SEISMOLOGY

- Utilizes seismic (sound) waves to make statements about the Earth's structure.
- By far the most high-resolution geophysical technique.
- As a *Geophysical* discipline, consists of:
  - Measurements ('data acquisition');
    - Emphasis on efficient acquisition techniques, vast volumes of data;
  - Data processing;
    - Very important and computer-based;
  - Interpretation in terms of models and geological concepts:
    - Forward (direct) modelling – predict seismic observations in a known subsurface structure;
    - Inverse modelling - Given the observed wavefield (travel times), determine the structure *and its uncertainty*.
      - Usually integrated with surface and borehole observations.
- Reading:
  - Telford et al., Chapter 1.
  - Sheriff and Geldart, Chapter 1.

Seismic Methods

- Rely on *contrasts in physical properties* associated with rock or mineral bodies:
  - Look for 'anomalies' (departures from 'regular behaviour').
- Specialized methods and tools to solve different problems:
  - Different *seismic methods* measure different properties (i.e., velocities, impedances);
  - Different *frequency bands*
  - The different kinds of data are combined during interpretation or 'simultaneous inversion'.
    - Most seismic inversion techniques are highly mathematically or computationally formalized.

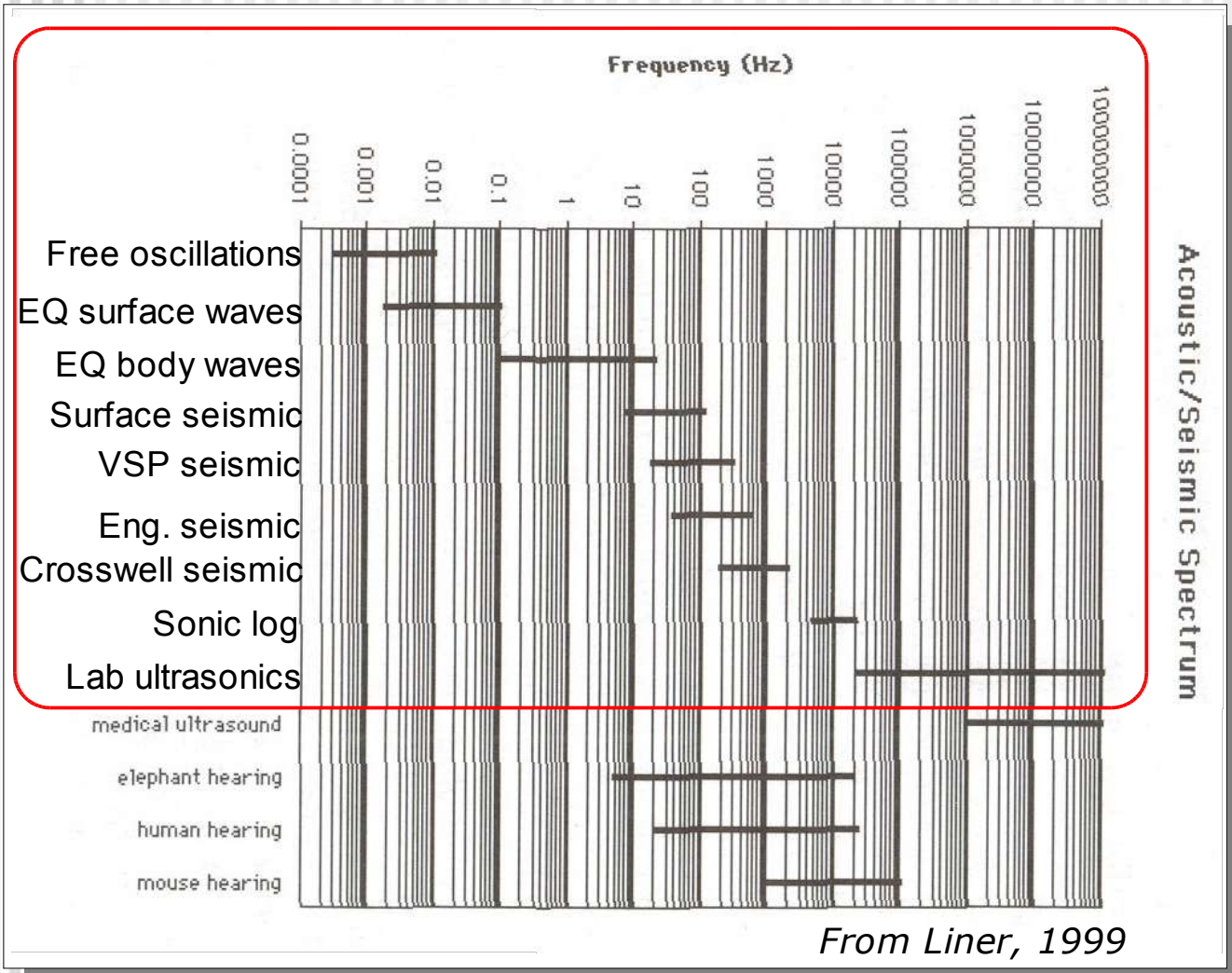
Seismic Methods

Their Resolution; 'Passive' and 'Active'

Method	*Property*	*Resolution*	*Value Measured*
Surface refraction	Velocities, velocity gradients	20 m-100 km	Travel times
Surface reflection	Impedance contrasts	0.5 – 20 m	Travel times, amplitudes, reflection patterns
Vertical seismic profiling	Velocities, reflectivity	0.2 – 5 m	Travel times, waveforms
Borehole acoustic logs	Velocities near the borehole, at ~10 – 50 kHz	0.1 m	Pulse time delays
Borehole cross-well	Velocity contrasts at ~10 - 50 kHz	~5 m	Travel-time delays
Laboratory ultrasonic	Velocities at ~100 kHz, anisotropy	1 – 5 cm	Travel times in samples
Surface waves	Velocity structure (primarily of S-waves)	10 m – 100 km	Phase spectra of waves from artificial and natural seismic sources; Dispersion curves
Monitoring	Location of creep within reservoirs and mines, natural earthquakes, weapons tests	100 m – 30 km	Travel times
Teleseismic	Location of earthquakes, velocity structures, reflecting and converting boundaries	30 – 100 km	Waveforms of body and surface waves (~1-1000 sec periods)
Normal modes	Whole-Earth oscillations	1000 km	Earth movements at > 1000 sec periods

Acoustic/Seismic Spectrum

- Key to *signal penetration* and *resolution*:
  - Resolution (the degree of resolvable detail) is typically *proportional* to frequency;
  - Signal penetration quickly *decreases* with increasing frequency.

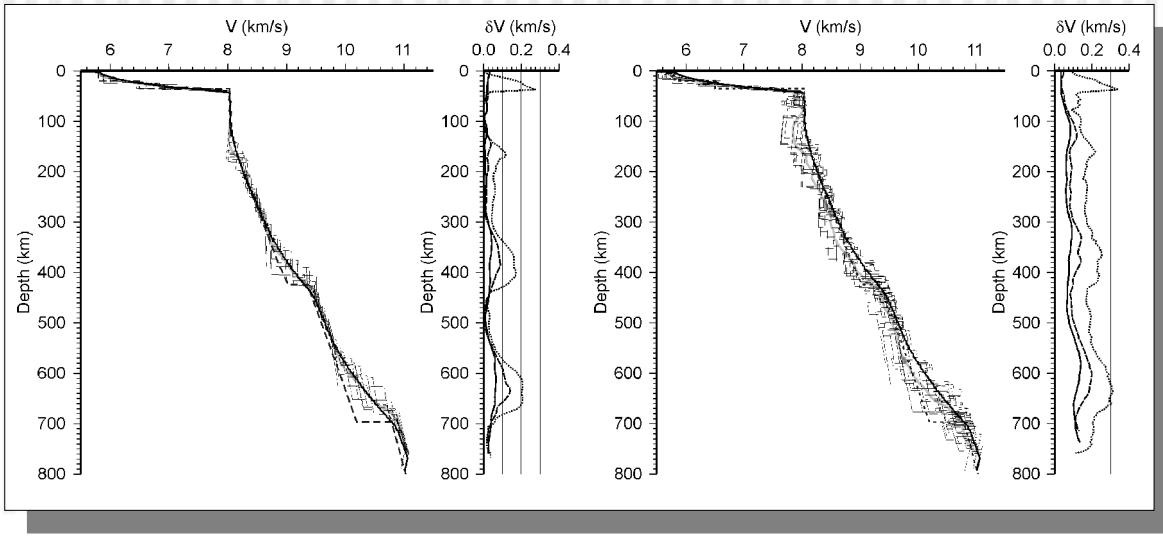


From Liner, 1999

Earth is complex

and so are the observations, but models are always simplified

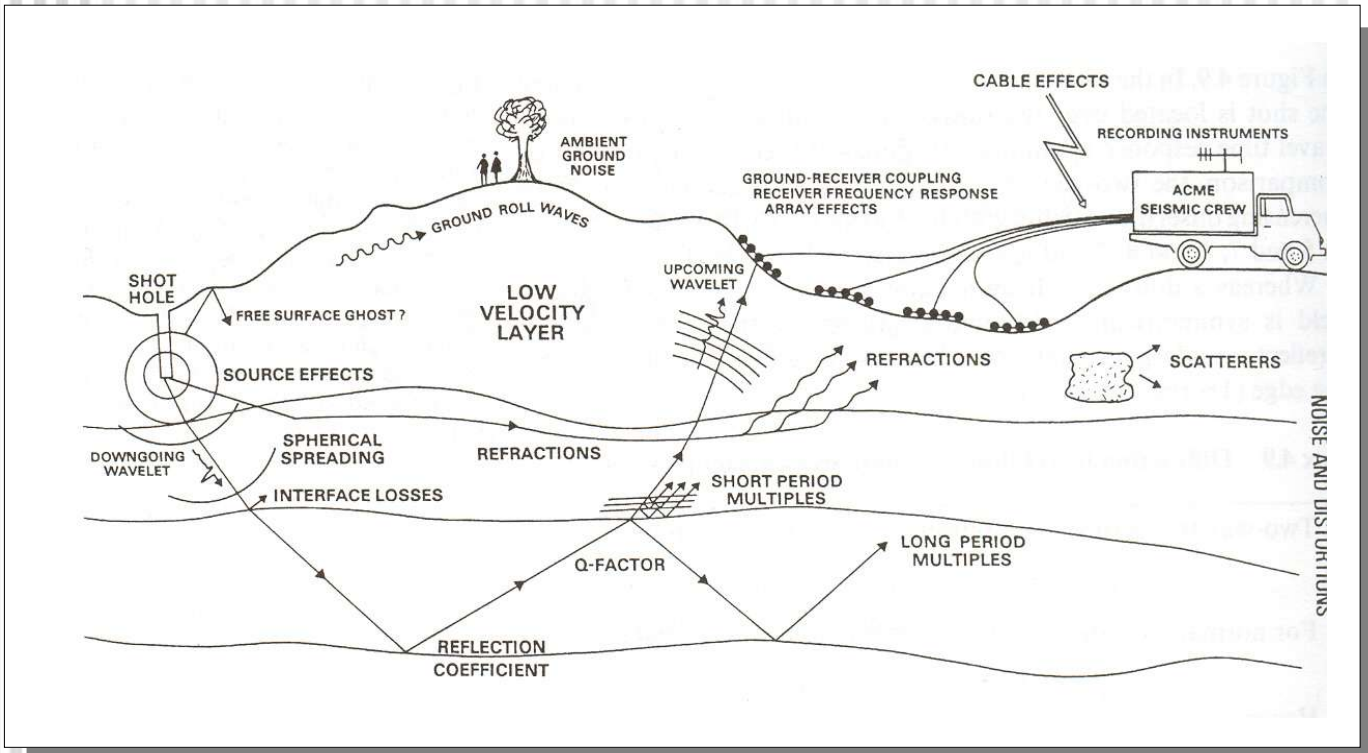
- Observations are limited to the surface or a few boreholes.
- Different rocks often have similar seismic properties:
  - Seismic waves are sensitive to combinations of V_P, V_S, and density;
  - Spatially-averaged and sample-derived properties are different;
  - Seismic properties are *frequency-dependent*.
- Therefore, ambiguities in interpretations are common.
- Solution – always estimate the errors and apply multiple methods to remove ambiguity.



Signal and Noise

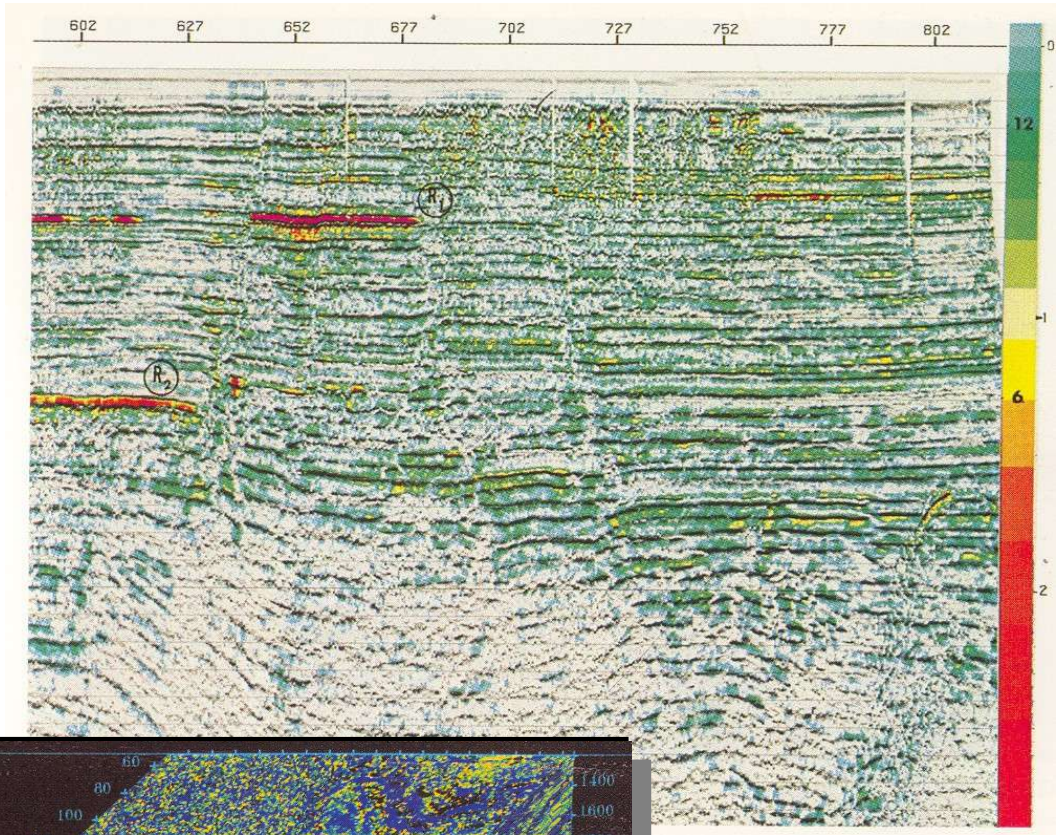
- Seismic data always contain SIGNAL and NOISE
  - Signal - 'deterministic' part consistent with the method employed (2-D, VSP)
  - Noise - anything else mixed into the observation
- Sources of noise:
  - Instrument
  - Geologic sources
  - Simplified theory (e.g., 2D sounding in a 3D Earth)
- Types of noise
  - Coherent (caused by the signal itself, worst of all)
  - Incoherent (random, coming from unrelated sources)
- Data processing is designed to increase the signal/noise (S/N) ratio

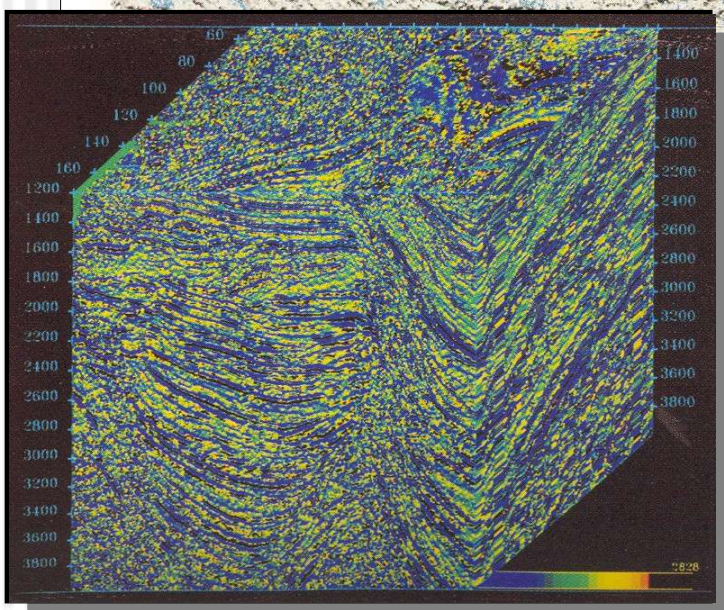
Seismic Noise



From Reynolds,1997

Seismic Data
(Exploration)

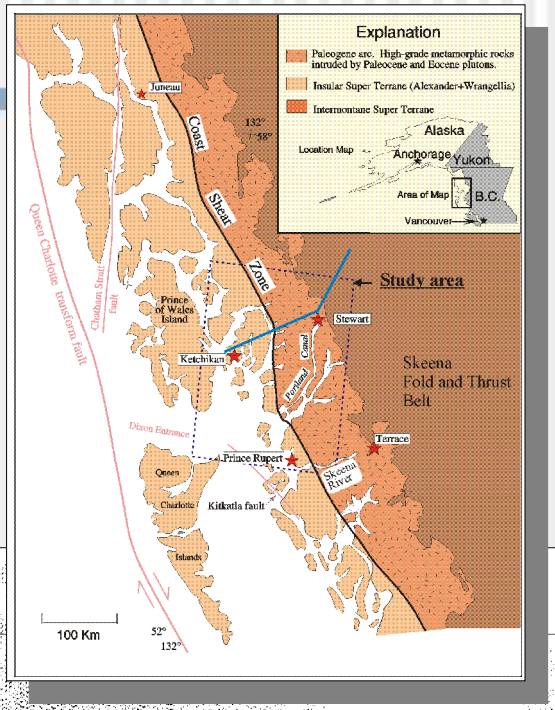


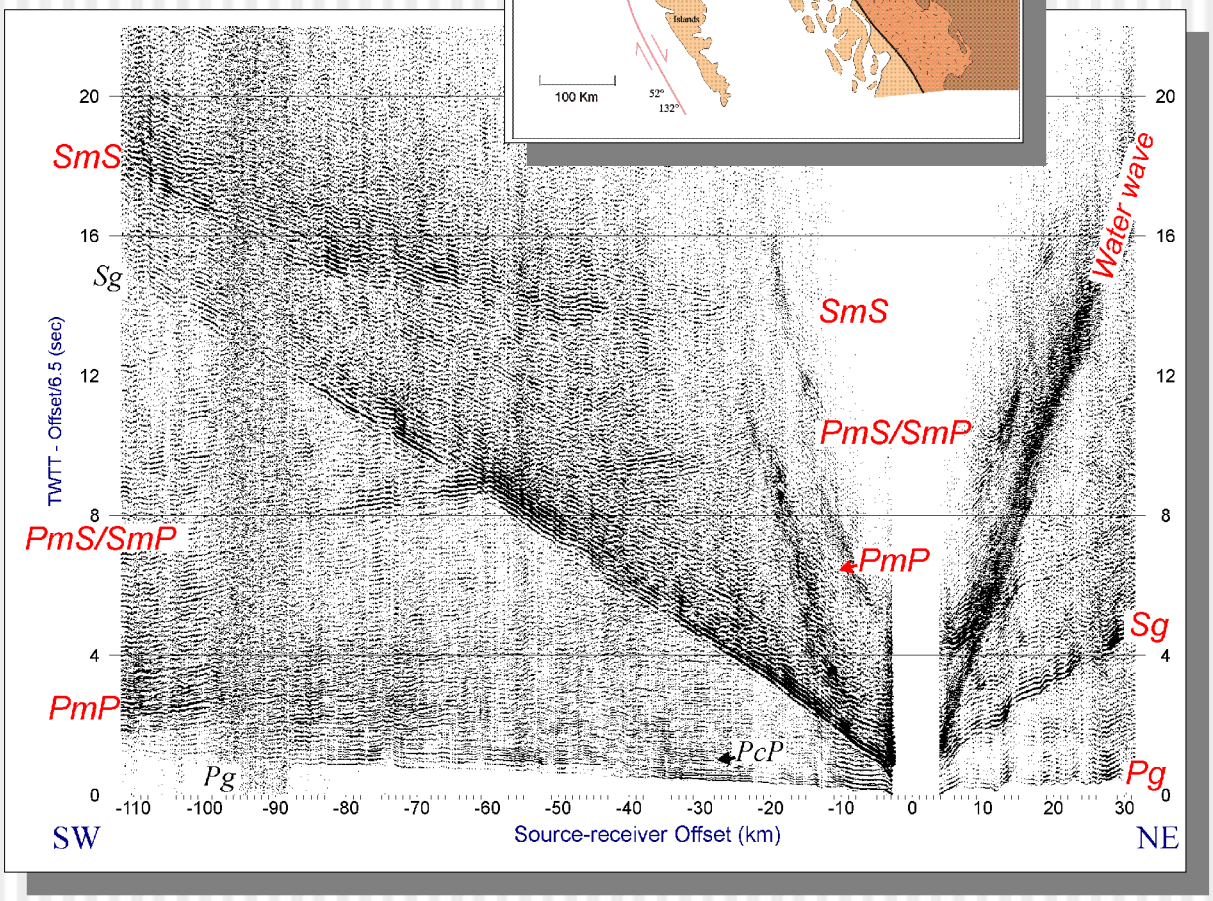


- Large volumes;
- Great amount of detail in the images;
- Multi-step and intricate processing

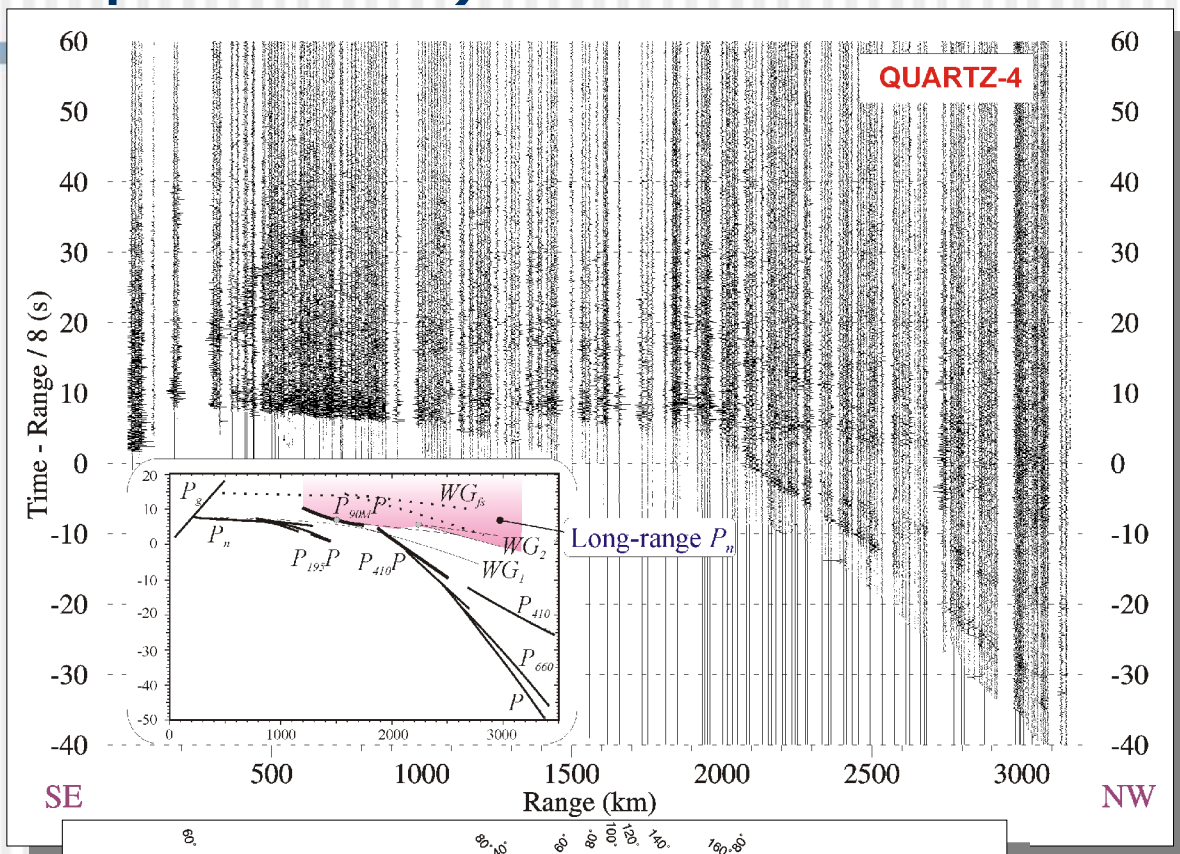
Seismic Data (Refraction-reflection crustal)

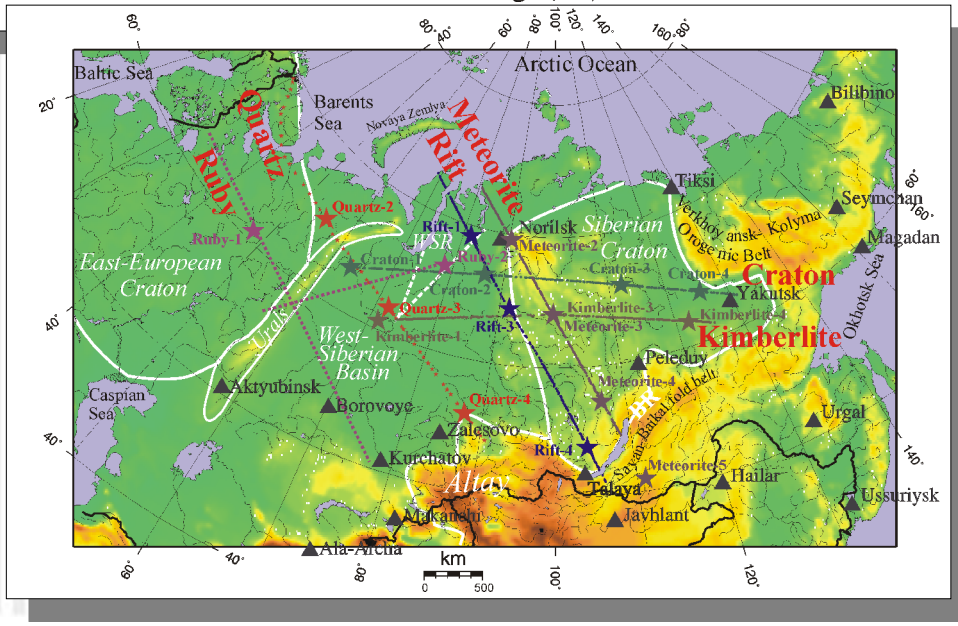
- Depth coverage to sub-Moho (~40 km);
- Good resolution of *velocities;*
- Strong reflections from the *base of the crust* (the 'Moho').





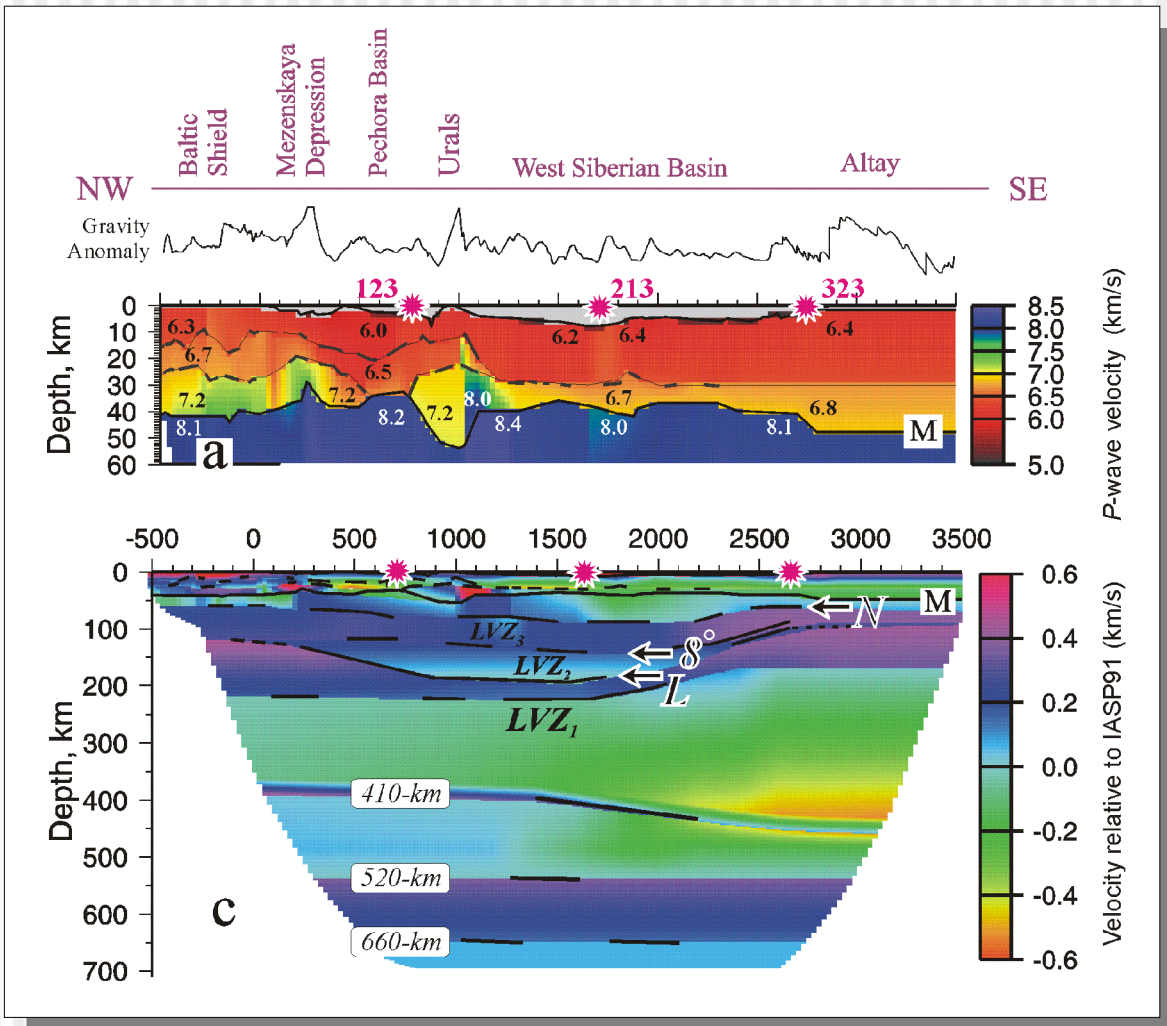
Seismic Data (Peaceful Nuclear Explosions)





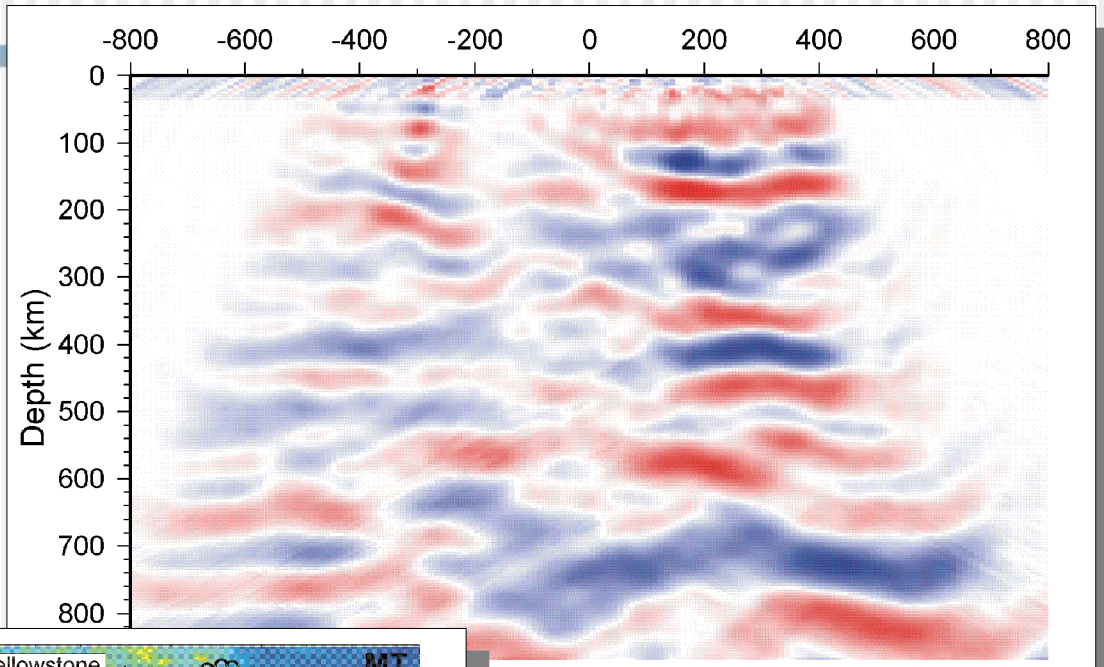
Seismic Models (From Peaceful Nuclear Explosions)

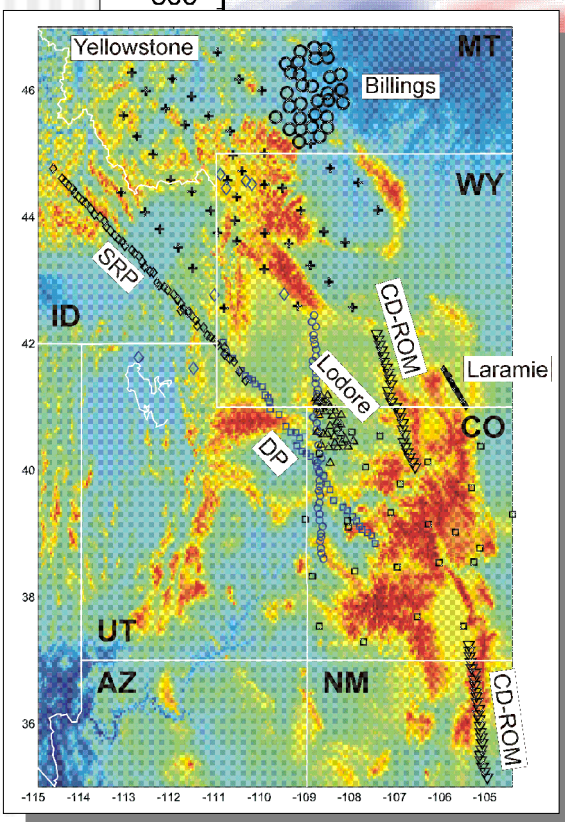
- Velocity heterogeneity;
- Reflecting boundaries;
- Attenuating zones (partial melts?) within the mantle.
- Scattering regions (?).



TeleSeismic Imaging

(Using seismic signals from earthquakes)





- Mantle velocity variations;
- *P*-*S* 'converting' boundaries within the mantle.

Major Organizations and Journals

- International Union of Geodesy and Geophysics (IUGG).
- International Association of Seismology and Physics of the Earth's Interior (IASPEI)
  - Mainly global (earthquake) seismology.
- Incorporated Research Institutions for Seismology (IRIS)
  - Collects and disseminates data from global networks.
- Seismological Society of America
  - “Bulletin of the Seismological Soc. of America”.
- Canadian Geophysical Union (CGU).
- Canadian Society of Exploration Geophysicists (CSEG)
  - “'Canadian Journal of Exploration Geophysics”, “Recorder”.
- American Geophysical Union (AGU)
  - “Journal of Geophysical Research”, “Geophysical. Research Letters”,“Reviews of Geophysics”.
- Society of Exploration Geophysicists (SEG)
  - 'Geophysics', 'The Leading Edge'.
- European Association of Exploration Geophysicists (EAEG)
  - “Geophysical Prospecting”.