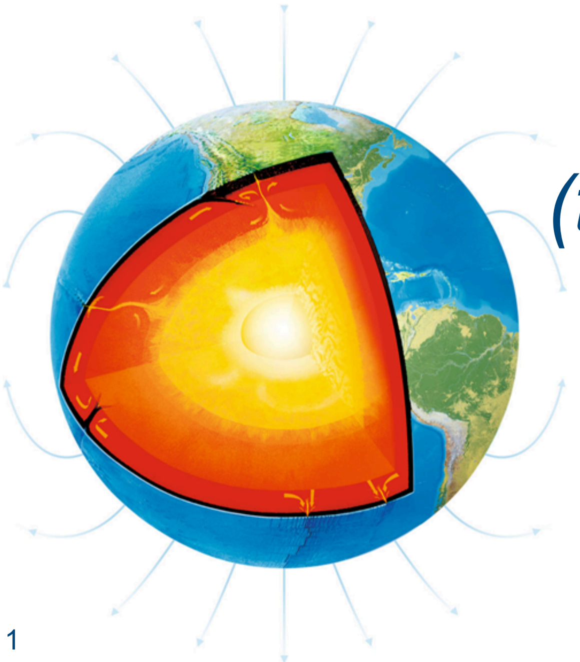
Einführung in die Geophysik
Teil 11: Seismik

2. BSc Geophysik und Geoinformatik (BGIP)

Thomas Günther
(thomas.guenther@geophysik.tu-freiberg.de)



Previously on AnGy

1. ~~Gravimetrie (1.5)~~
2. ~~Geomagnetik (2.5)~~
3. ~~Geoelektrik+Inversion (3)~~
4. ~~Induktive Elektromagnetik (1.5)~~
5. ~~Georadar (0.5)~~
6. Seismik (2)

Termine

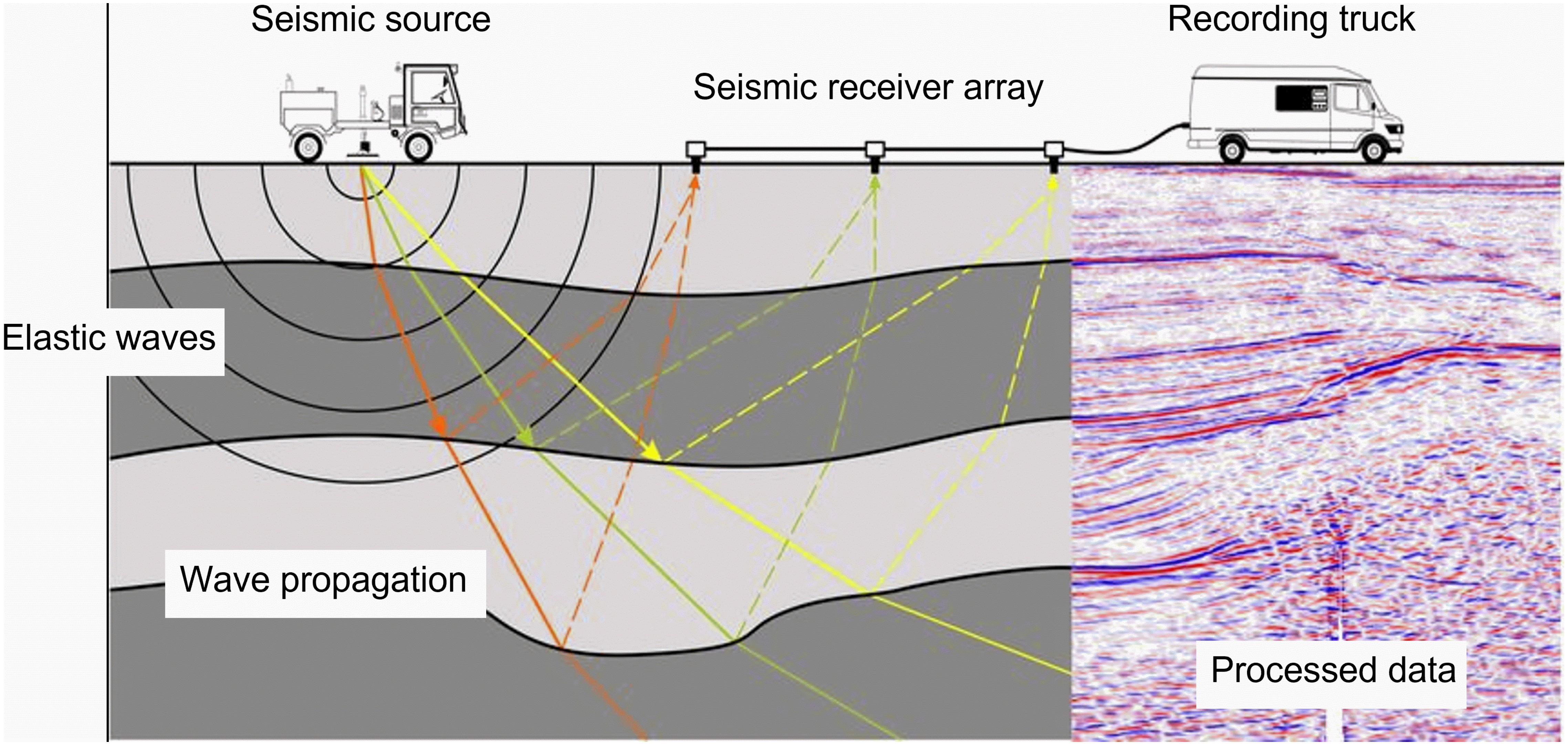
- heute (17.6.): dies academicus ab 13 Uhr (Unisportolympiade)
- morgen (18.6.): dies academicus bis 13 Uhr (Firmenkontaktmesse)

Übungen jeweils Freitags, 08-09:30 Uhr

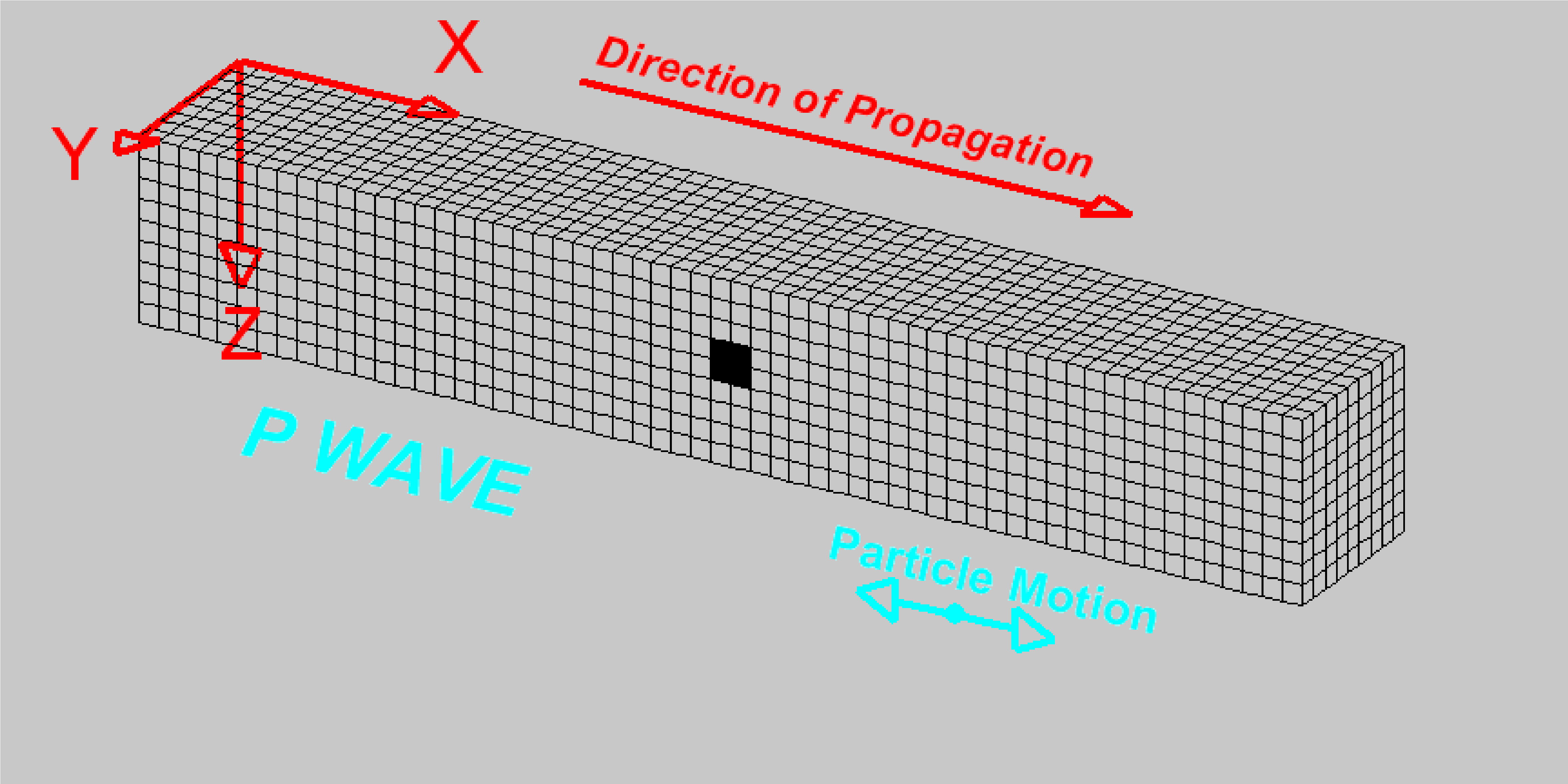
- 20.06. Versuch Georadar + EM38
- 27.06. Versuch Refraktions-Seismik
- 04.07. Auswertung EM + Seismik
- 11.07. Zusammenfassung und Fragestunde

Auswertung Geoelektrik

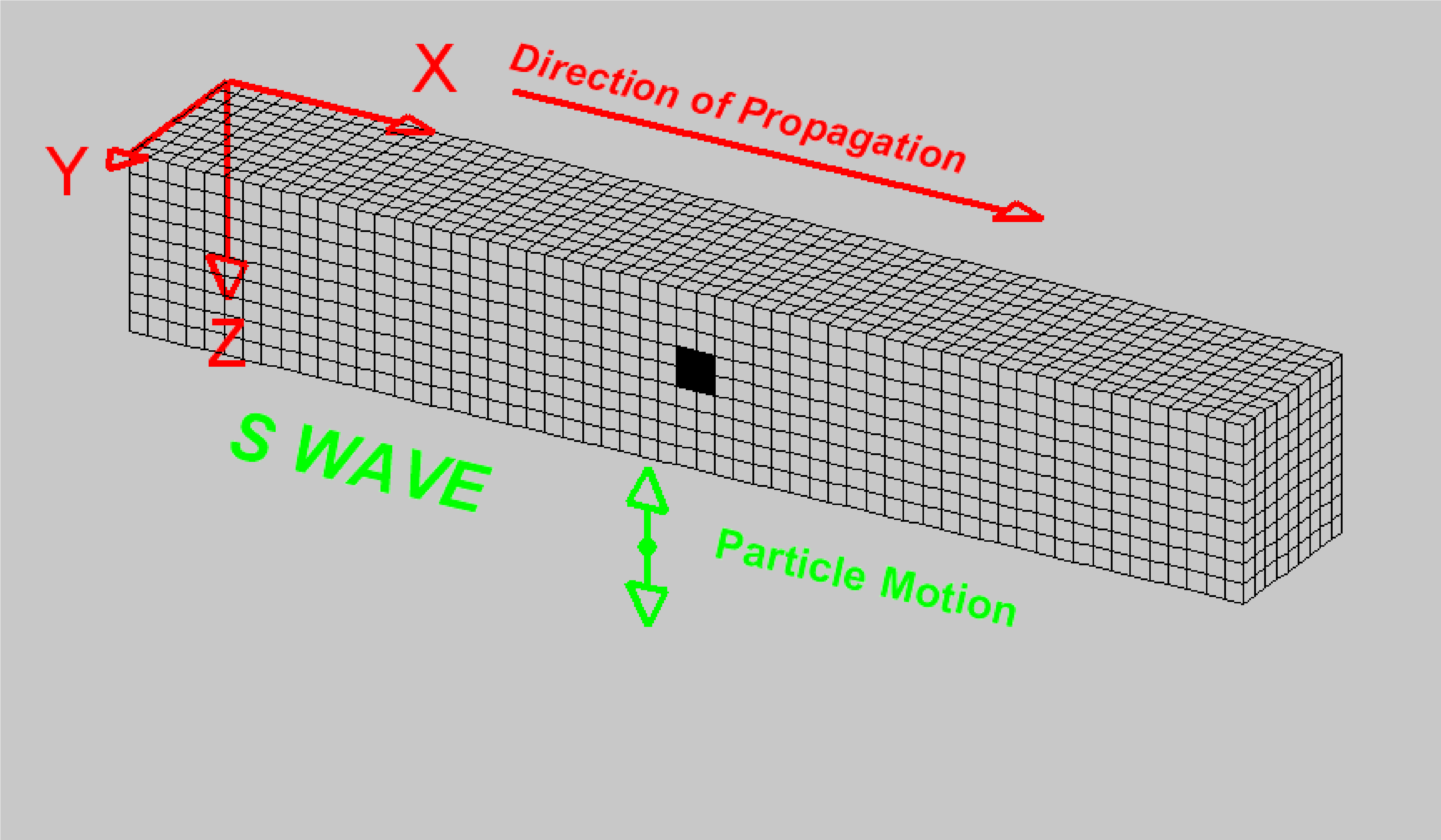
Seismik


Seismic source
Recording truck
Seismic receiver array
Elastic waves
Wave propagation
Processed data

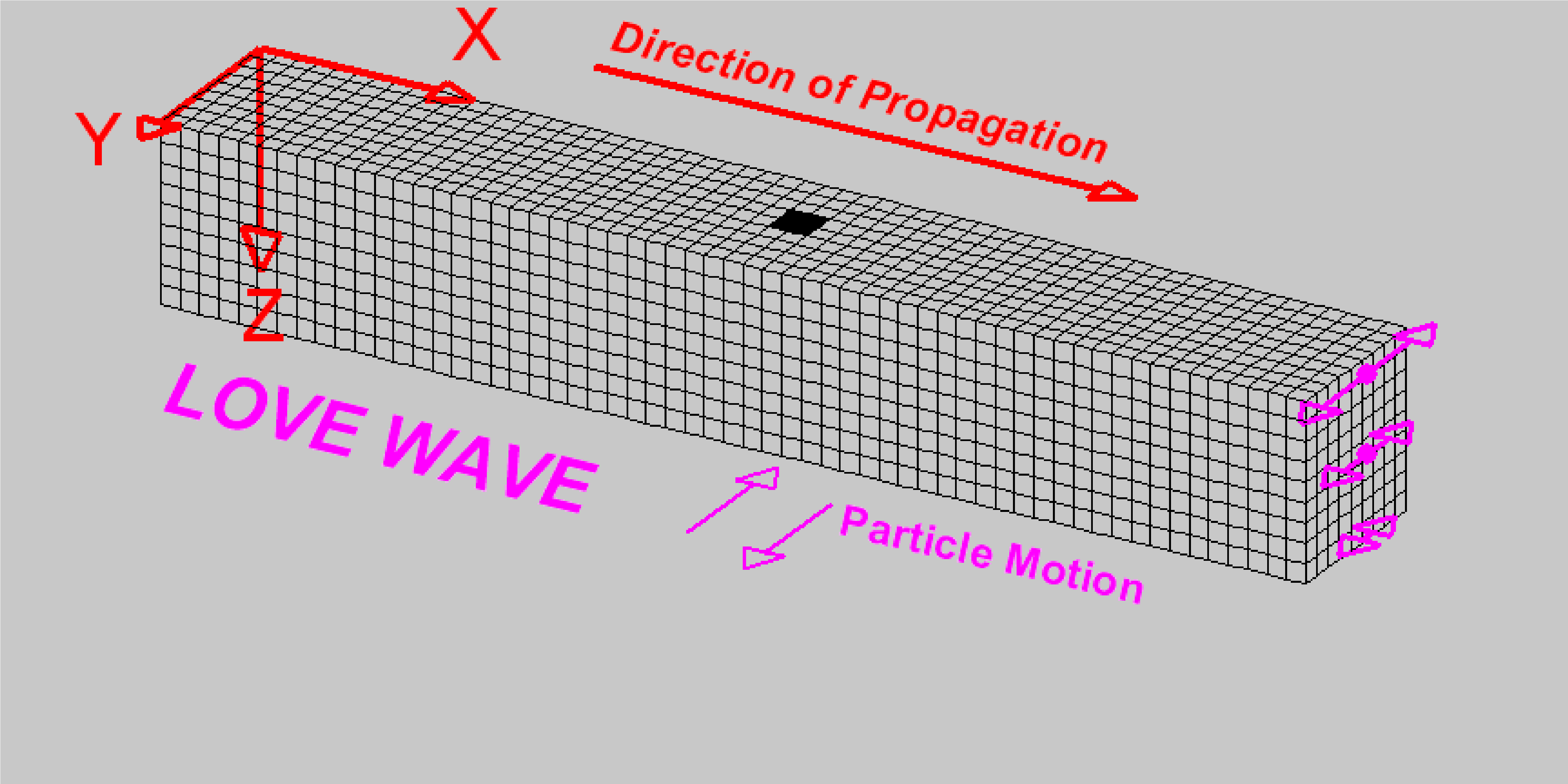
Raumwellen: P-Welle



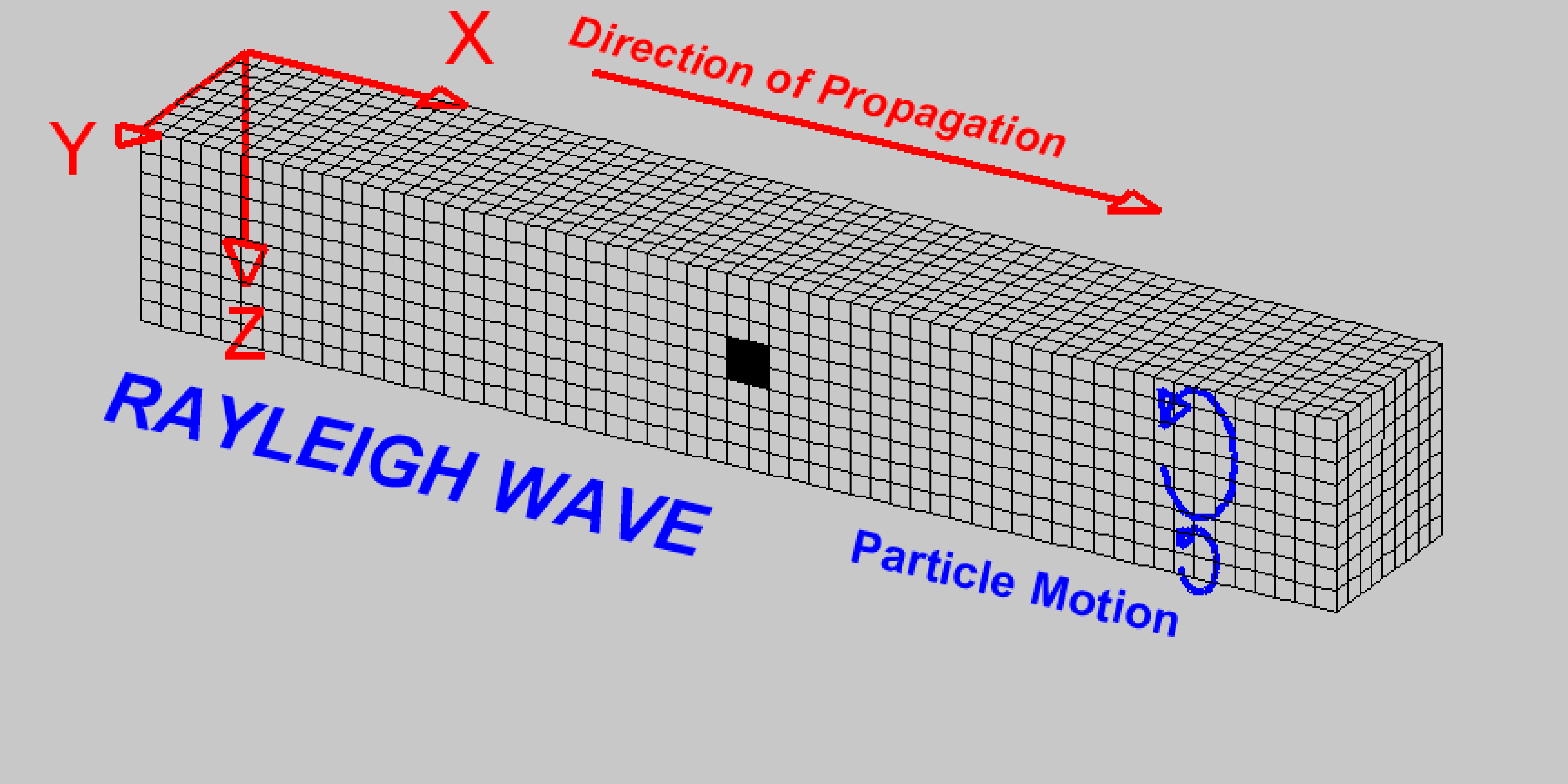
Raumwellen: S-Welle



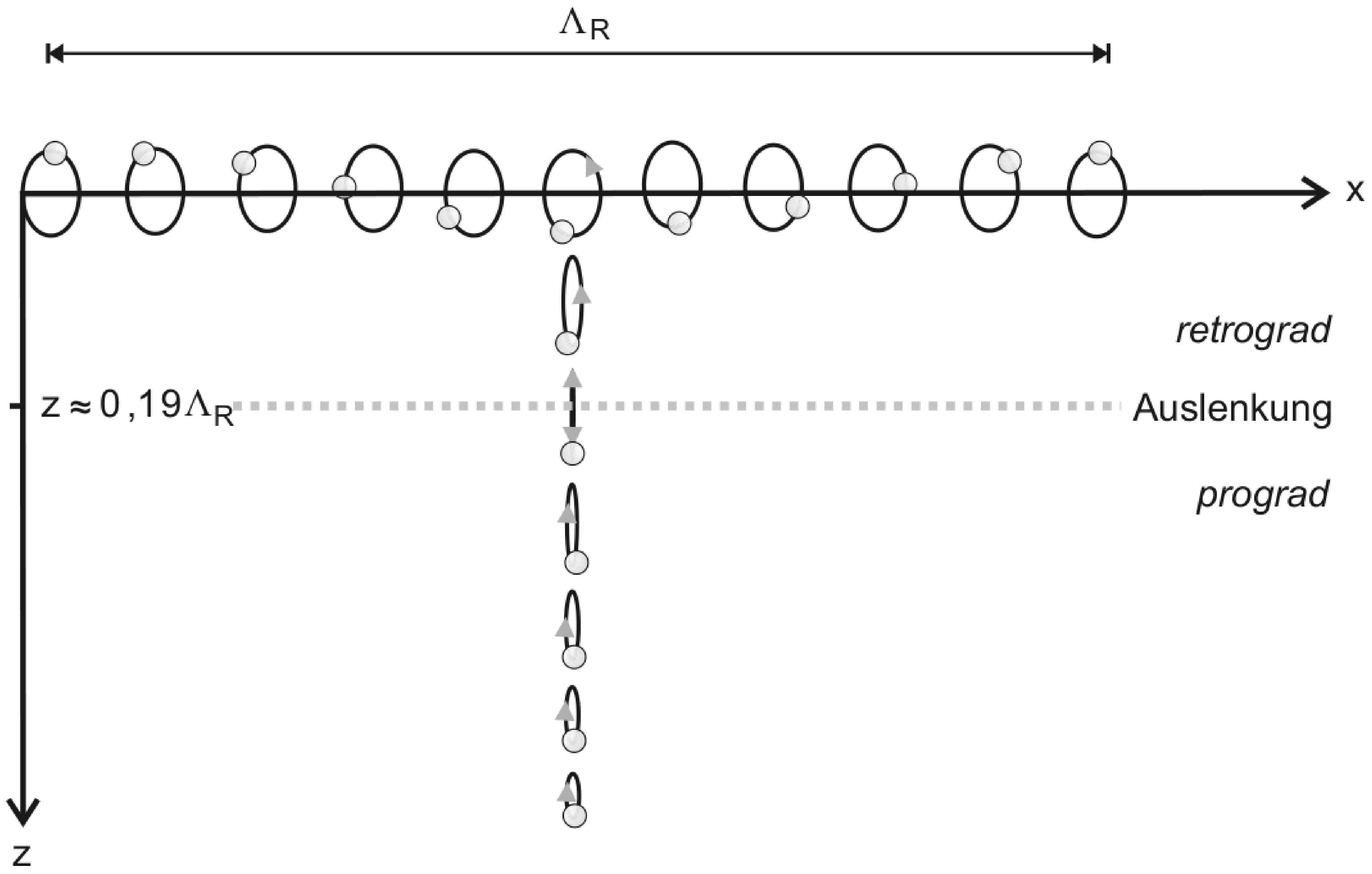
Oberflächenwellen: Love-Welle



Oberflächenwellen: Rayleigh-Welle



Oberflächenwellen: Rayleigh-Welle



Seismische Geschwindigkeiten

	P-wave	S-wave [km/s]		P-wave	S-wave [km/s]
Loose Dry Sand	0.2-0.5	0.05-0.3	Rock Salt	4.5-5.0	2.6-3.0
Loose Wet Sand	1.5-2.0	0.05-0.3	Anhydrite	4.5-6.5	2.6-3.8
Stiff Dry Sand	0.5-1.3	0.4-0.6	Gypsum	2.0-4.5	0.7-2.6
Stiff Wet Sand	1.8-2.3	0.4-0.6	Granite	5.5-6.0	3.2-3.5
Clay	1.0-2.5	0.1-1.5	Gabbro	6.5-7.0	3.8-4.1
Permafrost (???)	3.5-4.0	1.2-2.2	Ultramafic Rocks	7.5-8.5	4.4-5.0
Tertiary Sandstone	2.0-2.5	1.2-1.5	Air	0.33	0.0
Pennant Sandstone	4.0-4.5	2.3-2.7	Water	1.45-1.5	0.0
Cambrian Quartzite	5.5-6.0	3.2-3.5	Ice	3.4	2.0
Cretaceous Limestone	2.0-2.5	0.7-1.5	Petroleum	1.3 -1.4	0.0
Carboniferous Limest.	5.0-5.5	3.0-3.2			
Dolomites	2.5-6.5	1.5-3.8			

Reflektion & Transmission

- Akustische Impedanz $Z = v\varrho$ (Geschwindigkeit*Dichte)
- Grenzflächen Z (v oder ϱ) ändert sich: Reflektion & Transmission
- Reflektionskoeffizient $R = \frac{A_R}{A_0}$, Transmissionskoeffizient $T = \frac{A_T}{A_0}$
- Impulserhaltung: $R + T = 1$
- Energieerhaltung: $E = ZA^2$=const: $Z_1 A_0^2 = Z_1 A_1^2 + Z_2 A_2^2$
  - $Z_1 = Z_1 R^2 + Z_2 T^2 = Z_1(1-T)^2 + Z_2 T^2$
  - $0 = (Z_1 + Z_2)T^2 - 2Z_1 T$
  - $\Rightarrow T = \frac{2Z_1}{Z1+Z2} \Rightarrow R = \frac{Z_2 - Z_1}{Z_1 + Z_2}$

Reflektion & Transmission

- Akustische Impedanz $Z = v\varrho$ (Geschwindigkeit*Dichte)
- Grenzflächen Z (v oder ϱ) ändert sich: Reflektion & Transmission
- Reflektionskoeffizient $R = \frac{A_R}{A_0} = \frac{Z_2 - Z_1}{Z_1 + Z_2}$ $(-1 \leq R \leq +1)$
- Transmissionskoeffizient $T = \frac{A_T}{A_0} = \frac{2Z_1}{Z_1 + Z_2}$ $(0 \leq T \leq 2)$
- Extremfälle:
  - $Z_1 = Z_2$: R=0, T=1 (pure Transmission)
  - $Z_1 \gg Z_2$: R=-1, T=2 (Reflektion am losen Ende)
  - $Z_1 \ll Z_2$: R=1, T=0 (Reflektion am festen Ende)

Hyberbolic equations

Acoustic wave equation in 1D

$$\frac{\partial^2 u}{\partial t^2} - c^2 \frac{\partial^2 u}{\partial x^2} = 0$$

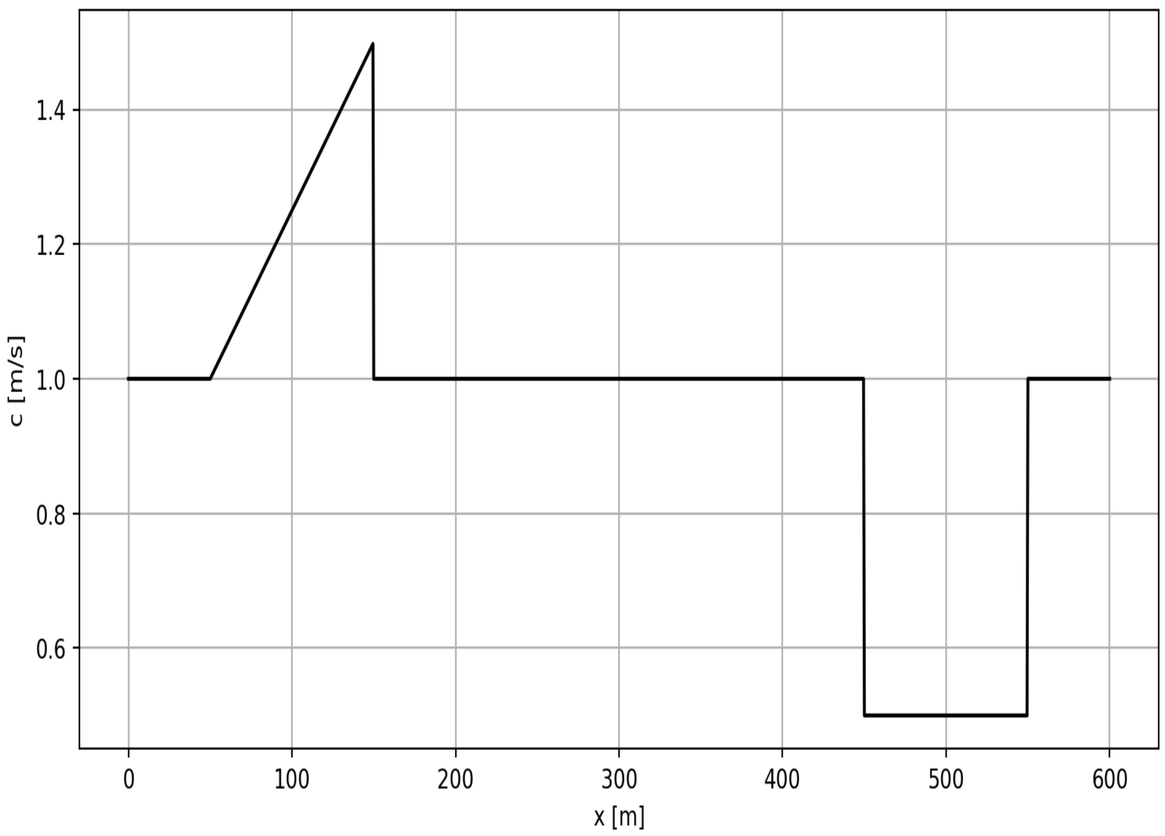
u..pressure/velocity/displacement, c..velocity

Damped (mixed parabolic-hyperbolic) wave equation

$$\frac{\partial^2 u}{\partial t^2} - a \frac{\partial u}{\partial t} - c^2 \frac{\partial^2 u}{\partial x^2} = 0$$

Example: velocity distribution

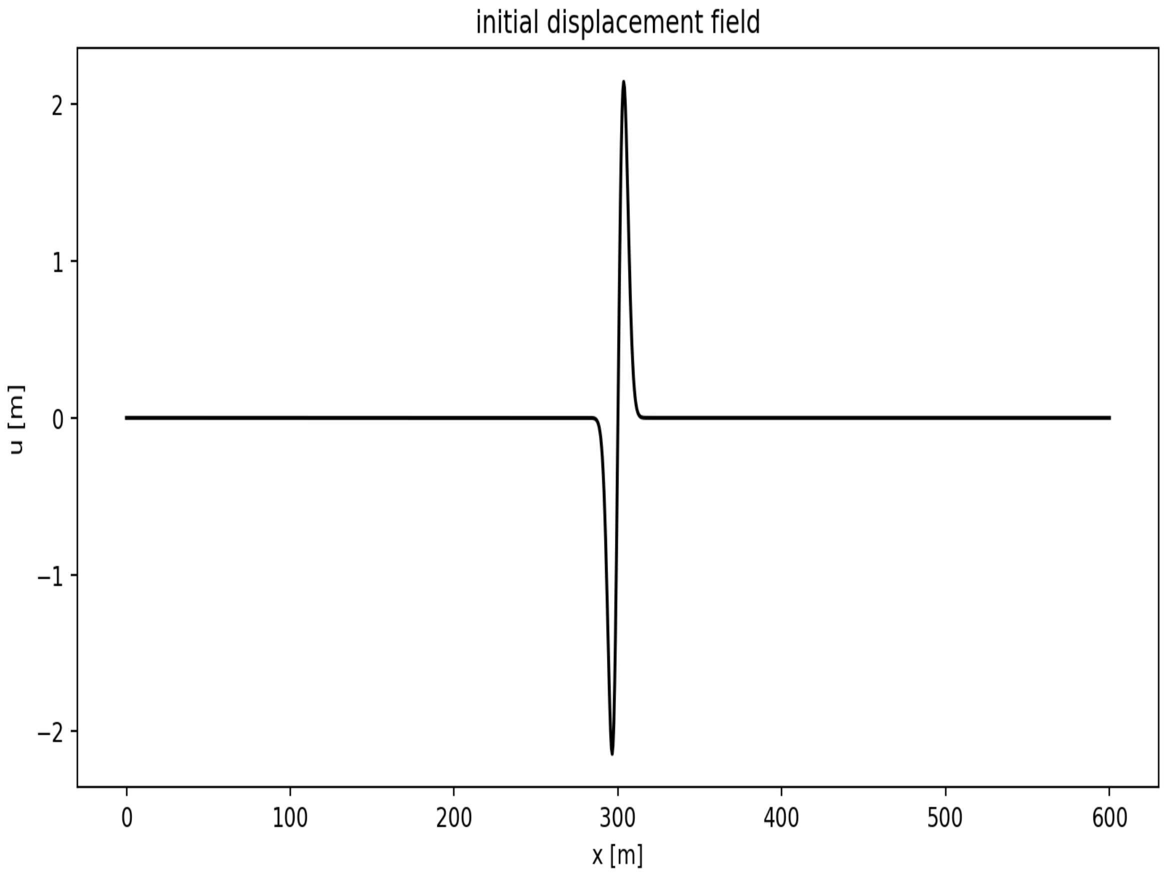
```python
import numpy as np
import matplotlib.pyplot as plt
x=np.arange(0, 600.01, 0.5)
c = 1.0*np.ones_like(x) # velocity in m/s
c[100:300] = 1 + np.arange(0,0.5,0.0025)
c[900:1100] = 0.5  # low velocity zone

# Plot velocity distribution.
plt.plot(x,c,'k')
plt.xlabel('x [m]')
plt.ylabel('c [m/s]')
plt.grid()
```



Initial displacement

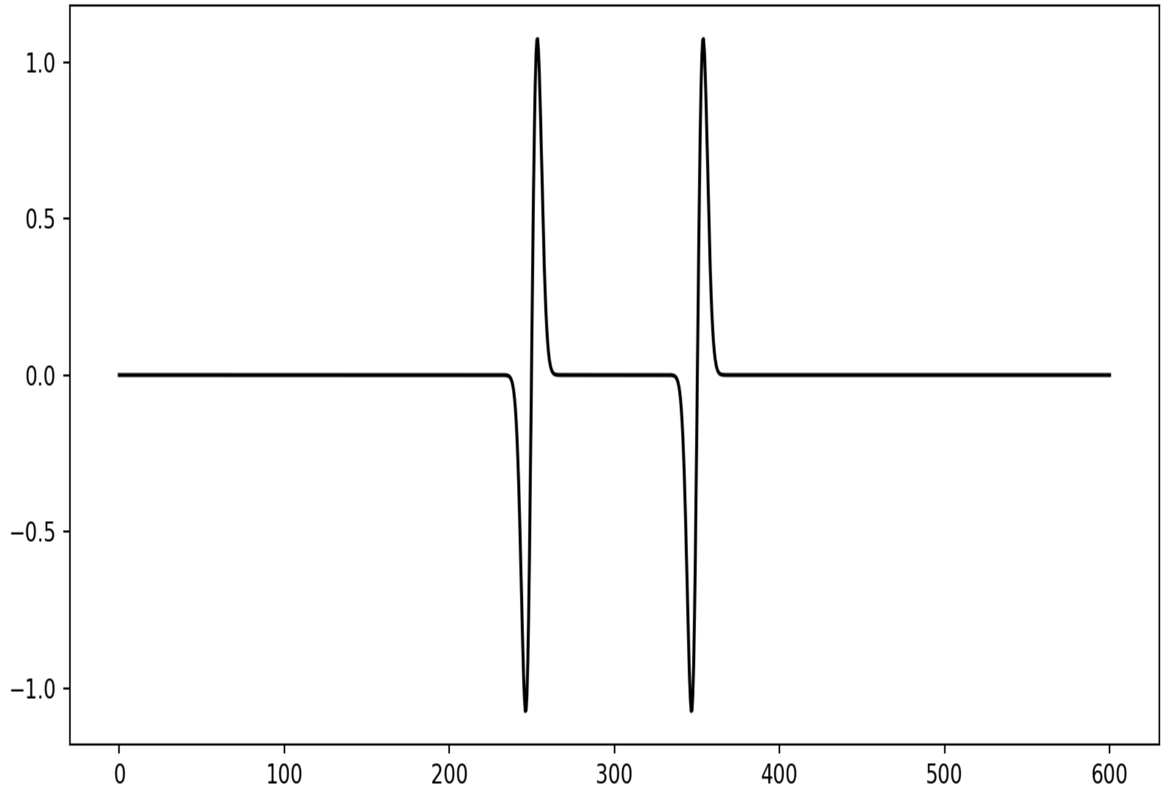
Derivative of Gaussian (Ricker wavelet)

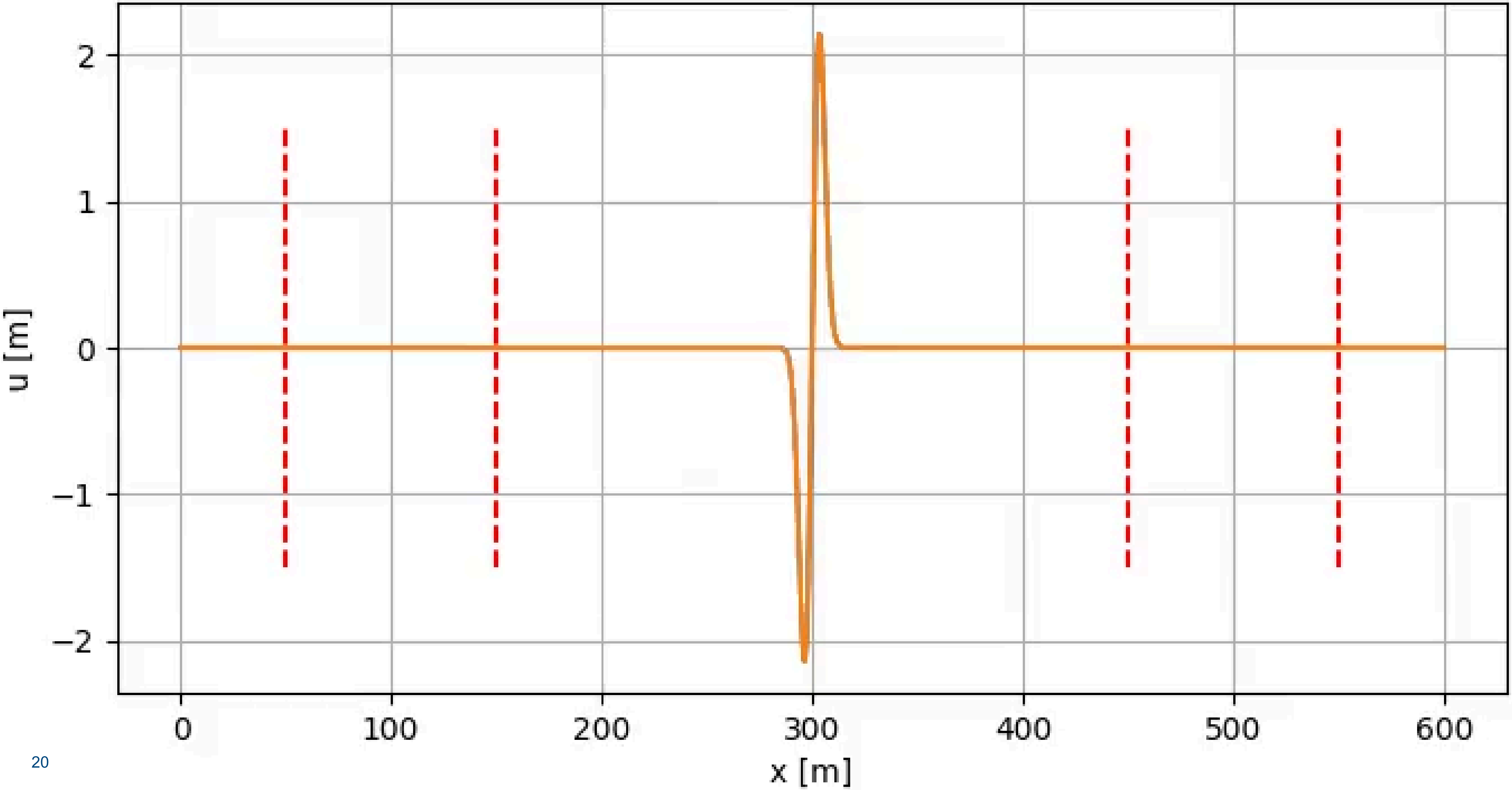
```python
l=5.0

# Initial displacement field [m].
u=(x-300.0)*np.exp(-(x-300.0)**2/l**2)
# Plot initial displacement field.
plt.plot(x,u,'k')
plt.xlabel('x [m]')
plt.ylabel('u [m]')
plt.title('initial displacement field')
plt.show()
```



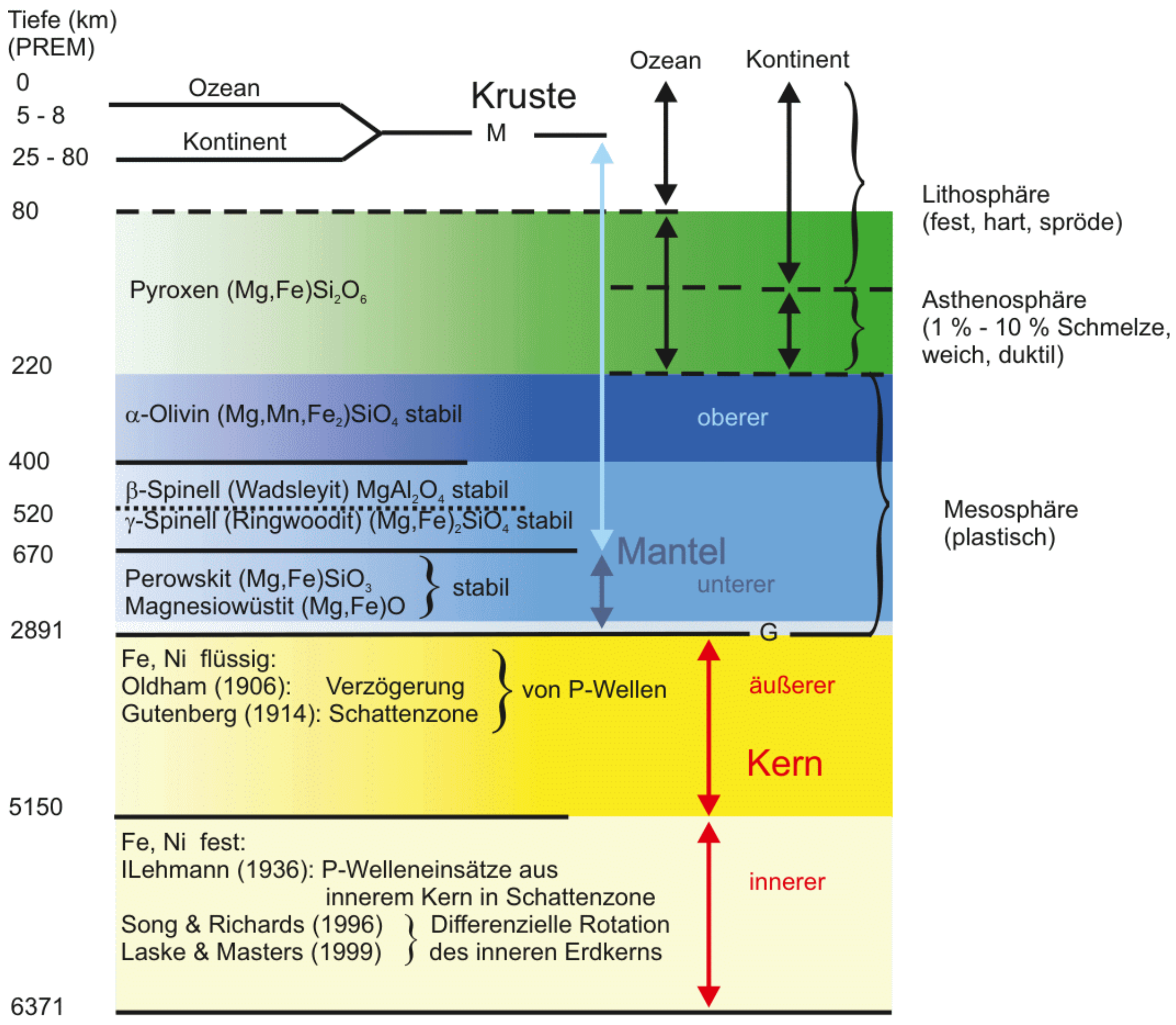
Time propagation

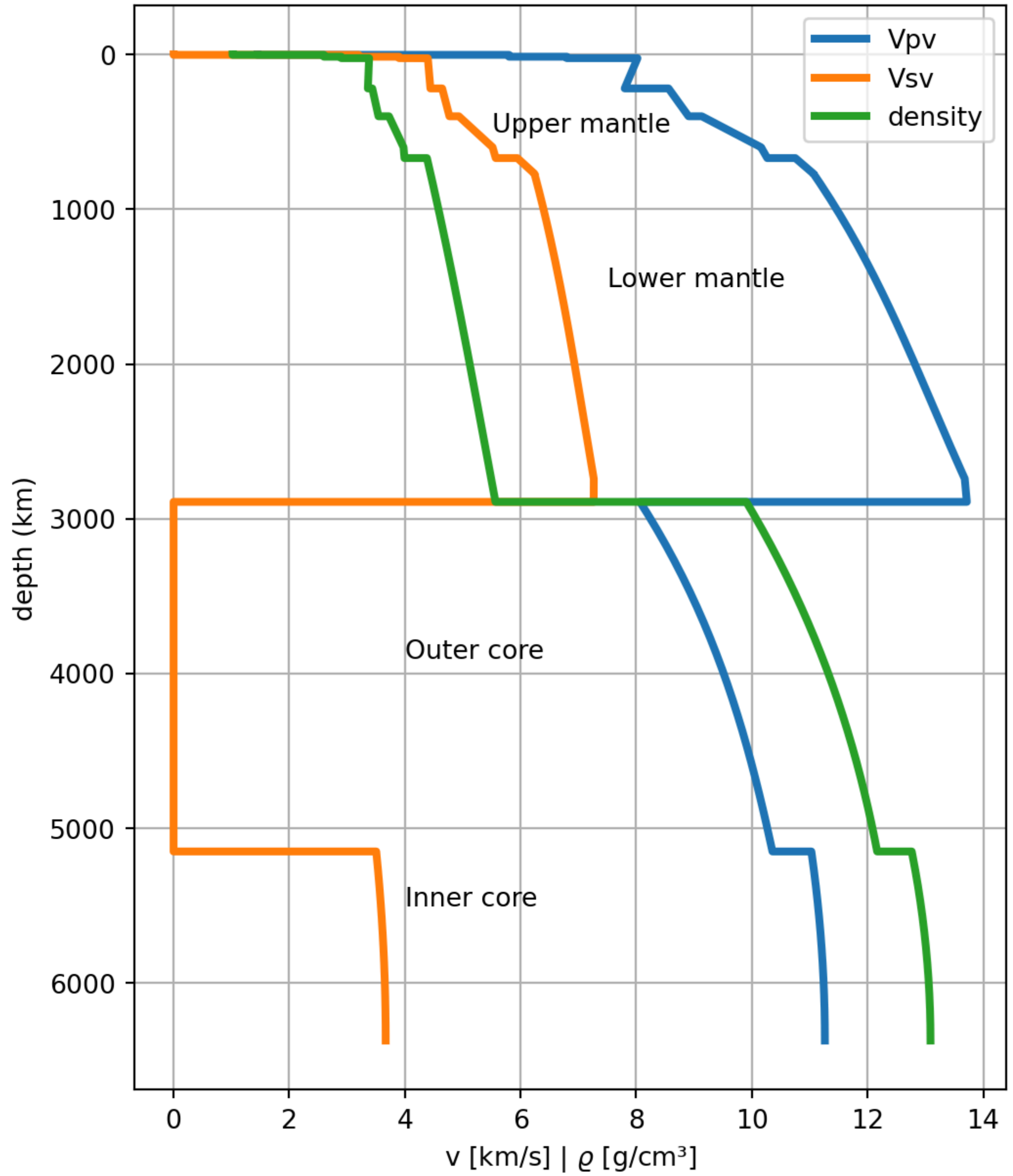
```
u_last=u
dt = 0.5
ddu = np.zeros_like(u)
dx = np.diff(x)
for i in range(100):
    dudx = np.diff(u)/dx
    ddu[1:-1] = np.diff(dudx)/dx[:-1]
    u_next = 2*u-u_last+ddu*c**2 * dt**2
    u_last = u
    u = u_next

plt.plot(x,u,'k')
```




2
1
0
−1
−2
u [m]
0
100
200
300
400
500
600
x [m]

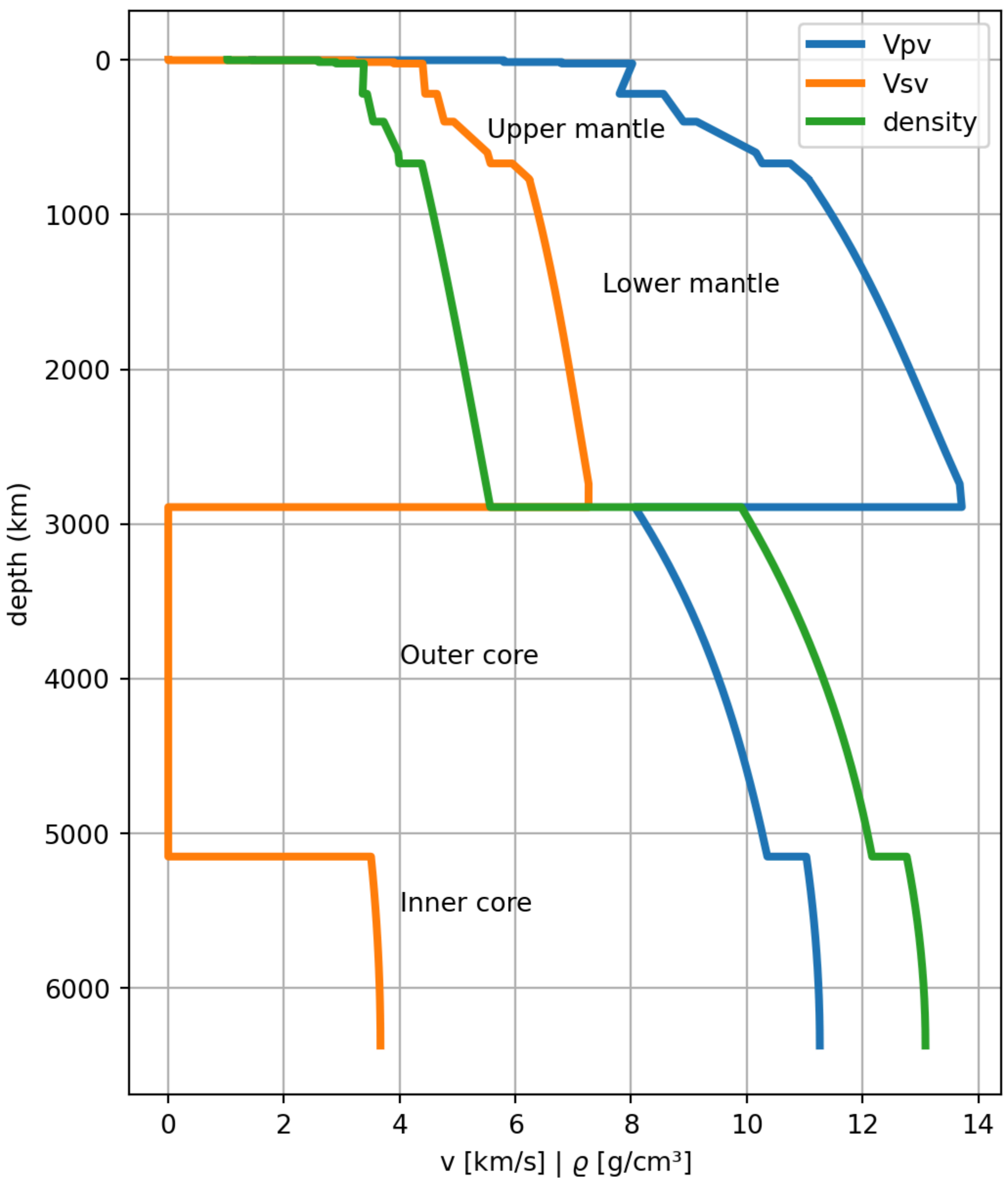
Das Preliminary Earth Model (PREM)



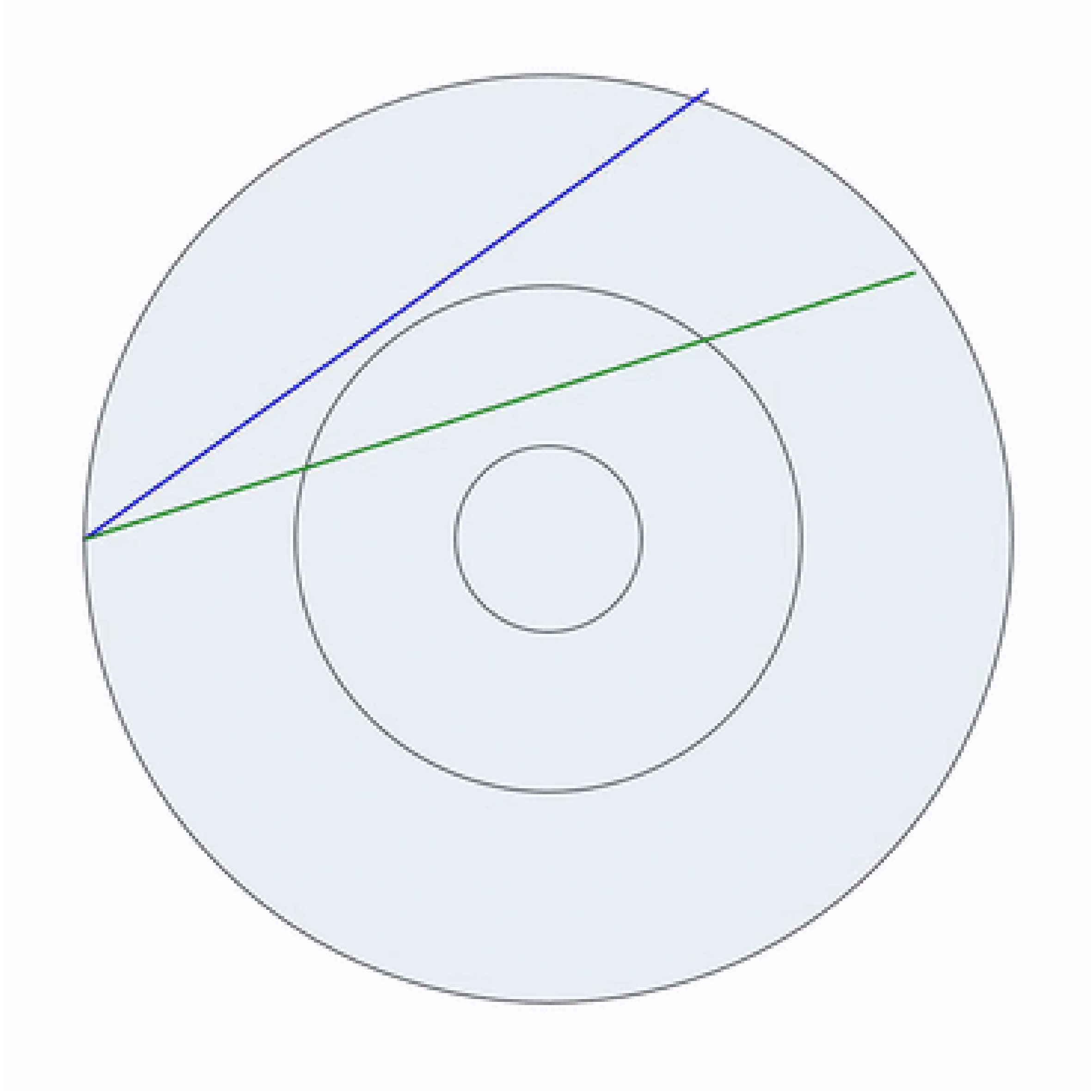


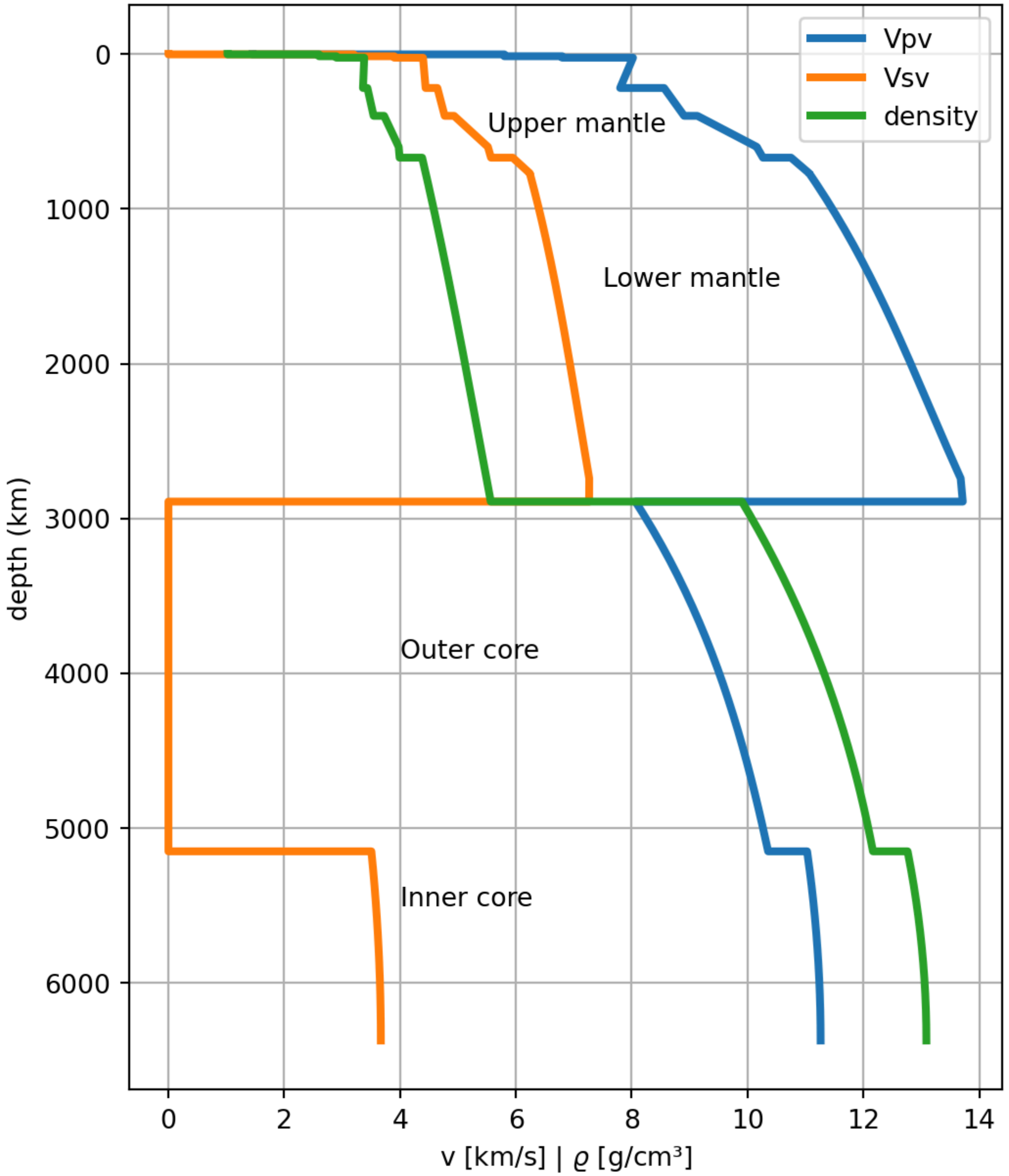
PREM - Parameter

```python
# !pip install rockhound
import rockhound as rh

prem = rh.fetch_prem()
fig, ax = plt.subplots(figsize=(6, 7.5))
for term in ["Vpv", "Vsv", "density"]:
    prem.plot(term, "depth", lw=3,
        legend=False, ax=ax, label=term)

ax.invert_yaxis()
ax.grid()
ax.legend()
ax.set_xlabel(r"v [km/s] | $\varrho$ [g/cm³]")
ax.set_ylabel("depth (km)")
ax.text(4, 5500, "Inner core")
ax.text(4, 3900, "Outer core")
ax.text(7.5, 1500, "Lower mantle")
ax.text(5.5, 500, "Upper mantle");
```



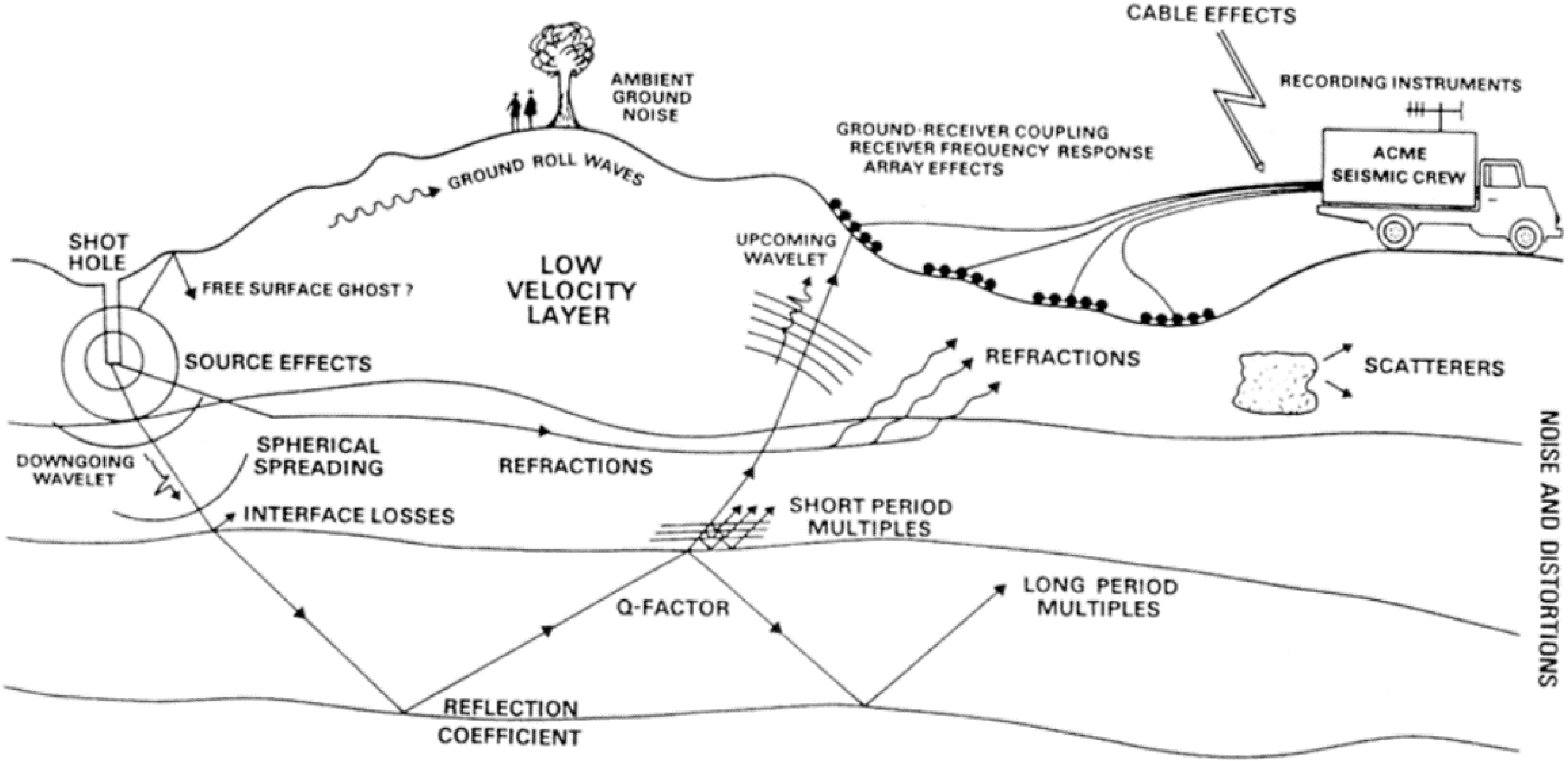
Simulation von Erdbebenwellen



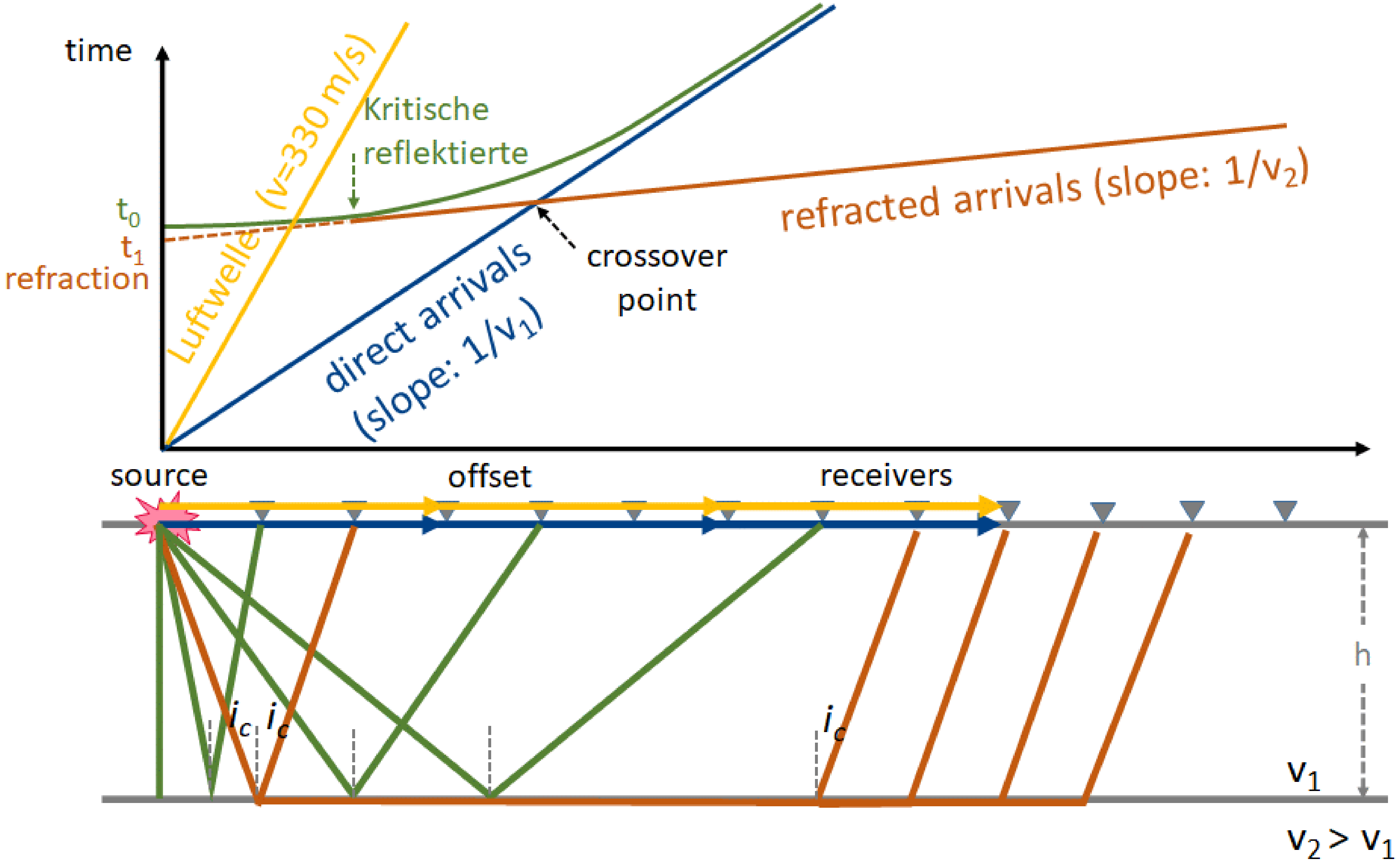


Vpv
Vsv
density
Upper mantle
Lower mantle
Outer core
Inner core
depth (km)
0
1000
2000
3000
4000
5000
6000
0
2
4
6
8
10
12
14
v [km/s] | ϱ [g/cm³]

Ausbreitung



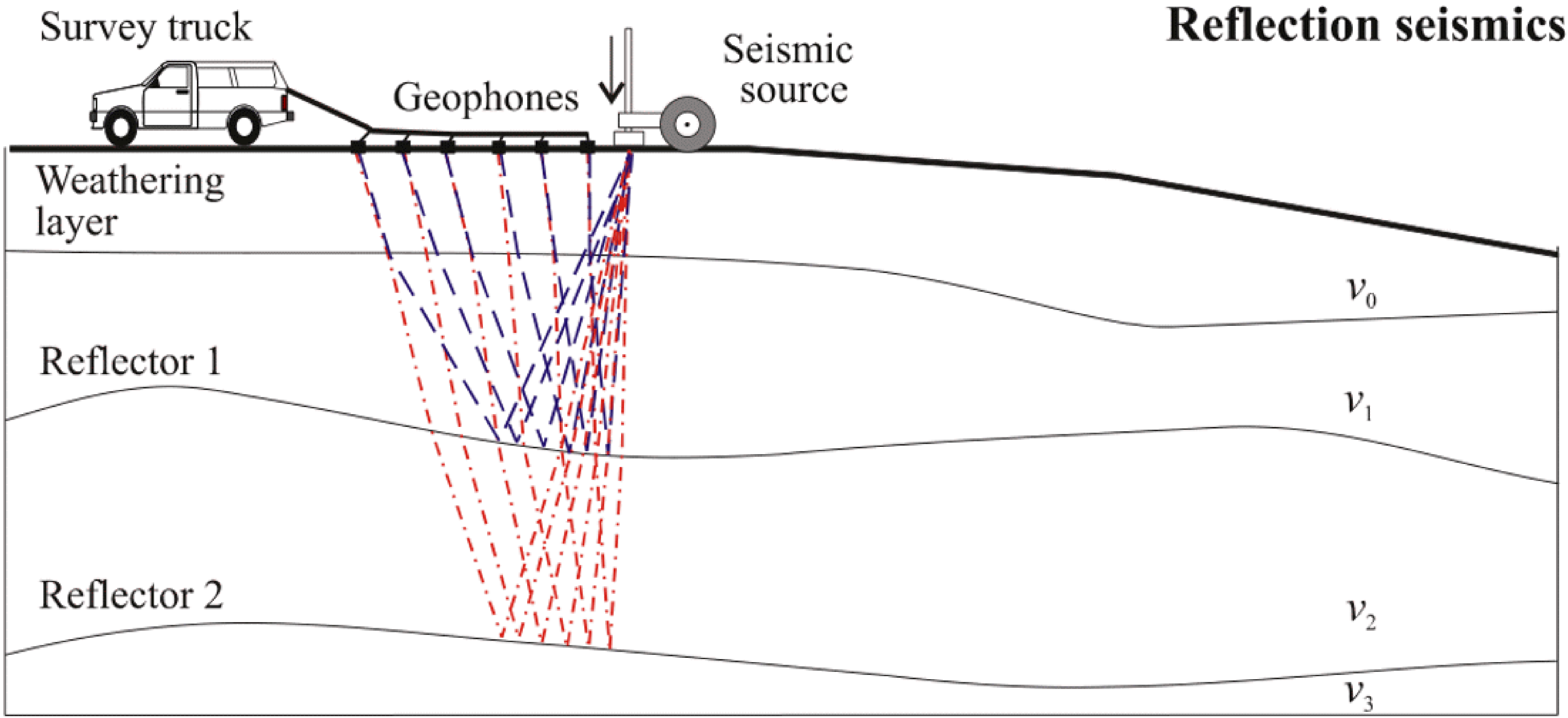
Ausbreitungswege



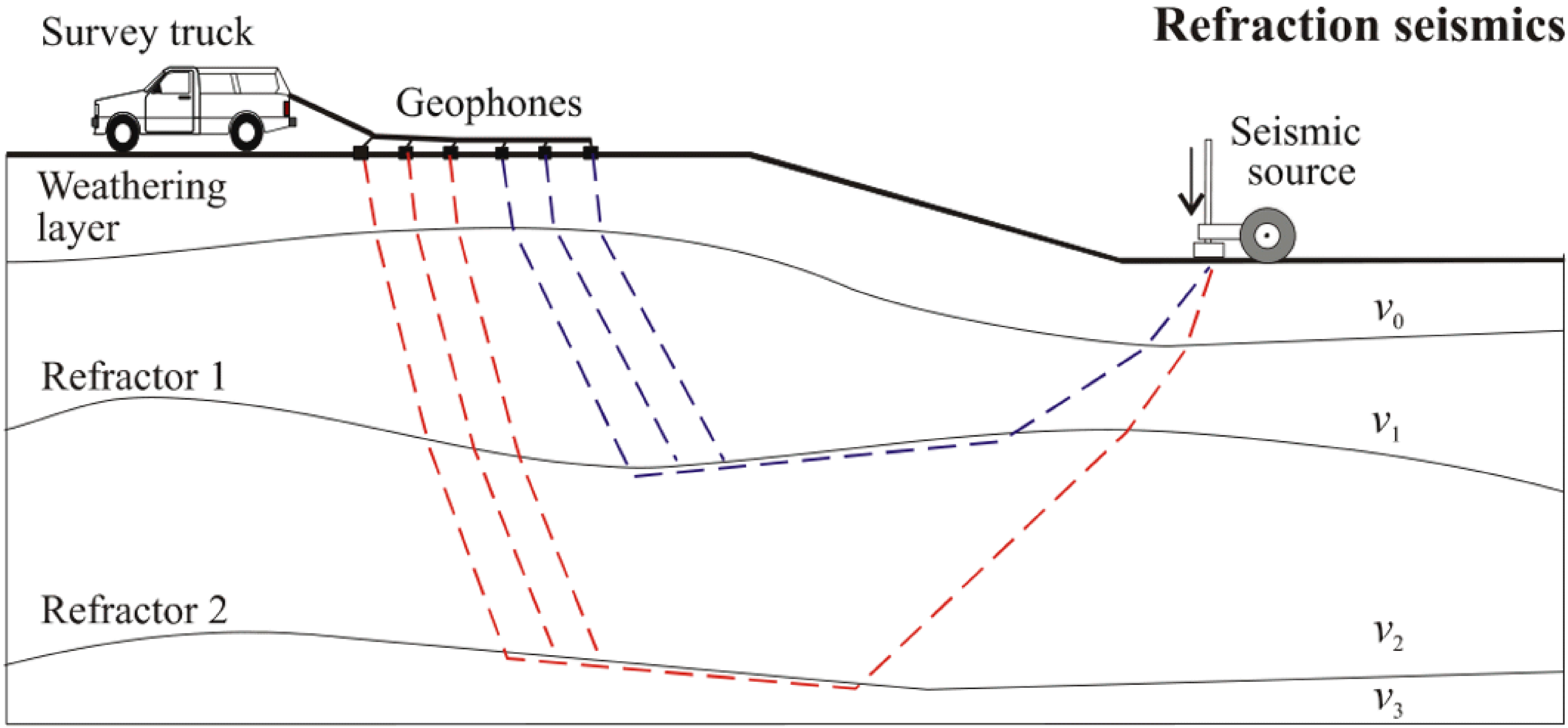
Seismische Erkundung

- Reflektions-Seismik
- Refraktions-Seismik
- Oberflächenwellen-Seismik
- Crosshole-Tomographie

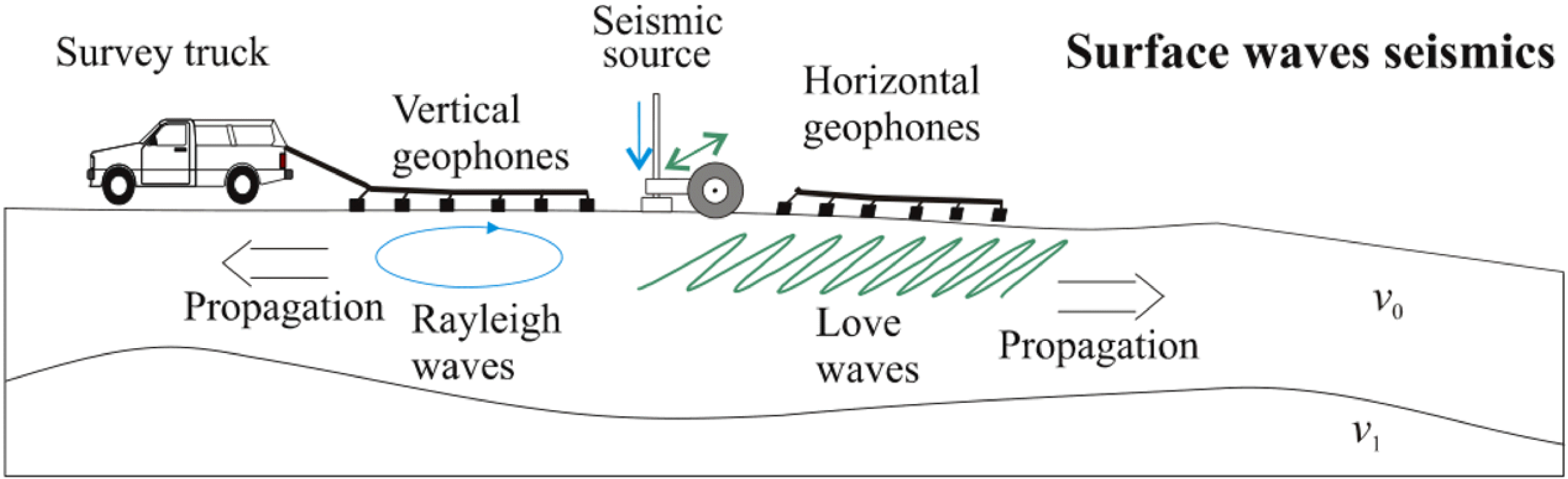
Reflektions-Seismik



Refraktions-Seismik



Oberflächenwellen-Seismik



VSP und Crosshole-Tomographie