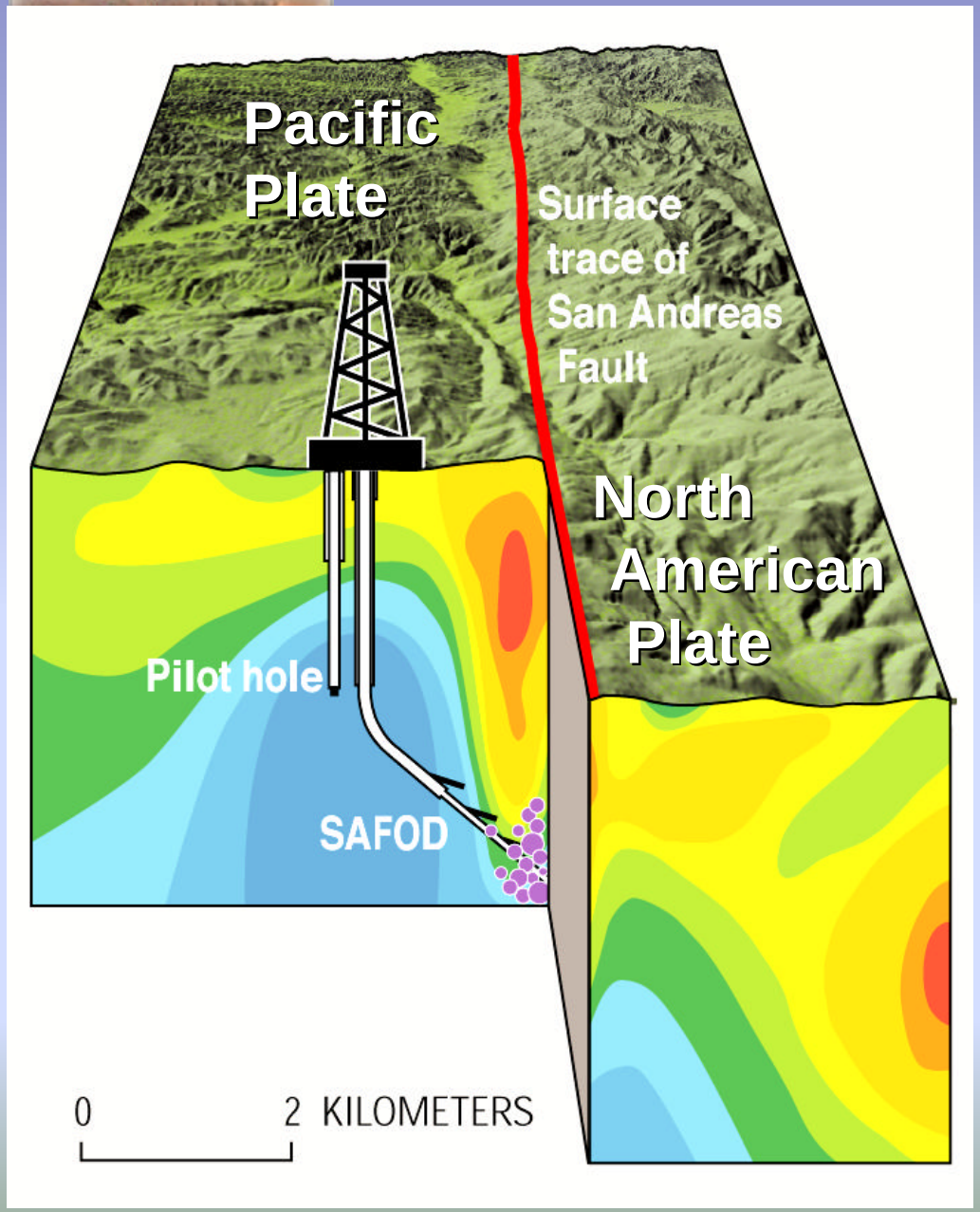
USGS science for a changing world

Earthquake Hazards Program

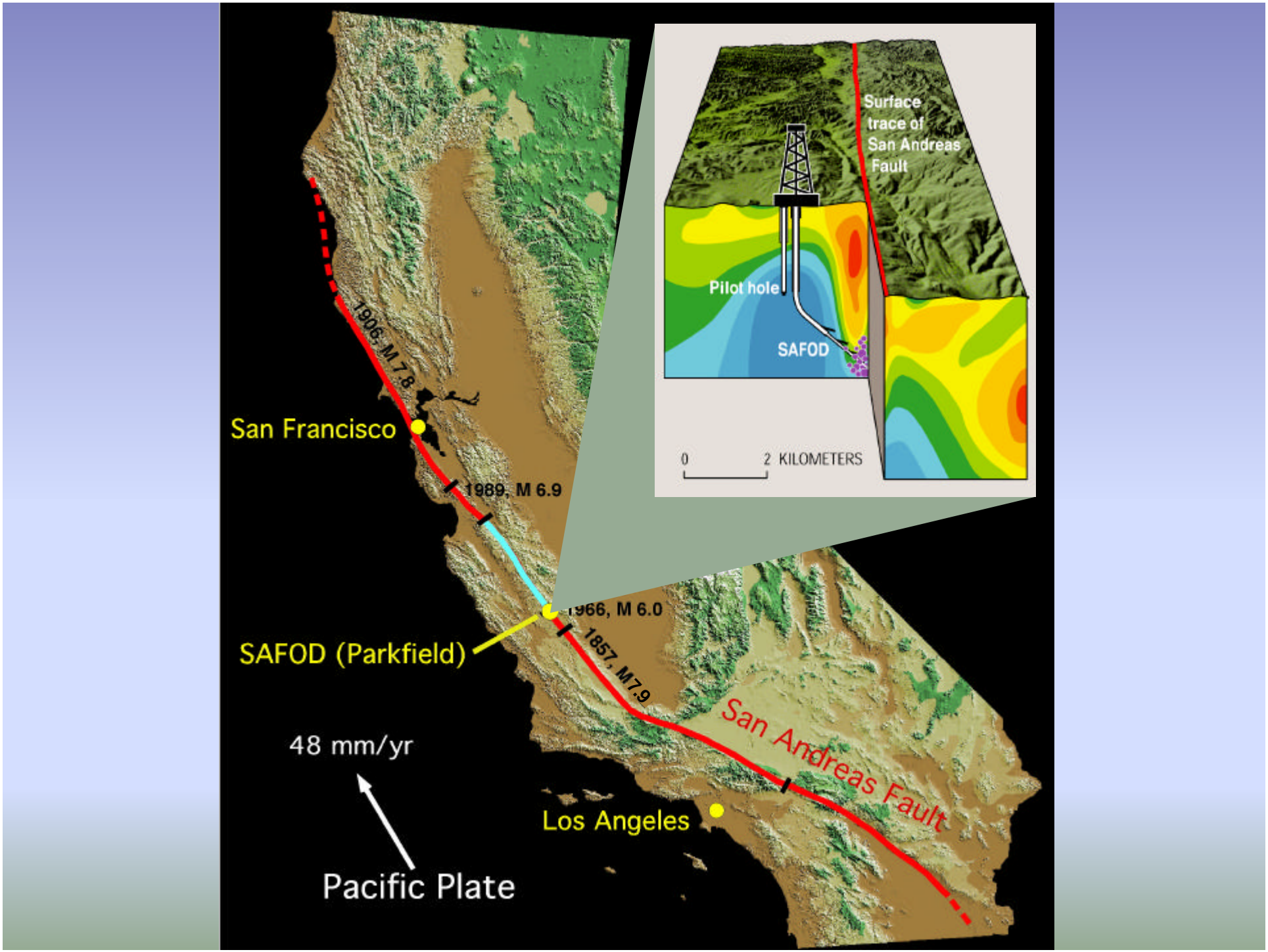
The San Andreas Fault Observatory at Depth: Recent Site Characterization Studies and the 2.2-Km-Deep Pilot Hole

Steve Hickman and Bill Ellsworth (USGS)
Mark Zoback (Stanford University)
and the Pre-EarthScope SAFOD Science Team

San Andreas Fault Observatory at Depth (SAFOD)



The central scientific objective of SAFOD is to study directly the physical and chemical processes that control deformation and earthquake generation within an active plate-bounding fault zone.


Surface trace of San Andreas Fault
Pilot hole
SAFOD
0
2 KILOMETERS
1906, M 7.8
San Francisco
1989, M 6.9
1966, M 6.0
SAFOD (Parkfield)
1857, M7.9
San Andreas Fault
48 mm/yr
Los Angeles
Pacific Plate

San Andreas Fault Observatory at Depth: Project Overview and Science Goals

Test fundamental theories of earthquake mechanics:

- Determine structure and composition of the fault zone.
- Measure stress, permeability and pore pressure conditions in situ.
- Determine frictional behavior, physical properties and chemical processes controlling faulting through laboratory analyses of fault rocks and fluids.

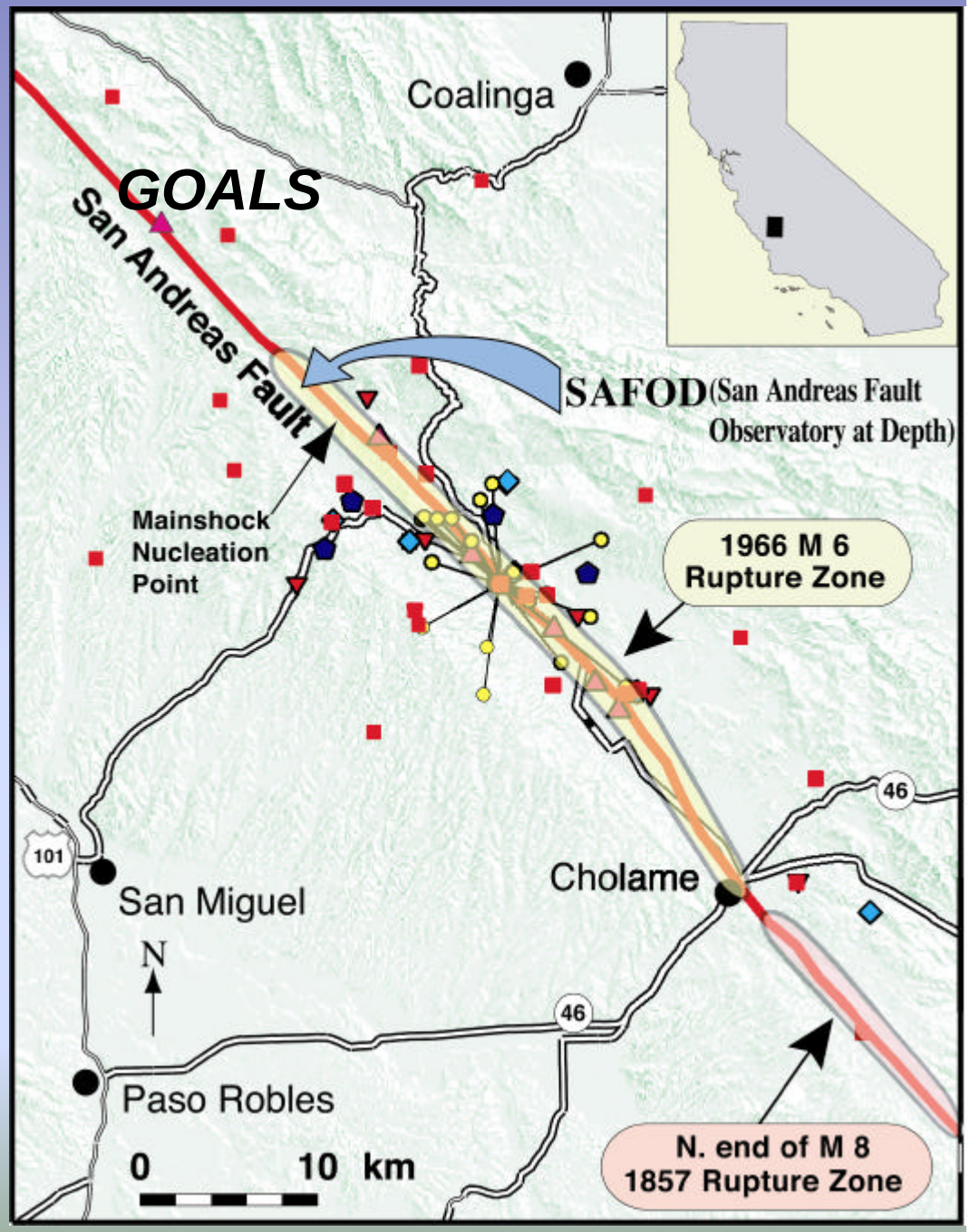
Establish a long-term observatory in the fault zone:

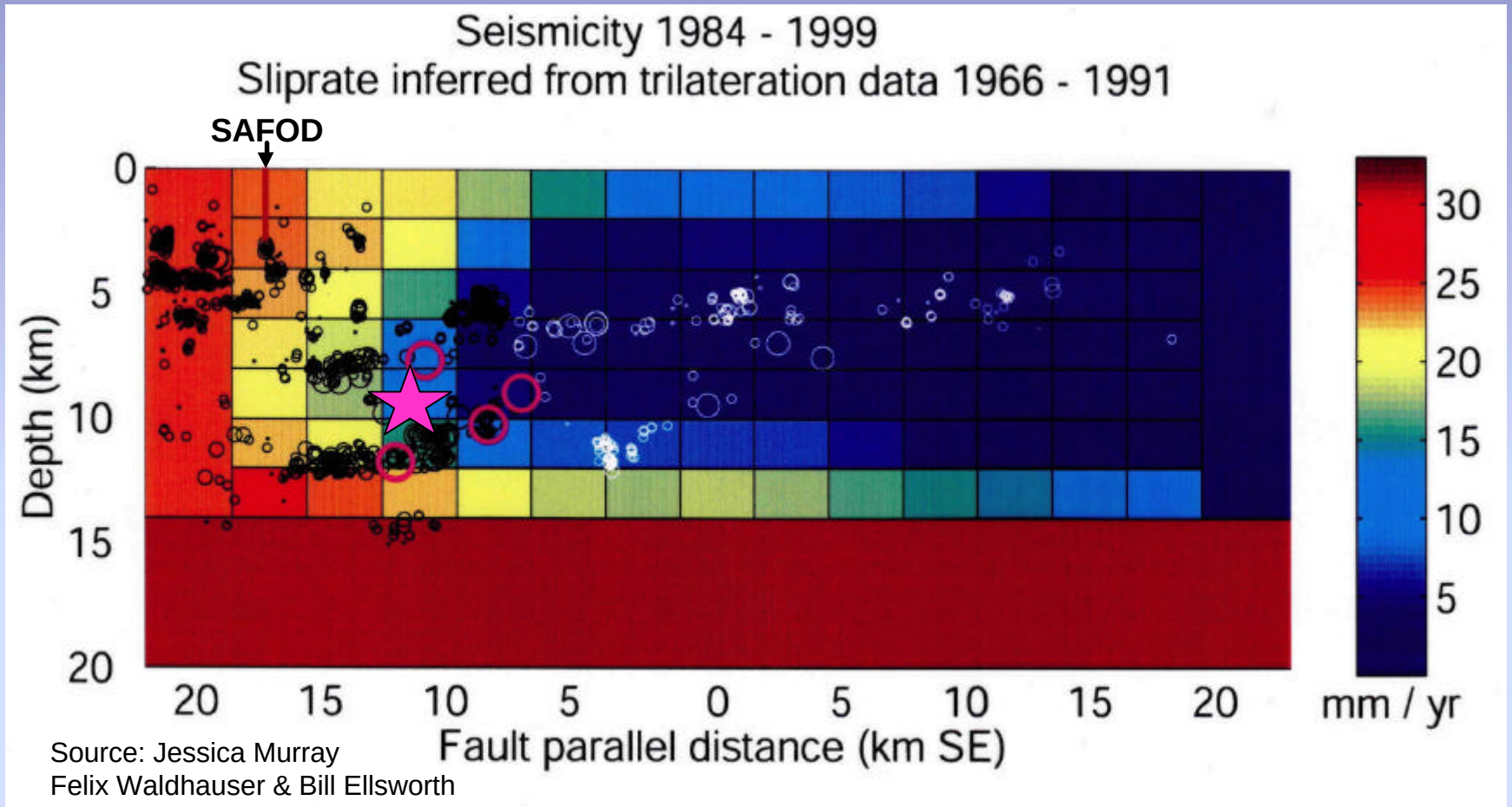
- Characterize 3-D volume of crust containing the fault.
- Monitor strain, pore pressure and temperature during the cycle of repeating microearthquakes.
- Observe earthquake nucleation and rupture processes in the near field.


San Andreas Fault
Drill site

Parkfield Experiment

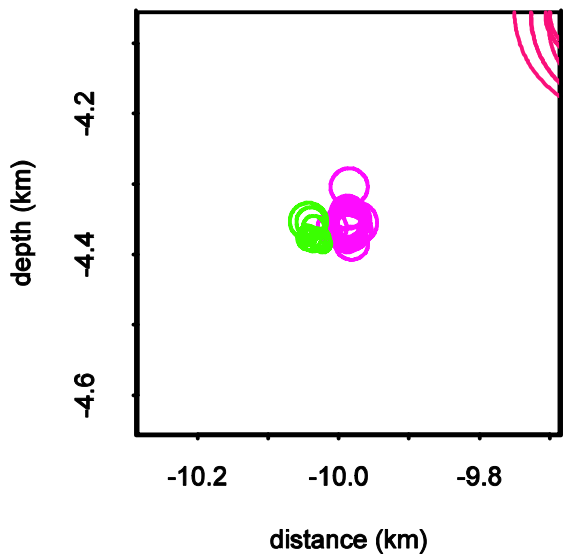
- Observe the build-up and release of stresses on the San Andreas Fault through multiple earthquake cycles.
- Test the feasibility of short-term earthquake prediction.
- Measure near-fault shaking during earthquake rupture, and learn how to predict the amplification of shaking caused by different soil types for improving building codes and designs.

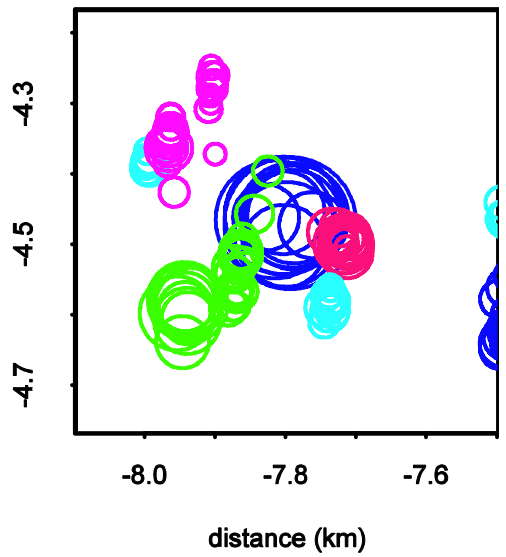




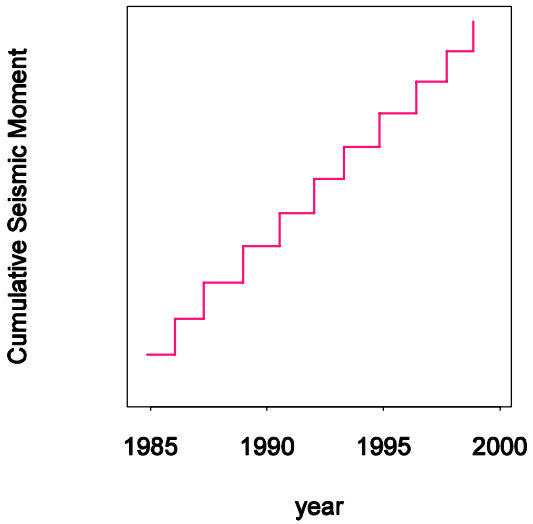
Source: Jessica Murray
Felix Waldhauser & Bill Ellsworth

Examples of Repeating Earthquakes

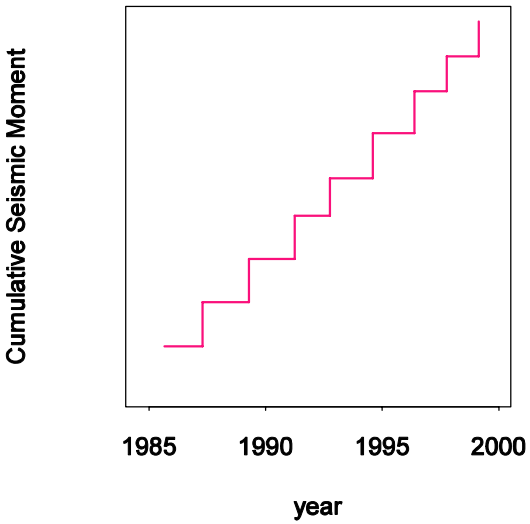




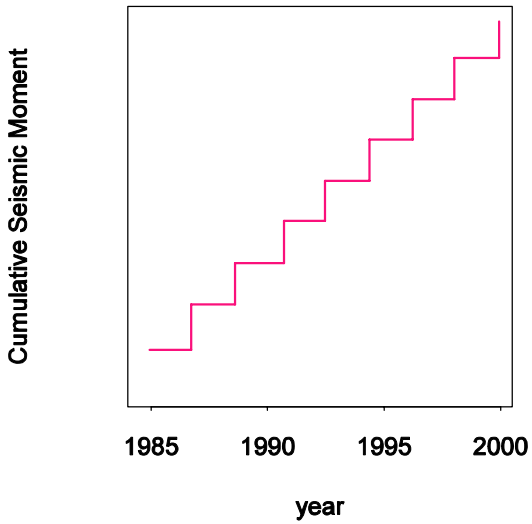
2.2.f M=1.5

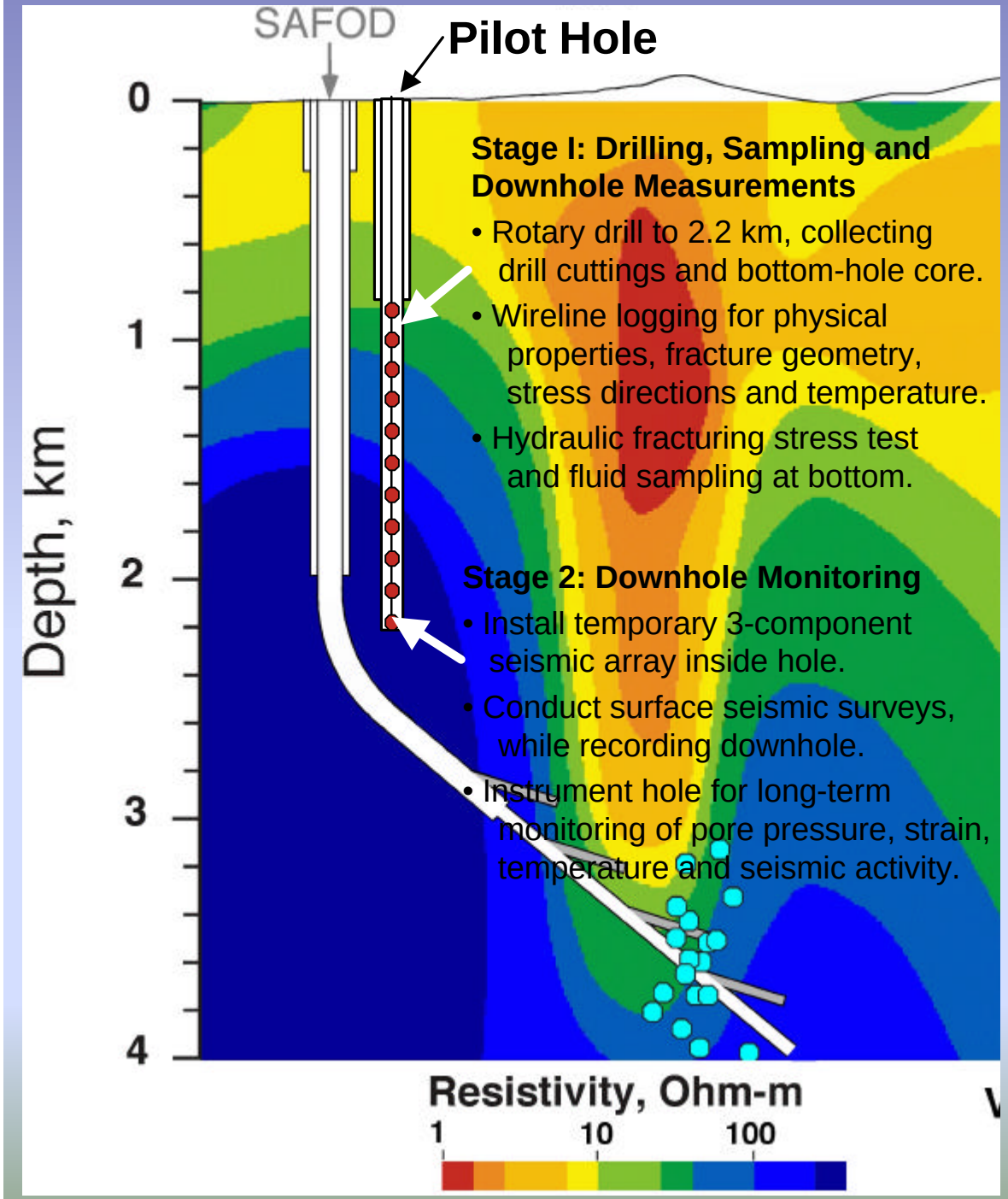


2.5.b M=1.3



1.b M=2



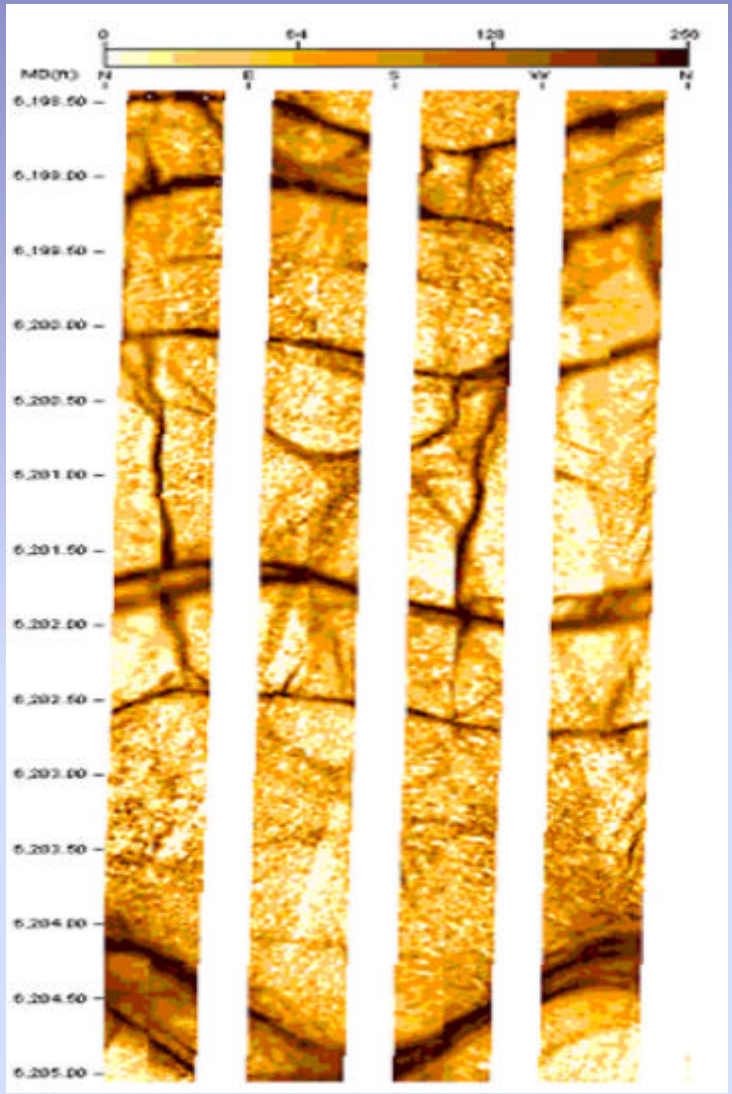


SAFOD Pilot Hole Goals

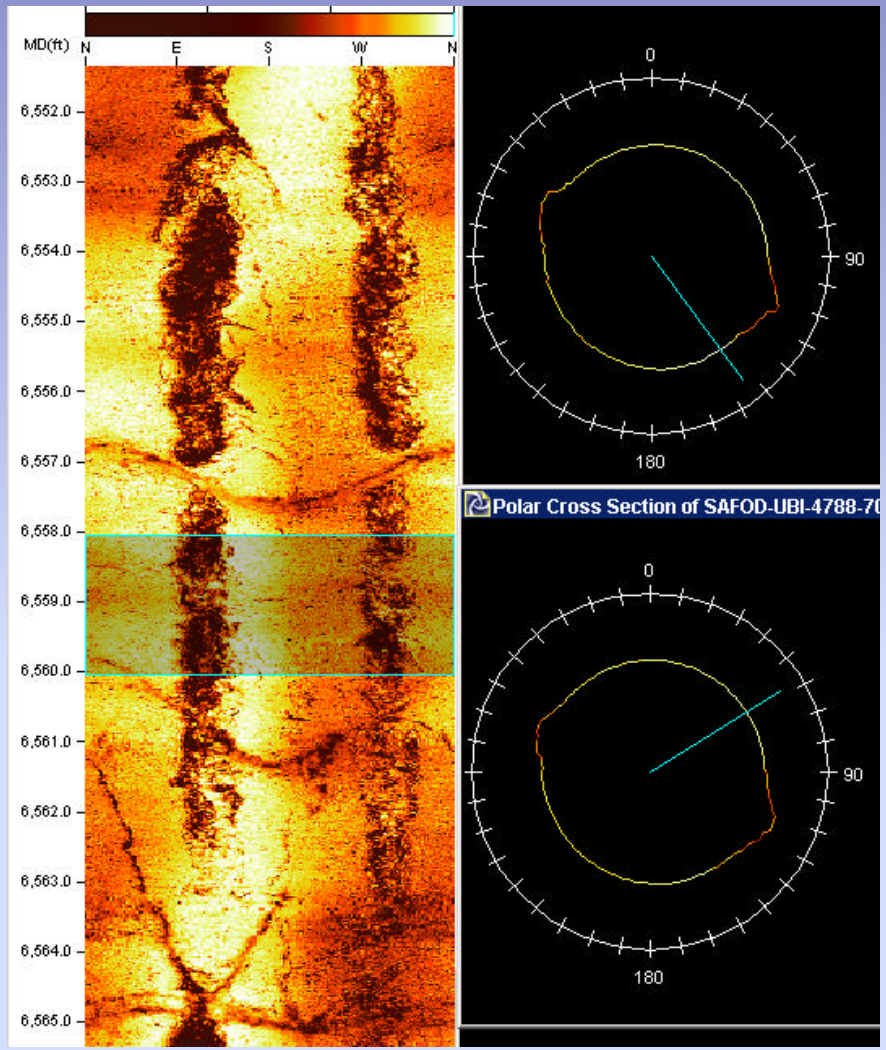
- Provide technical information about drilling conditions prior to SAFOD.
- Measure stress, fluid pressure and heat flow adjacent to the fault zone.
- Record surface sources during seismic experiments in 2002 and 2003.
- Facilitate precise location of target earthquakes for SAFOD.
- Test seismic, pressure, and strain monitoring instruments for SAFOD.
- “Calibrate” physical properties from surface geophysical surveys.
- Reveal nature and extent of fluid/rock interaction adjacent to fault zone.


GEO data


Schlumberger

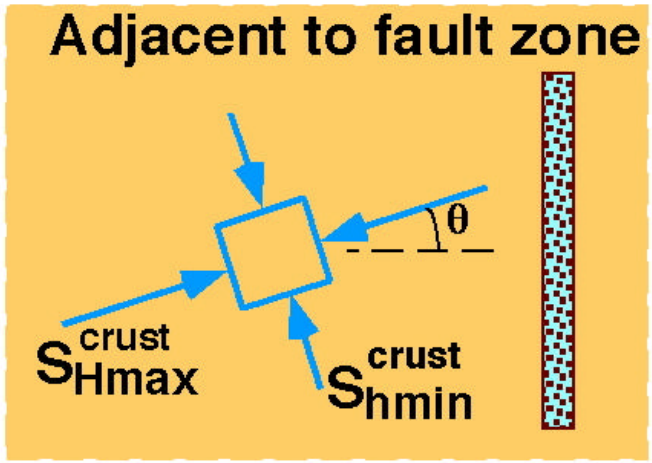


Electrical Imaging Reveals Distribution and Orientation of Faults and Fractures

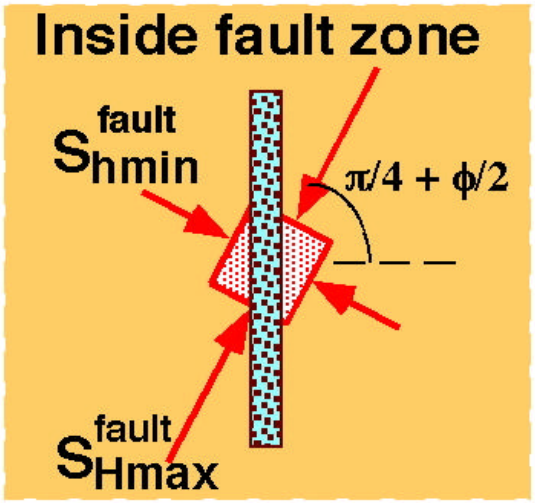


Ultrasonic Imaging Reveals Stress-Induced Breakouts That Yield Stress Orientation

Frictional failure in vertical fault zone and in the adjacent crust (after Rice, 1992)

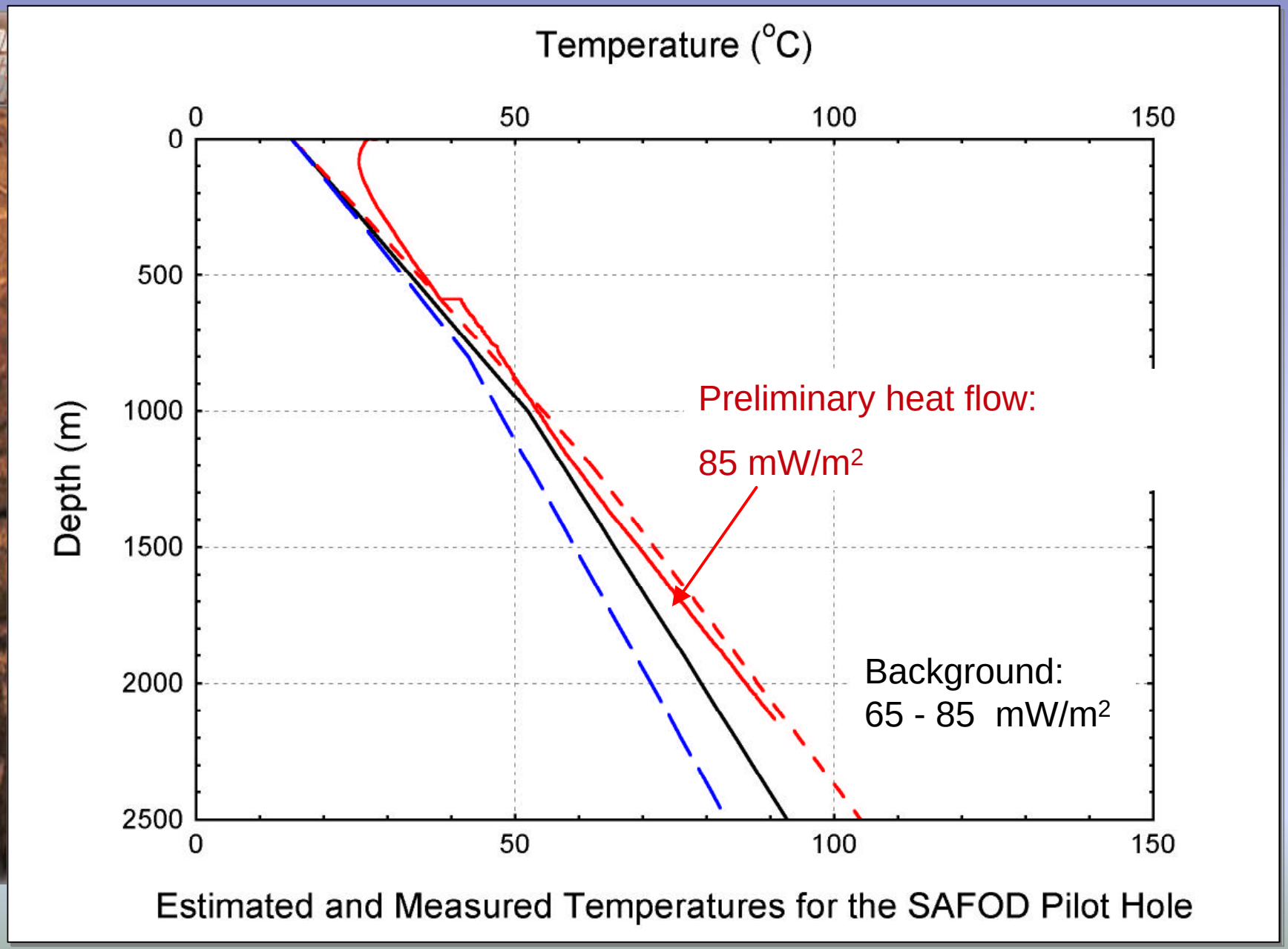


"Fault-normal" compression
Normal fluid pressure



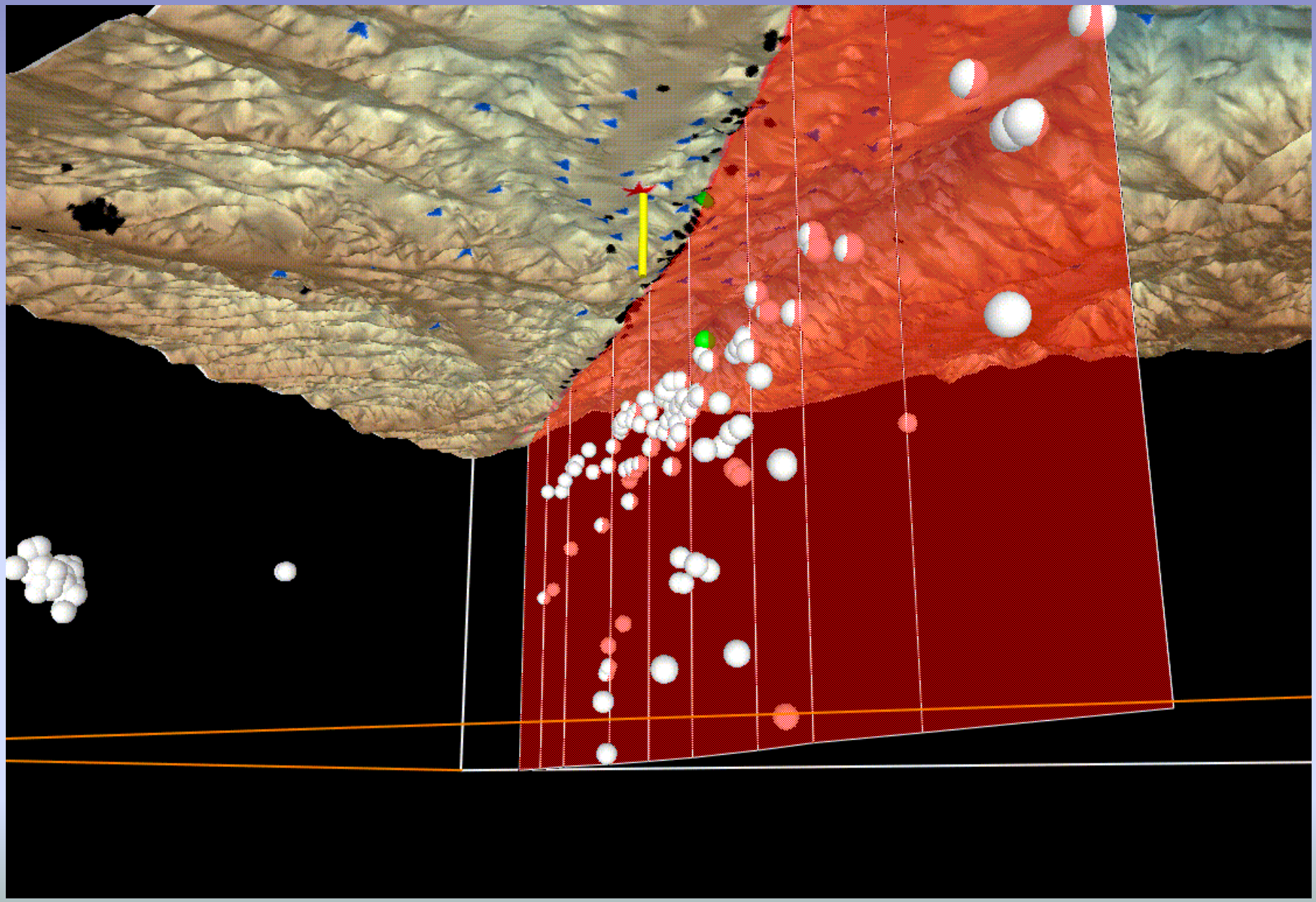
Elevated stress magnitudes
Superlithostatic fluid pressure

Temperature Log From the Pilot Hole (Aug 6)

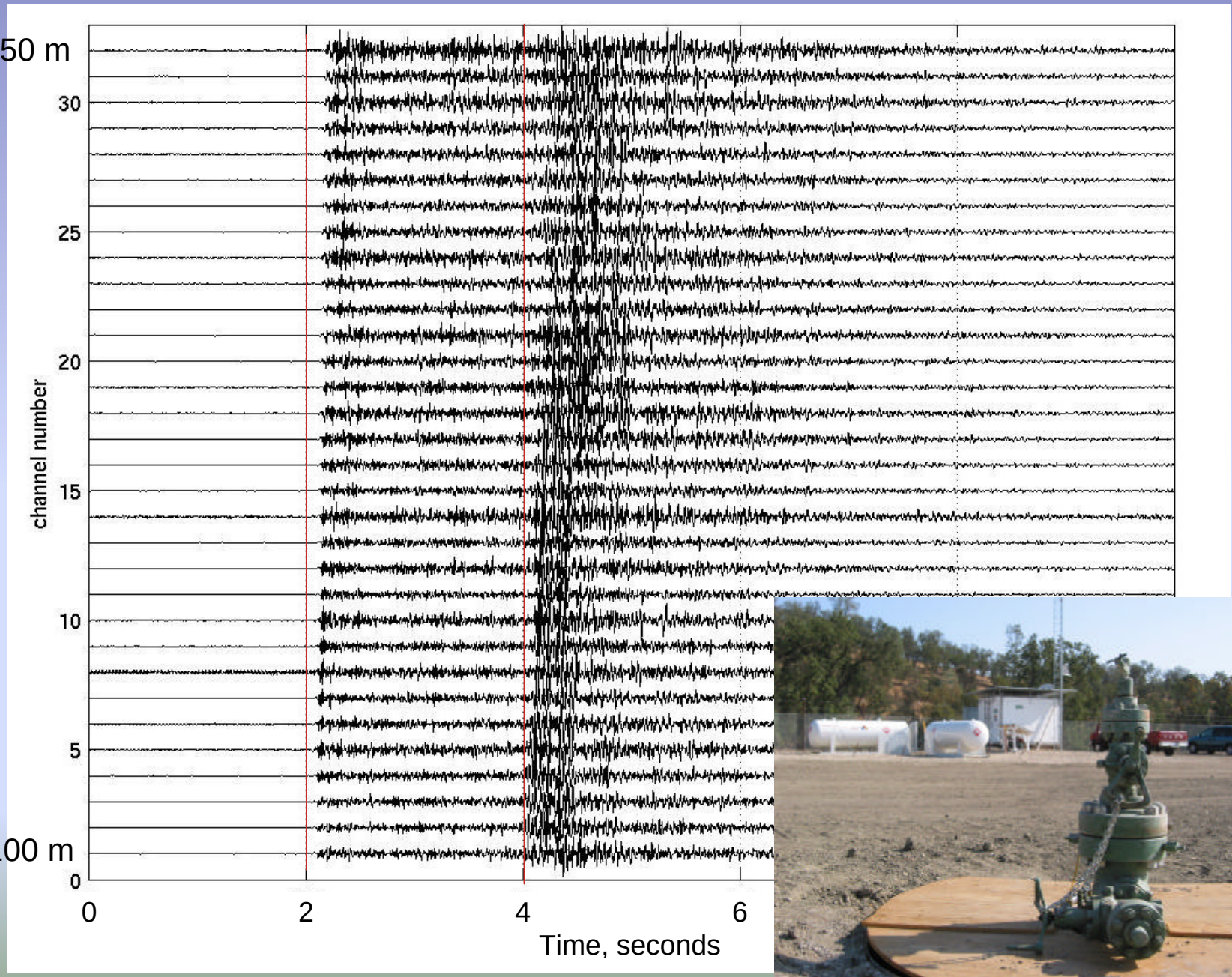


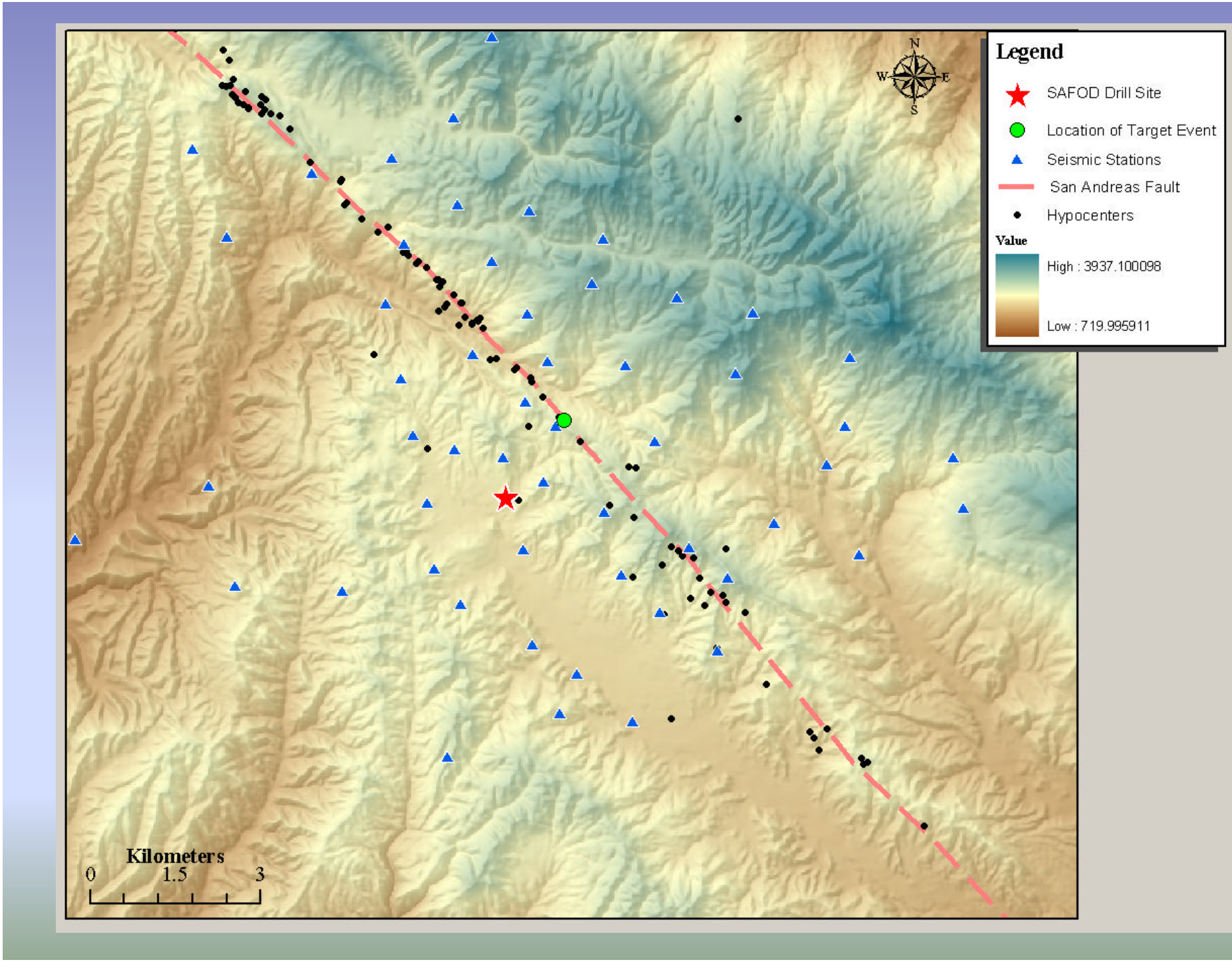
From Colin Williams

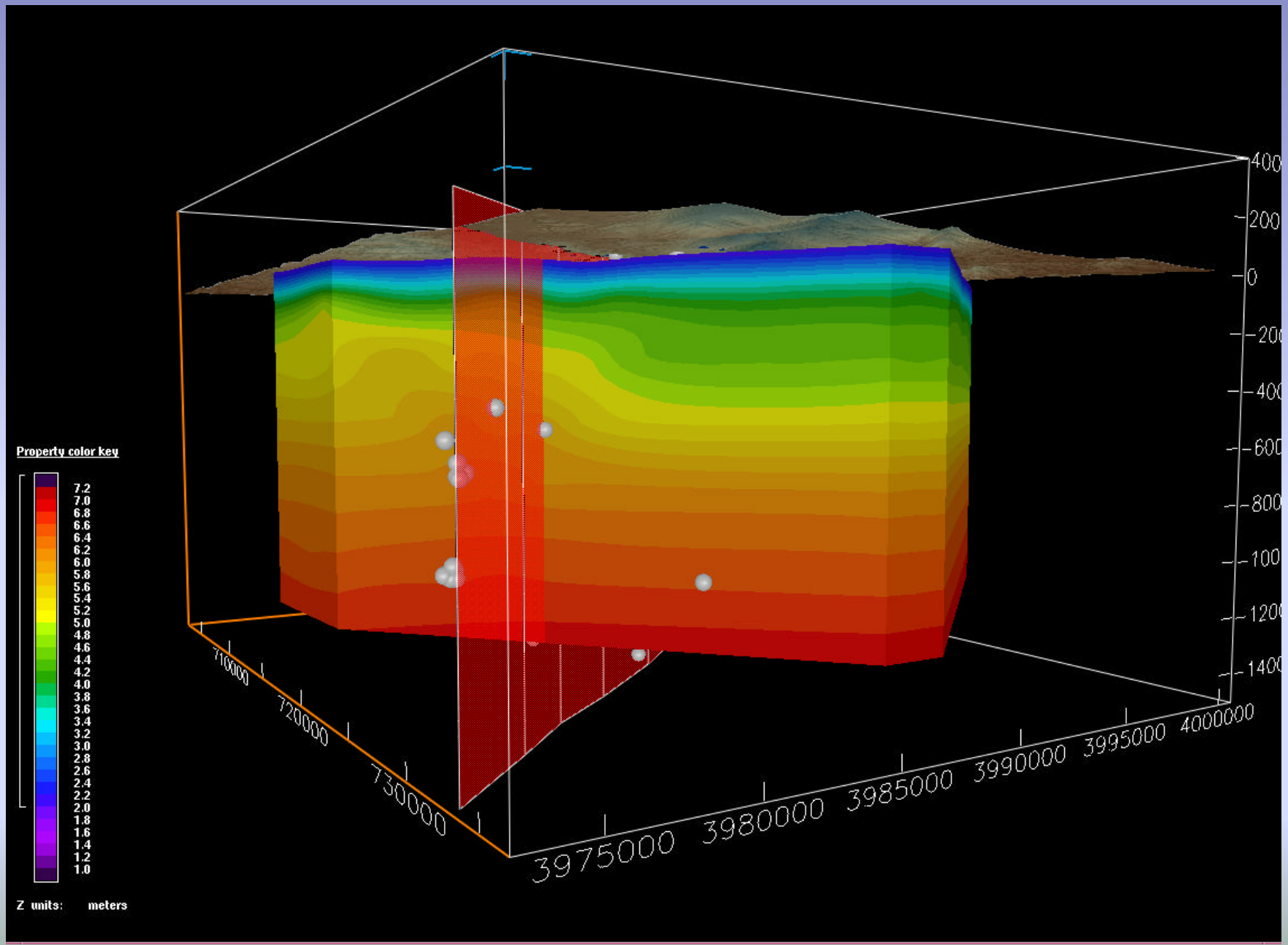
Installing the Pilot Hole Seismic Array



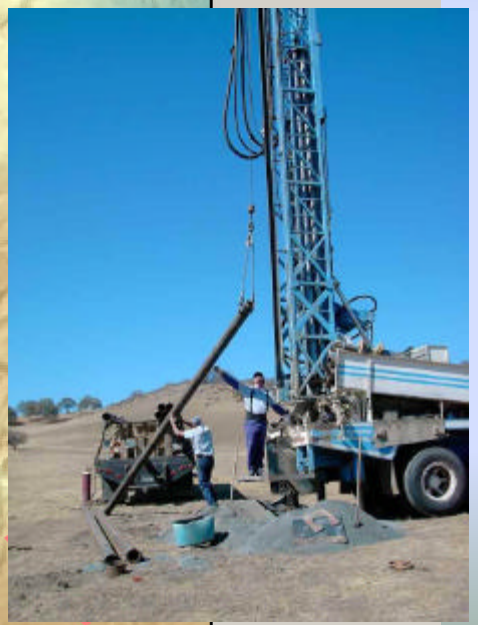
Pilot Hole Array: M 3.8 Earthquake on 9/4/02 (17 km to SE)




Legend
SAFOD Drill Site
Location of Target Event
Seismic Stations
San Andreas Fault
Hypocenters
Value
High : 3937.100098
Low : 719.995911
N
W
E
S
Kilometers
0
1.5
3


Property color key
7.2
7.0
6.8
6.6
6.4
6.2
6.0
5.8
5.6
5.4
5.2
5.0
4.8
4.6
4.4
4.2
4.0
3.8
3.6
3.4
3.2
3.0
2.8
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
Z units: meters
710000
720000
730000
3975000
3980000
3985000
3990000
3995000
4000000
400
200
0
-200
-400
-600
-800
-100
-120
-1400

Seismic Calibration Shots Conducted in October 2002



Legend

SAFOD Drill Site

Location of Target Event

Seismic Stations

San Andreas Fault

Hypocenters

Value

High : 3937.100098

Low : 719.995911

N

W

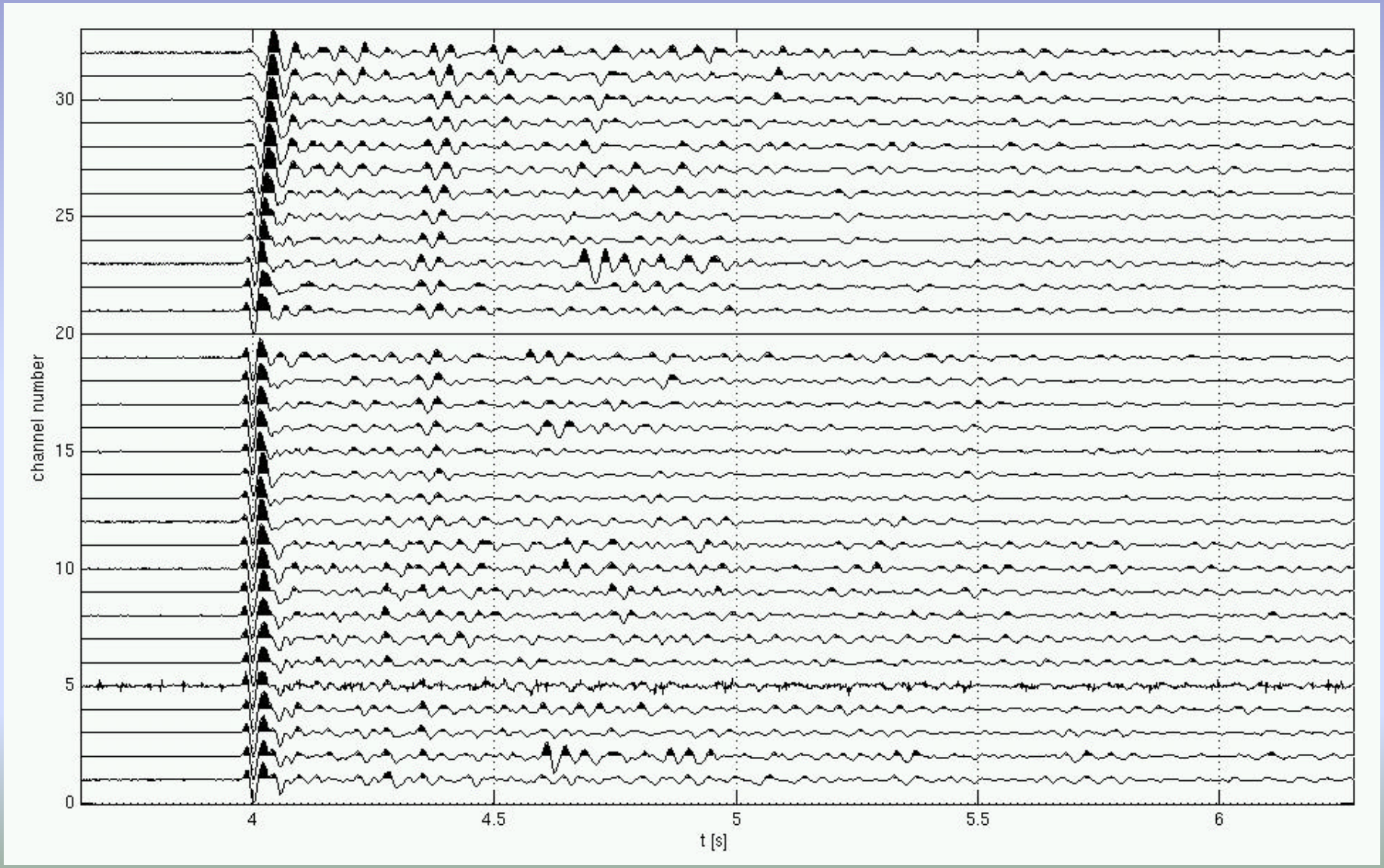
E

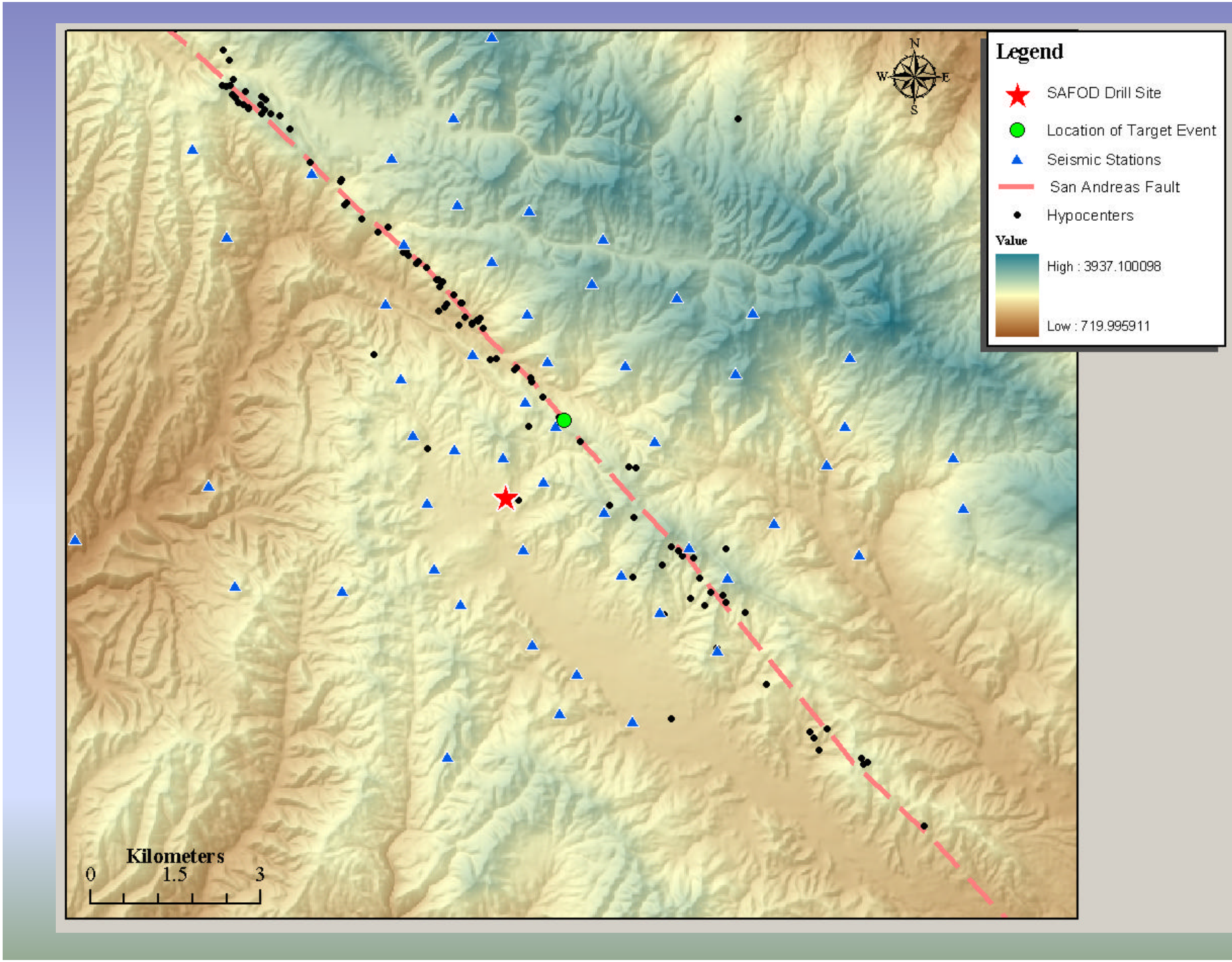
S

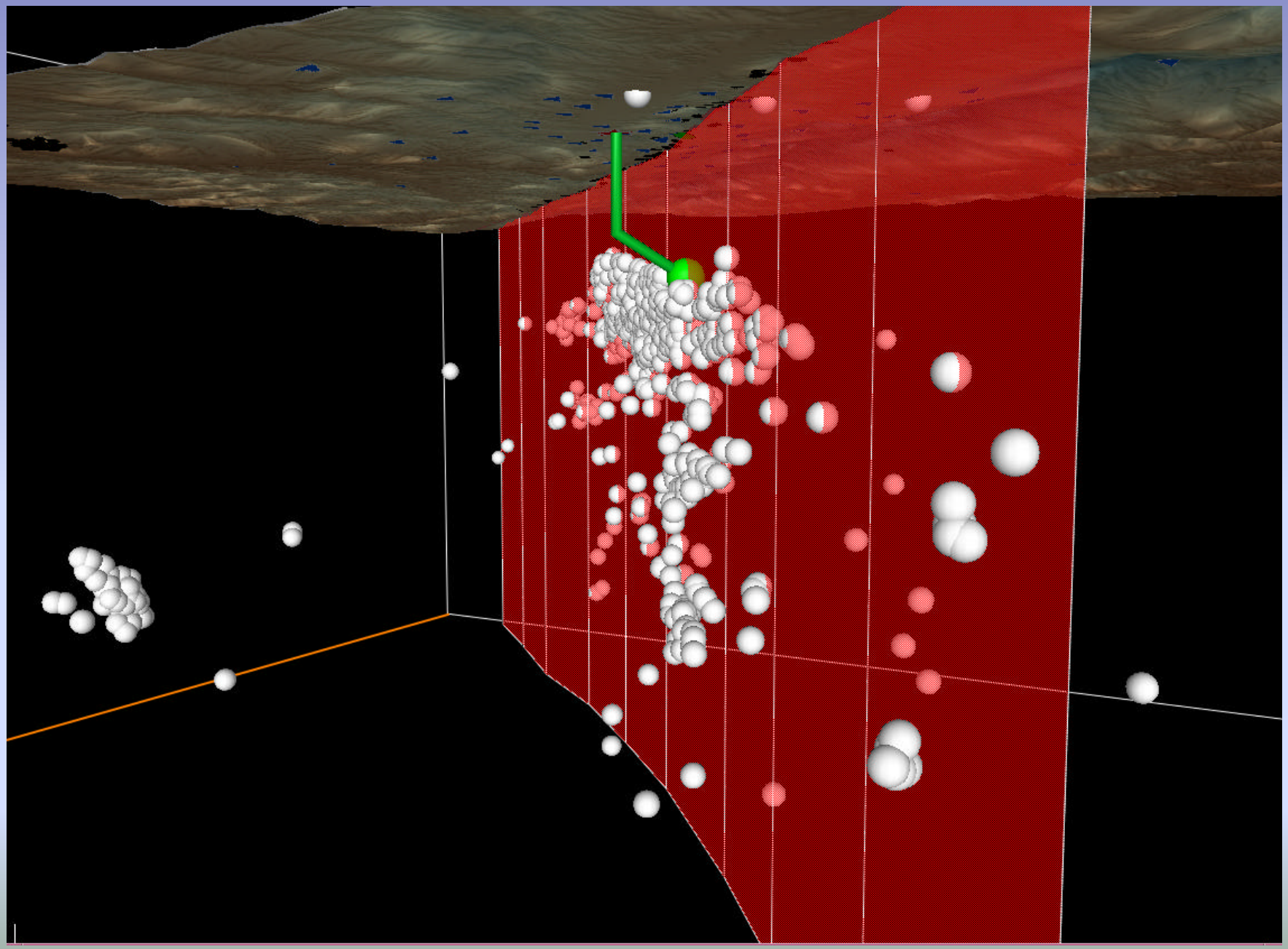
Kilometers

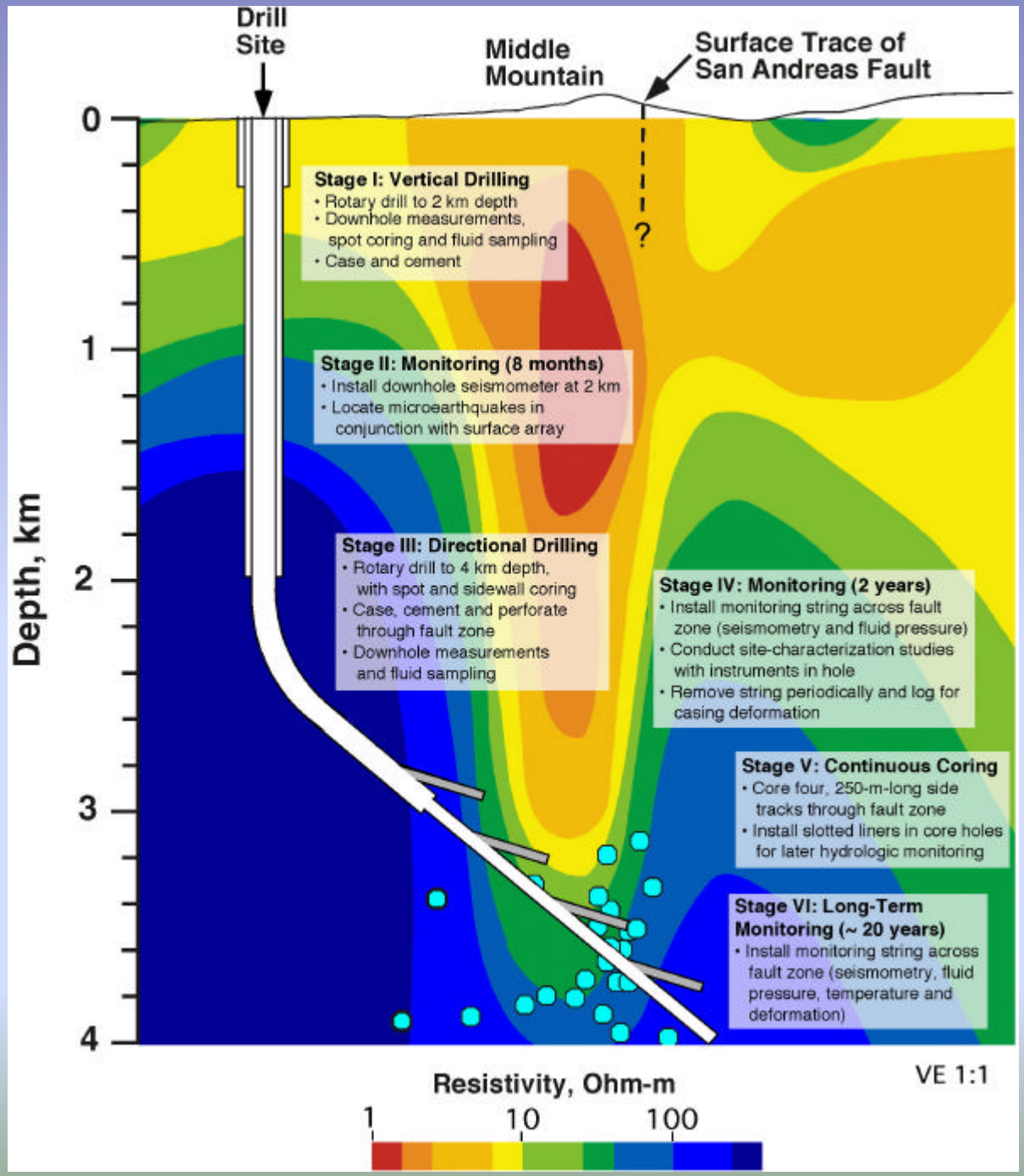
0 1.5 3

Explosion 5 Km west of SAFOD




Legend
SAFOD Drill Site
Location of Target Event
Seismic Stations
San Andreas Fault
Hypocenters
Value
High : 3937.100098
Low : 719.995911
N
W
E
S
Kilometers
0
1.5
3




Drill Site
Middle Mountain
Surface Trace of San Andreas Fault
0
1
2
3
4
Depth, km
?
Stage I: Vertical Drilling
• Rotary drill to 2 km depth
• Downhole measurements, spot coring and fluid sampling
• Case and cement
Stage II: Monitoring (8 months)
• Install downhole seismometer at 2 km
• Locate microearthquakes in conjunction with surface array
Stage III: Directional Drilling
• Rotary drill to 4 km depth, with spot and sidewall coring
• Case, cement and perforate through fault zone
• Downhole measurements and fluid sampling
Stage IV: Monitoring (2 years)
• Install monitoring string across fault zone (seismometry and fluid pressure)
• Conduct site-characterization studies with instruments in hole
• Remove string periodically and log for casing deformation
Stage V: Continuous Coring
• Core four, 250-m-long side tracks through fault zone
• Install slotted liners in core holes for later hydrologic monitoring
Stage VI: Long-Term Monitoring (~ 20 years)
• Install monitoring string across fault zone (seismometry, fluid pressure, temperature and deformation)
Resistivity, Ohm-m
1
10
100
VE 1:1

All components of EarthScope must work together in the planning, execution and interpretation of experiments aimed at understanding the SAFOD "crustal volume".

SAFOD

PBO

USArray

InSAR

Integrated physics-based models for faulting and earthquake generation along the San Andreas Fault that combine measurements made in the drill hole with crustal-scale measurements of the displacement field, seismic velocity, density, conductivity and other properties.

Drilling of Main SAFOD Hole in 2004(?)

SAFOD is an open experiment.

Monitoring data from the observatory will be freely available to all without restriction.