Today

1. Global energy consumption & supply
2. Reflection seismology theory
3. Data acquisition

SAGE 2025 Application Details

Applications

Opening: Sunday, December 1st
Closing: Saturday, March 14th
Acceptance Letters: by March 31st
Student Decisions: by April 18th

Application Form: https://forms.gle/YhZnZY7z3fdtamho8
Recommendation Form: https://forms.gle/fDFcn1Fv9xnYBAFM7

SAGE 2025 Plans

SAGE 2025 will be a hybrid program. In-person attendance, including practical outdoor work, a field trip, and classroom activities, will span from June 15th to July 2nd. Students should expect a month of part-time SAGE activities from mid-May to the start of SAGE, which should include some introductory Zoom calls and material discussions, as well as two-three weeks of more intense remote activity following the end of in-person attendance, which should include lectures, group projects, and final presentations for each group.

Who Attends SAGE?

Students

SAGE accepts applications from qualified undergraduate and graduate students from all over the world. Students typically major in geophysics, geology, physics, math, engineering or a related field. Successful applicants will have a strong background in math and physics (see required coursework below), and will have **completed at least their sophomore year of undergraduate studies** prior to the start of the program.
Course credit may be available (and must be arranged prior to arrival at SAGE and subject to approval of your home institution and advisor).

Applying to SAGE

How to Apply to SAGE

Step 1: Review Coursework Requirements

The following coursework is required to be considered for SAGE:

- Minimum of one year (two semesters or three quarters) of college physics. Coursework should include electricity and magnetism.
- Minimum of three semesters of calculus; four semesters preferred. Coursework should include multivariable calculus.
- Structural geology and introductory geophysics is recommended but not required

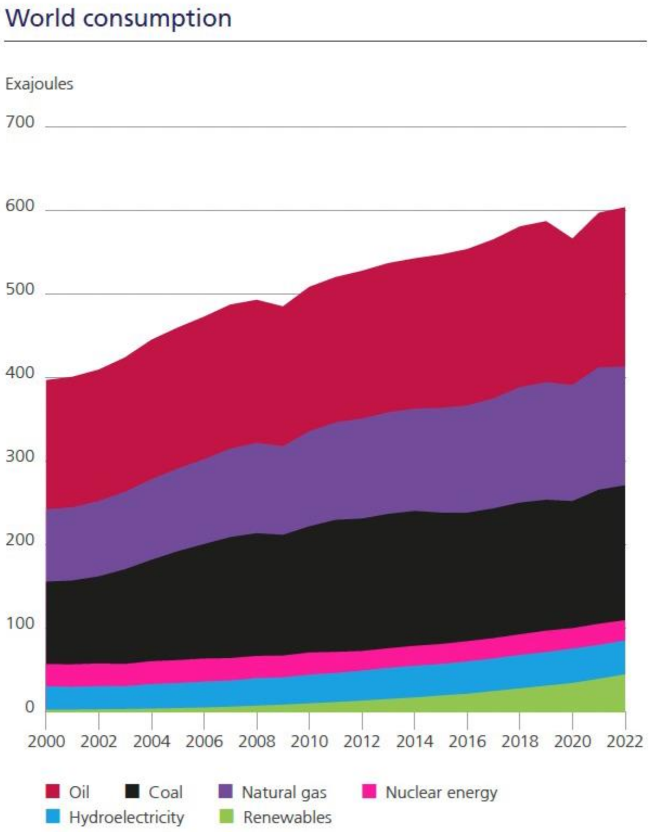
Note: Required coursework must be completed prior to attending SAGE, but does not have to be completed prior to submitting an application. Applicants currently enrolled in the above coursework will be considered to have met the coursework requirement.

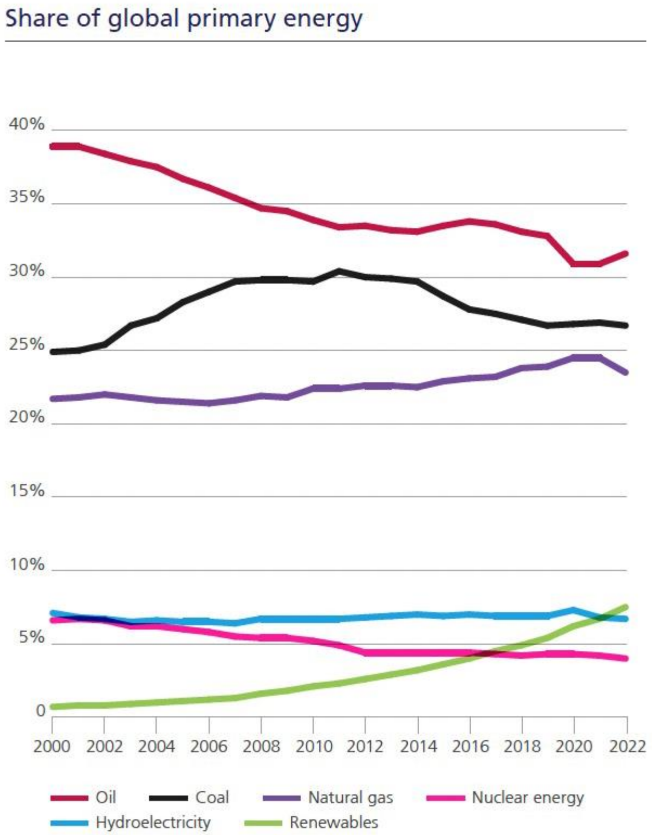
Step 2: Complete Online Application Form

Please fill out the online application form to the best of your ability, which will be a Google Form posted here at the start of the application period.

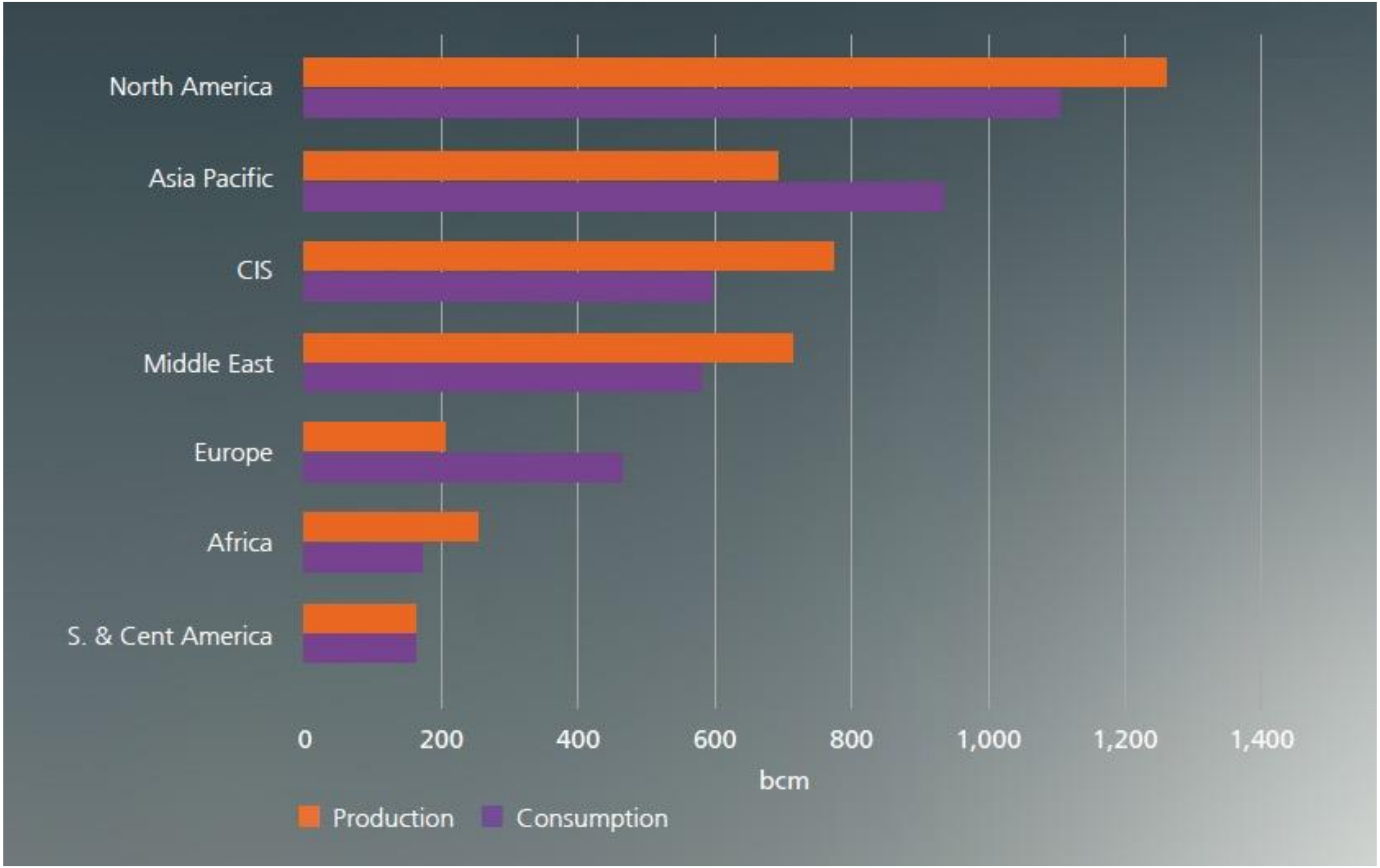
Submit a letter (limit one page, single-spaced) explaining how your educational background, courses,

World Energy Consumption



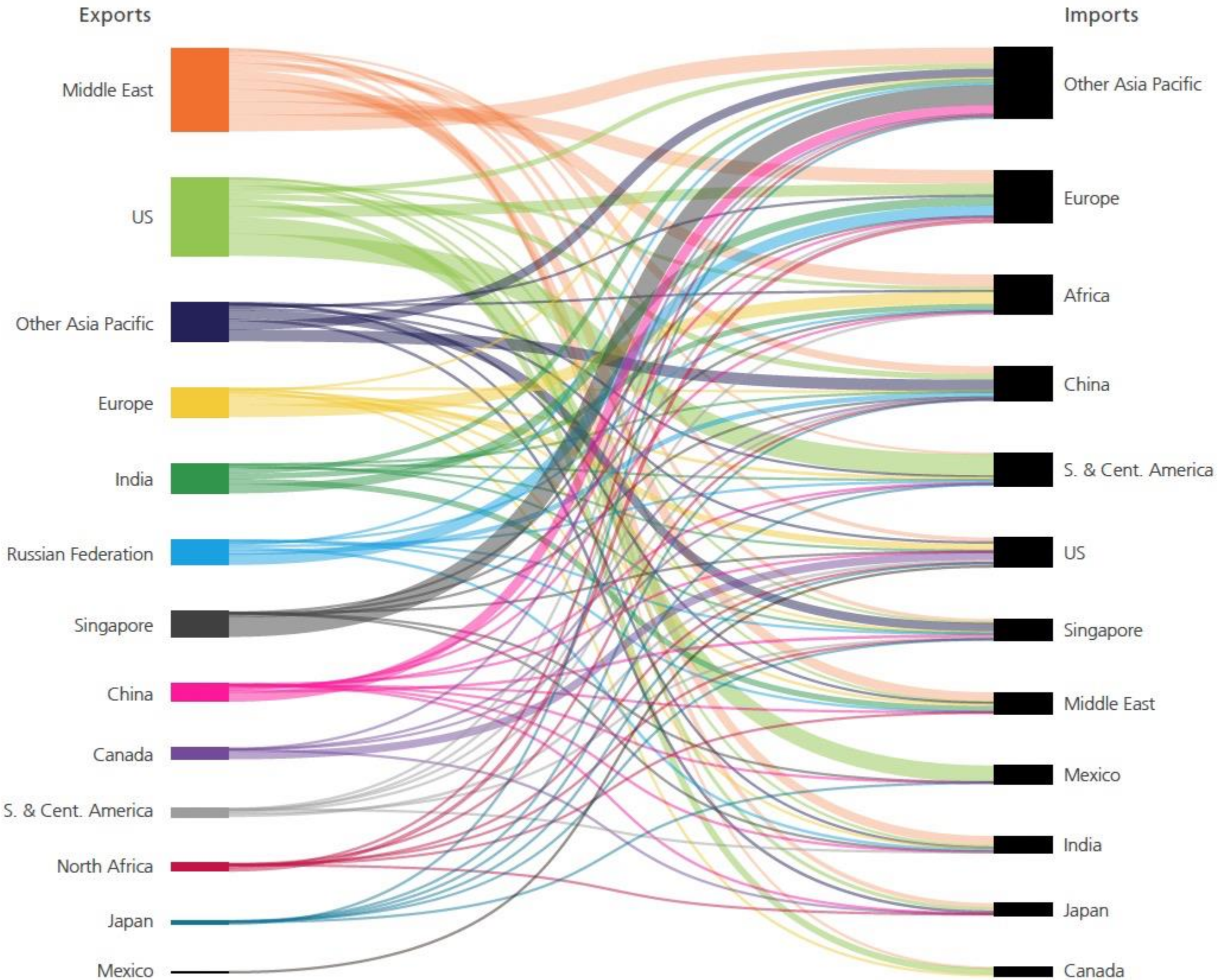


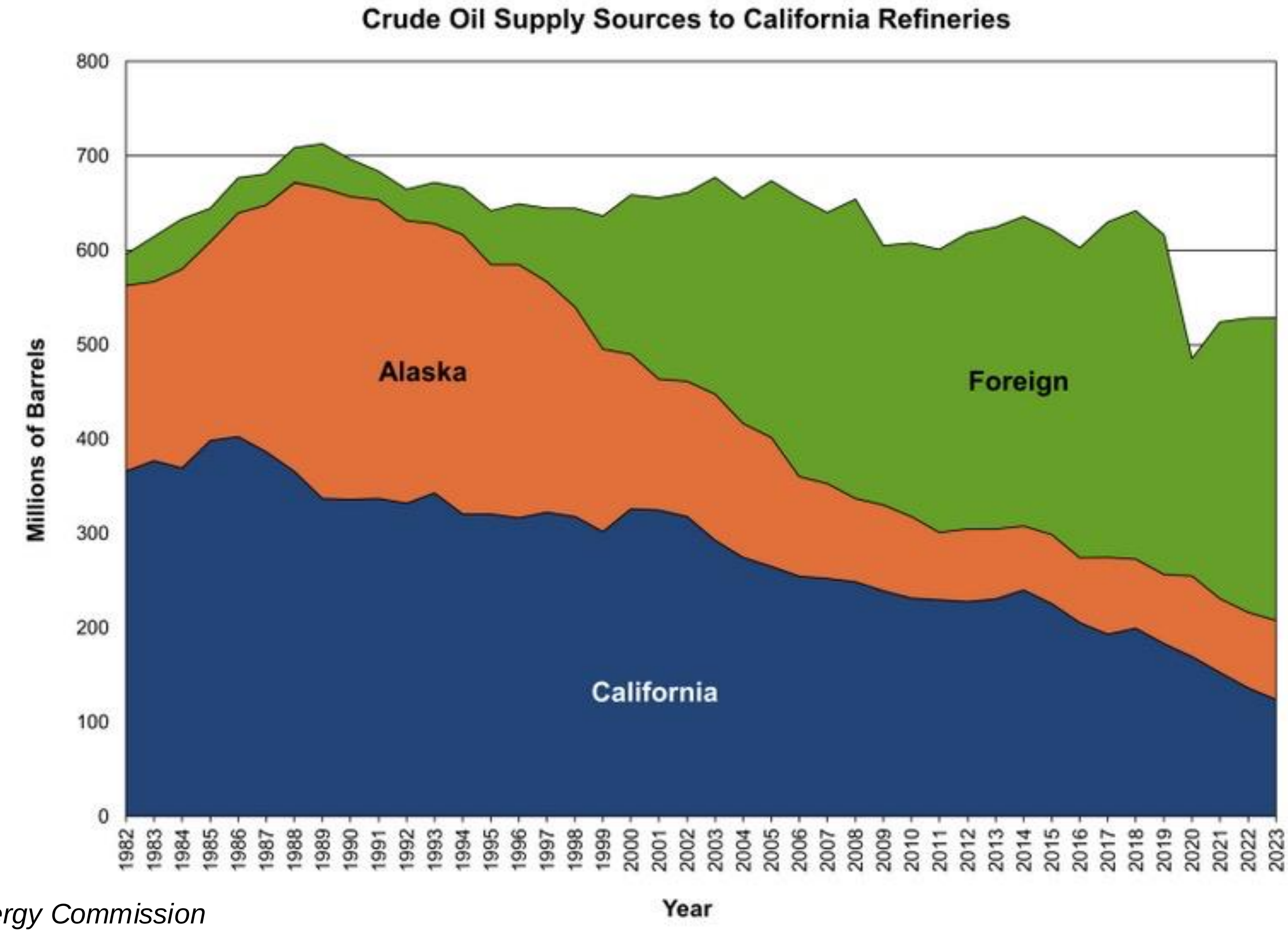
Energy Institute, 2023



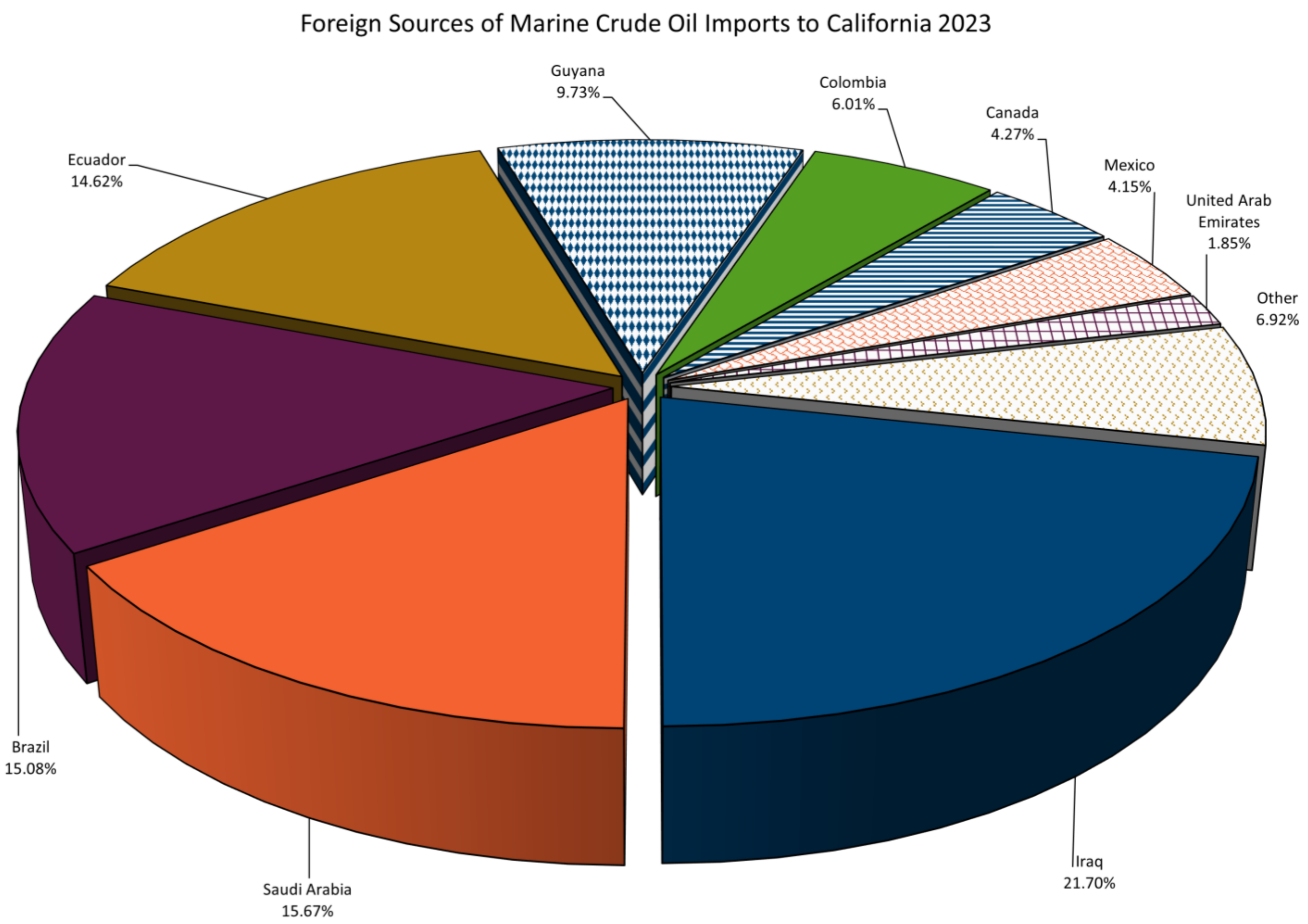
North America
Asia Pacific
CIS
Middle East
Europe
Africa
S. & Cent America
0
200
400
600
800
1,000
1,200
1,400
bcm
Production
Consumption

Oil Inter-area movements 2023 – Refined product



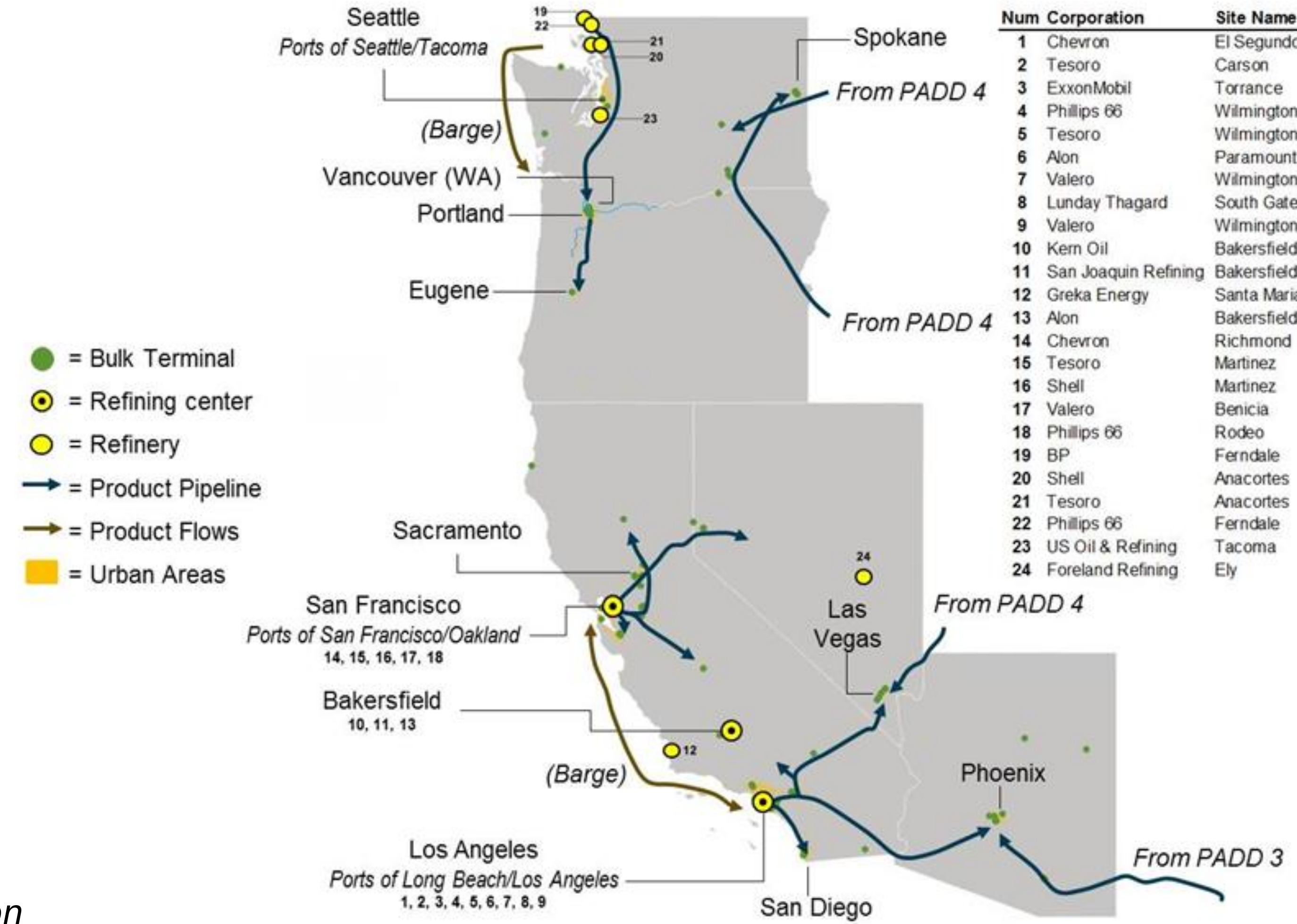


California Energy Commission



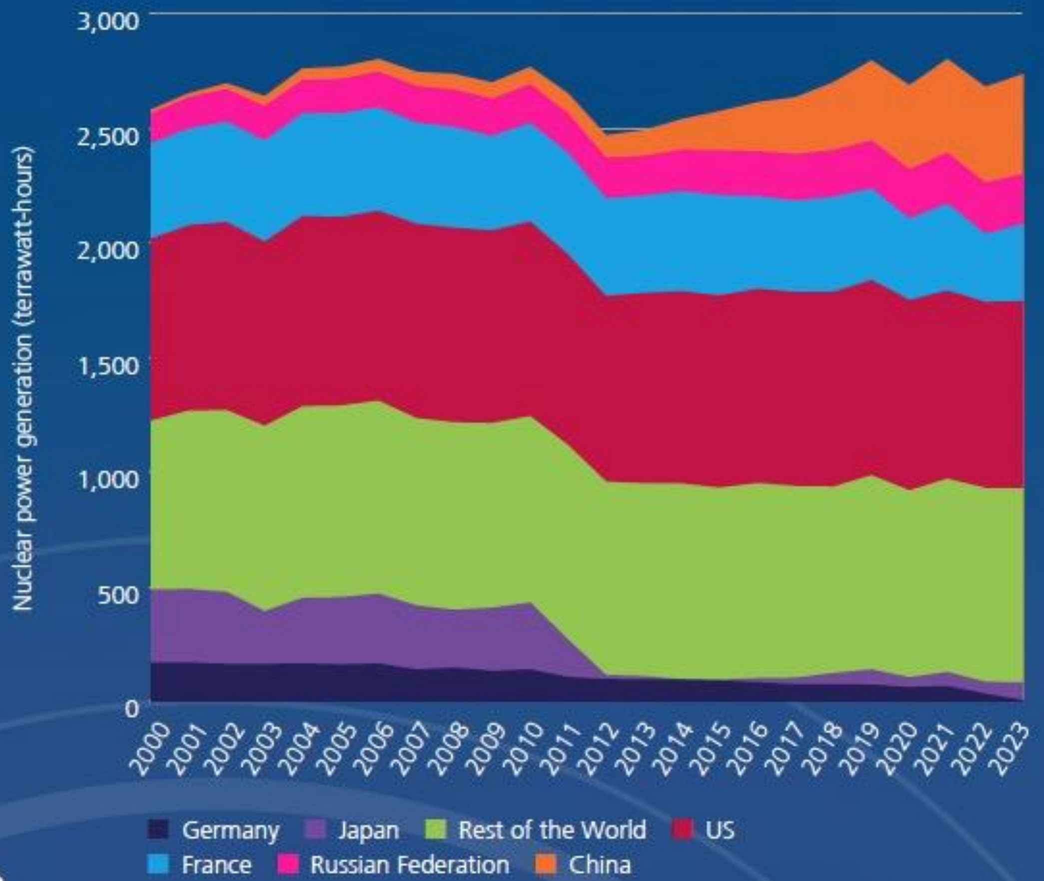
California Energy Commission

West Coast petroleum product supply map

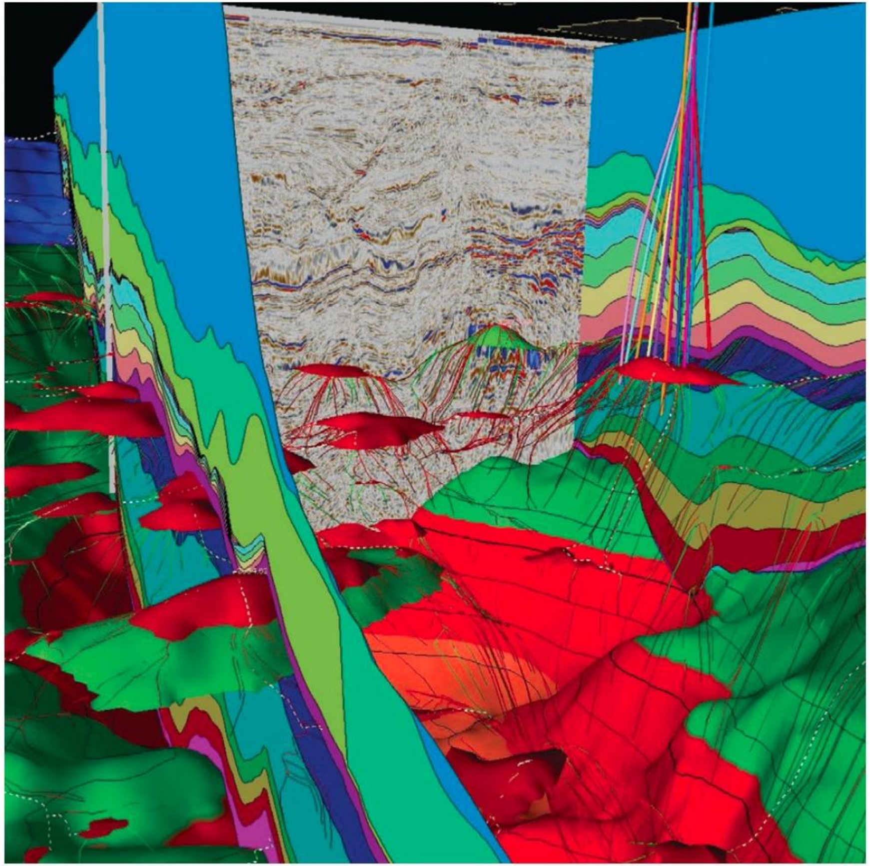


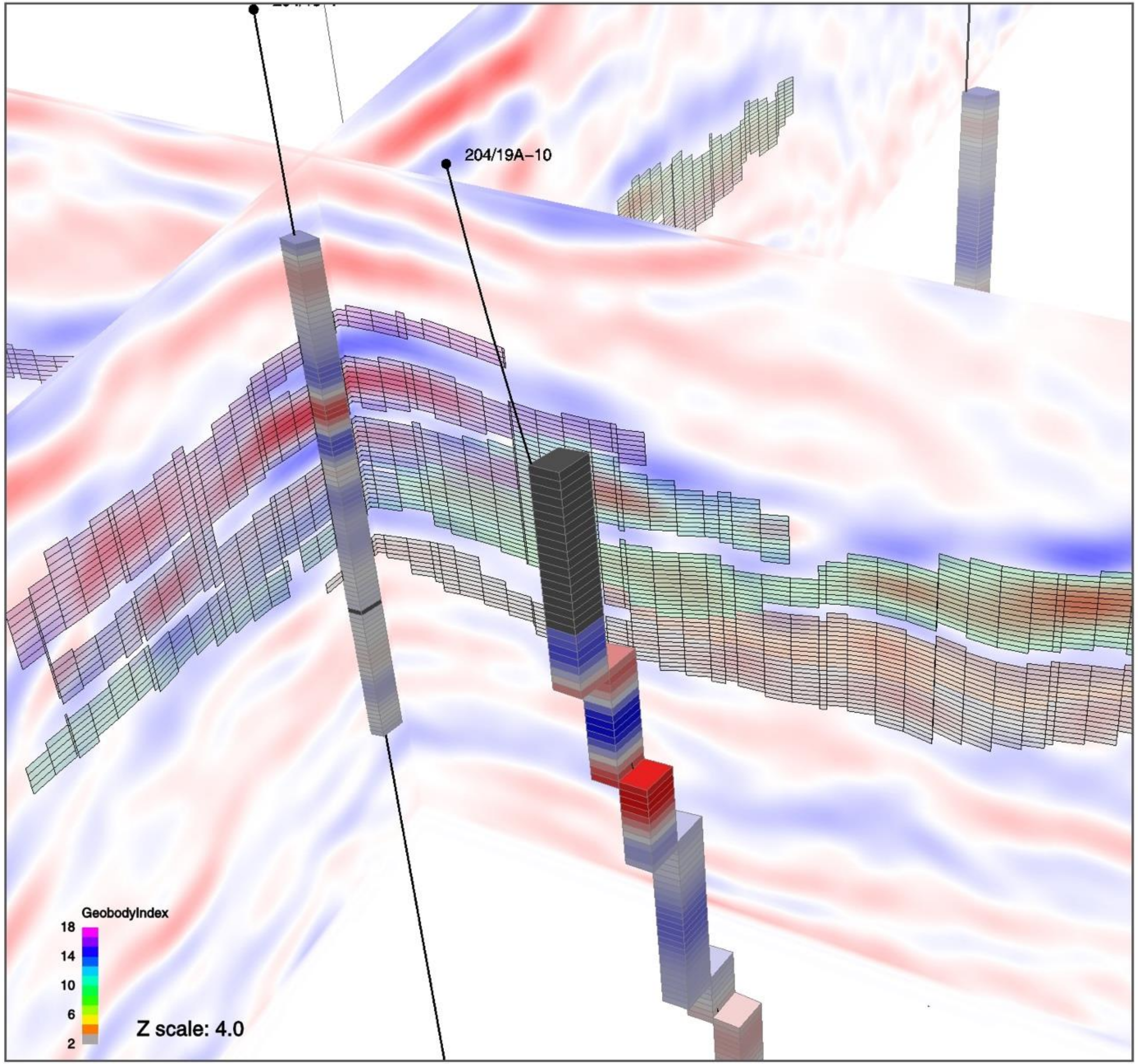
Num	Corporation	Site Name	Capacity (bbl/d)
1	Chevron	El Segundo	269,000
2	Tesoro	Carson	251,000
3	ExxonMobil	Torrance	149,500
4	Phillips 66	Wilmington	139,000
5	Tesoro	Wilmington	104,500
6	Alon	Paramount	Idle
7	Valero	Wilmington	78,000
8	Lunday Thagard	South Gate	8,500
9	Valero	Wilmington (asphalt)	6,300
10	Kern Oil	Bakersfield	26,000
11	San Joaquin Refining	Bakersfield	15,000
12	Greka Energy	Santa Maria	9,500
13	Alon	Bakersfield	No CDU
14	Chevron	Richmond	245,271
15	Tesoro	Martinez	166,000
16	Shell	Martinez	156,400
17	Valero	Benicia	132,000
18	Phillips 66	Rodeo	120,200
19	BP	Ferndale	225,000
20	Shell	Anacortes	145,000
21	Tesoro	Anacortes	120,000
22	Phillips 66	Ferndale	101,000
23	US Oil & Refining	Tacoma	40,700
24	Foreland Refining	Ely	2,000

Before Fukushima in 2011, nuclear met 25% of Japan's electricity demand and 23% of Germany's. In 2023, it met only around 8% in Japan and just 2% in Germany

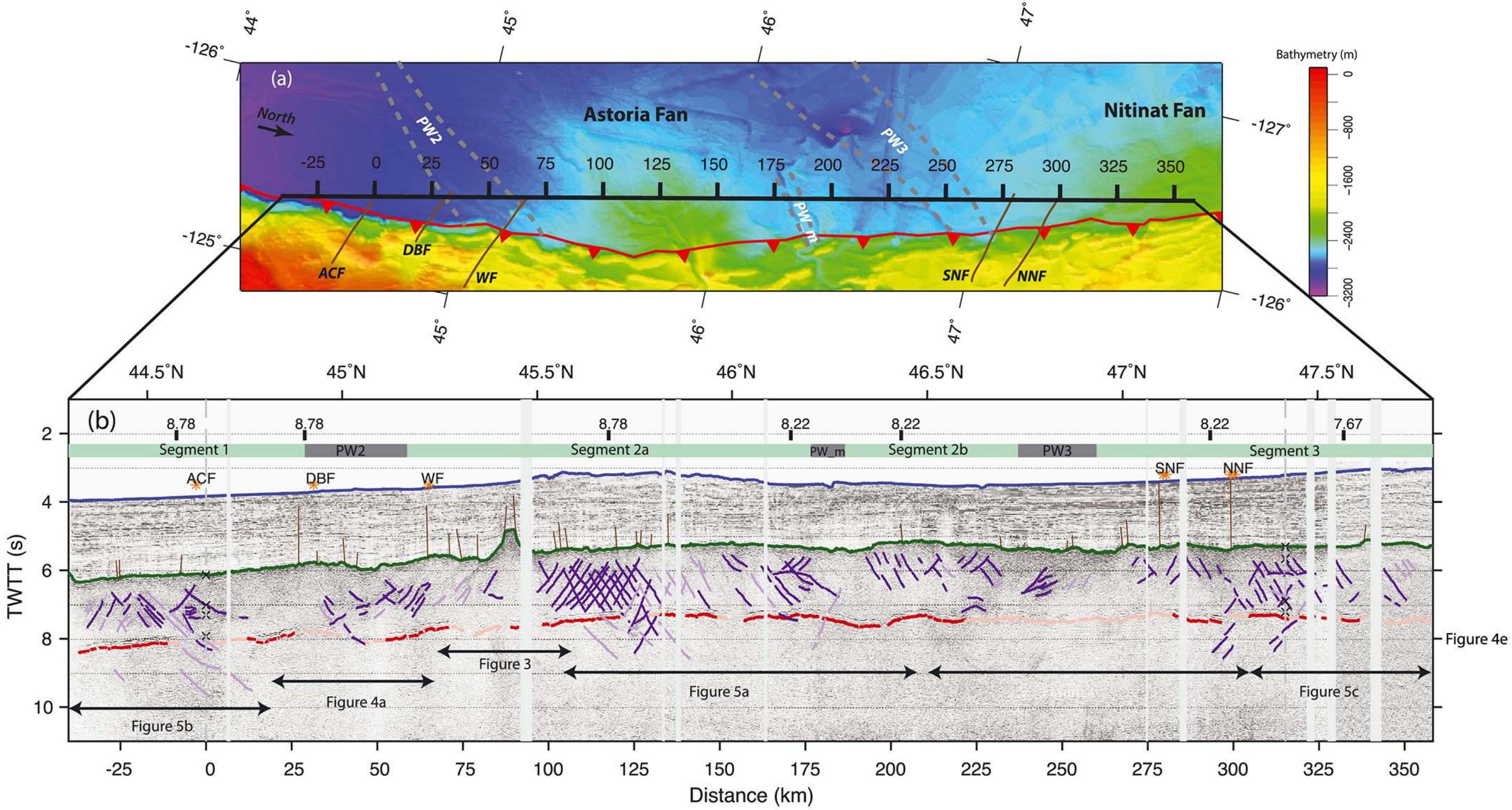


Exploration & Development

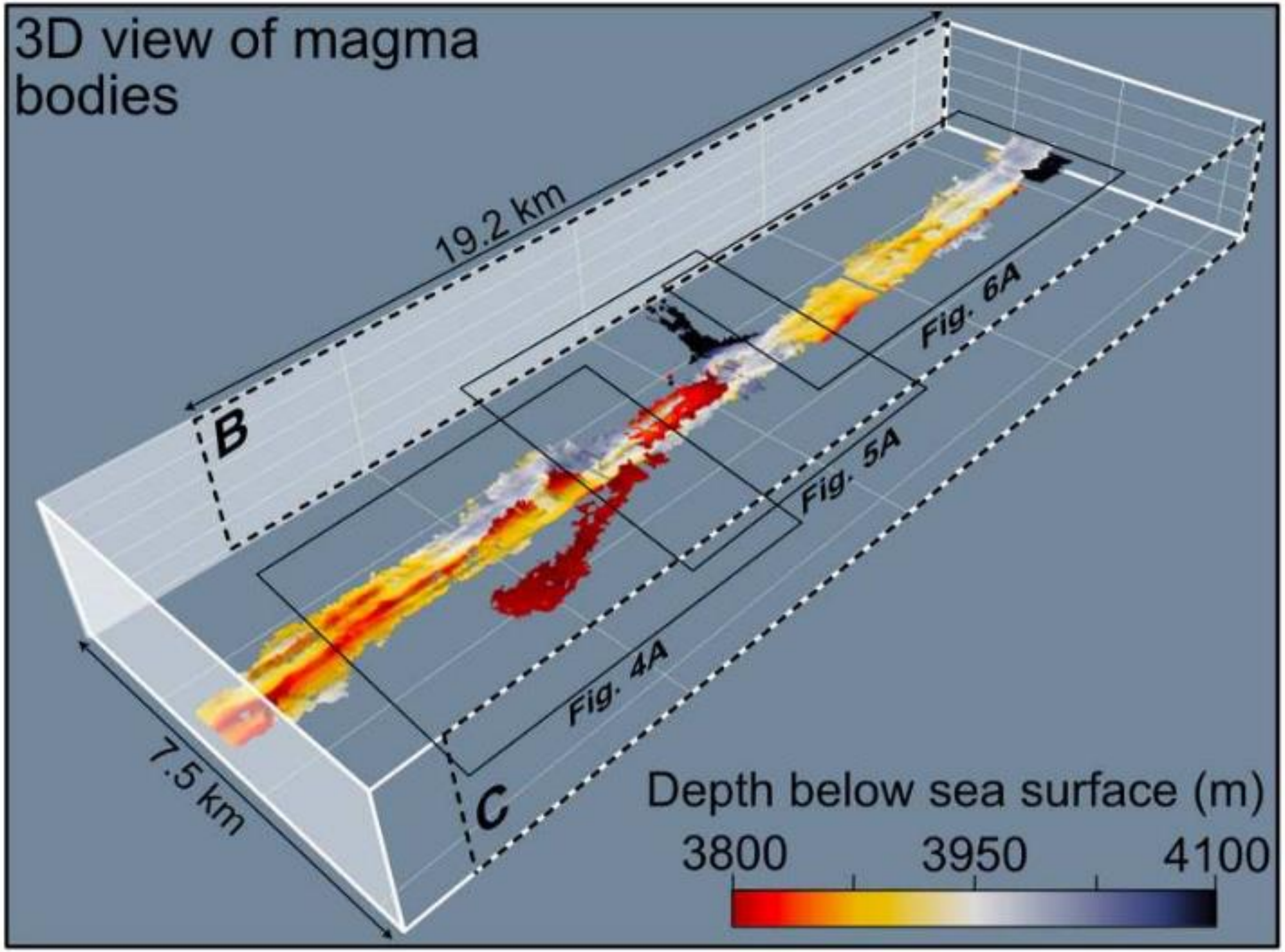




204/19A-10
GeobodyIndex
18
14
10
6
2
Z scale: 4.0

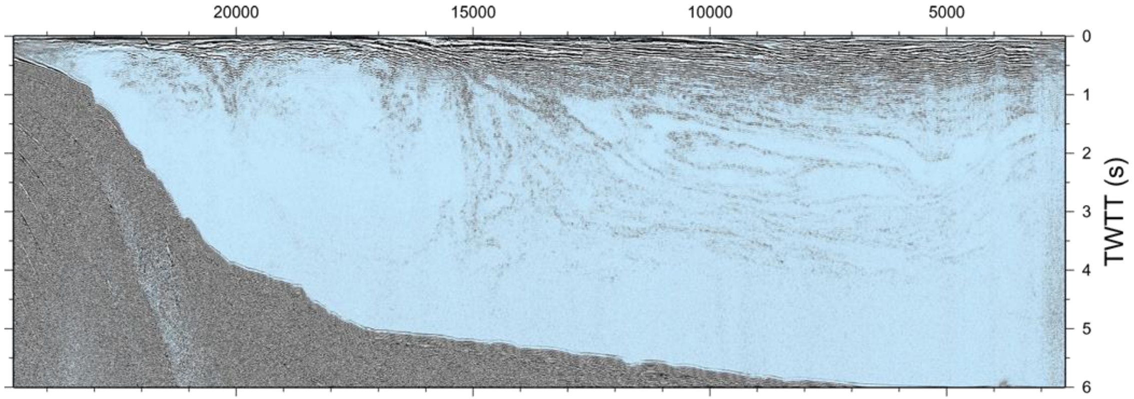


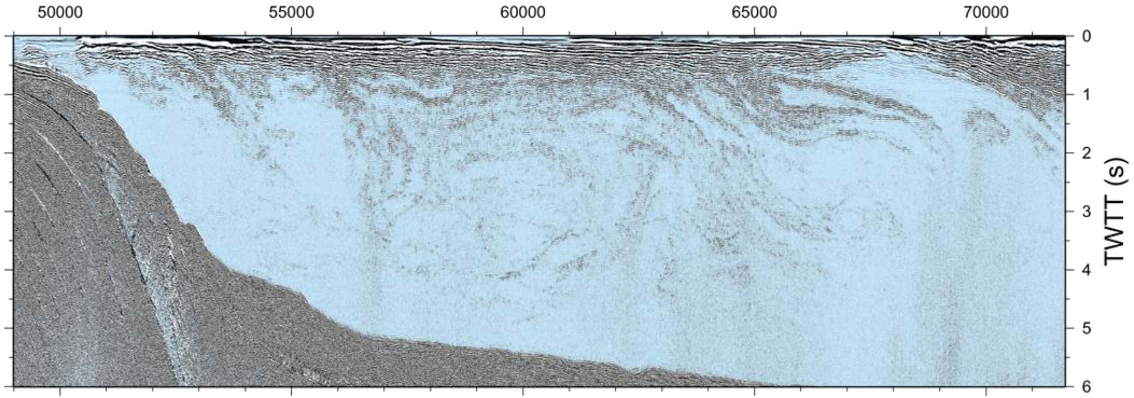
Han et al., 2018



Marjanović et al., 2023

Seismic oceanography



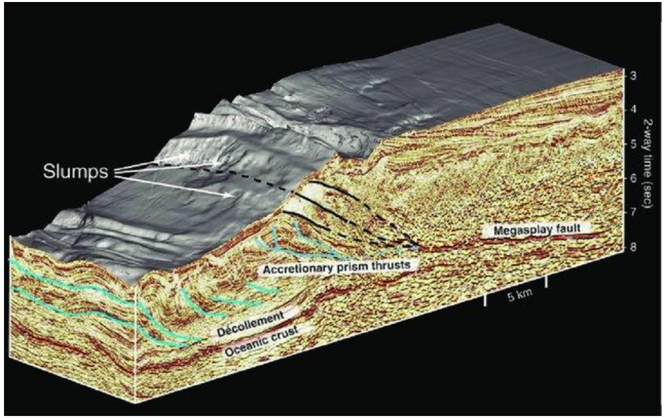


Steven Holbrook

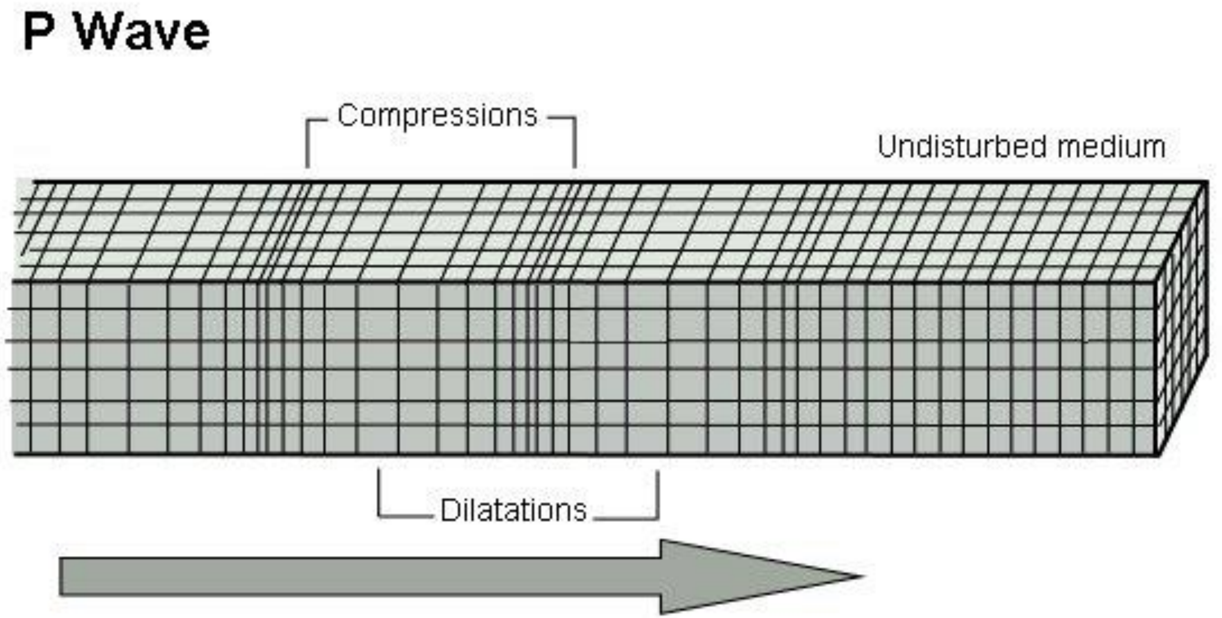
Basic Principles

1. Generate acoustic energy (controlled source)
2. Reflection and transmission occurs at interfaces
3. Record energy
4. Process
5. Interpret

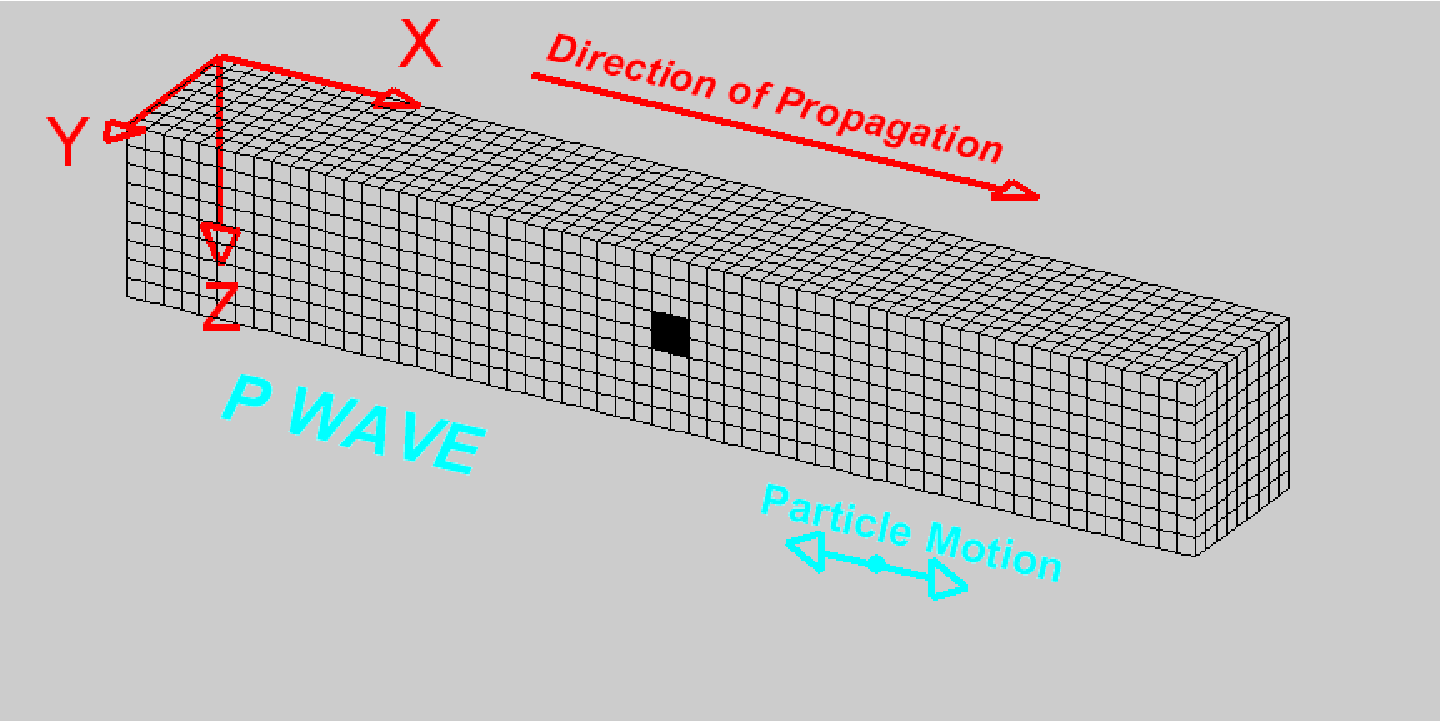
Energy must penetrate at sub-critical angles...i.e. close to normal incidence



Body Waves: P-waves



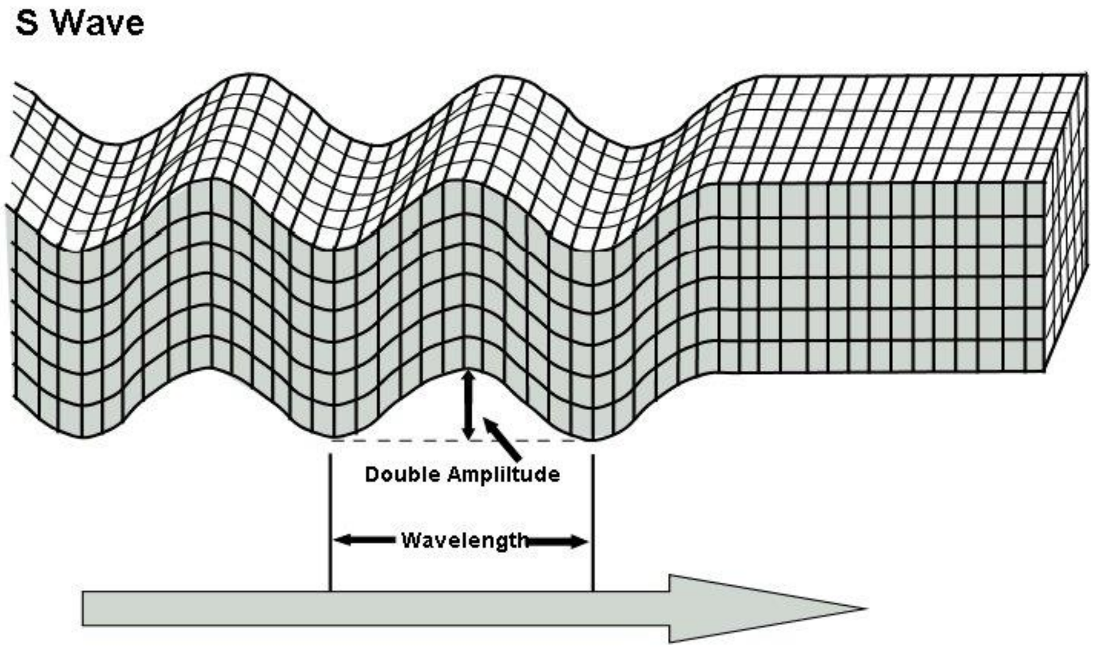
Primary Wave: P wave is a **compressional** (or longitudinal) wave in which rock (particles) vibrates back and forth **parallel** to the direction of wave propagation. P-waves are the first arriving wave and have high frequencies but their amplitude tends not to be very large



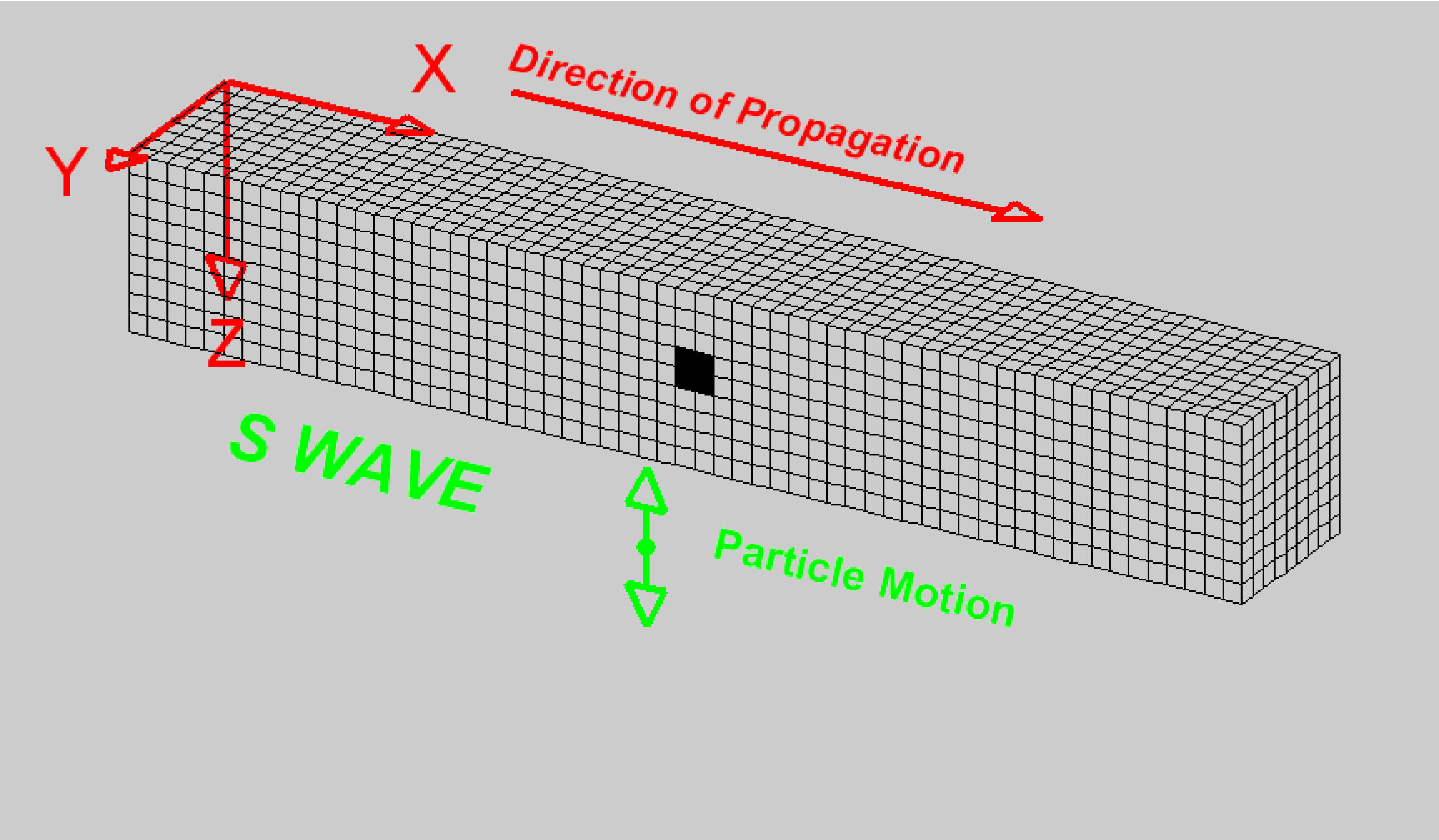
5 – 7 km/s in Earth's crust
> 8 km/s in Earth's mantle and core
1.5 km/s in water; 0.3 km/s in air

L. Braile, Purdue University

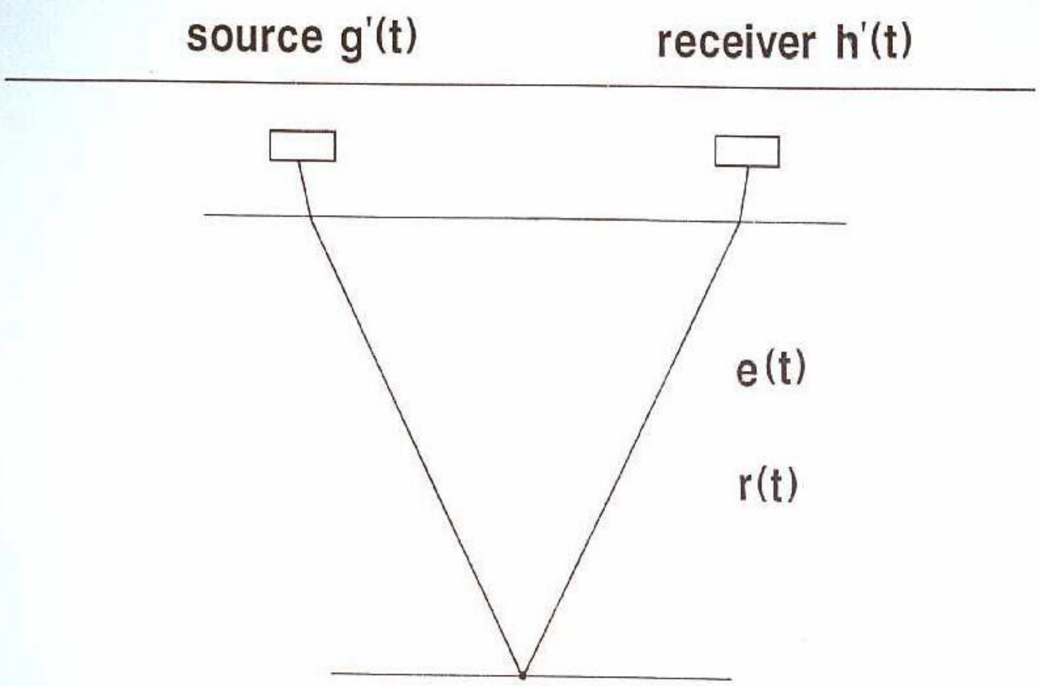
Body Waves: S-waves



Secondary Wave: S wave is a slower, **transverse** wave propagated by shearing motion much like that of a stretched, shaken rope. The rock (particles) vibrate **perpendicular** to the direction of wave propagation. They tend to have higher amplitudes and lower frequencies than P-waves. S-waves cannot travel through liquids (i.e., the outer core, the oceans)



L. Braile, Purdue University



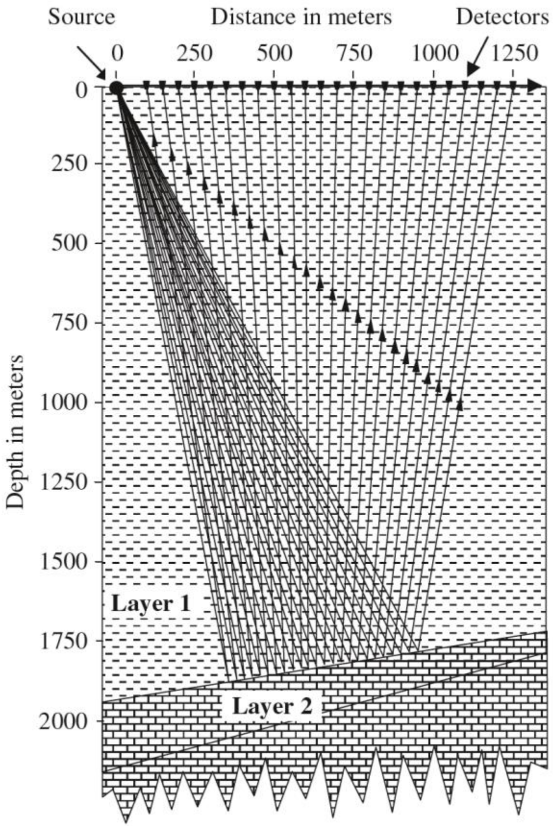
g'(t)	source response
h'(t)	receiver response
e(t)	effects of absorption Q
r(t)	reflectivity series

In a nutshell

acquisition		*processing*		*interpretation*
How data were acquired	+	What has been done to it	→	What it can tell you...and what it **cannot**!

- Data acquisition may have imposed fundamental limitations on what can be achieved
- Processing can always be improved

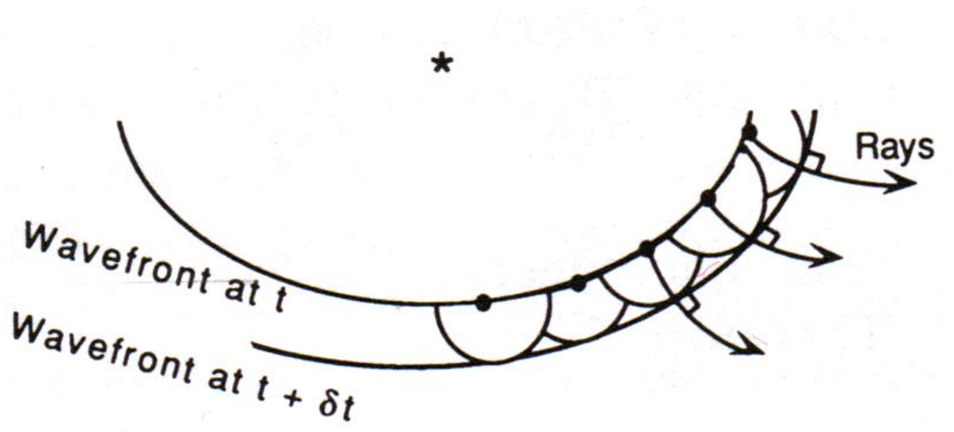
Key elements



- Source
- Wavefront and rays (Huygens principle...)
- Receiver
- Reflecting interface
- Acoustic impedance
- Seismic trace
- Two-way travel time > depth
- Seismic velocity

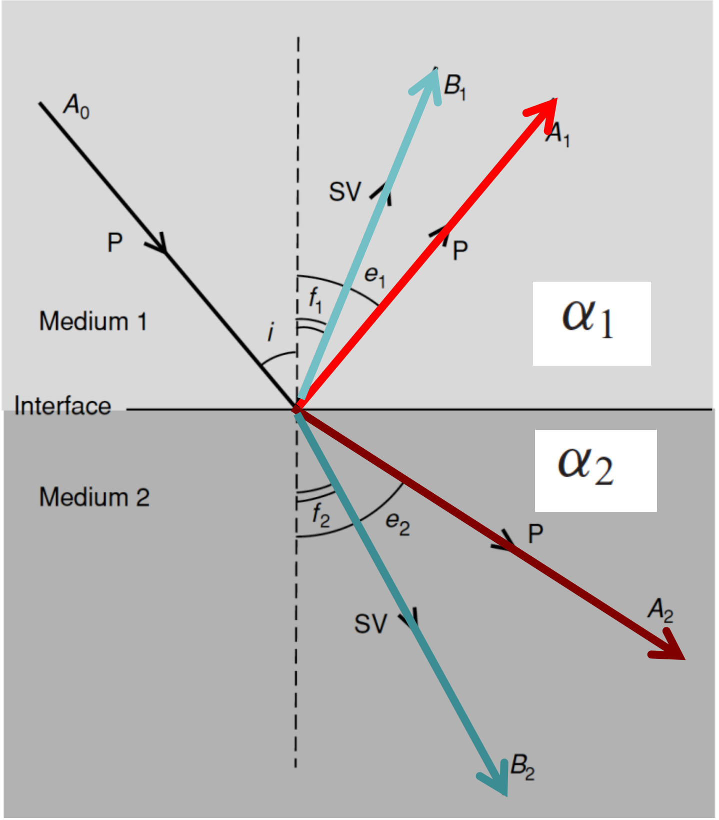
Rays and wavefronts

- Each point on the wavefront serves as a **secondary source**
- The tangent surface of the expanding waves gives the wavefront at later times



Huygens *Treatise on Light*, 1690

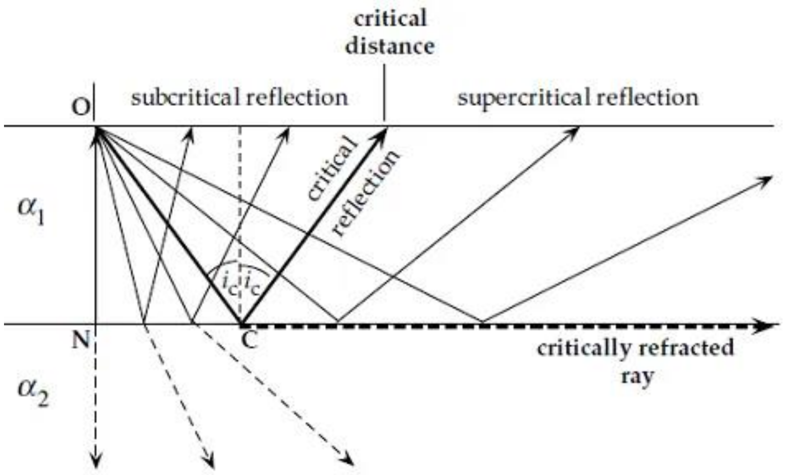
Snell's Law



Incident P-wave has amplitude A_0, angle of incidence i

$$\frac{\sin i}{\alpha_1} = \frac{\sin e_1}{\alpha_1} = \frac{\sin f_1}{\beta_1} = \frac{\sin e_2}{\alpha_2} = \frac{\sin f_2}{\beta_2}$$

Critical angles

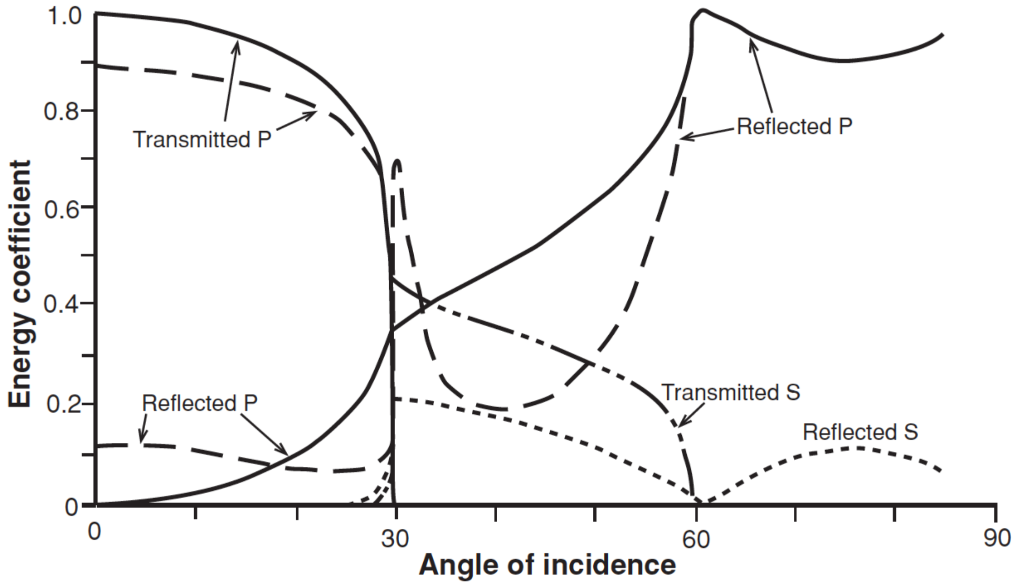


At *i* < critical angle, most of energy is transmitted - only small amount is reflected back at each interface

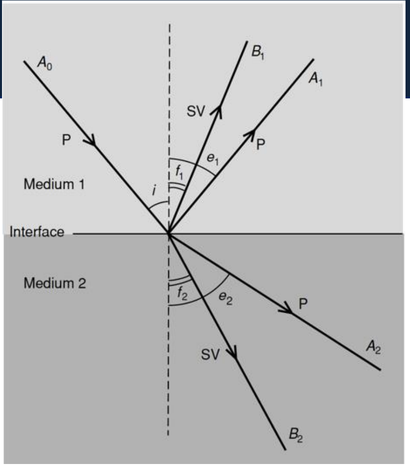
- Amplitude of subcritical reflections is very small
- Experiment designed to boost signal to noise ratio

Reflection coefficient

Reflection coefficient: ratio of the reflected or transmitted amplitude to the incident amplitude



Zoeppritz equations



To determine **relative** amplitudes, need displacements and stresses resulting from the wave fields

$$A_1 \cos e_1 - B_1 \sin f_1 + A_2 \cos e_2 + B_2 \sin f_2 = A_0 \cos i$$

$$A_1 \sin e_1 + B_1 \cos f_1 - A_2 \sin e_2 + B_2 \cos f_2 = -A_0 \sin i$$

$$A_1 Z_1 \cos(2f_1) - B_1 W_1 \sin(2f_1) - A_2 Z_2 \cos(2f_2) - B_2 W_2 \sin(2f_2) = -A_0 Z_1 \cos(2f_1)$$

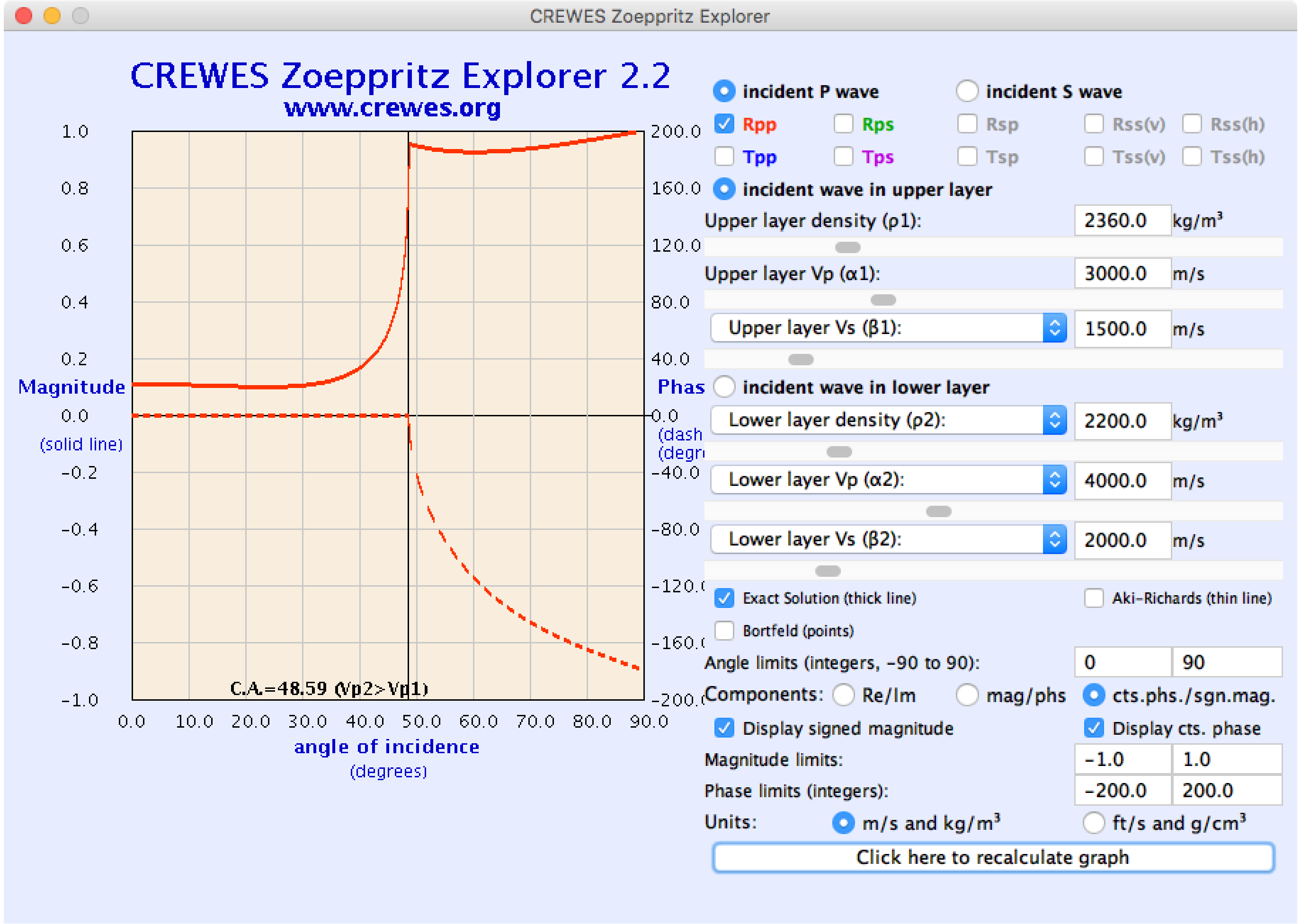
$$A_1 \gamma_1 W_1 \sin(2e_1) + B_1 W_1 \cos(2f_1) + A_2 \gamma_2 W_2 \sin(2e_2) - B_2 W_2 \cos(2f_2) = A_0 \gamma_1 W_1 \sin(2i)$$

$$Z_1 = \rho_1 \alpha_1, \qquad Z_2 = \rho_2 \alpha_2$$

$$W_1 = \rho_1 \beta_1, \qquad W_2 = \rho_2 \beta_2$$

$$\gamma_1 = \frac{\beta_1}{\alpha_1}, \qquad \gamma_2 = \frac{\beta_2}{\alpha_2}$$

Acoustic impedances Z and W: product of the density and seismic velocity



https://www.crewes.org/ResearchLinks/ExplorerPrograms/ZE/ZEcrewes2_2.html

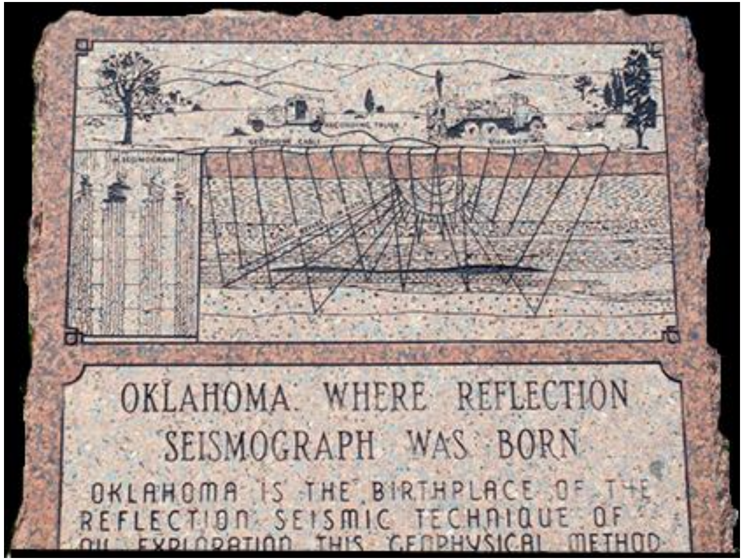
Reflection imaging in practice

Read: Kearey & Brooks, Chapter 4
Sections 4.4, 4.9, and 4.10

Key concepts

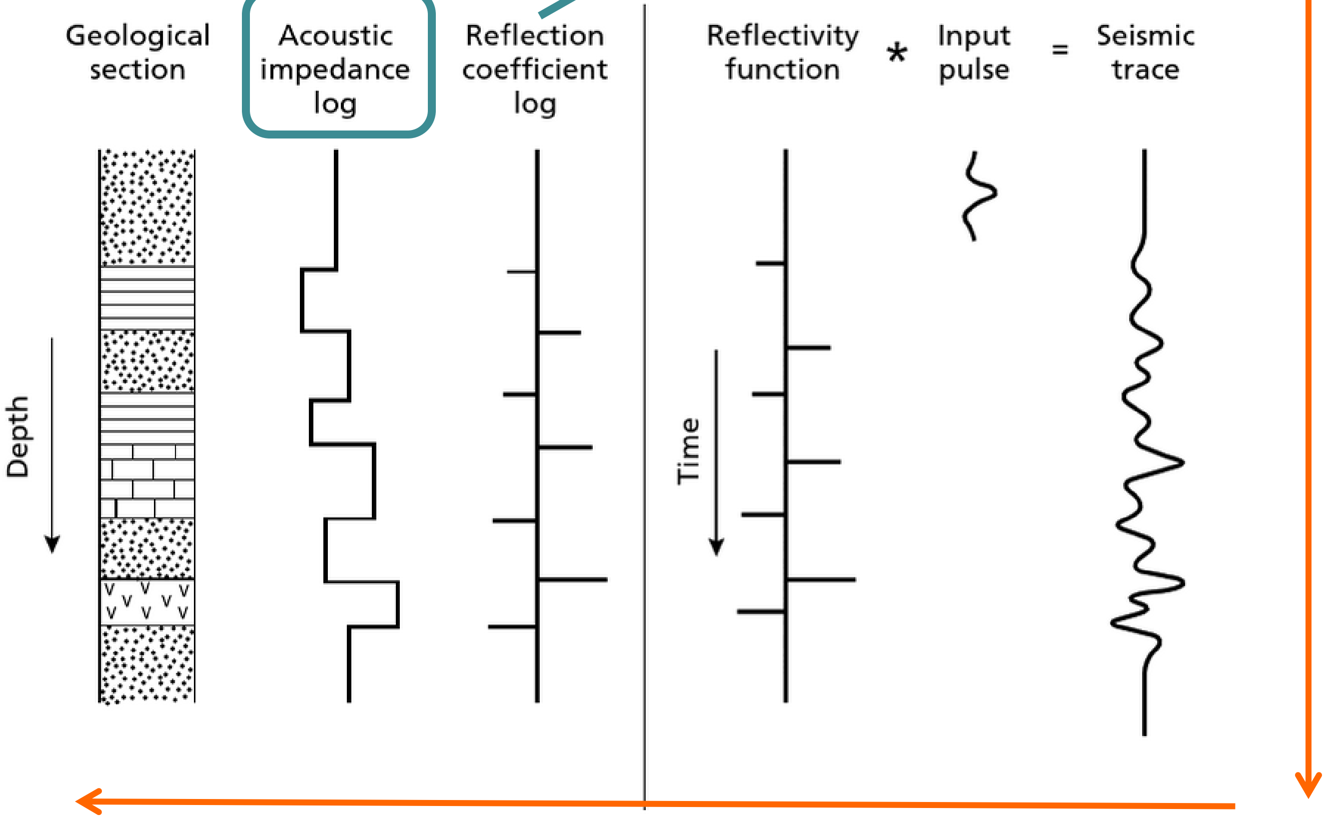
1. Convolution model
2. Shot gather vs. CMP gather
3. NMO and **stacking**
4. Migration

1. Surveys: sources and receivers



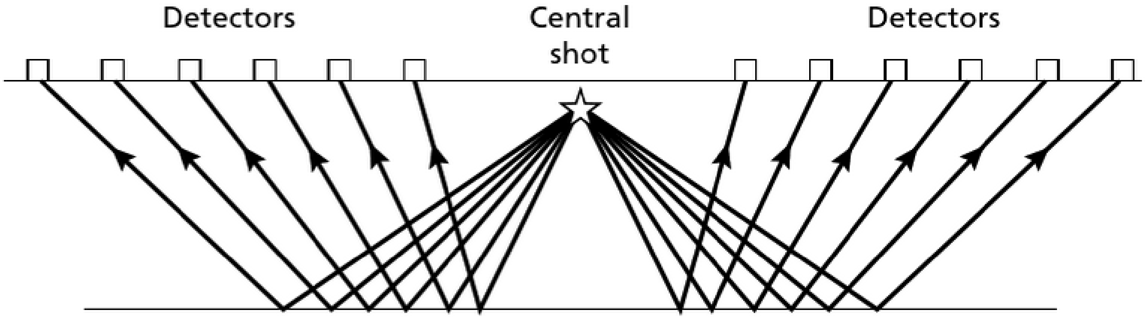
Convolution model

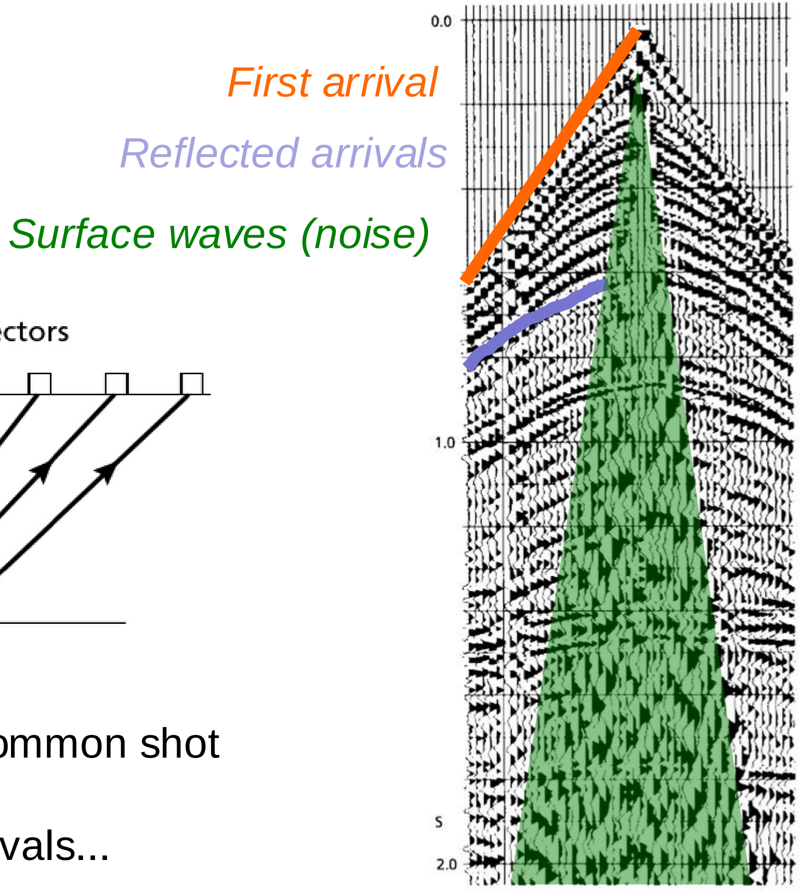
$$R_i = \frac{Z_1 - Z_2}{Z_1 + Z_2}$$



- Remove noise
- Determine/remove input pulse = reflectivity function
- Determine velocity function: conversion from time to depth
- Determine acoustic impedances (density, velocity) of rocks

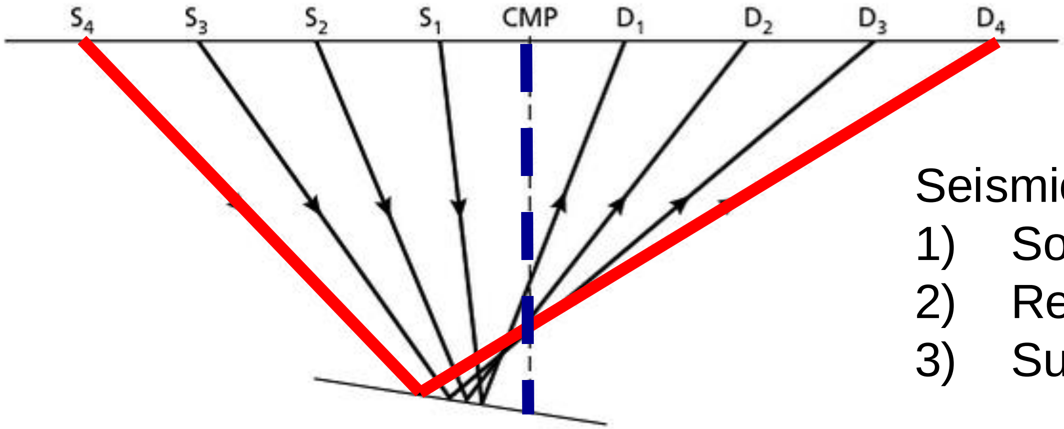
Shot gather





- Groups of seismic traces recorded from a common shot
- Useful initial QC step
- Note **hyperbolic move-out** on reflected arrivals...

Common mid-point (CMP) gather



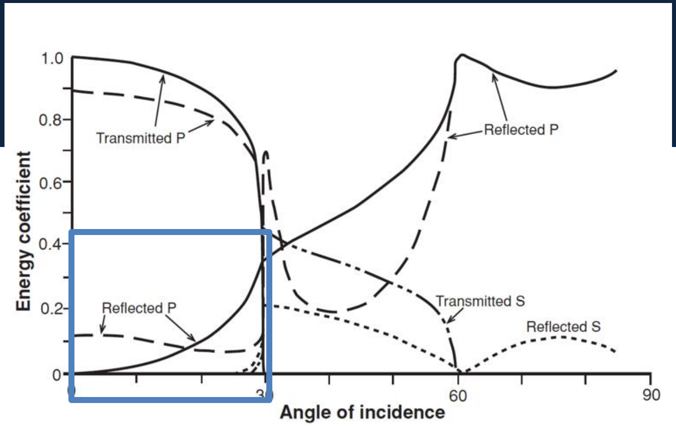
Seismic trace:

1) Source position
2) Receiver position
3) Subsurface reflection point

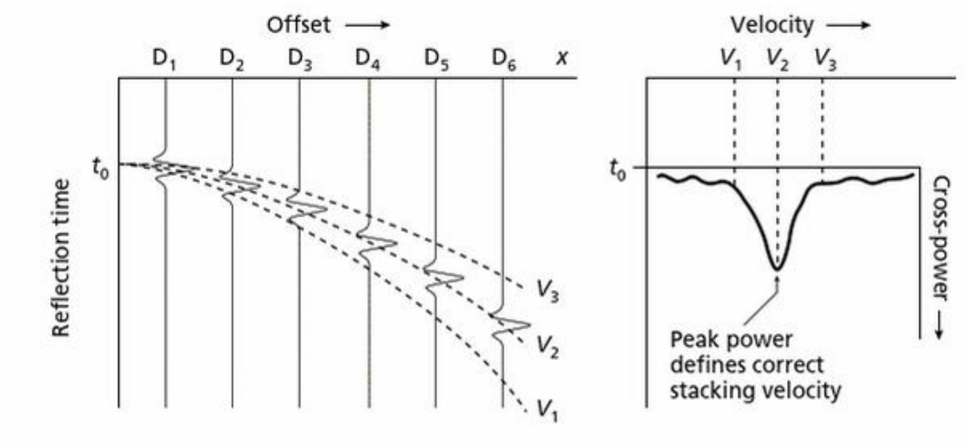
***CMP approximation**: reflection point lies vertically under the position on the surface mid-way between the shot and receiver for that trace*

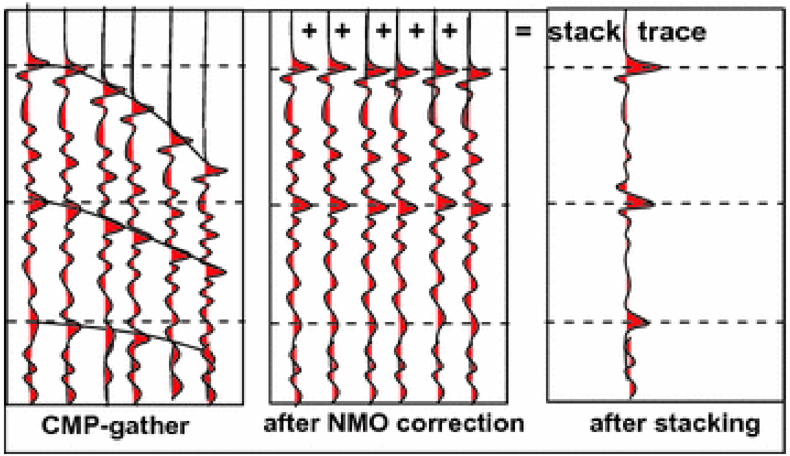
Noise, move-out, and stacking

Reflected seismic energy is usually very weak

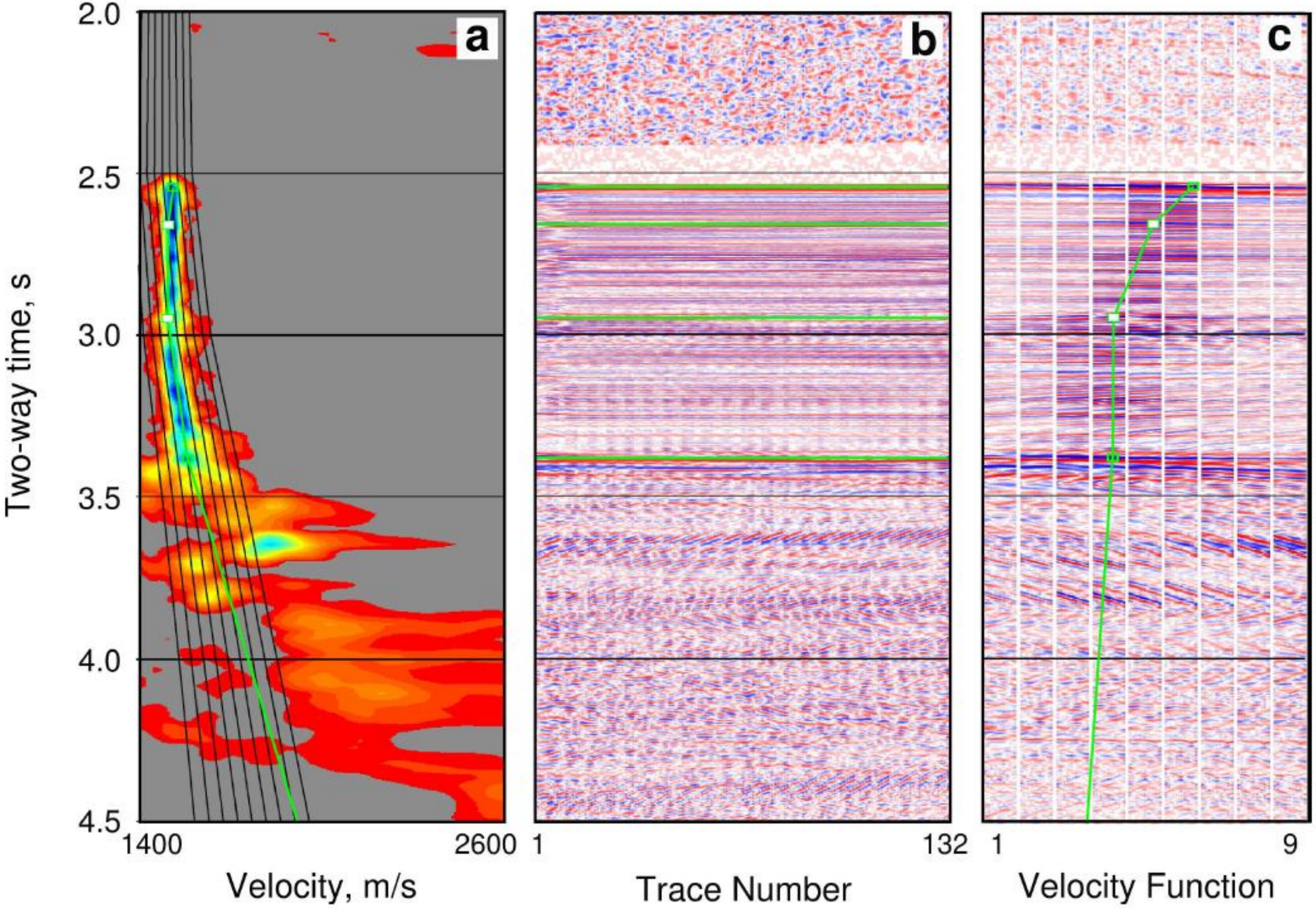


Normal move-out correction





- NMO corrected using a range of **trial velocity values** v1, v2, v3
- Cross-power is calculated as a function of v
- **Stacking velocity** produces peak cross-power

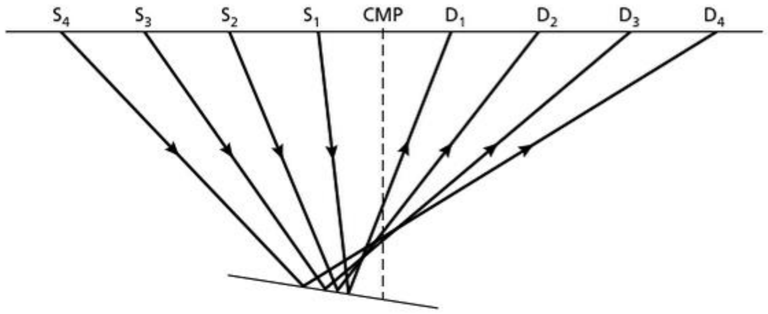

a
b
c
2.0
2.5
3.0
3.5
4.0
4.5
Two-way time, s
1400
2600
Velocity, m/s
1
132
Trace Number
1
9
Velocity Function

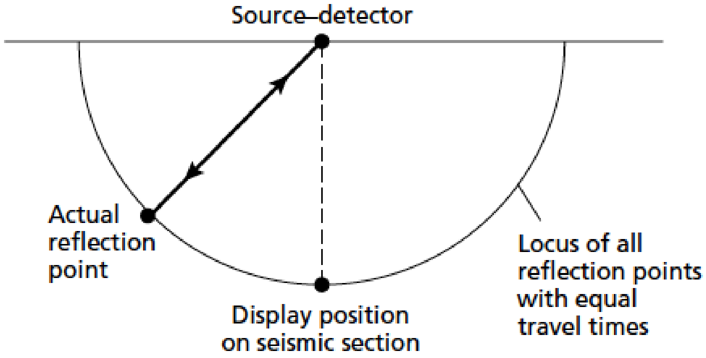
Migration

- CMP assumption: reflection point is located beneath the mid-point
- Only if the reflector is **horizontal**...

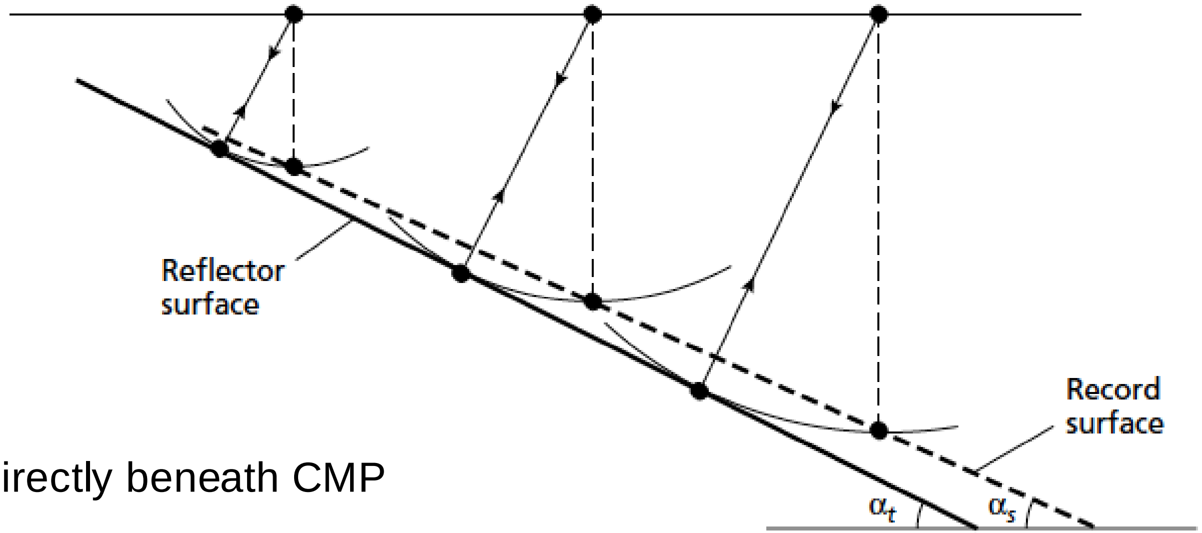
- Migration reconstructs seismic section so that reflection events are **repositioned** under their correct surface location and at a corrected vertical reflection **time**

- Time migration: vertical dimension = time
- Depth migration: times converted into reflector depths using appropriate **velocity**

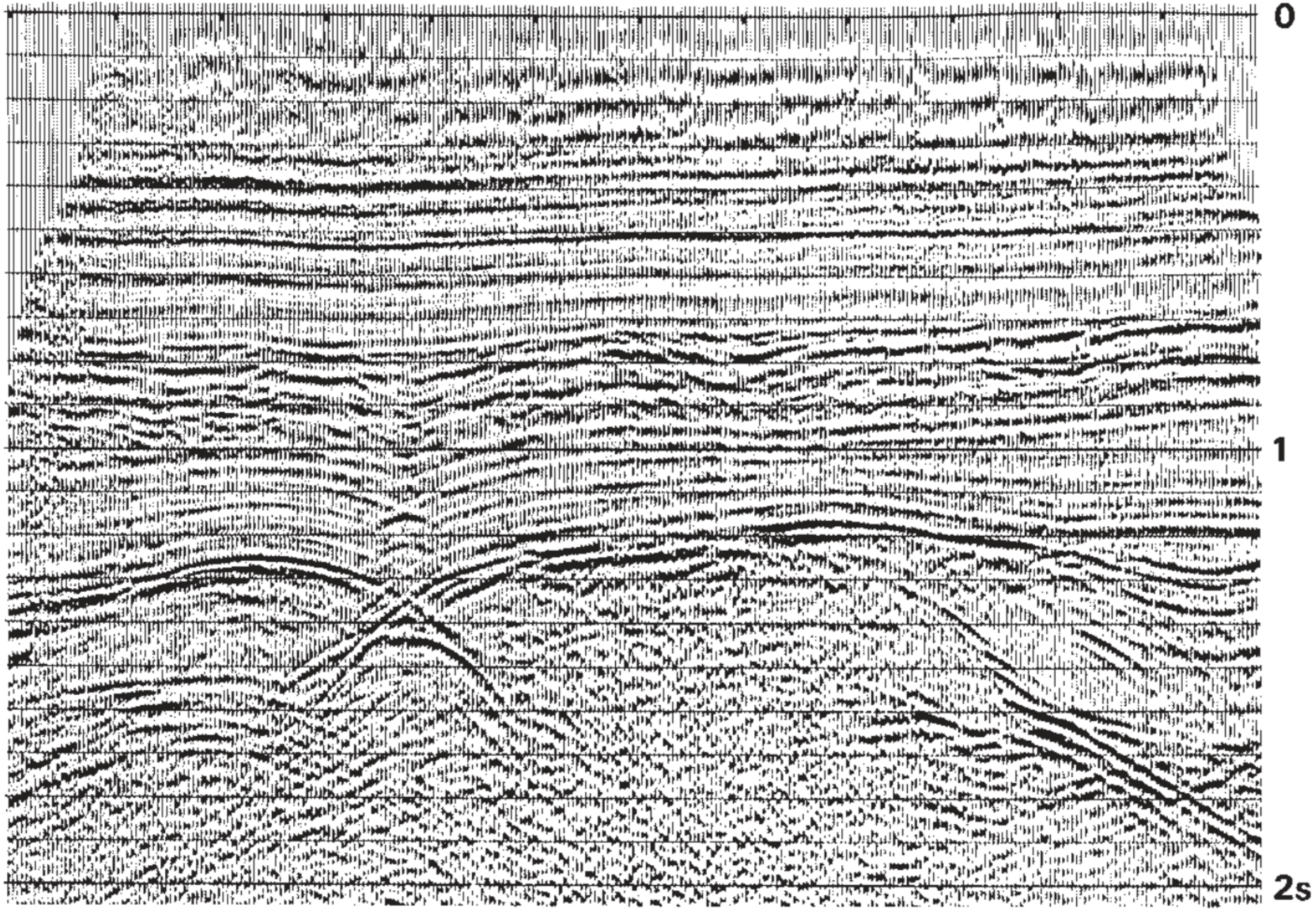


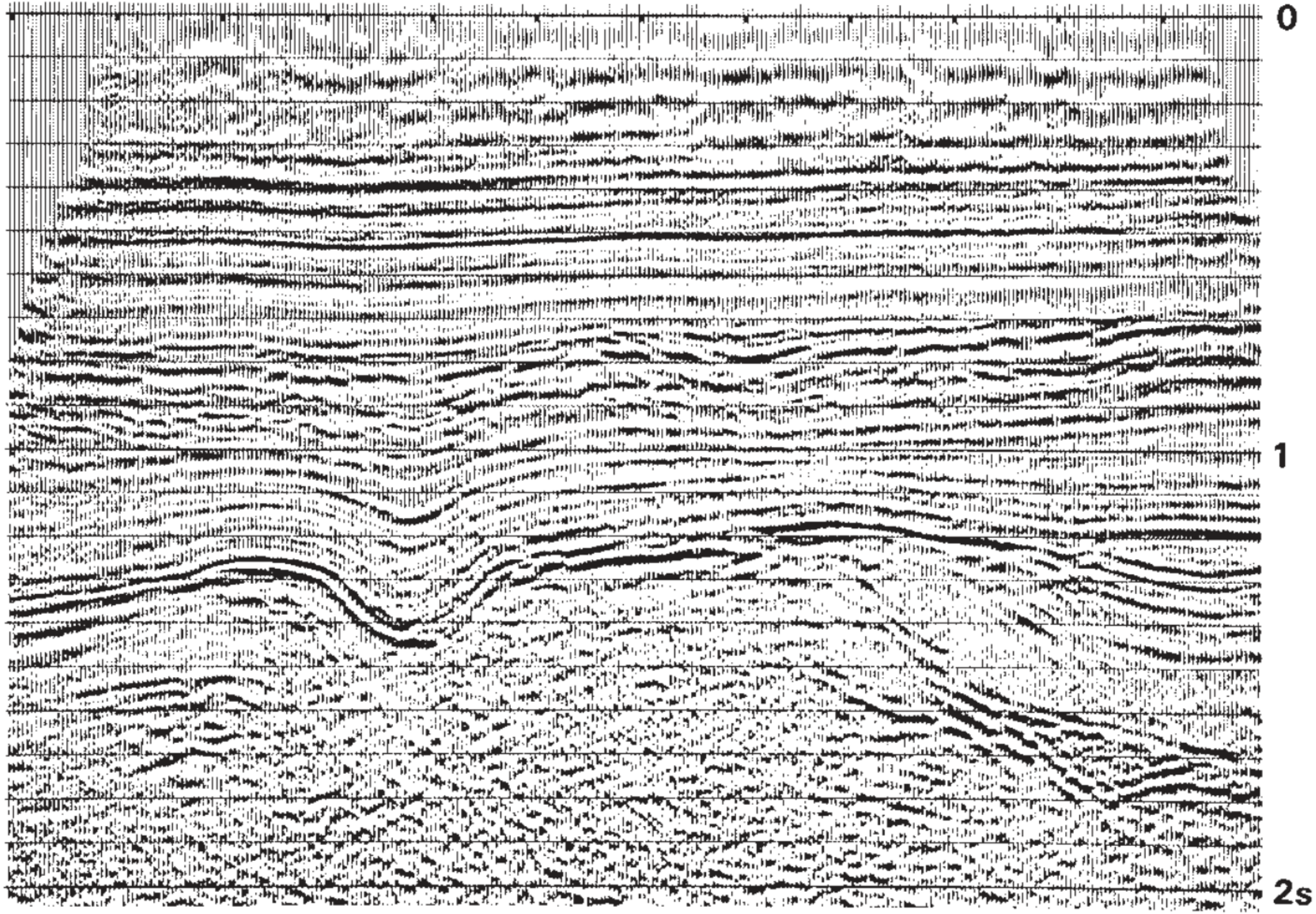


Migration

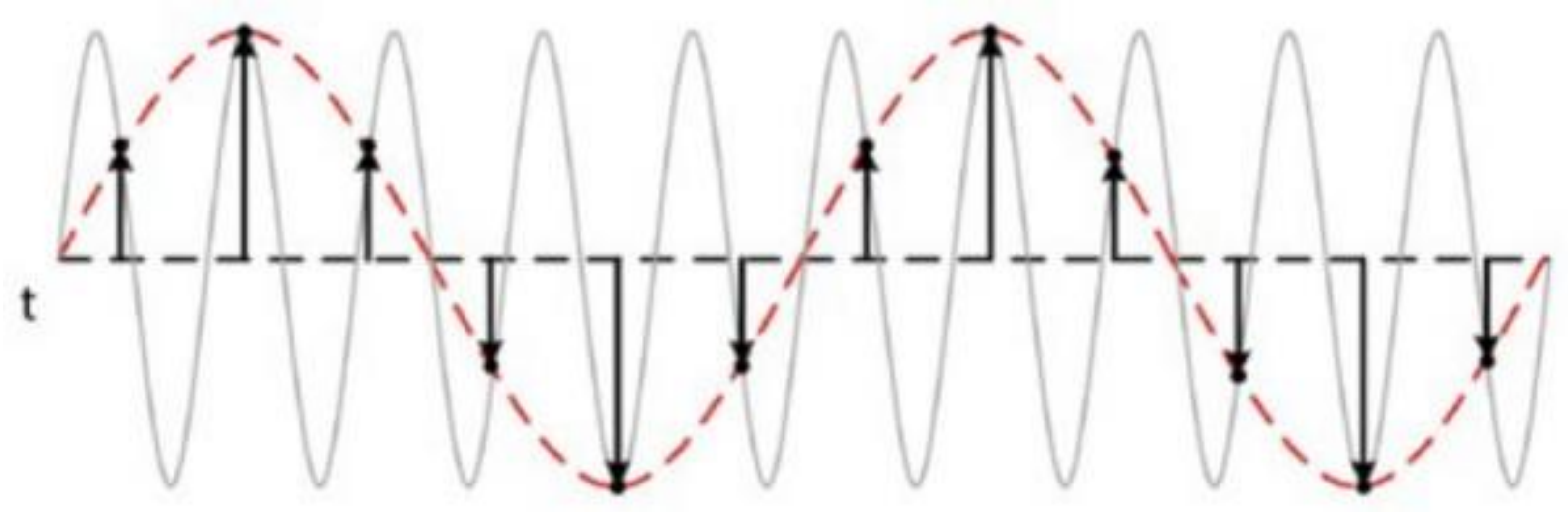


- Reflection events mapped directly beneath CMP
- BUT, could lie anywhere on a semi-circle centered on source–detector position
- Arcs of circles (wavefront segments) through all the mapped reflection points enables the actual reflector geometry to be mapped

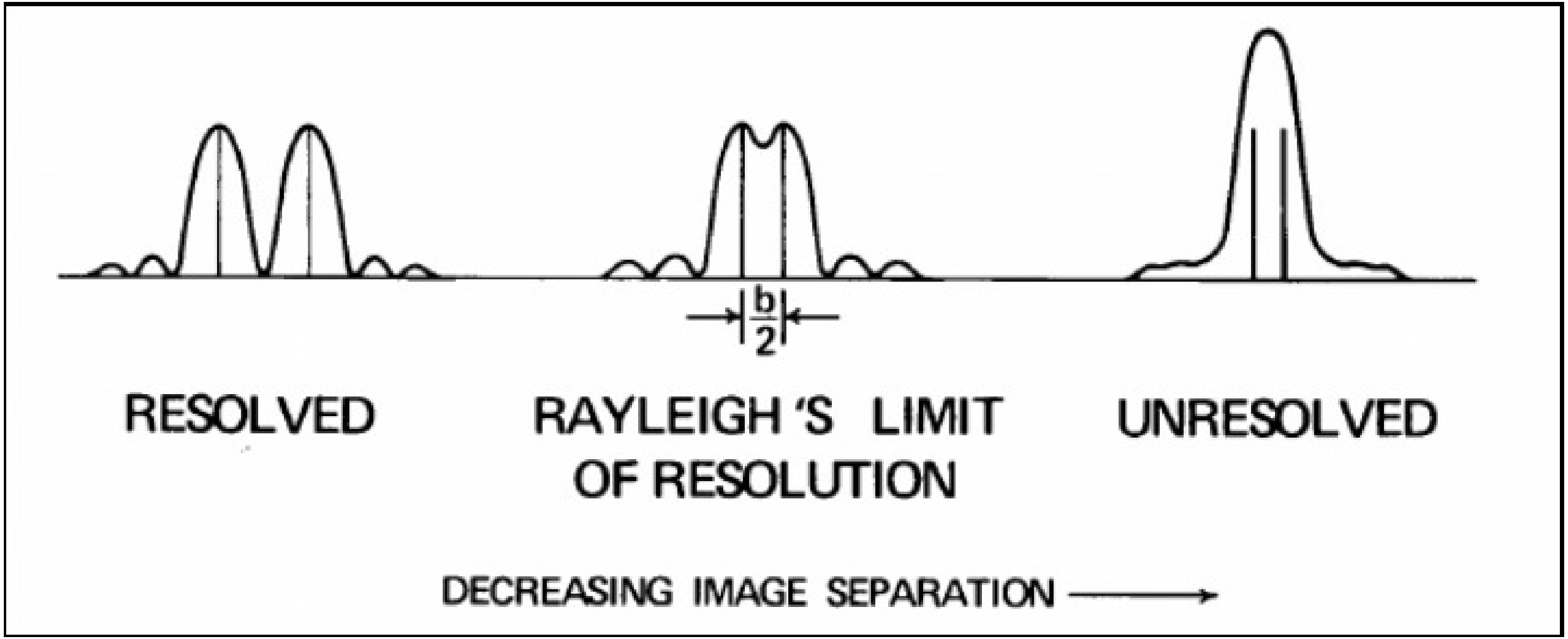

0
1
2s


0
1
2s

Sampling rate and Nyquist frequency



Vertical Resolution



Tuning thickness