Detectable by Seismix and MT

Controlled and Natural Source
Frontier #1

- Deep Fluids
  - Detection
  - Identification
  - Monitoring
Earthquakes

May 12, 2008
Sichuan, China
M = 7.9
Deep Fluids and Seismogenesis
Seismic imaging of moving fluid pulse, SEI330

Haynes et al. 2004
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

After Ross et al., 2002
Measuring the seismic properties of Tibetan bright spots: Evidence for free aqueous fluids in the Tibetan middle crust

Yizhaq Makovskiy and Simon L. Klemperer
Department of Geophysics, Stanford University, Stanford, California
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

INSAR

Larsen et al. (1986)

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
- CO$_2$ 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, 2000
Suppose we could add an strain arrow to each reflector!
Frontier #3

The Rest of the World
Continental Deep Seismic Reflection Profiling