# GEL2150

# Felt- og metodekurs i geologi og geofysikk

# Oppbygging av kurset

- Geofysiske undersøkelsesmetoder (MH, ØP)
  - Teori
  - Praktiske øvelser
- Syntetisk seismikk (MH, JJ)
  - Innledning
  - Feltkurs Ringerike
- Tektonikk og Sedimentasjon (JPN, JJ)
  - Innledning
  - Feltkurs Mjøsa-traktene
- Geologiske Feltmetoder (ON)
  - Forelesninger
  - Feltkurs Nevlunghavn

# Geofysiske undersøkelsesmetoder

- **Mål:** Praktisk innledning i de viktigste geofysiske metodene som blir brukt i industrien og forskningen

- **Arbeidsplan:**
  - **Forelesning:** Innføring geofysiske metoder (26.3)
  - **Praksis:**
    - Seismisk tolkningsøvelse (27.3; 1 dag)
    - Innsamling seismikk øvelse (29.3; 1 dag)
    - Innsammling tyngdeanomali øvelse (30.3; 1 dag)

# Geofysiske undersøkelsesmetoder

- Teori
- Innsamling og Prosessering
- Styrke og Svakheter

# Geofysiske undersøkelsesmetoder

- **Passiv:**

  Metode som bruker Jordens naturlige egenskaper, f.e. tyngde og magnetisme

- **Aktiv:**

  Metode som krever input av kunstig generert energi, f.e. innsamling av seismisk refleksjons data

- **Mål med geofysikk**

  er å lokalisere eller oppdage tilstedeværelsen av strukturer og legemer som befinner seg under jordoverflaten og bestemme deres størrelse, omfang, dybde og fysiske egenskaper (tetthet, hastighet, porositet o.l.) + væske innhold

# Geofysiske undersøkelsesmetoder

| **Metode** | **Engelsk** | **Parameter som måles** | **Fysiske egenskap** | **Anvendelse** |
|---|---|---|---|---|
| Tyngde | Gravity | Romlige variasjoner i styrken til Jordens tyngdefelt | Tetthet | Fossile brennstoffer<br>Mineral avsetninger<br>Konstruksjon |
| Magnetisme | Magnetics | Romlige variasjoner i styrken til det geomagnetiske felt | Magnetisk mottagelighet og "remanence" | Fossile brennstoffer<br>Metalliske mineral avsetninger<br>Konstruksjon |
| Seismikk | Seismic | Gangtid av reflekterte/refrakterte seismiske bølger | Seismisk hastighet (og tetthet) | Fossile brennstoffer<br>Mineral avsetninger<br>Konstruksjon |
| Elektro-magnetisme (SeaBed Logging) | Electro-magnetics | Respons til elektromagnetisk stråling | Elektrisk ledningsevne/mot-stand<br>og induktanse | Fossile brennstoffer<br>Metalliske mineral avsetninger |
| Elektrisk<br>-Motstand<br><br>-Egenpotensial | Electrical<br>-Resistivity<br><br>-Self Potential | Jordens motstand<br><br>Elektriske potensialer | Elektrisk motstand<br><br>Elektrisk ledningsevne | Utbredt brukt, bl.a. i brønnlogging |
| Radar | Radar | Gangtid av reflekterte radar pulser | Dielektrisk konstante | Miljø<br>Konstruksjon |

# Litteratur


- Keary, P. & Brooks, M. (1991) An Introduction to Geophysical Exploration. Blackwell Scientific Publications.
- Mussett, A.E. & Khan, M. (2000) Looking into the Earth – An Introduction to Geological Geophysics. Cambridge University Press.*


http://www.learninggeoscience.net/modules.php

* This presentation contains several figures from this publication

# Gravity

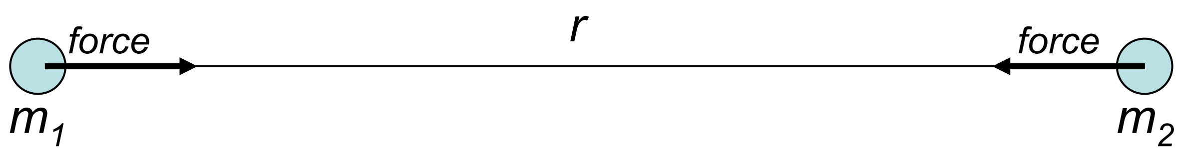
- Gravity surveying measures spatial variations in the Earth's gravitational field caused by differences in the *density* of sub-surface rocks
- In fact, it measures the variation in the *accelaration* due to gravity
- It is expressed in so called *gravity anomalies* (in milligal, $10^{-5}$ $ms^{-2}$), measured in respect to a reference level, usually the *geoid*
- Gravity is a scalar

# Gravity: Newton's Law of Gravitation

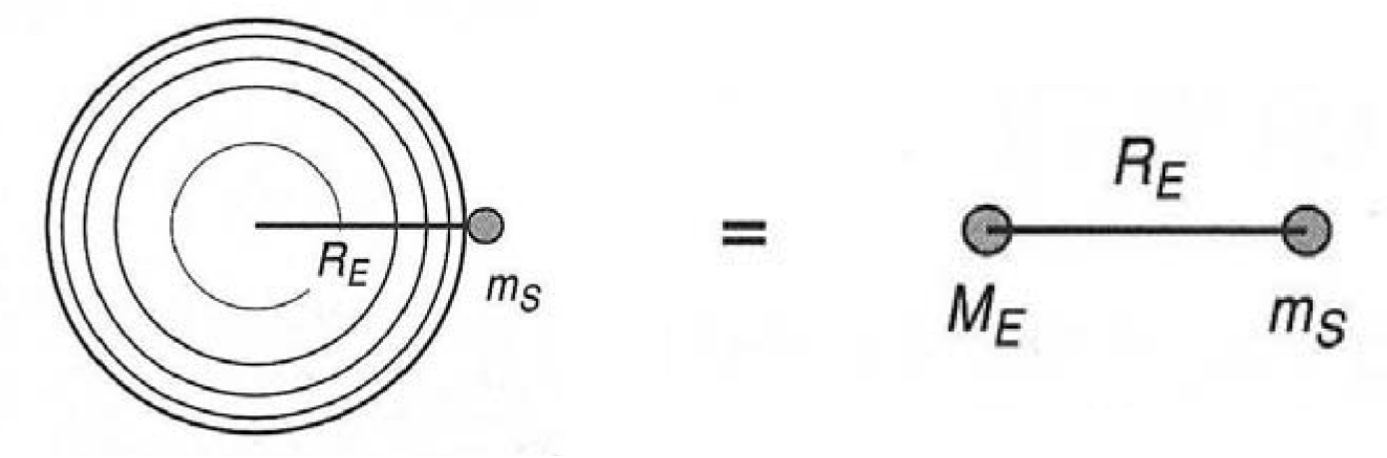
- Newton's Universal Law of Gravitation for small masses, $m_1$ and $m_2$ separated by a distance $r$, at the earth surface:

$$\textbf{Attractive force, } F = G\frac{m_1 m_2}{r^2}$$

  - With G ('big gee') is the Universal Gravitational Constant: $6.67 \times 10^{-11}\ m^3/kg^1 \cdot s^2$



# Gravity: Earth




$$F_E = \frac{G \times M_E \times m_s}{R_E^2} = m_s g \rightarrow g = \frac{G \times M_E}{R_E^2}$$

- Spherical
- Non-rotating
- Homogeneous

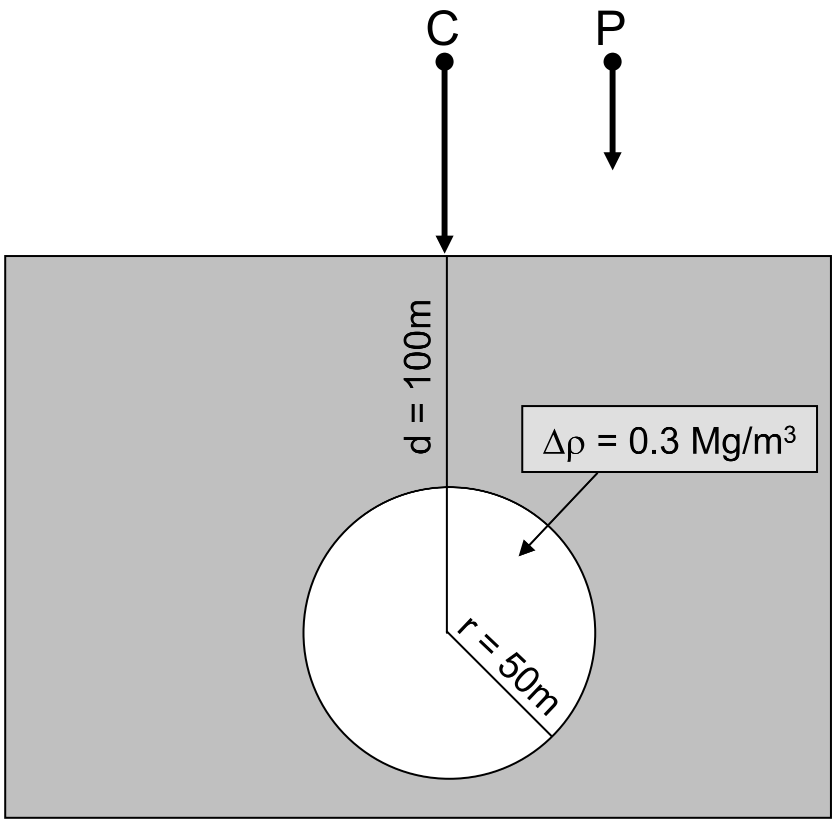
→ g ('little gee') is constant!

# Gravity

- Non-spherical → Ellipse of rotation
- Rotating → Centrifugal forces
- Non-homogeneous
  - Subsurface heterogeneities
  - Lateral density differences in the Earth

→ g ('little gee') is NOT constant

# Gravity units

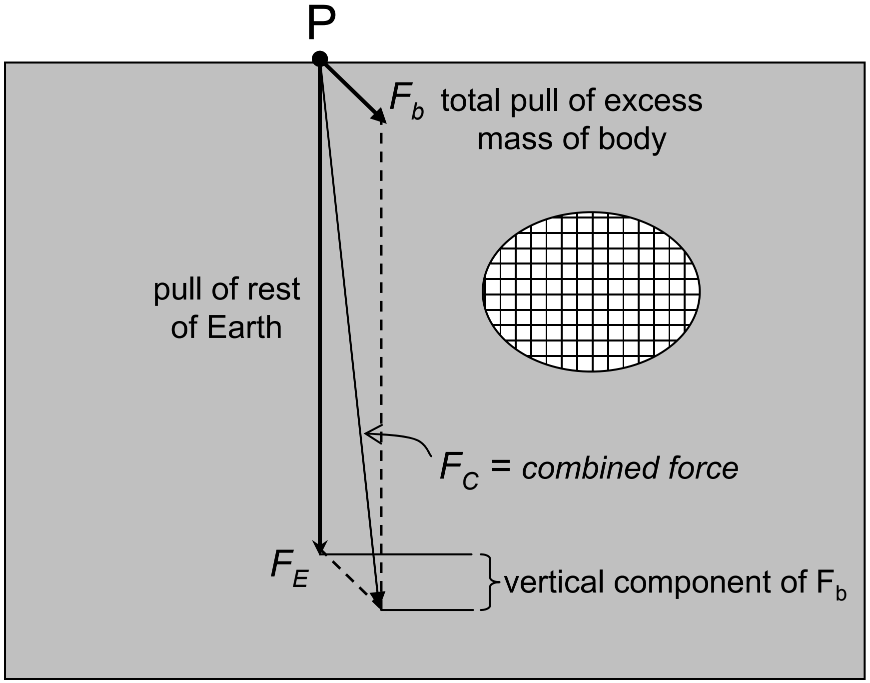



- An object dropped at C falls with a little greater acceleration than at P
- Difference in acceleration can be measured:

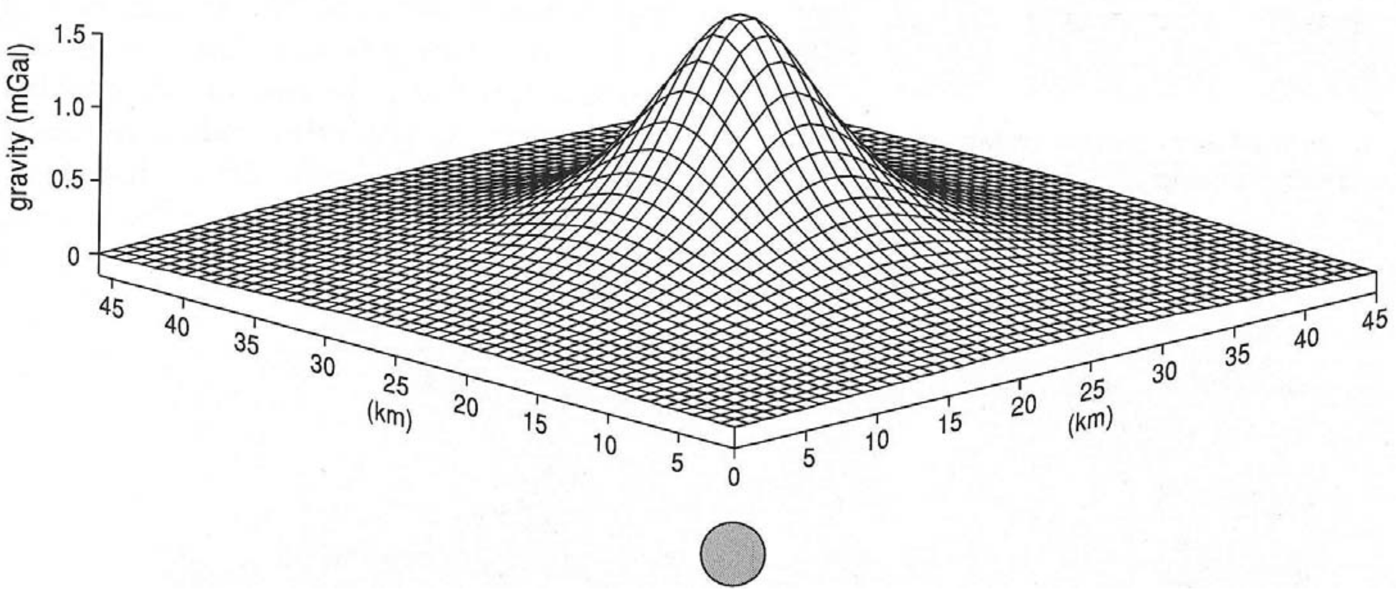
$$\delta g = G\frac{\Delta m}{d^2} = \frac{G}{d^2}\frac{4}{3}\pi r^3 \delta\rho$$

- Here: $\delta g = 1.048 \cdot 10^{-6}$ m/s$^2$
- Small values, therefore we measure gravity anomalies in milliGals (mGal), or gravity units, g.u.
- 1 mGal = 10 g.u. = $10^{-5}$ m/s$^2$ ~ $10^{-6} \cdot g$

# Gravity anomalies



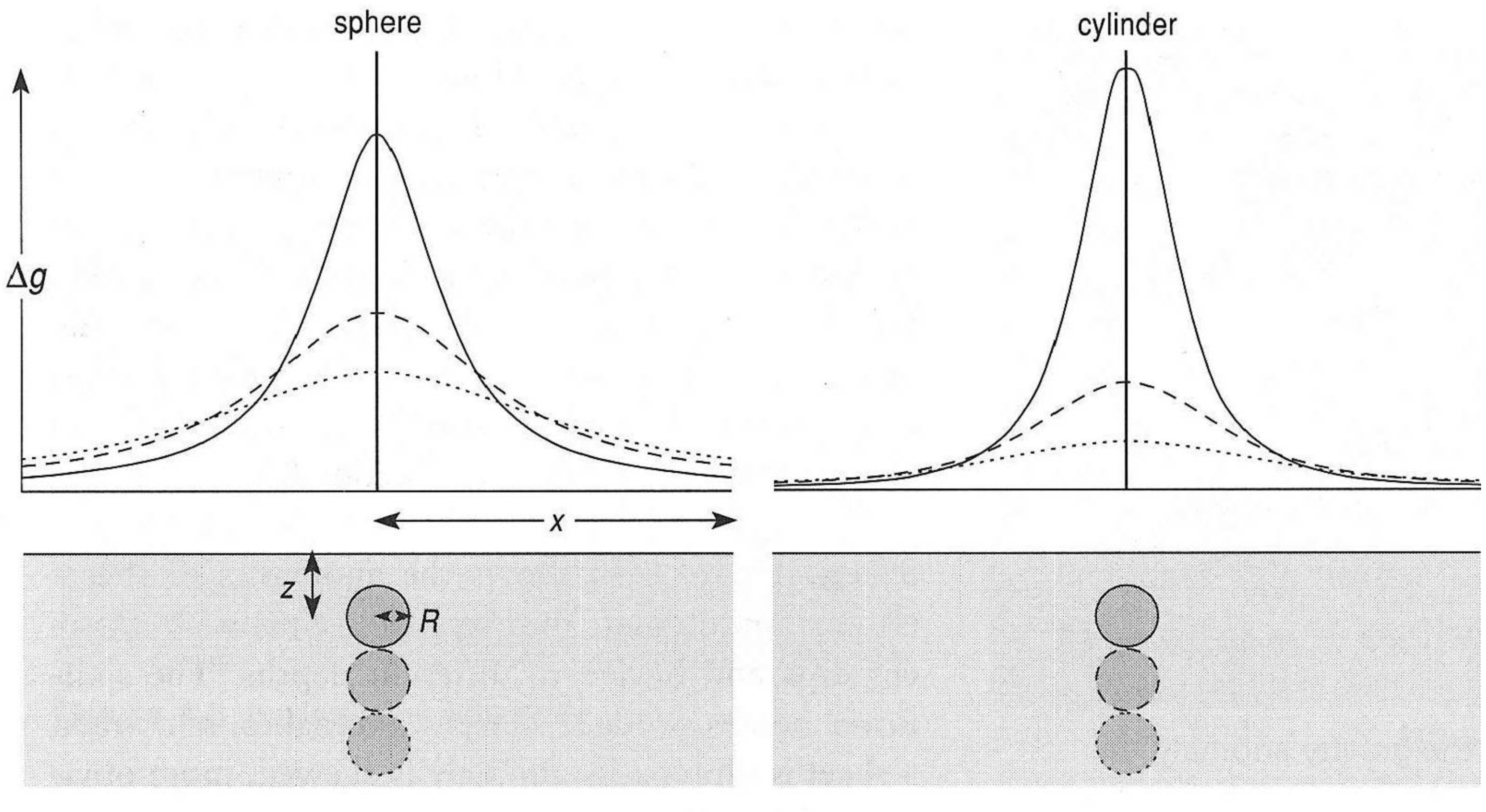

The Gravity anomaly is positive if the body is more dense than its surroundings, negative if less




Gravity is a scalar: the combined pull has approx. the same direction as the Earth pull; we measure therefore only the size, or magnitude, of *g*

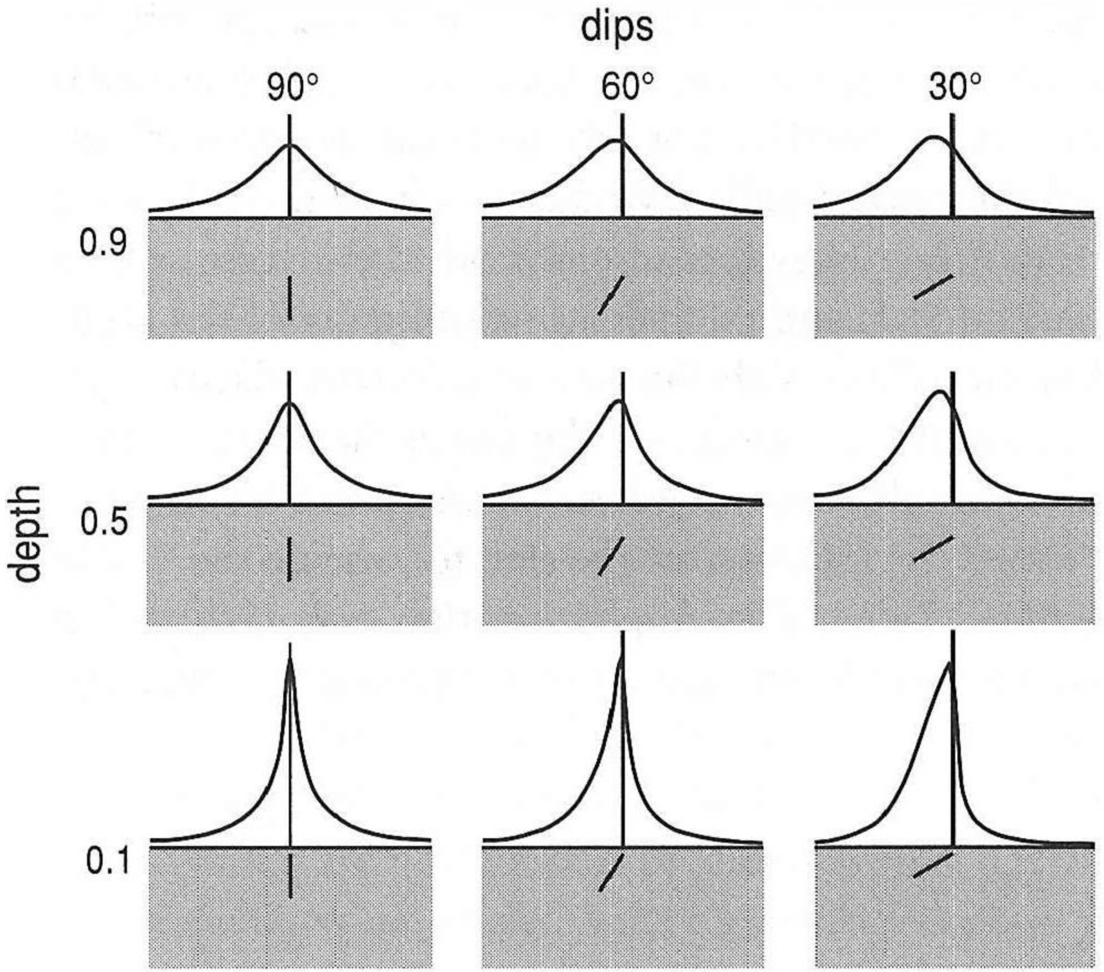
# Gravity anomalies of specific bodies

**sphere & horizontal cylinder** at different depths



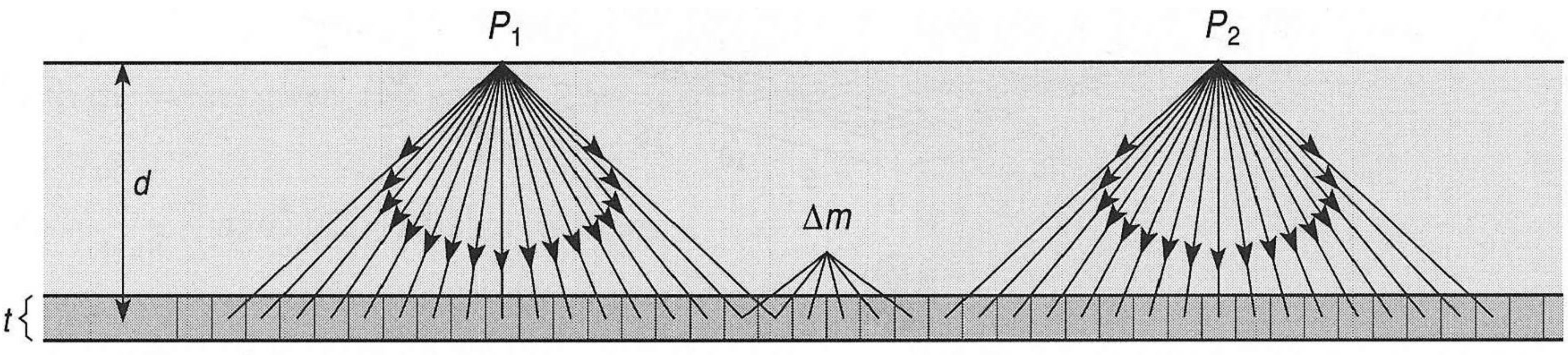
# Gravity anomalies of specific bodies

**sheets (dykes or veins)**



# Gravity anomalies of specific bodies

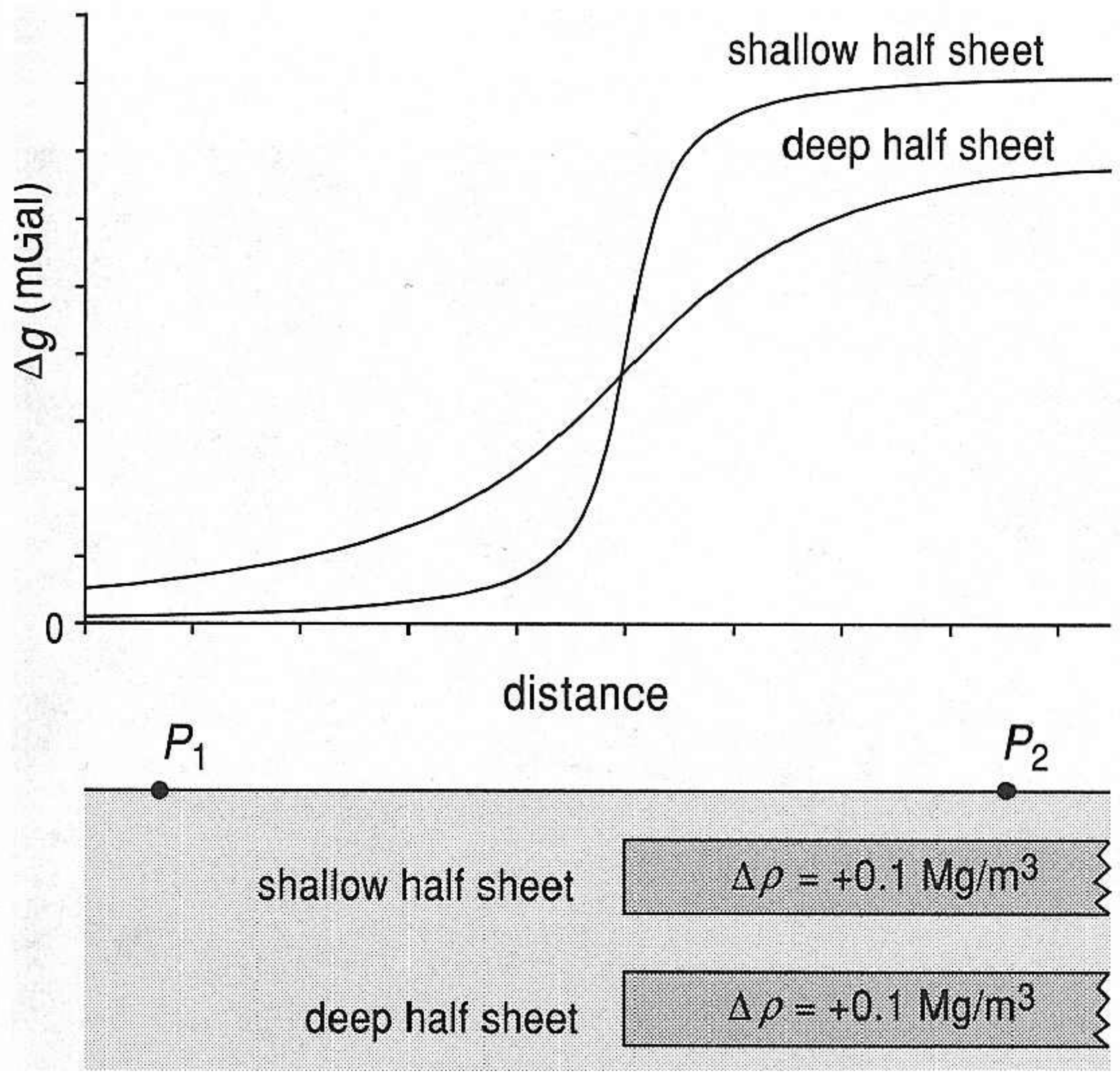
**horizontal sheet/slab**




$$\delta g = 2\pi G\, \Delta\rho t$$

# Gravity anomalies of specific bodies

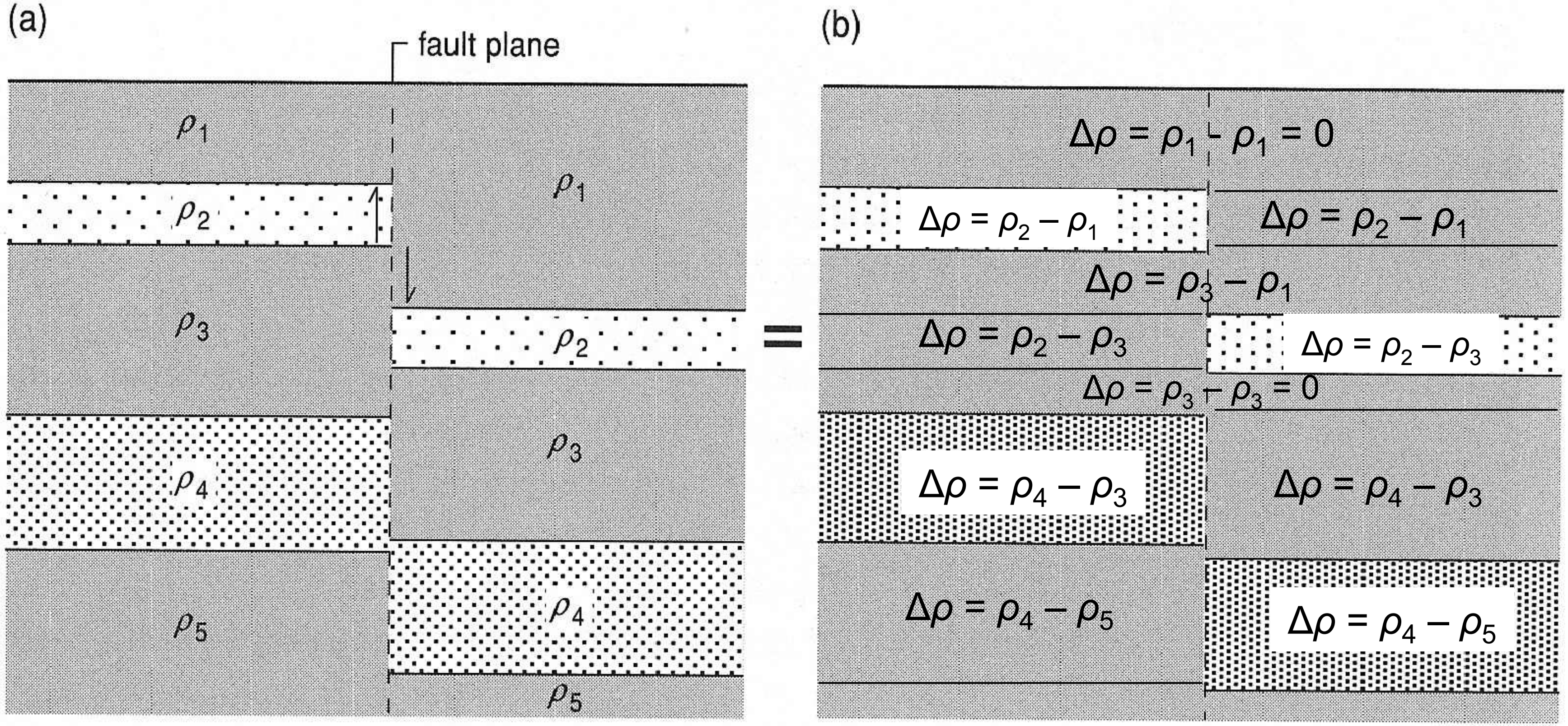
**horizontal half-sheet/half-slab**




$$\delta g = 2\pi G\,\Delta\rho t$$

# Gravity anomalies of specific bodies

**horizontal layers offset by vertical faulting**

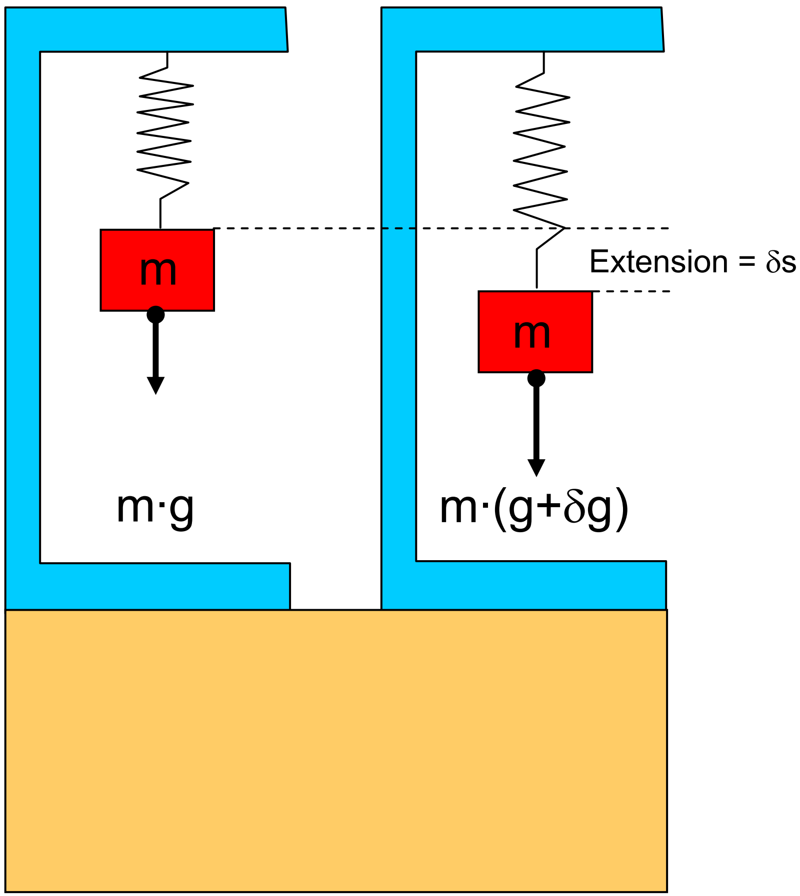



$$\delta g = 2\pi G \, \Delta\rho t$$

# Measurement of Gravity

- Absolute gravity difficult to measure
- Relative values of gravity, i.e. difference of gravity between locations is simpler and standard procedure in gravity surveying
- Absolute value at a location is obtained by measuring the relative gravity between that location and a location with a known absolute gravity value (IGSN, 1971)

# Measurements of Gravity

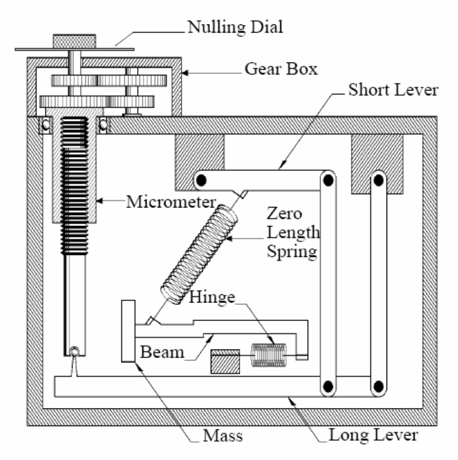



- Spring or Beam
  - Hooke's Law:
    - $m\delta g = k\delta s$

    with k is the elastic spring constant
- Corrections
  - Instrumental drift and tidal
  - Latitude
  - Elevation
  - Eötvös

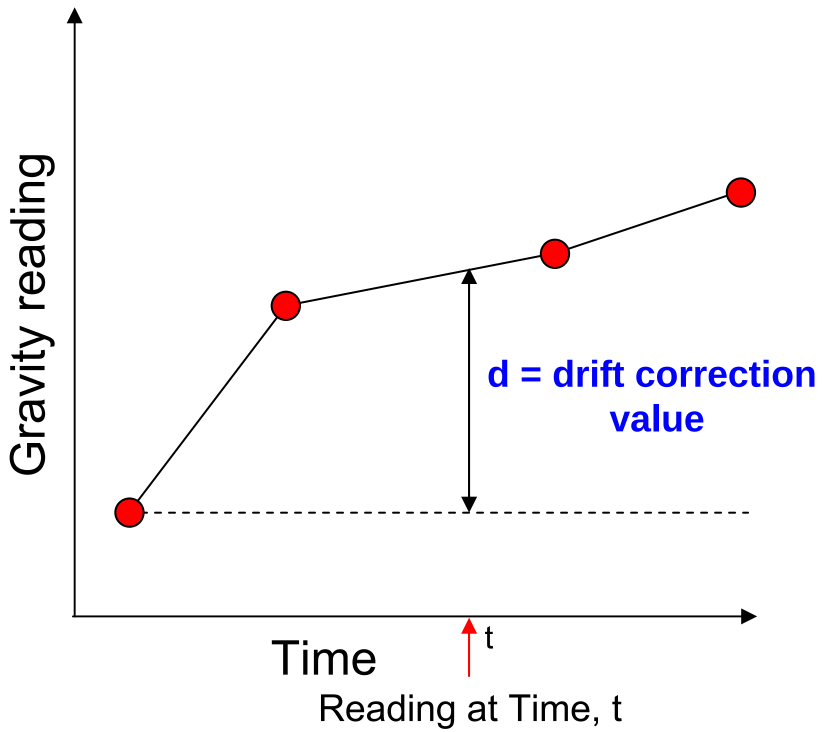
# Gravity meter at IG, UiO

## *LaCoste & Romberg Model G*




# Gravity correction - *Drift*

- Correction for instrumental drift and tidal influence is based on repeated reading at the base station (red dots) at recorded times during the day
- Drift correction, d, is subtracted from the observed value
- After drift correction, the difference in gravity between an observation point and the base is found by multiplication of the difference in meter reading with the calibration factor of the gravimeter



- Lat ... the Ear...
  - – ... stance ... ro at
  - – ... the
- Co... Gravity Formula):


$$g_\lambda = 978031.8\left(1 + 0.0053024\sin^2\lambda - 0.0000059\sin^2\lambda\right)\mathrm{mGal}$$

- For surveys not extending more than some tens of kilometers, the variation can be regarded as simply proportional to distance:

$$\delta g = 0.812\sin 2\lambda \quad \mathrm{mGal/km\ polewards}$$

# Gravity correction - *Eötvös*

- Only needed if gravity is measured from a moving vehicle, like a ship or air-plane
- The motion of the vehicle causes a centrifugal force, depending on which way the vehicle is moving
- The correction is:

$$\delta g_{\text{Eötvös}} = 4.040\, v \sin\alpha \cos\lambda + 0.001211\, v^2 \text{ mGal}$$

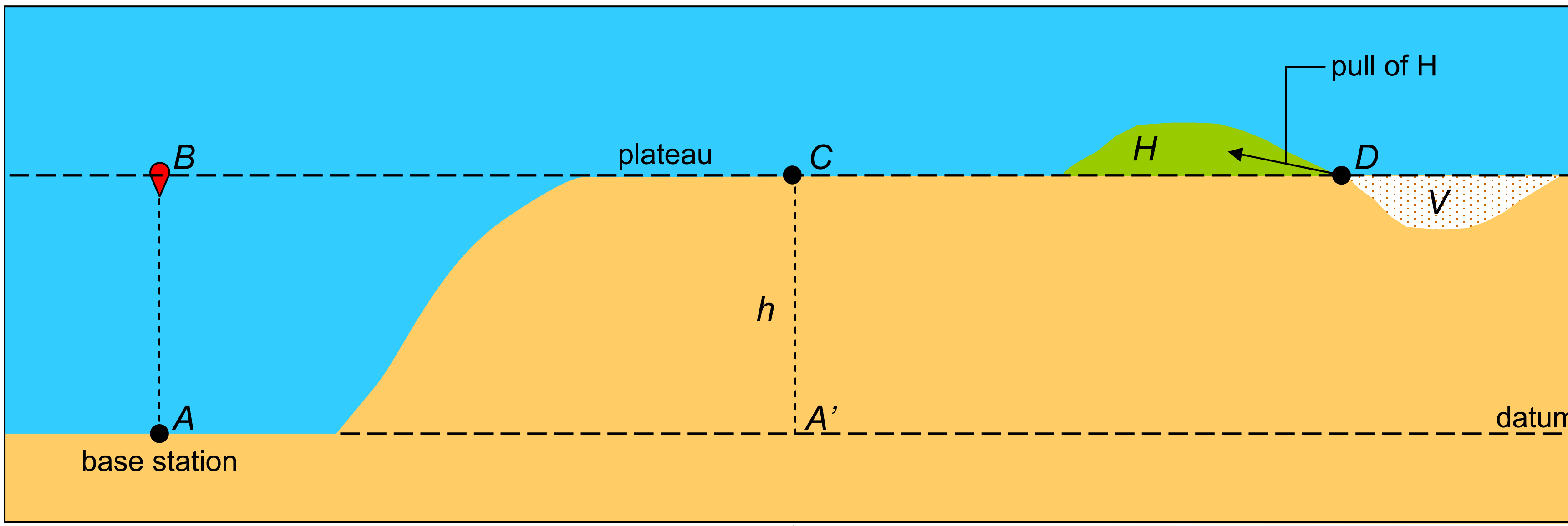
  - with *v* is the speed in km/h
  - $\lambda$ is the latitude
  - $\alpha$ is the direction of travel measured clockwise from north, since only E-W motion matters

- For 55°N, the correction is about +2½ mGal for each km/h in an east-west direction

# Gravity correction - *Elevation*

- Correction is necessary for changes in elevation; three separate effects have to be taken into account:
  - Free-air correction (FAA)
  - Bouguer correction (BC)
  - Terrain correction (TC)

} *Bouguer Anomaly*




$$\delta g = g_A - g_B = GM_E\left(R_A^2 - R_B^2\right)^{-1}$$

*g* decreases with 0.3086 mGal/m

**FAC = 0.3086·*h* mGal**

infinite sheet:

$$\delta g = g_{A'} - g_c = 2\pi G\rho h$$

**BC = 0.04192 *ρh* mGal**

Pull of H reduces *g*

$$\delta g = h\left(0.3086 - 0.04192\rho\right)\,\mathrm{mGal}$$

# Gravity Anamolies

- Free Air Anomaly (FAA):

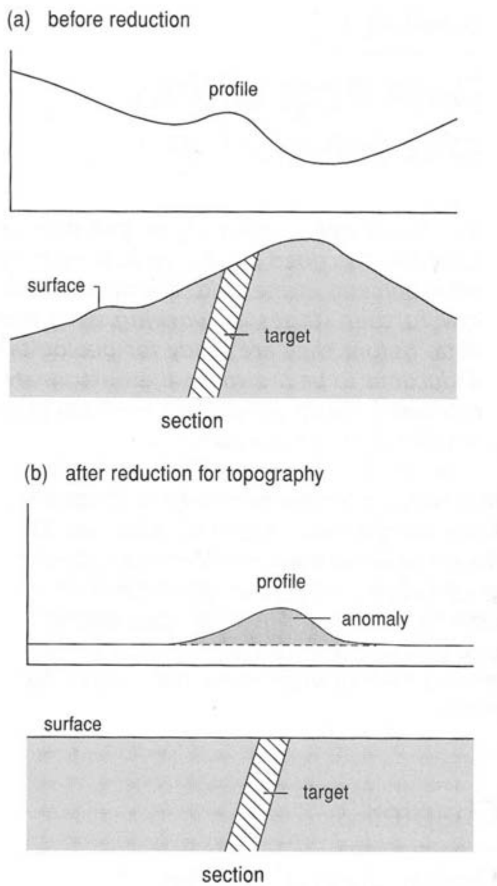
$$= g_{obs} - g_{\lambda} + FAC\ (\pm EC)$$

- Bouguer Anomaly (BA)

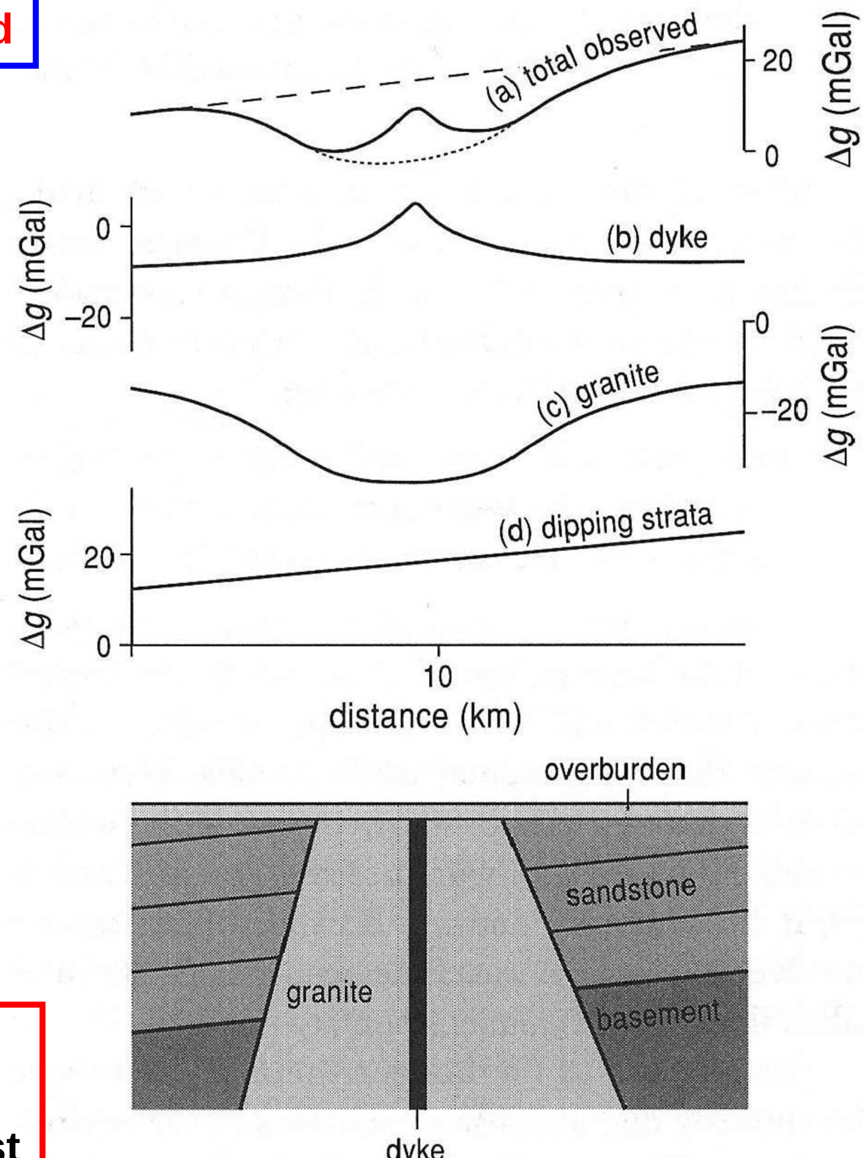
$$= g_{obs} - g_{\lambda} + FAC - BC\ (+ TC \pm EC)$$

# *Residual* and *Regional* anomalies

**residual anomaly = observed field – regional field**



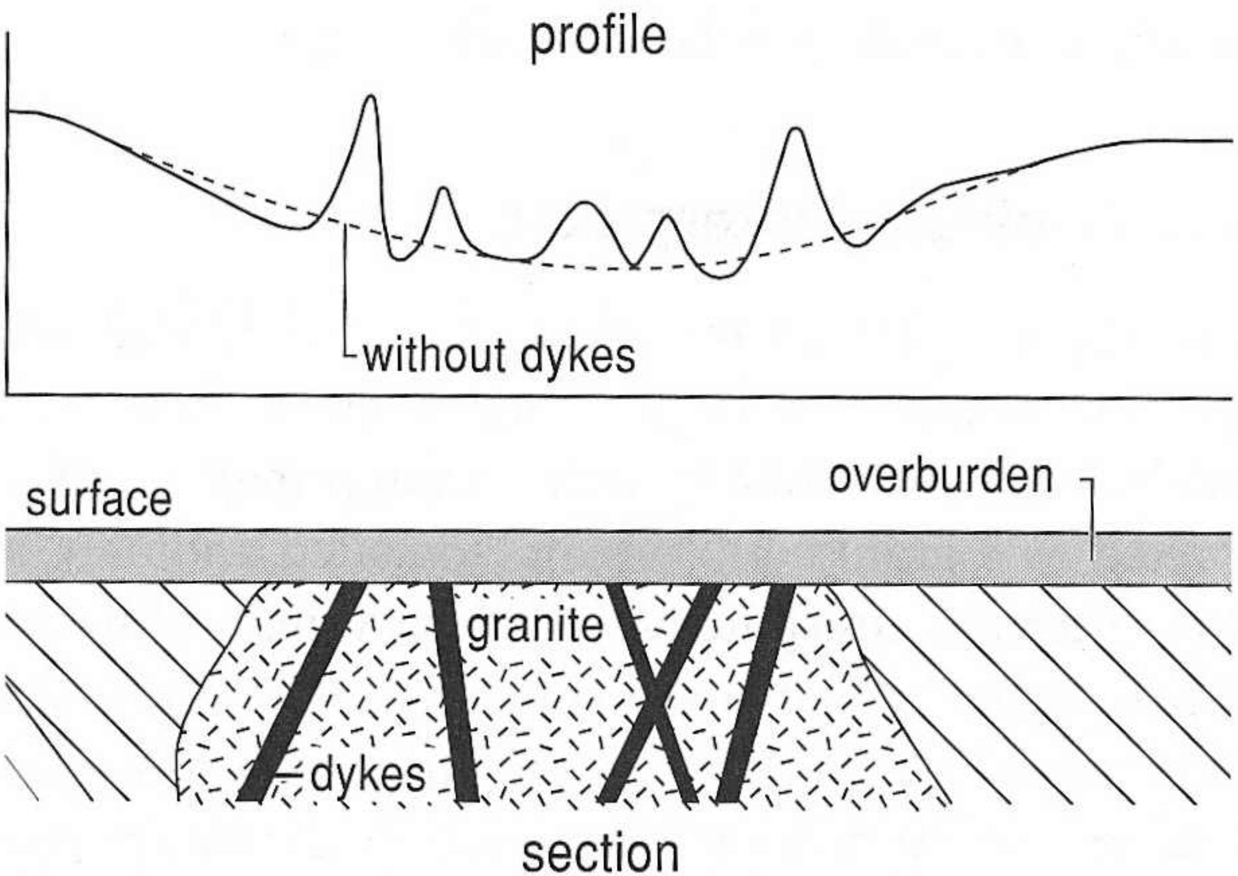

background value of *g*




→ signal vs. noise
→ residual anomaly vs. regional field/anomaly
**concepts depending on the survey target interest**

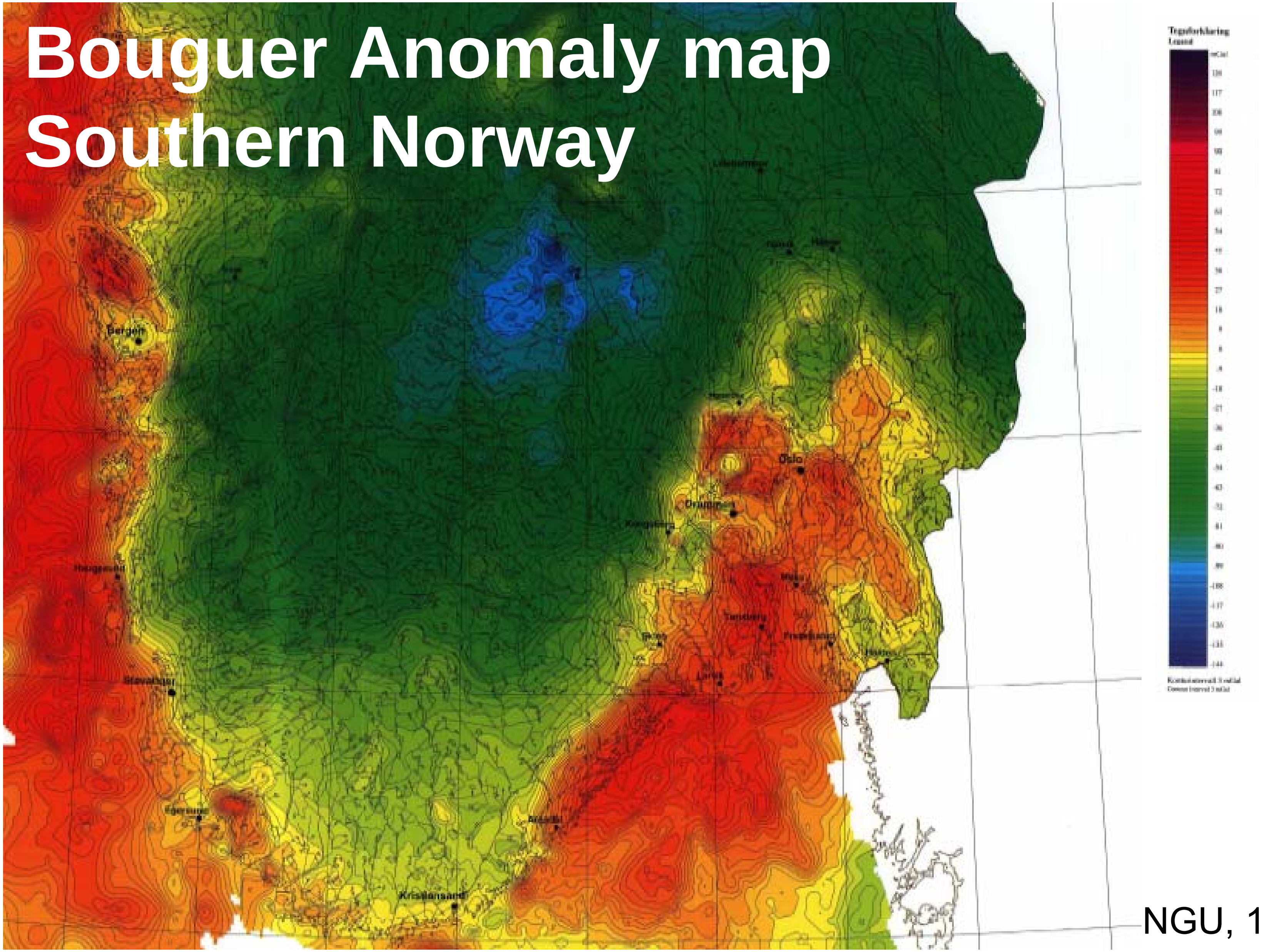
# Residual and Regional anomalies

→ signal vs. noise
→ residual anomaly vs. regional field/anomaly
**concepts depending on the survey target interest**




By filtering away the large wavelenghts of the regional field, we obtain gravity anomalies that represent small scaled bodies at shallow depth

# Bouguer Anomaly map Southern Norway




NGU, 1992

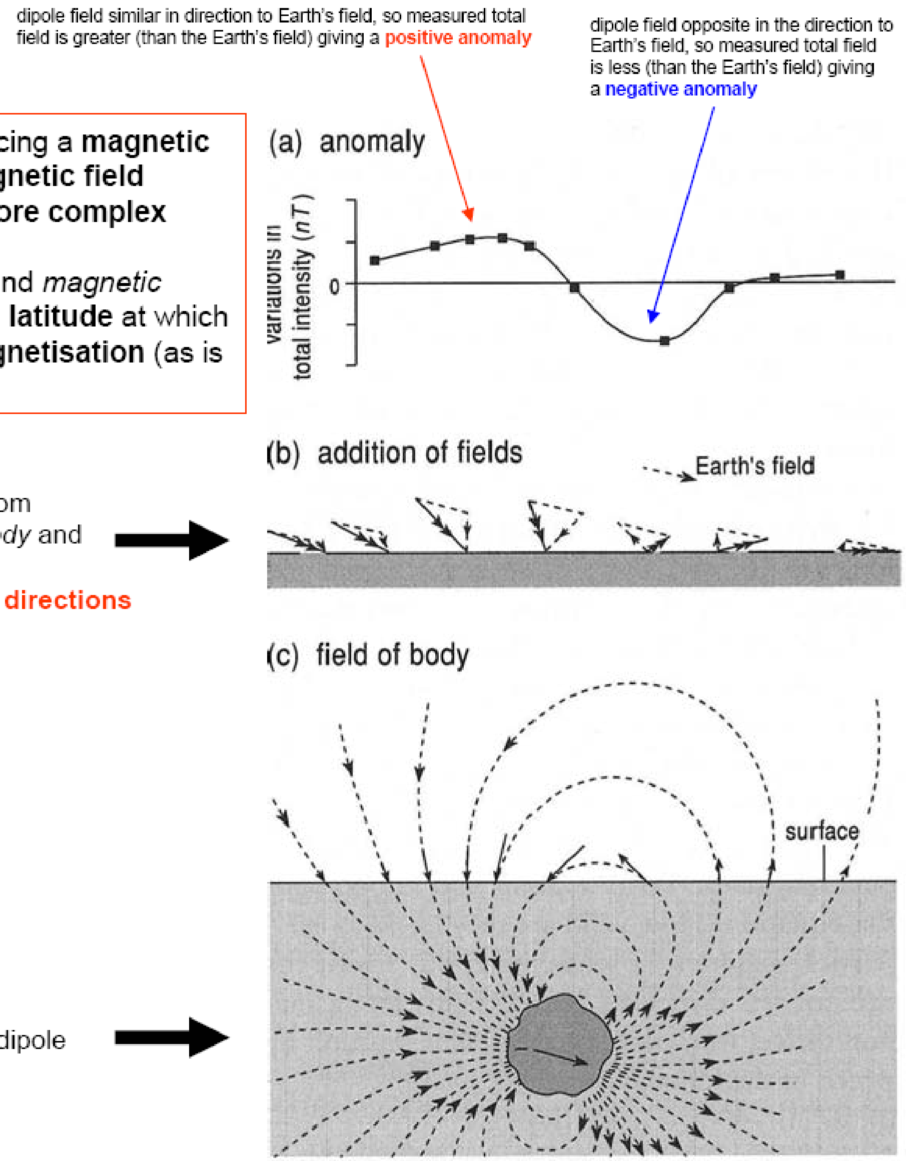
# Magnetics

- Magnetic surveying aims to investigate the subsurface geology by measuring the strength or intensity of the Earth's magnetic field.
- Lateral variation in *magnetic susceptibility* and *remanence* give rise to spatial variations in the magnetic field
- It is expressed in so called *magnetic anomalies*, i.e. deviations from the Earth's magnetic field.
- The unit of measurement is the *tesla* (T) which is volts·s·m$^{-2}$ In magnetic surveying the *nanotesla* is used (1nT = $10^{-9}$ T)
- The magnetic field is a vector
- Natural magnetic elements: iron, cobalt, nickel, gadolinium
- Ferromagnetic minerals: magnetite, ilmenite, hematite, pyrrhotite

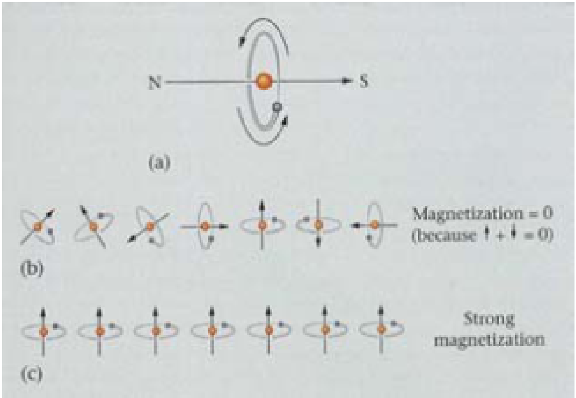
→ Magnetic surveying depends on the target producing a **magnetic anomaly by locally modifying the Earth's magnetic field**
→ the relationship of the anomaly to its source is **more complex than for gravity**
→ for as well as depending on the *source's shape* and *magnetic properties*, it also depends on its **orientation**, the **latitude** at which the anomaly occurs and if it has a **remanent magnetisation** (as is usual) upon its history

the measured **total field** derives from **adding together** the *field of the body* and the *Earth's field*:
**vector addition of strengths and directions**

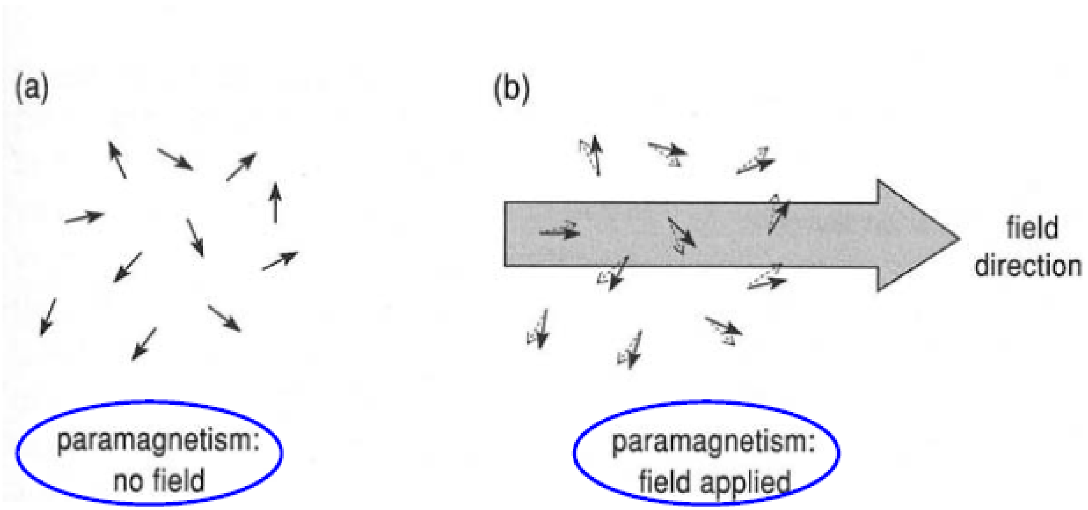
Buried: short, but powerful dipole



# Remanent & Induced Magnetisations




**remanent magnetisation**: the ability to retain magnetisation in the absence of a field or in the presence of a different magnetic field




*alignment and hence magnetisation disappears as soon as the field is removed*

*directions of the magnetisations of the magnetic atoms spontaneous align*
*[iron materials & its compounds, e.g. magnetite]*

# Mineral magnetism

| Mineral | Chemical formula | Saturation remanence (kA/m) | Curie temperature (°C) | Susceptibility* (rationalised SI units) |
|---|---|---|---|---|
| magnetite | $Fe_3O_4$ | 5–50† | 585 | 0.07–20 |
| haematite | $Fe_2O_3$ | 1 | 675 | 0.0004–0.038 |
| maghaemite | $Fe_2O_3$ | 80–85 | c. 740 | |
| goethite | FeO·OH | ≤1 | c. 120 | |
| pyrrhotite | c. $Fe_7O_8$ | 1–20 | c. 300 | 0.001–6.3 |
| (iron) | Fe | | 780 | 0.2 |

*Defined in Section 10.6
†All ranges, which are from various sources, are approximate.

**Magnetic susceptibility ($\chi$)**: the ability of a rock to become temporarily magnetised while a magnetic field is applied to it

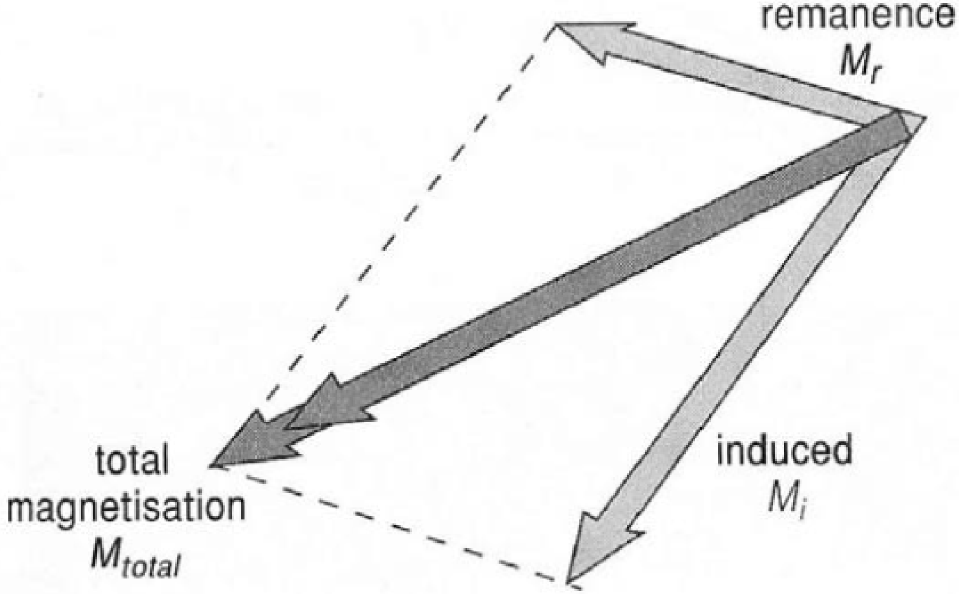
*paramagnetic materials* → become magnetised only when the field is present
*ferromagnetic materials* → increase their magnetisation while a field is applied

} this temporary magnetisation is called **induced magnetisation**

strength of the magnetic field

$$M_i = \chi \times H$$

induced magnetization = susceptibility × field

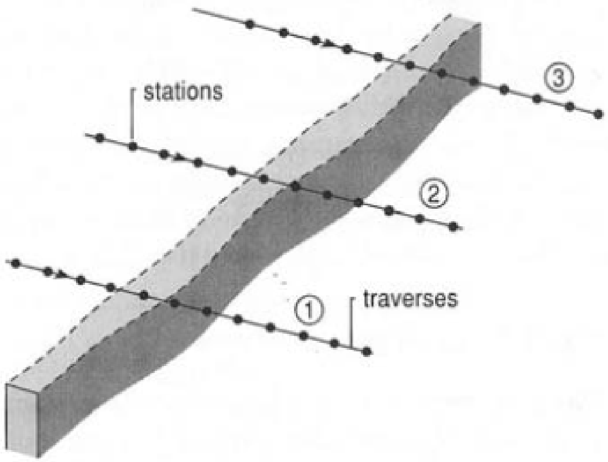


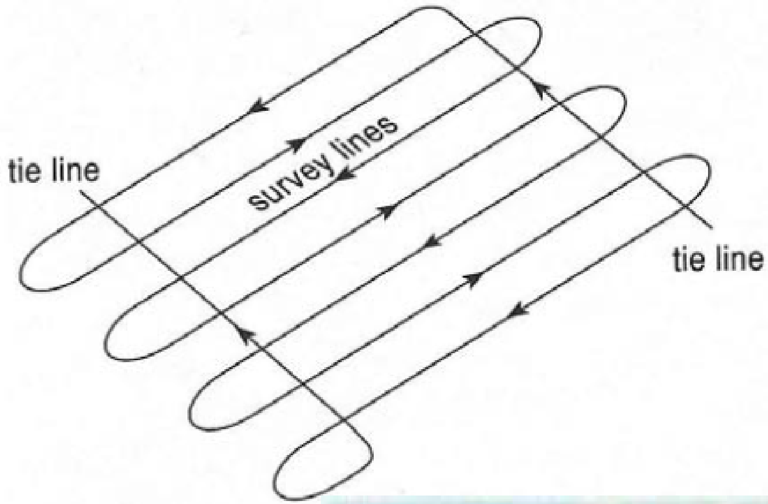

| Rock type | Susceptibility (rationalised SI units) |
|---|---|
| *Sediments* | |
| chalk | c. 0 |
| limestone | 0.00001-0.025* |
| salt | –0.00001 |
| sandstone | 0–0.2 |
| shale | 0.0006–0.02 |
| *Igneous and metamorphic* | |
| basalt | 0.0005–0.18 |
| gabbro | 0.0008–0.08 |
| gneiss | 0–0.003 |
| granite | 0.00002–0.05 |
| peridotite | 0.09–0.2 |
| rhyolite | 0.0002–0.04 |
| serpentinite | 0.003–0.08 |
| slate | 0–004 |
| *Other* | |
| water, ice | –0.000009 |

*Ranges, which are from several sources, are approximate.

# Magnetic Data Acquisition

## Land surveys



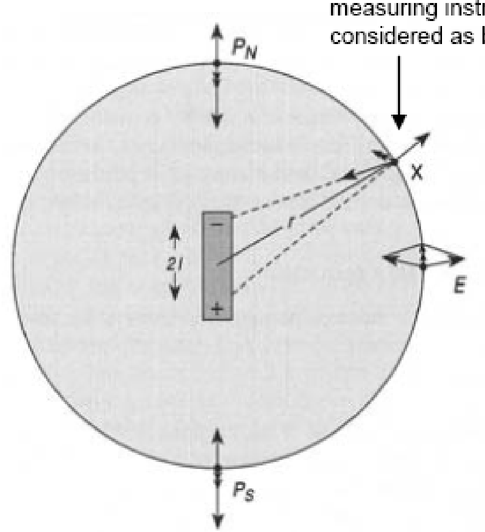

## Aeromagnetic surveys

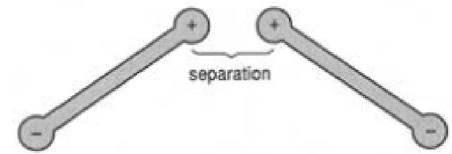
- covers large and, otherwise, inaccessible areas
- looses in resolution [due to the height of the plane]

# Magnetic anomalies of simple shaped bodies

## 1. The field of a dipole

the field of each pole is found separately and then added



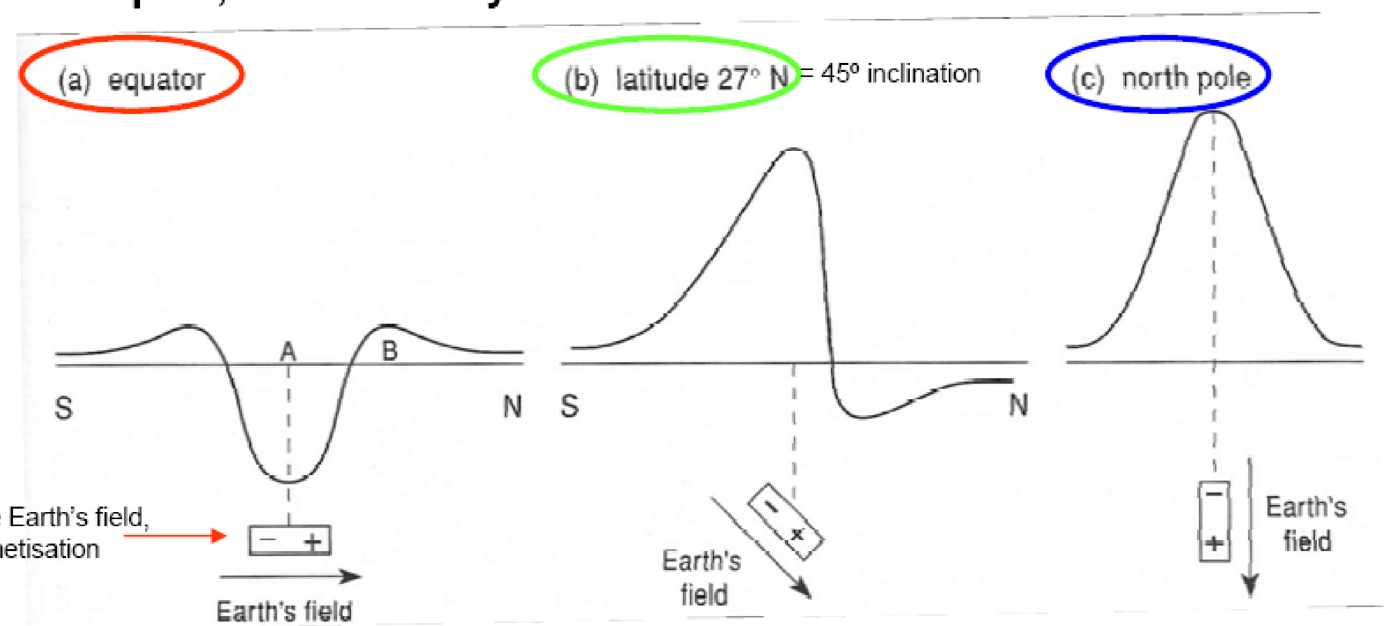




**magnets with isolated poles**

a magnetic body is thought of as being made of **+/- magnetic poles**

$$\underset{\text{inclination}}{\tan I} = \underset{\text{latitude}}{2 \tan \lambda}$$

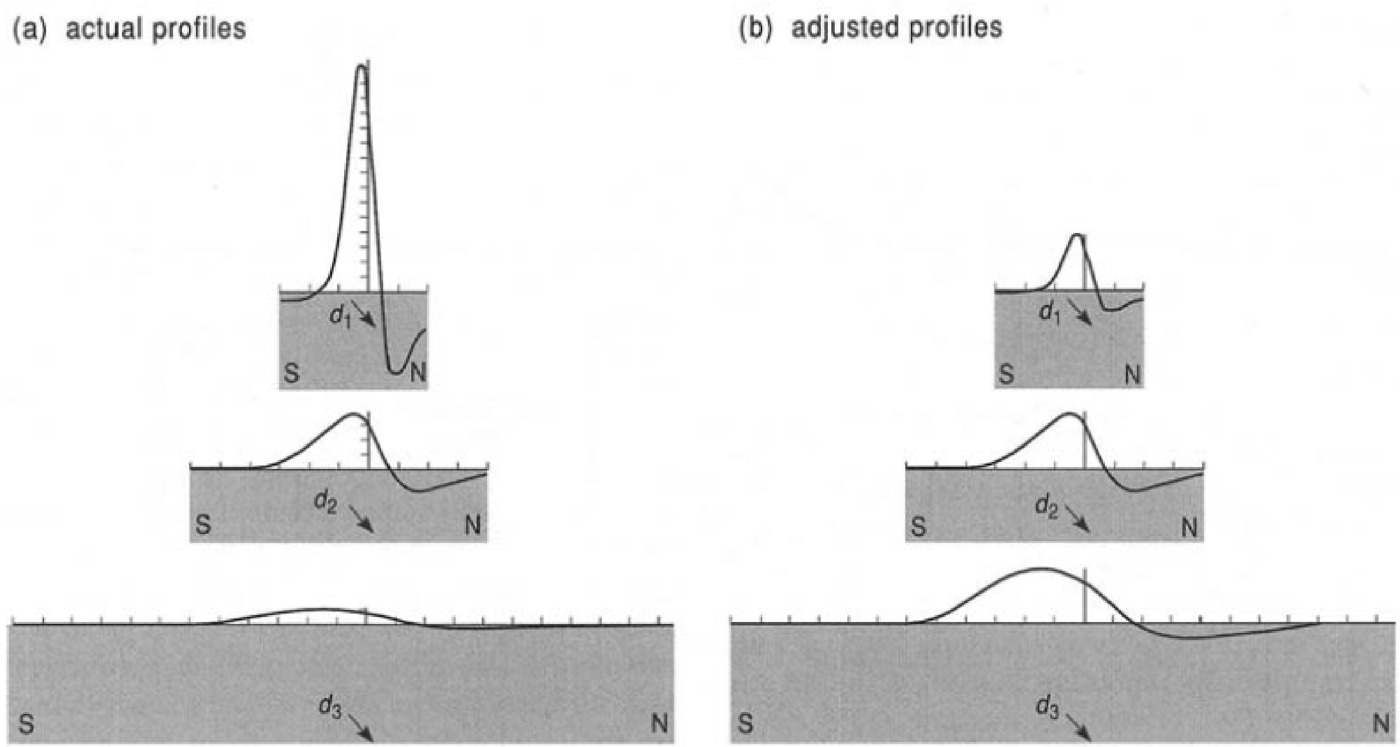
## 2. Anomaly of a dipole, or small body



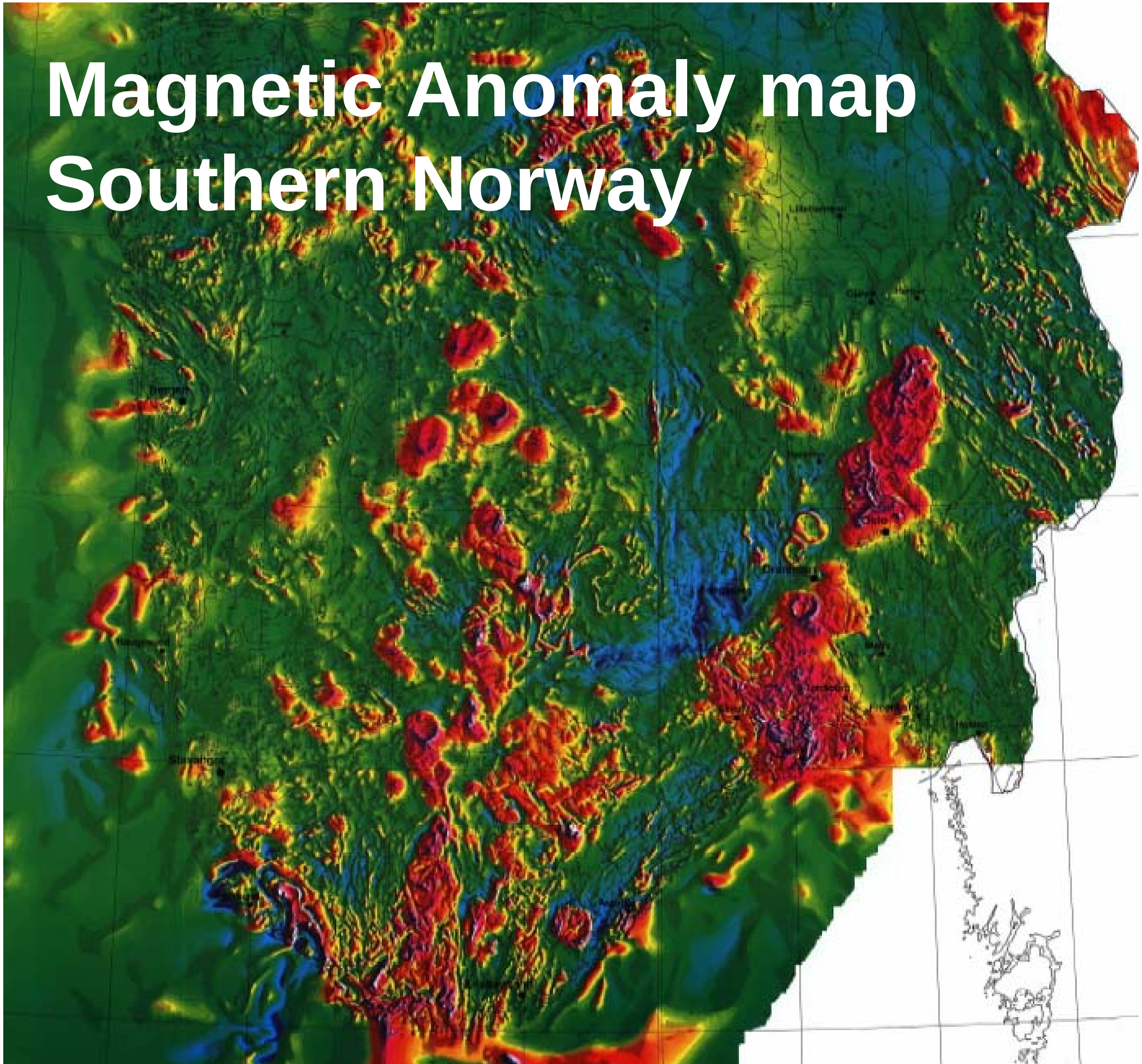

dipole aligned with the Earth's field, i.e. only induced magnetisation

# Depth of a magnetic body

similar with gravity:
- ***the shallower a body, the sharper & larger the anomaly***
- ***the deeper the body the broader the anomaly***



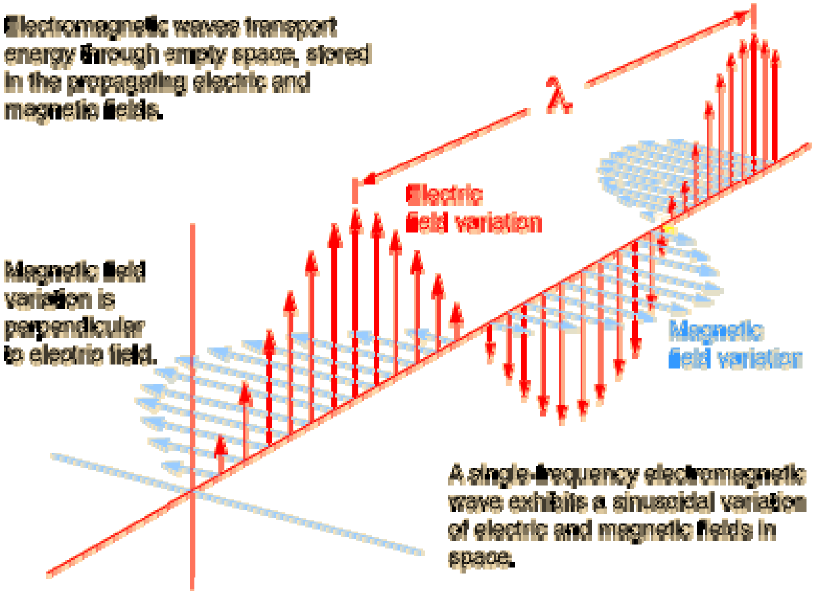
# Magnetic Anomaly map Southern Norway



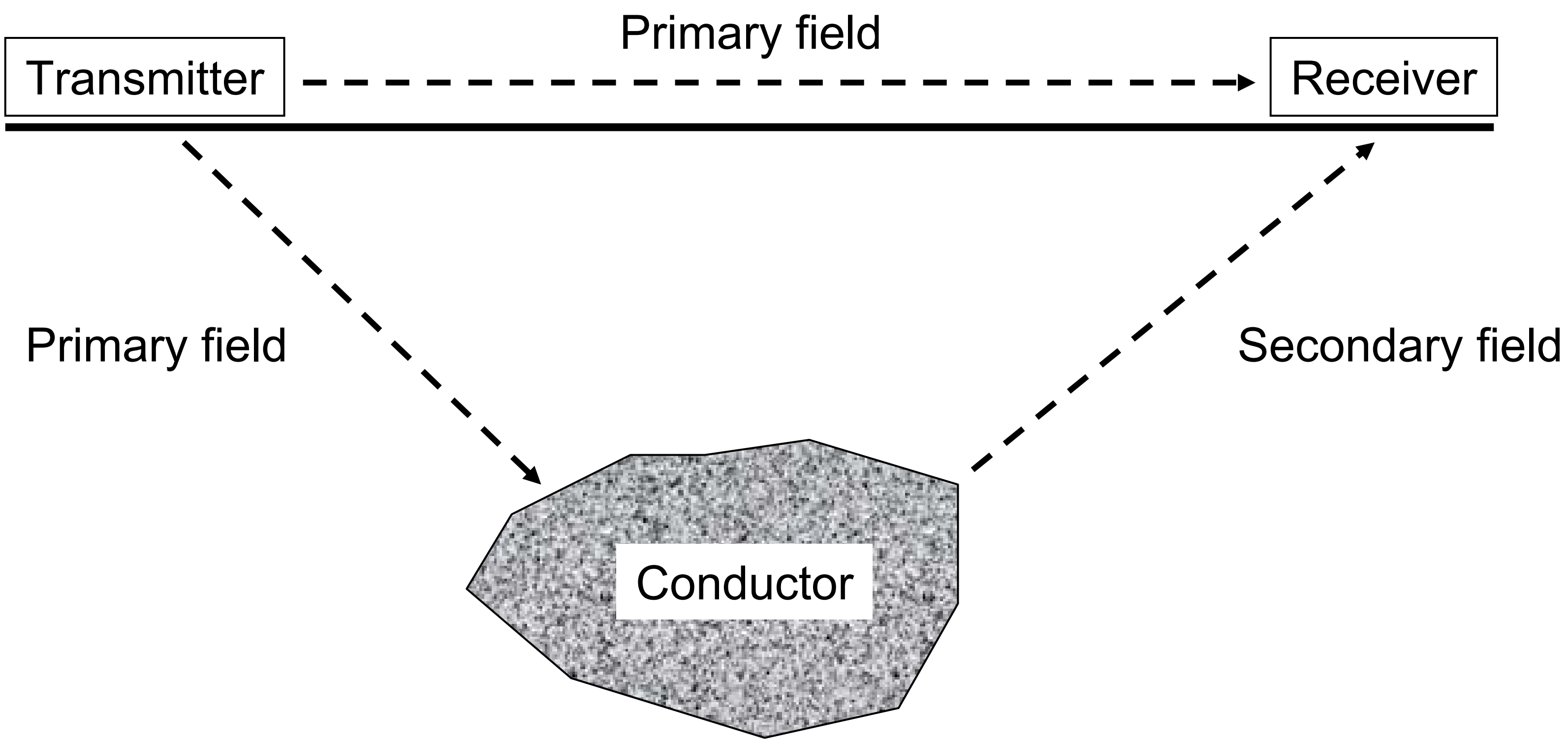
NGU, 1992

# Electromagnetics

Electromagnetic methods use the response of the ground to the propagation of incident alternating electromagnetic waves, made up of two orthogonal vector components, an electrical intensity (E) and a magnetizing force (H) in a plane perpendicular to the direction of travel



# Electromagnetics




Electromagnetic anomaly = Primary Field – Secondary Field

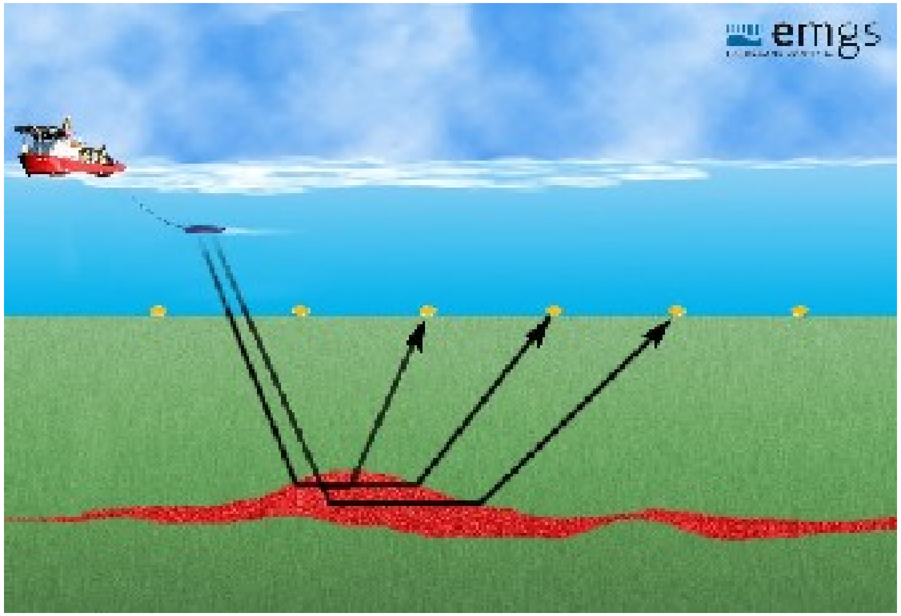
# Electromagnetics – Sea Bed Logging

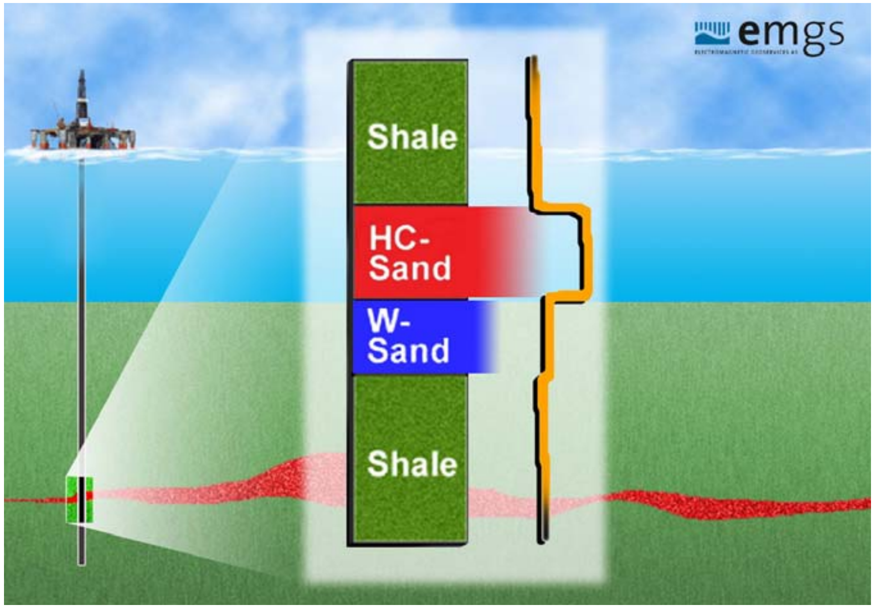
SBL is a marine electromagnetic method that has the ability to map the subsurface resistivity remotely from the seafloor.

The basis of SBL is the use of a mobile horizontal electric dipole (HED) source transmitting a low frequency electromagnetic signal and an array of seafloor electric field receivers.

A hydrocarbon filled reservoir will typically have high resistivity compared with shale and a water filled reservoirs.

SBL therefore has the unique potential of distinguishing between a hydrocarbon filled and a water filled reservoir





# Reflection Seismology

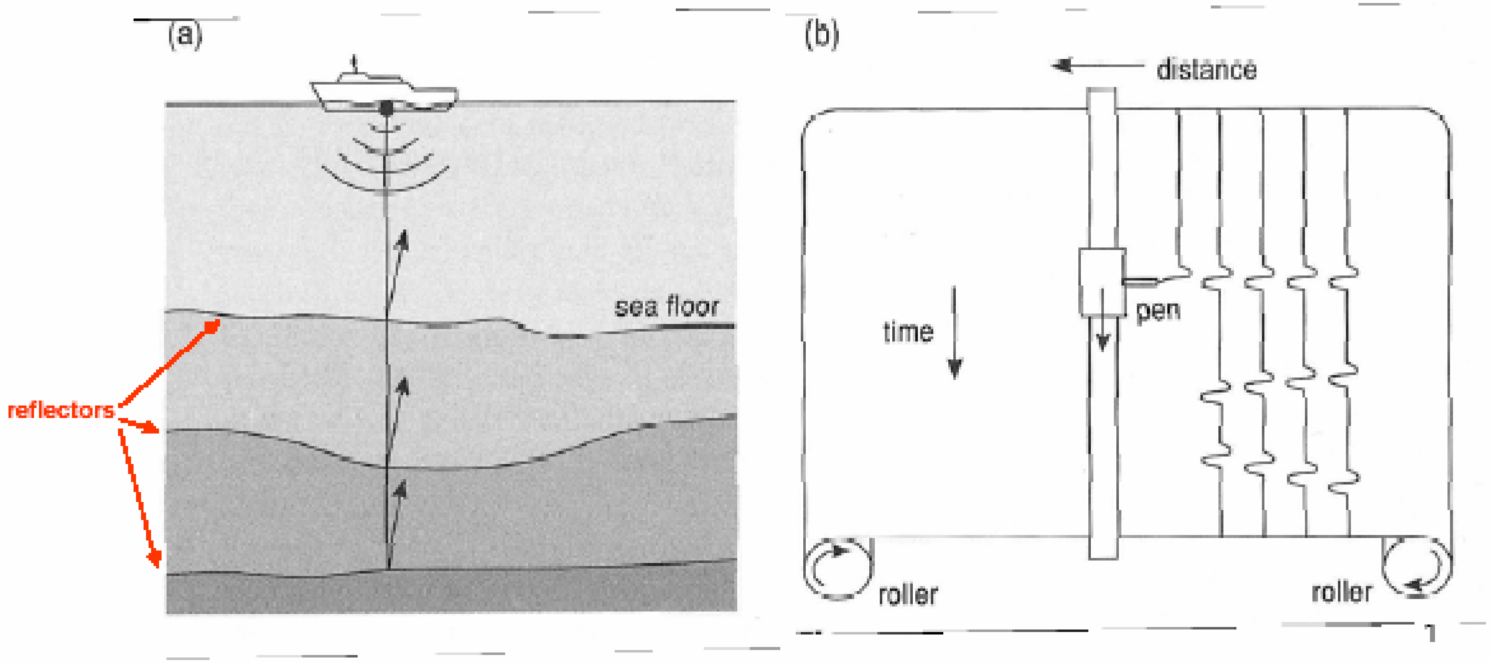
- Principle of reflection seismology
  - What is reflection seismology
  - Seismic wave propagation
  - Acquisition – collecting seismic data
  - Prosessing
- Limitations and Pitfalls
  - Resolution (Horizontal and Vertical)
  - Velocity Effects (Seismic velocities – Depth Conversion
  - Geometrical Effects (Migration)
  - Seismic Modelling (Synthetic seismograms)
- 2D vs. 3D seismic reflection

# Reflection Seismology

## Reflection Seismology

- most important tool for **2D/3D mapping of subsurface**
  [reveals layering, structural features such as faulting & folding]
- extensively used by the **oil & gas industry** to search for hydrocarbon fields

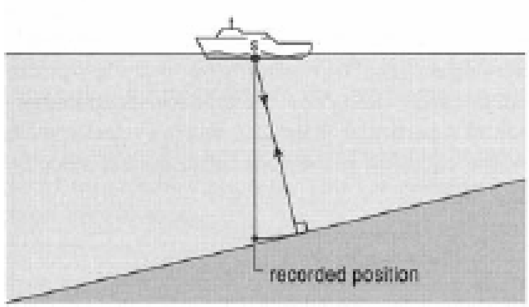
Reflection seismology can be considered as *echo or depth sounding* & it is easier performed at **sea** than on **land**

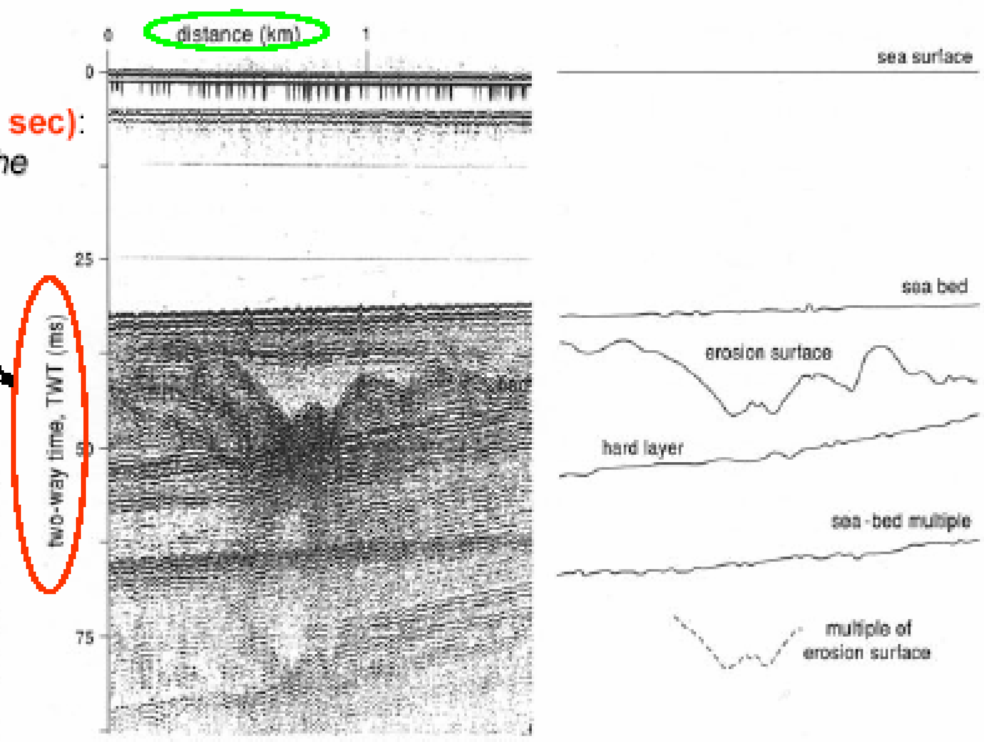


# Reflection Seismology

**Reflection seismics output**: seismic section (seismic reflection profile)

vertical scale not in depth (m),
but in **two-way travel-time (TWT, sec)**:
the time it takes the ray *to reach the reflector & return back*

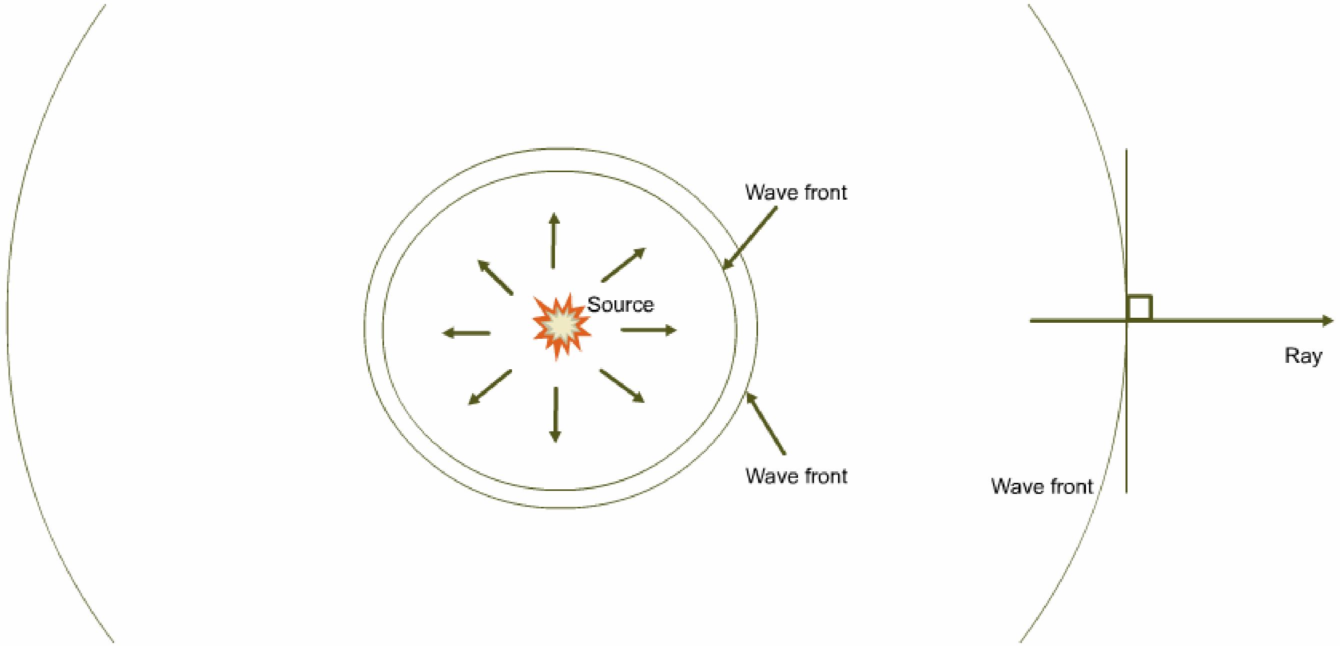



<u>one of the problems</u>: reflections may not come directly below the source, since they reflect at right angle to the interface, but the recording takes no account of this

# Reflection Seismology

Seismic waves can be considered both as energy distributed along wave fronts, and as rays. In an isotropic (same velocity in all directions) and homogeneous medium the energy will propagate spherically from the source.

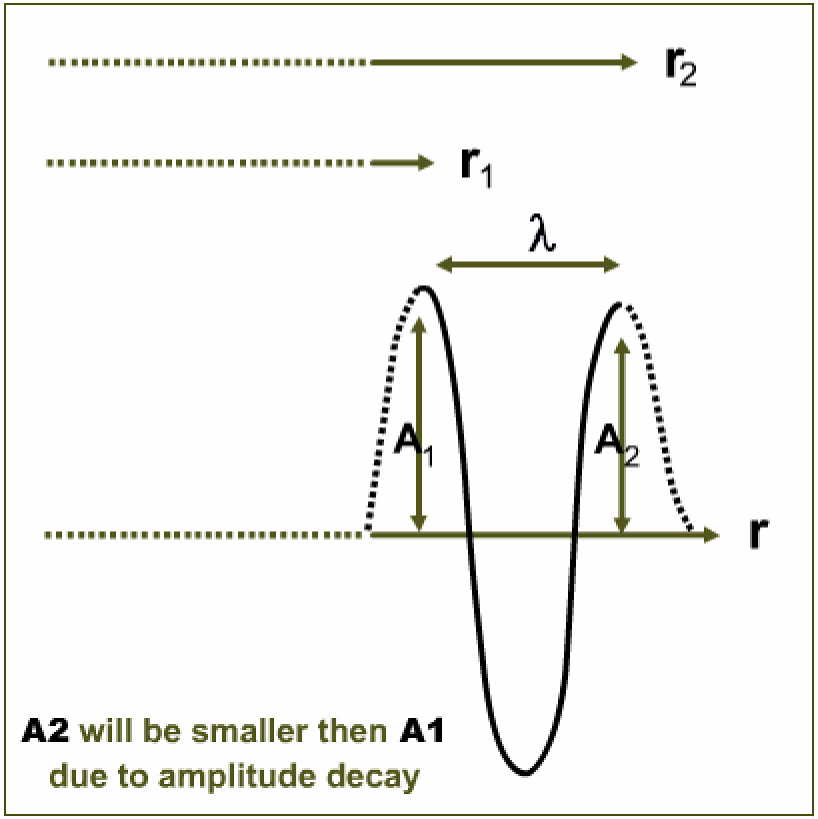


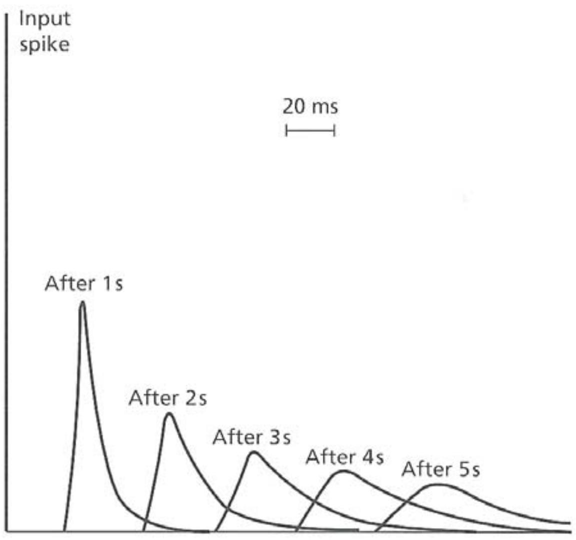

The seismic wave along one wave front has always the same phase. At large distance from the source the wave front is close to planar, and the wave is called a plane wave.

The seismic ray points in the direction of propagation and is perpendicular to the wave front in isotropic media

# Reflection Seismology

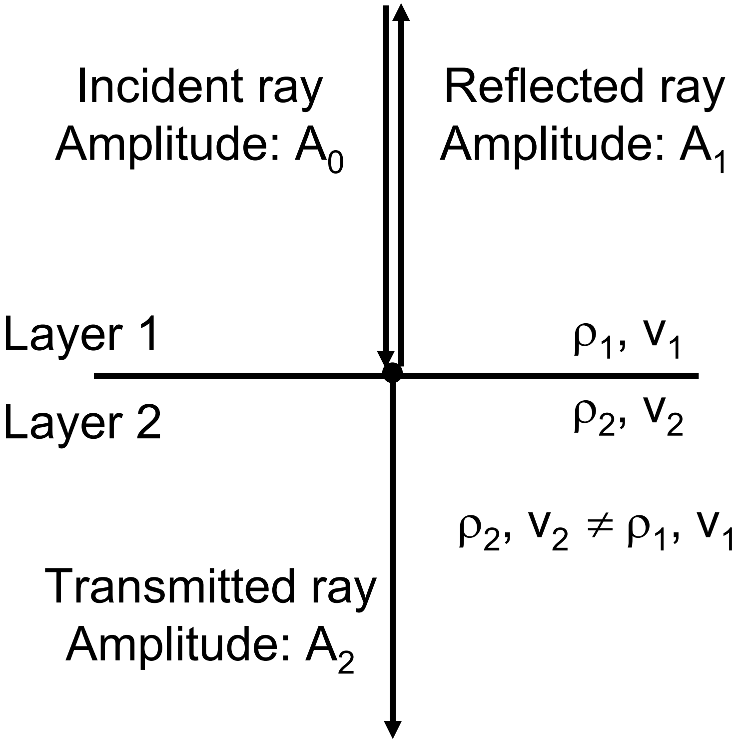
The amplitude of a seismic waves decays due to spherical spreading, as the energy in the wave is distributed along a wave front increasing steadily in size, absorption, which is friction in the rock as the wave propagates, and reflections and P-S conversions at each interface.




- Spherical spreading
- Absorption
- Transmission/conversion

# Reflection Seismology




Acoustic Impedance: $Z = \rho \cdot v$

Reflection Coefficient: $R = A_1/A_0$

$$R = \frac{\rho_2 v_2 - \rho_1 v_1}{\rho_2 v_2 + \rho_1 v_1} = \frac{Z_2 - Z_1}{Z_2 + Z_1}$$

Transmission Coefficient: $T = A_2/A_0$

$$T = \frac{2\rho_1 v_1}{\rho_2 v_2 + \rho_1 v_1}$$

$-1 \leq R \leq 1$

$R = 0$ → All incident energy transmitted ($Z_1 = Z_2$) → no reflection
$R = -1$ or $+1$ → All incident energy reflected → strong reflection
$R < 0$ → Phase change (180°) in reflected wave

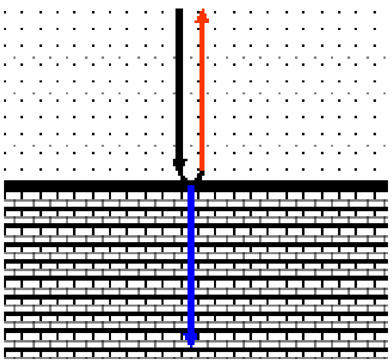
# Reflection Seismology

reflected energy: $R^2$
transmitted energy: $T^2$

$R^2 + T^2 = 1$

**Table 7.1** Seismic velocities and densities either side of an interface

| Rock | Range of velocity, $v_p$ | Range of density, $\rho$ |
|---|---|---|
| Upper layer: sandstone | 2 to 6 km/sec | 2.05 to 2.55 Mg/m³ |
| Lower layer: limestone | 2 to 6 km/sec | 2.60 to 2.80 Mg/m³ |



$$R = \frac{(2.80 \times 6) - (2.05 \times 2)}{(2.80 \times 6) + (2.05 \times 2)} = 0.608$$

& reflected energy = $0.608^2 = 0.37$
*(strong reflector with 37% of energy reflected)*

If top & lower layers have the same acoustic impedance then:

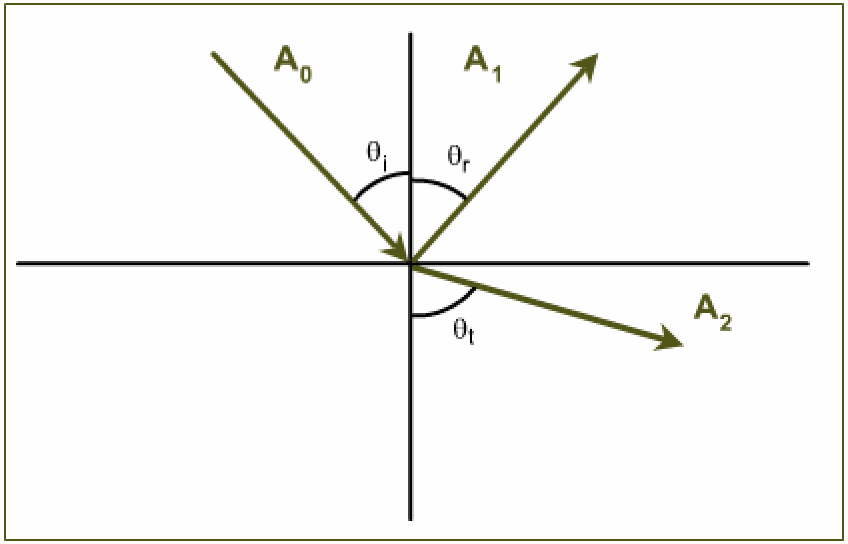
$$R = \frac{(2.64 \times 3) - (2.40 \times 3.3)}{(2.64 \times 3) + (2.40 \times 3.3)} = 0$$

- meaning that although there is a lithological boundary there is no seismic reflector
- rare to have similar acoustic impedance [more common weak reflection]
- geological interface # seismic interface

# Reflection Seismology

The angle with which the reflected wave departs from an interface is equal to the incoming angle.

teta r = teta i




The transmitted wave is refracted according to Snell's law...... .

**Snell's Law**

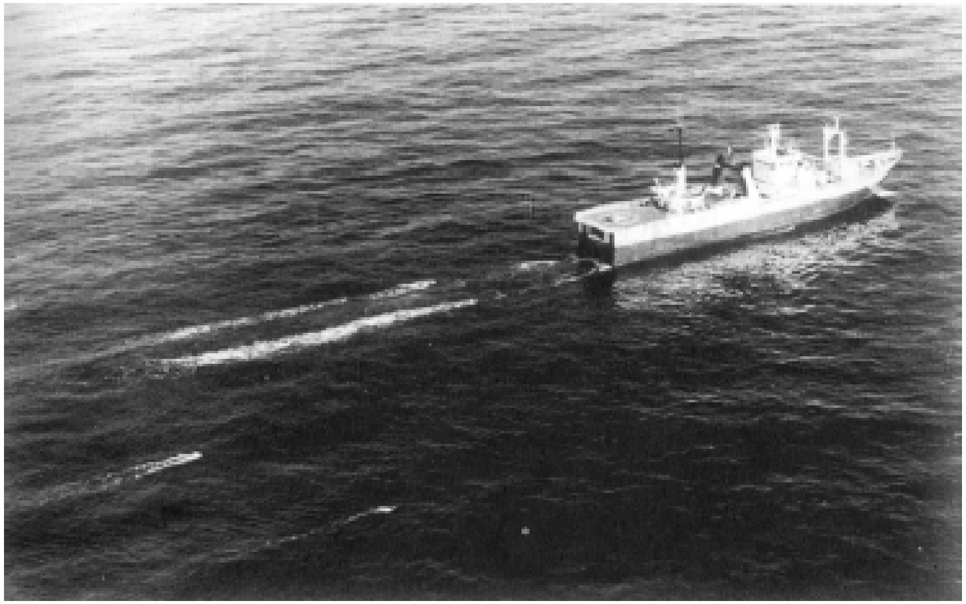
$$\frac{\sin\theta_t}{V_t} = \frac{\sin\theta_i}{V_i} \qquad \frac{\sin\theta_r}{V_r} = \frac{\sin\theta_i}{V_i}$$

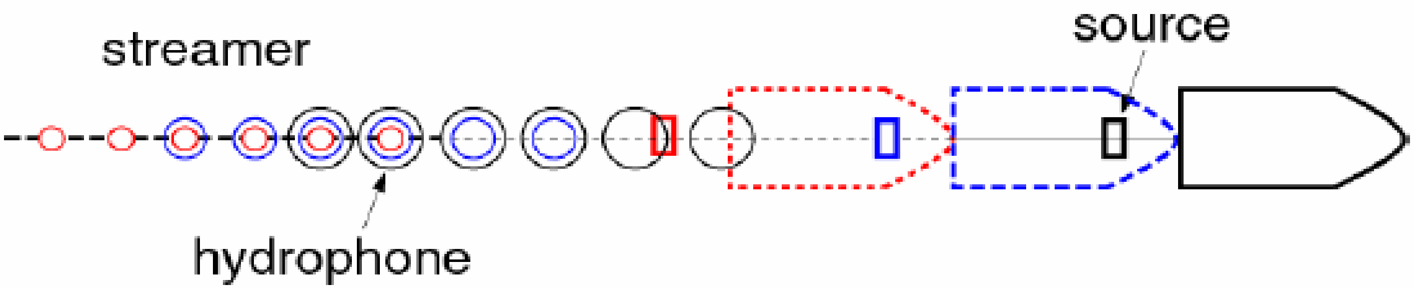
When the transmitted wave propagates along the interface, the incoming angle is called critical angle, and the transmitted wave is called head wave. In case of a velocity gradient in the layer, the wave will 'dive' within this layer (diving wave).

# Reflection Seismology

**SEISMIC REFLECTION SURVEYING: Data Acquisition**

**2D Multi-channel Reflection Surveying: Marine Surveys**





# Acquisition – Seismic source 1 of 4

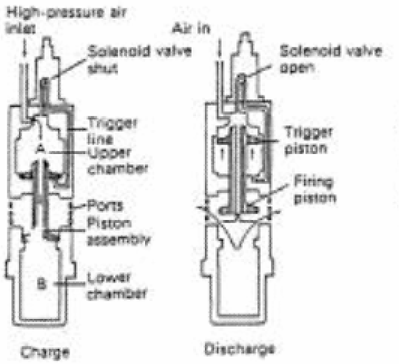
Marine seismic surveys use air guns to send out the seismic signal. An air-gun works by releasing air under high pressure (140 bar) into the water. The air-gun is towed, usually in an array with other guns, 5-15 m depth behind the ship.
The high pressured air is generated by a compressor on the ship, and the timing of the shot comes from the navigation system via a gun controller.

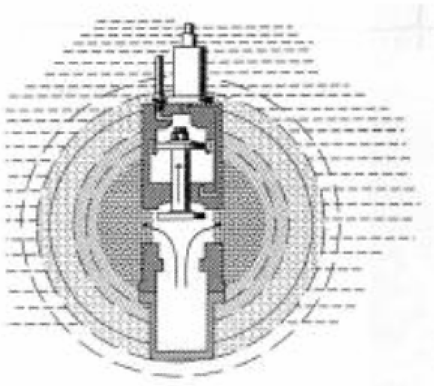
The high-pressured air is stored in two chambers inside the air-gun (see figure).

The firing signal is sent as an electric signal to the magnetic sensor on the air-gun. Air is released under the upper piston causing the air in the lowermost chamber to be released instantaneously as an explosion.

When the shot has been fired, a signal is sent from the magnetic sensor to the gun controller.

If the shot was not fired at exactly zero time, the gun controller will adjust the shot-time for the next shot.



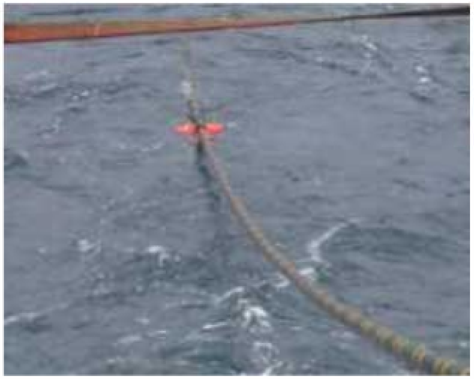
# Acquisition – Seismic receiver 2 of 4

The streamer lead signals from the receivers to the registration instruments.

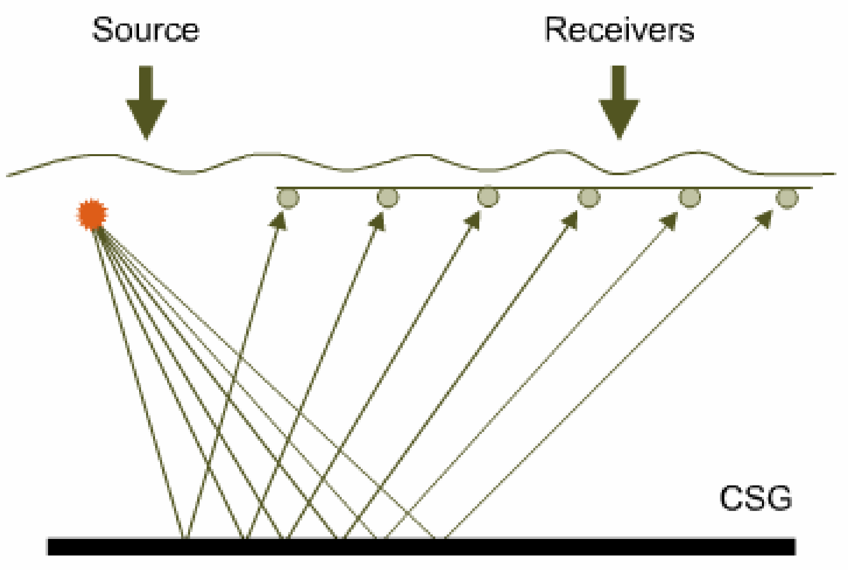
The components of a streamer-system (advanced):

- Deck-cable from recording laboratory to the reel.
- Cable reel.
- Lead-in cable.
- Depressor paravane; weight.
- Compliant section. This is a stretch section to reduce drag in the streamer.
- Active streamer: 2.5-12 km long, divided in 100 m sections with hydrophones coupled in series and parallel; group length 6.25,12.5,25 or 50 m. The skin of the streamer is flexible, and it is filled with oil to assure natural buoyancy. Thin steel cables inside provide strength.
- Compliant section.
- Towing cable.
- Tail-buoy with radar reflector and navigation system.
- 10-15 birds with compass are distributed along the streamer. These measure and adjust the depth of the streamer.

Modern 3-D vessels can handle up to 20 streamers, with 25-100 m spacing towed behind the boat.



# Reflection Seismology

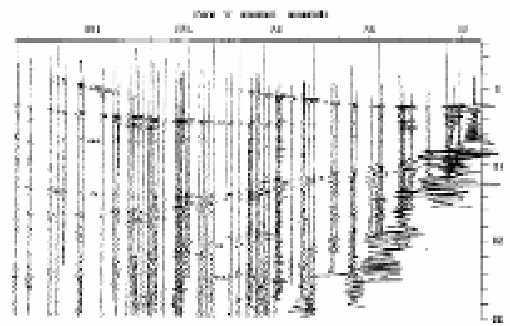


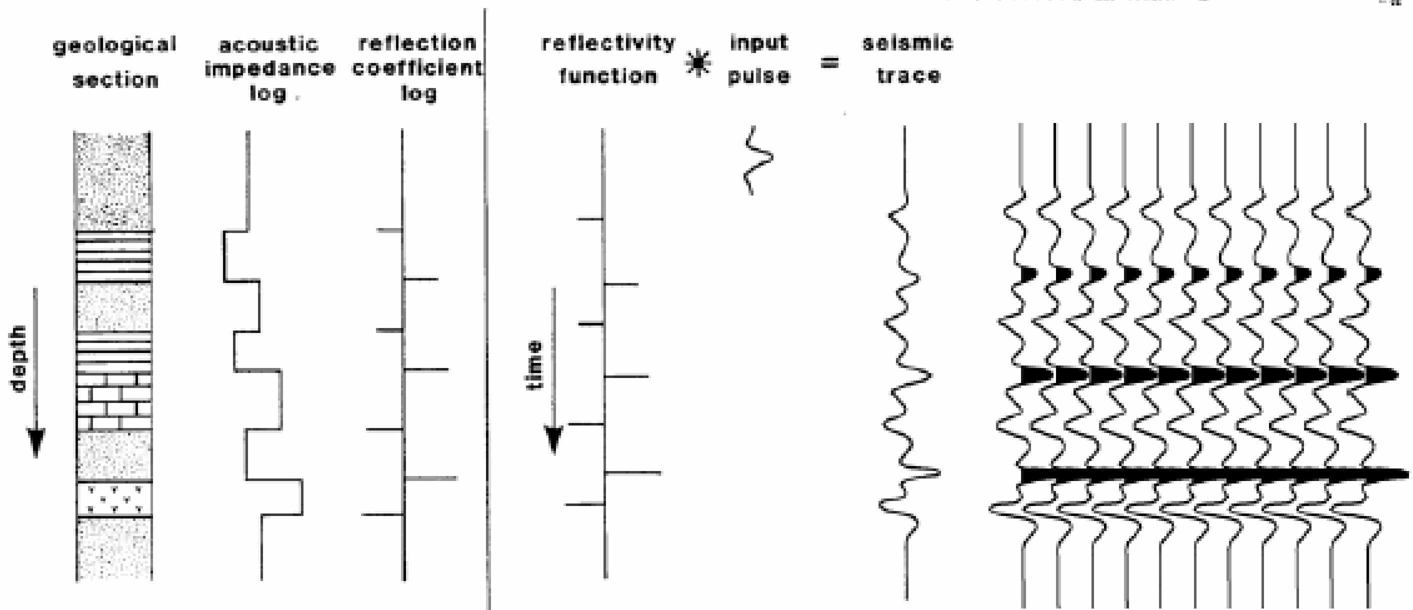

- Shotpoint interval 60 seconds
- 25-120 receivers
- Sampling rate 4 milliseconds
- Normal seismic line ca. 8 sTWT

# Reflection Seismology

## SEISMIC TRACE (REFLECTION SEISMOGRAM)

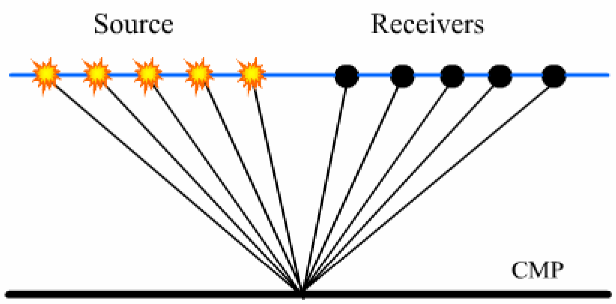
***Seismic trace**:*
*amplified oscillographic recording of each detector (geo-/ hydro-phone)*

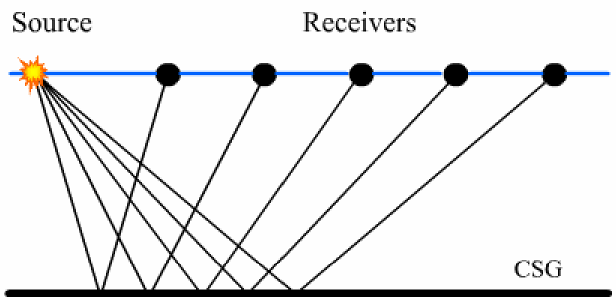




# Processing – CMP - CSG

Common Shot Gather and Common Mid-Point are two essential terms used in seismic processing. Look at the animations below to understand how it works.




CMP animation

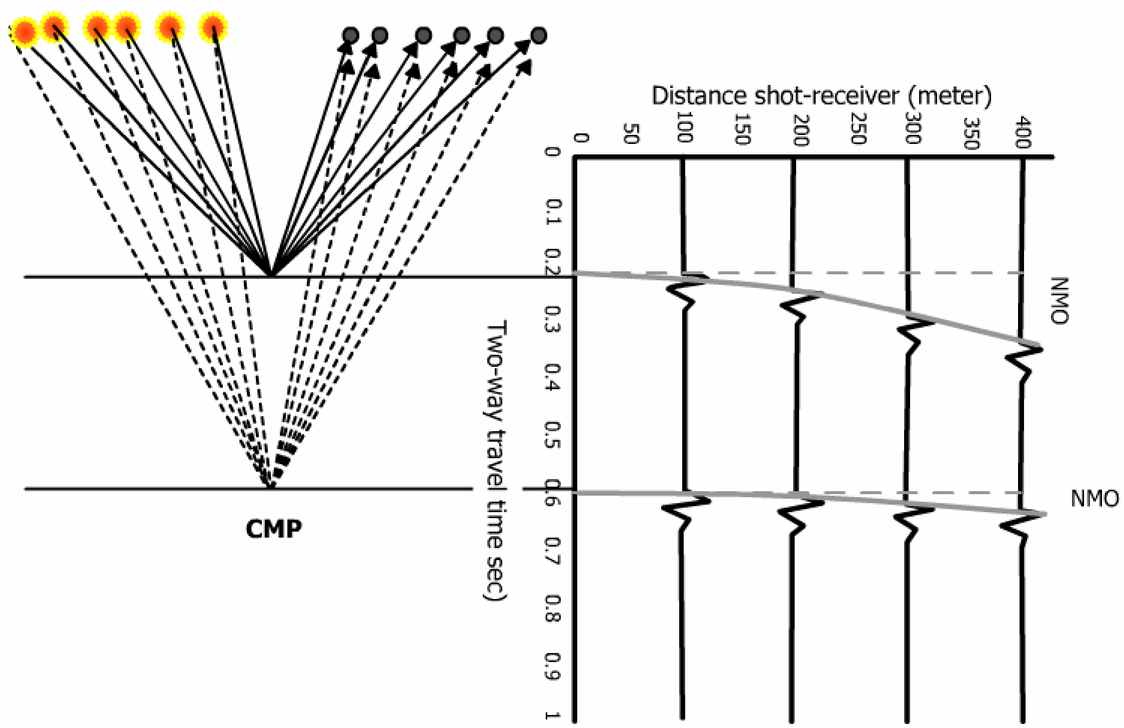
CSG animation

CSG: Common Shot Gather, all seismic traces recorded from one shot.

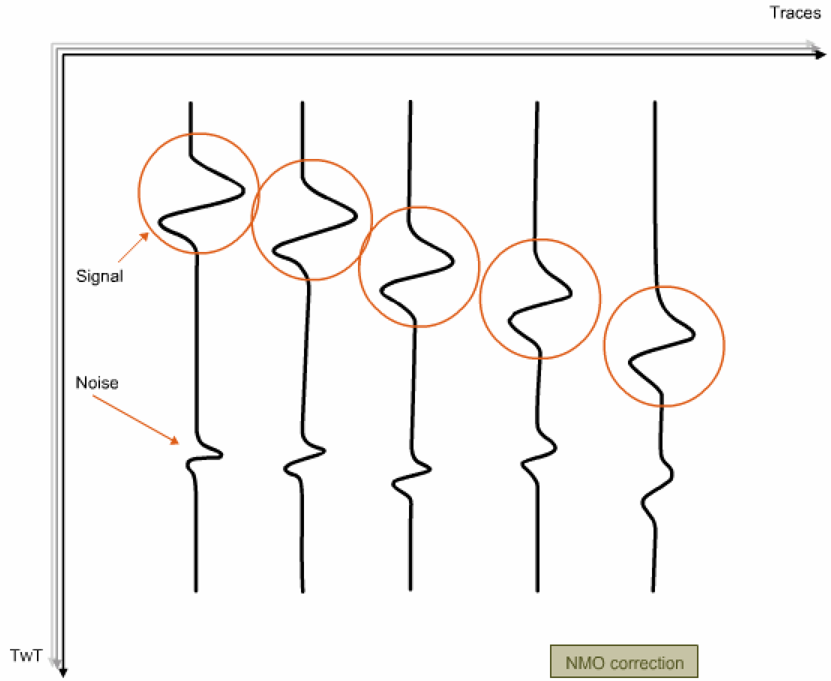
CMP: Common Mid-Point Gather, all seismic traces from subsequent shots rearranged in order to map the same point; the mid point between shot and receiver.

# Processing – NMO

The figure shows an example of a CMP-gather, containing reflections from two reflectors recorded by four channels (assuming straight ray-paths). The figure shows that increasing the shot-receiver distance, increases the travel-time. The difference between (assumed) vertical two-way travel-time and observed travel-time is called normal-move-out (NMO).



# Processing – Stacking




NMO correction

INTRODUCTION

MULTICHANNEL REFLECTION SEISMICS

Acquisition

Processing

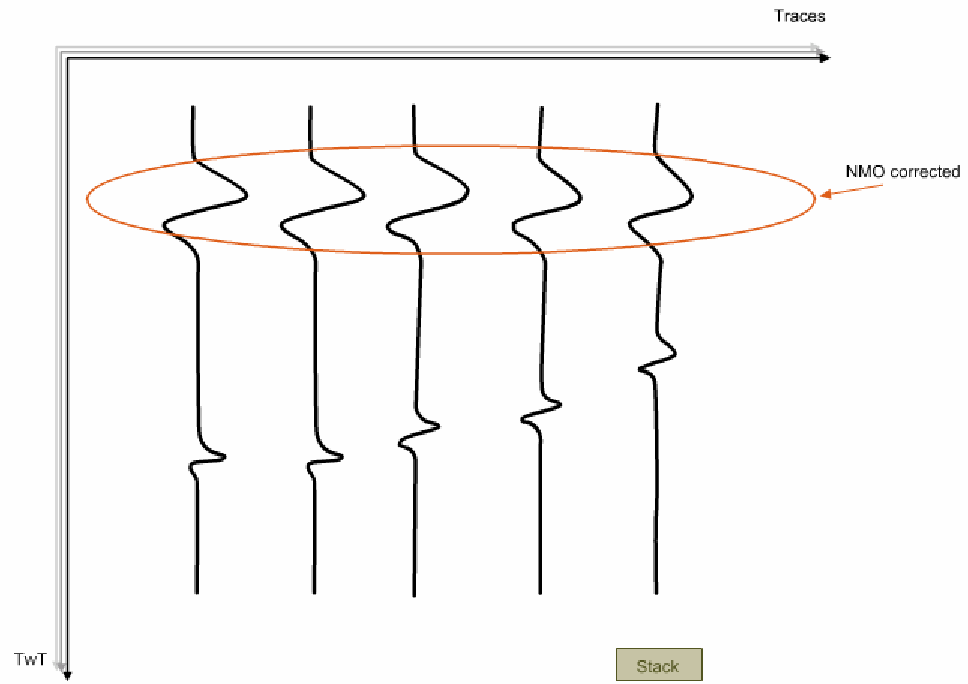
Filter
CMP – CSG
NMO
NMO correction
Stacking
Scheme

Interpretation

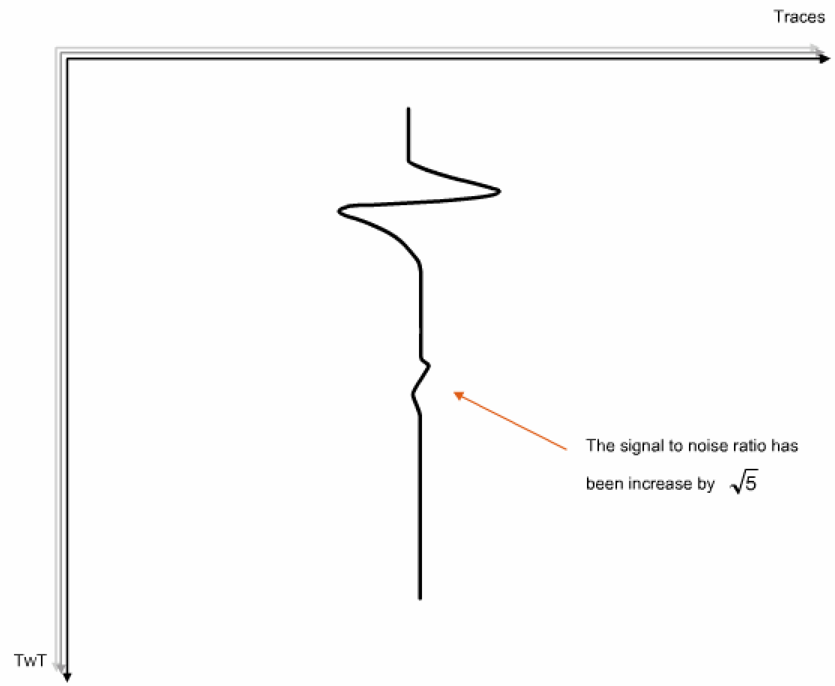
OCEAN BOTTOM SEISMICS

4D SEISMICS

# Processing – Stacking



# Processing – Stacking



# Reflection Seismology

- SEISMIC PROSESSING
  - The objective of seismic prosessing is to enhance the signal-to-noise ration by means of e.g. filtering

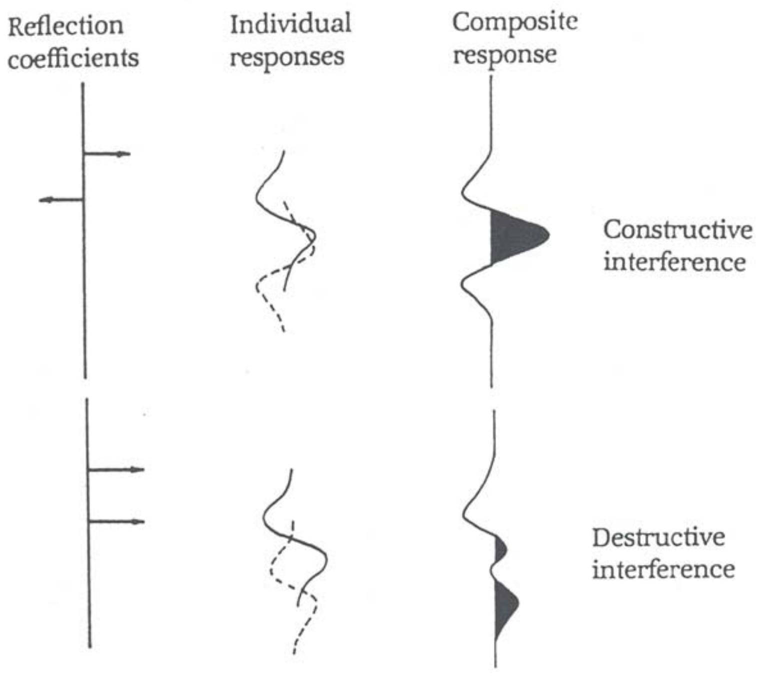
# Reflection Seismology

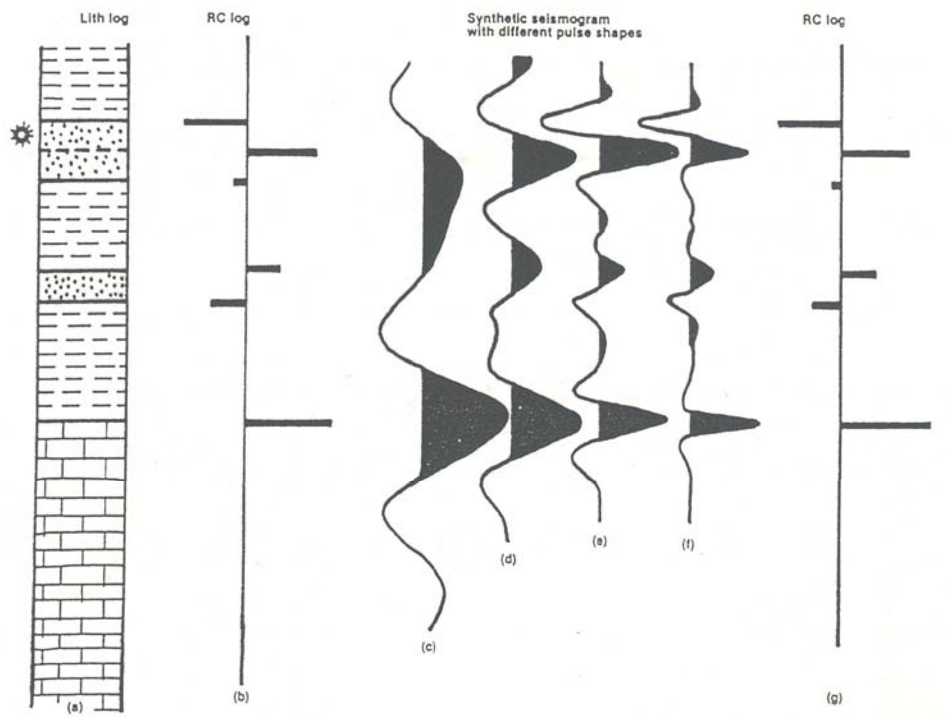
- Limitations and Pitfalls
  - Interference
  - Horizontal and Vertical Resolution
  - Velocity Effects
  - Geometrical Effects
  - Multiples

# INTERFERENCE

# Reflection Seismology

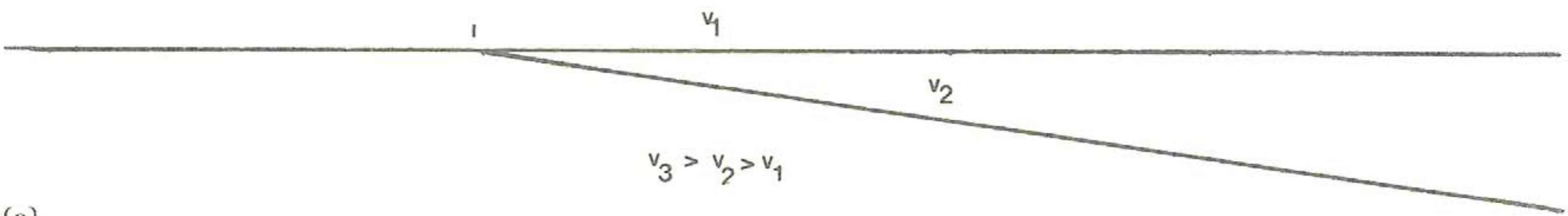
## Interference



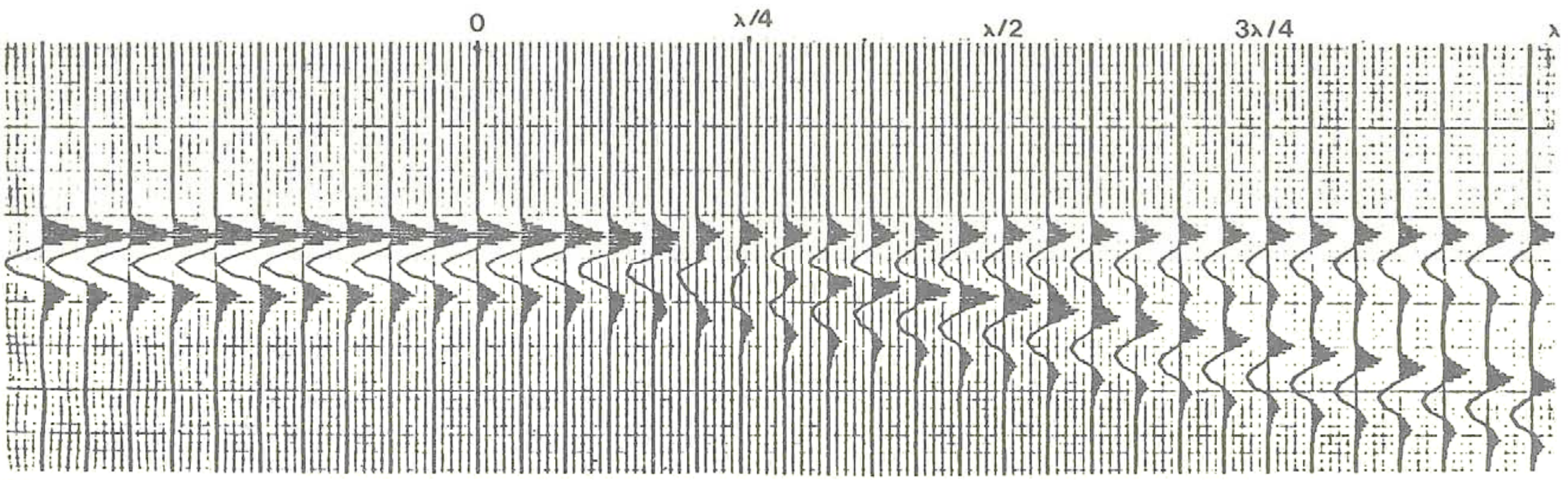



# Reflection Seismology

## Interference



(a)



(b)

# VERTICAL RESOLUTION

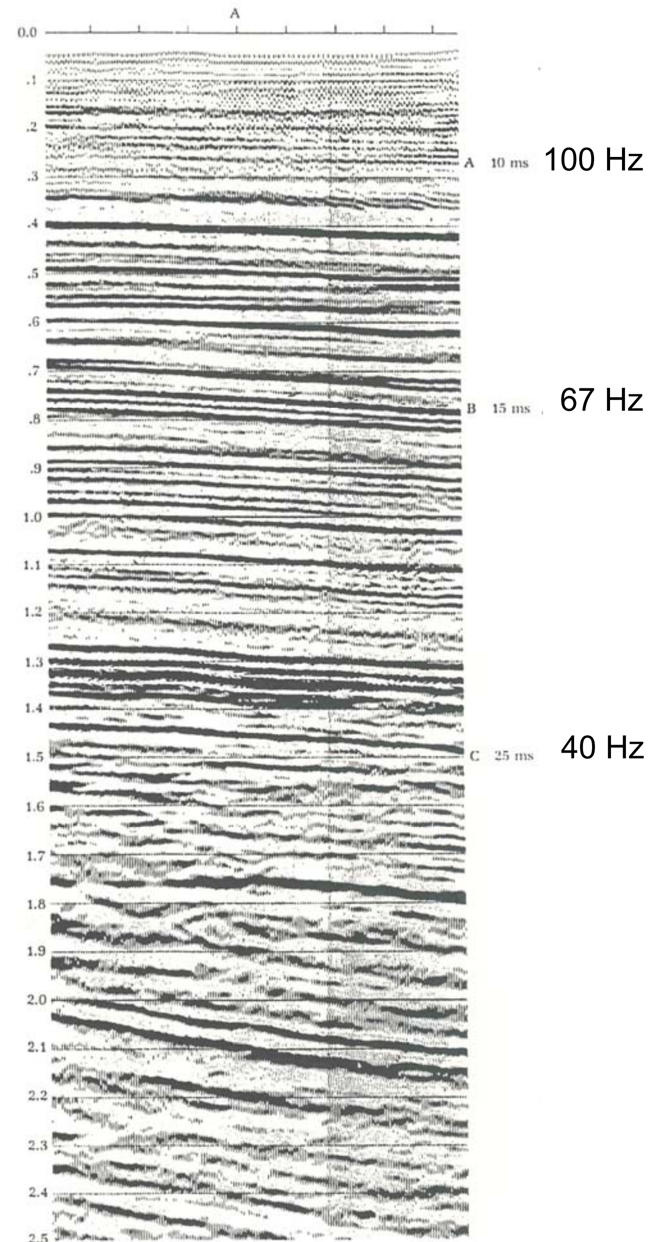
# Reflection Seismology

Wavelength increases
Frequency decreases
} with depth

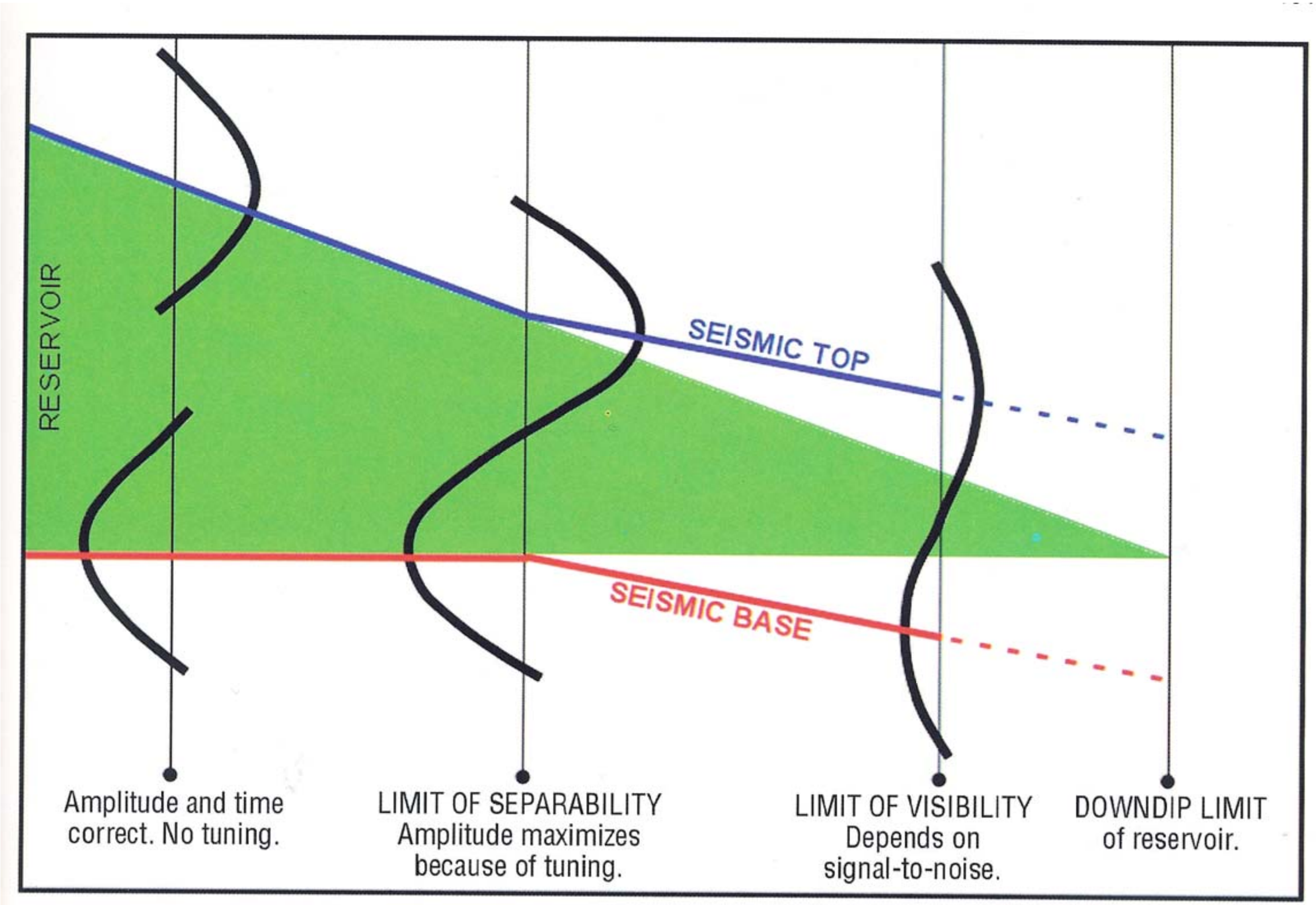
↓

Reduced vertical resolution

| f | v | λ | λ/4 | z |
|---|---|---|---|---|
| 100 Hz | 2 km/s | 20 m | 5 m | ~250 m |
| 40 Hz | 4 km/s | 100 m | 25 m | ~2250 m |



# Reflection Seismology




(Brown 1999)

# Reflection Seismology

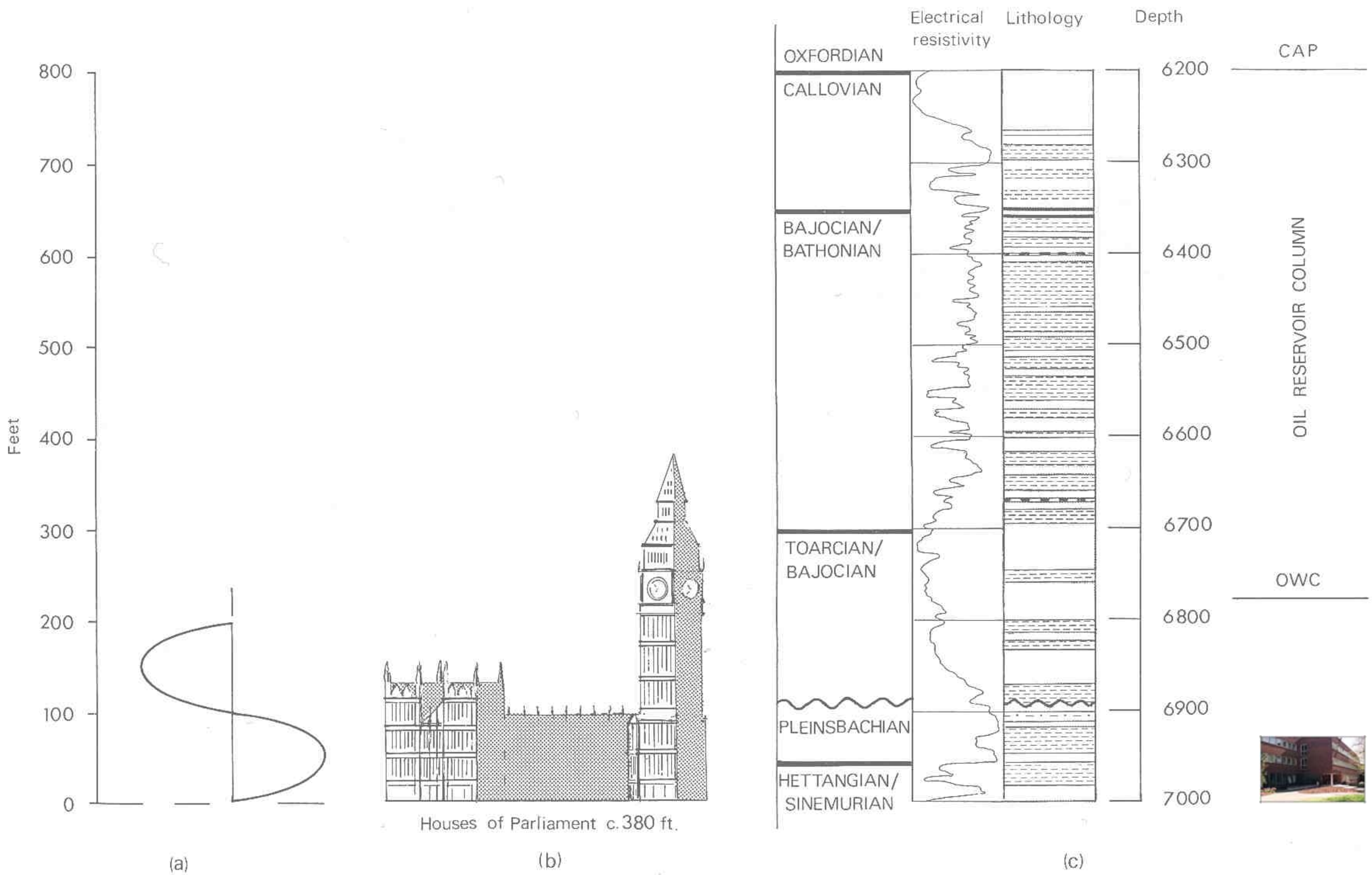
**Table 1-1.** Typical Limits of Visibility and Separability for a range of geologic situations.

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Age of rocks | | | | VERY YOUNG | YOUNG | MEDIUM | OLD | VERY OLD |
| Depth of target | | | | VERY SHALLOW | SHALLOW | MEDIUM | DEEP | VERY DEEP |
| Formation Velocity (m/s) | | | | 1600 | 2000 | 3500 | 5000 | 6000 |
| Predominant Frequency (Hz) | | | | 70 | 50 | 35 | 25 | 20 |
| Wavelength (m) | | | $\lambda$ | 23 | 40 | 100 | 200 | 300 |
| LIMIT OF SEPARABILITY | | | $\frac{\lambda}{4}$ | 6 | 10 | 25 | 50 | 75 |
| LIMIT OF VISIBILITY: Poor S/N | e.g. | Water sand poor data | $\sim\frac{\lambda}{8}$ | 3 | 5 | 13 | 25 | 38 |
| LIMIT OF VISIBILITY: Moderate S/N | e.g. | Water or oil sand fairly good data | $\sim\frac{\lambda}{12}$ | 2 | 3 | 8 | 17 | 25 |
| LIMIT OF VISIBILITY: High S/N | e.g. | Gas sand good data | $\sim\frac{\lambda}{20}$ | 1 | 2 | 5 | 10 | 15 |
| LIMIT OF VISIBILITY: Outstanding S/N | e.g. | Gas sand excellent data | $\sim\frac{\lambda}{30}$ | <1 | 1 | 3 | 7 | 10 |

units are meters

(Brown 1999)

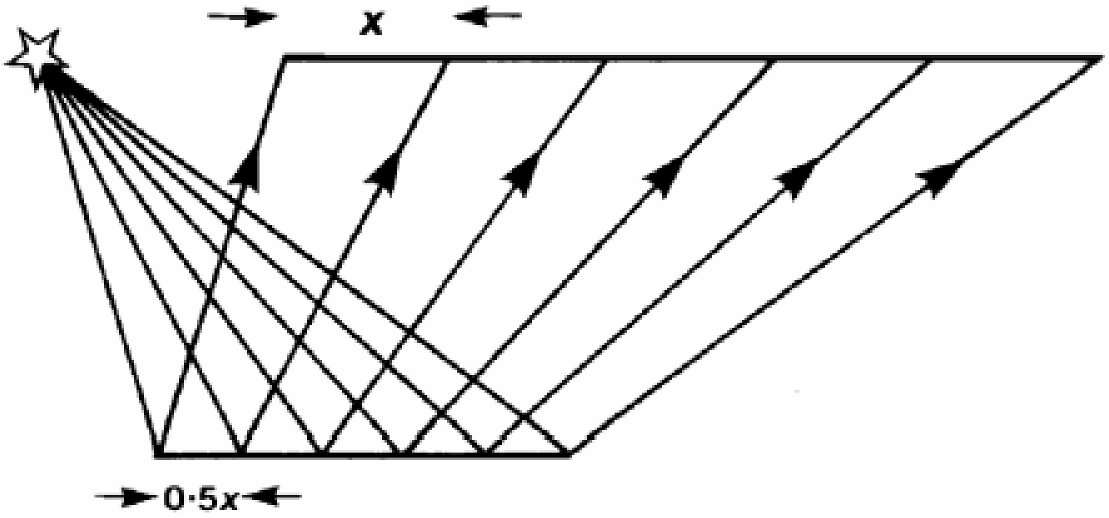
# Reflection Seismology



# HORIZONTAL RESOLUTION

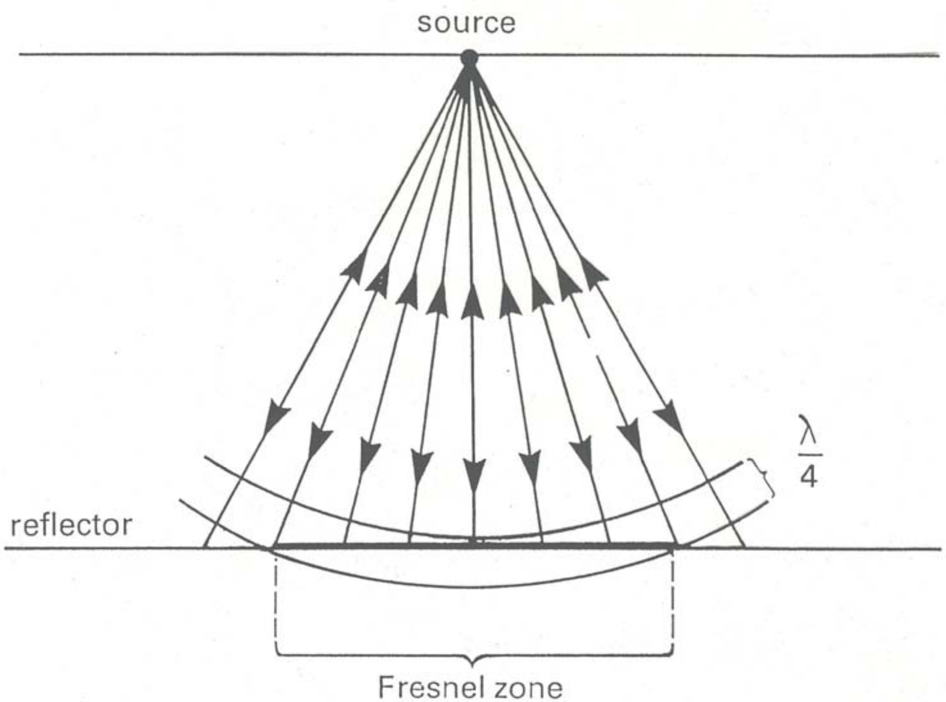
# Reflection Seismology

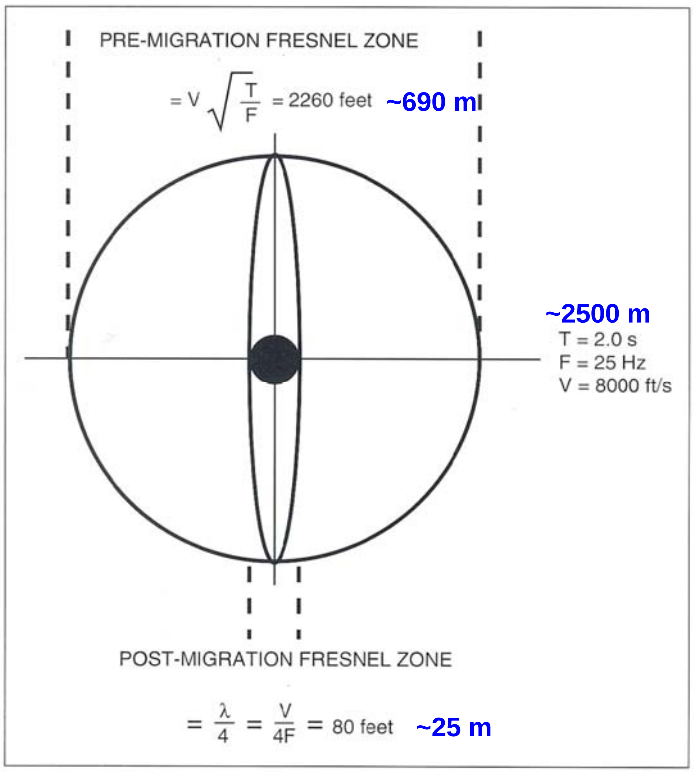
Horizontal Resolution



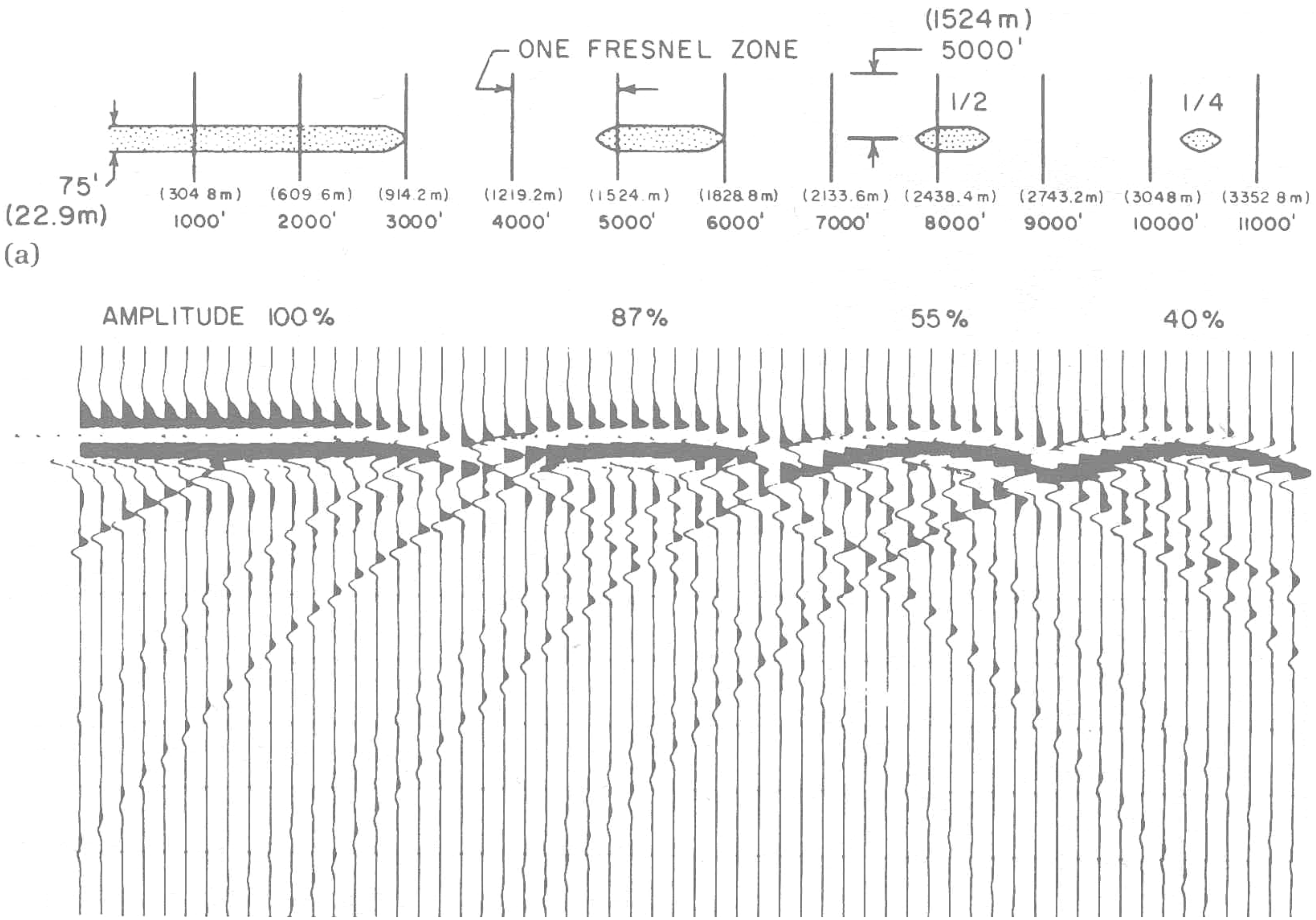

Horizontal Resolution = half the detector spacing

# Reflection Seismology

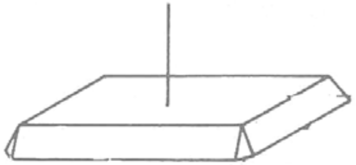


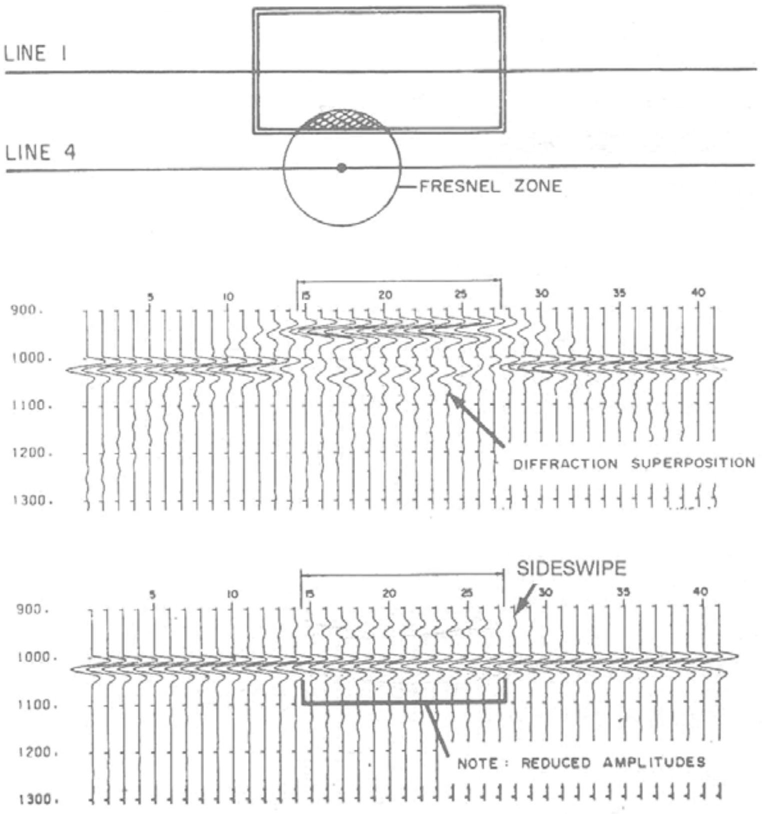
# Reflection Seismology



# Reflection Seismology



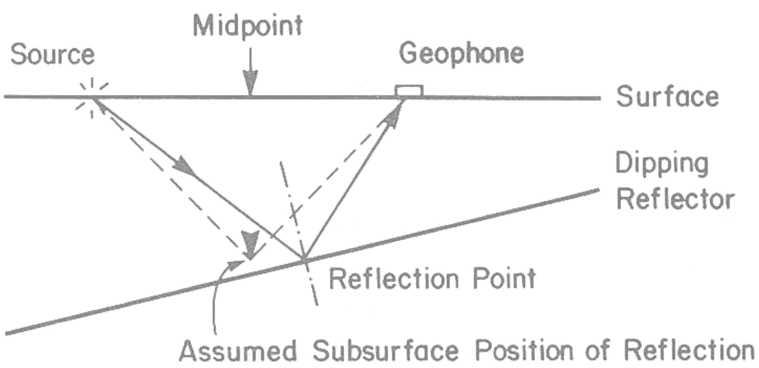
(a)

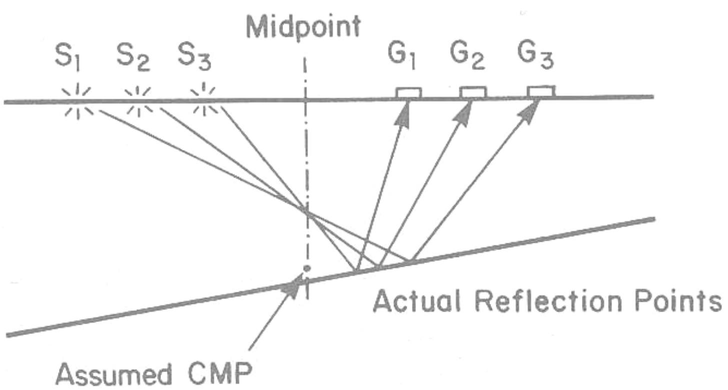



(b)

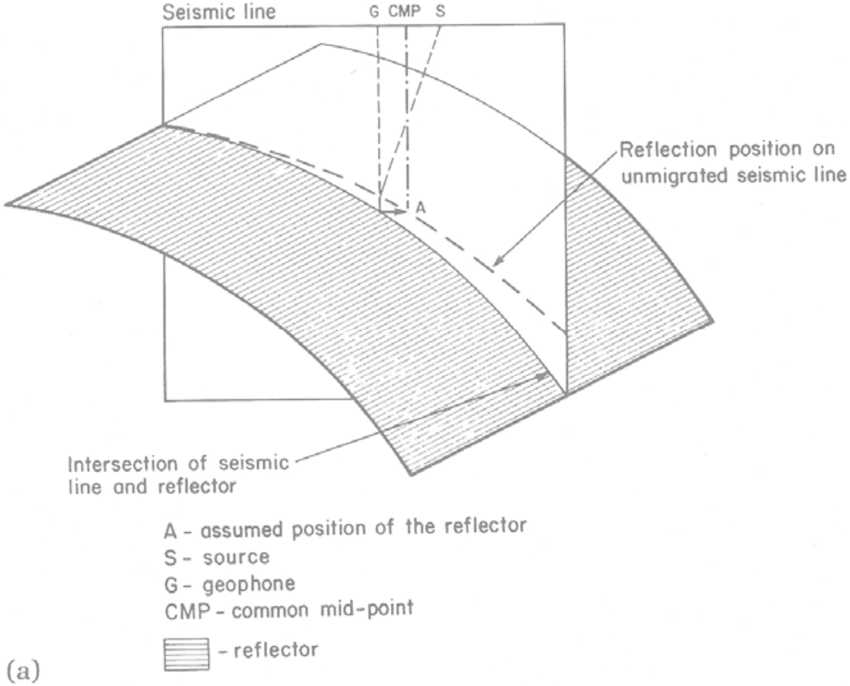
# GEOMETRICAL EFFECTS

# Reflection Seismology

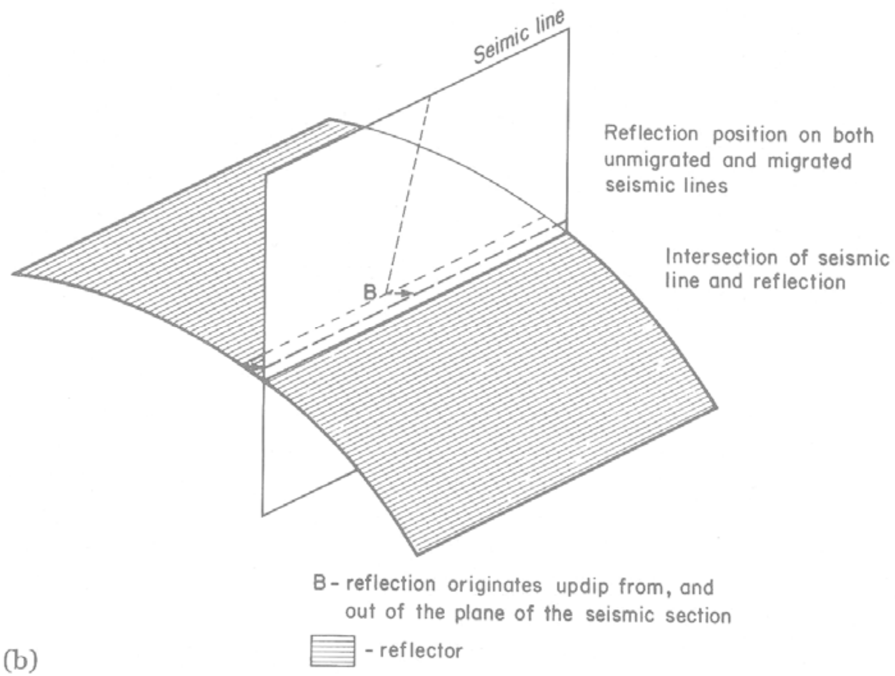


# Reflection Seismology

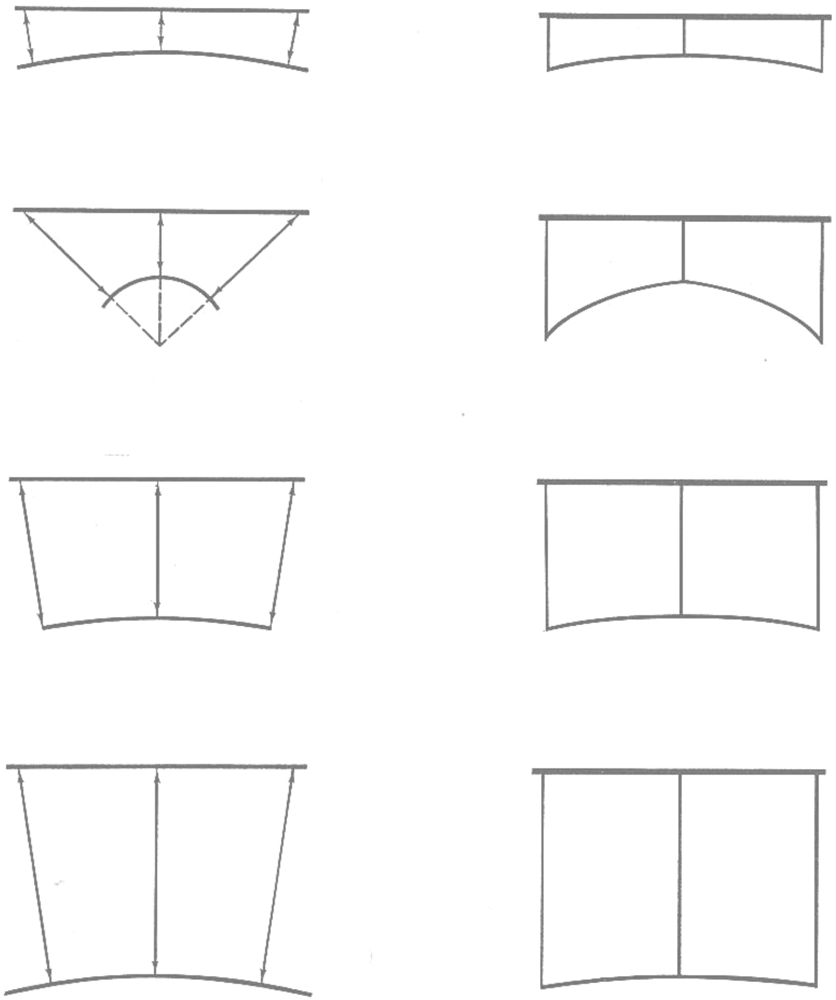



(a)



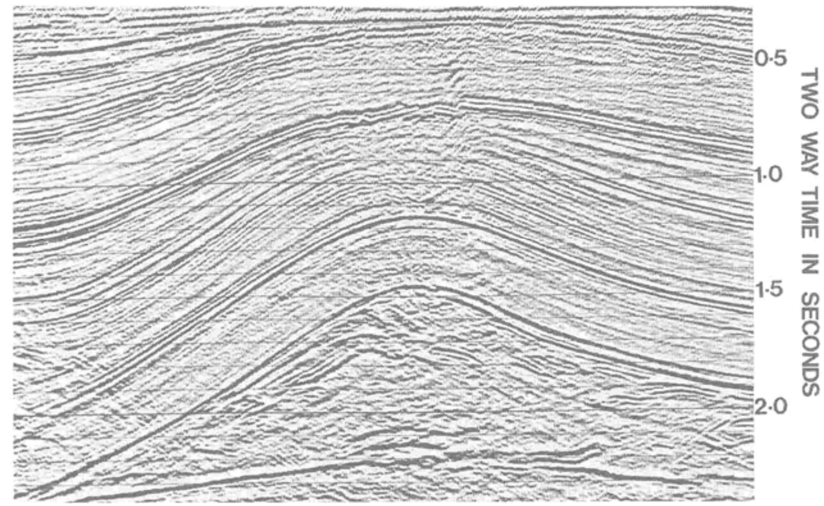

(b)

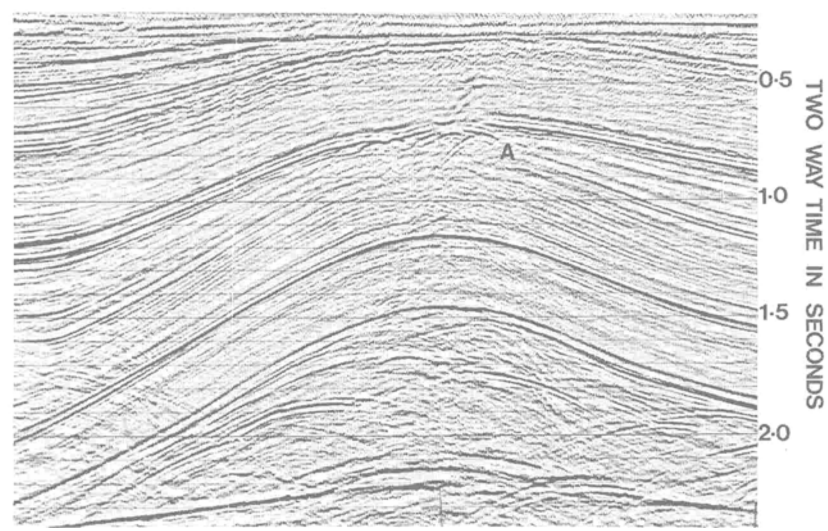
## Anticline



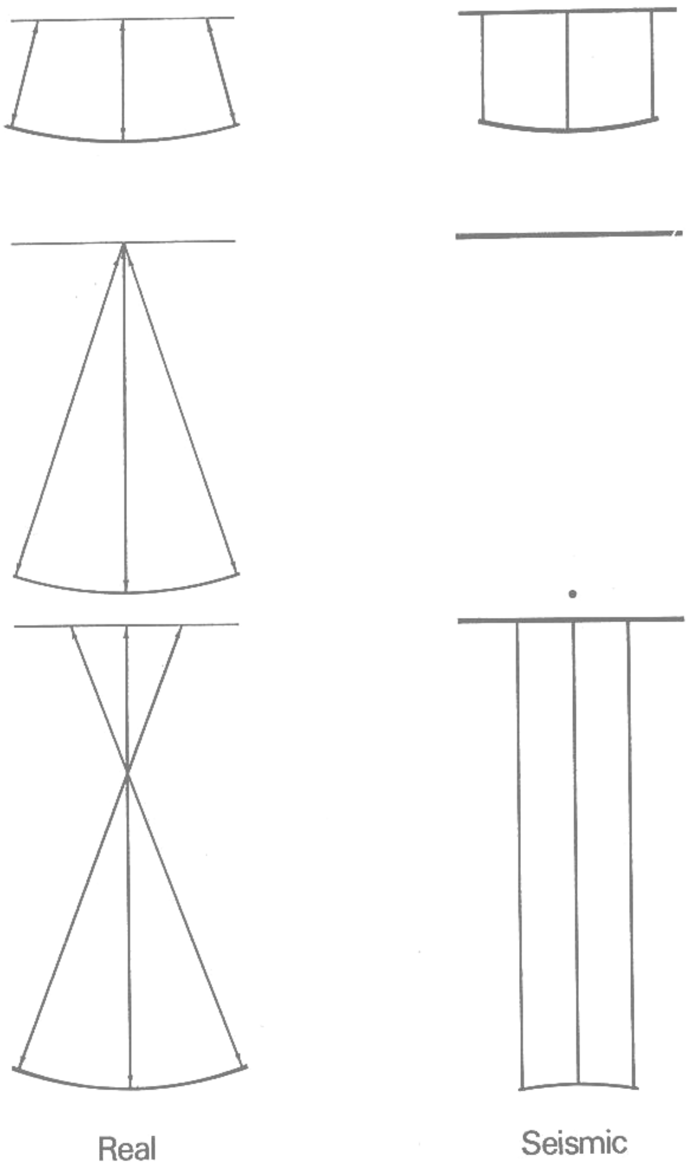
Real

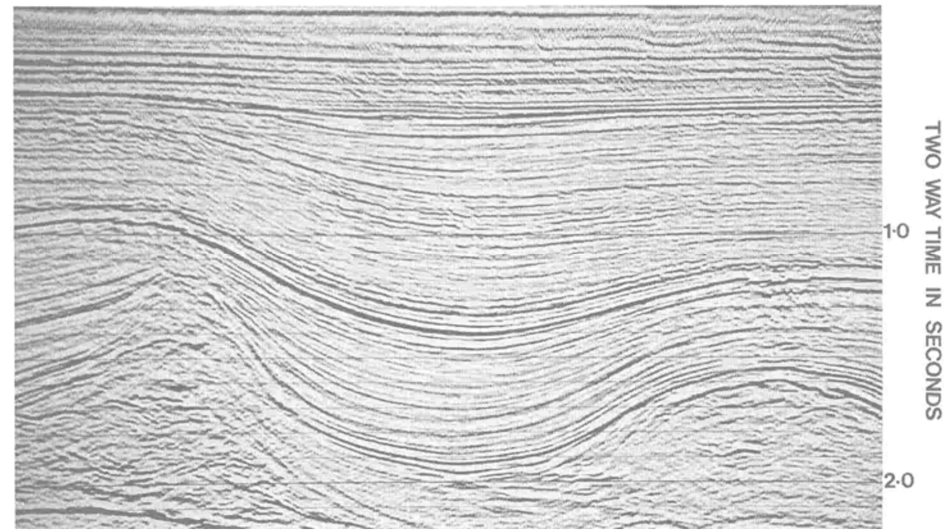
Seismic

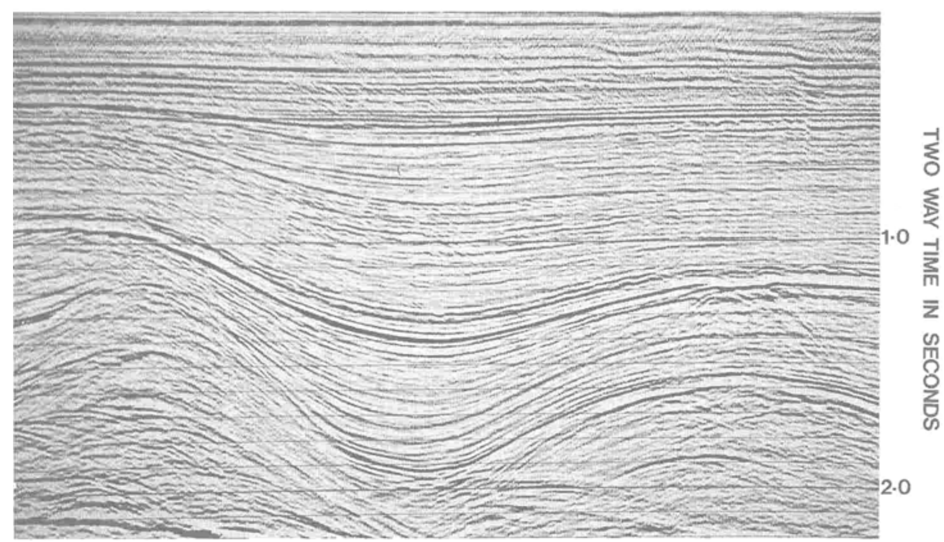


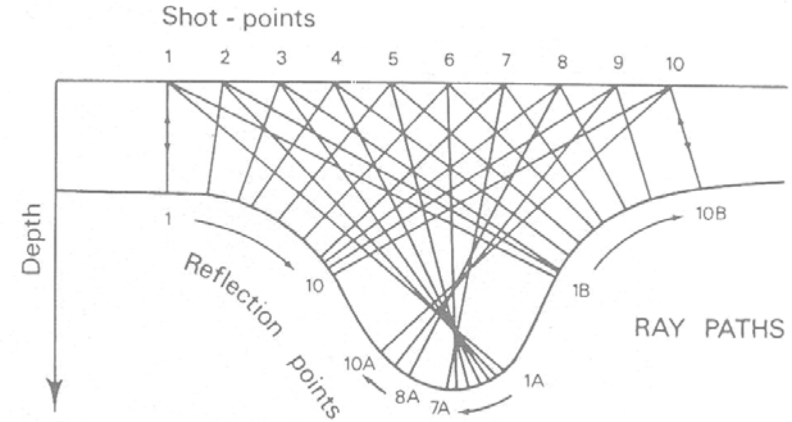



## Synclines

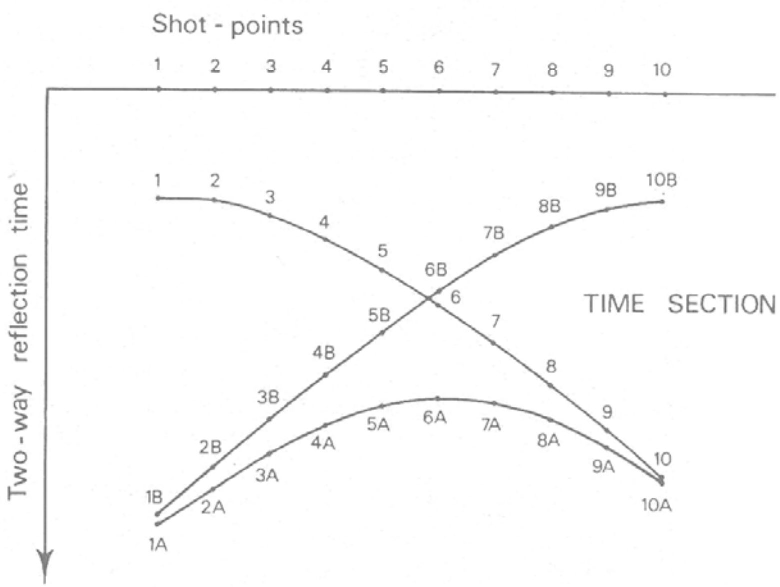

Real
Seismic


TWO WAY TIME IN SECONDS
1·0
2·0

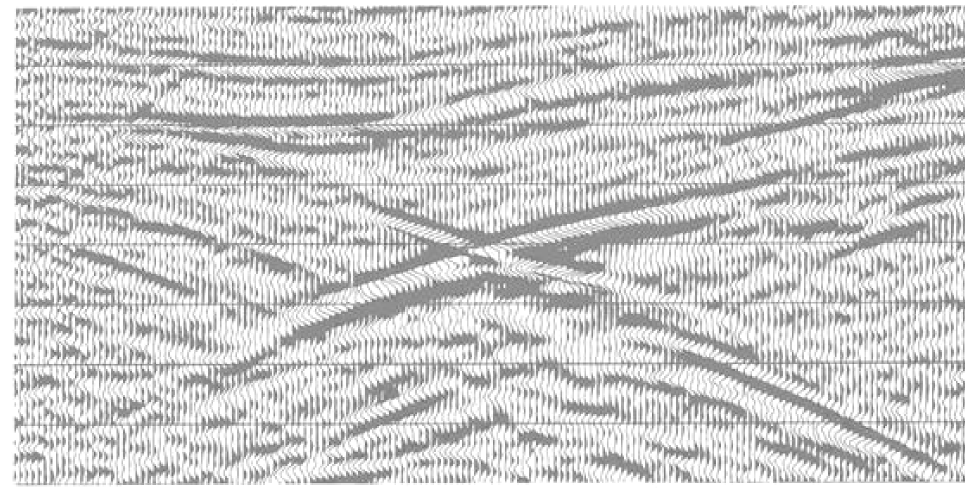

TWO WAY TIME IN SECONDS
1·0
2·0


Shot - points
1
2
3
4
5
6
7
8
9
10
Depth
1
10
Reflection points
10A
8A
7A
1A
1B
10B
RAY PATHS

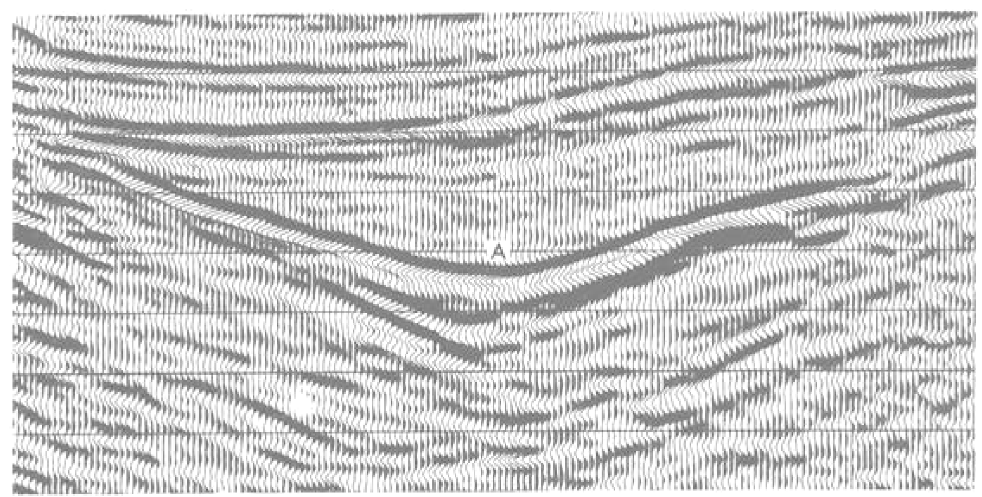
(a)


Shot - points
1
2
3
4
5
6
7
8
9
10
Two-way reflection time
TIME SECTION
1B
2B
3B
4B
5B
6B
7B
8B
9B
10B
1A
2A
3A
4A
5A
6A
7A
8A
9A
10A

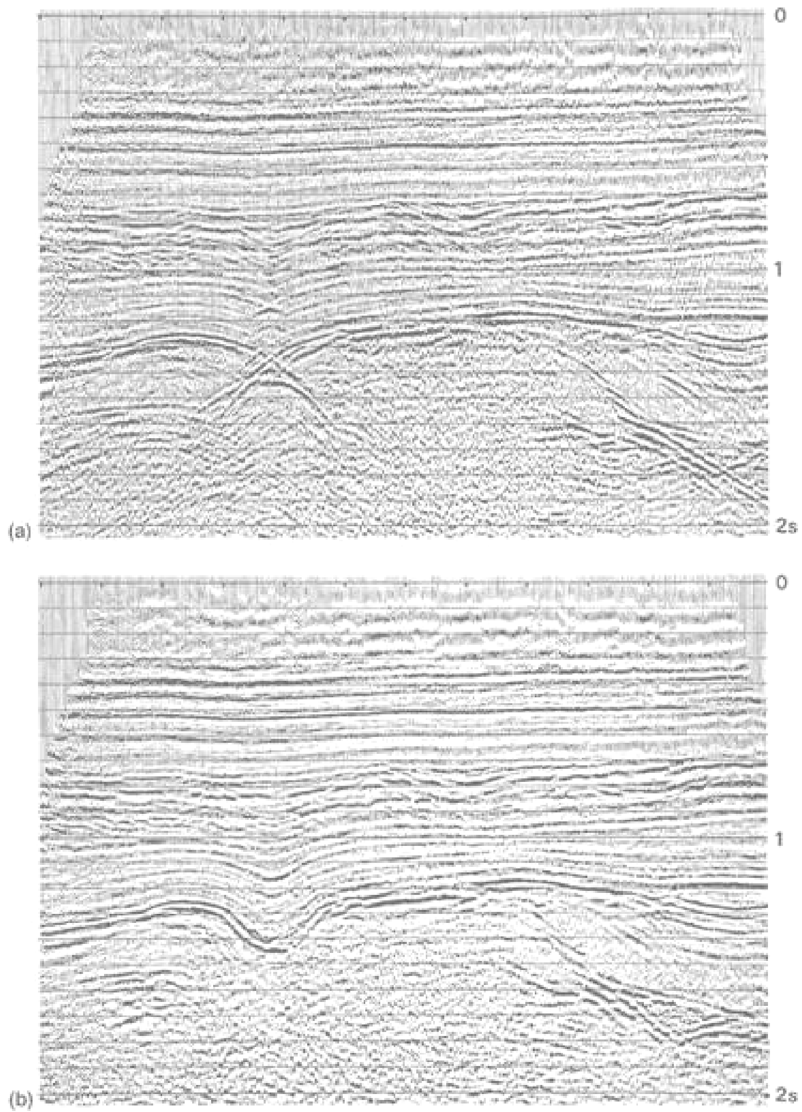
(b)

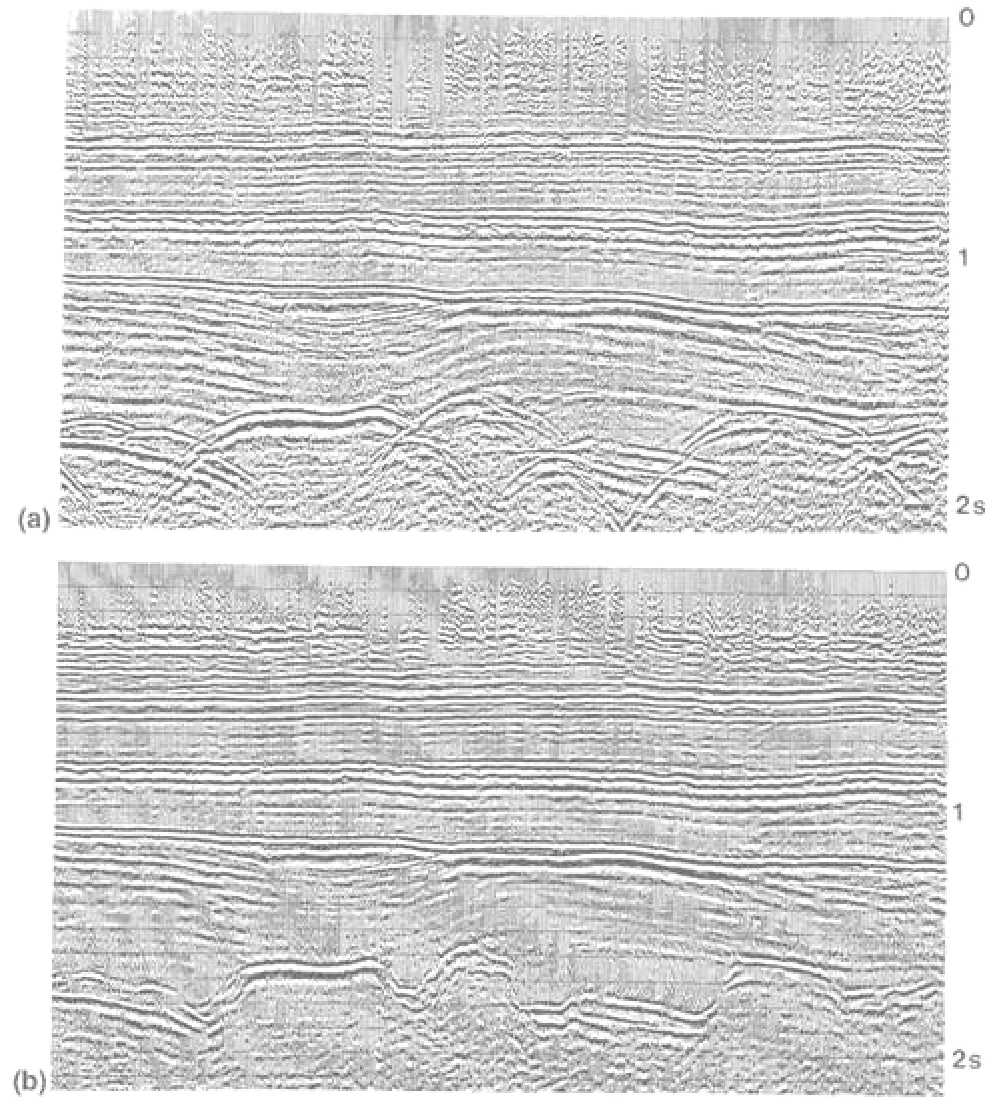


(a)

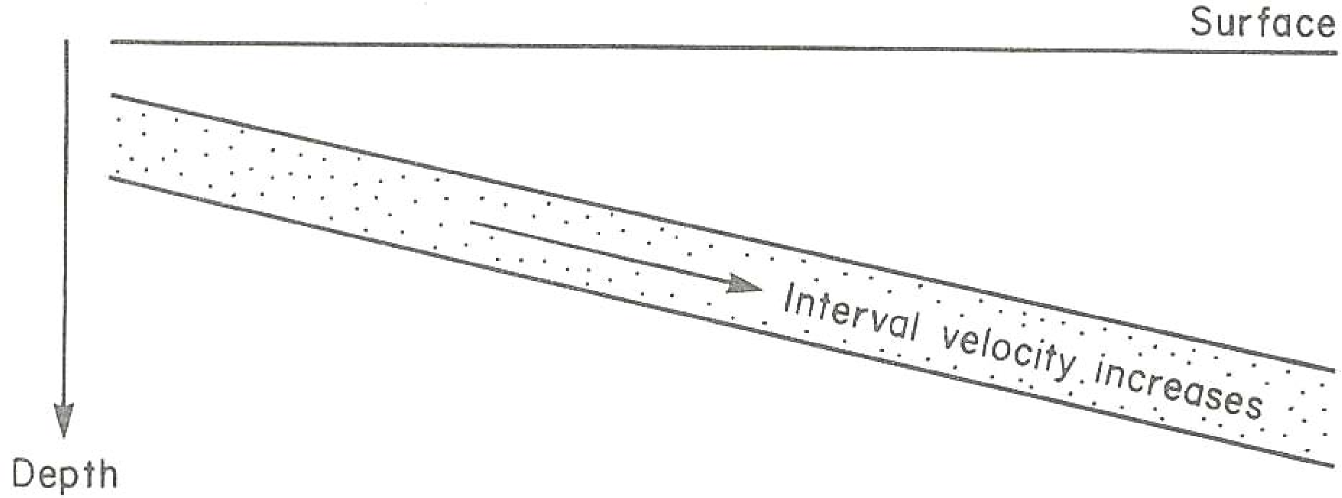

A

(b)

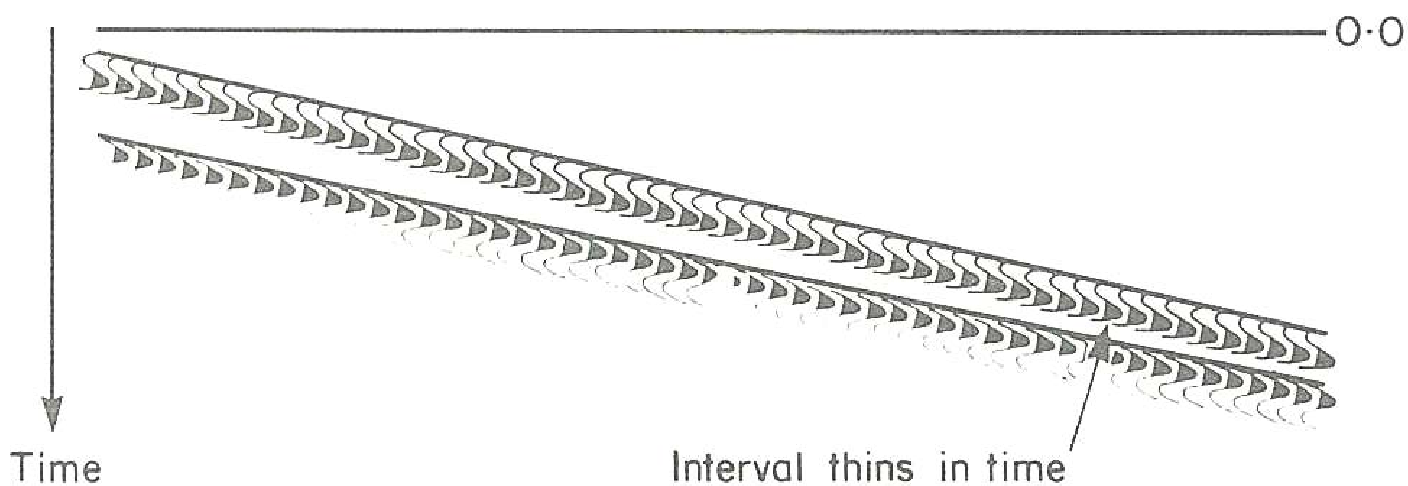

0
1
(a)
2s
0
1
(b)
2s


0
1
(a)
2s
0
1
(b)
2s

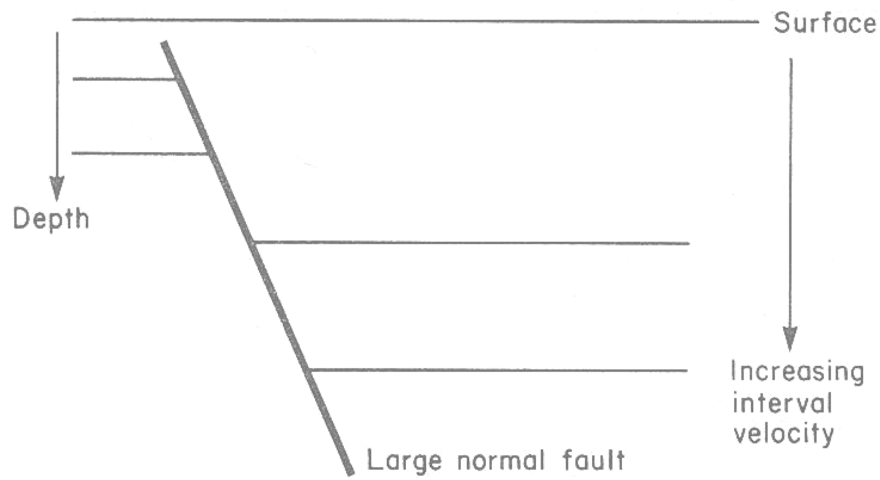
# VELOCITY EFFECTS


Surface
Interval velocity increases
Depth

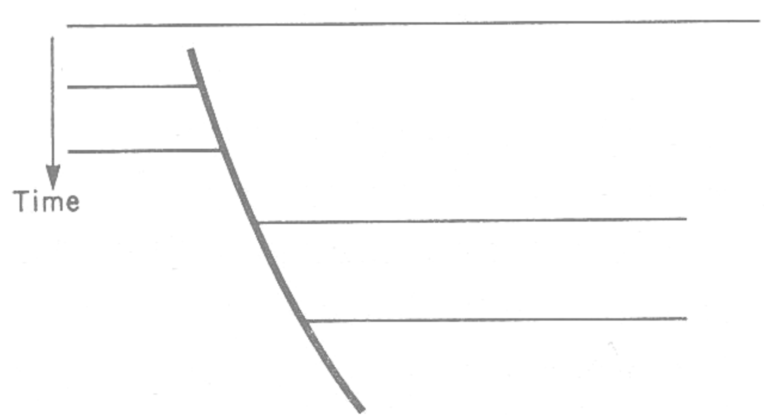
(a)


0·0
Time
Interval thins in time

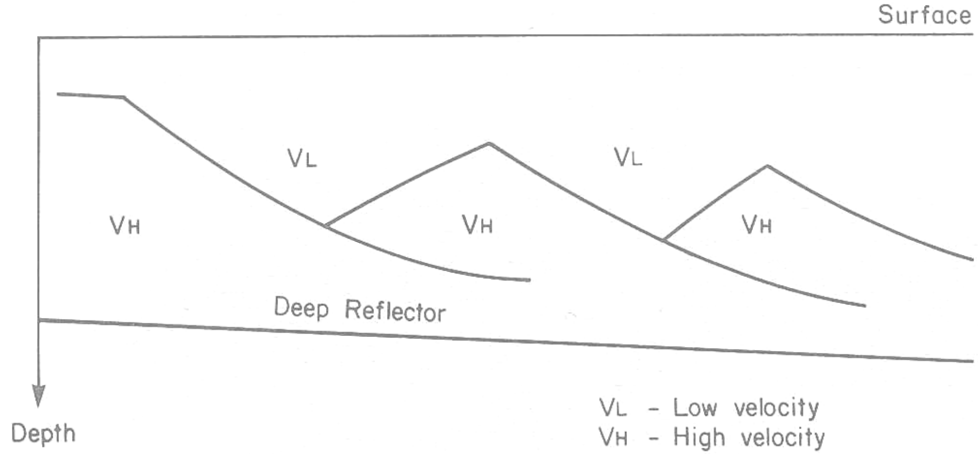
(b)


Surface
Depth
Increasing
interval
velocity
Large normal fault

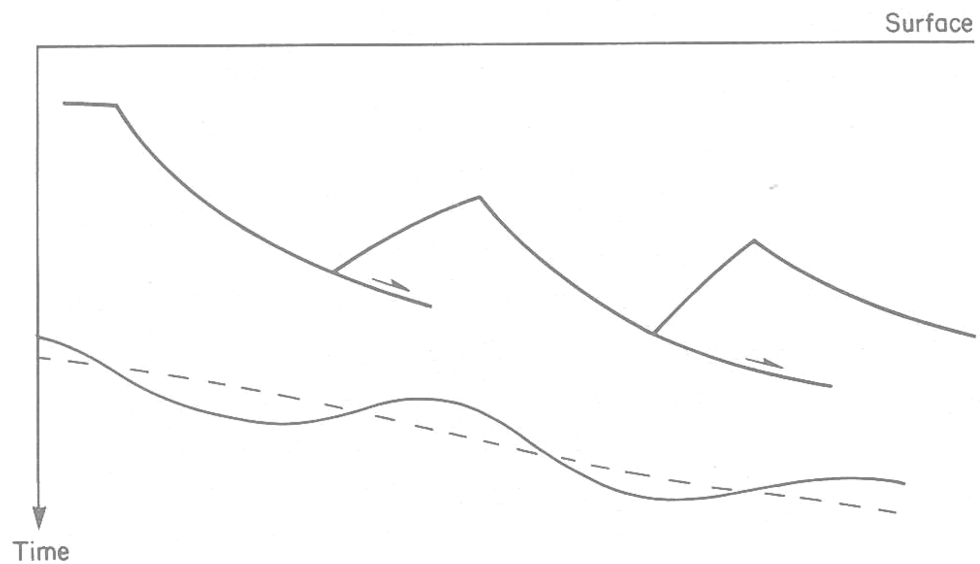
(a)


Time

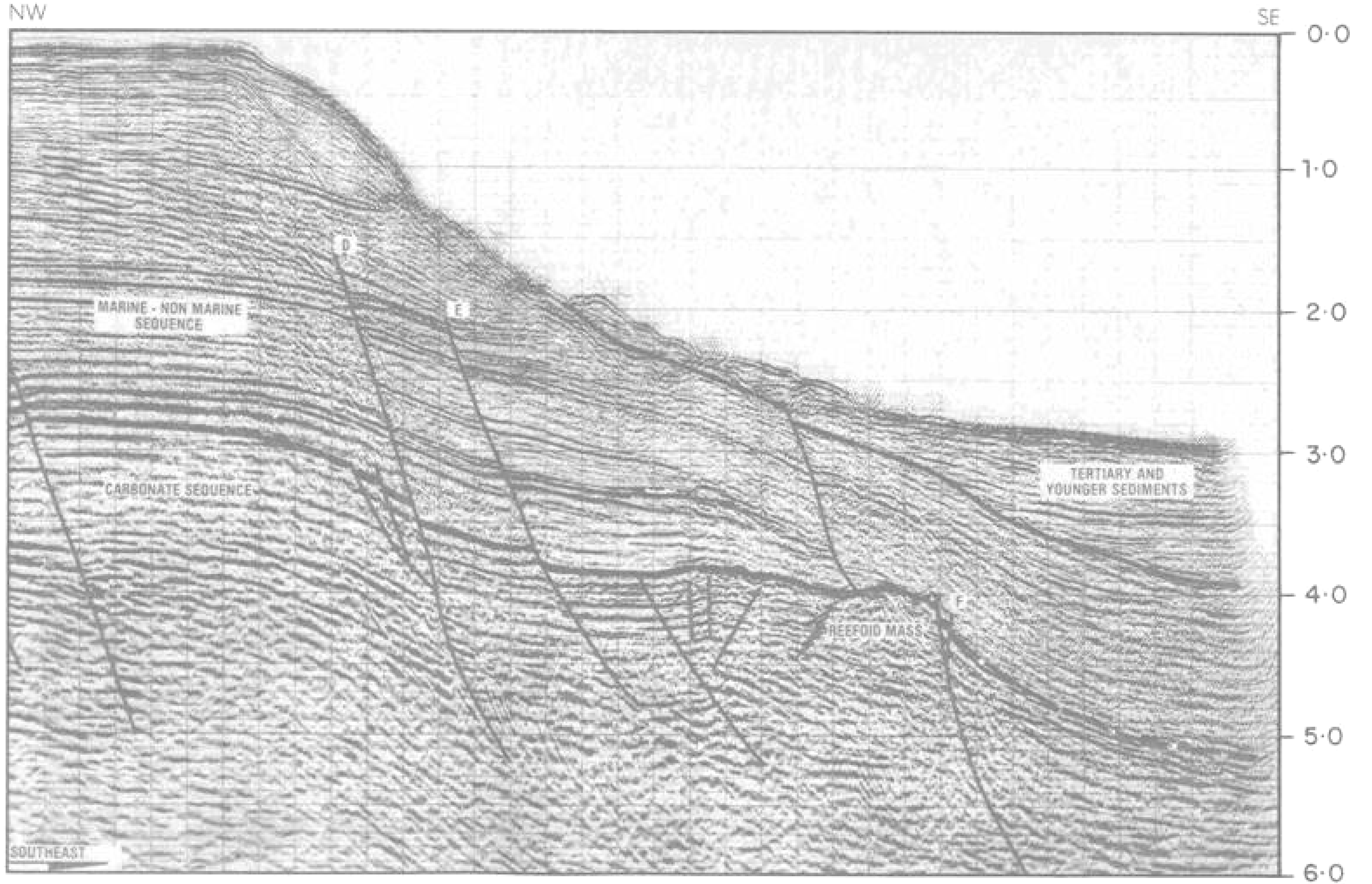
(b)


Surface
VL
VL
VH
VH
VH
Deep Reflector
Depth
VL - Low velocity
VH - High velocity

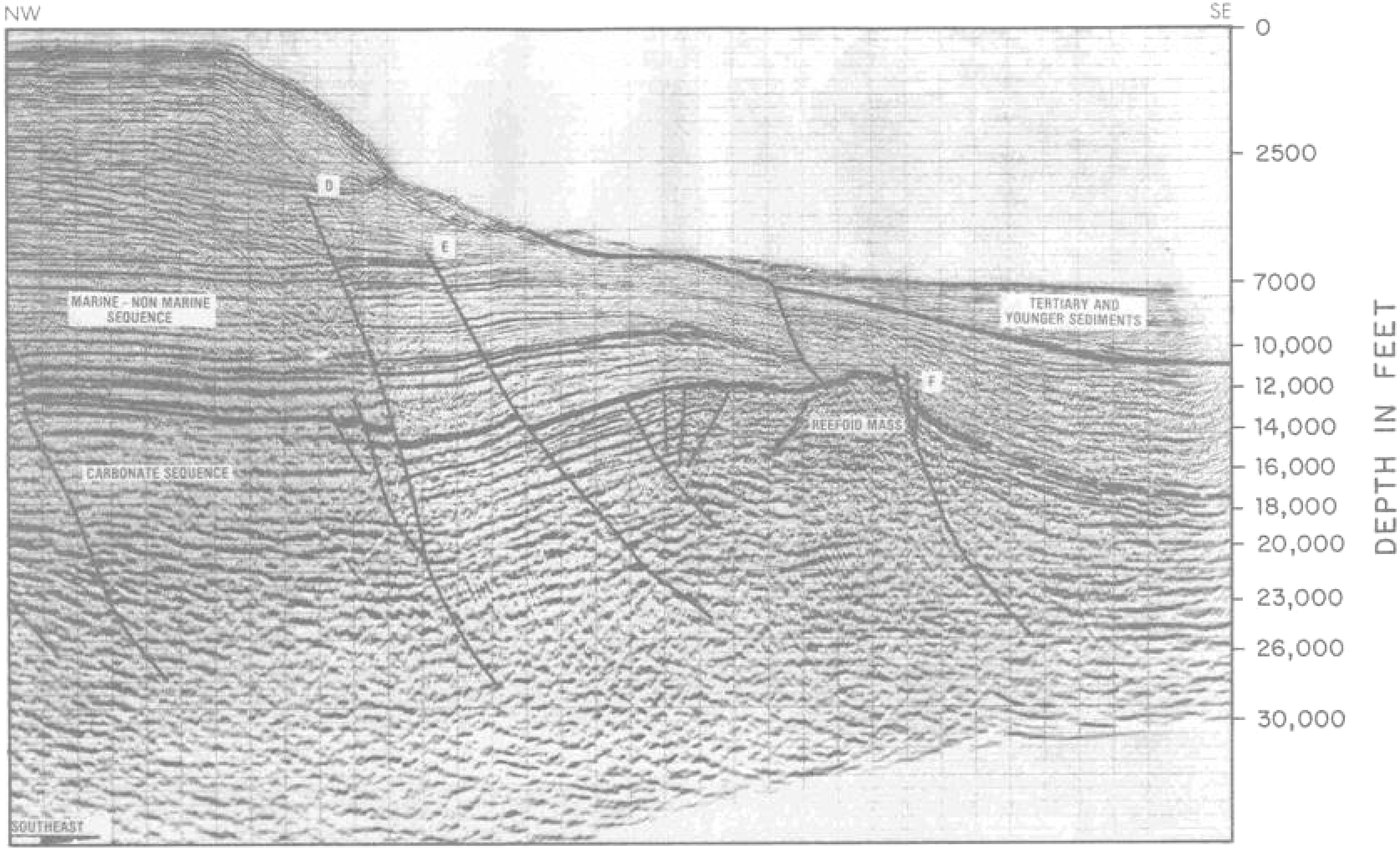
(a)


Surface
Time

(b)


NW
SE
0·0
1·0
2·0
3·0
4·0
5·0
6·0
TWO-WAY TIME IN SECONDS
D
E
F
MARINE - NON MARINE SEQUENCE
CARBONATE SEQUENCE
TERTIARY AND YOUNGER SEDIMENTS
REEFOID MASS
SOUTHEAST

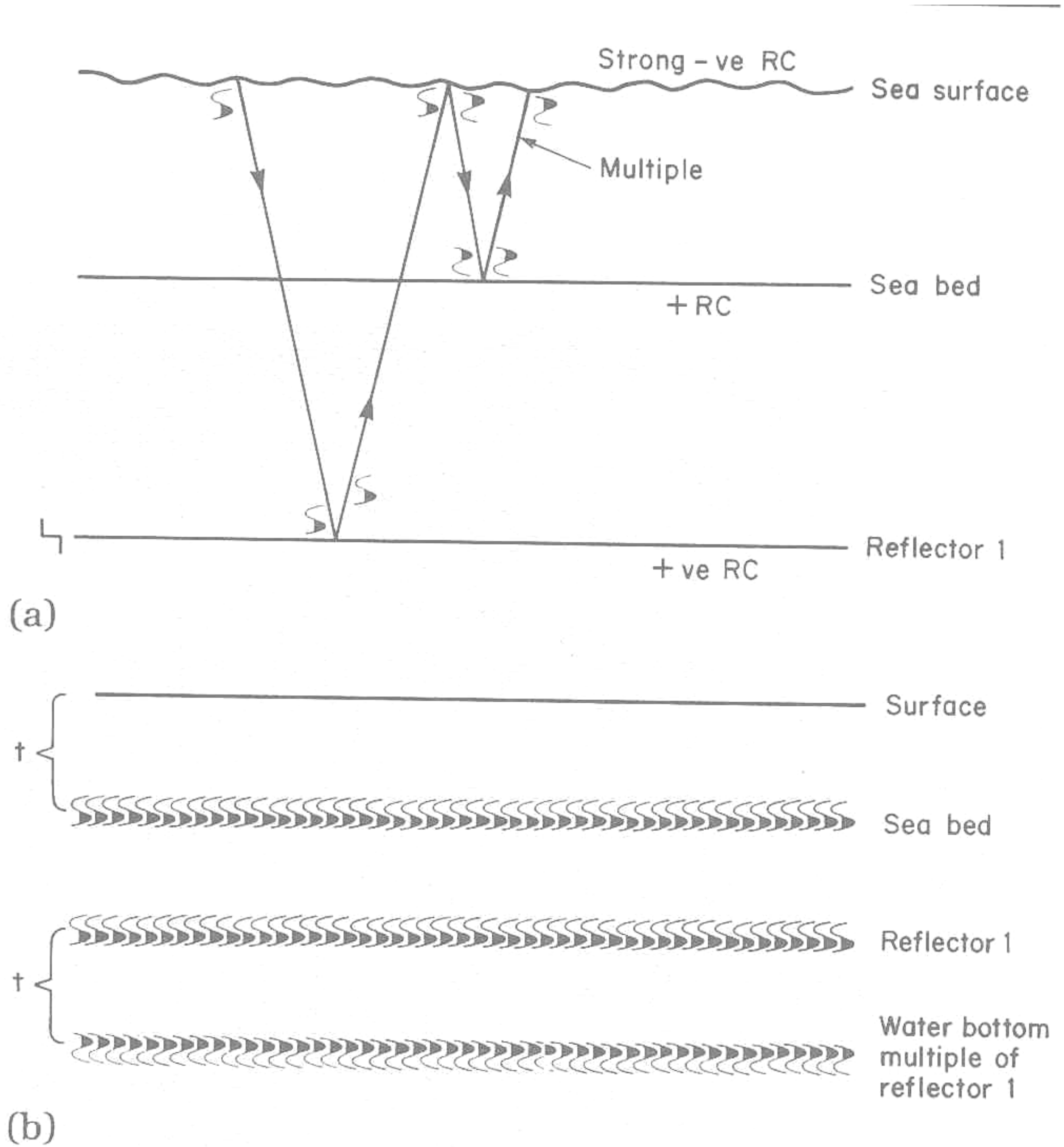
(a)

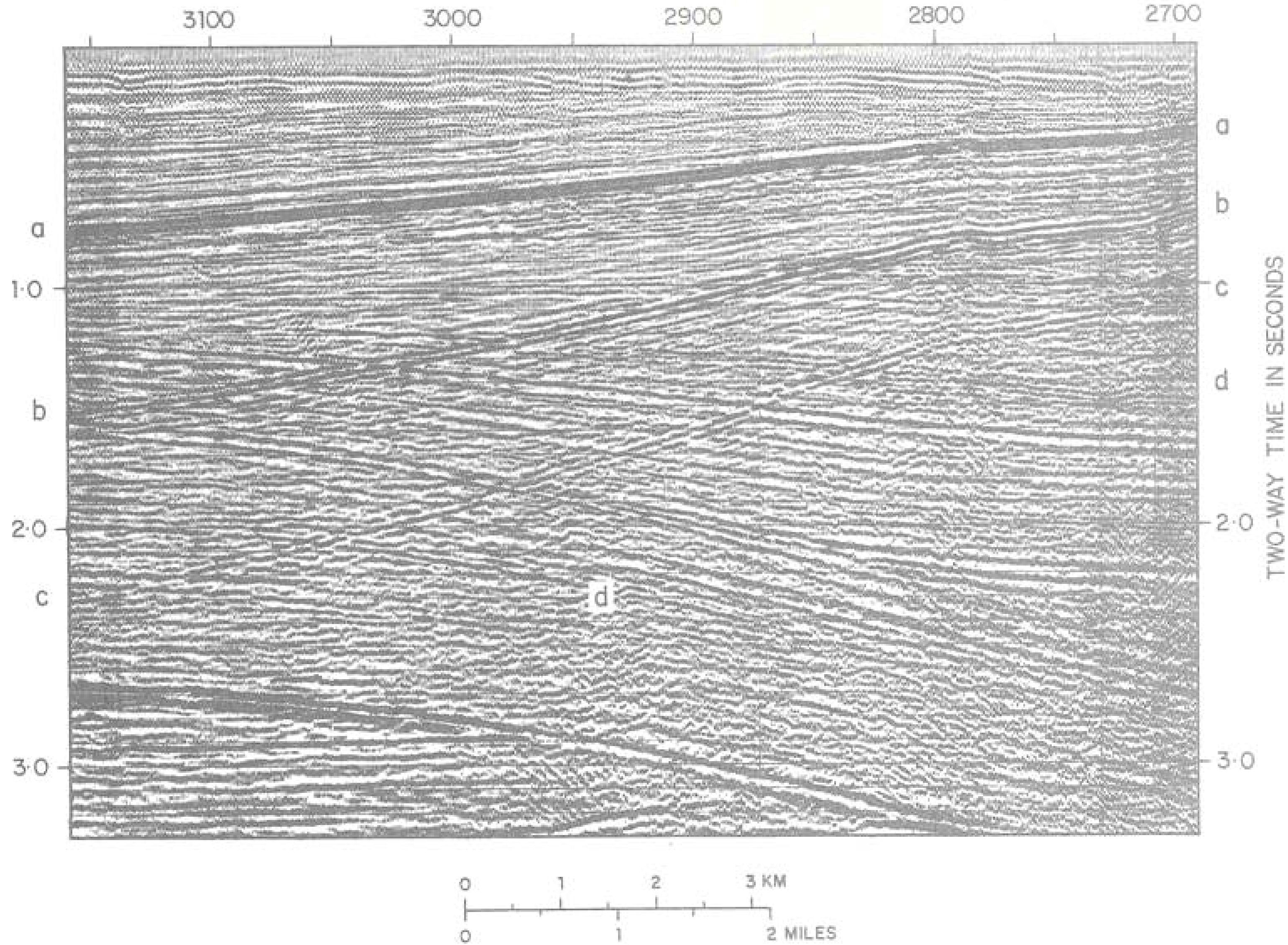


NW
SE
0
2500
7000
10,000
12,000
14,000
16,000
18,000
20,000
23,000
26,000
30,000
DEPTH IN FEET
D
E
F
MARINE - NON MARINE SEQUENCE
TERTIARY AND YOUNGER SEDIMENTS
REEFOID MASS
CARBONATE SEQUENCE
SOUTHEAST

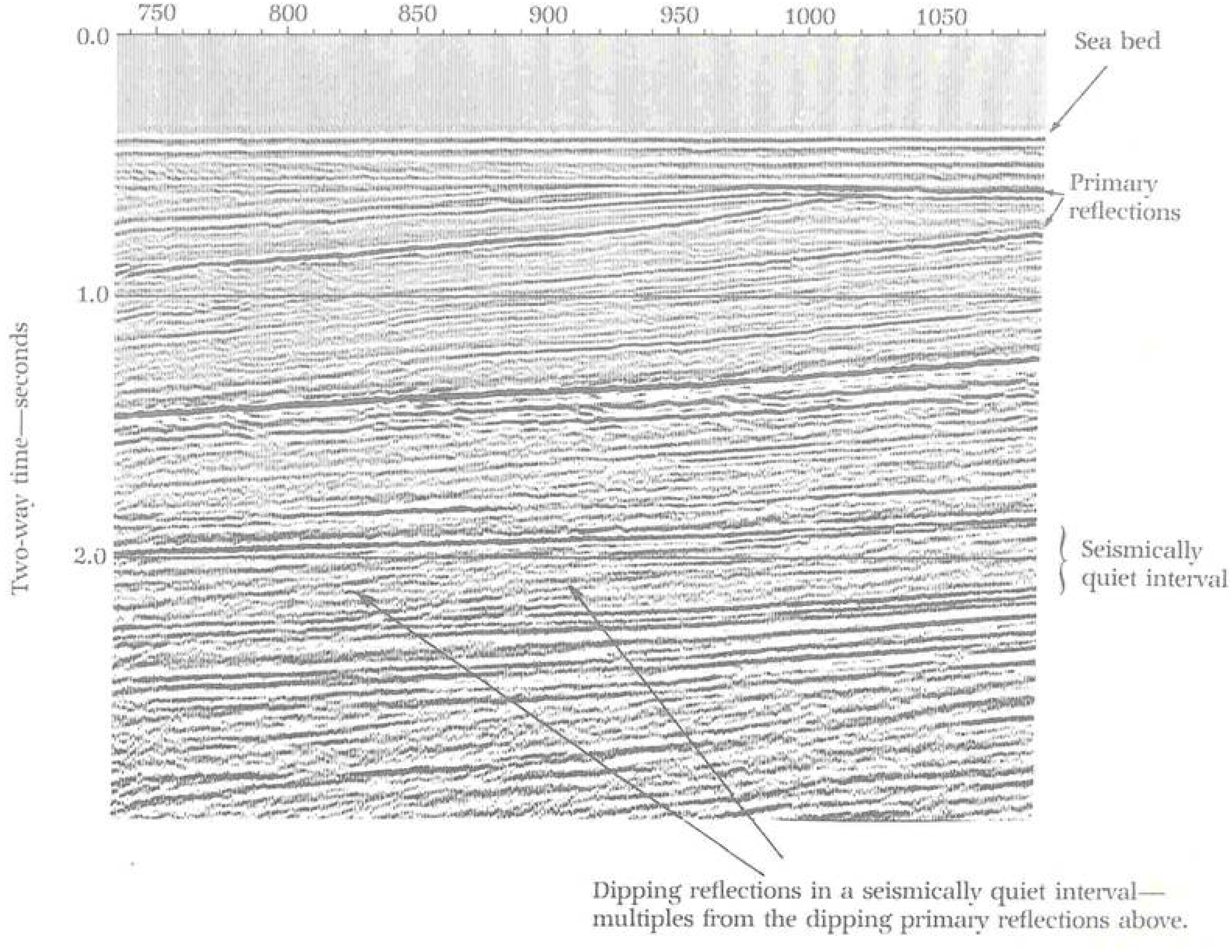

(b)

# MULTIPLES


Strong - ve RC
Sea surface
Multiple
Sea bed
+ RC
Reflector 1
+ ve RC
(a)
Surface
t
Sea bed
Reflector 1
t
Water bottom multiple of reflector 1
(b)



3100
3000
2900
2800
2700
a
b
c
d
1·0
2·0
3·0
TWO-WAY TIME IN SECONDS
0 1 2 3 KM
0 1 2 MILES


750
800
850
900
950
1000
1050
0.0
1.0
2.0
Two-way time—seconds
Sea bed
Primary reflections
Seismically quiet interval
Dipping reflections in a seismically quiet interval—multiples from the dipping primary reflections above.

# Magnetics

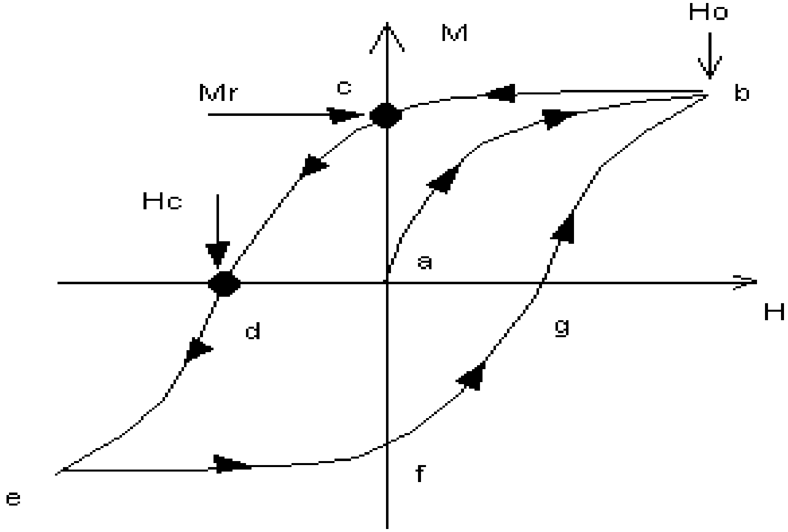
- *Magnetic susceptibility*

  a dimensionless property which in essence is a measure of how susceptible a material is to becoming magnetized

- Sedimentary Rocks
  - Limestone: 10-25.000
  - Sandstone: 0-21.000
  - Shale: 60-18.600
- Igneous Rocks
  - Granite: 10-65
  - Peridotite: 95.500-196.000
- Minerals
  - Quartz: -15
  - Magnetite: 70.000-2x$10^7$

# Magnetics

- Induced and remanent magnetization
- Intensity of magnetization, J




- Magnetic anomaly = regional - residual