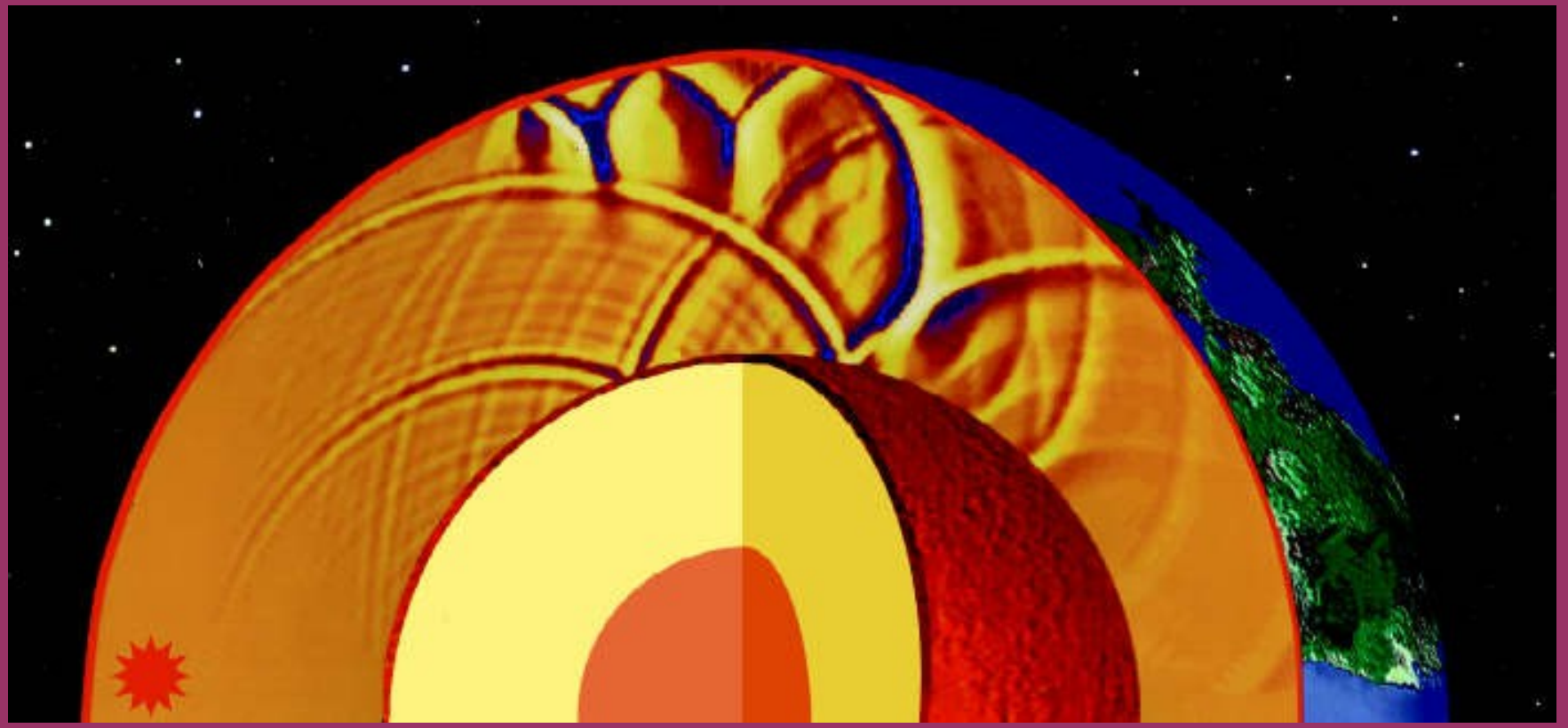
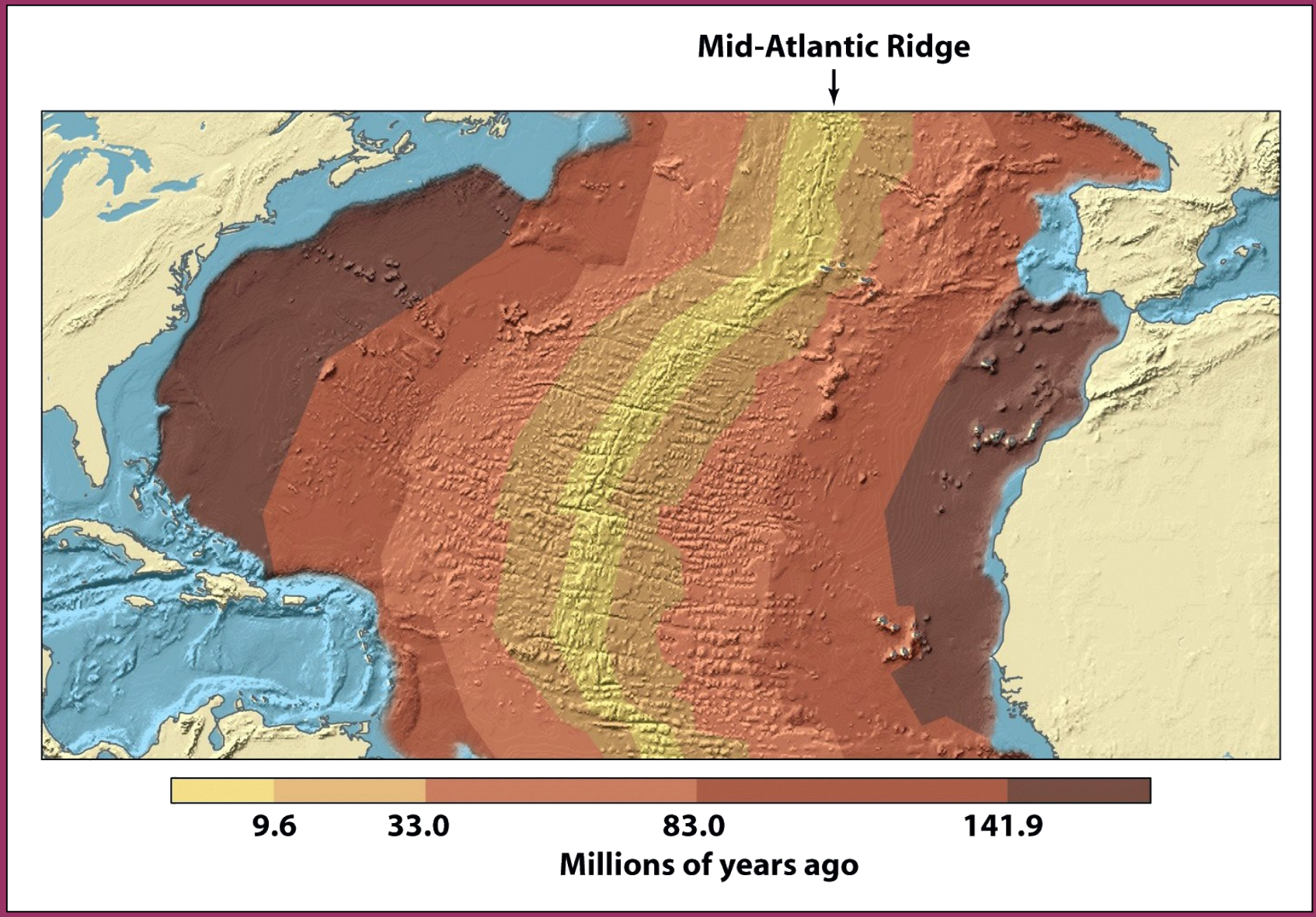
Surface waves



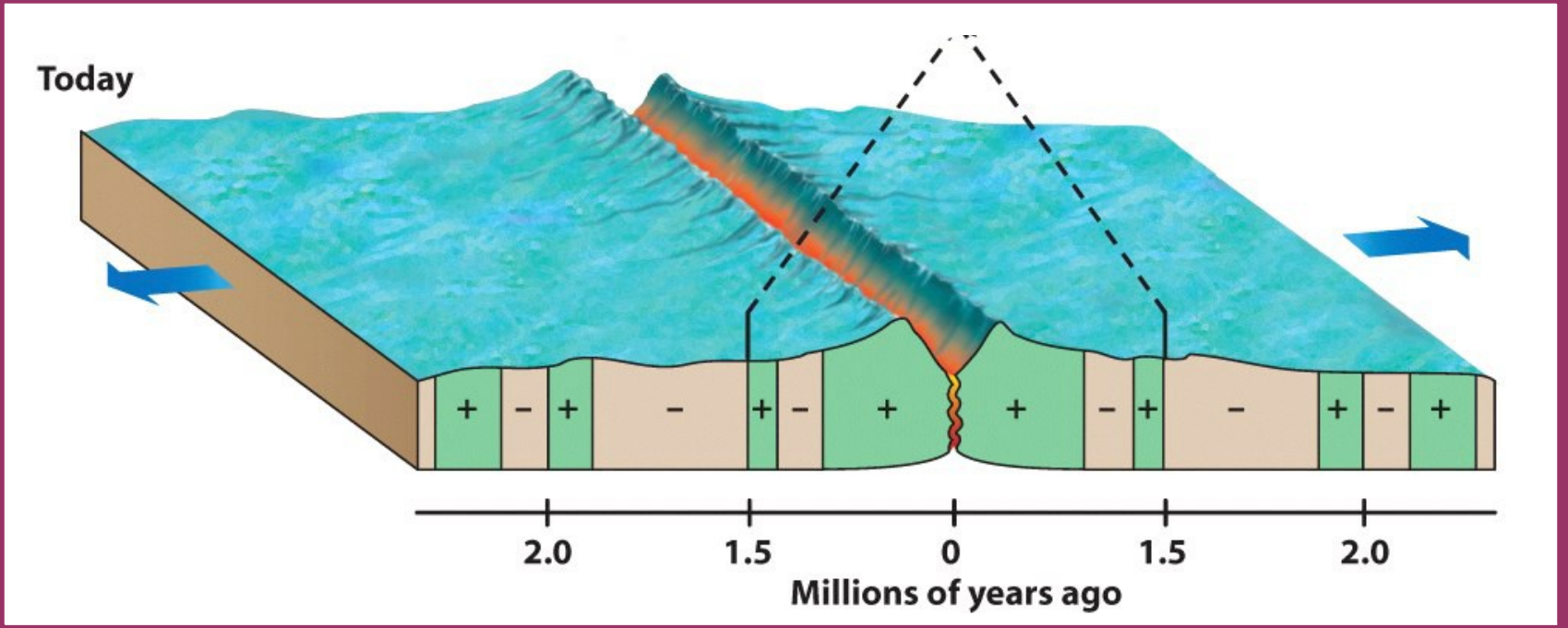
- Earthquakes generate both ***body waves*** (P, S) and ***surface waves***
- ***Surface waves*** are generated along any free surface in the medium
- In the Earth, free surfaces exist at the surface and at the core-mantle boundary (CMB).

Seismic Waves Traveling through the Oceanic Lithosphere



- Surface waves helped us discover the anisotropic properties of olivine in the Earth's mantle lithosphere.

Seismic Waves Traveling through the Oceanic Lithosphere



- Which waves travel faster ? Why ?
- Surface waves traveling ***parallel*** to the spreading axis ?
- Or surface waves traveling ***perpendicular*** to the axis ?

Surface waves and Anisotropy in the Oceanic Mantle

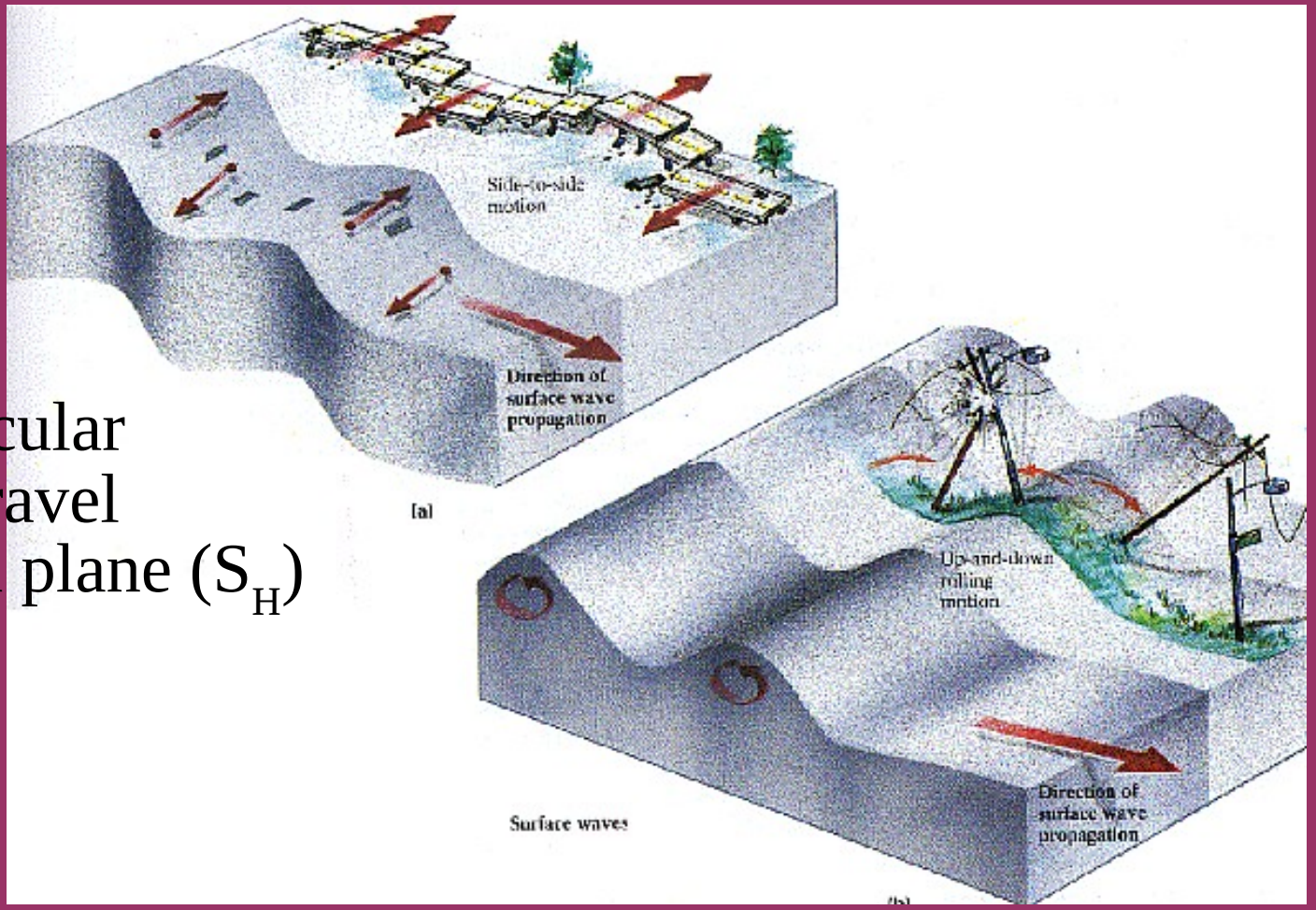
- Surface waves were used to first discover "*seismic anisotropy*" in the oceans along the Mendocino Fracture Zone by Harry Hess in 1964.

- ***Love waves*** propagating in the same direction as ***Rayleigh waves*** traveled at different speeds!

- This was key evidence for the study of anisotropic properties in minerals such as olivine.

Surface Waves in the Earth

Love waves:
Propagate perpendicular
to the direction of travel
along the horizontal plane (S_H)



Rayleigh waves:
Also propagate perpendicular
to the direction of travel
but in the vertical plane (S_V)

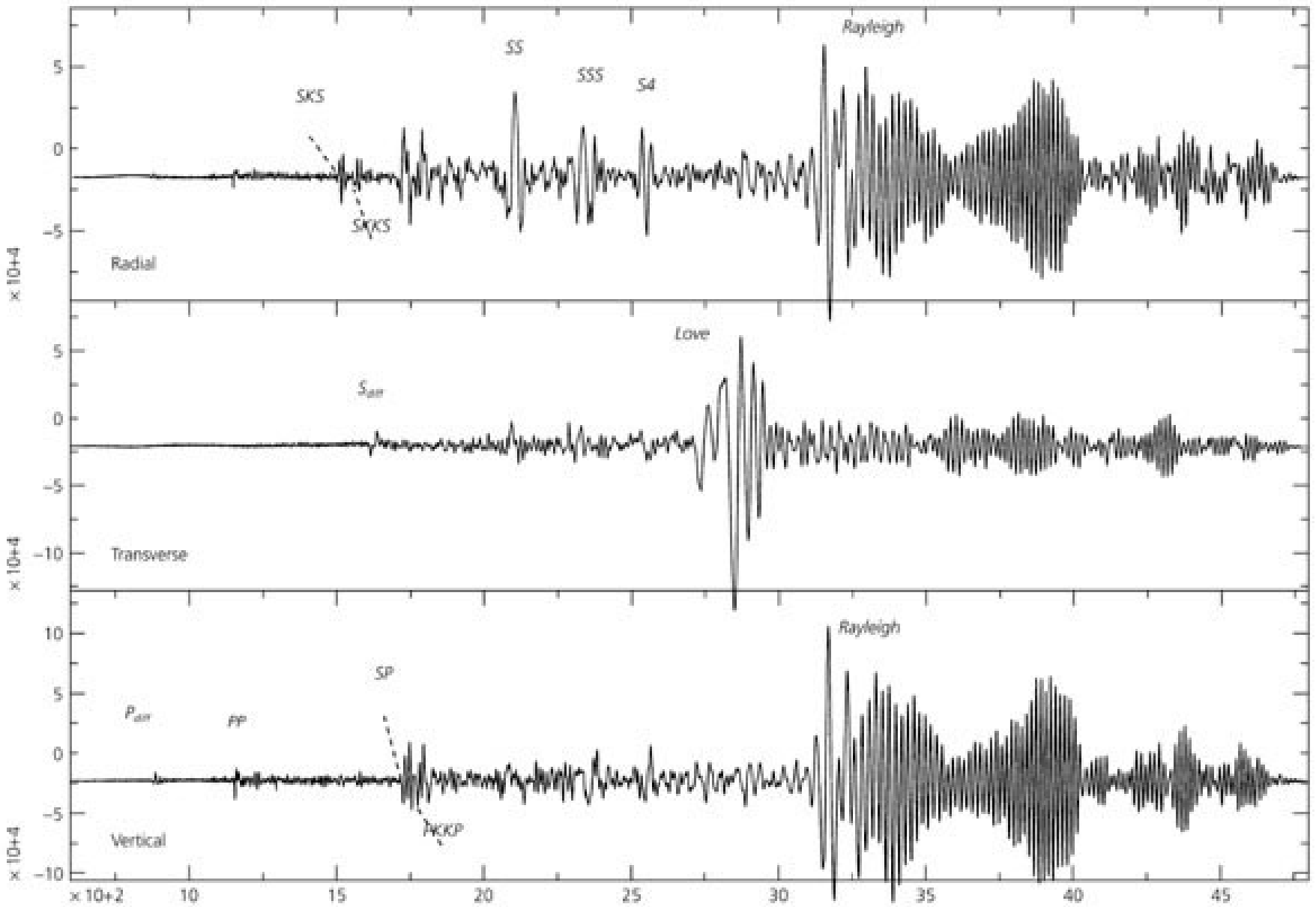
Surface waves During an Earthquake

The epicentre of the Kobe earthquake was near to the city.

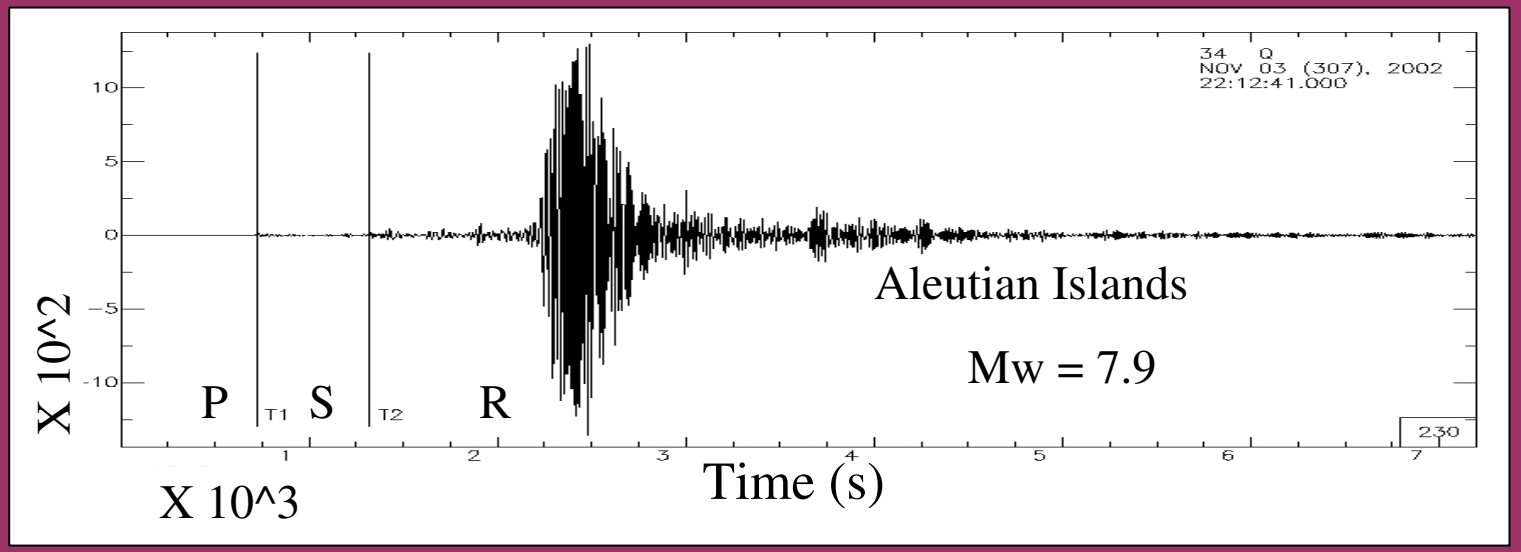
- Because surface waves are the ***largest amplitude*** signal on a seismogram, they can amplify displacement where sediment is thick.

- In the Mexico City earthquake (1985) streets were observed to rise and fall as the surface waves passed, causing great damage from high amplitude displacements.

Figure 2.7-1: Seismograms recorded at a distance of 110°, showing surface waves.

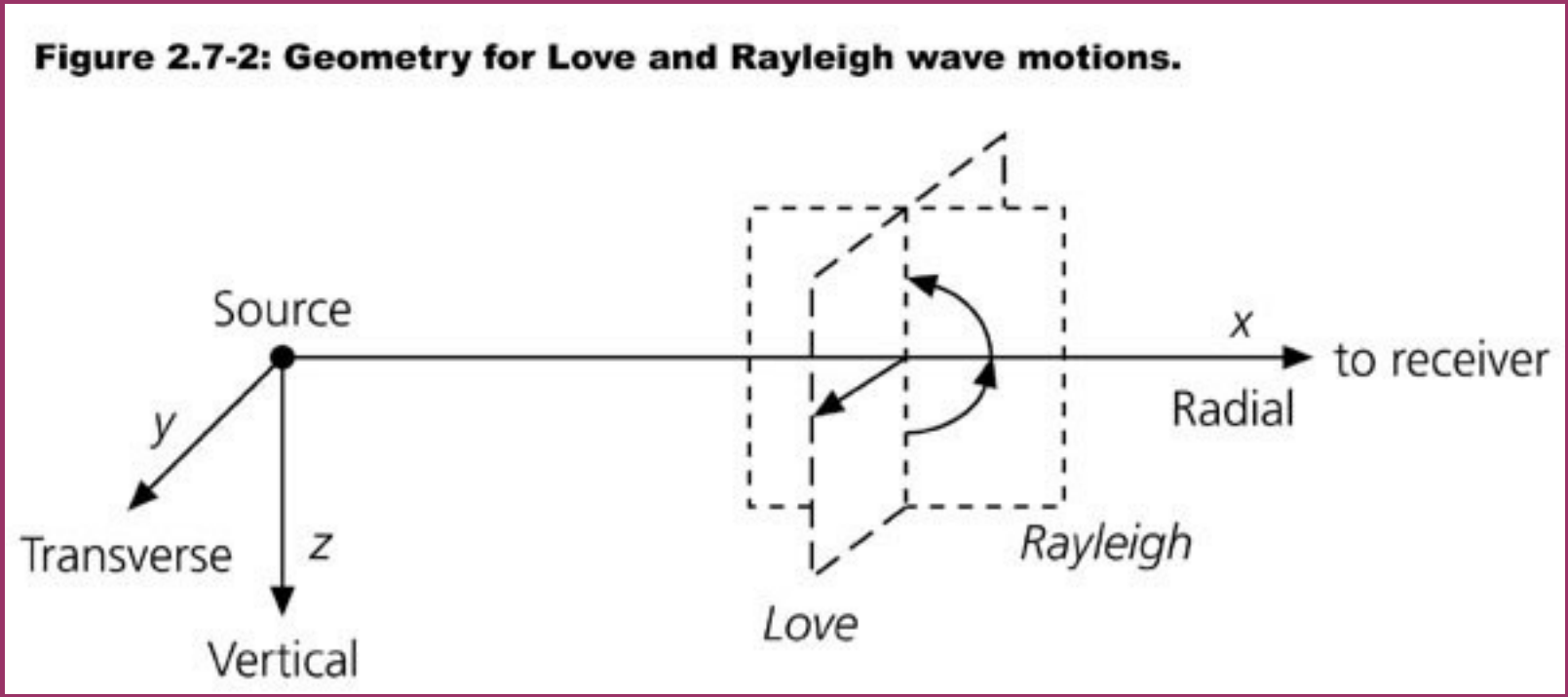


Surface waves on the Seismogram



- Surface waves are the ***largest amplitude*** signal on the wave train
- Surfaces ***arrive after*** the P and S waves, because they travel along the surface layers of the Earth where velocities are lower.
- Surfaces wave energy (amplitudes) decay with distance as $\mathbf{1 / r}$
- Body wave energy decays as $\mathbf{1 / r^2}$
- *So at a given distance, which will have more energy ?*

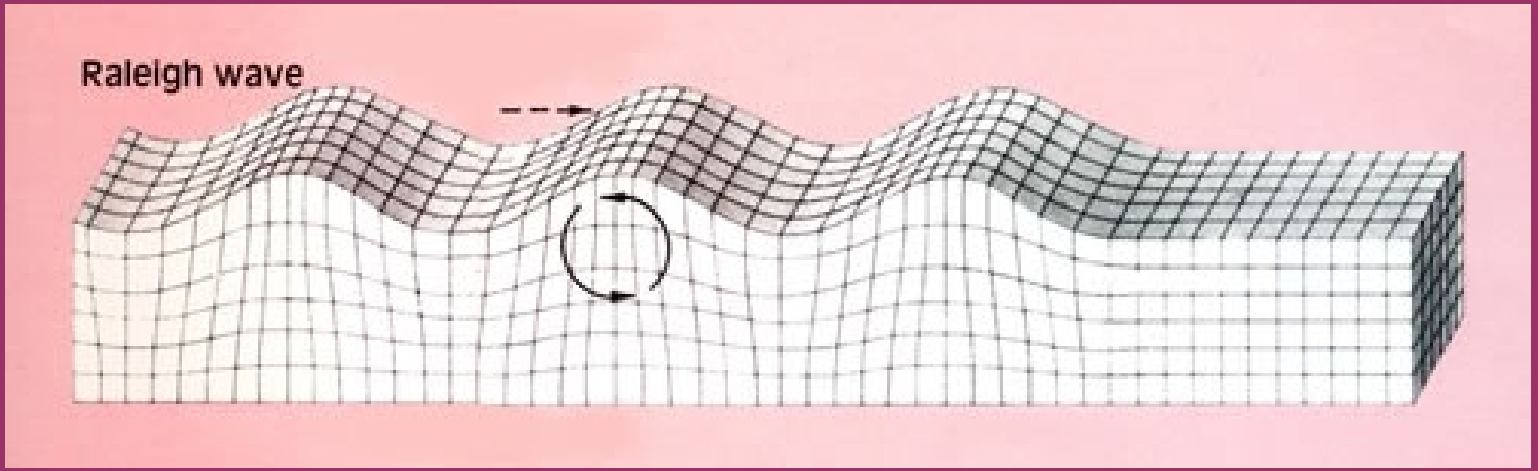
Propagation of Surface Waves



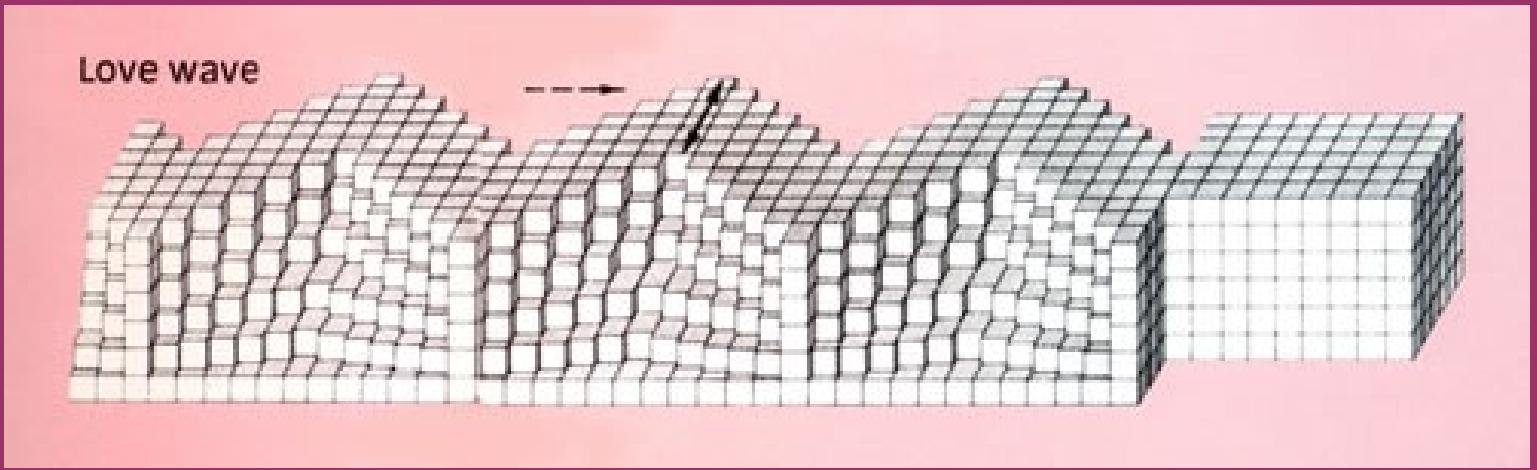
- Rayleigh waves travel in the vertical (z) and ***radial*** (x) plane and exhibit a combination of S_V and P energy

- Love waves travel in the horizontal (y) or ***transverse*** plane and exhibit S_H energy only

Propagation of Surface Waves

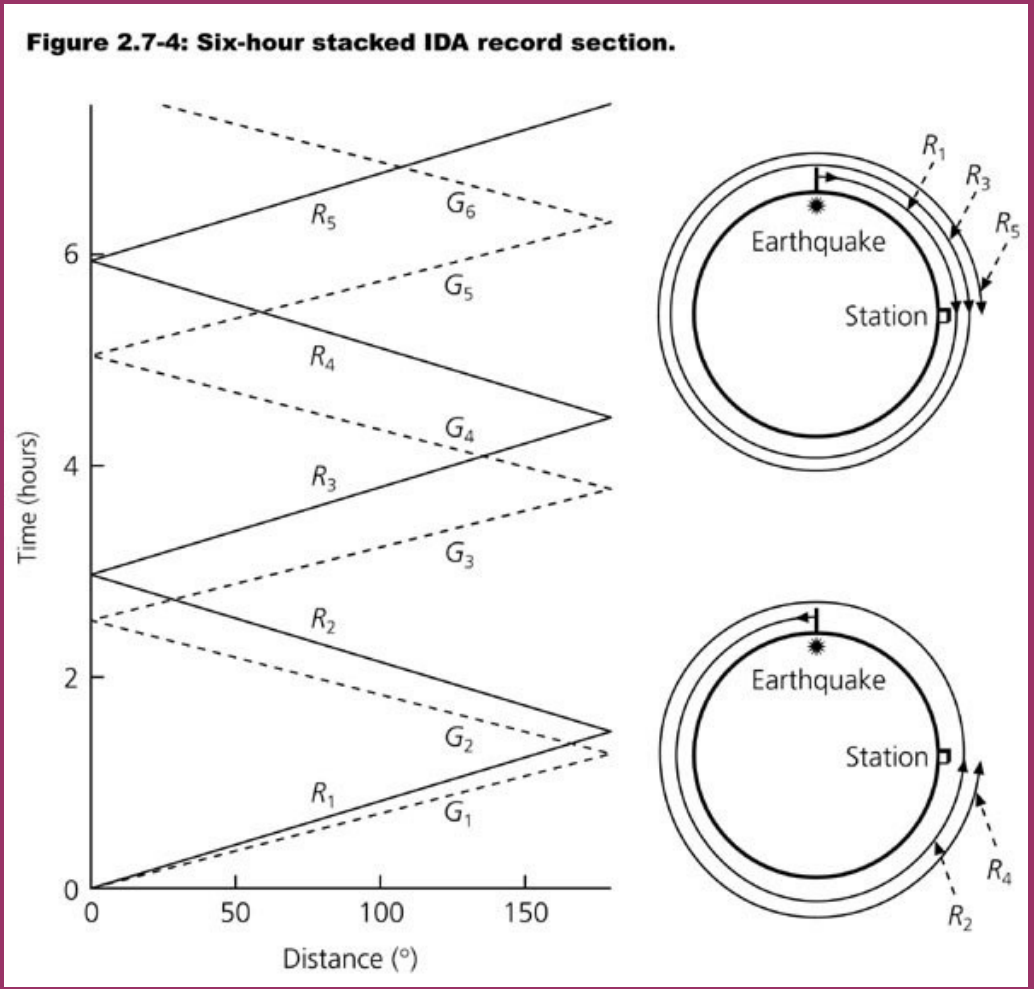


- ***Rayleigh wave*** displacement occurs by *retrograde elliptical* motion



- ***Love waves*** propagate side-to-side, trapped within a layer

Fundamental and Multiple Surface Waves



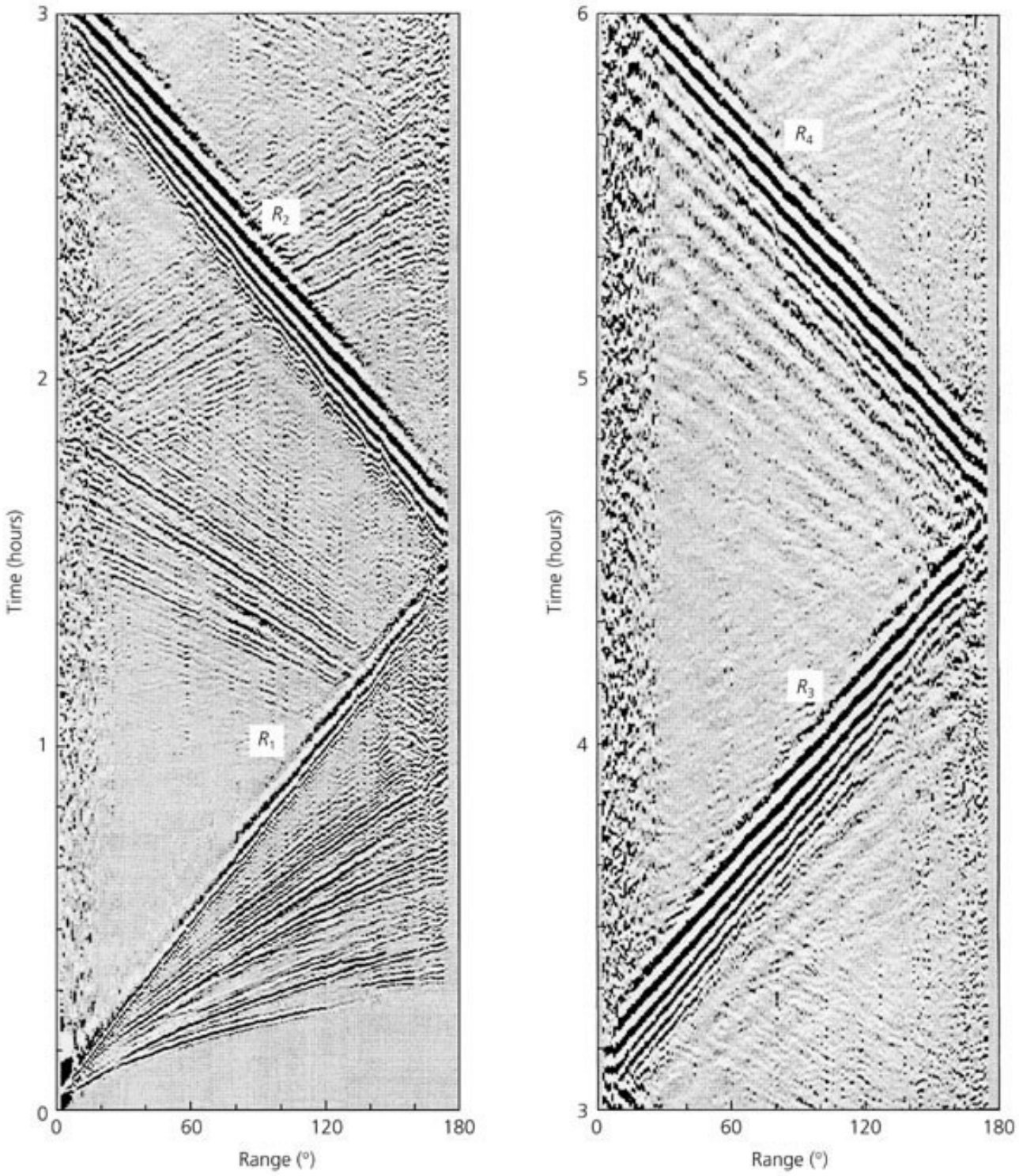
- Because surfaces wave amplitudes are slow to decay, they can travel around the globe many times

- The R1, R2 (Rayleigh), or G1, G2 (Love) travel paths are shown

- Record section of vertical components from the IDA (International Deployment of Accelerometers) network.

- Body wave arrivals are early and appear as steeper slopes

Figure 2.7-4: Six-hour stacked IDA record section.

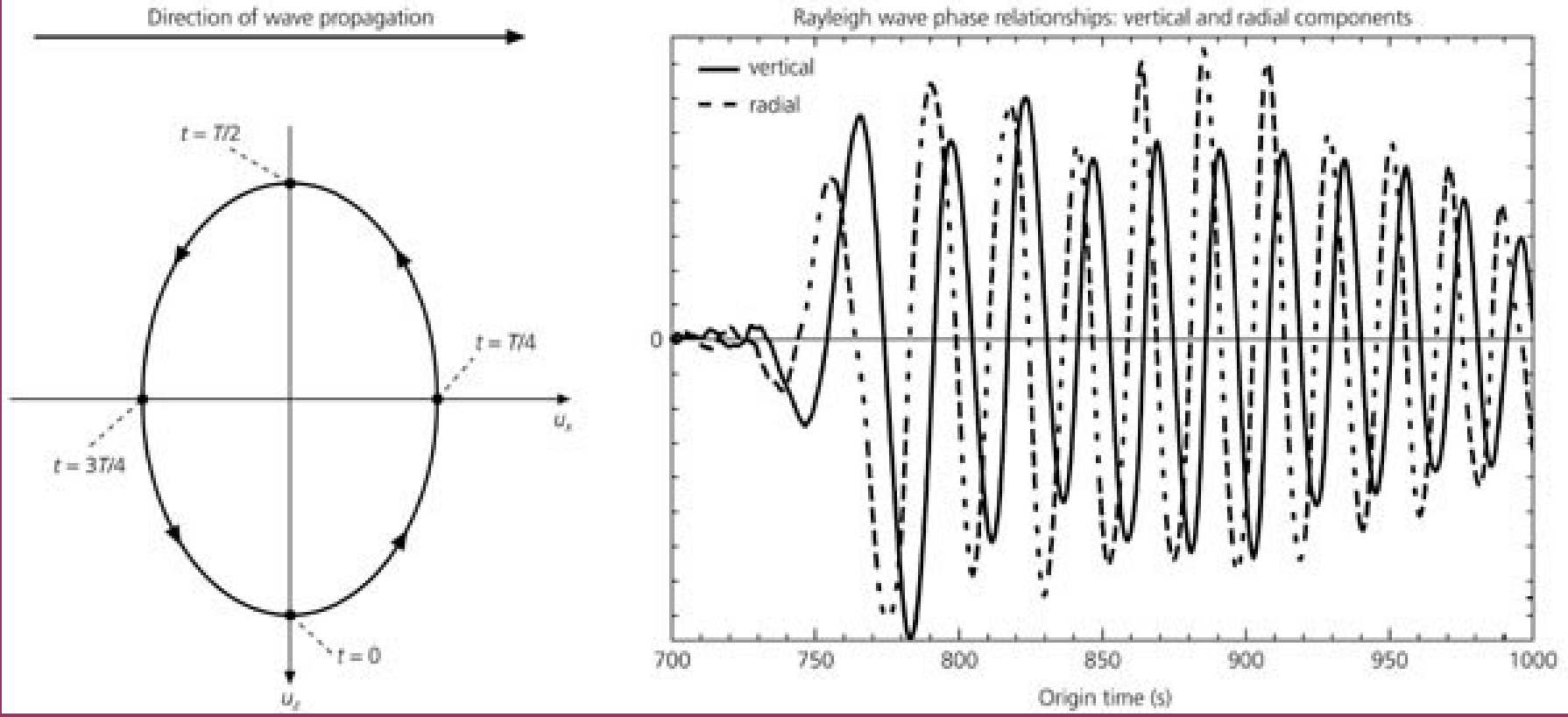


Class Notes

- Love Waves
- Rayleigh Waves

Rayleigh Wave Particle Motion

Figure 2.7-6: Horizontal and vertical Rayleigh wave motions.

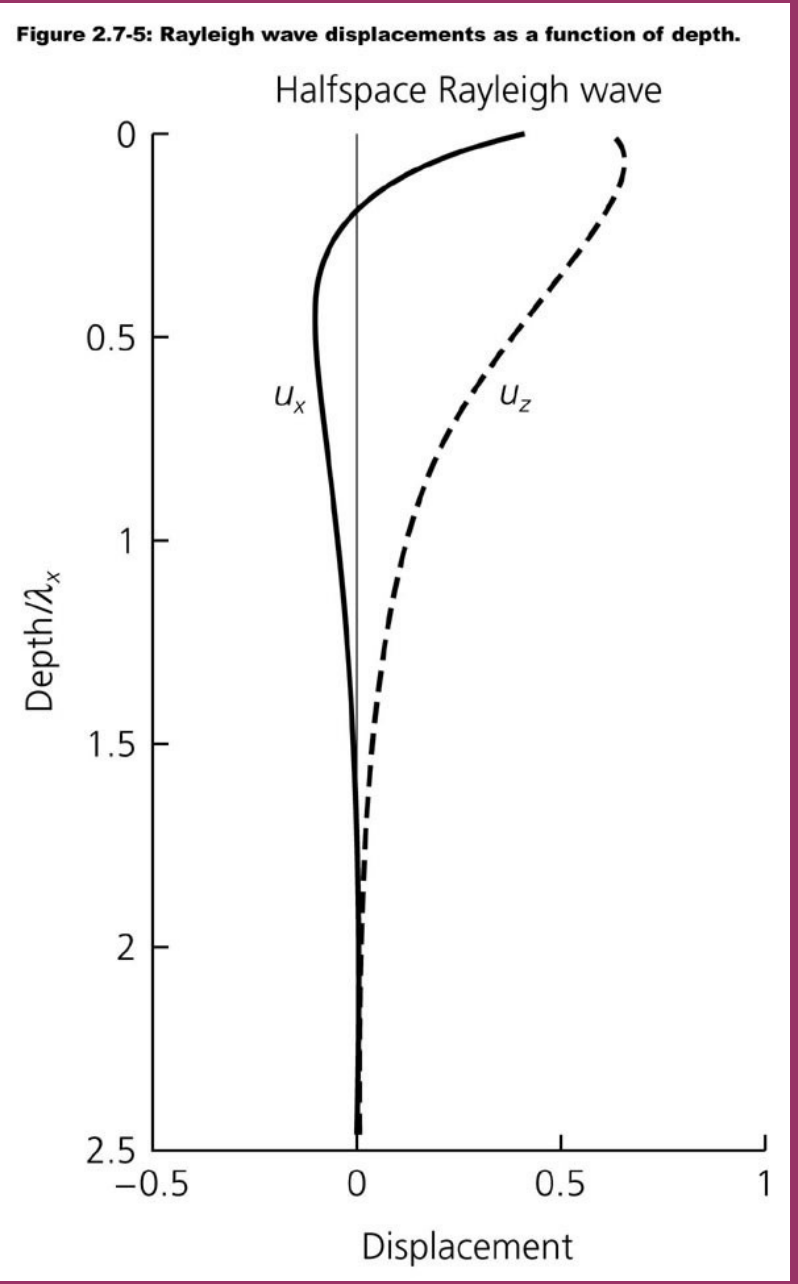


- P and Sv amplitudes are out of phase by $\pi/2$
- This results in elliptical motion (retrograde)

Evanescent Waves

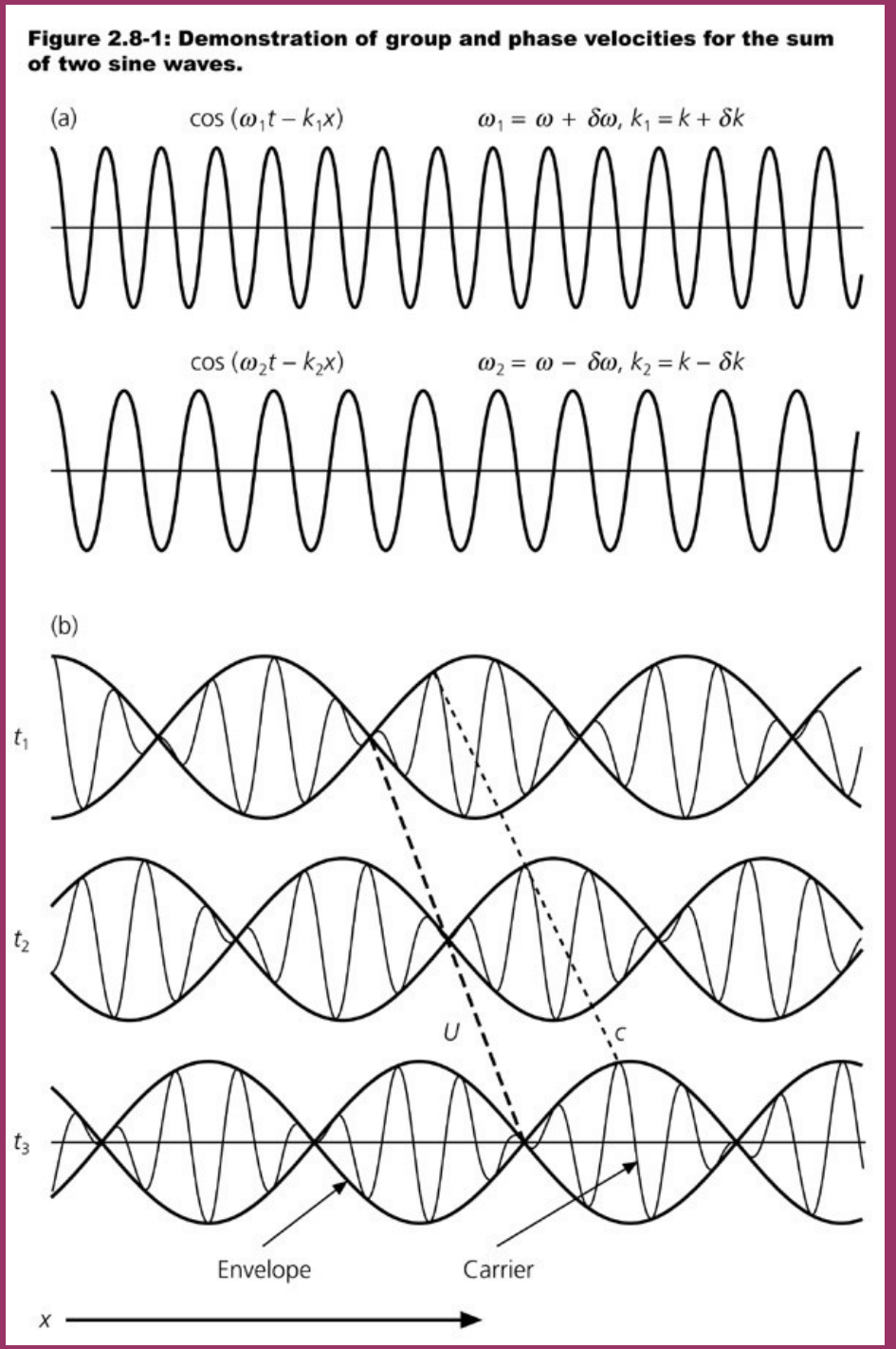
- Rayleigh wave amplitudes decay with depth in the Earth and are termed “evanescent”

(Also see Fig 8.3 in your text book)



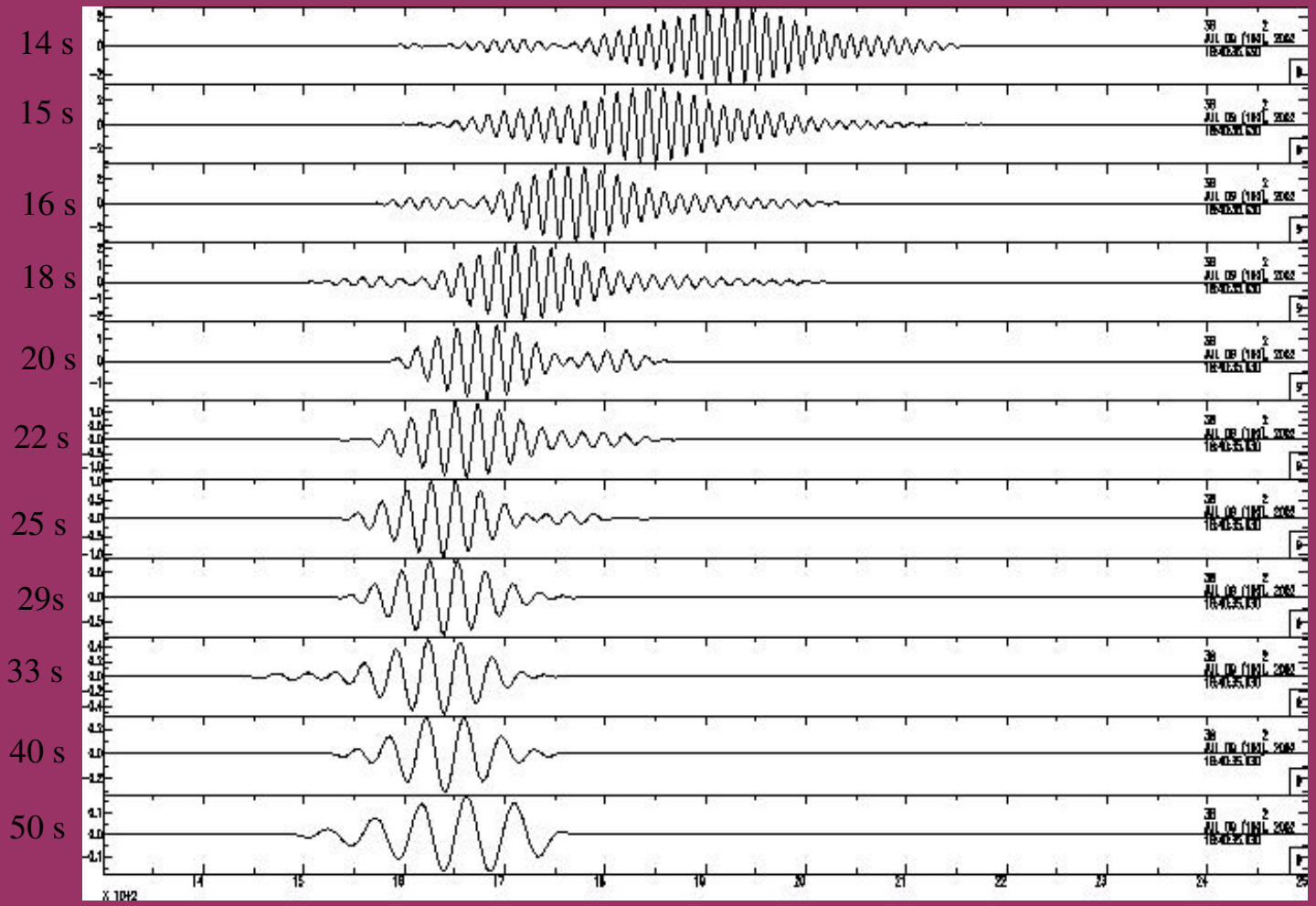
Surface Wave Dispersion

- ***Phase velocity*** (C) travels at a different (slower) speed than the ***Group velocity*** (U) envelope.



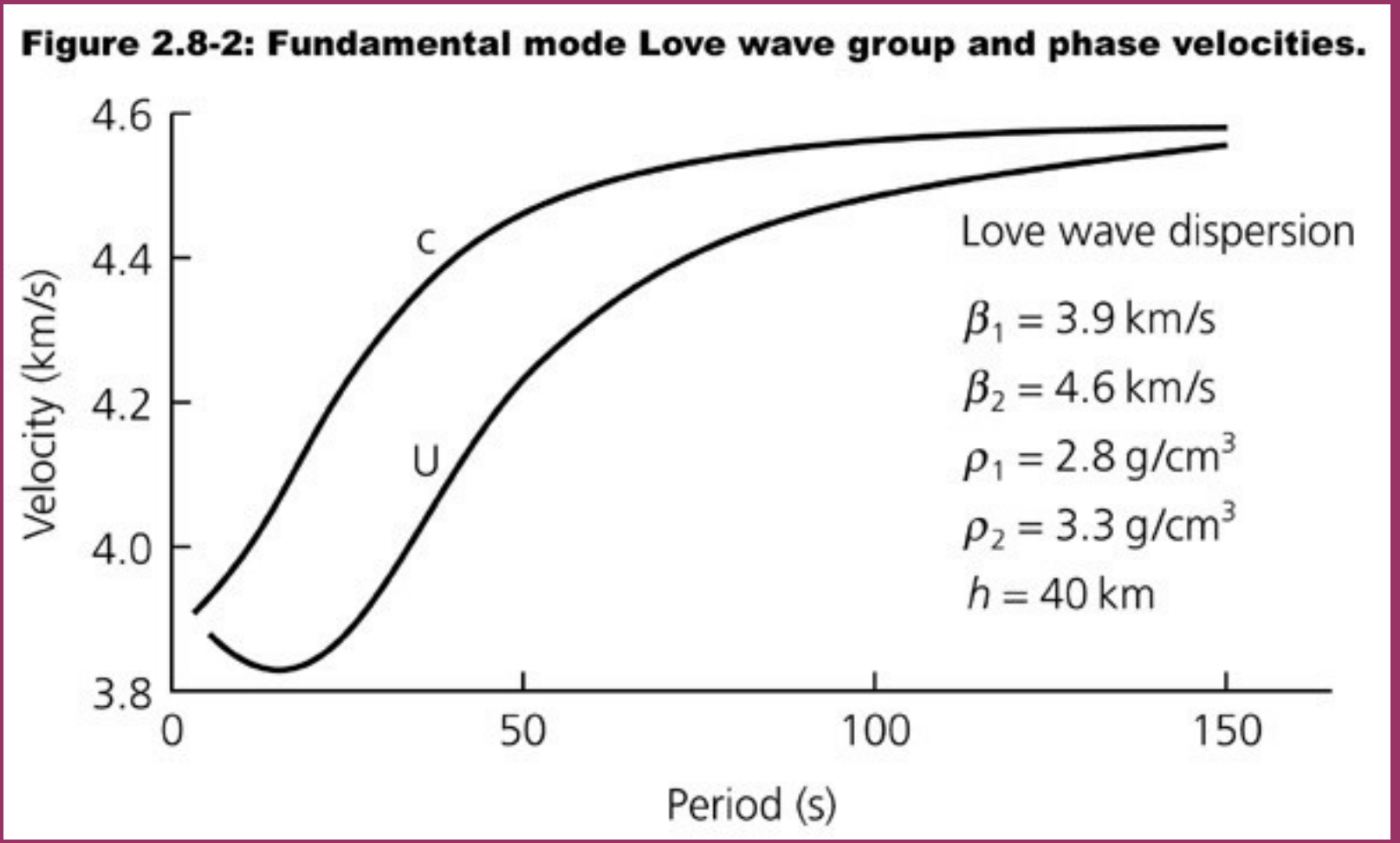
Surface Wave Dispersion

Filtered Seismogram



- ***Phase velocity*** (C) travels at a different (slower) speed than The ***Group velocity*** (U) envelope.

Dispersion Curves



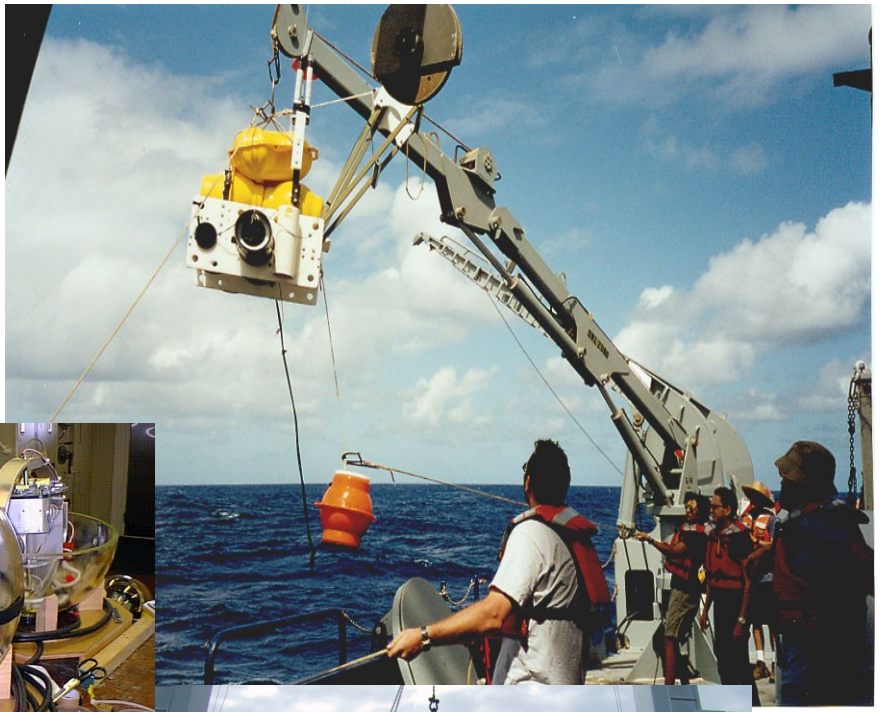
- Group velocities are slower than phase velocities for both Love waves and Rayleigh Waves

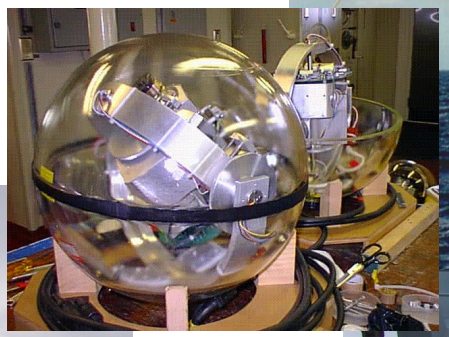
- Rapid velocity increase at short periods samples crustal velocities
- Slower velocity increase at longer periods samples deeper mantle

GLIMPSE Experiment

(Gravity Lineations and Intraplate Melting Petrology and Seismic Expedition)

COOK16/Melville November, 2001
VANC04/Melville November, 2002



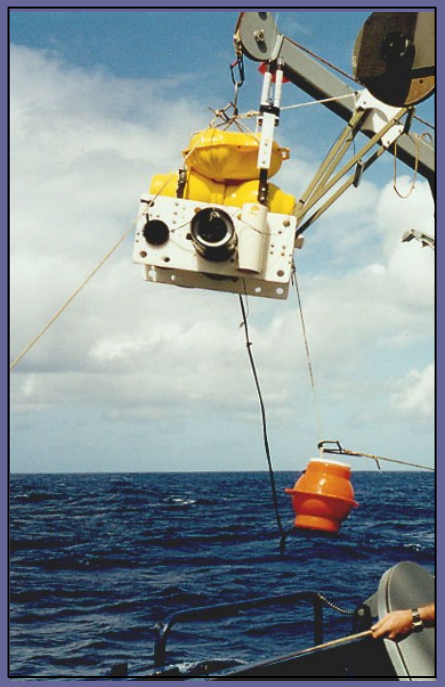


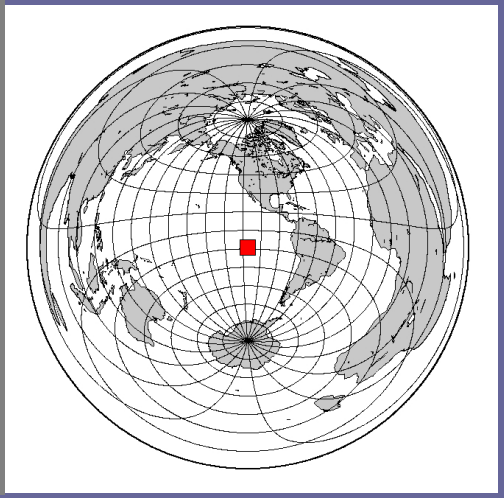
Brown University
Lamont Doherty Observatory
Oregon State University

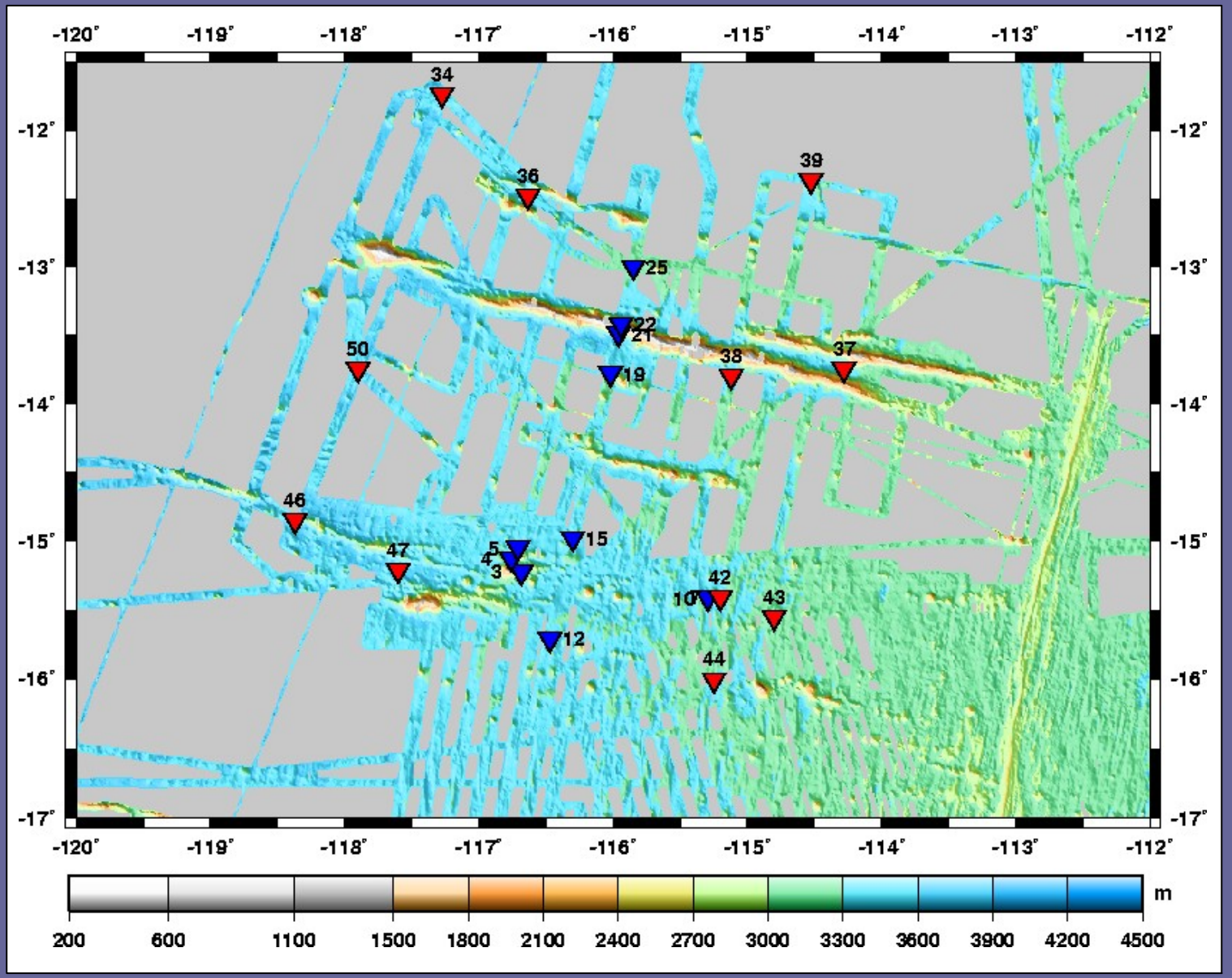
Ocean Bottom Seismometer (OBS) Deployment

Co-authors: Donald W. Forsyth[1], Yingjie Yang[1], Spahr Webb[2]

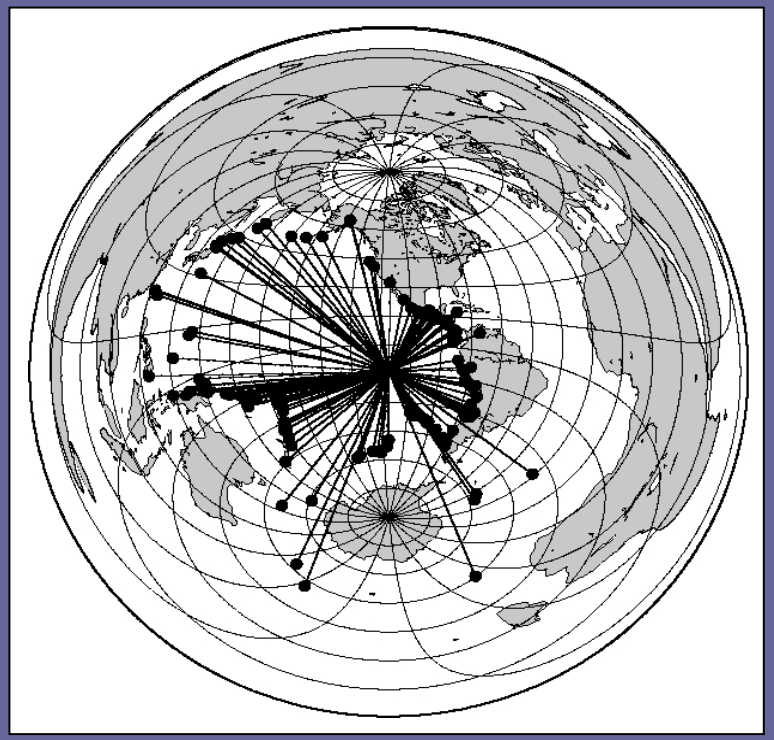
1. Brown University, 2. Lamont Doherty Observatory



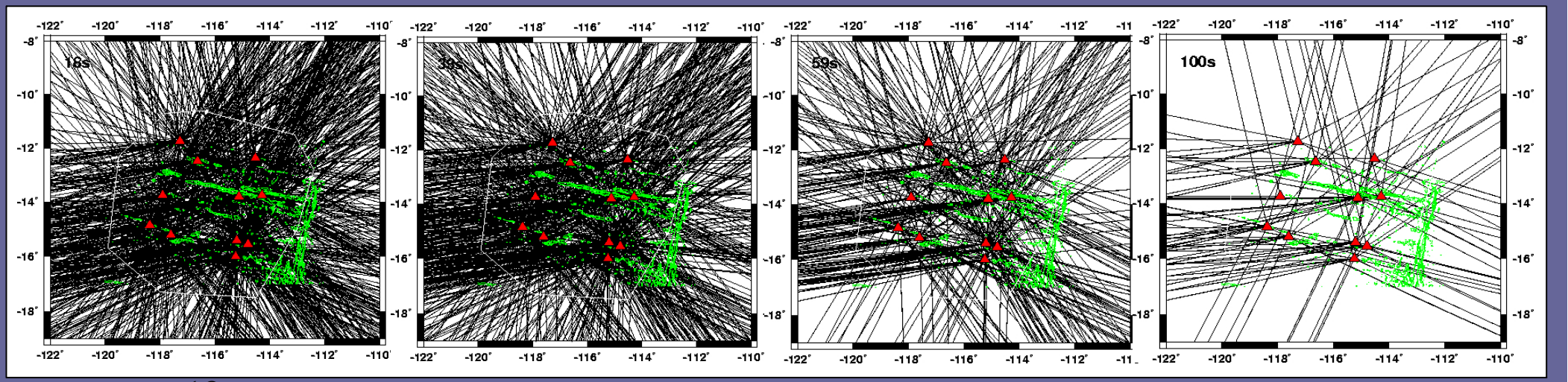




Azimuthal Distribution of Earthquakes and Raypaths



* Ideal azimuthal distribution
* 155 Earthquakes
* 4.5 < Ms < 7.8

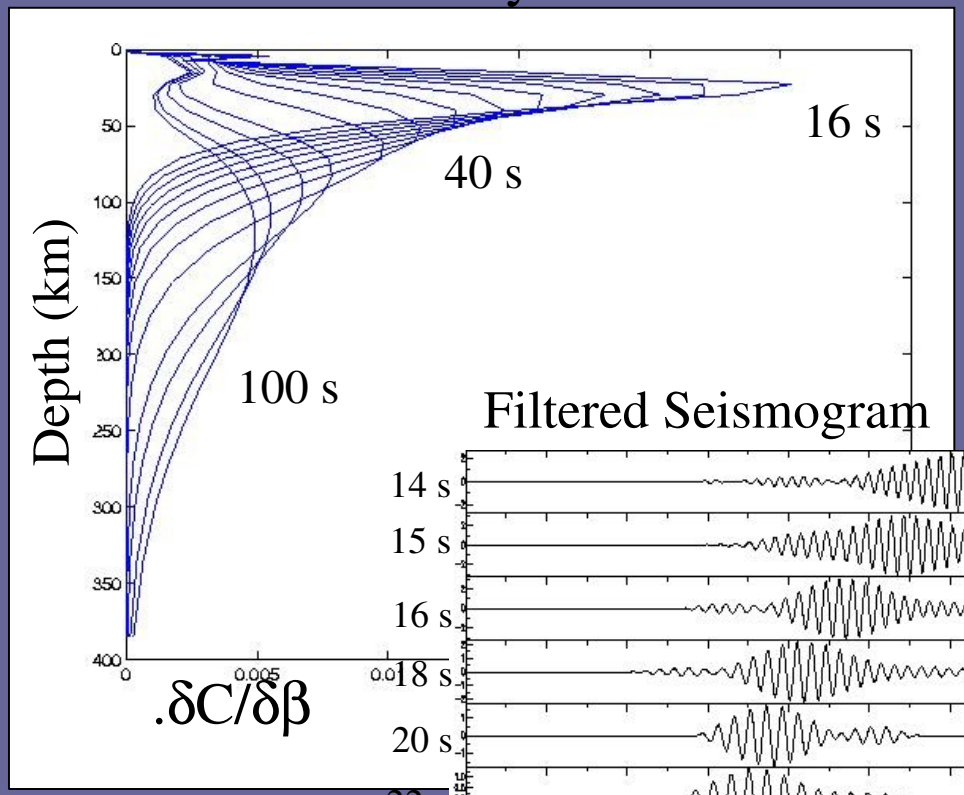


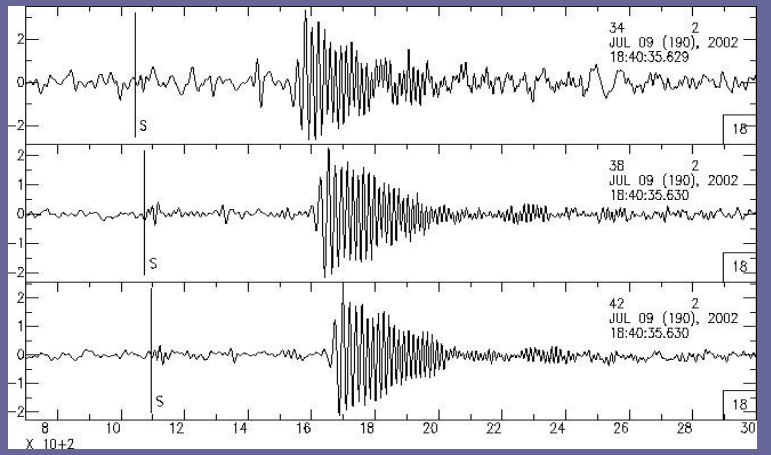
18s 33s 59s 100s

Raypath density varies from 1565 to 132 paths with increasing period.

Rayleigh Wave Dispersion and Sensitivity

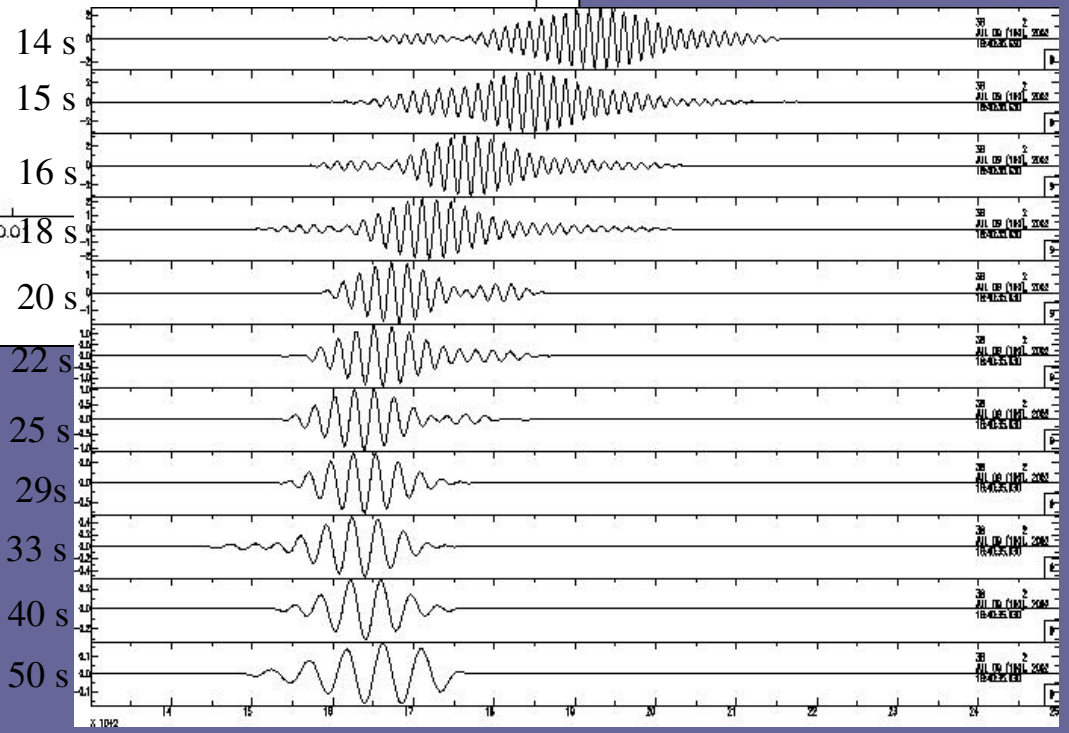
Sensitivity Kernels





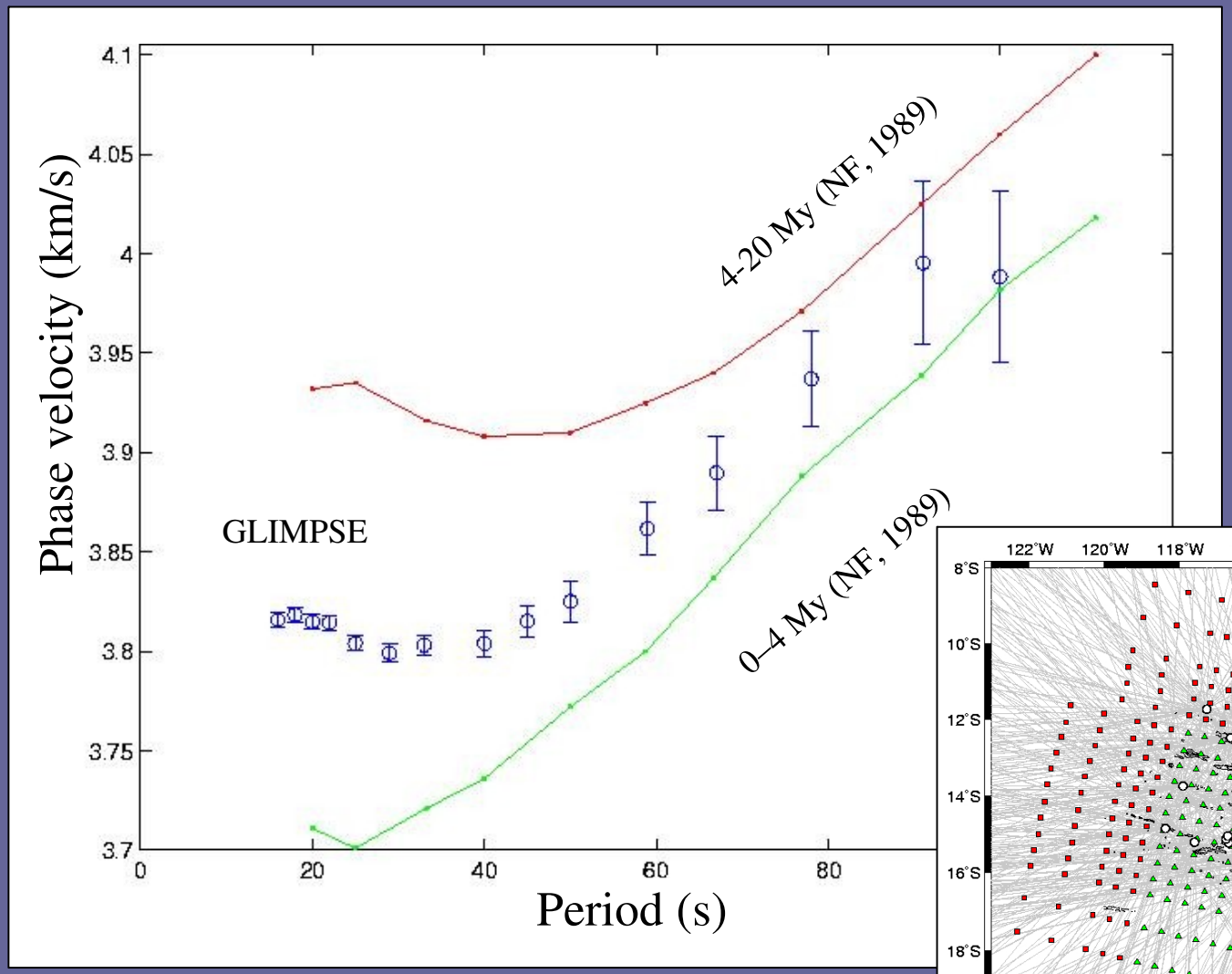
Juan de Fuca event, Ms 5.5

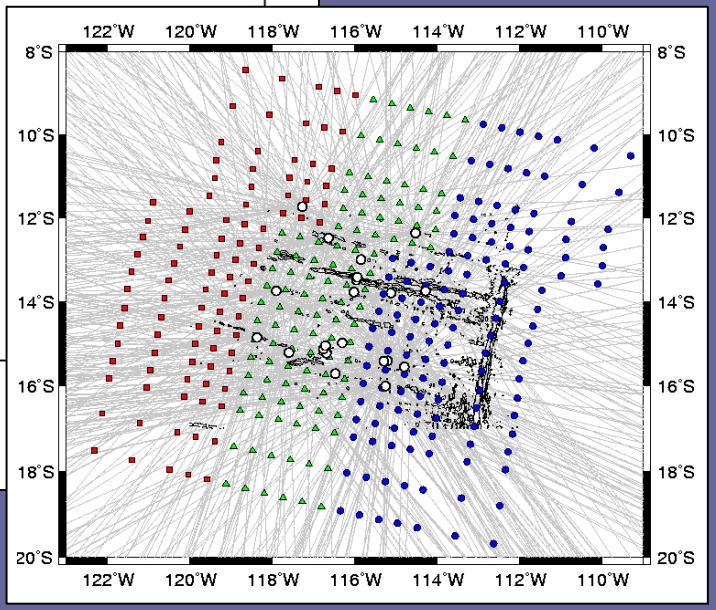
Filtered Seismogram



* Seismograms filtered at different periods are sensitive to different depths.
* The depth of peak sensitivity increases with period.

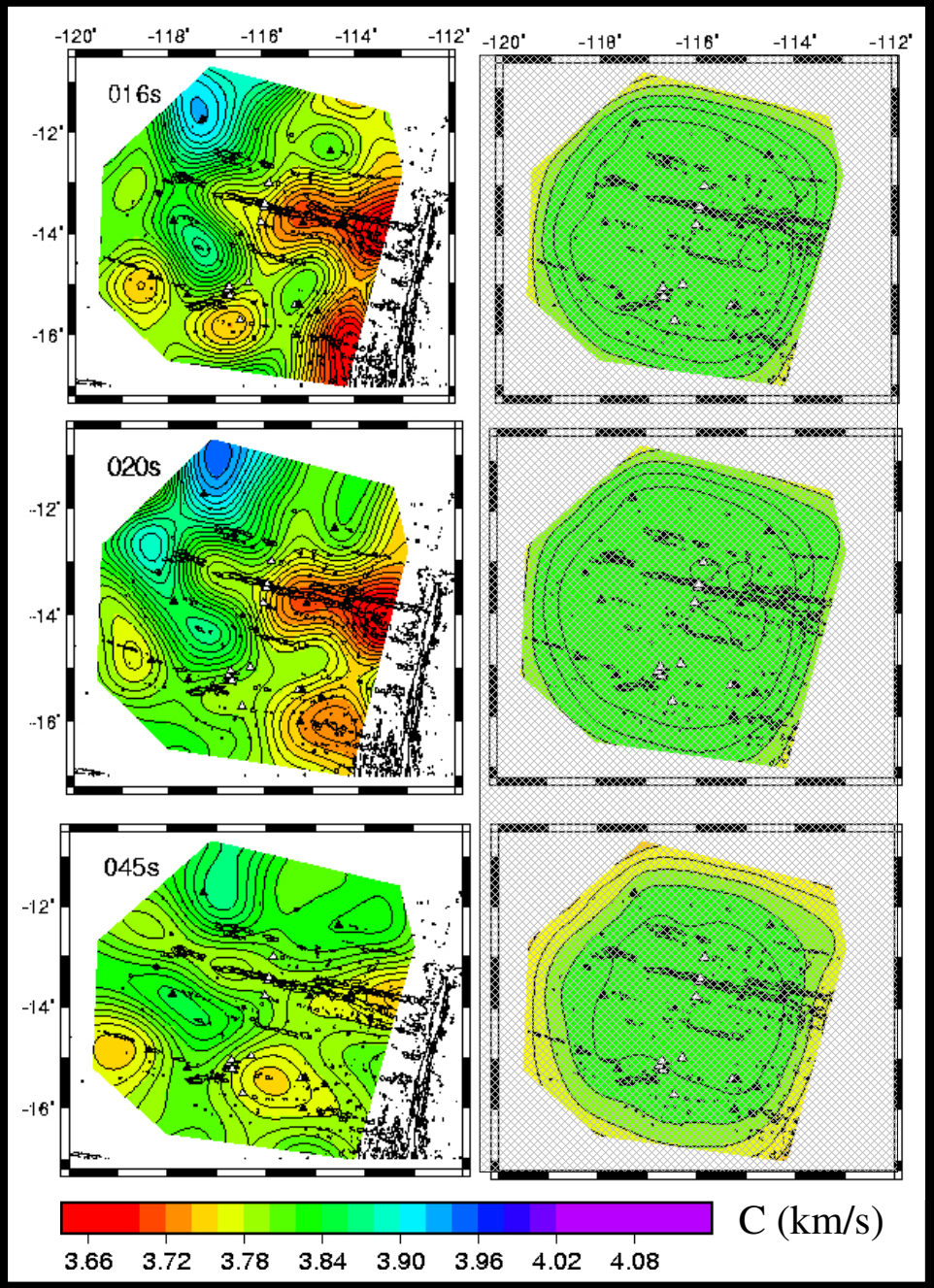
Rayleigh Wave Phase Velocities

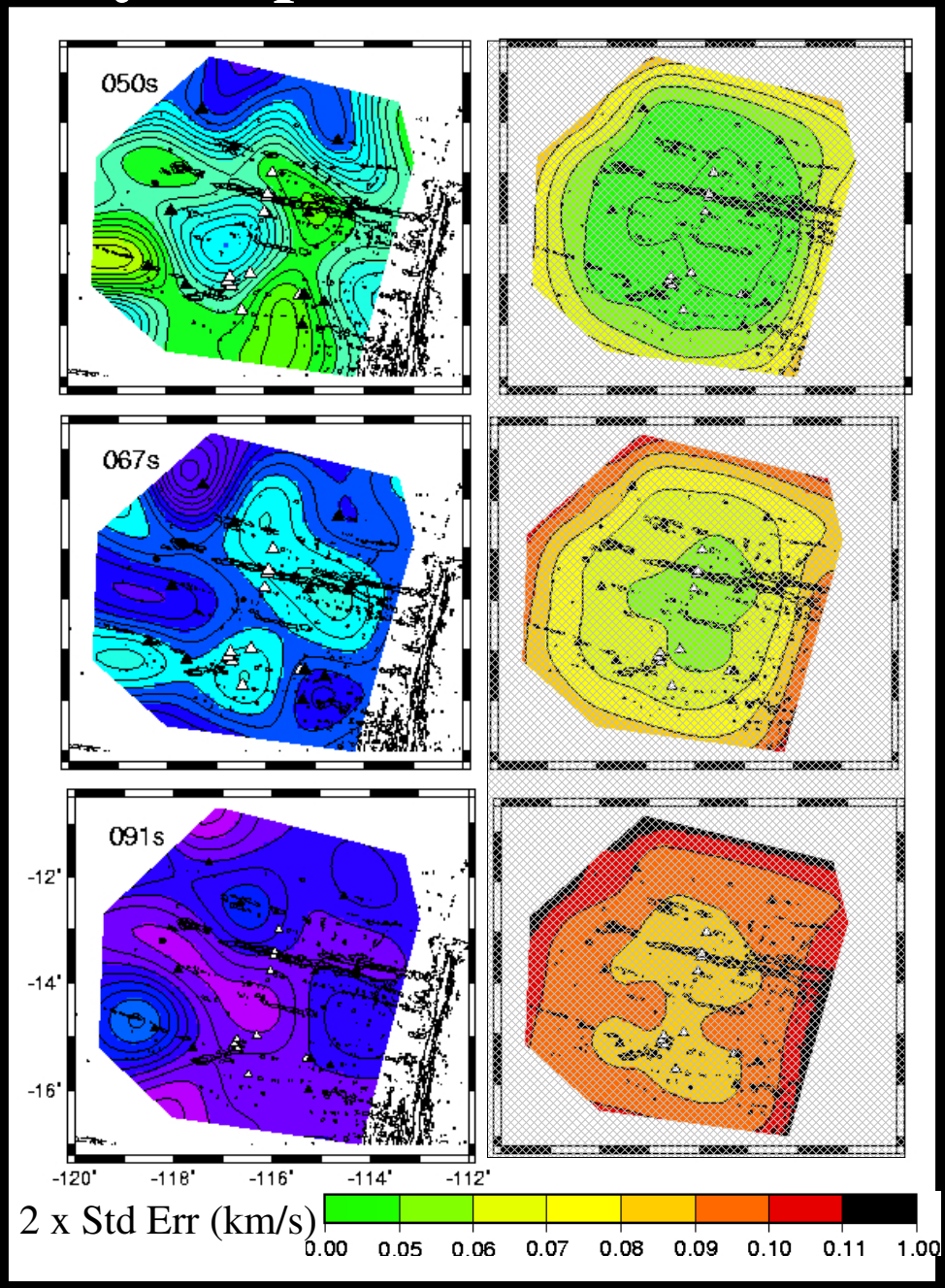




* Lowest phase velocities from 22 – 40 s
* Velocities increase steadily 40 – 100 s
* Resolution of the base of the LVZ ?

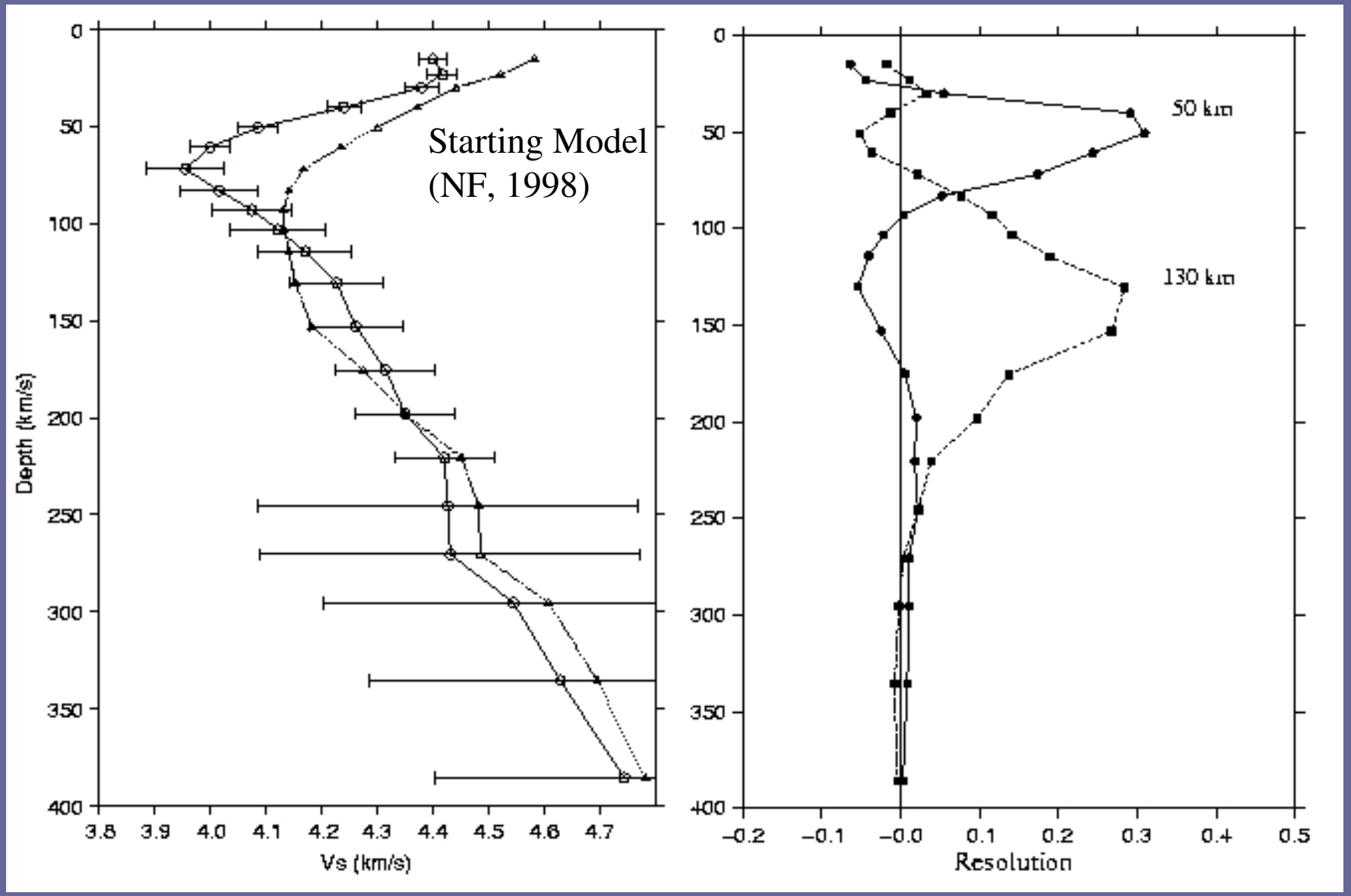
Phase Velocity Maps





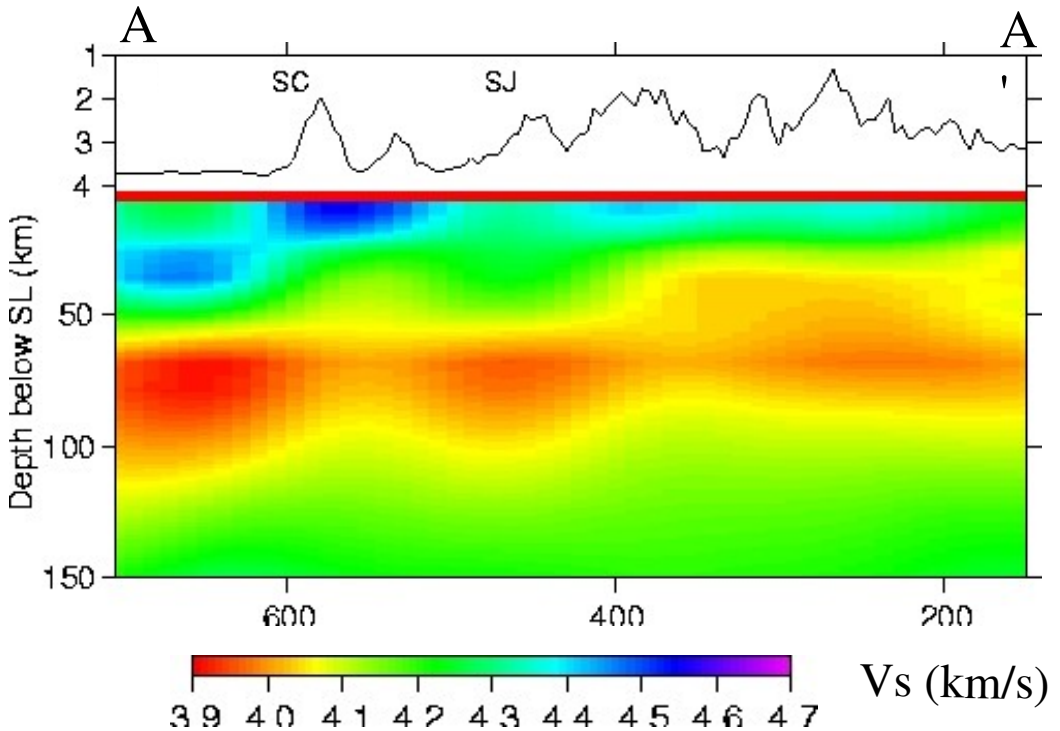
* Largest velocity variations are observed at short periods.
* Low velocity anomalies observed beneath seamount chains to 67 s period.

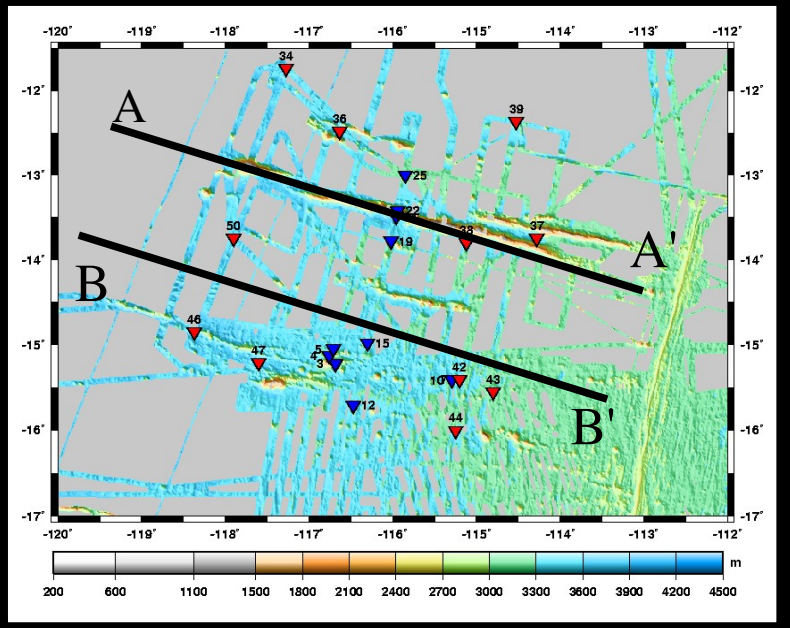
1-D Shear Wave Velocities in the Oceanic Mantle



* High velocity lithosphere extends to 60 km +/- 20 km.
* Steep positive velocity gradient identifies the base of the LVZ at ~110 km.

Shear Wave Velocity Structure



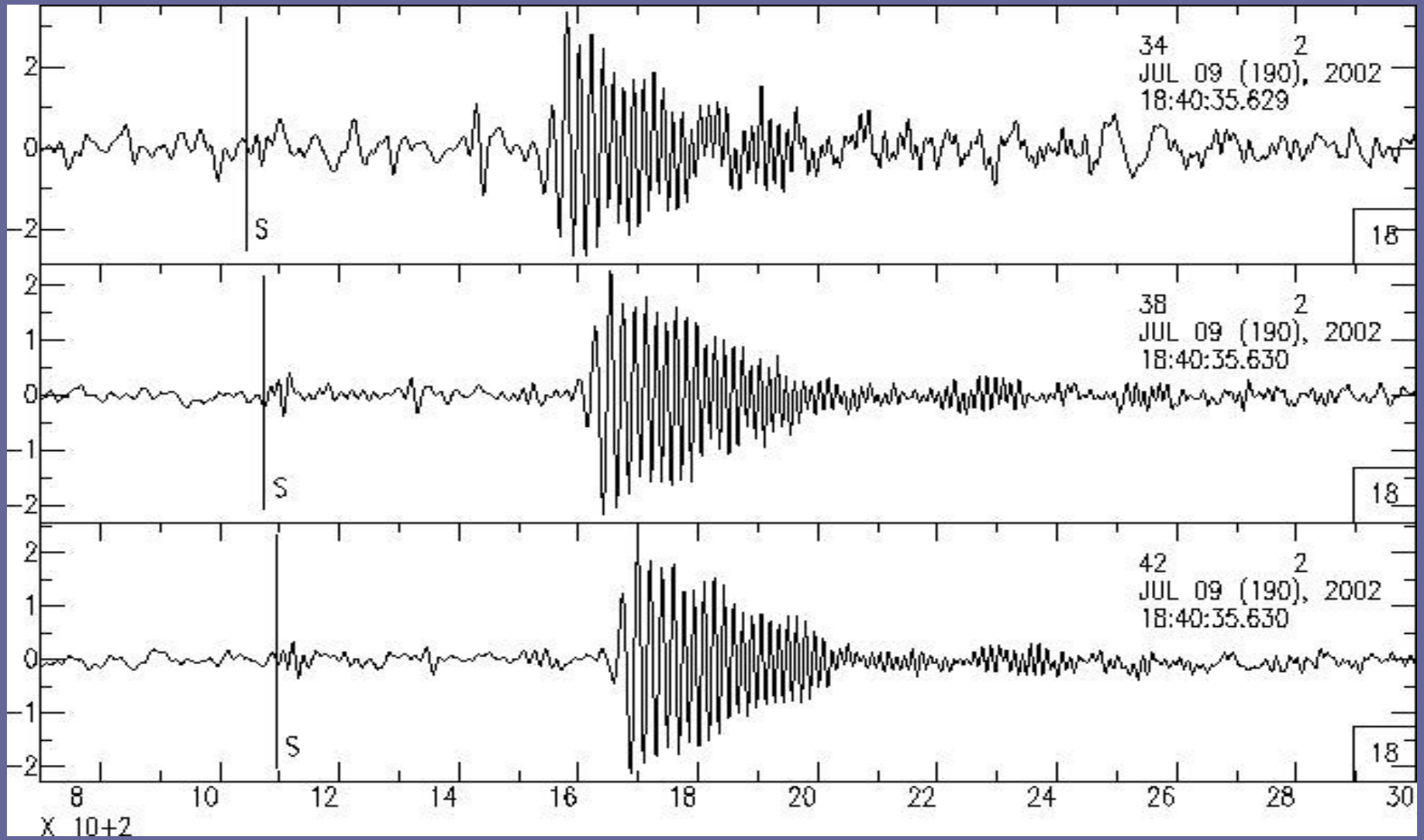


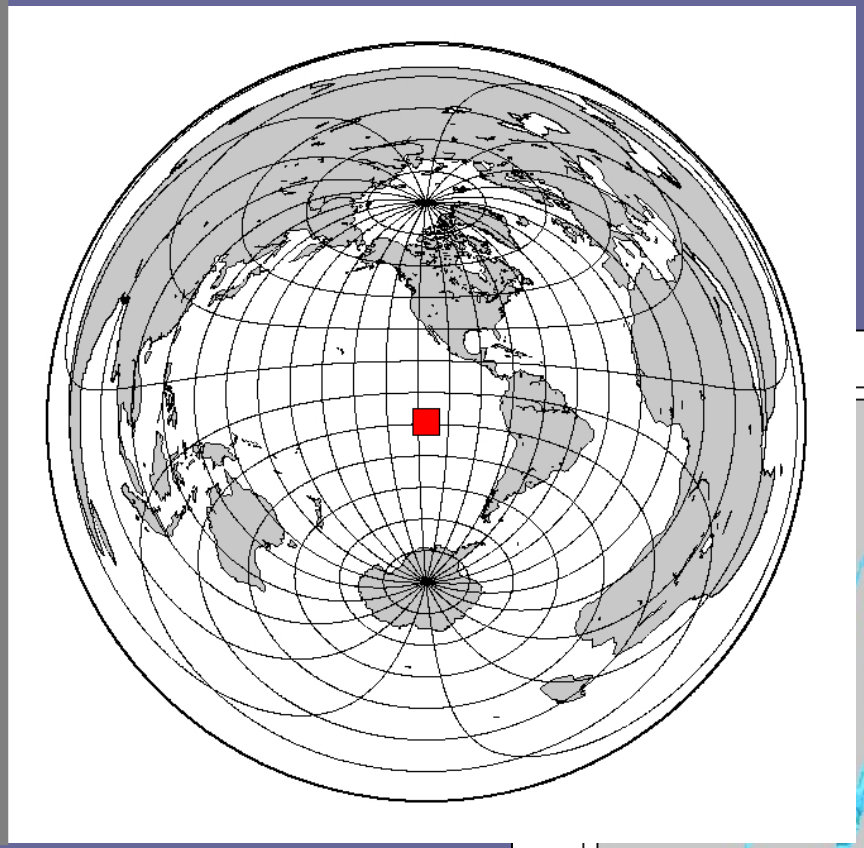
* High velocity lithosphere and LVZ are well resolved.

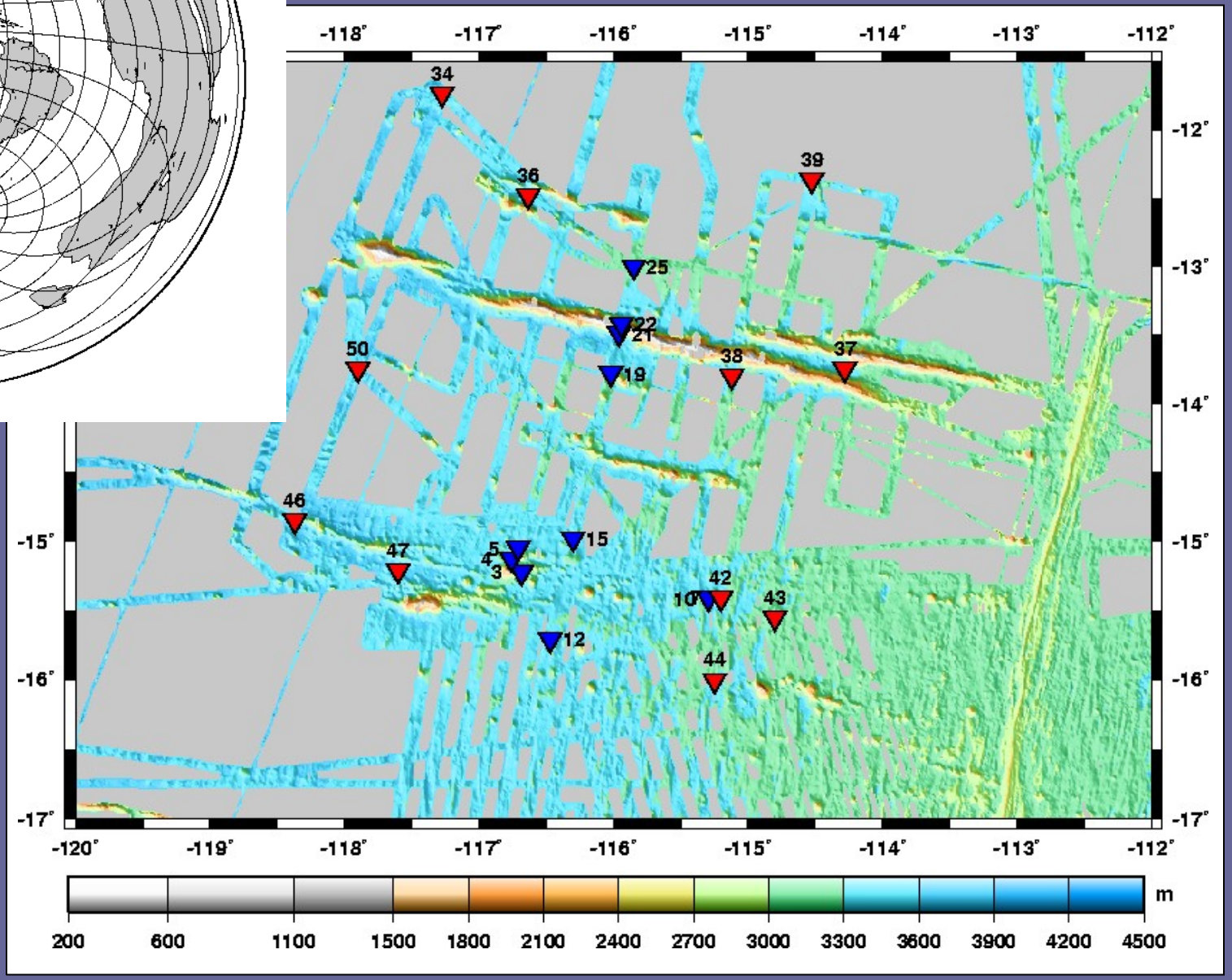
*Low velocities are observed beneath seamount chains.

*Lithospheric thinning beneath Sojourn ridge.

Rayleigh Wave Dispersion and Sensitivity
ACTIVITY






-118°
-117°
-116°
-115°
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