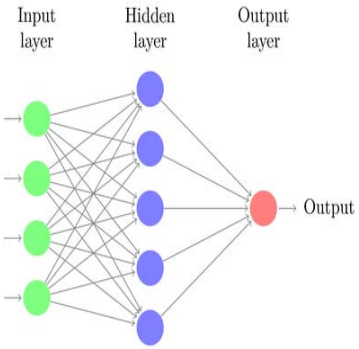

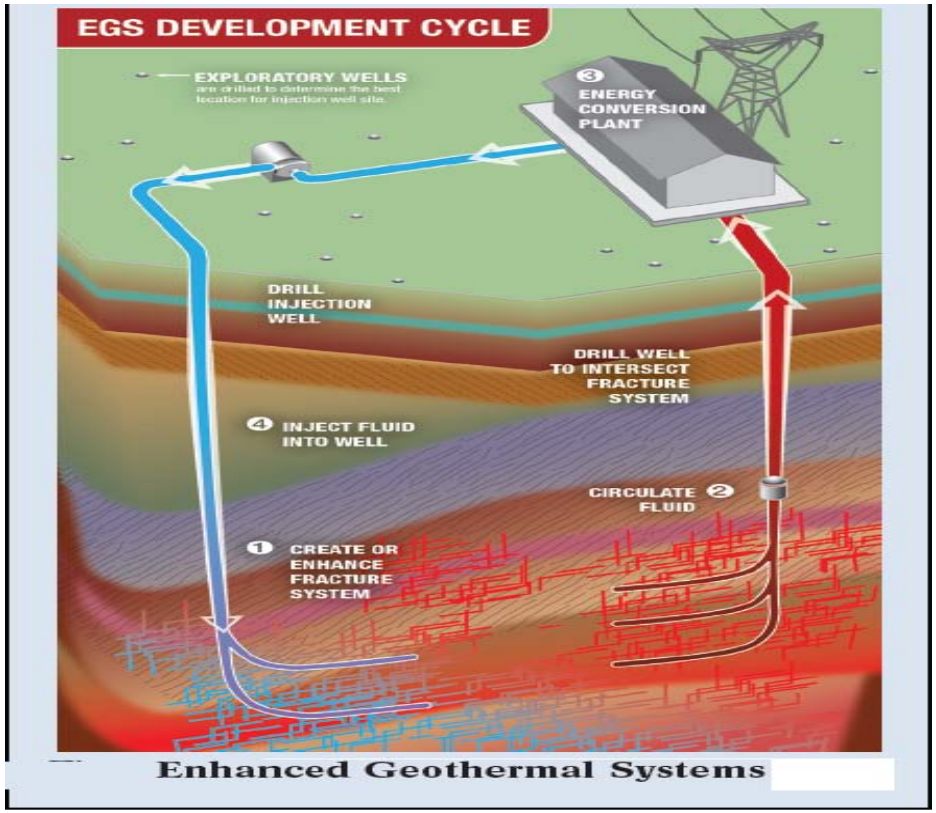

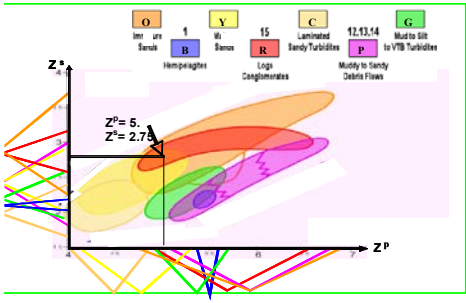

Zp=5, Zs=2.75

$\mu_{sand,immature}$ = 0.13, $\mu_{sand,mature}$=0.5, $\mu_{conglomerate}$=0.37

Characterizing Fractures in the Geysers Geothermal Field by Micro-seismic Data, Using Soft Computing, Fractals, and Shear Wave Anisotropy

May , 2010

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University of Southern California

DOE Grant DE-FOA-0000075-23

Project Team

USC

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Mo Sahimi (Petroleum Engineering)

Charles Sammis (Earth Sciences)

LBNL

Ernie Majer

Leon Thomsen

Calpine

Mark Walters

Project Timeline and Budget

Time	Q1-2010	Q2-2010	Q3-2010	Q4-2010	Q1-2011	Q2-2011	Q3-2011	Q4-2011
Data Evaluation								
Anisotropy (i)								
Fractal (ii)								
Neurofuzy (iiia)								
Neurofuzy (iiib)								
Neurofuzy (iiic)								

Project Starts

Decision Point

Project Completes

Budget

DOE Funding	**$1, 500K**
Matching and other External Funding	
USC	**$200K**
Calpine	**$300K**
Total	**$2, 000K**

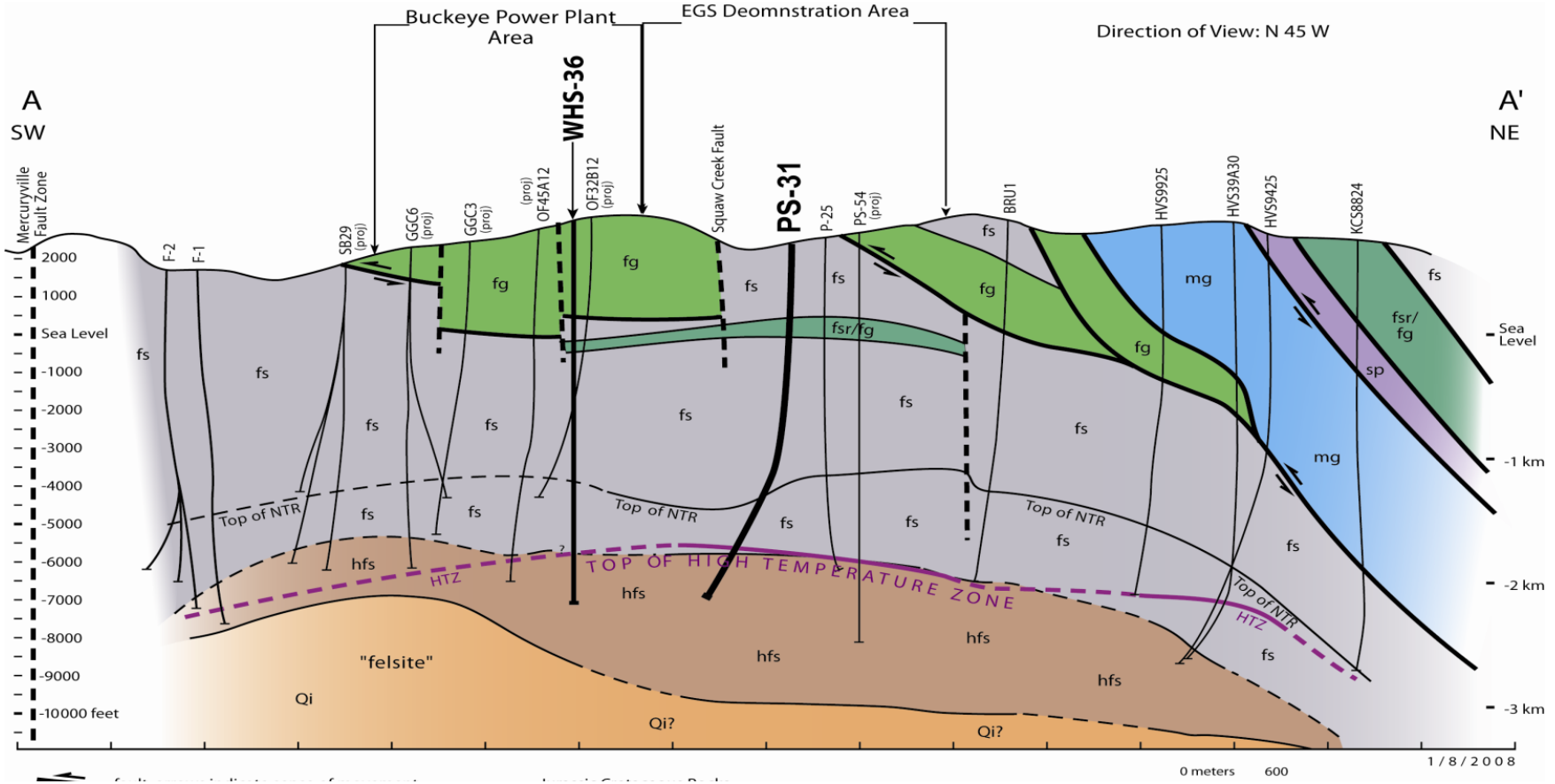
The Geysers, California

Site Name	Location	Technology Description	Well Depth (meters)	Temperature (Celsius)	Resource Type
The Geysers Geothermal Area	North of San Francisco, California	The world's largest dry-steam geo-thermal steam field hosts 22 power plants with capaci-ties ranging from 20 to 120 MWe, pro-ducing a net total of over 750 MWe.	650-3350	240°-250°	 Hydrothermal Dry Steam

- Low permeability
- Determine if fracturing could be used to enhance permeability, and whether dilution of existing fluids with injected water would lower corrosivity enough to allow economic production of power
- Municipal wastewater

Geologic cross-section of the Geysers and location of EGS candidate well PS-31

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

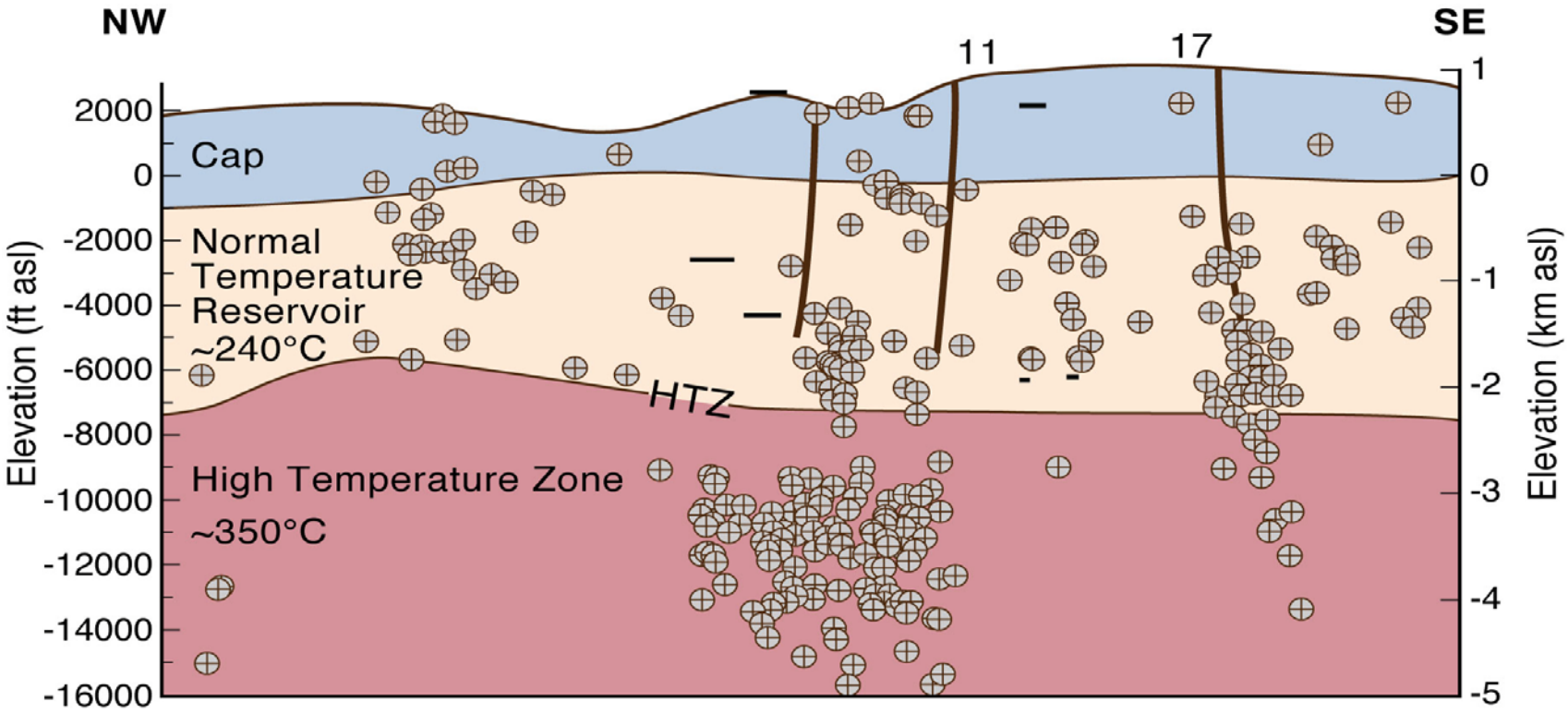


Major faulting

General geologic features

More subtle faults and fractures will require application of our soft computing-based techniques, exploiting their anisotropic and fractal behavior that will help their identification and mapping.

Northwest-southeast cross-section through the Geysers geothermal field



2002 MEQ hypocenters, injection wells, power plants, and top of the high temperature zone (HTZ) (Stark, 2003)

Noticeable distribution of the seismicity below and around the injection wells

Project Deliverables

Develop
Neuro-Fuzzy Process for Picking MEQ Events

Create
Reservoir Image
(Velocity Field / Faults)

Create
Fractures Spatial Distribution Map

Develop
An Understanding of Anisotropy

Monitor Changes
Created by the Injection of Cold Water into Hot Water, already Fractured Rock.

Use of Soft Computing to analyze passive seismic data

Neuro-Fuzzy Auto-Picker

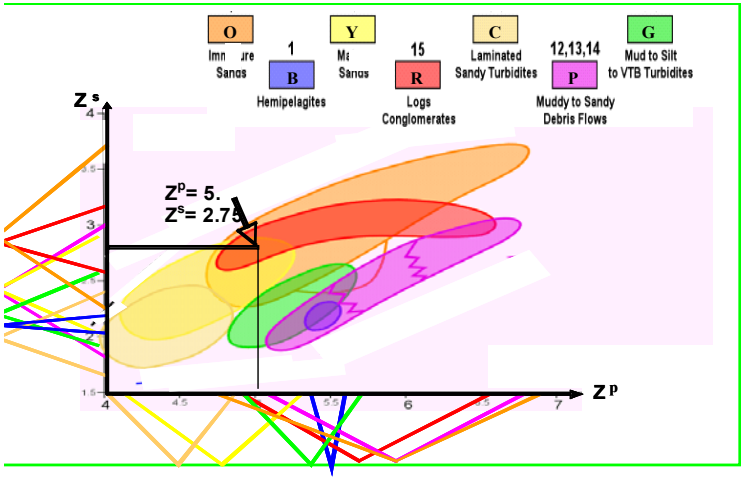
Pick the Subtle MEQs Events

Improve the Efficiency of the Process

Compressional velocity fields

Simultaneous analysis of shear wave and P-wave data

fuzzy relationships between the shear wave velocities for different rock types



Zp=5, Zs=2.75

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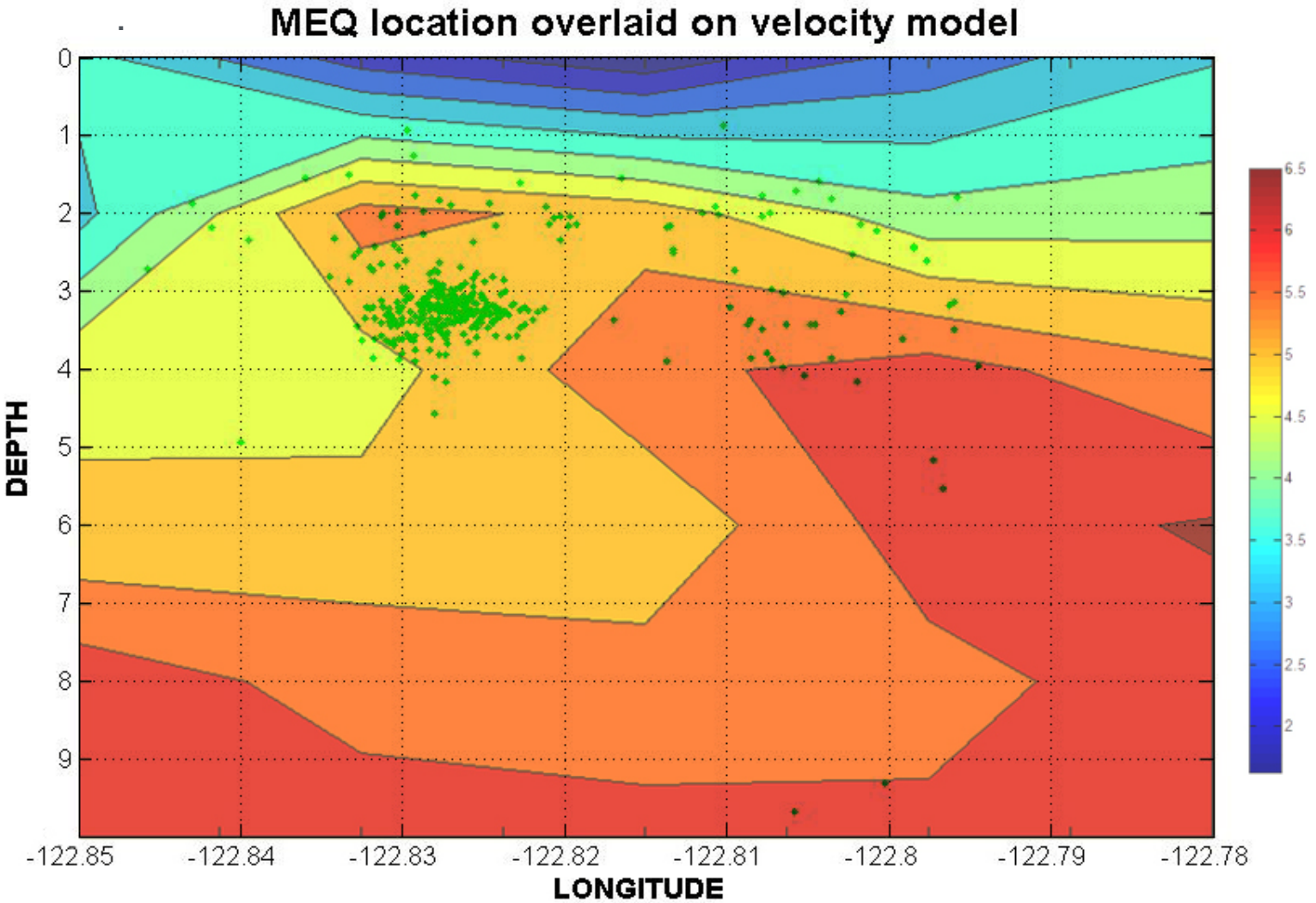
MEQs events overlaid on the velocity model for the 38.843 latitude section



Using microseismicity to map the fractal structure of the fracture network

Field Observation | Geomechanical Modeling

Injection-induced seismicity at the Geysers geothermal field is the result of shear failure on critically stressed fractures caused by the reduction of normal stress associated with thermal contraction.

spatial analysis

Locations of induced events | Sizes of induced events | source mechanism of induced events

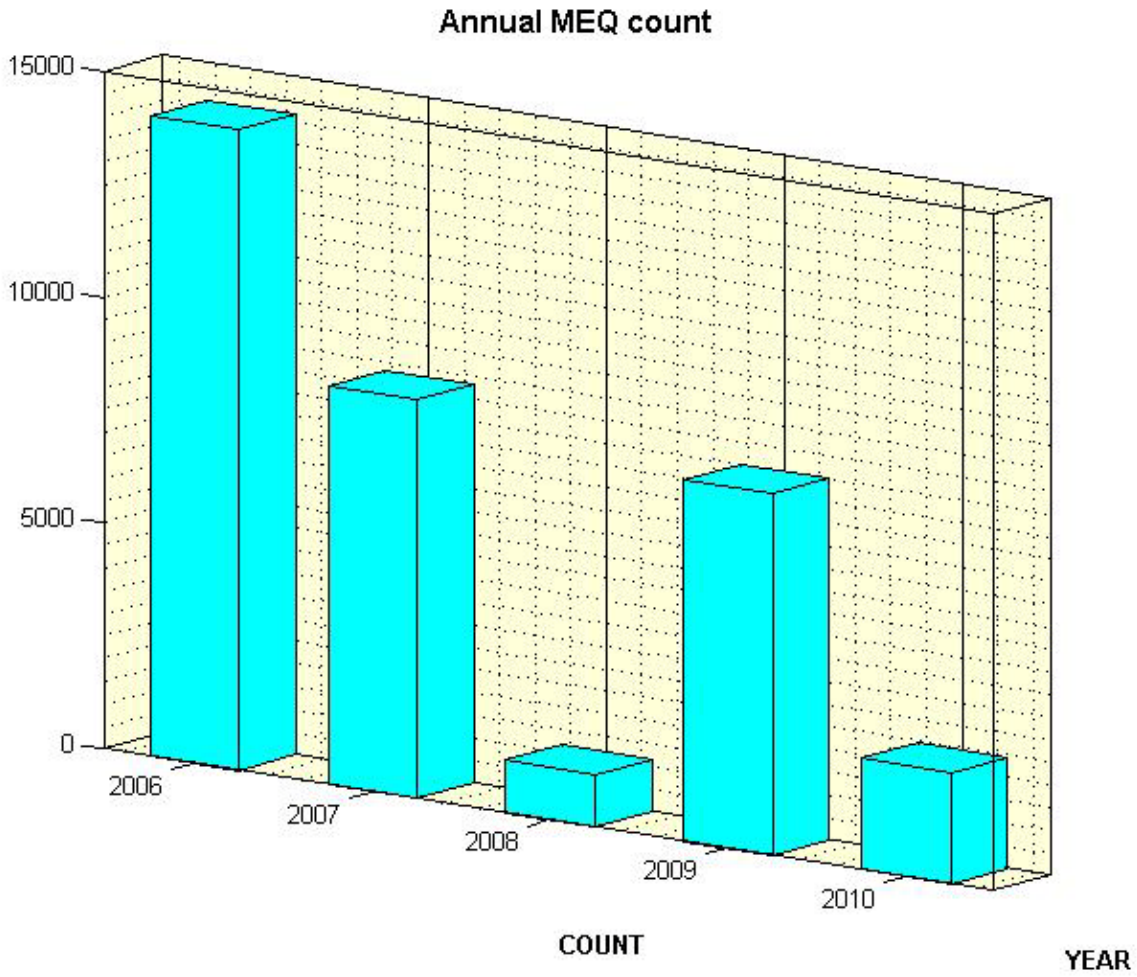
Structure of the fracture network in the Geysers reservoir

Anisotropic Velocity Tomography

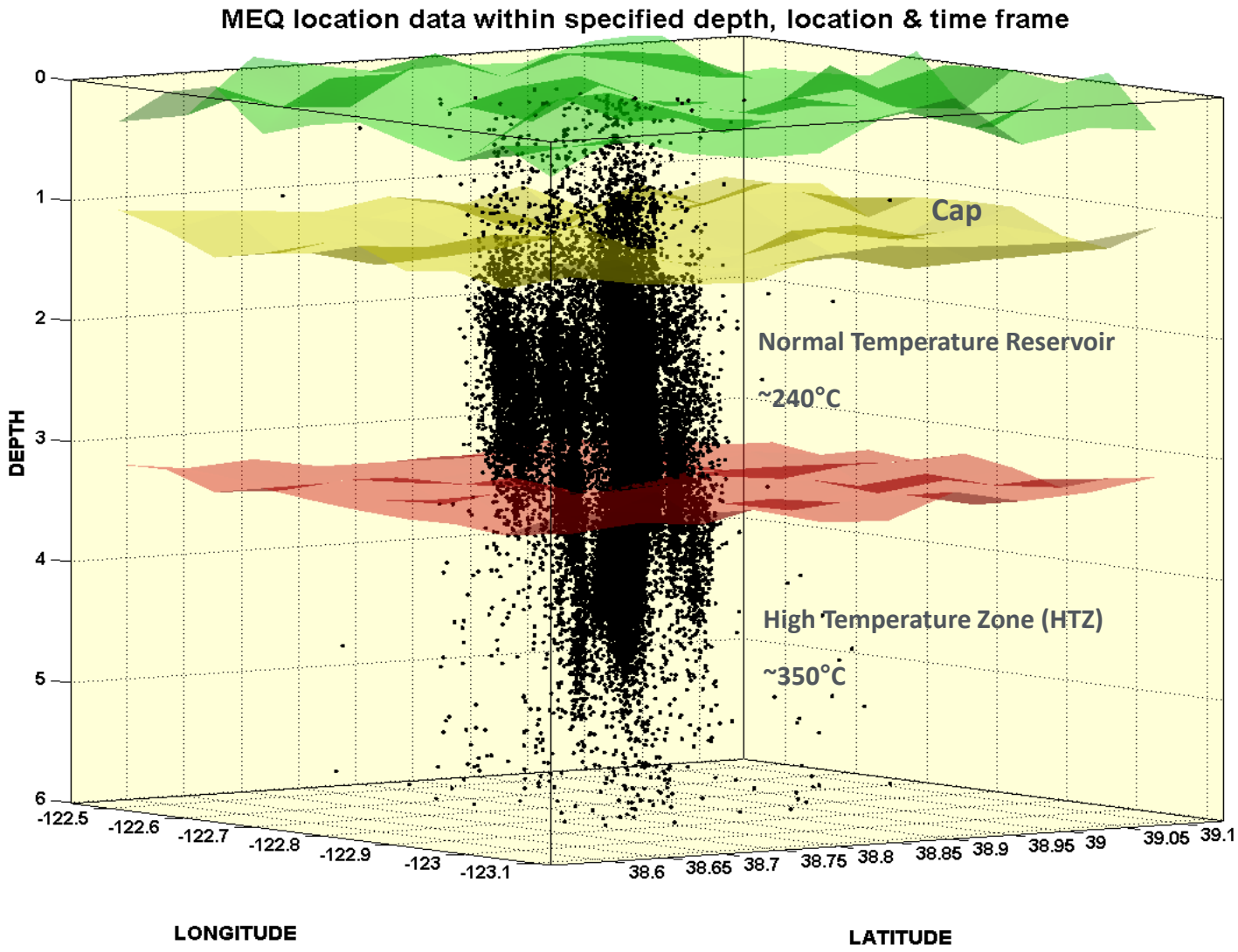
- Form initial isotropic P-velocity field, MEQs locations are determined.
- The error-ellipsoids for each location are calculated.
- Refinements to the velocity field are driven by these error-ellipsoids.
- Refined error-ellipsoids for each location are calculated.
- A lower symmetry of anisotropy is selected (eg,Tilted orthorhombic)
- Refinements to the anisotropic velocity field (ie distributions of anisotropic parameters) are driven by the error-ellipsoids.
- Refined error-ellipsoids for each location are calculated.
- Steps 5-8 are repeated until no significant further precision in the locations is achieved.

If data quality permits, the distribution of S-wave anisotropic parameters will be estimated, following a similar program but also taking advantage of the special phenomena of shear-wave splitting.

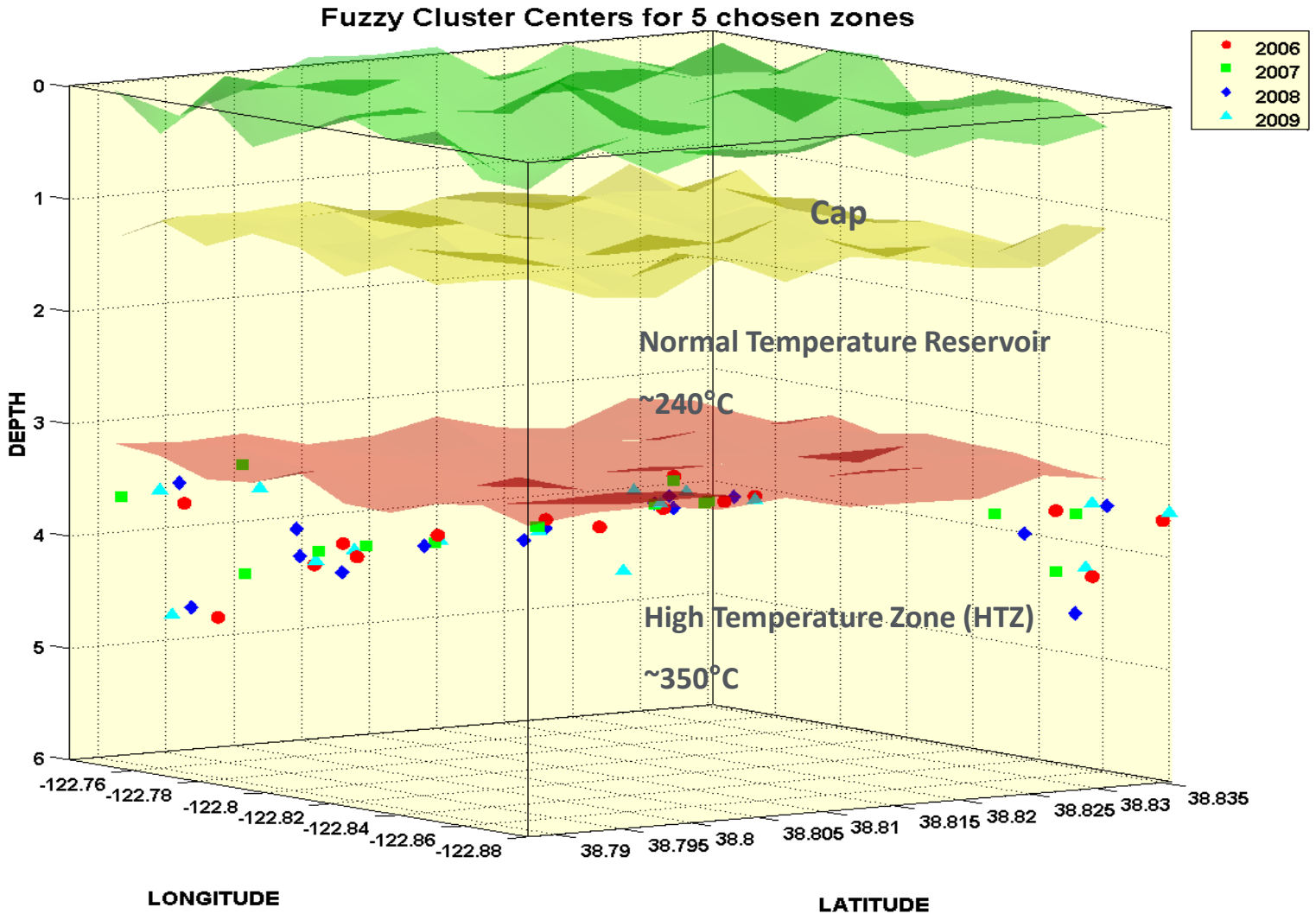
Number of micro-seimic events in each year at the Geyser



Distribution of MEQ events at the Geyser for the years 2006 - 2009



Cluster centers for all the years at the HTZ zone.



Cluster center movement from 2006 to 2009