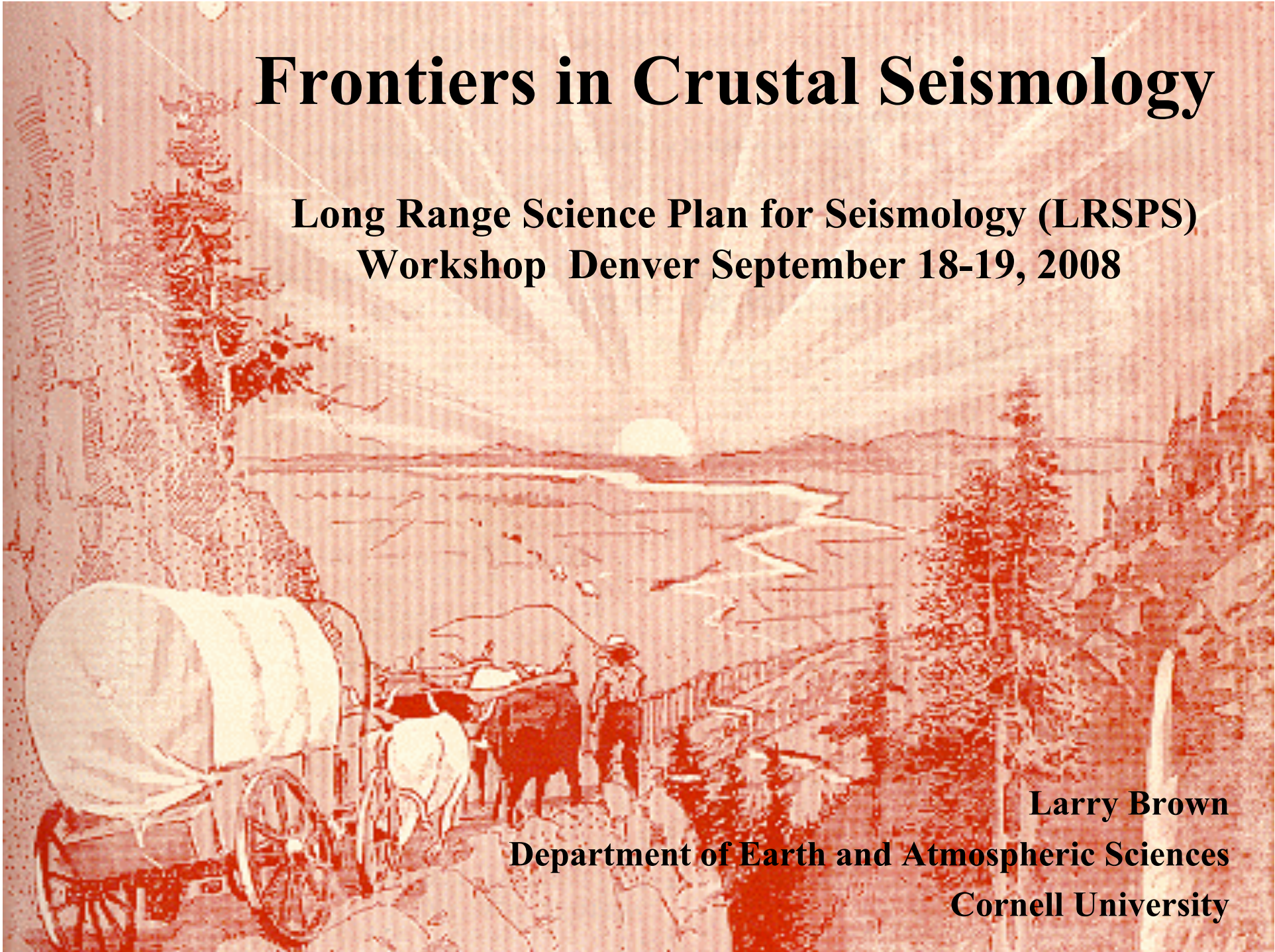


Frontiers in Crustal Seismology

**Long Range Science Plan for Seismology (LRSPS)
Workshop Denver September 18-19, 2008**

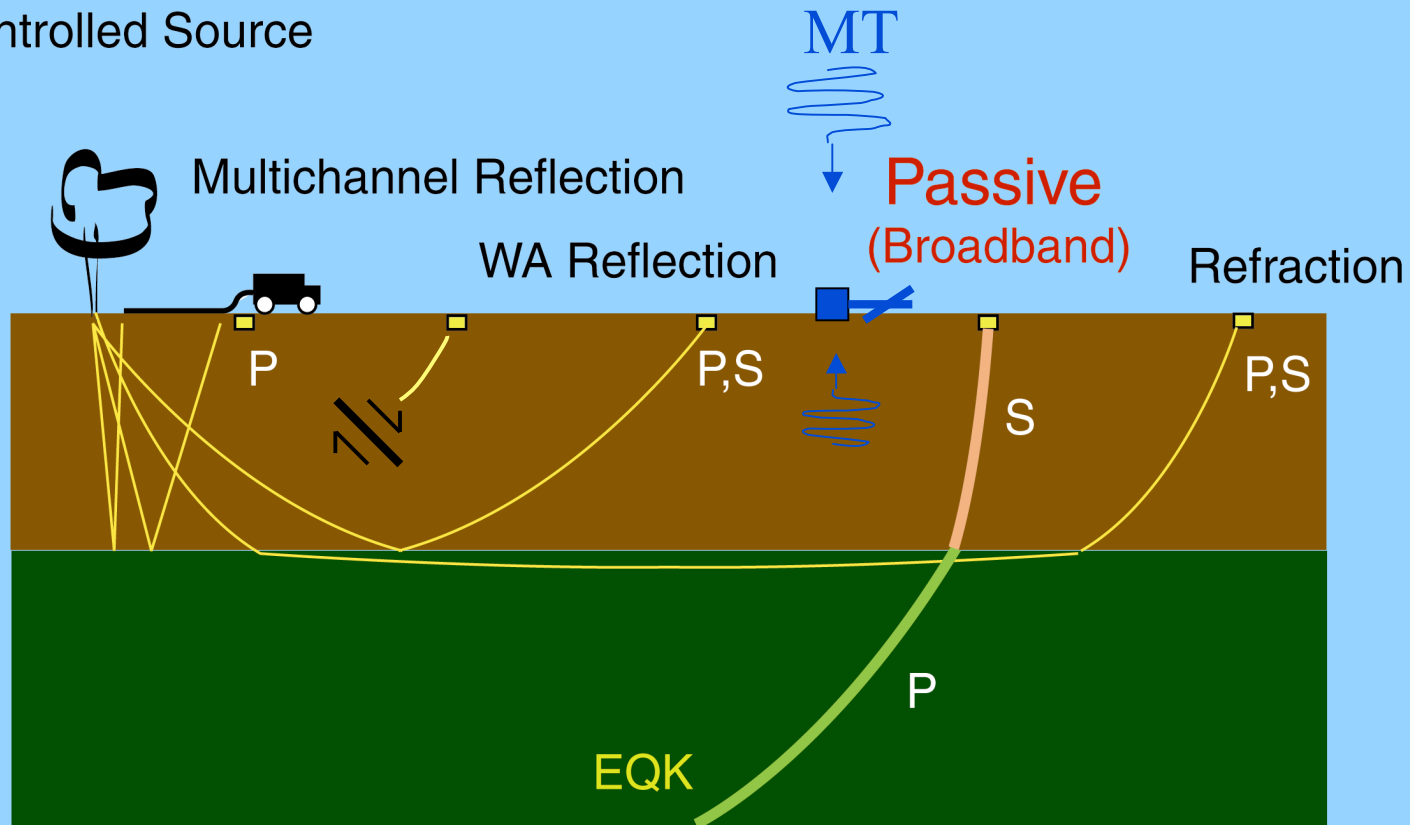
**Larry Brown
Department of Earth and Atmospheric Sciences
Cornell University**



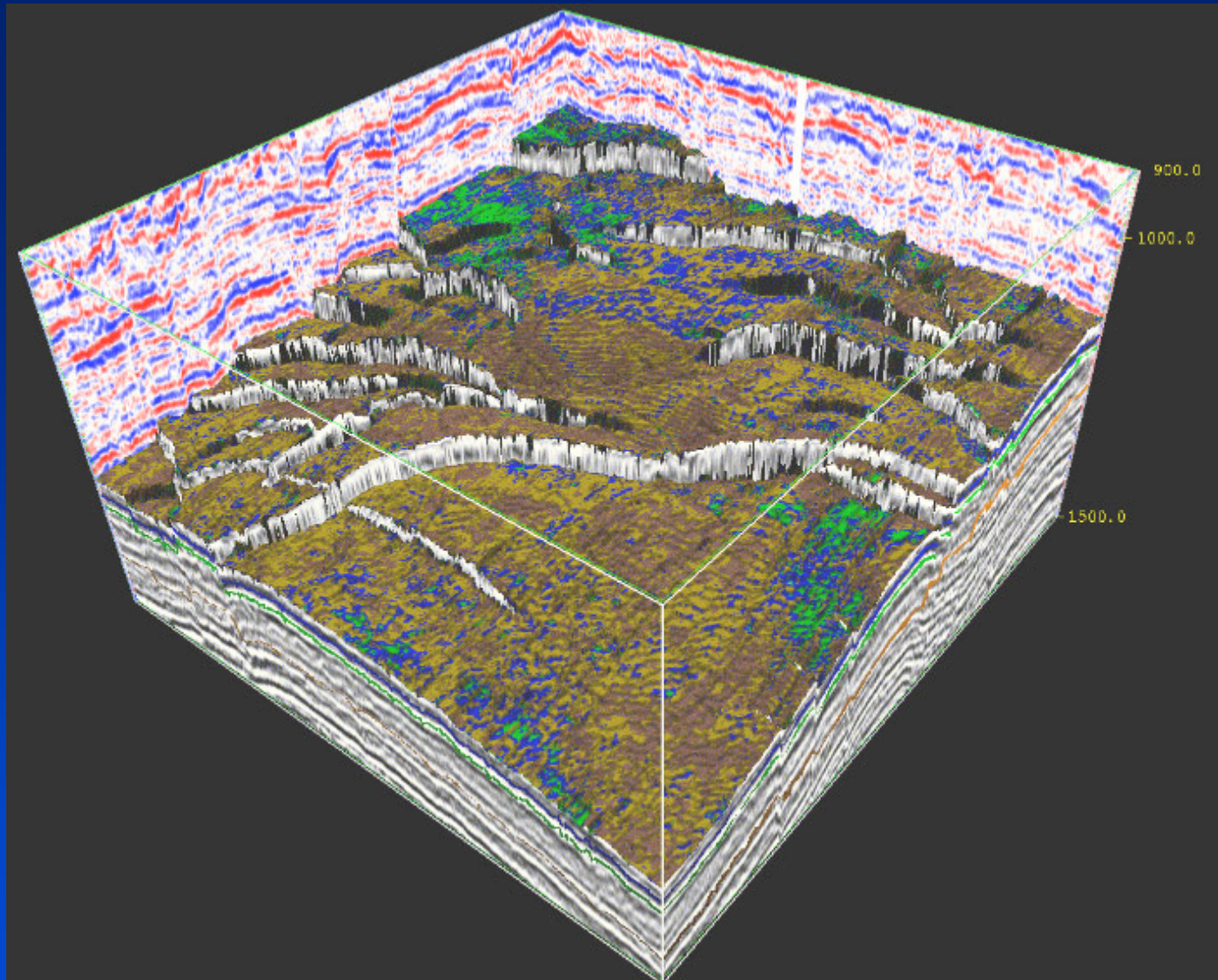
Detectable by Seismix and MT

Controlled and Natural Source

Controlled Source



3D



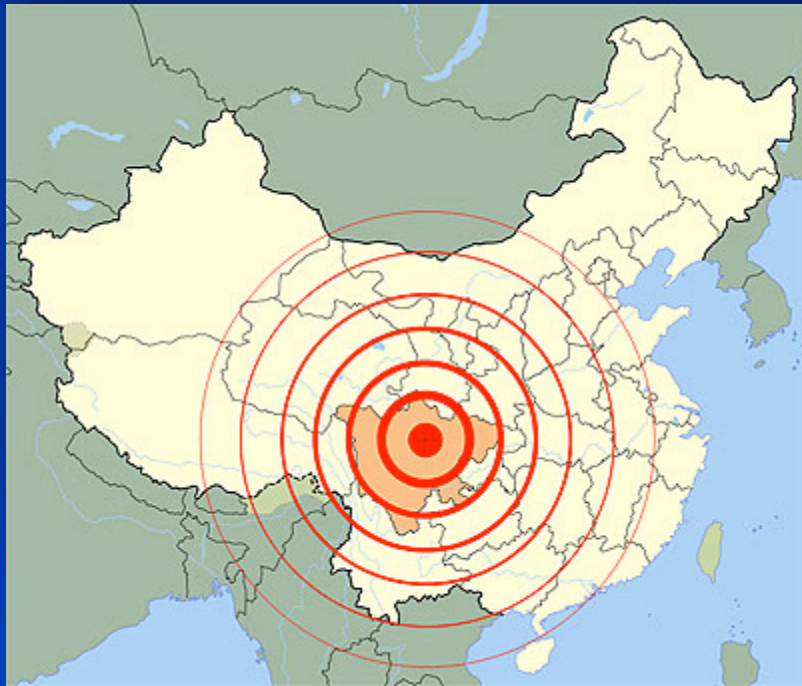
www.unil.ch/igp/page22862_en.html

A long-exposure photograph of a starry night sky. A prominent, bright, diagonal streak of light, likely a meteor or a satellite, cuts across the frame from the upper left towards the lower right. The background is filled with numerous stars, some appearing as short, faint streaks due to the camera's movement or the Earth's rotation. The overall color palette is dominated by deep blues and purples, with the bright streak providing a stark contrast in white and yellow.

Frontier #1

- Deep Fluids
 - Detection
 - Identification
 - Monitoring

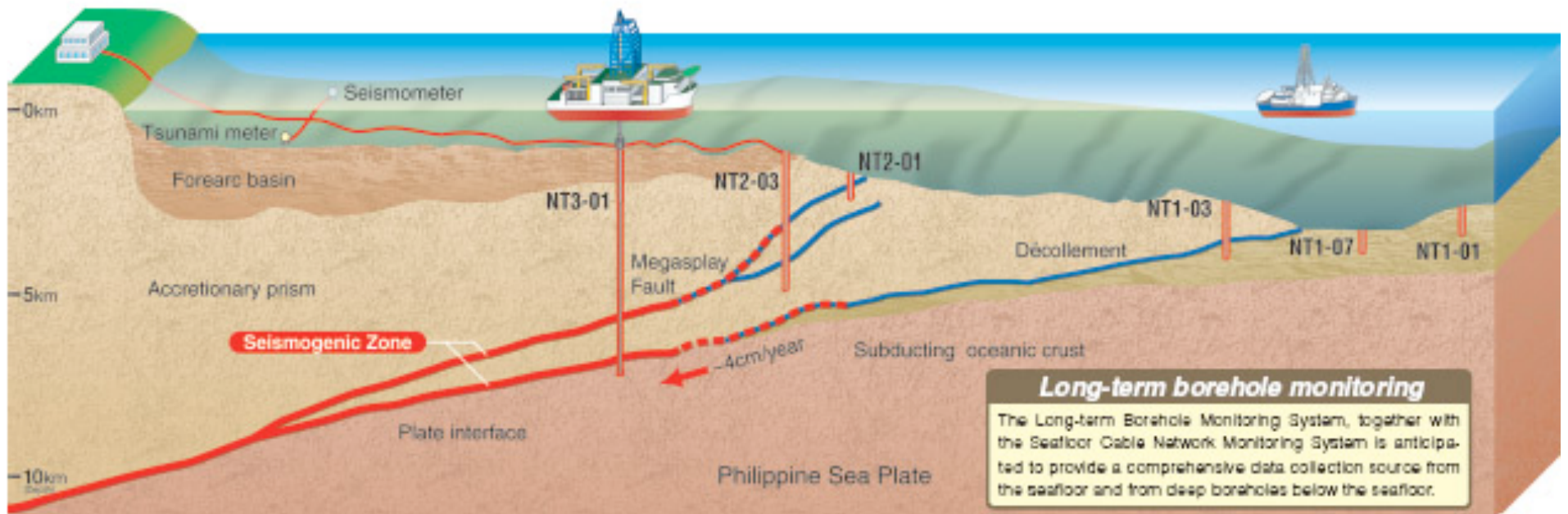
Earthquakes



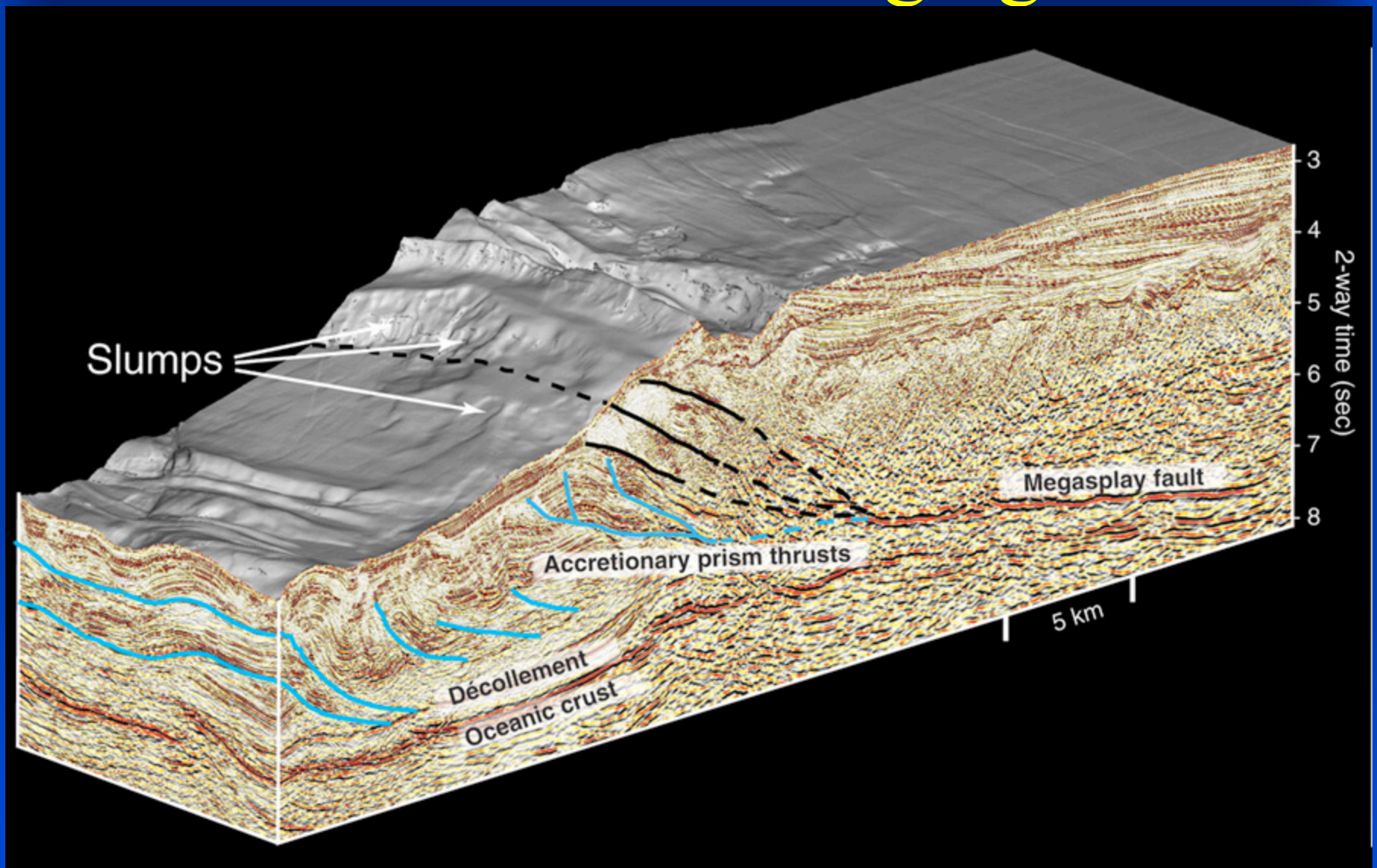
May 12, 2008
Sichuan, China
M= 7.9



Deep Fluids and Seismogenesis

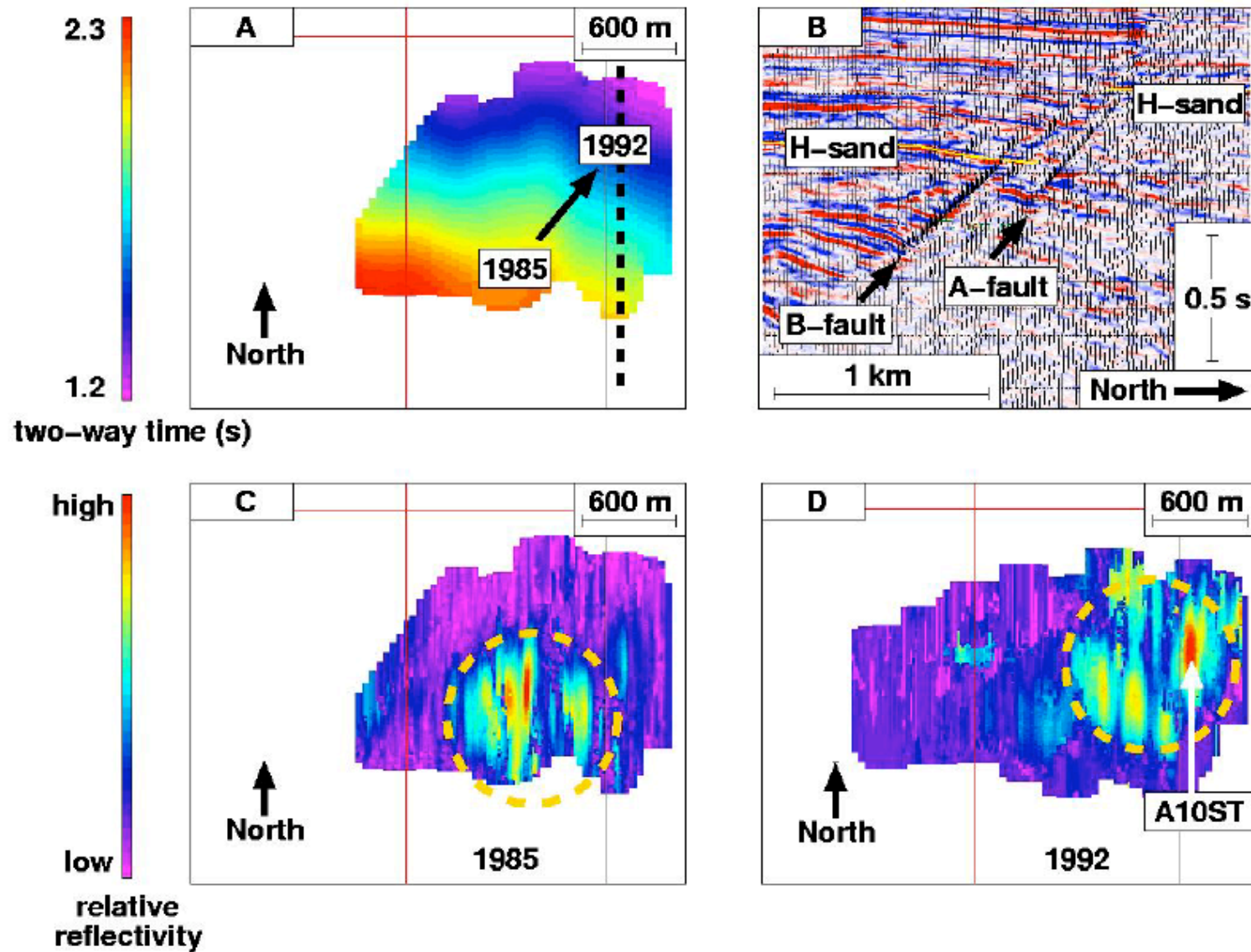


3D Seismic Imaging

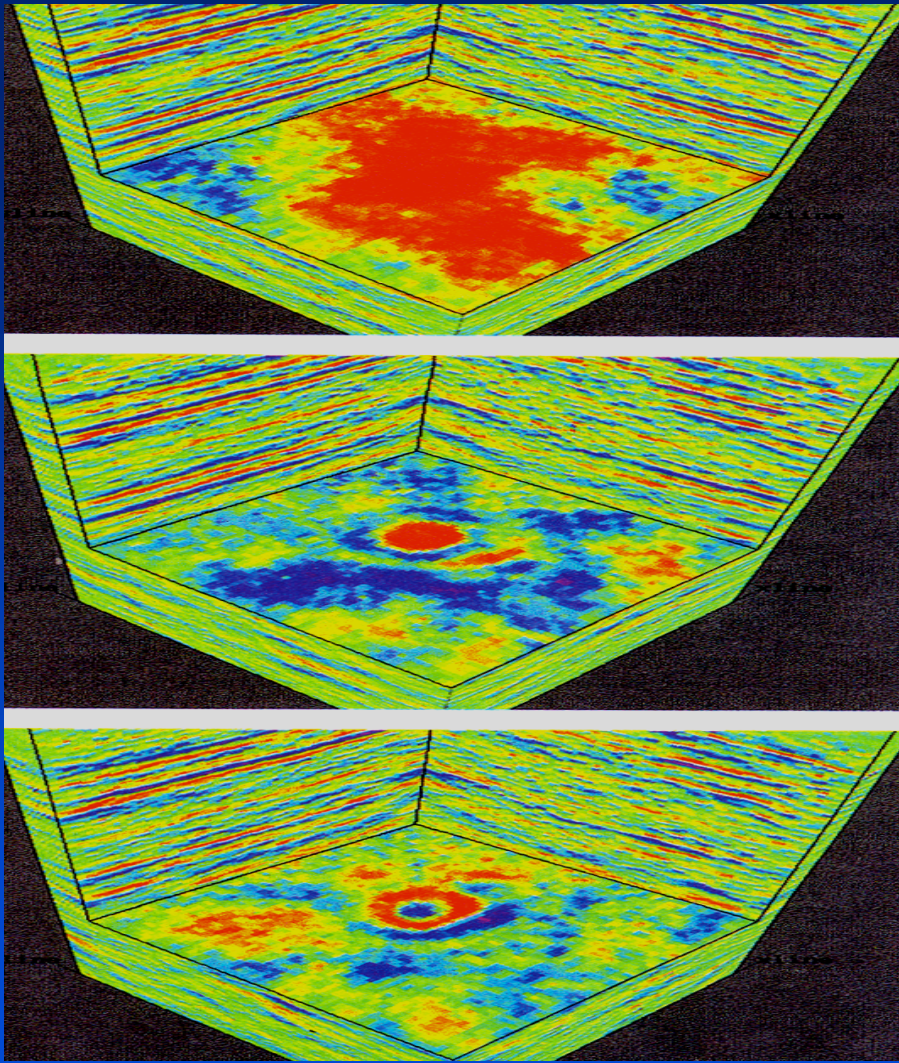


<http://www.jsg.utexas.edu/images/big/111507/f2.jpg>

Seismic imaging of moving fluid pulse, SEI330



4D Monitoring



Oil Field Example

Before Steam Injection

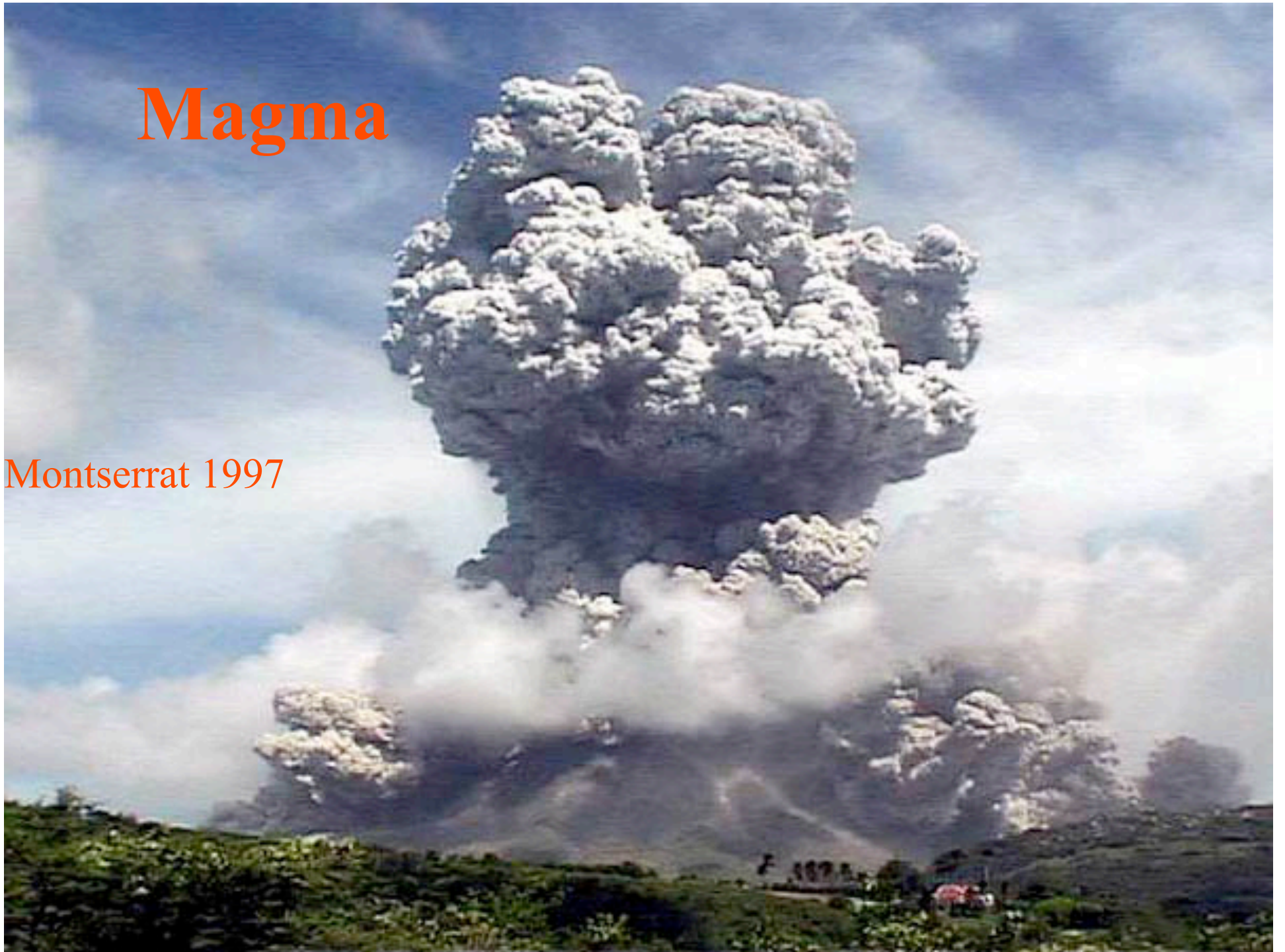
Steam Injection 5 mos

Steam Injection 13 mos

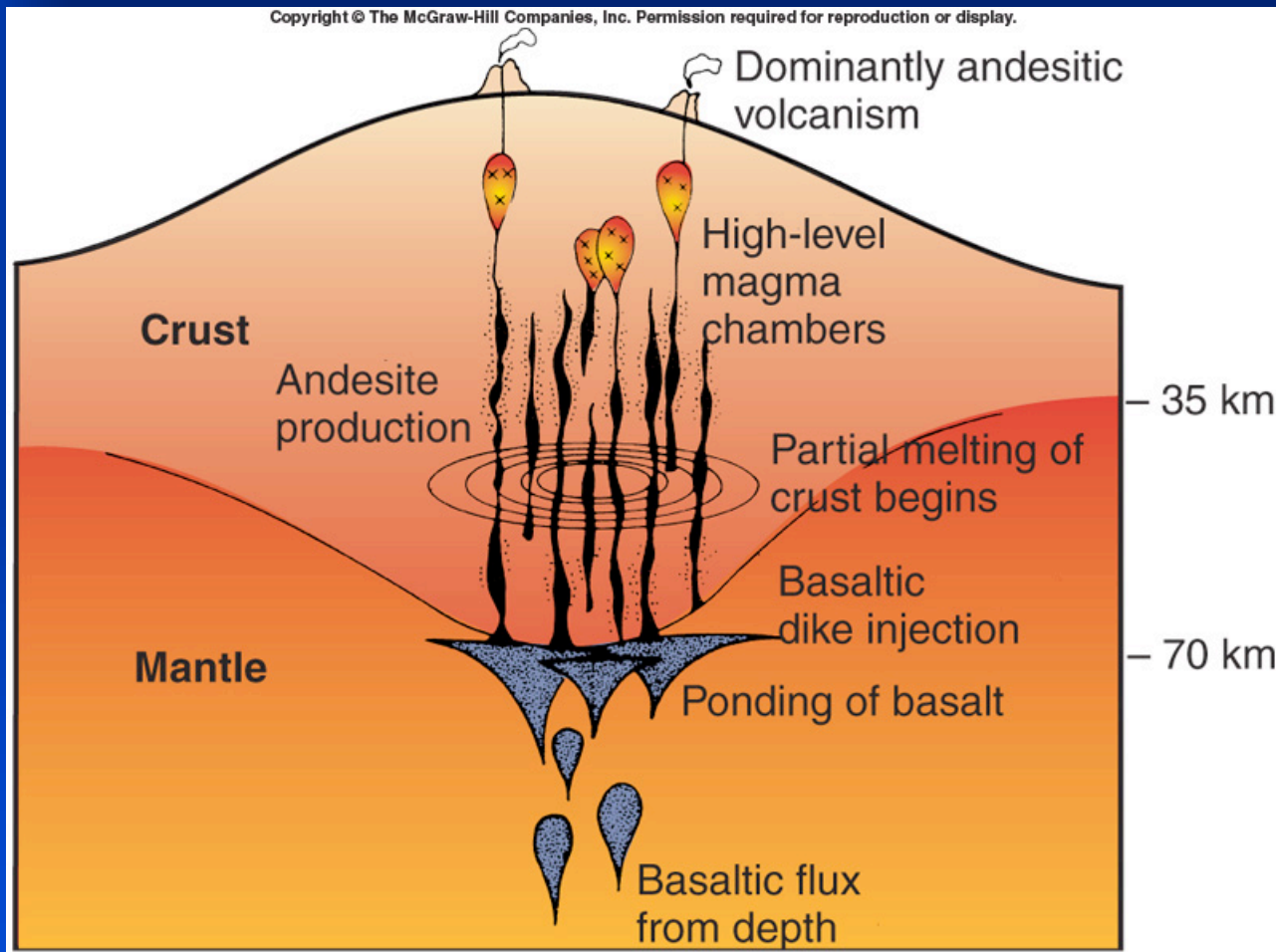
Alistair Brown, 1999

Magma

Montserrat 1997



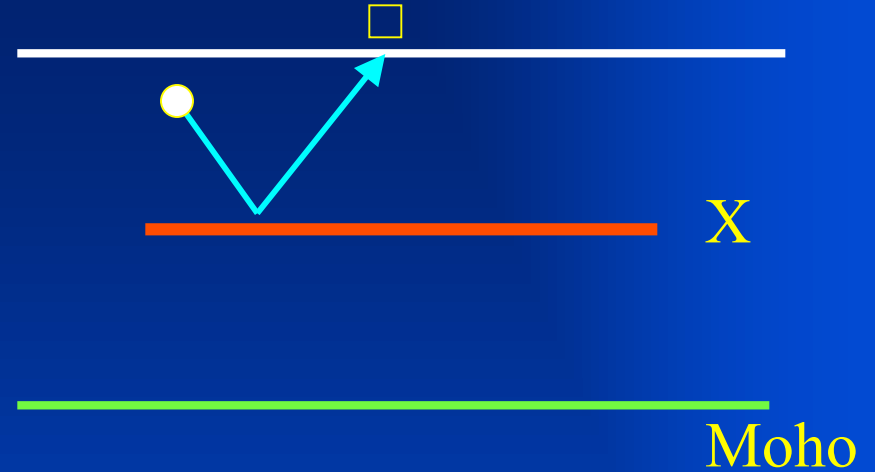
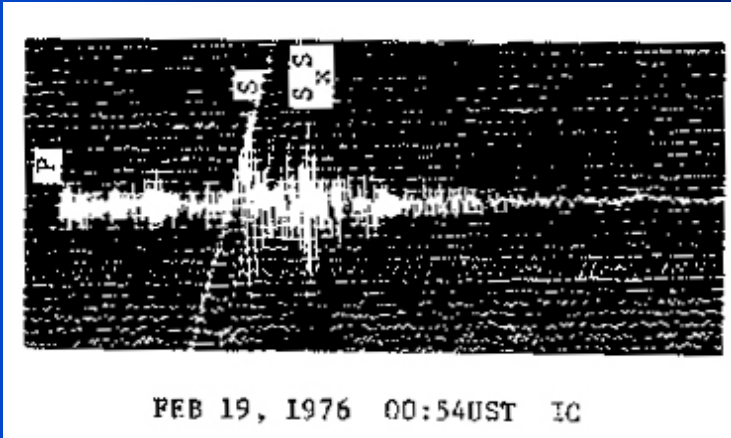
Magma Plumbing



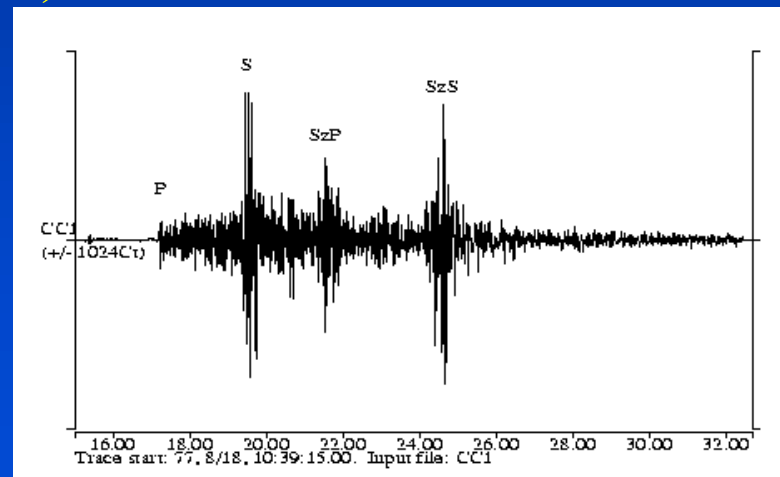
- Field Mapping
- Geochemistry
- Geodesy
- Geophysics
 - Gravity
 - MT
 - Seismology
 - Seismicity
 - Imaging
 - Active
 - Passive

Abbott, 2008

Anomalous S Waves

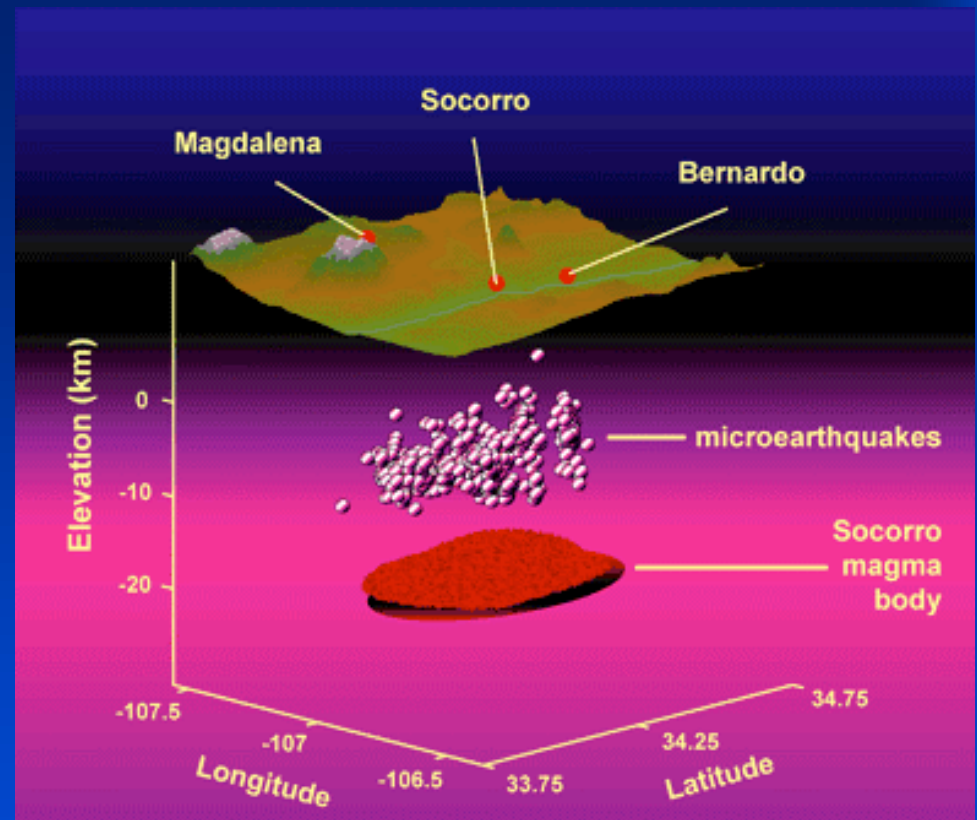
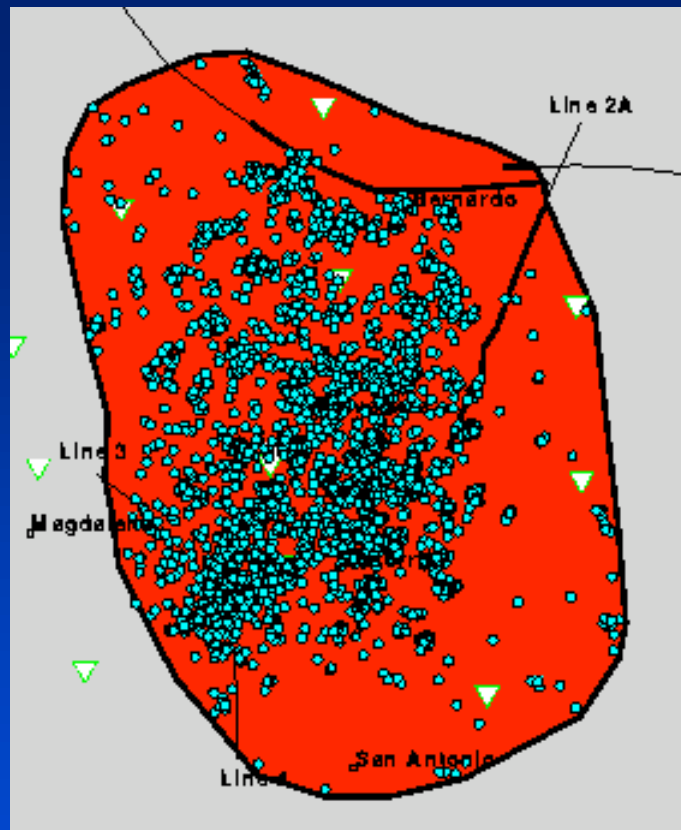


Sanford et al. (1977)



Balch et al.: <http://www.ees.nmt.edu/Geop/magma.html#extent>

Socorro Magma Body

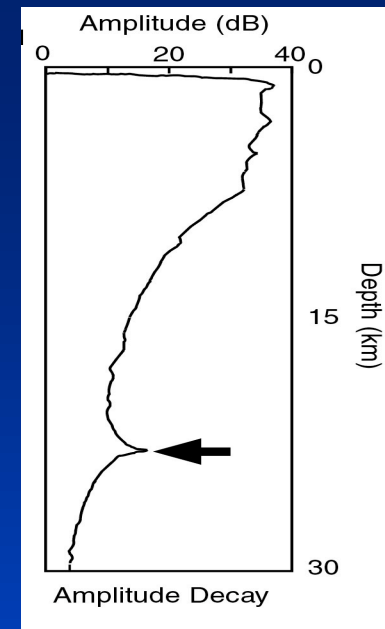
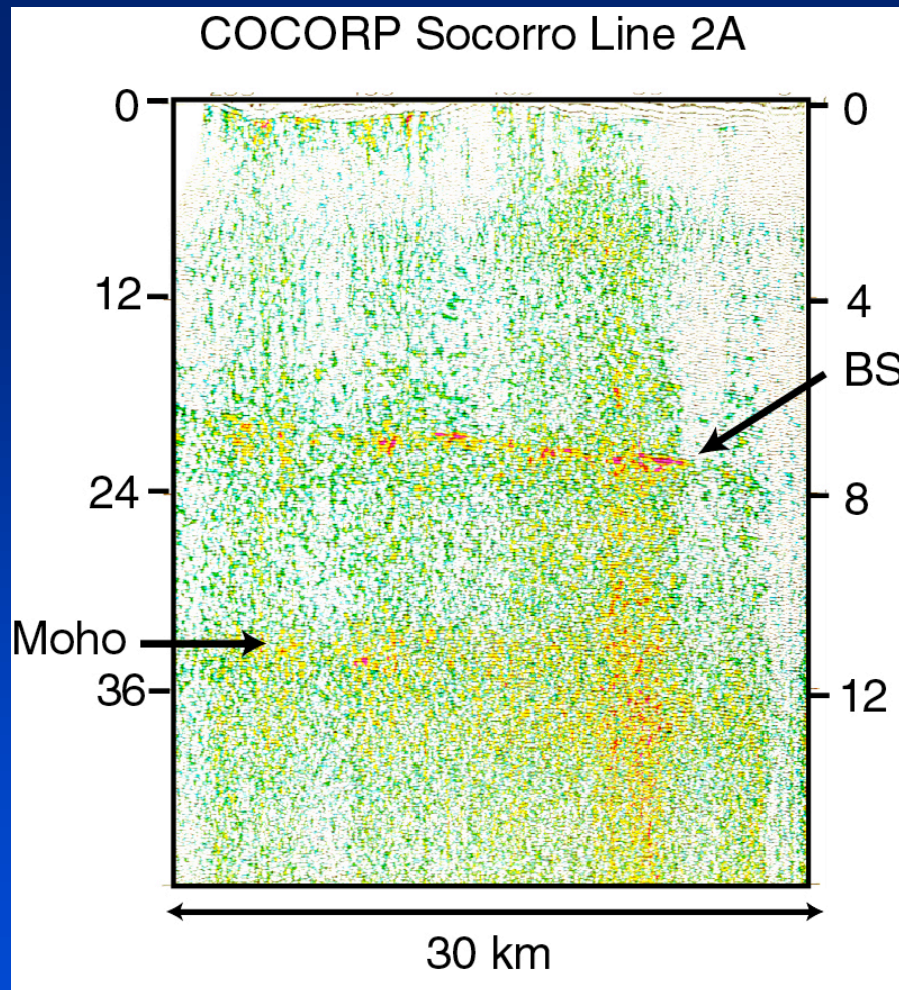


Balch et al.

<http://www.ees.nmt.edu/Geop/magma.html#extent>

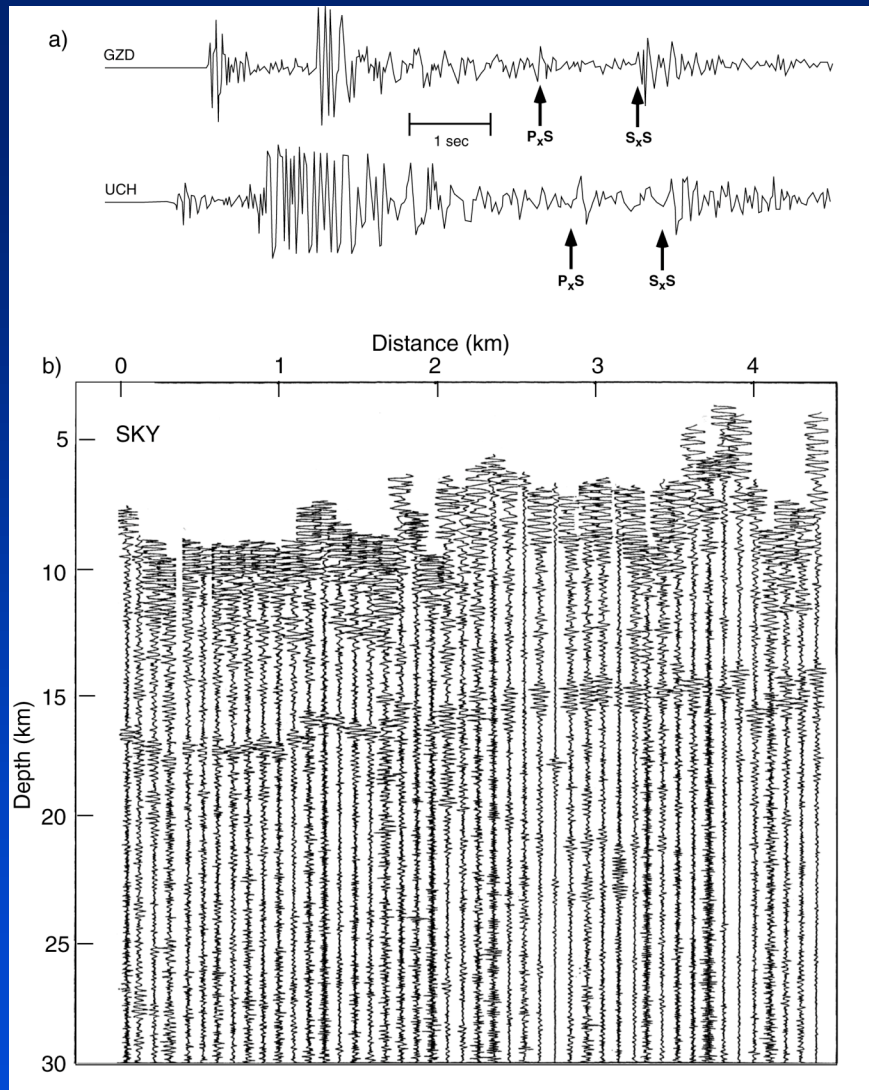
http://www.ees.nmt.edu/Geop/NM_Seismology.html

Socorro Bright Spot



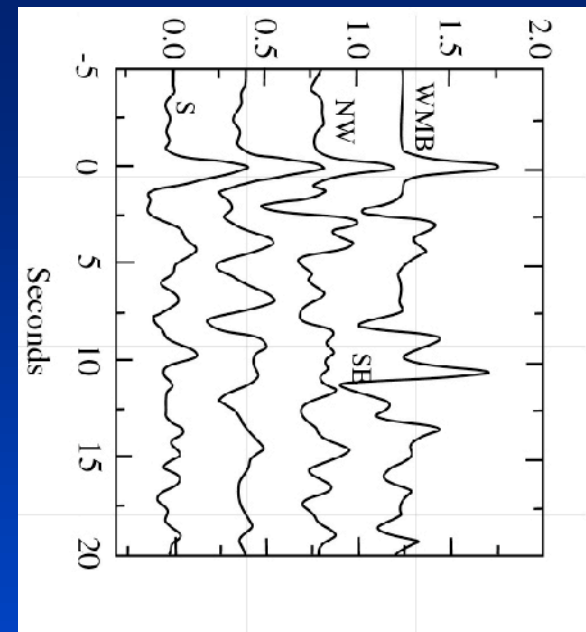
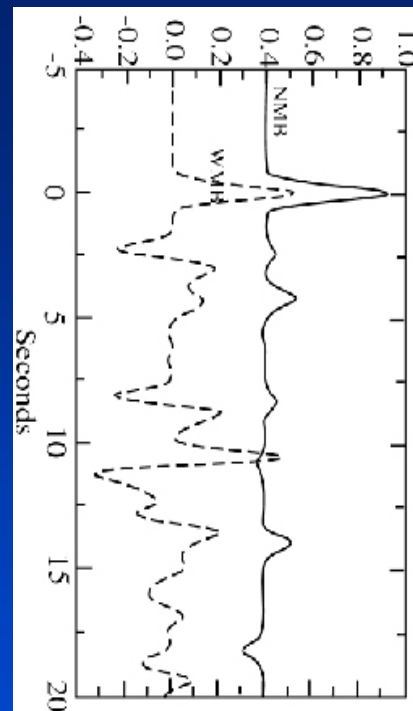
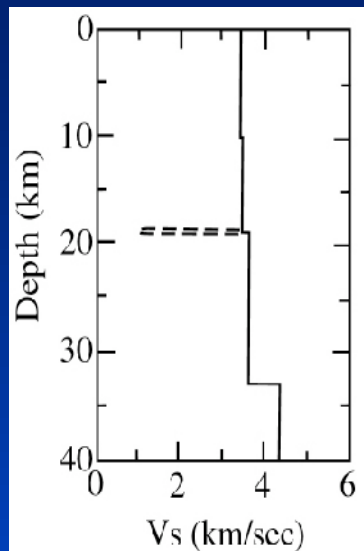
COCORP 1976

Anomalous S reflectors: Japan



Matsumoto and Hasegawa, 1996

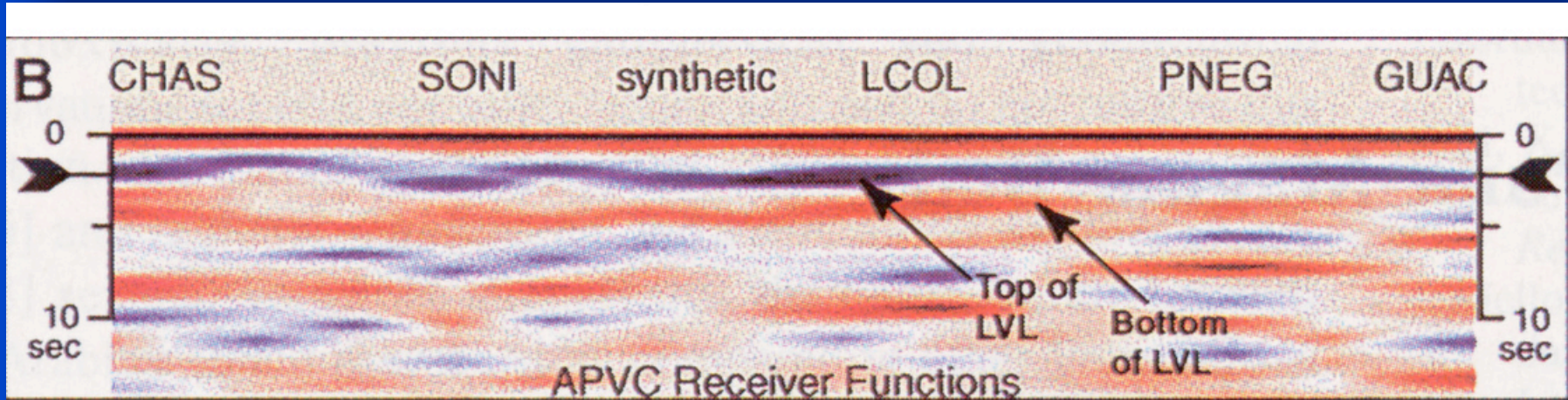
SBS: Detection by Receiver Functions



Sheetz and Schlue, 1992

Andean Bright Spots (Receiver Functions)

Altiplano-Puna

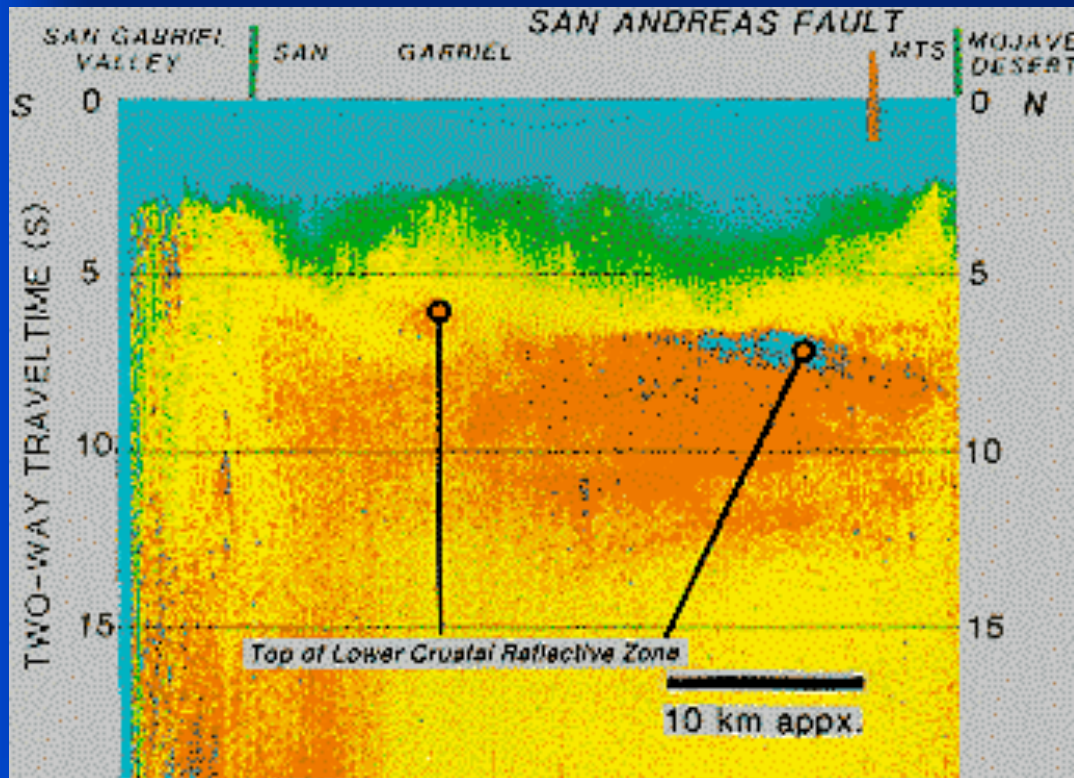


Chmielowski et al. (1999)

Socorro Bright Spot: The Case for Magma

- Beneath Cenozoic Rift
 - Tertiary volcanics
- High Heat Flow
- Swarm seismicity
- Strong P and S wave reflectivity
- S wave AVO
- Conductivity?

Fluid, but what fluid?



Fuis et al., 1996

Water?



“Volcano” 1997

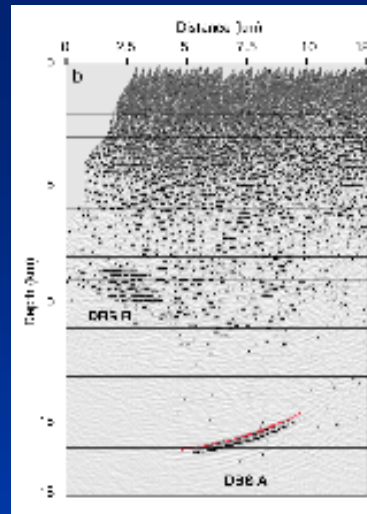
Physical Properties: Seismix + MT

Fluid “Bright Spots” (Tibet)

- P amplitude anomalies (CMP, WA)
- Negative polarity (CMP, BB)
- Strong P to S conversion (WA, BB)
- Complex shape (CMP)
- 15 km deep (CMP, WA, BB)
- Top of LVZ (BB)
- High conductivity (MT)
- Geothermal area (HF, SG)

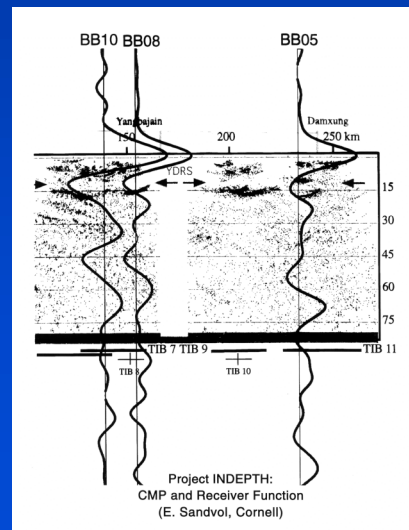
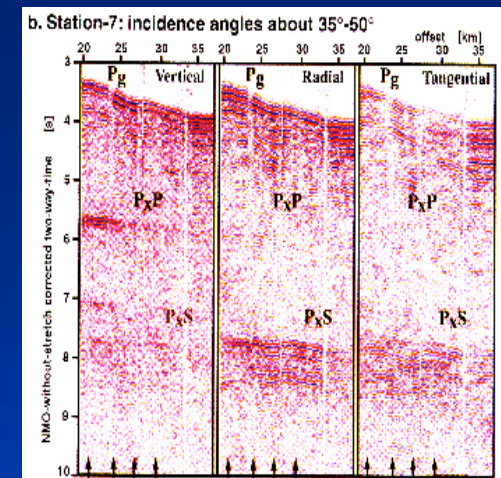


Fluids: yes ..Magma: probably



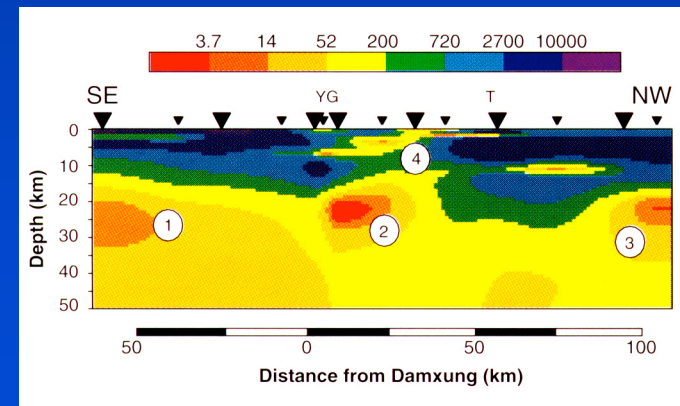
CMP

WA 3C



BB

MT



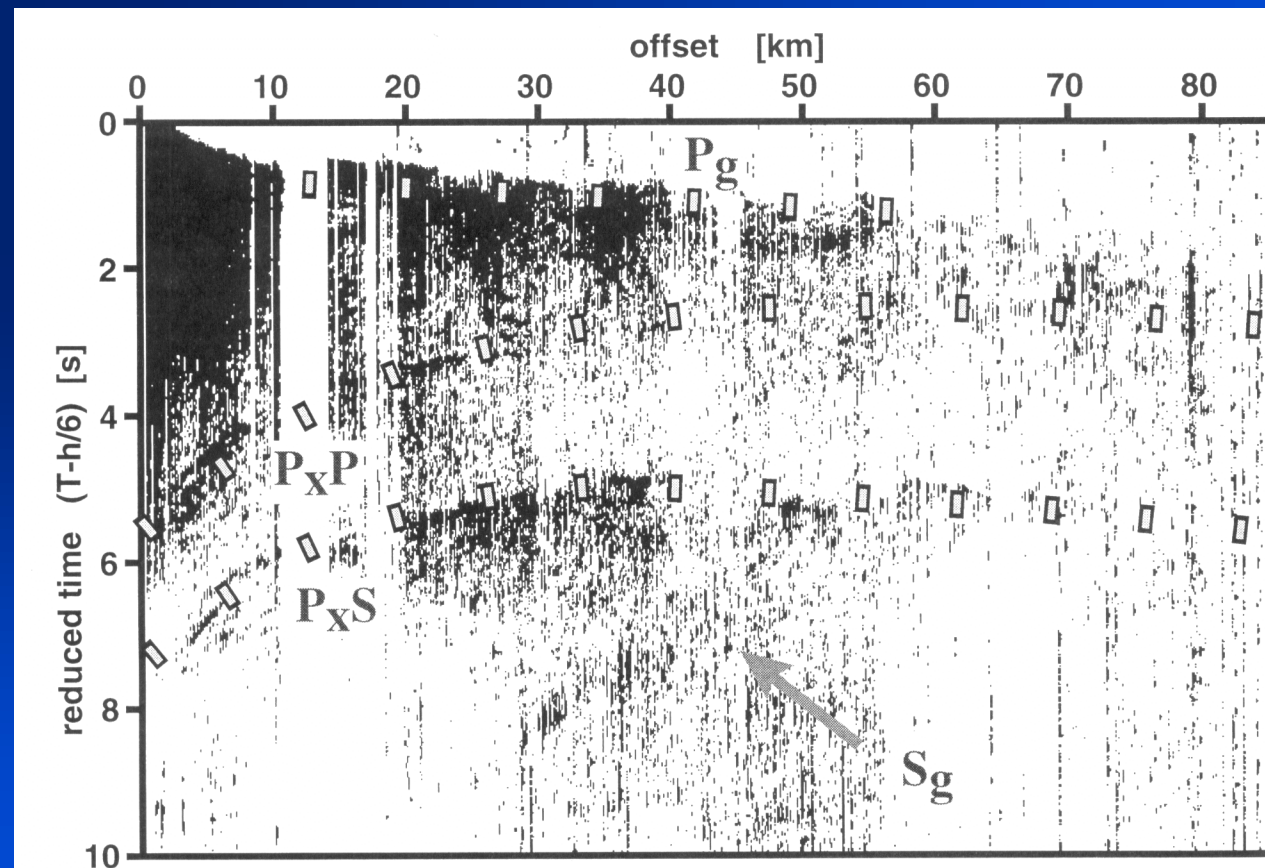
After Ross et al., 2002

Measuring the seismic properties of Tibetan bright spots: Evidence for free aqueous fluids in the Tibetan middle crust

Yizhaq Makovsky¹ and Simon L. Klemperer

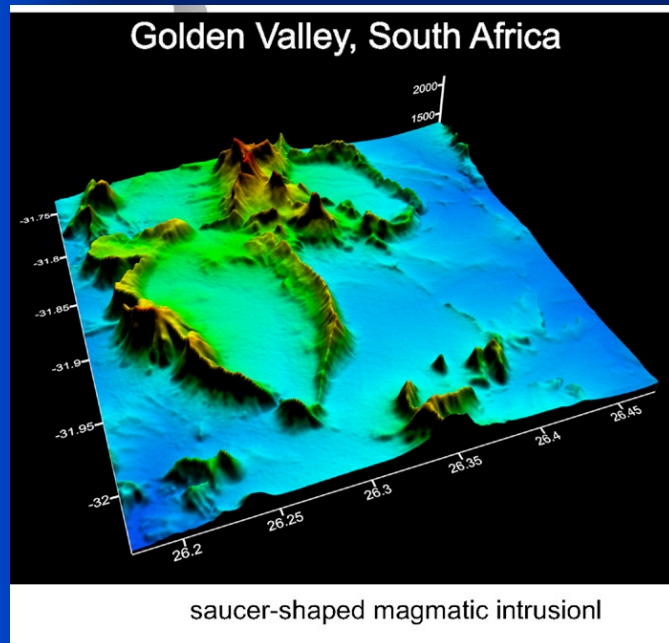
Department of Geophysics, Stanford University, Stanford, California

AVO

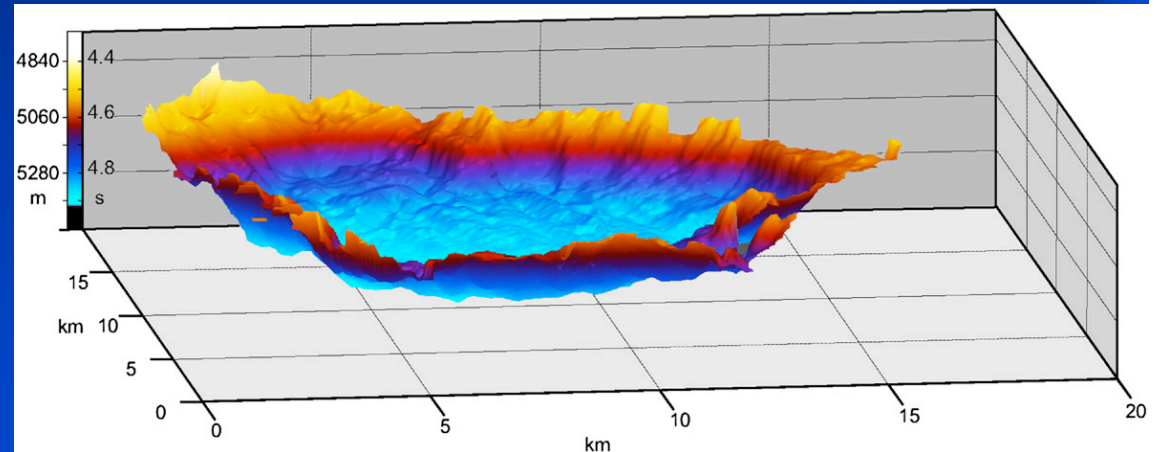


Cuspate (Saucer shaped) Reflectors

Polteau et al, 2008



Karoo Outcrop
South Africa

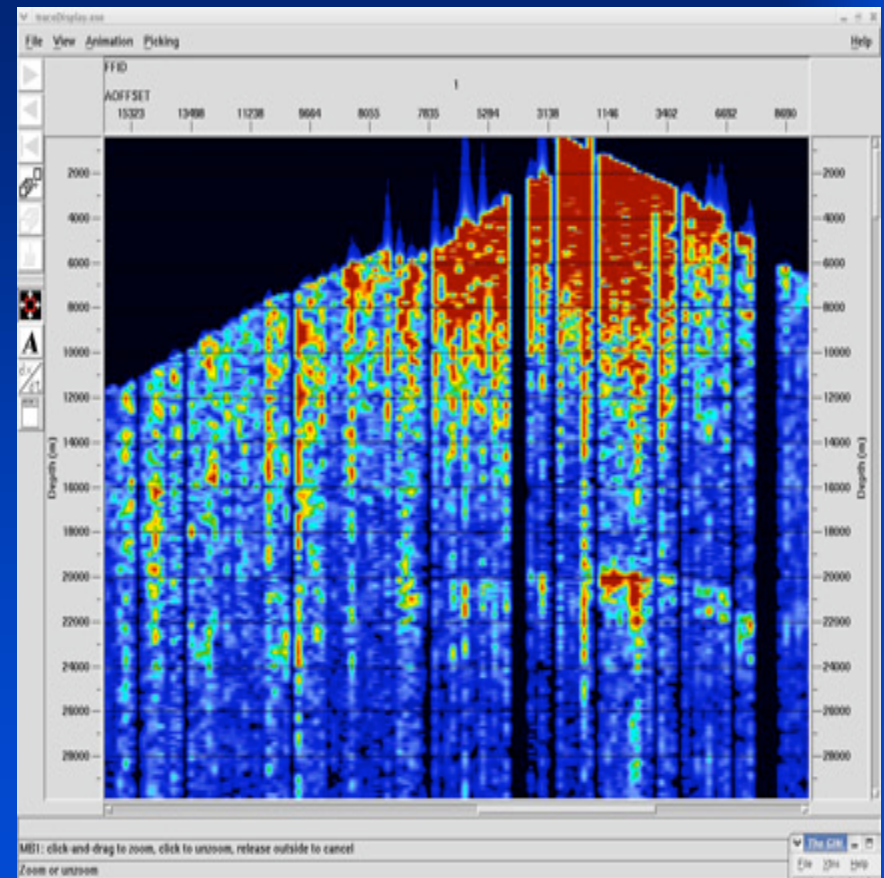
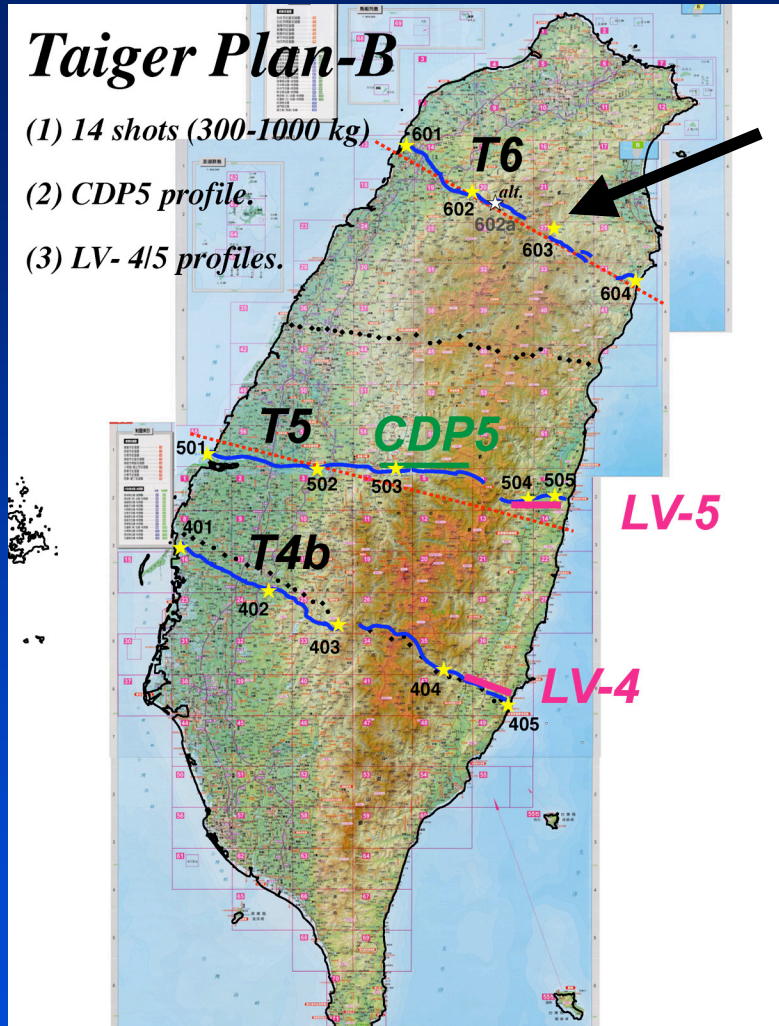


3D Seismics, Offshore Norway

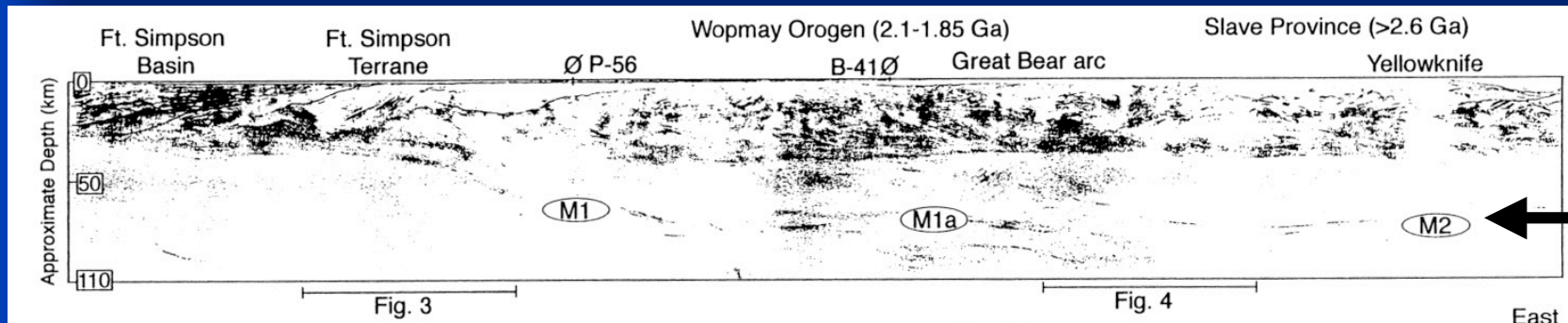
TAIGER 2008: New Bright Spot

Taiger Plan-B

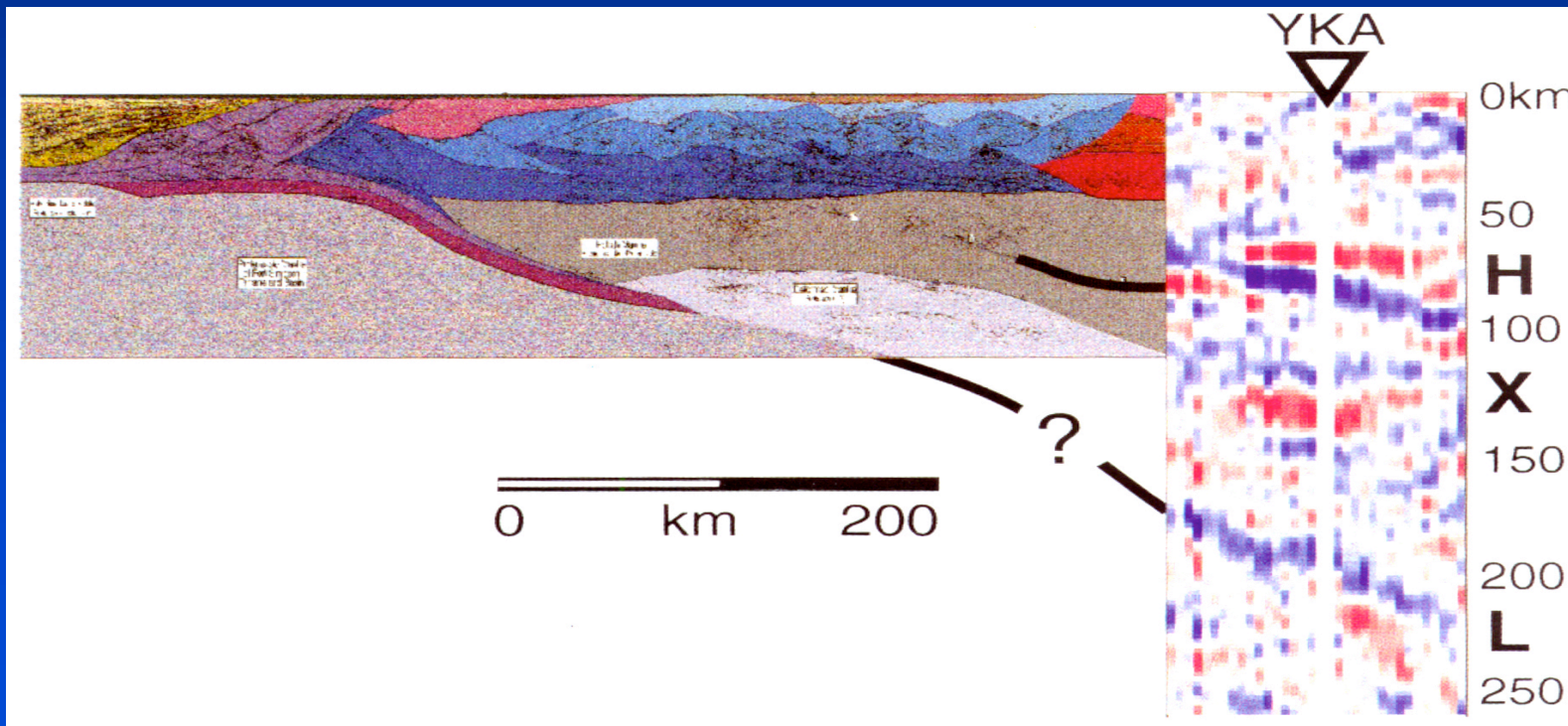
- (1) 14 shots (300-1000 kg)
- (2) CDP5 profile.
- (3) LV-4/5 profiles.



Passive + Active



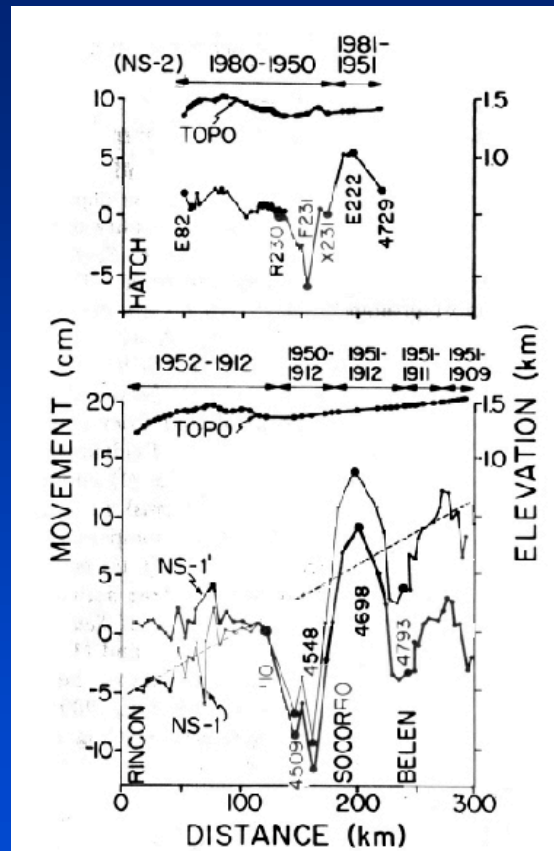
(Cook et al., 1998)



(Bostock, 1999)

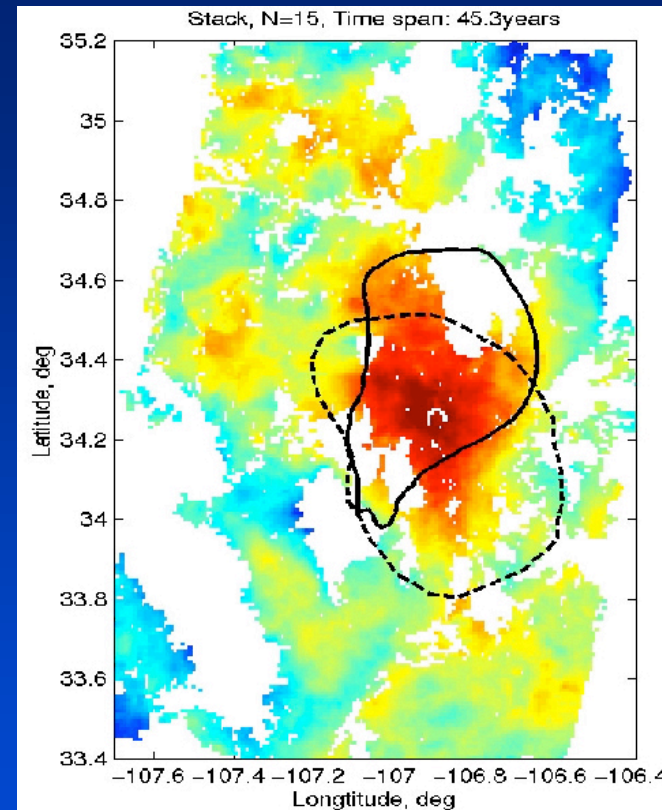
SBS: A Breather

Leveling



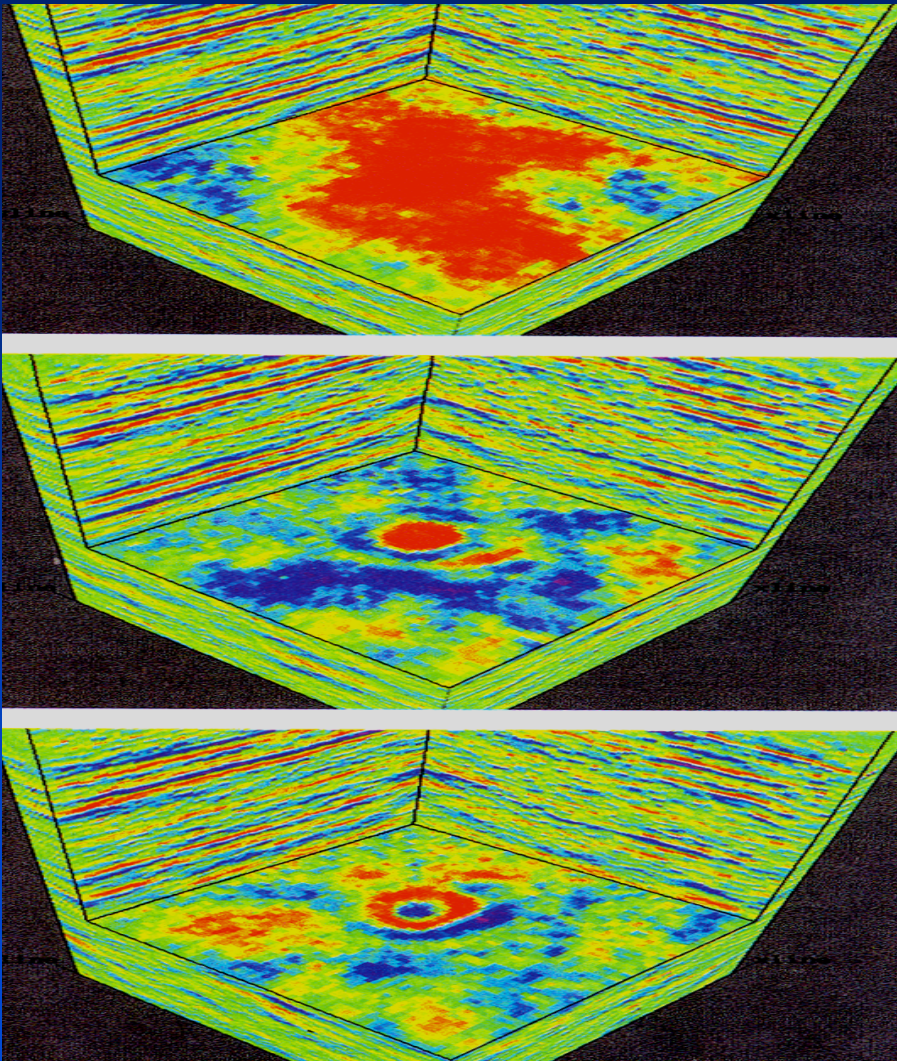
Larsen et al. (1986)

INSAR



Fialko and Simons (2001)

4D Monitoring



Oil Field Example

Before Steam Injection

Steam Injection 5 mos

Steam Injection 13 mos

Alistair Brown, 1999

The World of 4D

- Oil and Gas extraction
- CO₂ sequestration
- Geothermal energy extraction
- Underground coal gasification
- Seismogenic zone variations (fluids +)
- Evolution of magma plumbing
- Mantle gas migration

Frontier #2

Riding the Technology

- Source
- Receiver

Receivers

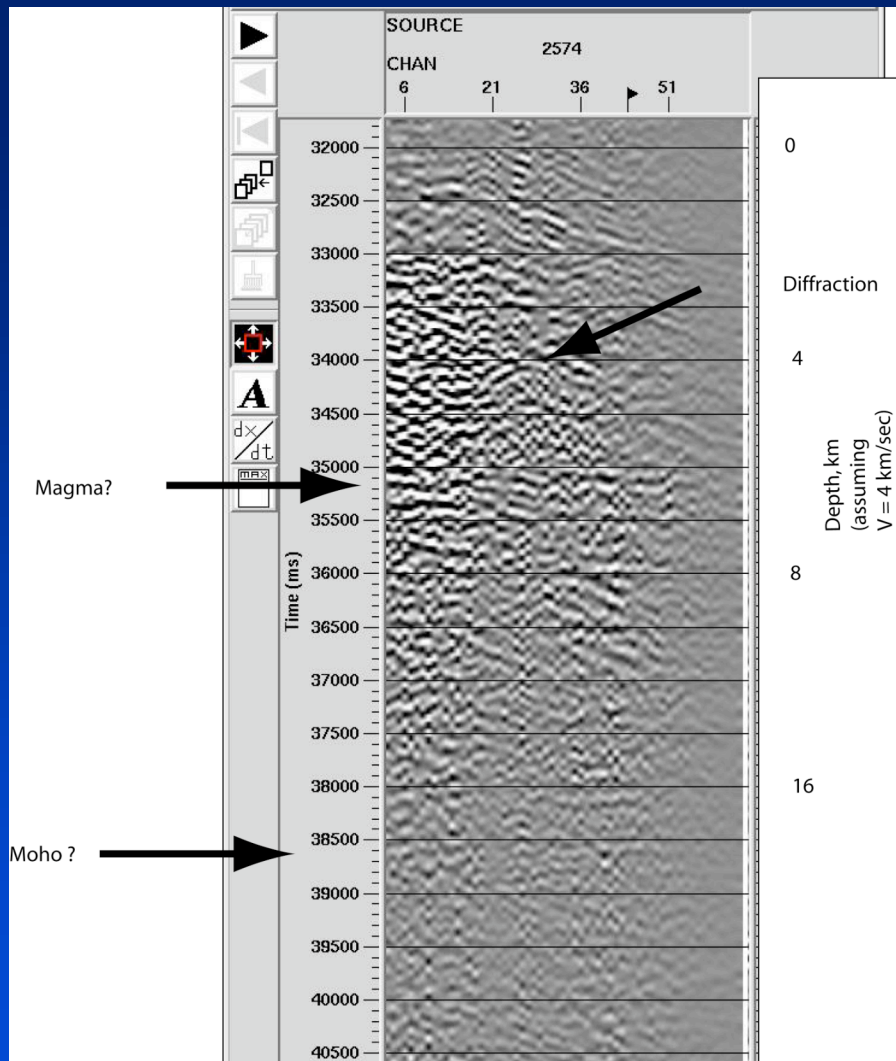
- Lots of them (3D)
 $\Delta X \sim \Delta Y < 100\text{m}$
- **3 component**
- **Broadband**

Go to the Source

- Hammers \$
- Vibroseis \$\$\$\$
- Explosions \$\$\$\$\$\$
- Earthquakes \$, but they don't follow orders

Need something ubiquitous and cheap ..

SEA-CALIPSO 2007



**Microearthquake
“Shot gather”**

Ambient Noise for Reflection?



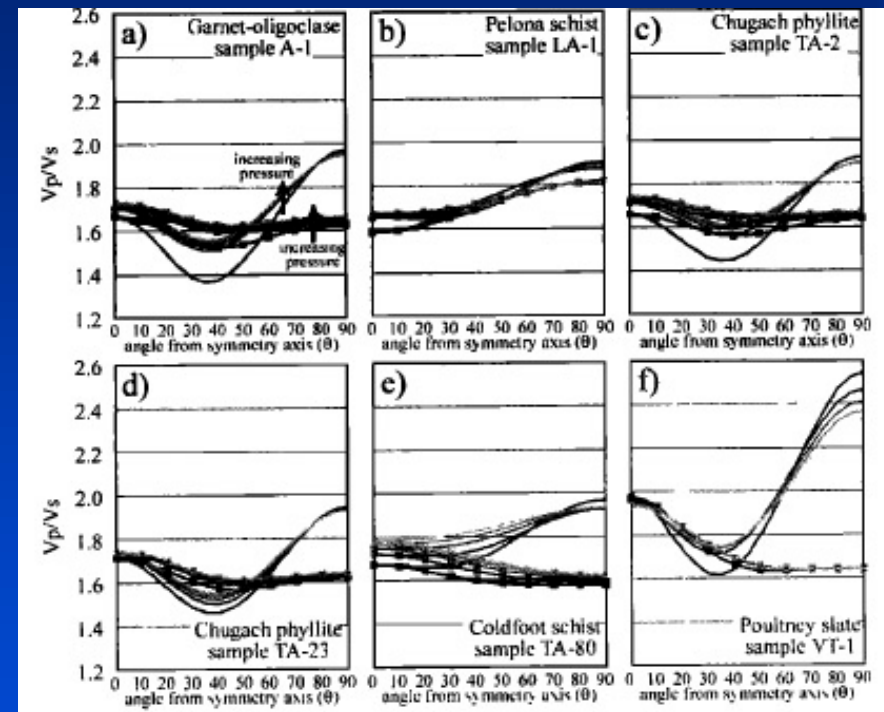
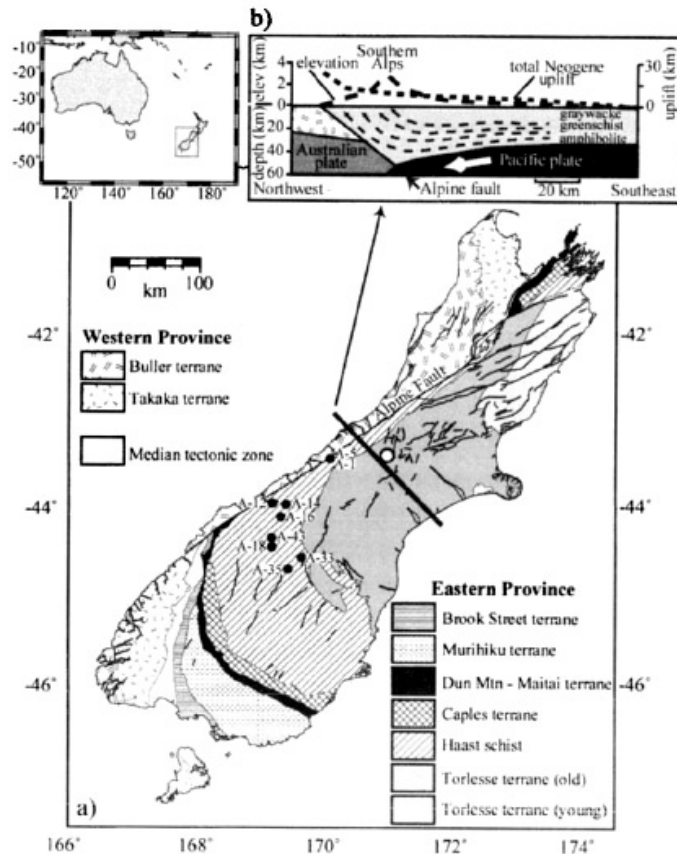
US Interstate Seismic Source System?

Receivers

- Lots of them (3D)
 $\Delta X \sim \Delta Y < 100\text{m}$
- **3 component**
 - Broadband
- Year long recording capacity!

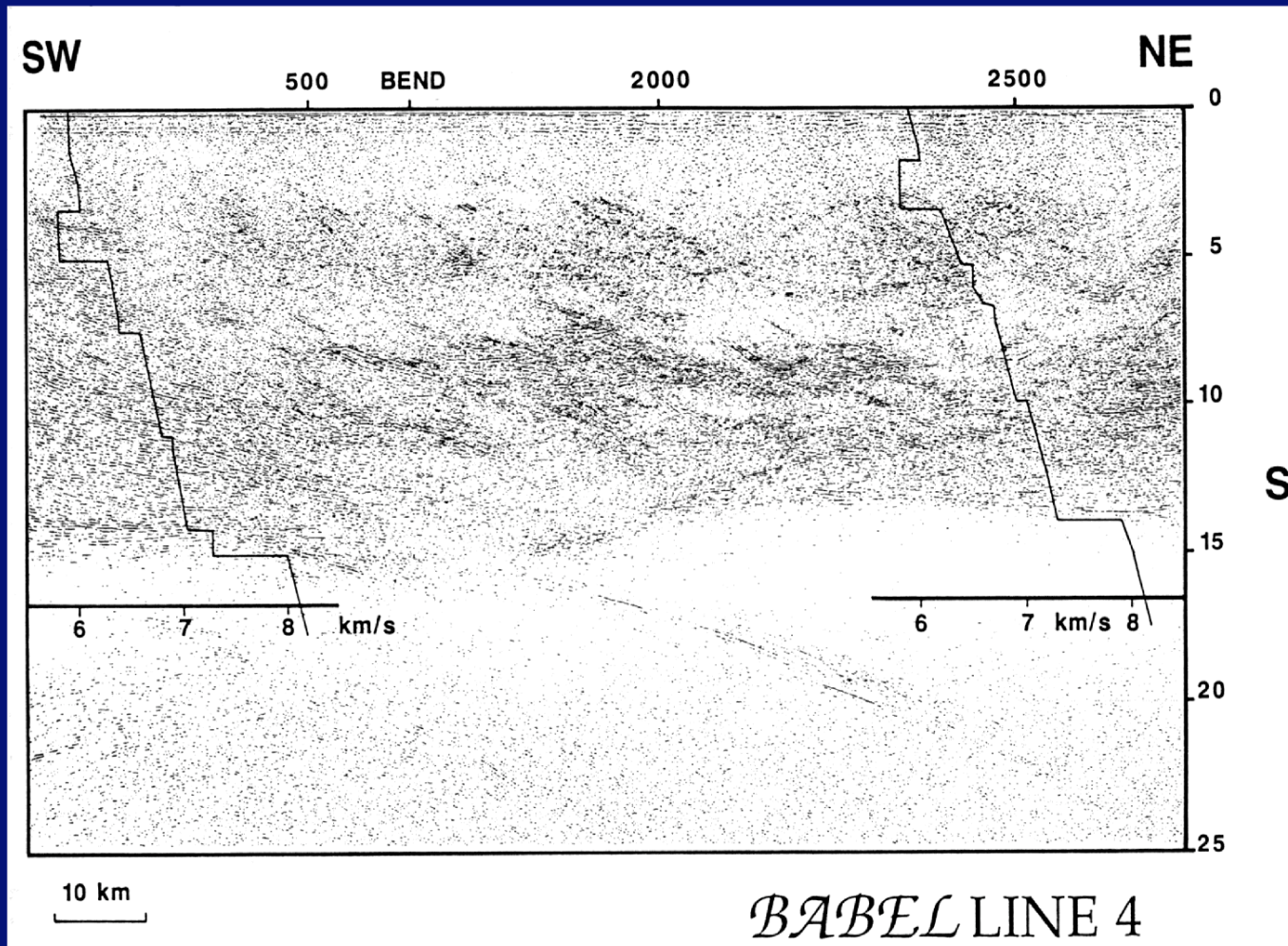
Imaging Strain Crustal Anisotropy

GODFREY ET AL.: CRUSTAL ANISOTROPY IN GLOBAL SCHIST BELTS



Godfrey et al, 2000

Suppose we could add a strain arrow to each reflector!



After McBride et al., 1992.

Frontier #3

The Rest of the World

Continental Deep Seismic Reflection Profiling

