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Deep Heat Mining Project Basel

Geological and hydraulic evaluation of the Basel 1 geothermal reservoir

Presentation at 5th Swiss Geoscience Meeting, Geneva 2007
16th-17th November 2007

Florentin Ladner / Ulrich Schanz / Markus Häring
Geothermal Explorers Ltd

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Content Part I

- General overview
- Characterization of the undisturbed reservoir Basel 1
- Hydraulic stimulation in Basel 1
- Summary

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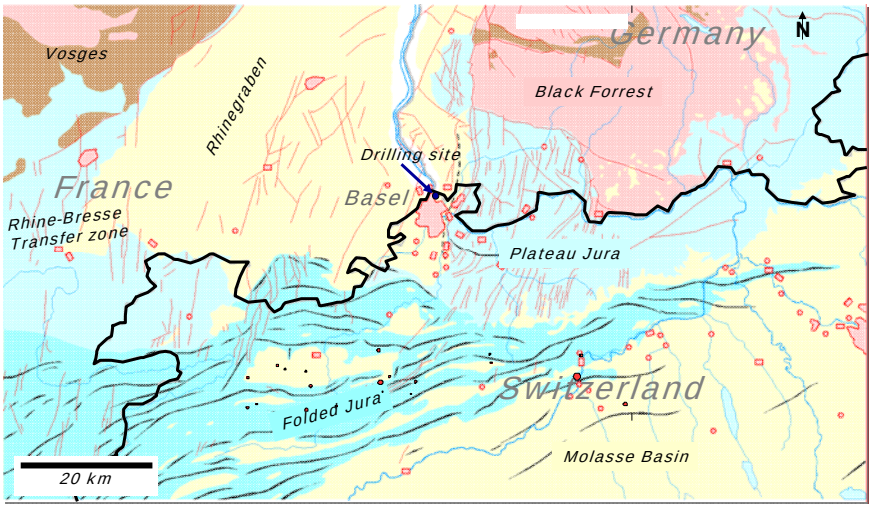
Tectonical Setting



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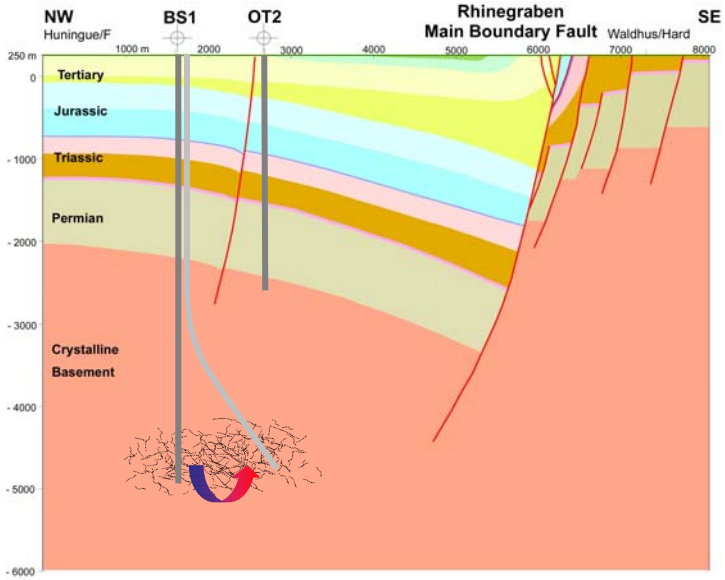
Project DHM, Basel



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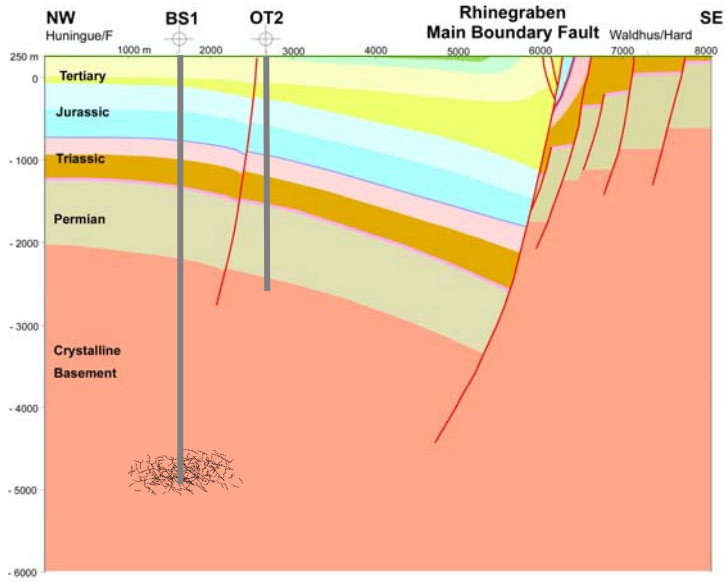
Project Status



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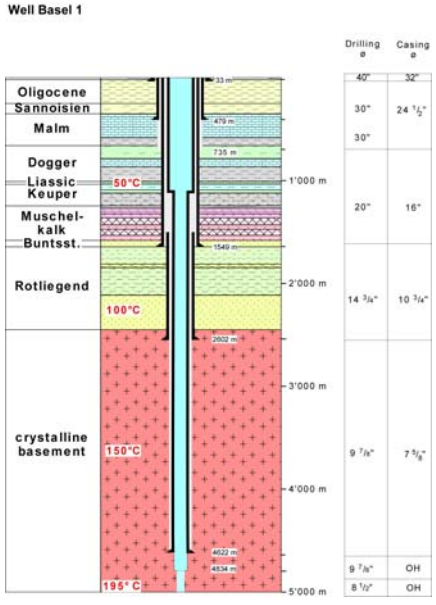
Geology Basel 1

- Sedimentary cover
- Top basement at 2‘507m
- Granitoid rocks
  - hornblende-bearing biotite granite
  - biotite-hornblende monzogranite to monzonite
  - magmatic dykes
- Reservoir temperature ~ 195°C



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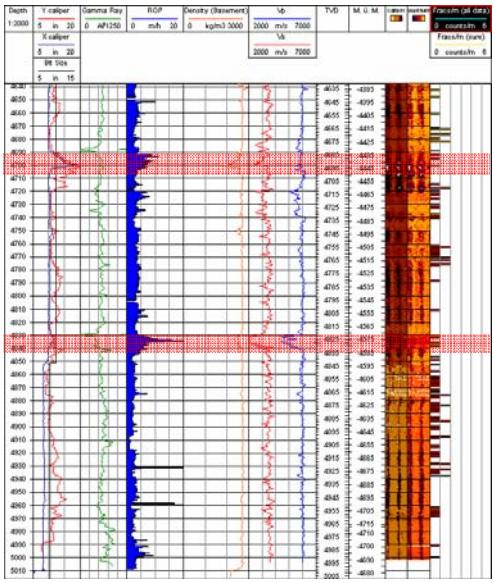
Reservoir Geology

- Fracture density
  - 0.3 per Meter
- Cataclastic fracture zones
  - argillic alteration
  - anhydrite bearing



Composite log of the open hole section (4'629 – 5'000 m below Surface)
Major fracture zones are indicated by red colours.

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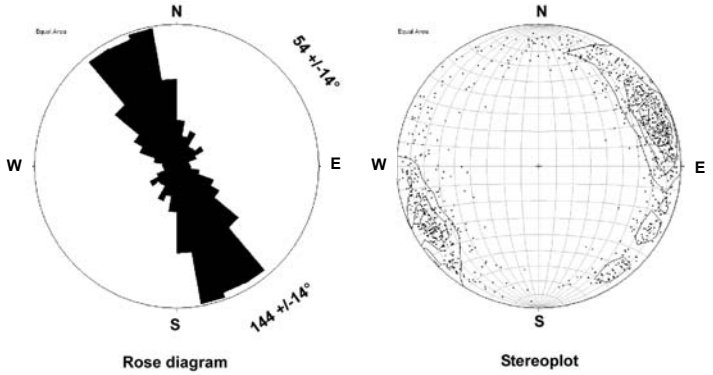
Orientations of stress and discontinuities



Rose diagram

Stereoplot

Strike direction of natural discontinuities

Azimuth of $S_1 = S_{Hmax}$ for borehole breakouts and drilling induced tension fractures

Azimuth of $S_3 = S_{hmin}$ for borehole breakouts and drilling induced tension fractures

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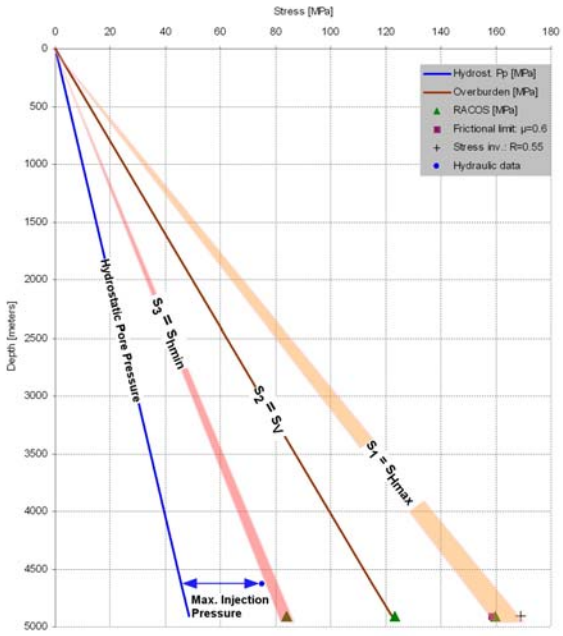
Stress magnitude

- Constraining the stress magnitudes
- Vertical stress profile is well defined
- Horizontal stress profile are still poorly defined

➢ Strike slip regime: $S_{Hmax} > S_v > S_{hmin}$

➢ Evidence for high deviatoric stresses



Assumed stress profile for Basel 1.

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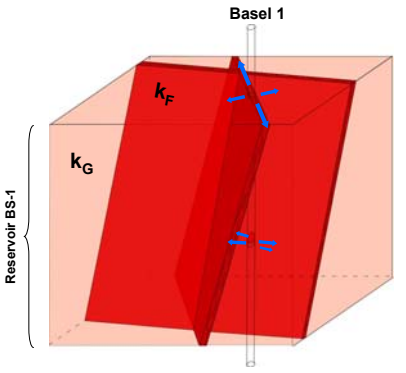
Reservoir Hydraulics

- Well testing analysis
  - $k_{eff} \sim 1*10^{-17}$ m²
  - Bilinear flow
  - $k_F >> k_G$
  - (Opalinus-Ton: $6*10^{-21}$ m²)



Model showing the hydraulic domains in the the open hole section of Basel 1.

Flow pathes during injection test

➢ Low-permeability reservoir rock

➢ Only few water-conducting fractures

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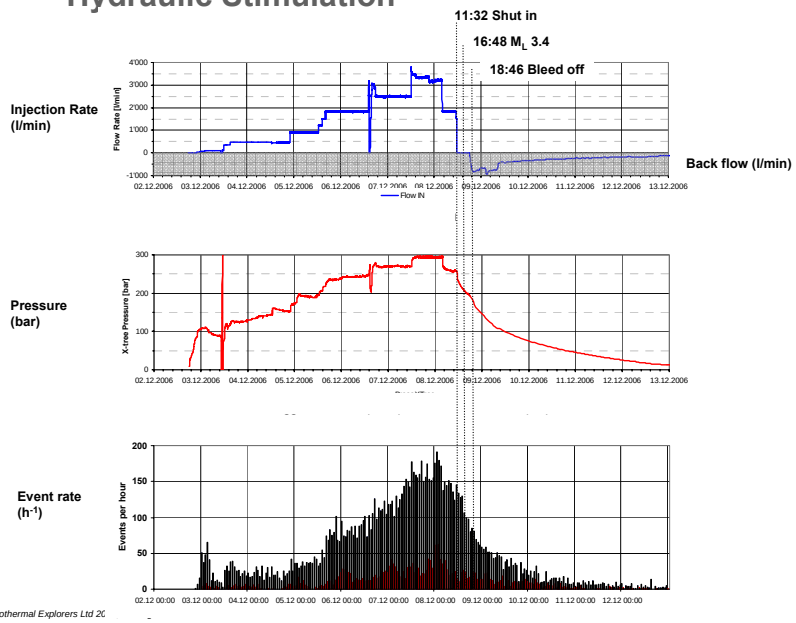
Hydraulic Stimulation



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Hydraulic stimulation

- Analysis of the hydraulic stimulation data
  - ➢ Increase of fracture transmissibility by a factor 400.
  - ➢ Fracture transmissibility at the end was irreversible indicating that shearing was a dominant process.
  - ➢ Post-stimulation tests are still outstanding because the project was suspended.
  - ➢ Non-conclusive assessment of the reservoir

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Shear failure analysis (I)

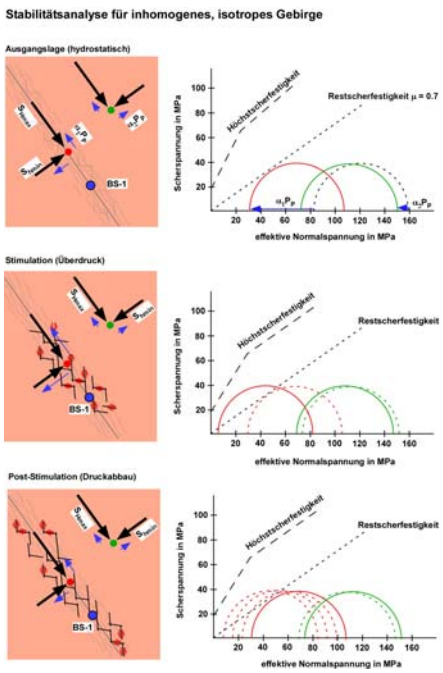
- Effective stress concept:

$$S_{eff} = S_{tot} - \alpha_i P_P$$

α_i … Effect of pore pressure

$\alpha_1 \approx 1$ (fractured rock)

$\alpha_2 \approx 0.2$ (dense rock matrix)



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Shear failure analysis (II)

- Effective stress concept:

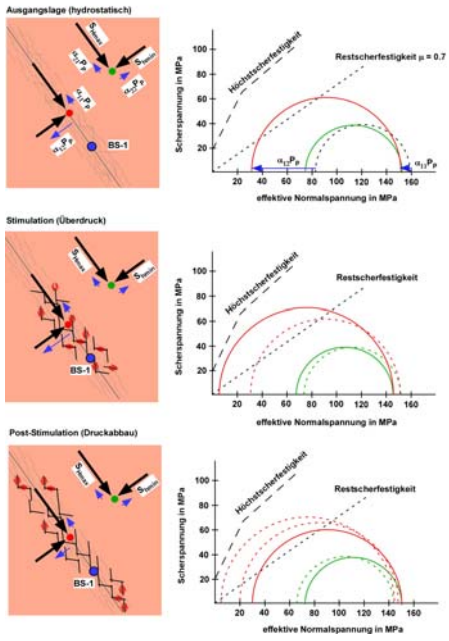
$$S_{ij}^{eff} = S_{ij}^{tot} - \alpha_{ij} P_P$$

α_{ij} … Effect of pore pressure

$\alpha_{11} \approx ?$ ($\parallel$ fracture zone)

$\alpha_{12} \approx 1$ ($\perp$ fracture zone)

$\alpha_{21} \approx \alpha_{22} \approx 0.2$ (dense rock matrix)



Summary

Geomechanics:

- Strike slip regime
- Evidence for high deviatoric stresses
- Orientation of S_{Hmax} and dominant fracture set are subparallel
- Effect of pore pressure

Hydraulics:

- Low-permeable rock matrix with few water conducting fractures
- Hydraulic behaviour is controlled by this fractures

Hydraulic stimulation:

- Enhancement of fracture permeability during stimulation by a factor 400
- Enhancement is irreversible
- Shearing was a dominating process

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Cooperation Partners

GEOdata
SOLEXPERTS Swiss Precision Geomonitoring
Precision Drilling
GEOTEC AG
GGA INSTITUT
Schlumberger
Centre de recherche en géothermie CREGE Neuchâtel - Suisse
ETH Eidgenössische Technische Hochschule Zürich
Université de Neuchâtel unine
DR. ROLAND BRAUN CONSULTANCY IN ROCK MECHANICS since 1978
UNI BASEL

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Deep Heat Mining Project Basel

Microseismic aspects of the Basel 1 geothermal reservoir

Prasentation at 5th Swiss Geoscience Meeting, Geneva 2007
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PRESENTATION OVERVIEW

- Concept of Hydraulic Induced Shearing
- Microseismic Network Array
- Seismic Response Procedure
- Microseismic Analysis
  - Event Distribution
  - Fault Plane Solutions
  - Large Event Characteristics
  - Proposed Geomechanical Model
- Migration Imaging of Features Outside the Reservoir
- Summary

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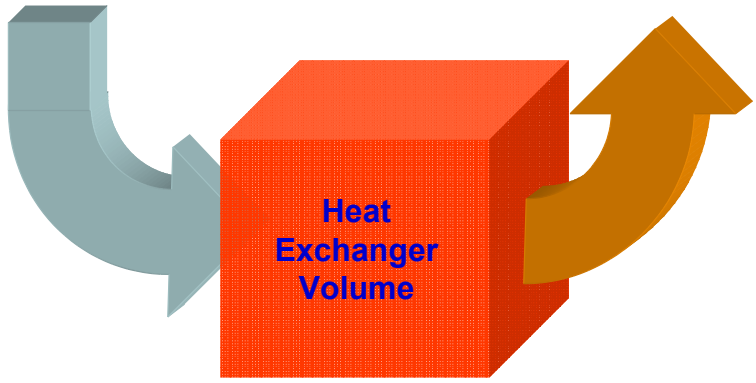
INTRODUCTION

Stimulation target:
Creation of an efficient subsurface heat exchanger

in: 50 kg/s

out: 50 kg/s



pressure impedance determines success or failure

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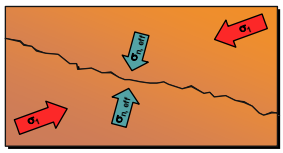
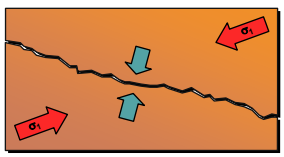
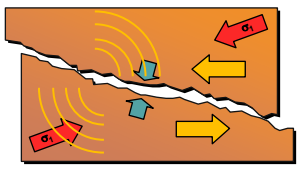
CONCEPT of INDUCED SHEARING



closed fracture
= weak zone



hydraulic injection reduces
friction on fracture planes



stress induced slipage

seismic signal used for location tracking

displaced interfaces do not match anymore
= fracture remains open

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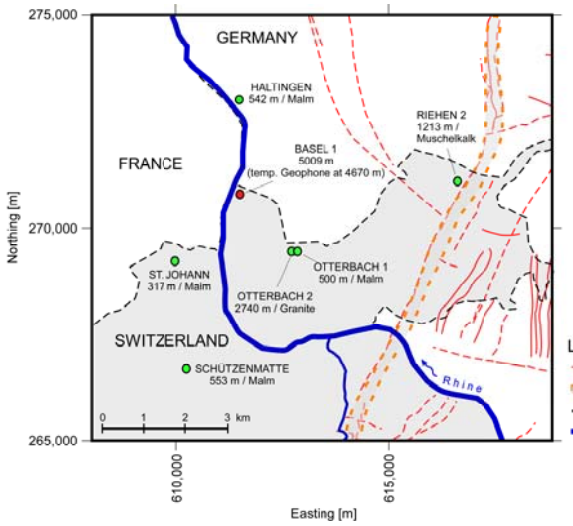
MICROSEISMIC NETWORK ARRAY



Network Modelling

- Sensitivity by wavefield propagation simulation
- Resolution analysis by raytrace simulation
- Result is optimized balance between network performance and financial investment

Velocity Model Calibration

- 200°C/100 MPa T zero 3C geophone deployed in the stimulation well for first 40 Hrs

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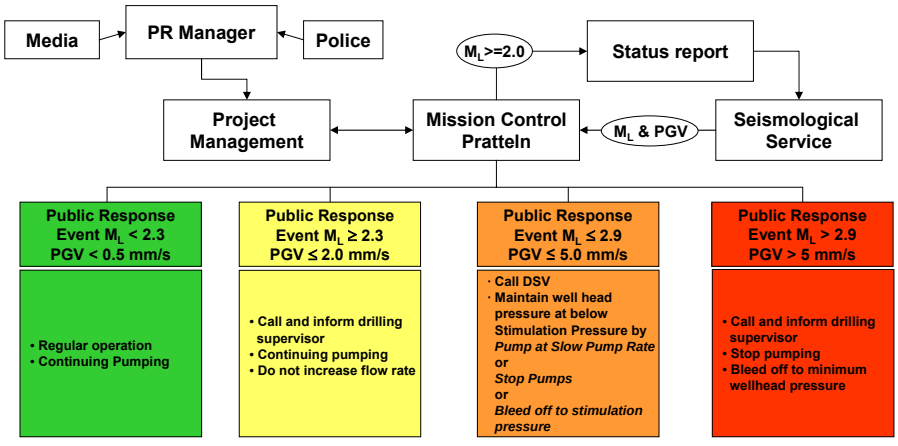
SEISMIC RESPONSE PROCEDURE



Explanations:

M_L – Local magnitude (provided by SED)

PGV – Peak ground velocity (provided by SED)

Stimulation Pressure – Surface Pressure where the first induced event occurs

Slow Pump Rate (SPR) and Stimulation Pressure to be defined in 48 hour look ahead every day

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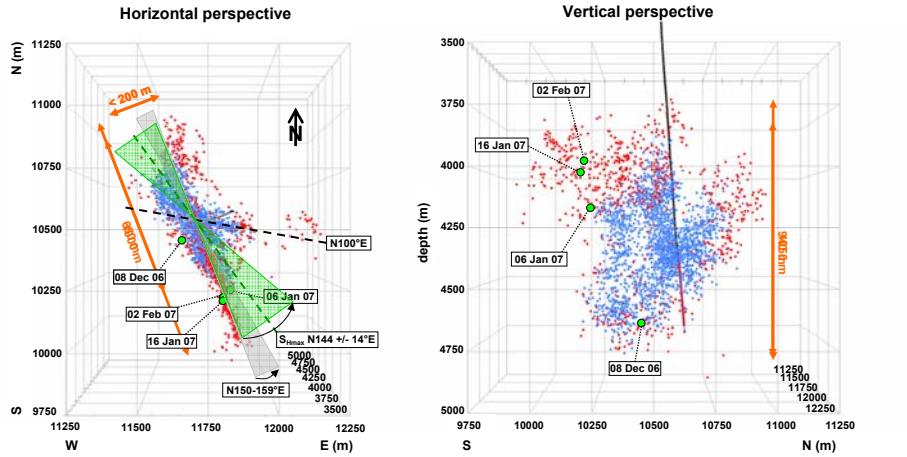
MICROSEISMIC RESERVOIR MAPPING



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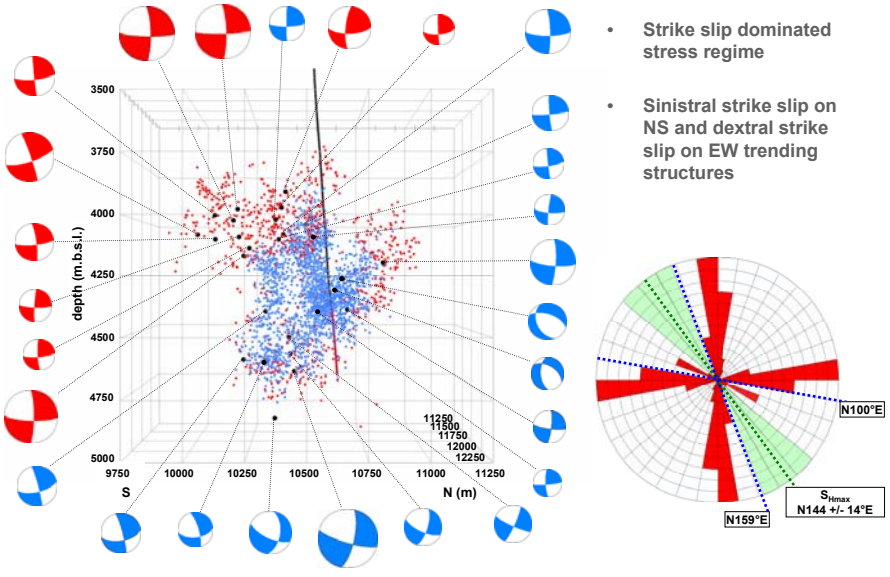
FAULT PLANE SOLUTIONS



- Strike slip dominated stress regime
- Sinistral strike slip on NS and dextral strike slip on EW trending structures

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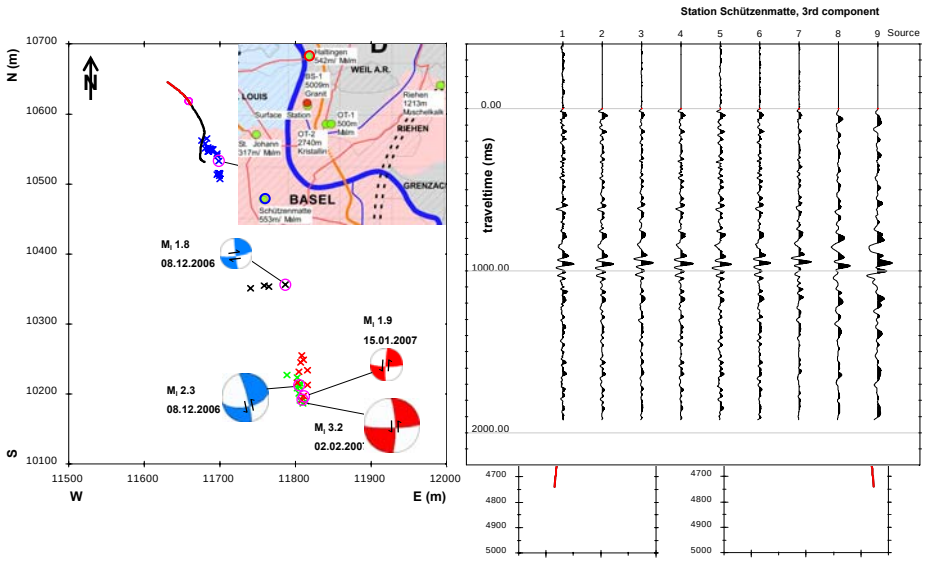
FAULT PLANE SOLUTIONS WITHIN EVENT CLUSTERS



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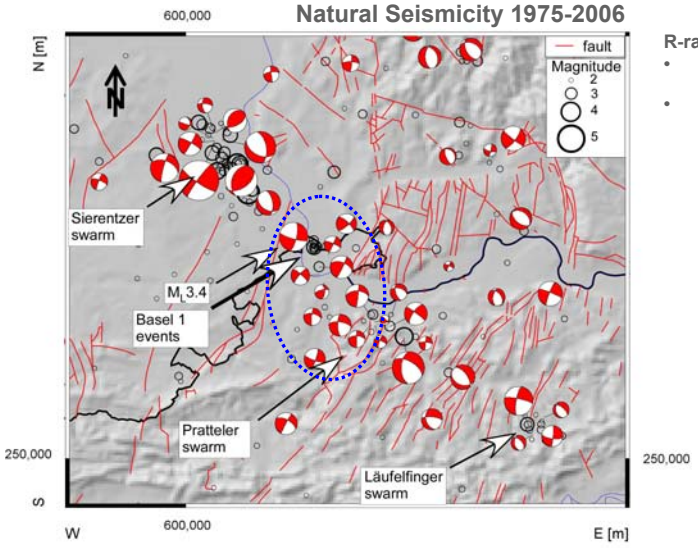
NATURAL SEISMICITY FAULT PLANE SOLUTIONS



R-ratio

- Plenefisch & Bonjer (1997): 0.55
- DHM fault plane solutions: ~0.55

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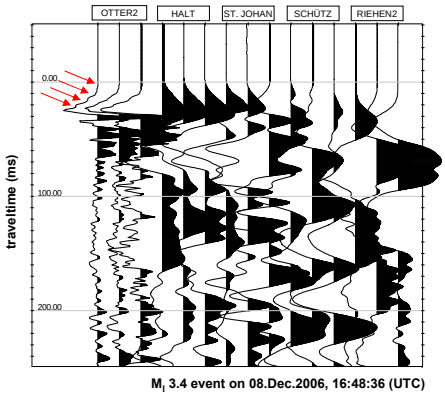
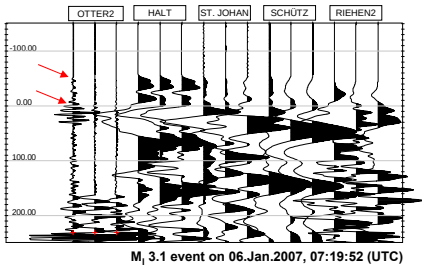
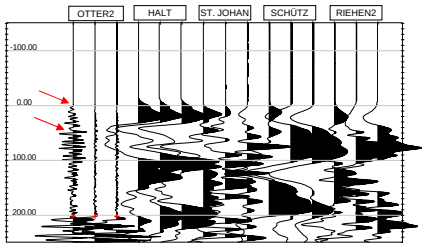
ML 3+ EVENTS SIGNAL CHARACTERISTICS



M_l 3.4 event on 08.Dec.2006, 16:48:36 (UTC)



M_l 3.1 event on 06.Jan.2007, 07:19:52 (UTC)



M_l 3.2 event on 02.Feb.2007, 03:54:27 (UTC)

- Stacking of successive events, a few ms up to several 10s ms apart

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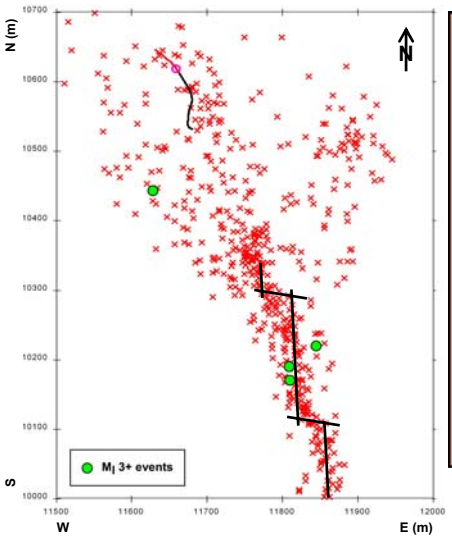
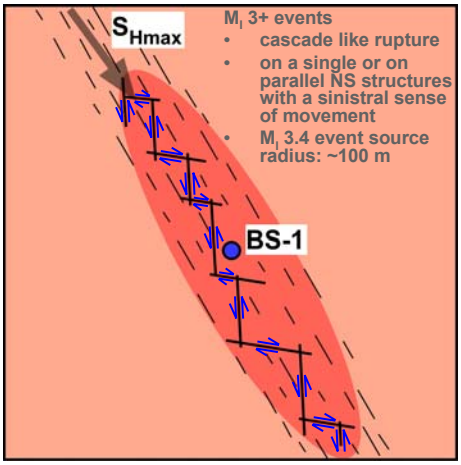
PROPOSED GEOMECHANICAL MODEL





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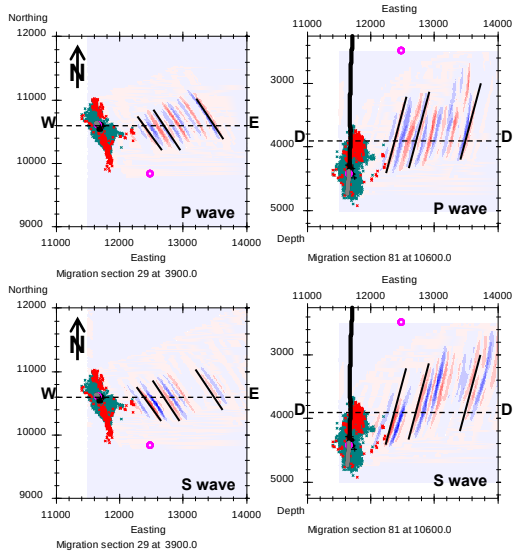
IMAGING FEATURES OUTSIDE THE RESERVOIR



- Migration imaging of features that are not seismically active
- Potential reflectors at 600 m, 1050 m, 1600 m offset from Basel 1
- Strike and dip similar to reservoir orientation
- Corresponding P and S migration images
- Greater S wave resolution

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Summary

- Priority has been safe operations within agreed procedures and an agreed level of seismicity.
- The reservoir has been mainly developping along a single pre-existing structure. The structure as a whole has not been sheared.
- Used Microseismic Migration to explore beyond the seismically active region.
- Acquired a complete microseismic and hydraulic dataset.
- Working on a geomechanical model of the reservoir development and large event mechanisms.
- Outlook: mitigate the risk of large events.

GEO POWER BASEL

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COOPERATION PARTNERS

Swiss Seismological Service

Semore Seismic Ltd

Rutishauser Ingenieurbüro

TOHOKU UNIVERSITY

Prof. H. Asanuma and Team
from Tohoku University, Sendai

INTEROIL

Interoil Exploration & Production
ASA (formerly Proseis AG)

SONDI AND CONSULTANTS
SEISMOLOGY & DOWNHOLE INSTRUMENTATION CO.

Prof. P. Malin and Team from Duke
University, North Carolina

UNI BASEL