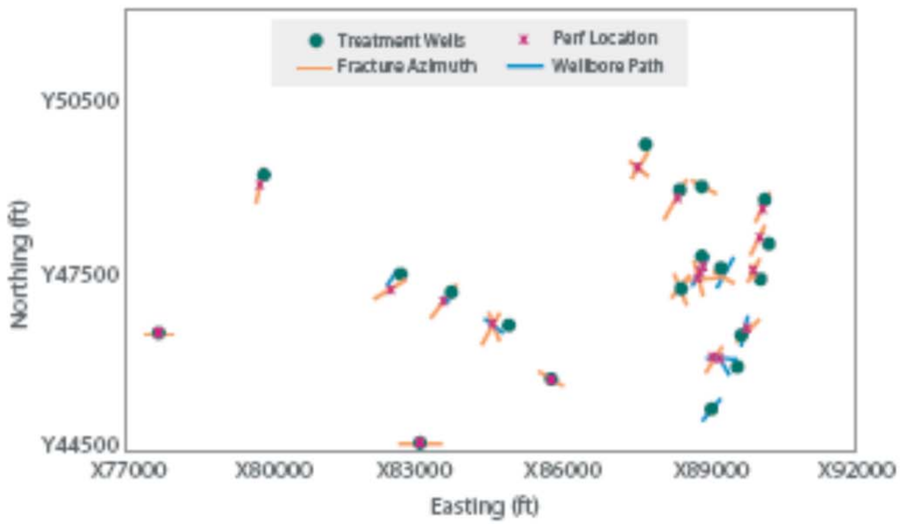
Case Studies

Case Study: Elk Hills, CA

increases/decreases caused by injection or
depletion may result in fracture reorientation.



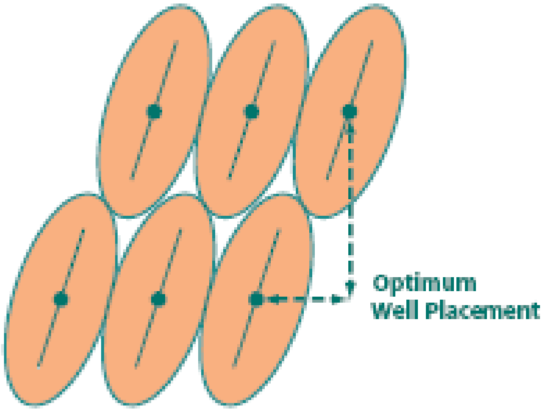
Location of southern San Joaquin Basin Oil fields. Elk Hills map illustrates 3 deep anticlines



Composite fracture orientation from surface tiltmapping shows variability in fracture azimuth.

Case Study: Optimization

Location of the Arcabuz-Culebra Field in Northern Mexico's Burgos Basin.



Optimum well placement in low-permeability Wilcox sands of Culebra portion of the Field. Illustration shows elliptical drainage pattern characteristic of low-perm hydraulically fractured reservoirs.