USC CENTER FOR GEOTHERMAL STUDIES (CGS)

DISTINGUISHED LECTURE PROGRAM (DLP)

presents

Importance of geo-mechanics in the enhancement of permeability for unconventional reservoir

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A SERIES OF OBSERVATIONS ARE PRESENTED TO SHOW THE SIGNIFICANCE OF GEOMECHANICS IN THE DEVELOPMENT OF UNCONVENTIONAL RESERVOIRS. I WILL BE USING ENHANCED GEOTHERMAL SYSTEMS (EGS) AS THE UNCONVENTIONAL RESERVOIR TYPE EXAMPLE.

BASIC EGS CONCEPT

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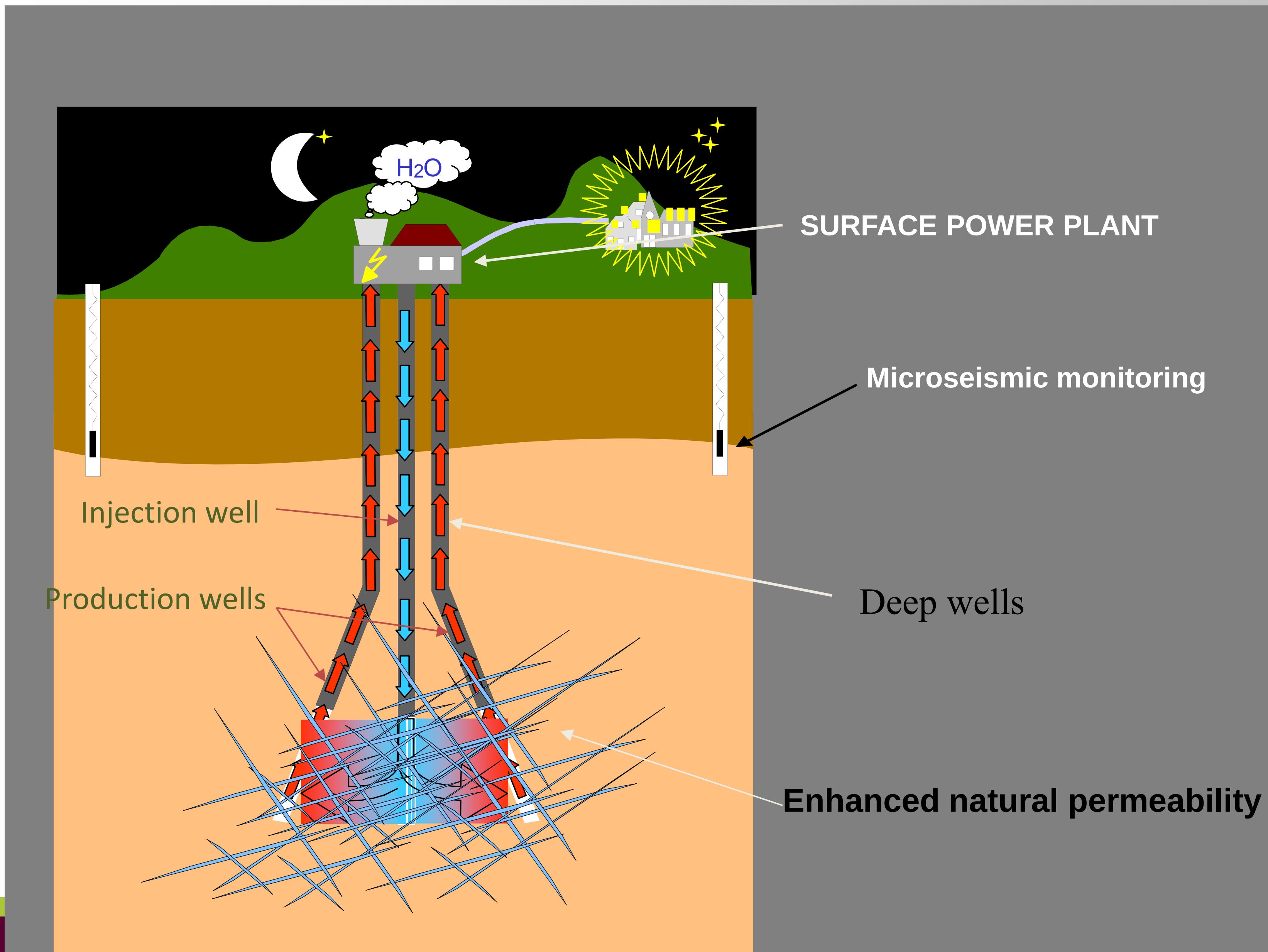


Reservoir stimulations

Two major reasons for reservoir stimulations are:

a. To increase permeability of a reservoir (enhance recovery)
b. To reduce near wellbore impedance (kh)

Main mechanisms of reservoir stimulations are:

1. Hydraulic fracturing: normally in sedimentary formation including shales. Complex viscous fluid are used in conjunction with proppant to maintain the artificial permeability created. Hydraulic fracturing of the rock mass creates new fractures. The newly created tension fractures are parallel to the maximum stress direction by exceeding the minimum stress and the rock property (tensile strength).

Mechanism of failure: **TENSILE**

Main mechanisms of reservoir stimulations are:

2. Shear stimulation: normally in hard rock (igneous) formation but less hard rocks also(e.g., sandstones). Fresh water, brine or the combination of the two is used for stimulation of existing fractures.
   Injection causes pore pressure in joints/fractures to increase, the joint aperture continues to increase and eventually the joint fails in shear when the normal stress is reduced to zero. This shearing action leaves a permanent residual aperture (permeability) caused by joints asperities. Joints that fail first are the critically aligned joints dictated by the in-situ stress regime & orientation (geo-mechanics).

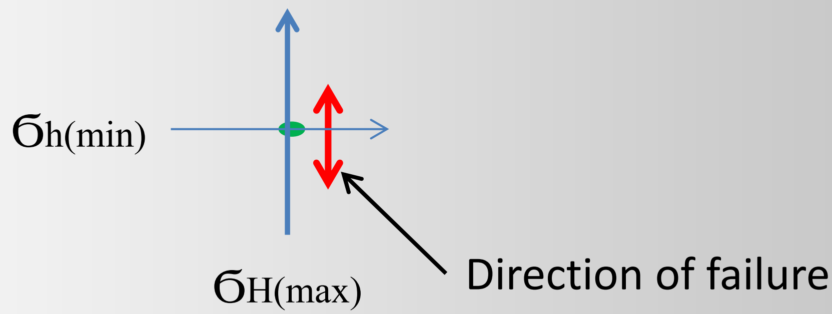
***Mechanism of failure:* SHEAR**

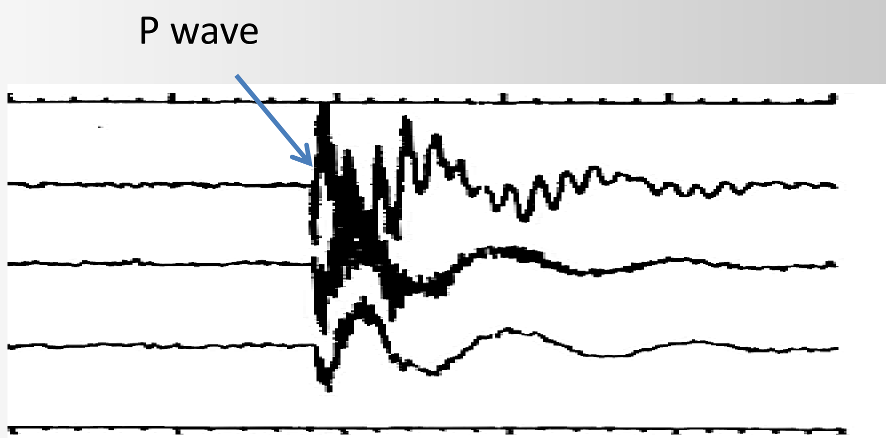
Reservoir Creation Mechanisms

Tensile failure

(less joints)

(Jell/proppant stimulation)





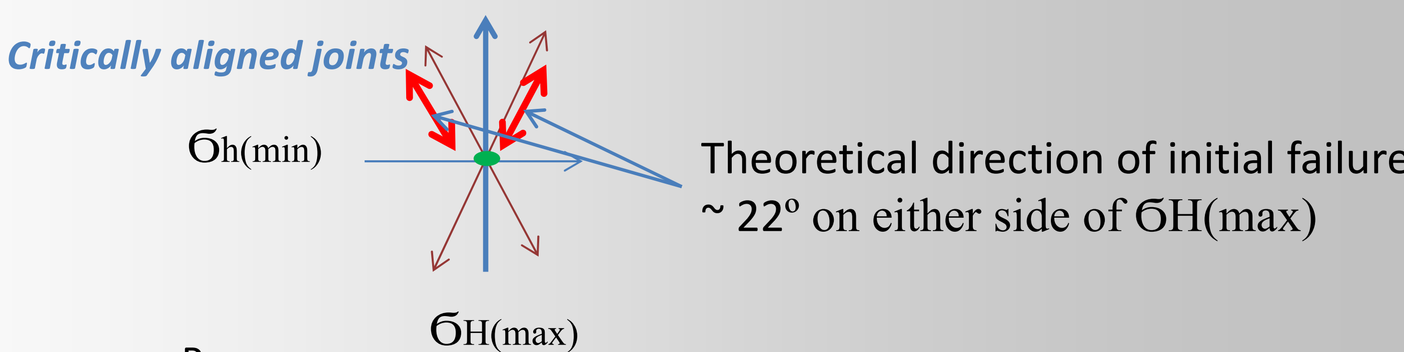
Seismic signature of a tensile failure

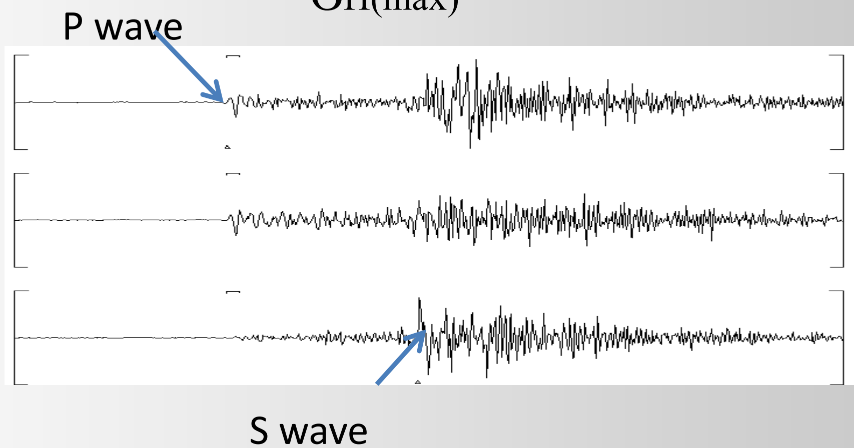
Reservoir Creation Mechanisms

Shear failure

(more joints)

(Fresh water or brine)





Seismic signature of a shear failure

ONE OF THE RESERVOIR CREATION MECHANISMS

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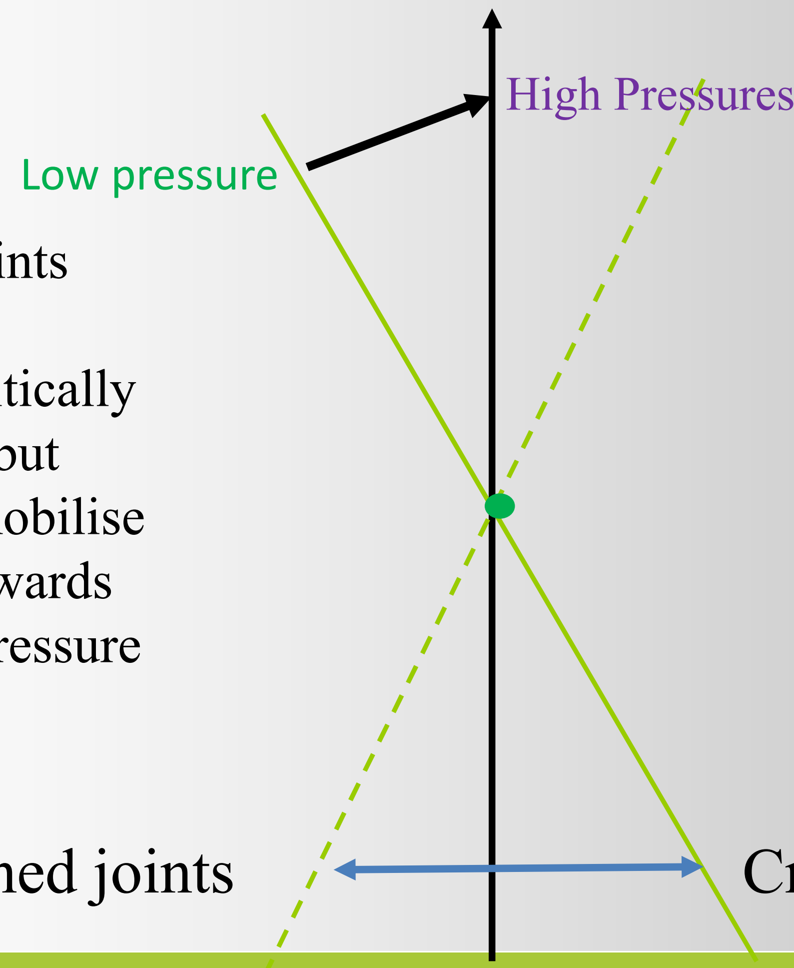
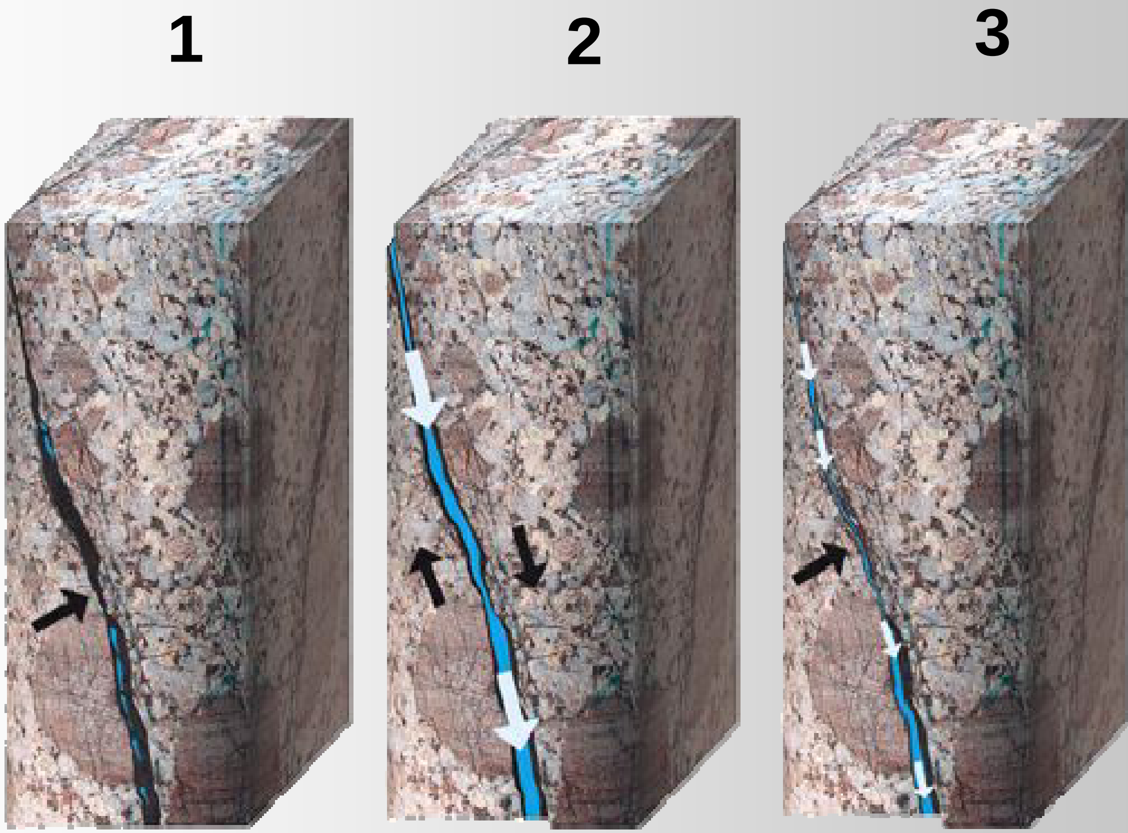
PREDOMINANT MODE DURING STIMULATION IS *SHEAR*



Plan view

Shearing of joints starts at lower pressure on critically aligned joints but continues to mobilise other joints towards ϬH(max) as pressure increases.

Shearing mechanism during a stimulation

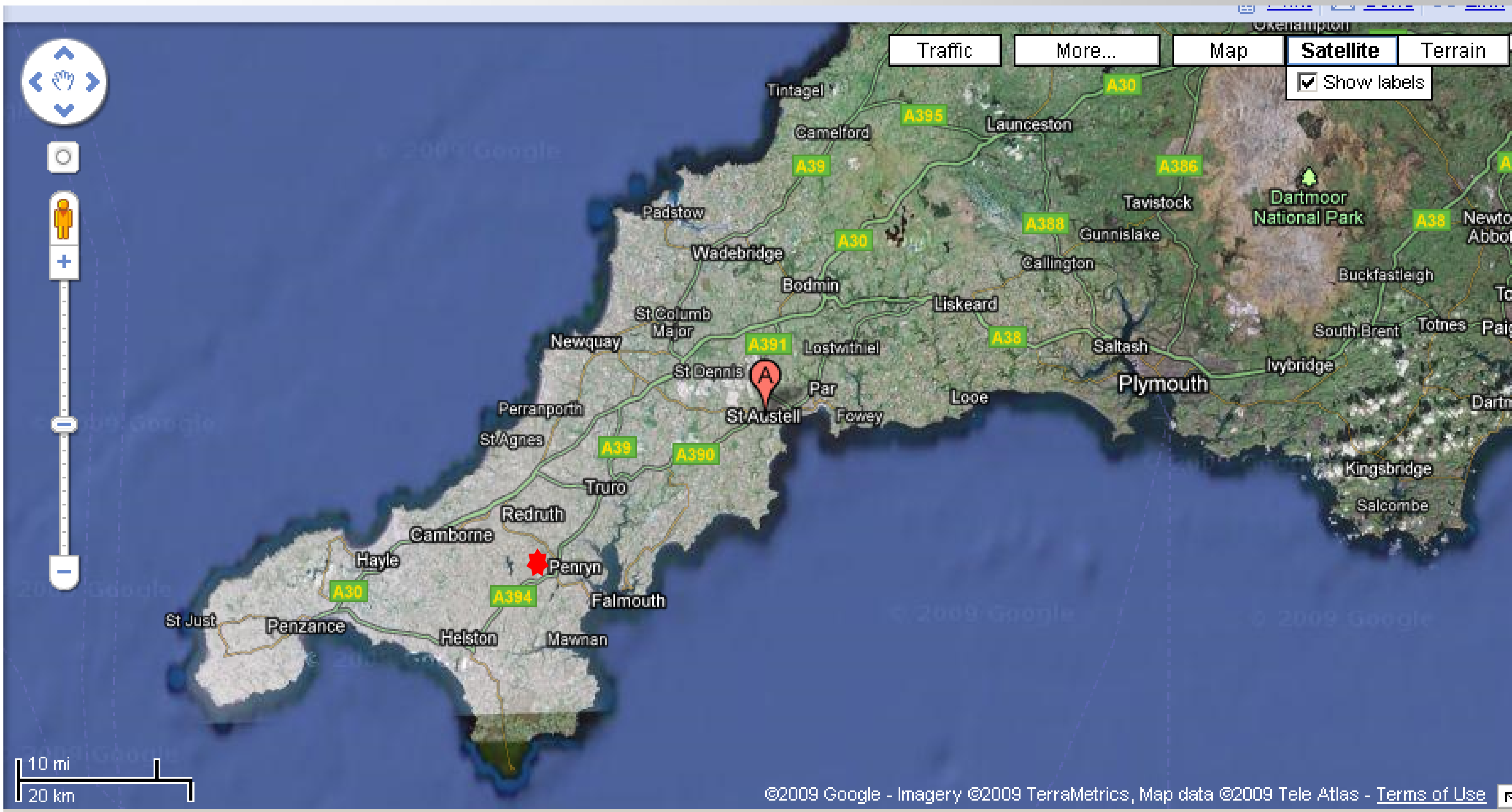


Fracture aperture before stimulation

Fracture aperture during stimulation (seismic event)

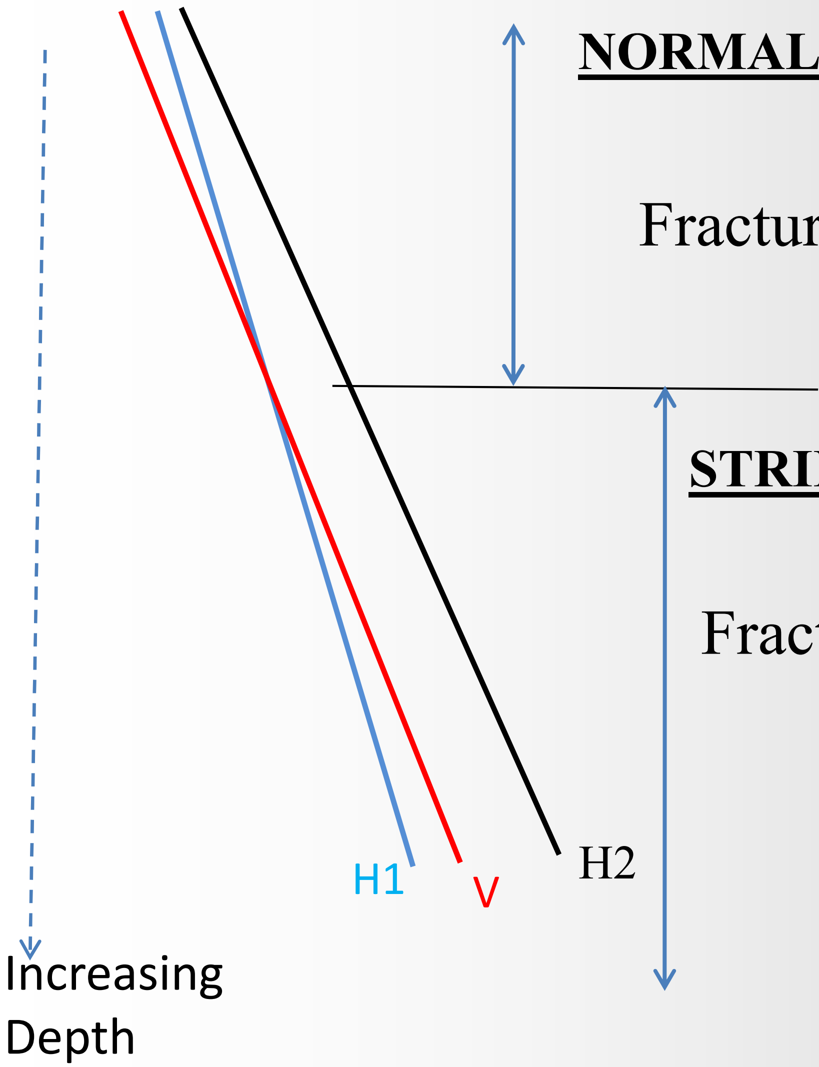
Increased fracture aperture after stimulation

EGS DEVELOPMENT IN THE UK
at the Rosemanowes site in Cornwall (1978-2002)



OBSERVED RESERVOIR GROWTH DIRECTIONS

Vertical view



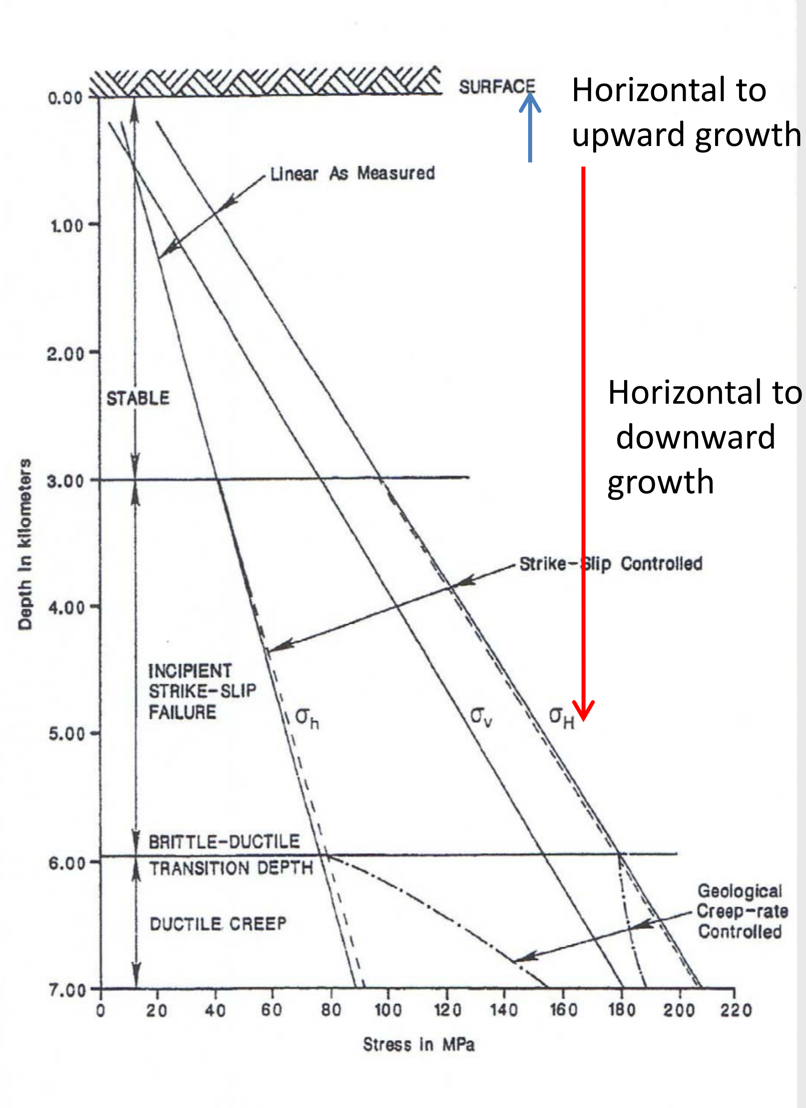
NORMAL FAULTING REGIME

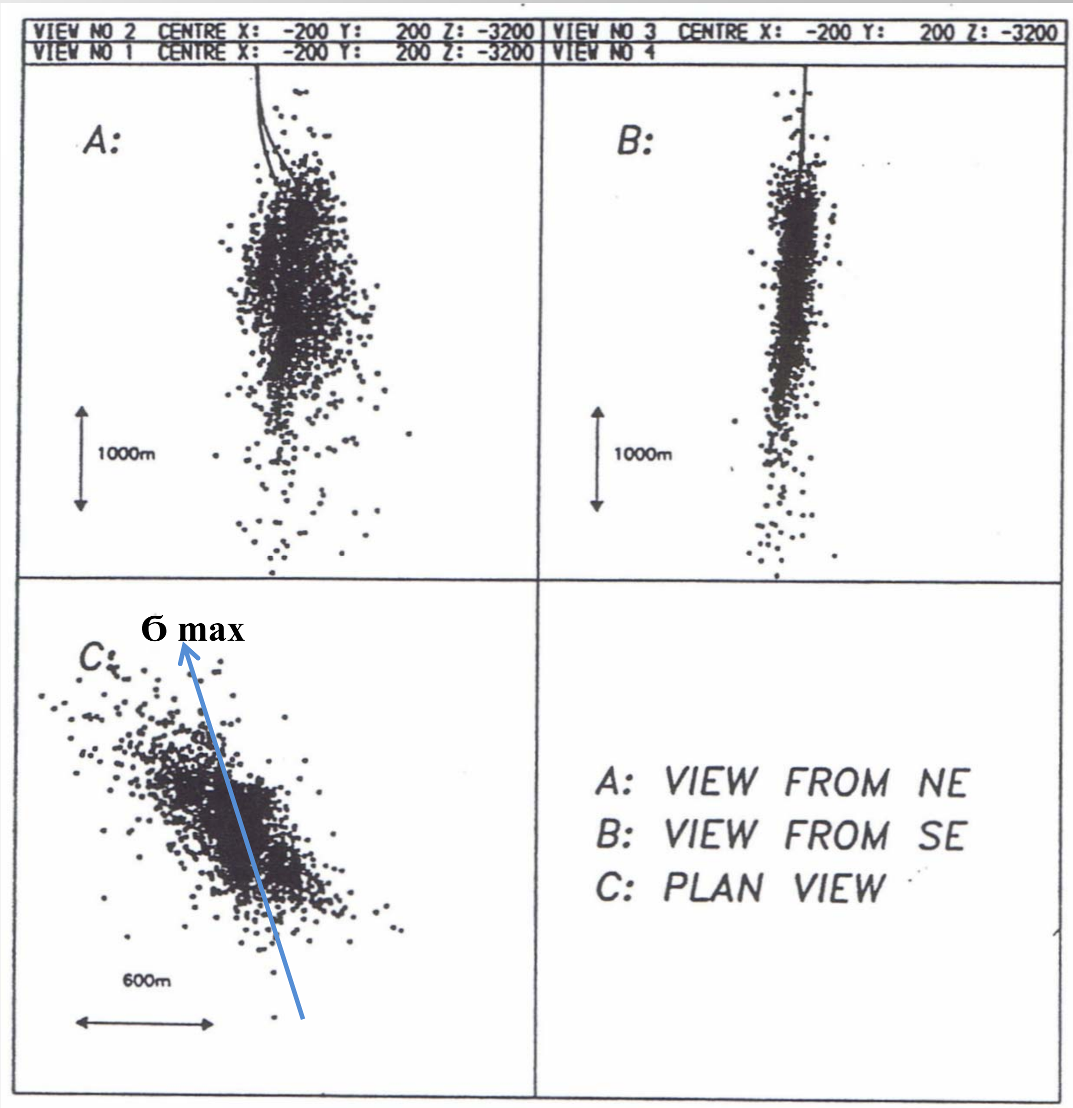
Fracture growth : Horizontal to upward

STRIKE-SLIP FAULTING REGIME

Fracture growth : Horizontal to downwards

Stress profile & Reservoir growth at Rosemanowes





WATER LOSS PROBLEM DURING 5 YEARS OF CIRCULATION @ Rosemanowes

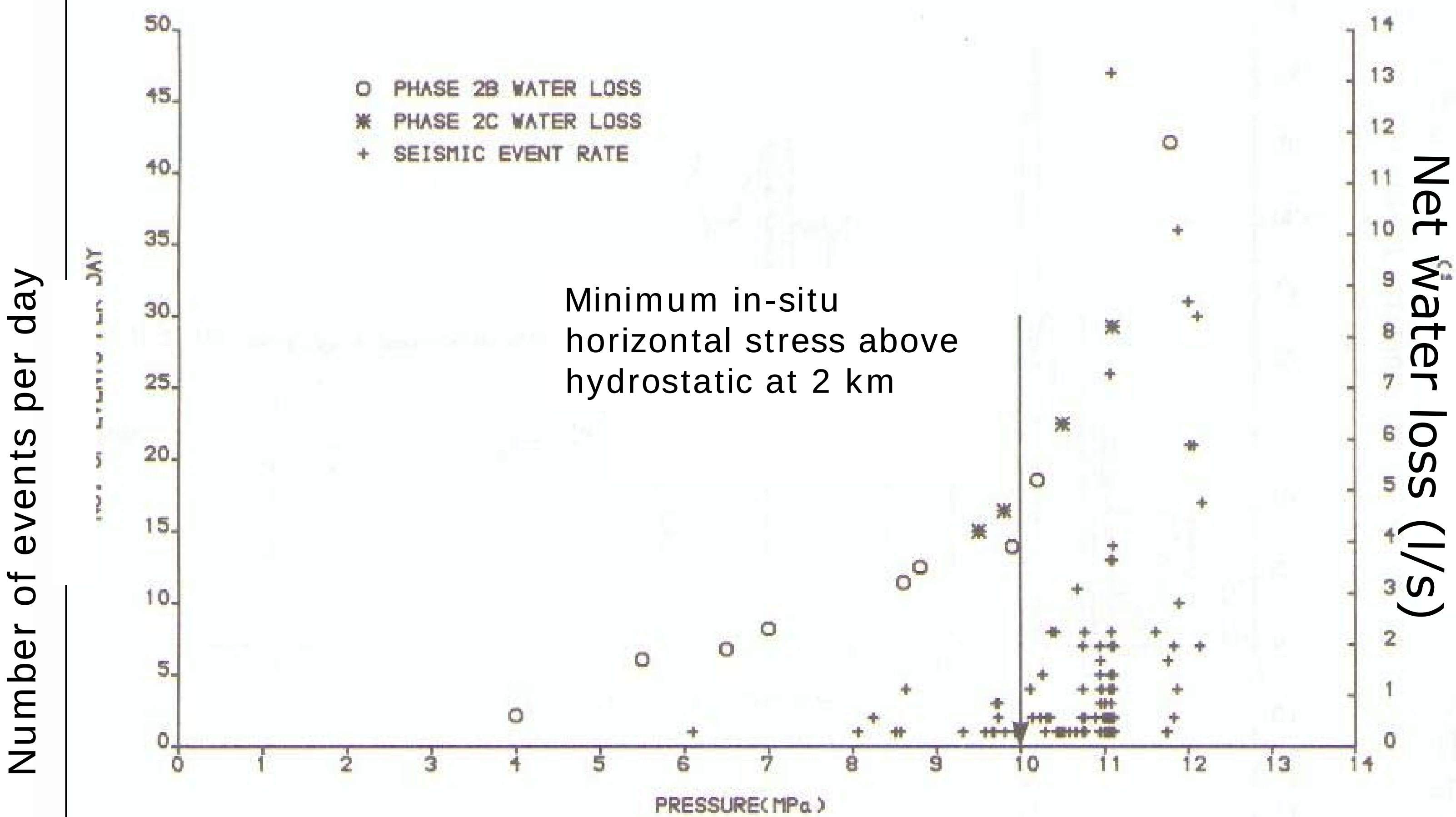
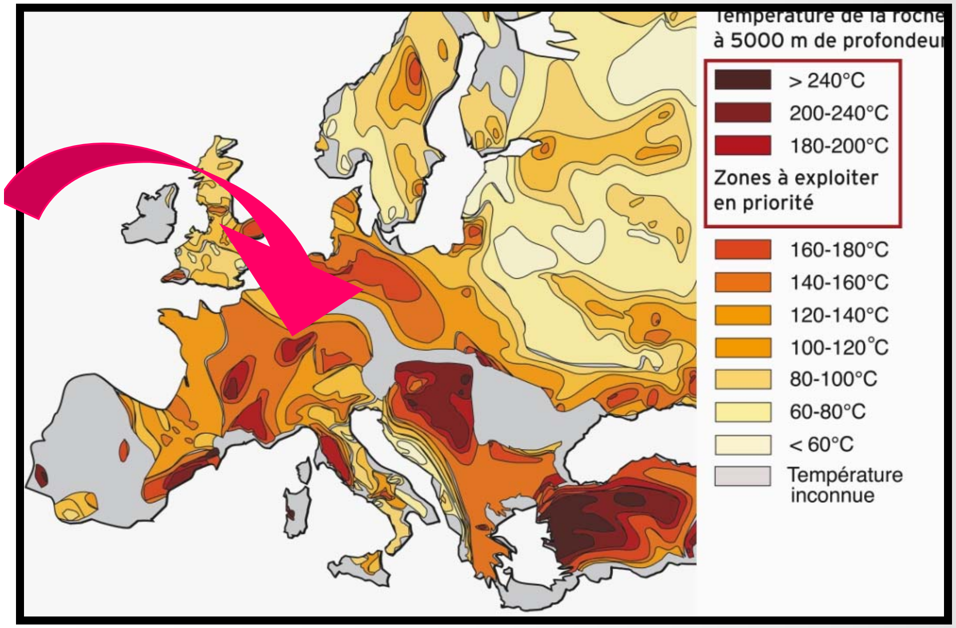
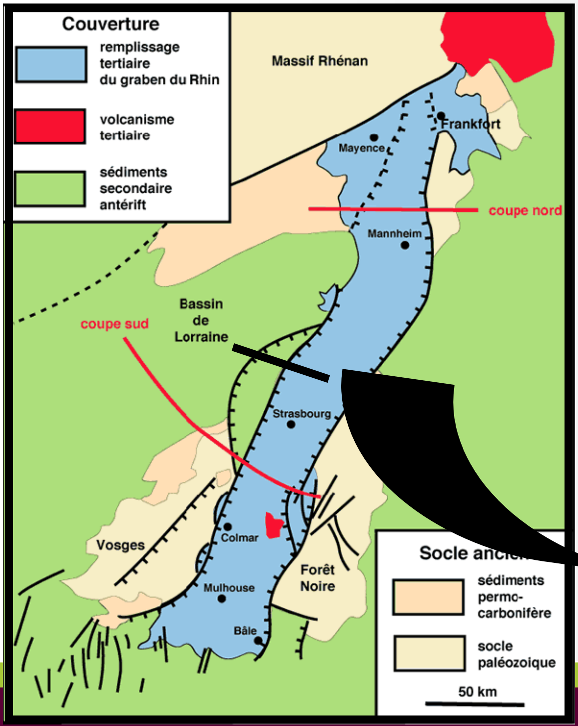
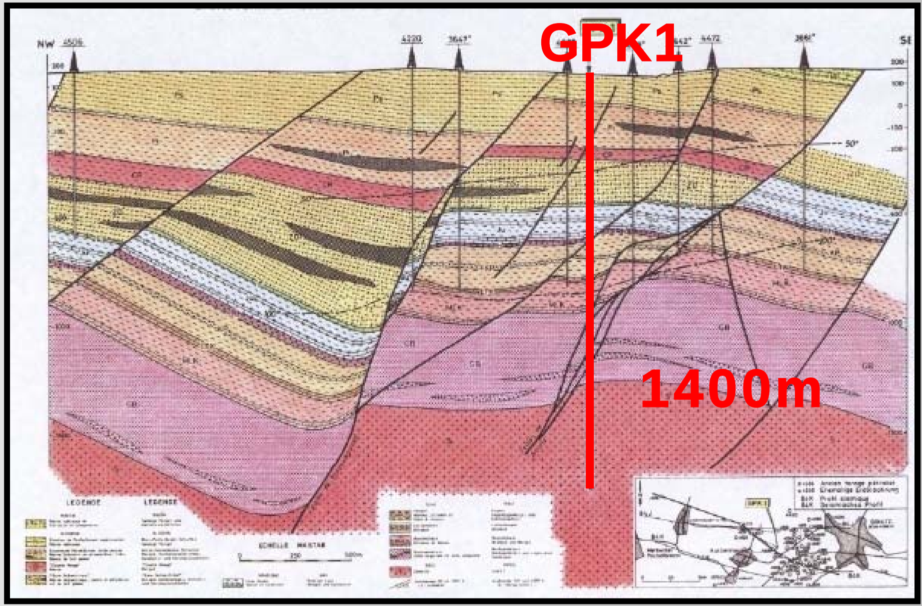


FIGURE 9 PRESSURE AGAINST DAILY SEISMIC EVENT RATE AND NET WATER LOSS FROM 5 AUGUST 1985 TO 30 JULY 1987

Location of the European EGS at Soultz, France



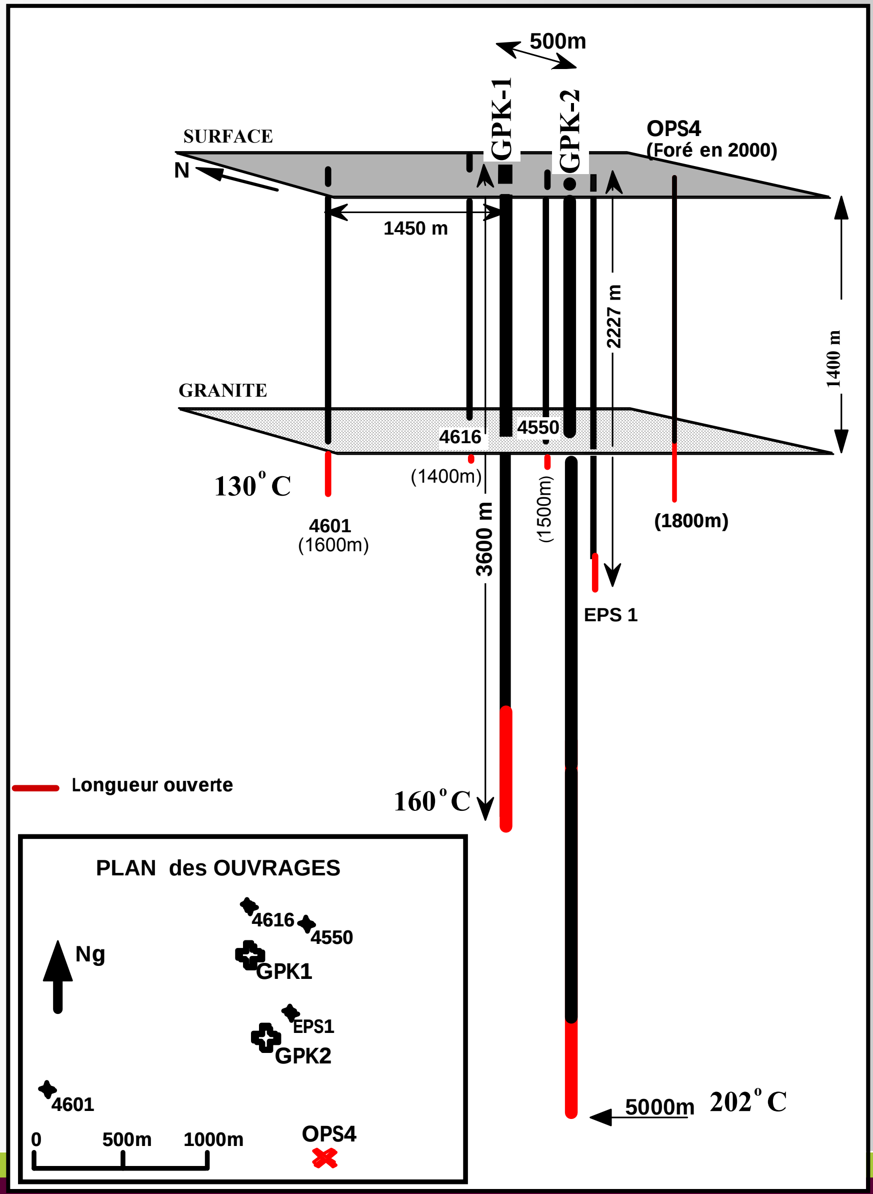




Pechelbronn oil field shallow basement

Rhine Graben Tectonics

Overview of wells & seismic monitoring system at The European EGS Project at Soultz, France



Shearing of Fractures principally occurred in the granite

THE OPEN HOLE SECTION OF THE WELL GPK2 (4500-5000m) WAS STIMULATED USING FRESH WATER.

- Flow logs were carried out to see where the flow was leaving the well.
- There were a number of exits from the well but the majority of the flow left at the bottom of the well.
- A microseismic location density map was constructed using 100 m thick depth slices to evaluate shape & direction of growth.

Stimulation of GPK2 & Targetting GPK 3

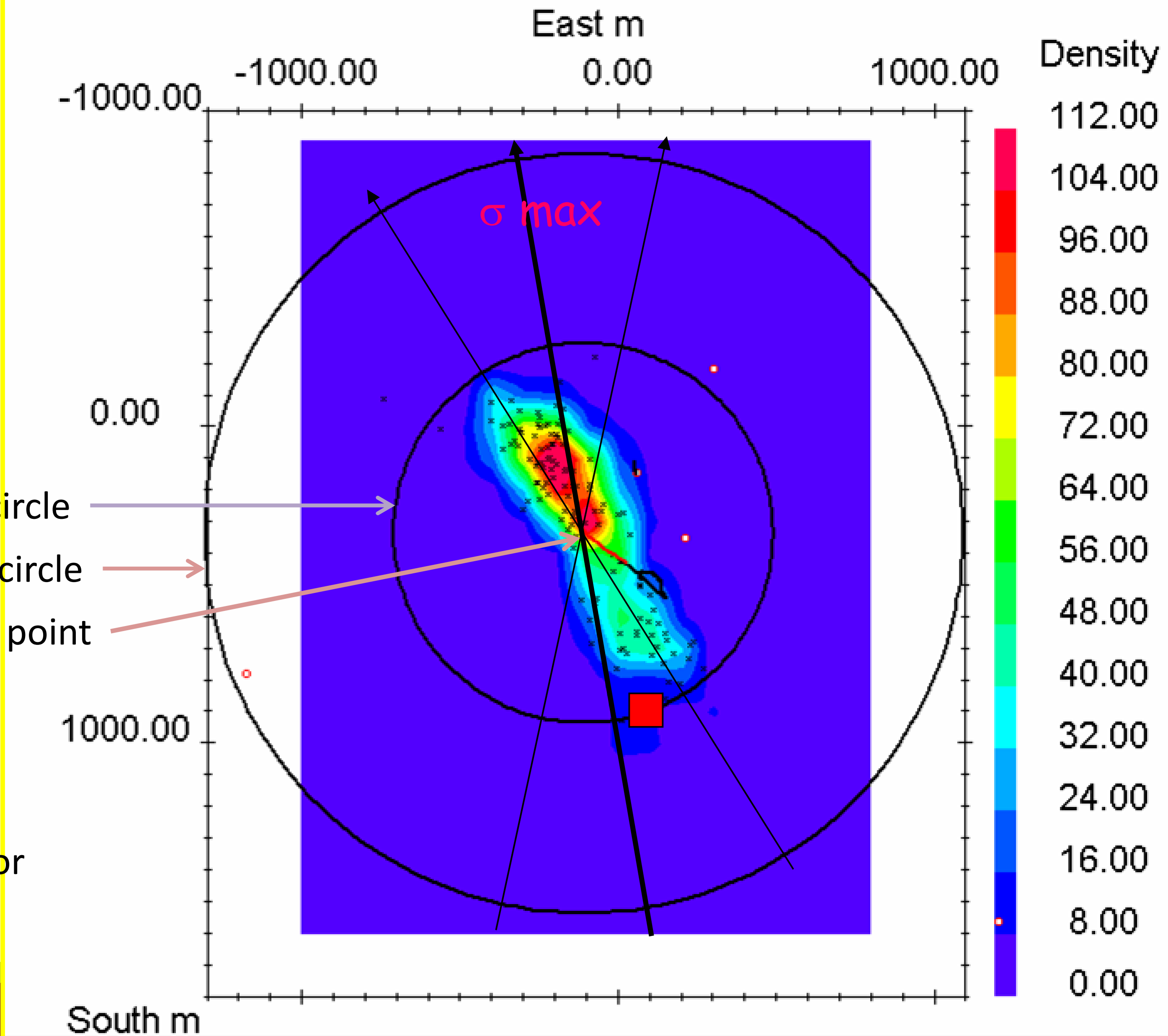
Depth Range:

4700 m – 4800 m

500 m radius circle

1000 m radius circle

Injection point

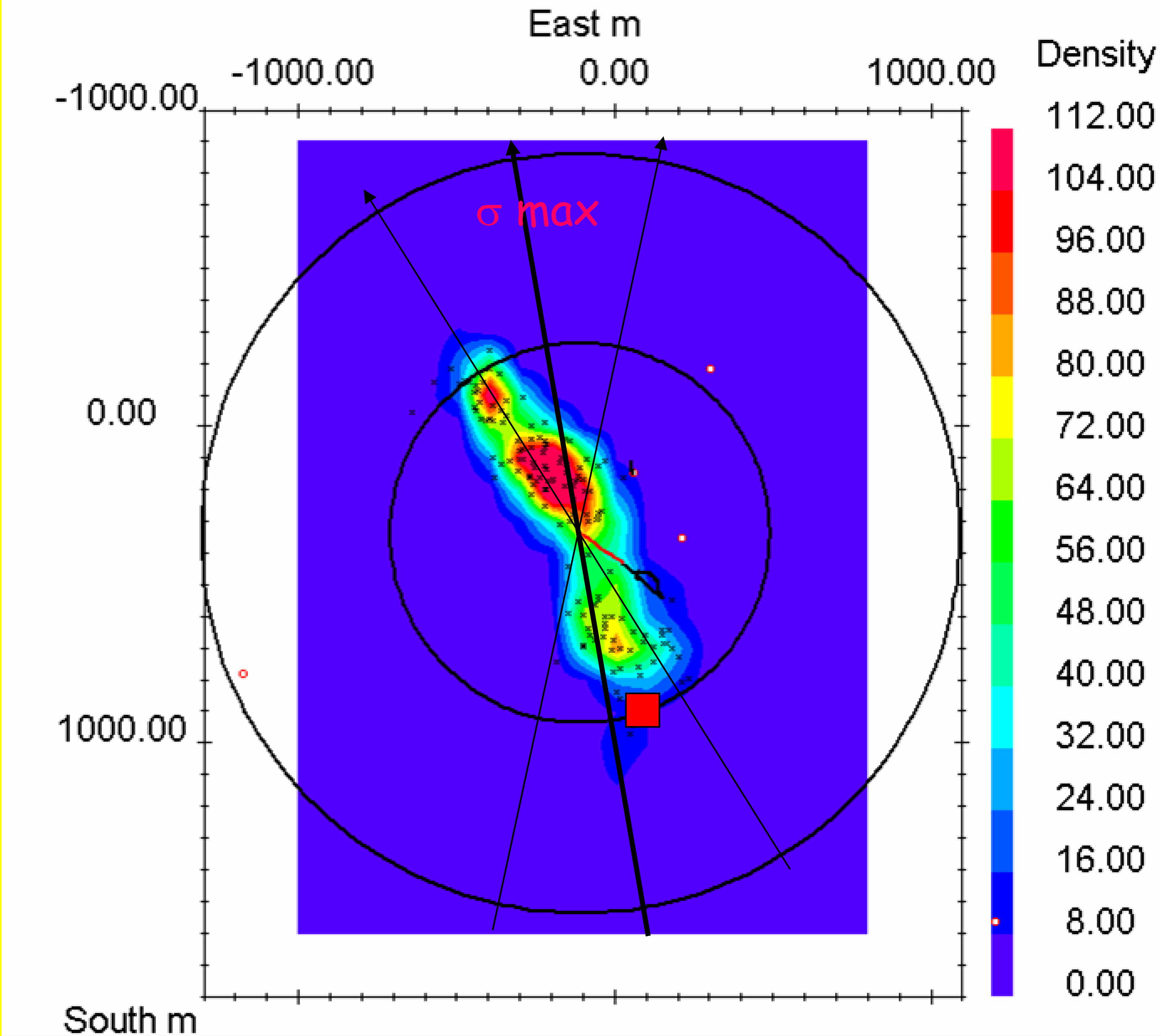


Selected position for the second well

Targetting GPK 3

Depth Range:

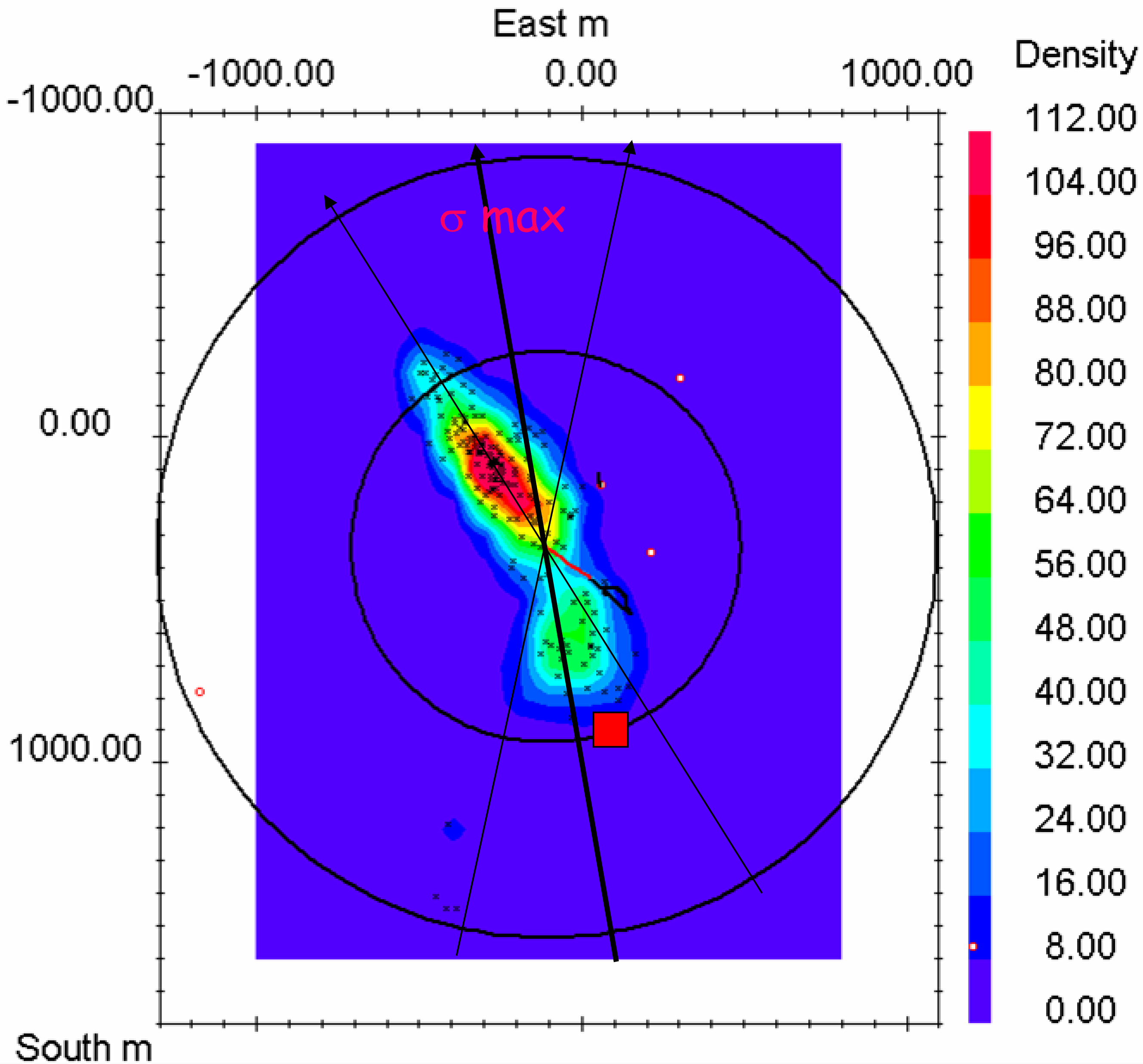
4800 m – 4900 m



Targetting GPK 3

Depth Range:

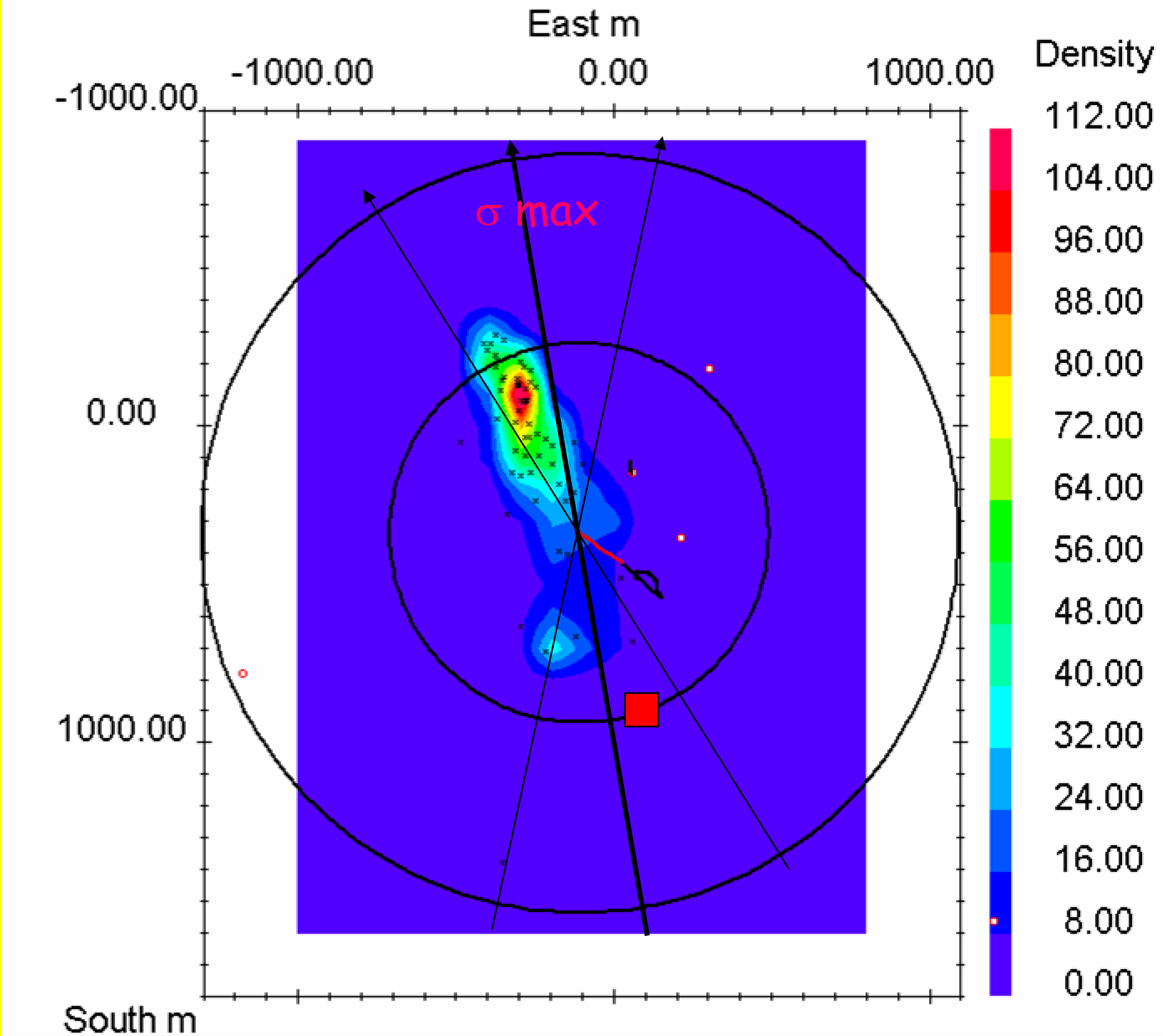
4900 m – 5000 m



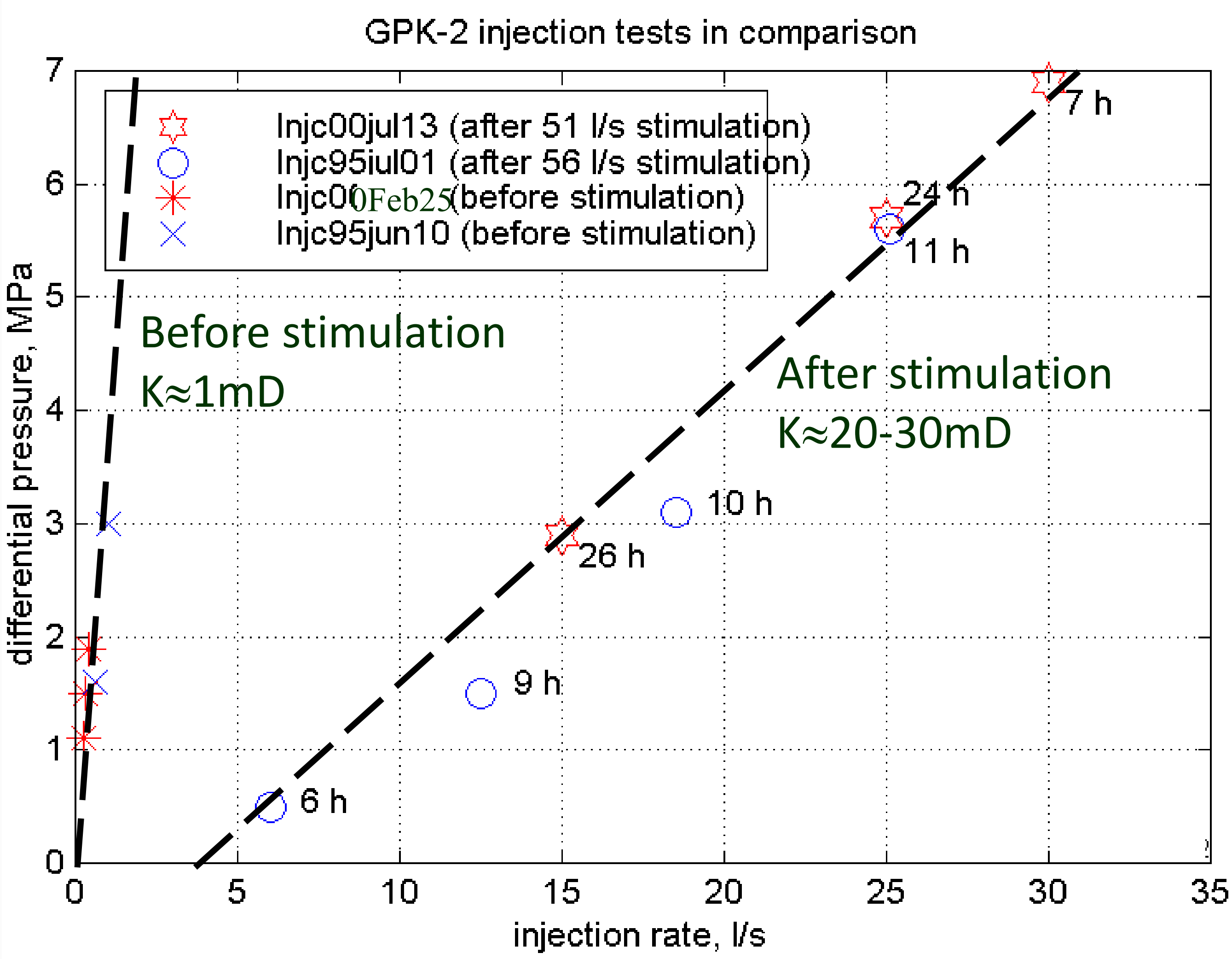
Targetting GPK 3

Depth Range:

5100 m – 5200 m



Injection test overpressures: 1995 & 2000



>> internal reservoir permeability was strongly enhanced (x20-30)

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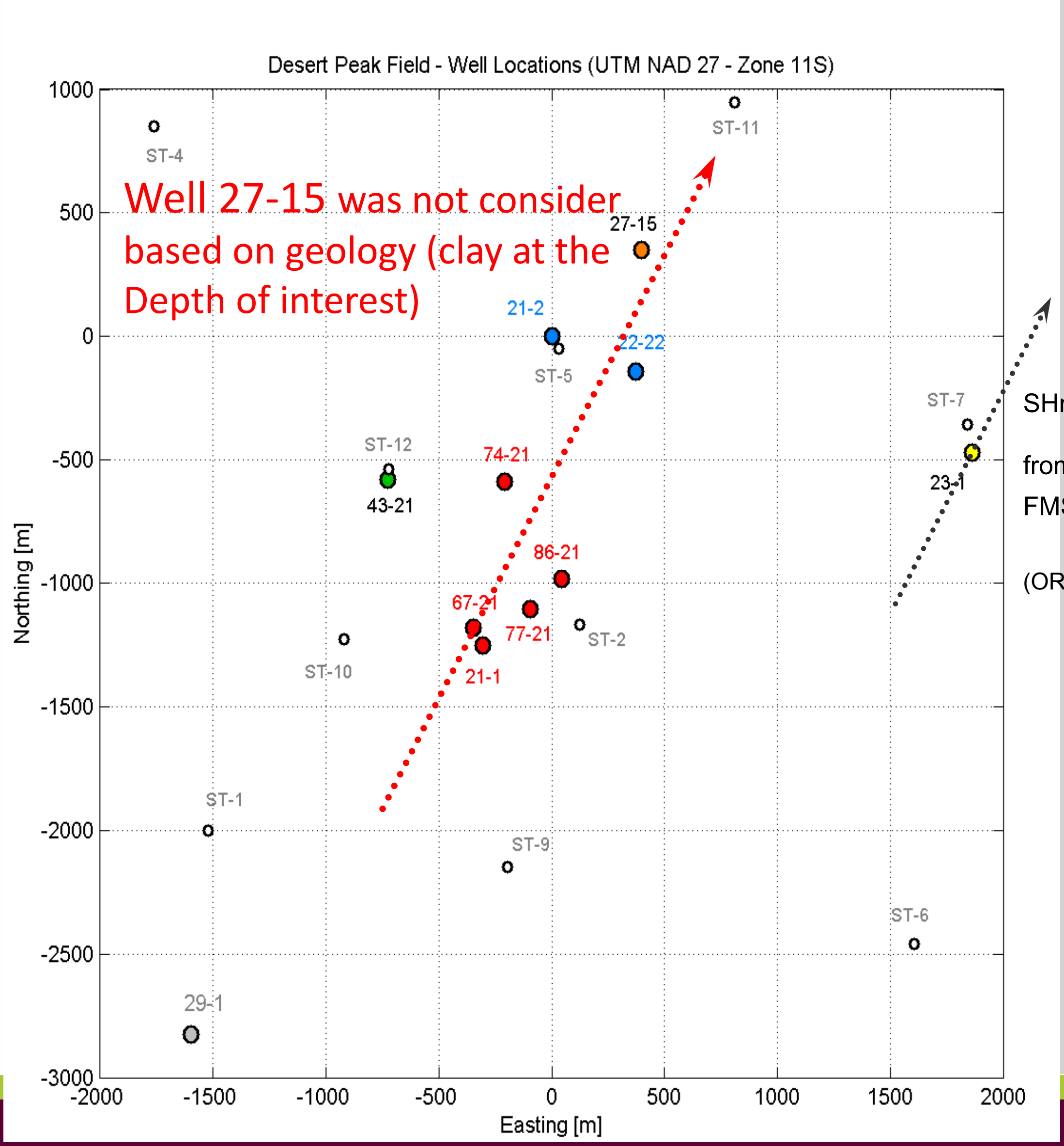
APPLICATION OF GEO-MECHANICS TO HYDROTHERMAL FIELD NEAR RENO, NEVADA

Plan view of Desert Peak hydrothermal production field



Well 23-1 was the first choice by GeothermEx

SHmax = N27°E

from FMS Log Analysis

(ORMAT & GeothermEx, 2006)

- Production Well
- Injection Well
- Proposed EGS Well
- Non-Commercial Wells
- Abandoned Well
- Stratigraphic Well

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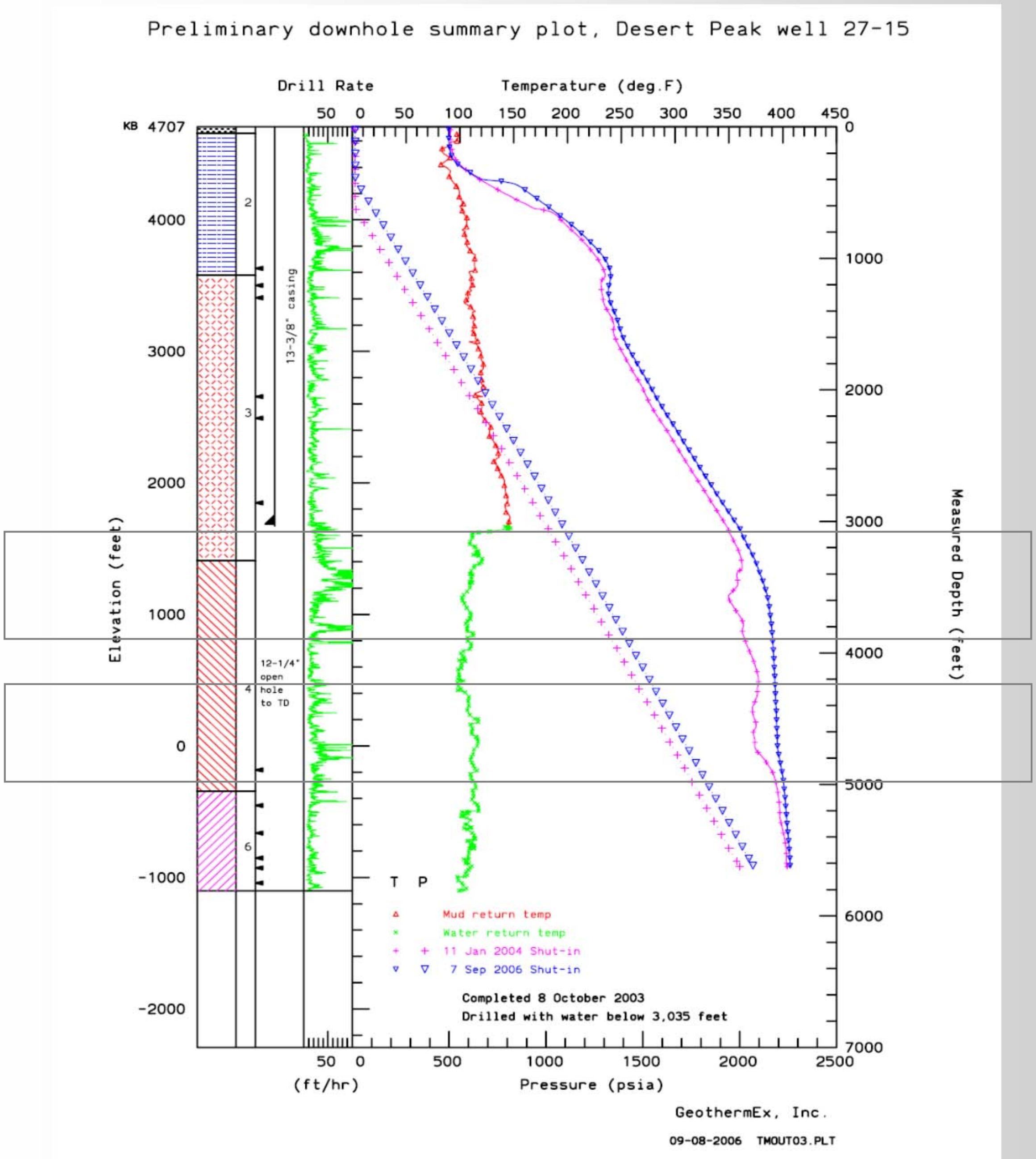
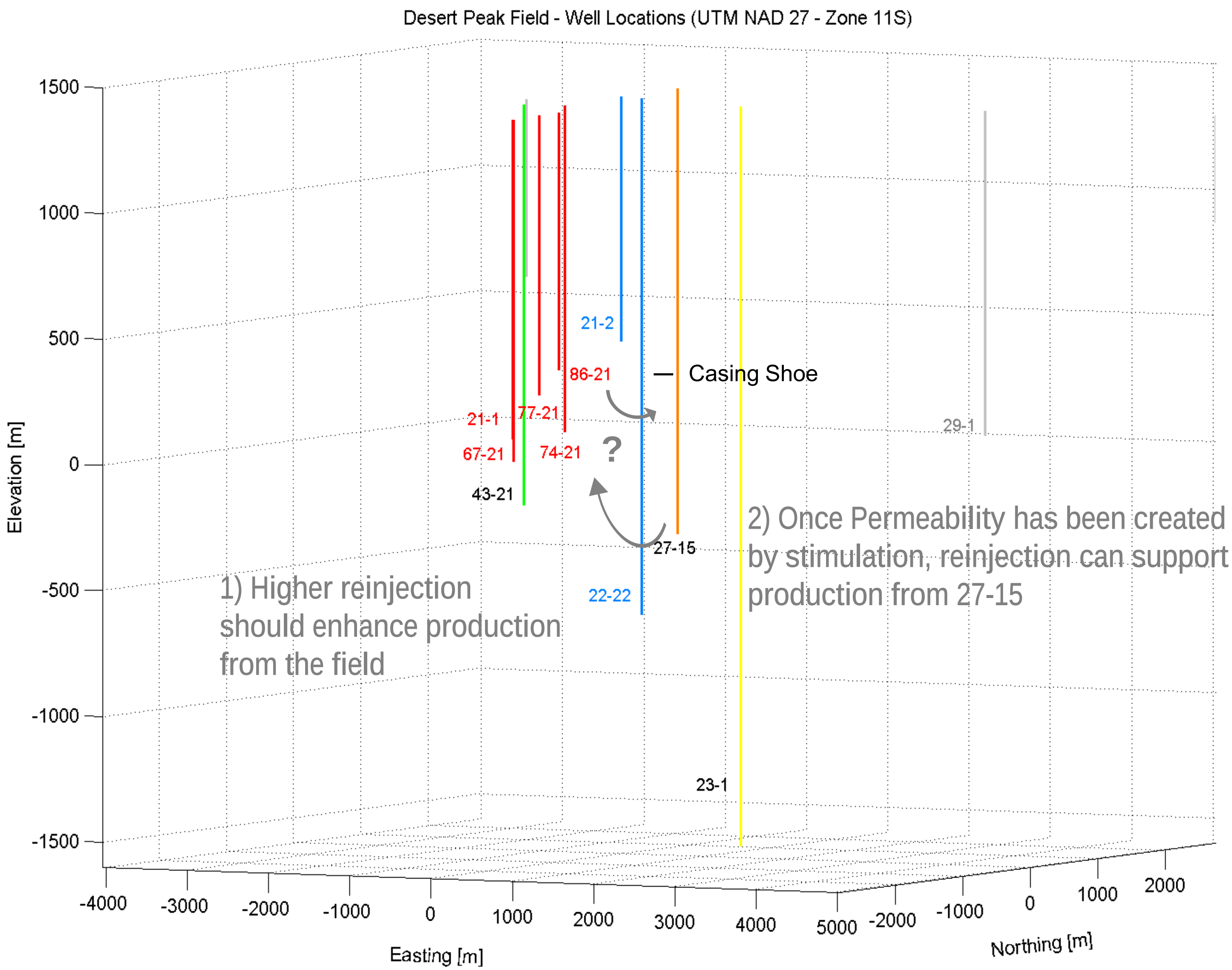


Zones with higher drilling penetration rate and some losses

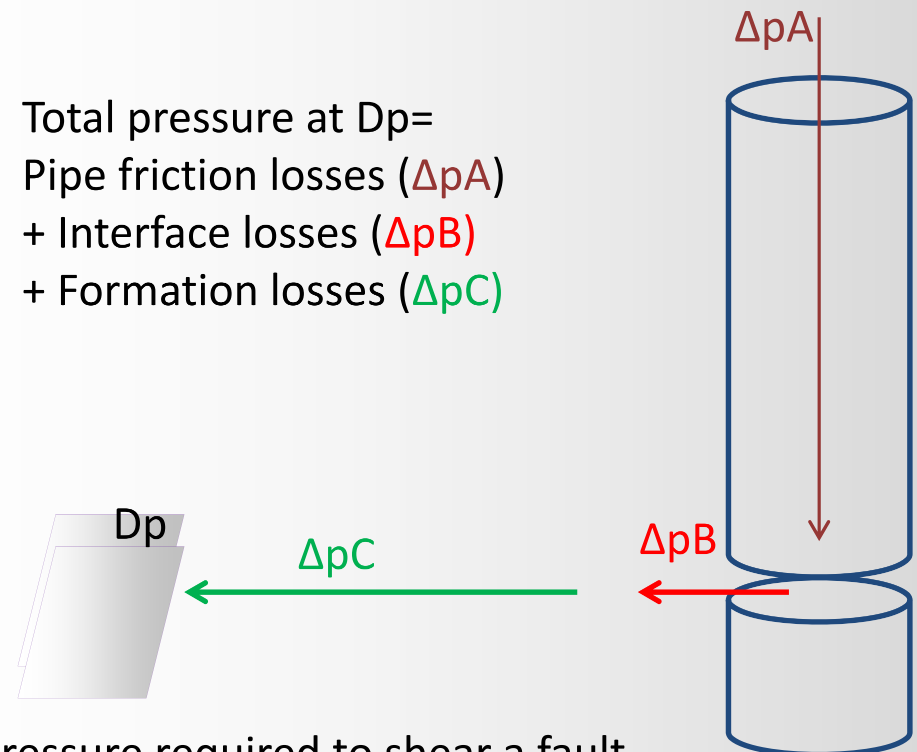
The flattening temperature gradient indicates convection in this area…
…permeability?

If the stimulation is successful:
Possible use of 27-15 as an injector or a producer



Shear Stimulation Phase (?)

Total pressure at Dp=
Pipe friction losses (ΔpA)
+ Interface losses (ΔpB)
+ Formation losses (ΔpC)



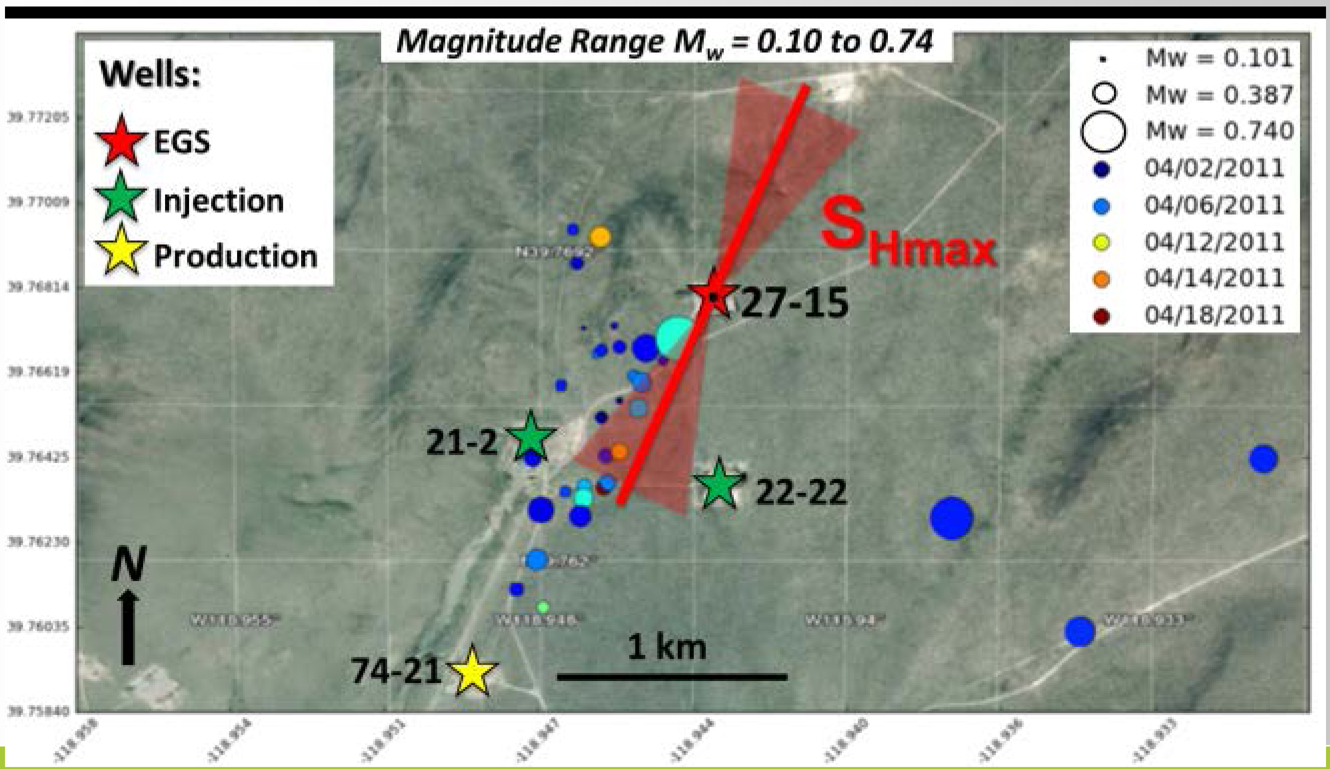
Dp= Pressure required to shear a fault

~4 to 6 gpm for ~10 days @450 psi
No seismic events generated

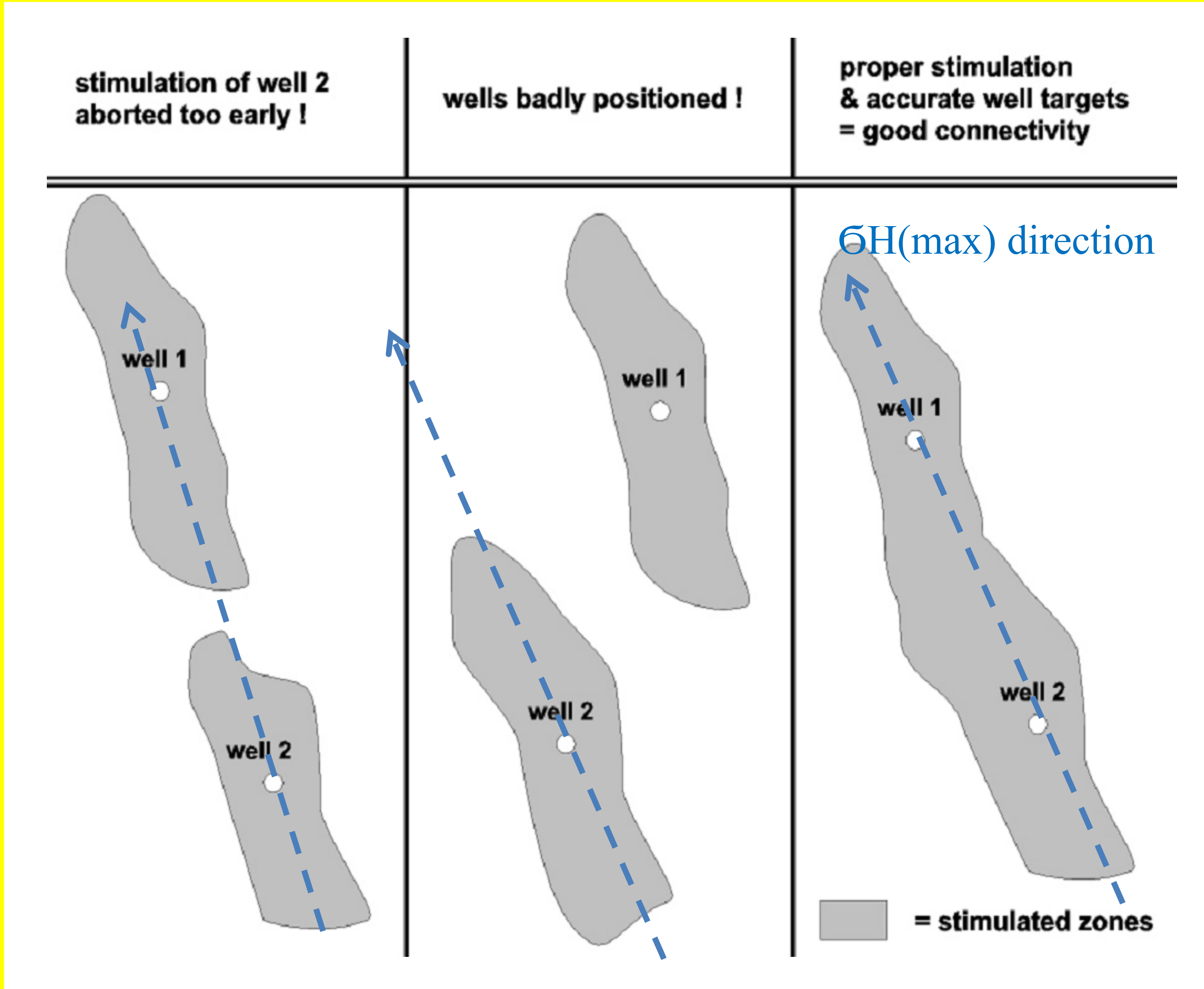
Rule of thumb:
If you wish to circulate at X l/s
You need to inject at 2X l/s.

High flow rate stimulation

- Constrained by limited pressure with wellhead & casing
- Injection flow was ~550, 735 & 1000 GPM with injection pressure of 1000, 835 & 1200 PSI resulting in an increase in injectivity from 0.012 to 2.1 GPM/PSI, an increase of 175 fold. This was a dramatic improvement in permeability & power output from the plant.



IMPORTANT STIMULATION STRATEGIES – WELL LAYOUT



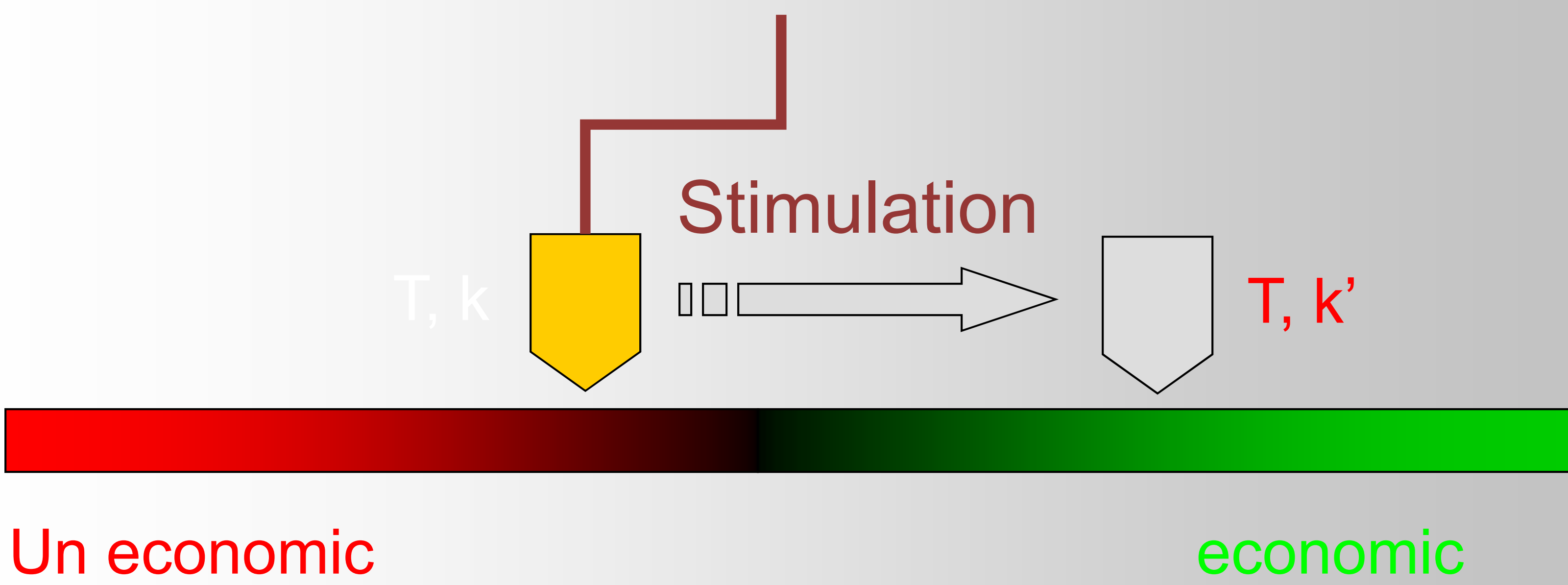
Review of some non commercial wells in (Nevada) for potential improvement.

Field A:	**43-33**	(1 wells)
Filed B:	**15-12, 18A-11**	(2 wells)
Fileld C:	**27-15, 11-27**	(2 wells)
Fileld D:	**14-34, 81-28, 81A-28RD, 46-28 & 33-11**	(5 wells)
Field E:	**57-8**	(1 wells)
Field F:	**86-16**	(1 wells)

12 wells out of 24 examined could be considered for stimulation. One suspects that similar potential for improvement lies at other hydrothermal fields as well.

POTENTIAL GEOTHERMAL RESERVOIR:

Temperature T & Permeability k



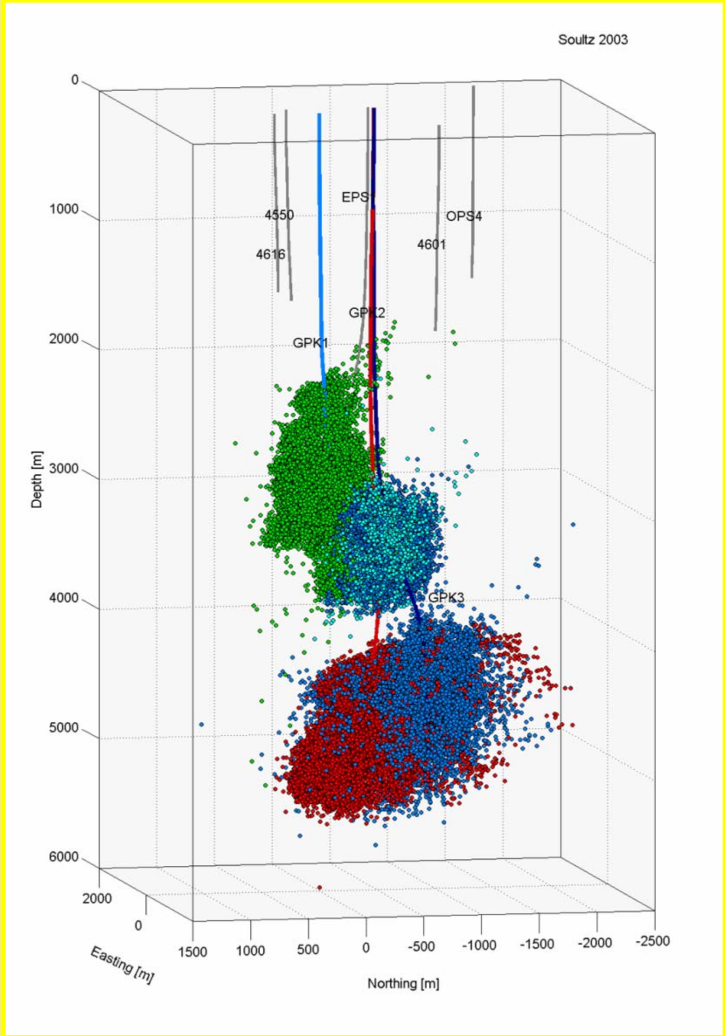
WHAT NEXT ?

THE MESSAGE:

DURING THE DEVELOPMENT AND IMPROVEMENT OF A RESERVOIR, IT IS IMPORTANT TO CONSIDER THE GEOMECHANIC ASPECTS TO INCREASE THE SUCCESS POTENTIAL. NUMERCIAL MODELLING CAN BE DONE TO SCOPE THE STIMULATION.

THE END

THANKS FOR YOUR COOPERATION



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