GEO4210

Introduction to Petroleum Geology and Geophysics

Geophysical Methods in Hydrocarbon Exploration

About this part of the course

- **Purpose:** to give an overview of the basic geophysical methods used in hydrocarbon exploration
- **Working Plan:**
  - **Lecture:** Principles + Intro to Exercise
  - **Practical:** Seismic Interpretation excercise

Lecture Contents

- Geophysical Methods
- Theory / Principles
- Extensional Sedimentary Basins and its Seismic Signature
- Introduction to the Exercise

Geophysical methods

- **Passive:**

  Method using the natural fields of the Earth, e.g. gravity and magnetic

- **Active:**

  Method that requires the input of artificially generated energy, e.g. seismic reflection

- **The objective of geophysics**

  is to locate or detect the presence of subsurface structures or bodies and determine their size, shape, depth, and physical properties (density, velocity, porosity…) + fluid content

Geophysical methods

Method	**Measured parameter**	**“Operative” physical property**
Gravity	Spatial variations in the strength of the gravitational field of the Earth	Density
Magnetic	Spatial variations in the strength of the geomagnetic field	Magnetic susceptibility and remanence
Electromagnetic (SeaBed Logging)	Response to electromagnetic radiation	Electric conductivity/resistivity and inductance
Seismic	Travel times of reflected/refracted seismic waves	Seismic velocity (and density)

Further reading

- 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.
- McQuillin, R., Bacon, M. & Barclay, W. (1984) An Introduction to Seismic Interpretation – Reflection Seismics in Petroleum Exploration. Graham & Trotman.
- Badley, M.E. (1985) Practical Seismic Interpretation. D. Reidel Publishing Company.

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

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}), i.e. deviations from a predefined reference level, *geoid* (a surface over which the gravitational field has equal value)
- Gravity is a scalar

Gravity

- Newton's Universal Law of Gravitation for small masses at the earth surface:

$$F = \frac{G \times M \times m}{R^2} = mg \rightarrow g = \frac{G \times M}{R^2}$$

  - G = $6.67 \times 10^{-11}\ m^3 kg^{-1} s^{-2}$
  - R is the Earth's radius
  - M is the mass of the Earth
  - m is the mass of a small mass

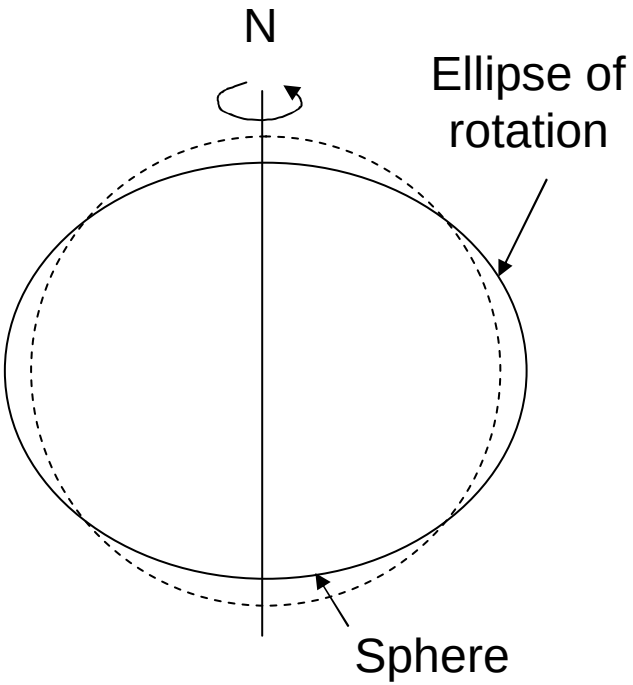
- Spherical
- Non-rotating
- Homogeneous

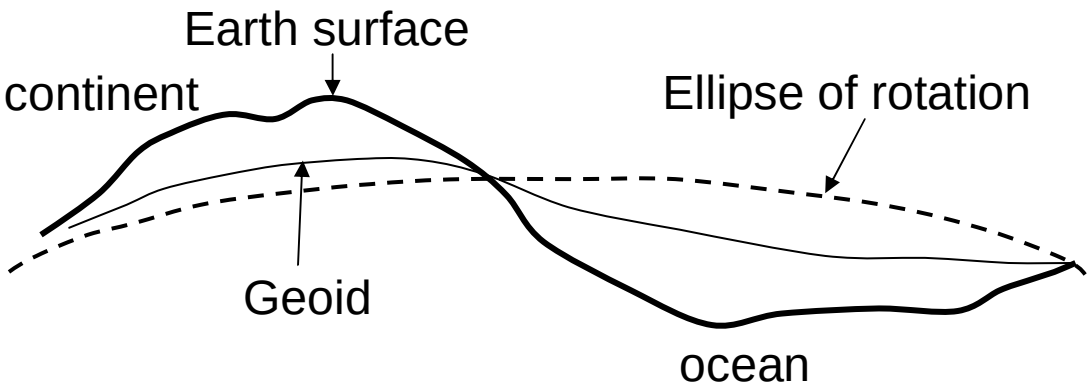
g is constant!

Gravity

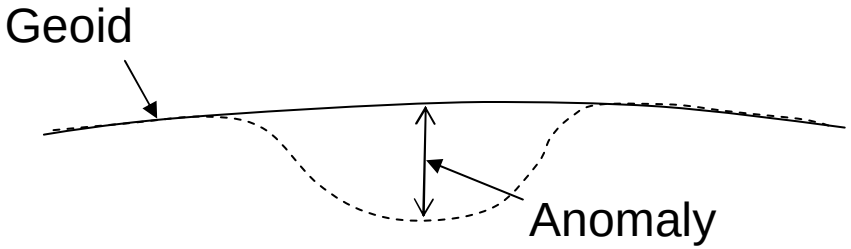
- Non-spherical Ellipse of rotation
- Rotating Centrifugal forces
- Non-homogeneous Subsurface heterogeneities

Disturbances in the acceleration





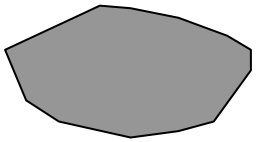
Geoid = main sea-level

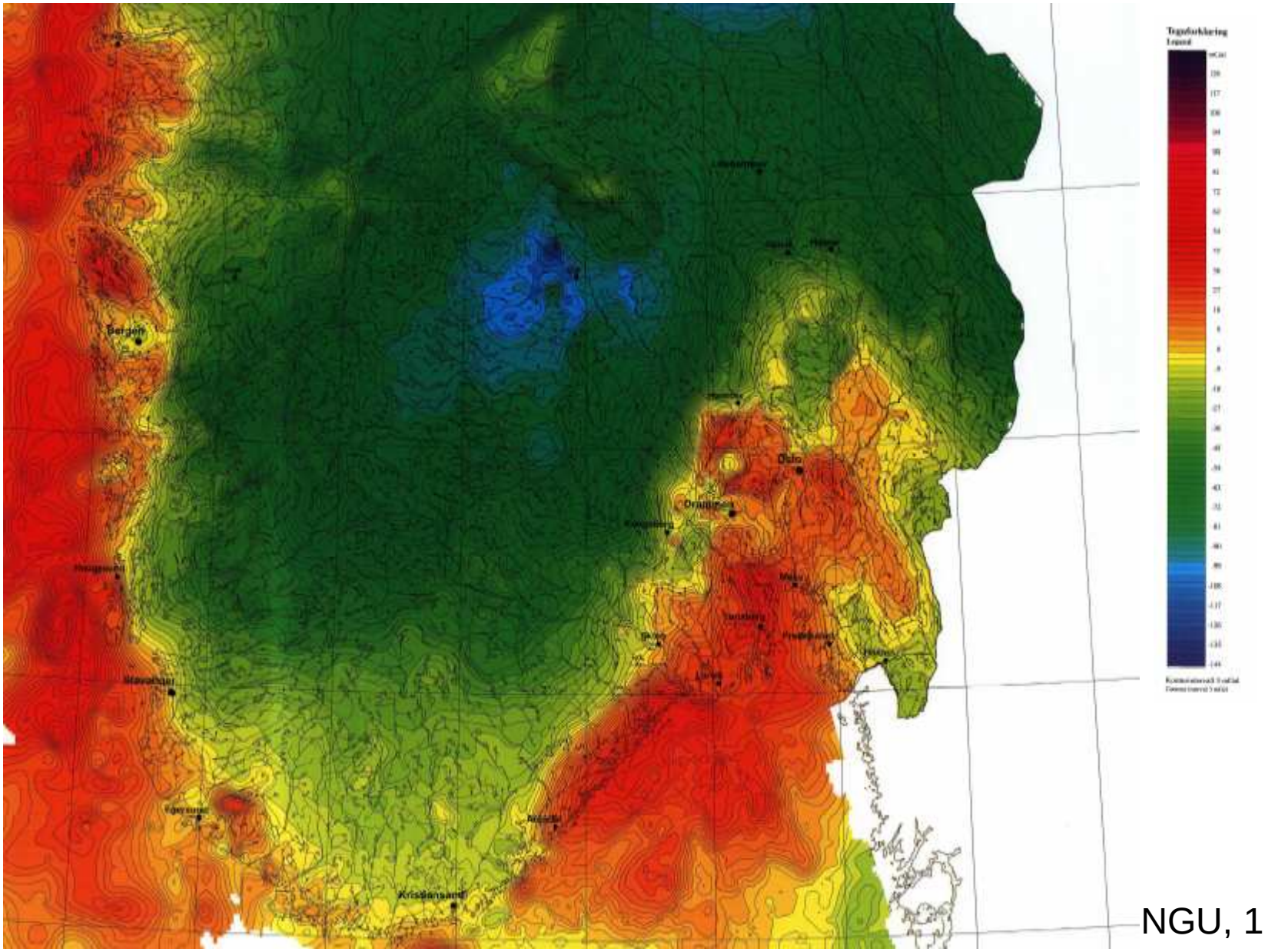


g_{av} = 9.81 m/s^2

g_{max} = 9.83 m/s^2 (pole)

g_{min} = 9.78 m/s^2 (equator)





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

Magnetics

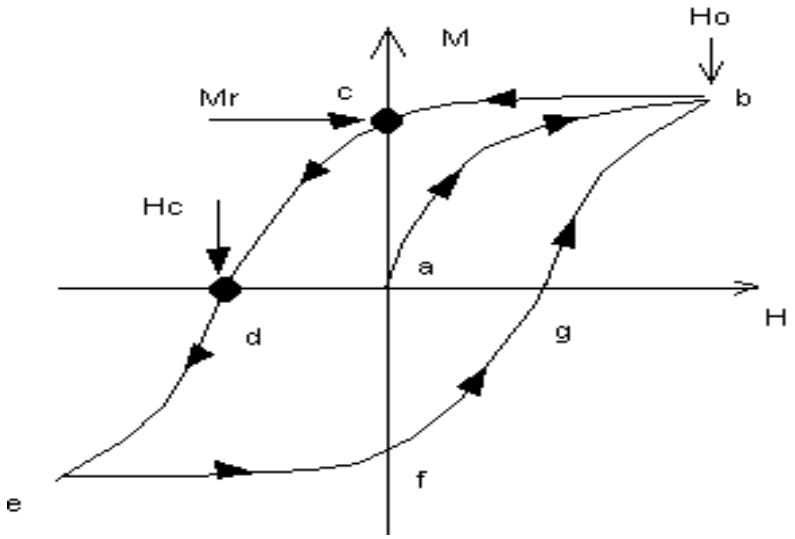
- *Magnetic susceptibility, k*

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

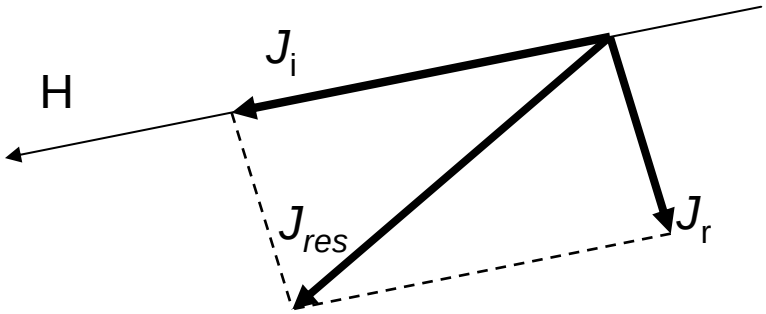
- Sedimentary Rocks
  - Limestone: 10-25.000
  - Sandstone: 0-21.000
  - Shale: 60-18.600
- Igneous Rocks
  - Granite: 10-65
  - Peridotite: 95.500-196.000
- Minerals
  - Quartz: -15
  - Magnetite: 70.000-2×10^7

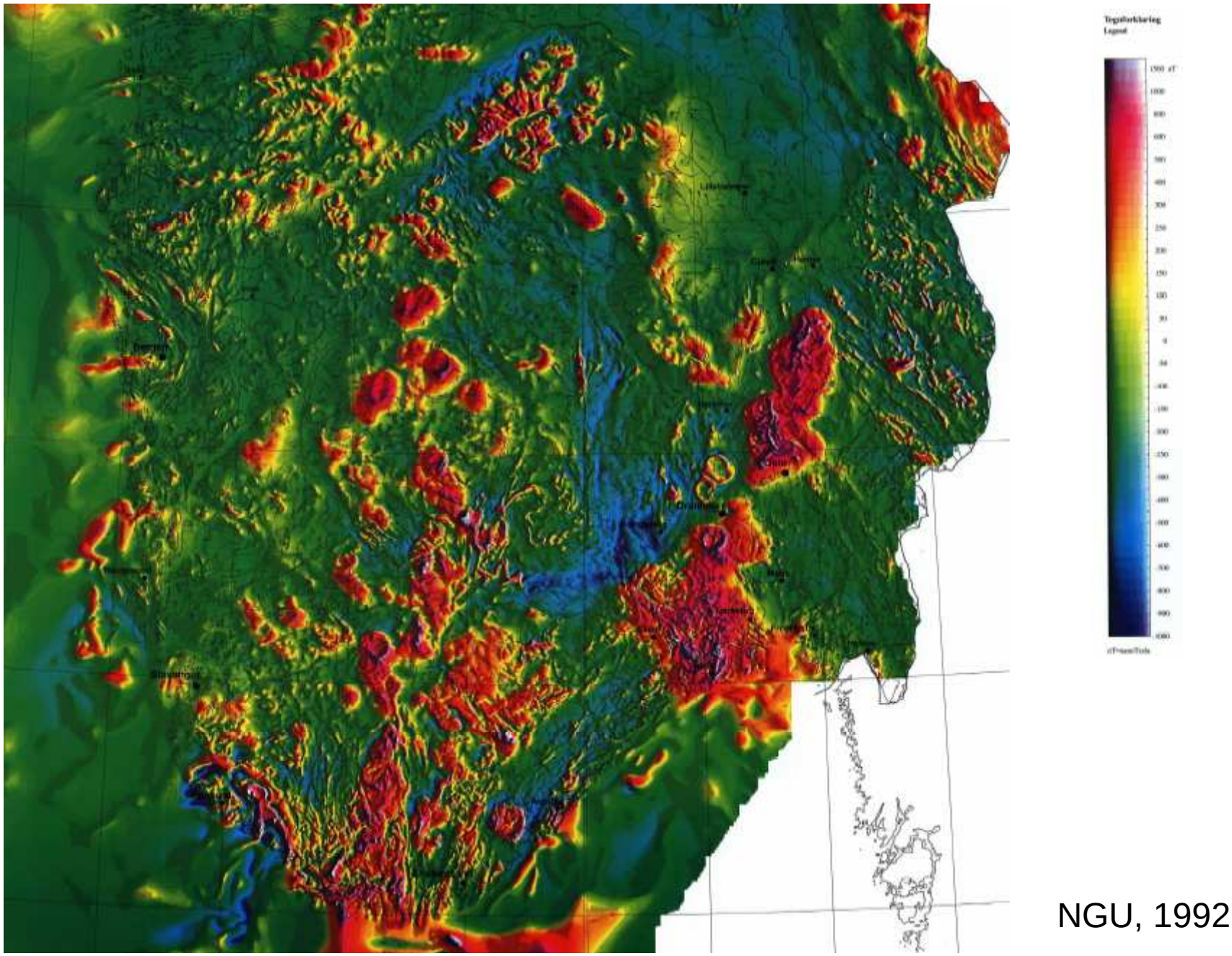
Magnetics

- Magnetic Force, H
- Intensity of induced magnetization, J_i
- $J_i = k \cdot H$
- Induced and remanent magnetization



- Magnetic anomaly = regional - residual

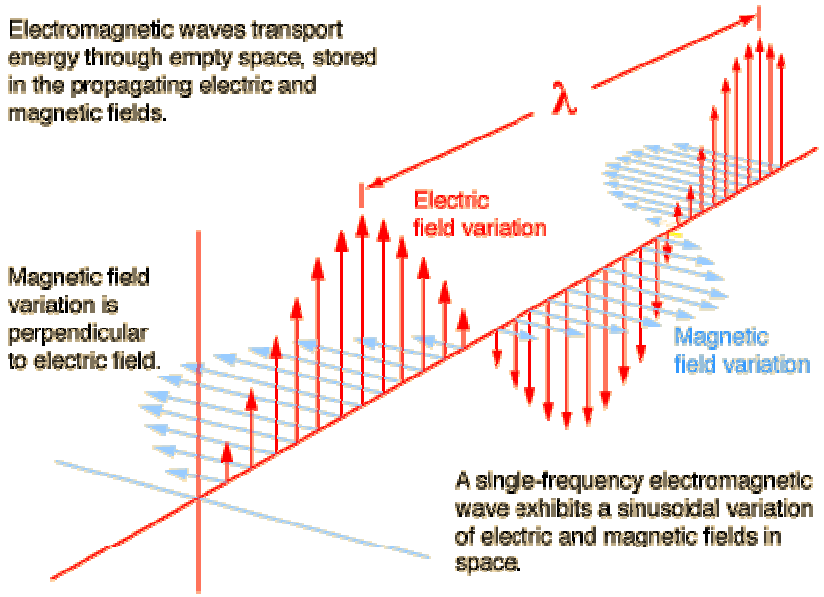




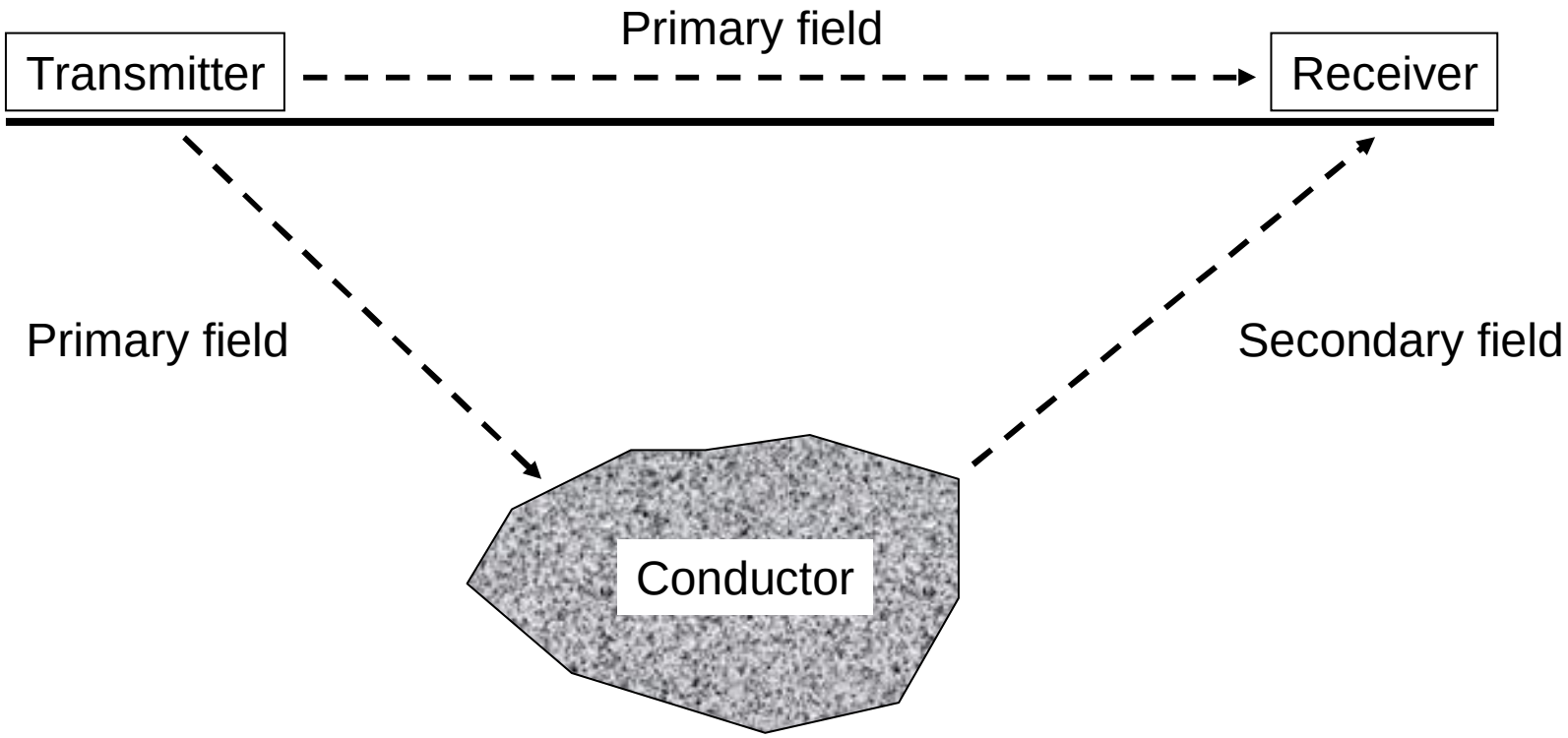
NGU, 1992

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

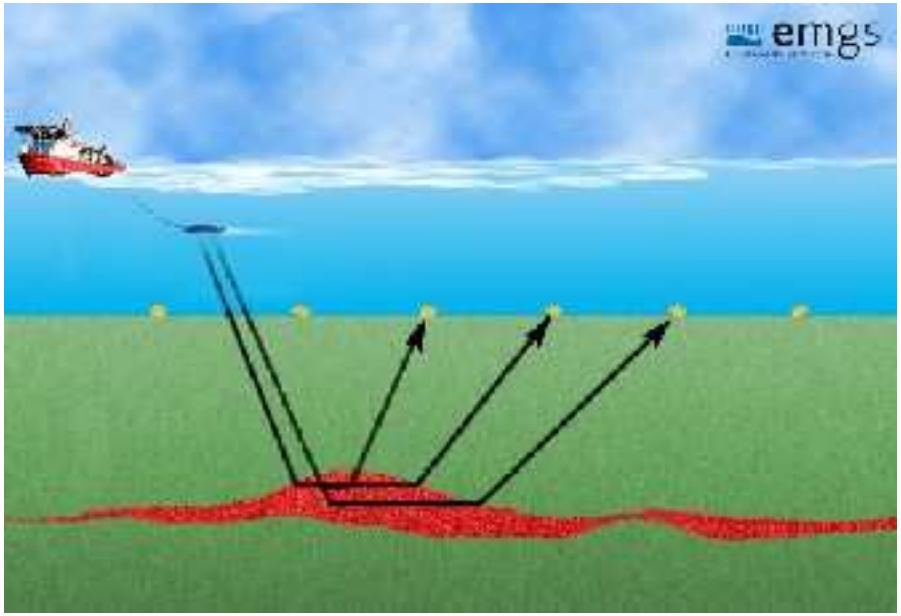
Electromagnetics – Sea Bed Logging

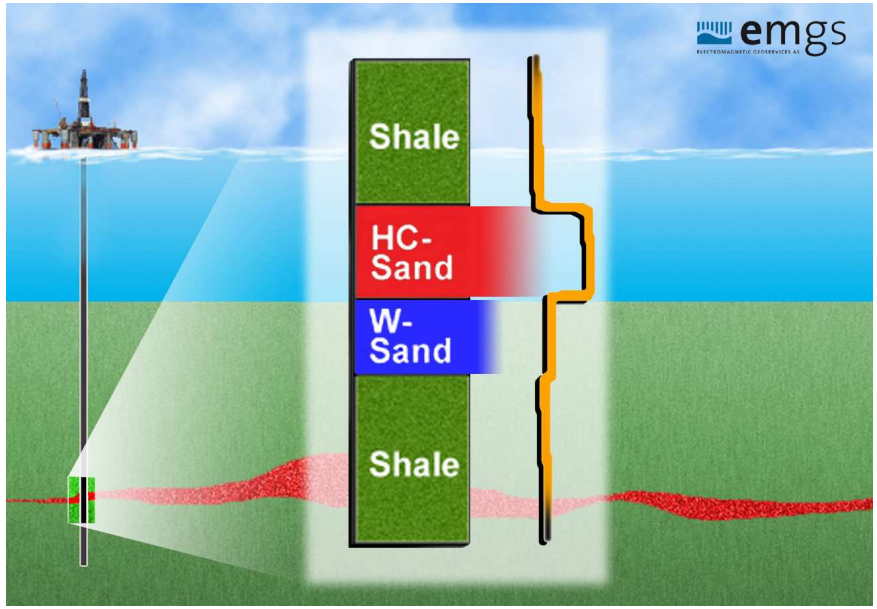
SBL is a marine electromagnetic method that has the ability to map the subsurface resistivity remotely from the seafloor.

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.

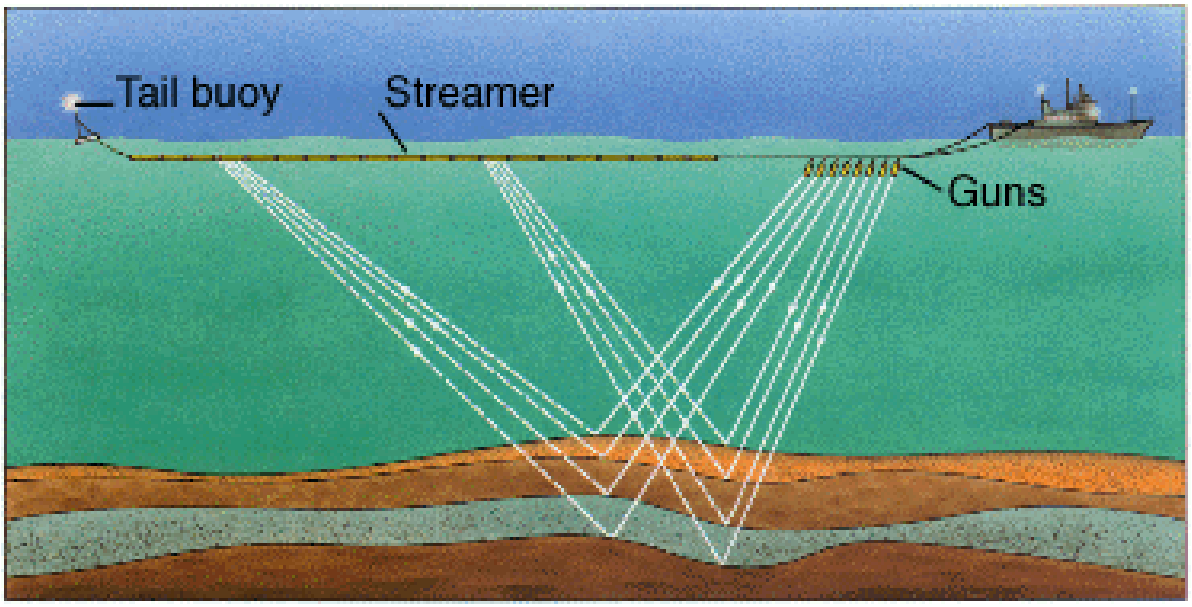
SBL therefore has the unique potential of distinguishing between a hydrocarbon filled and a water filled reservoir





Reflection Seismology

Marine multichannel seismic reflection data

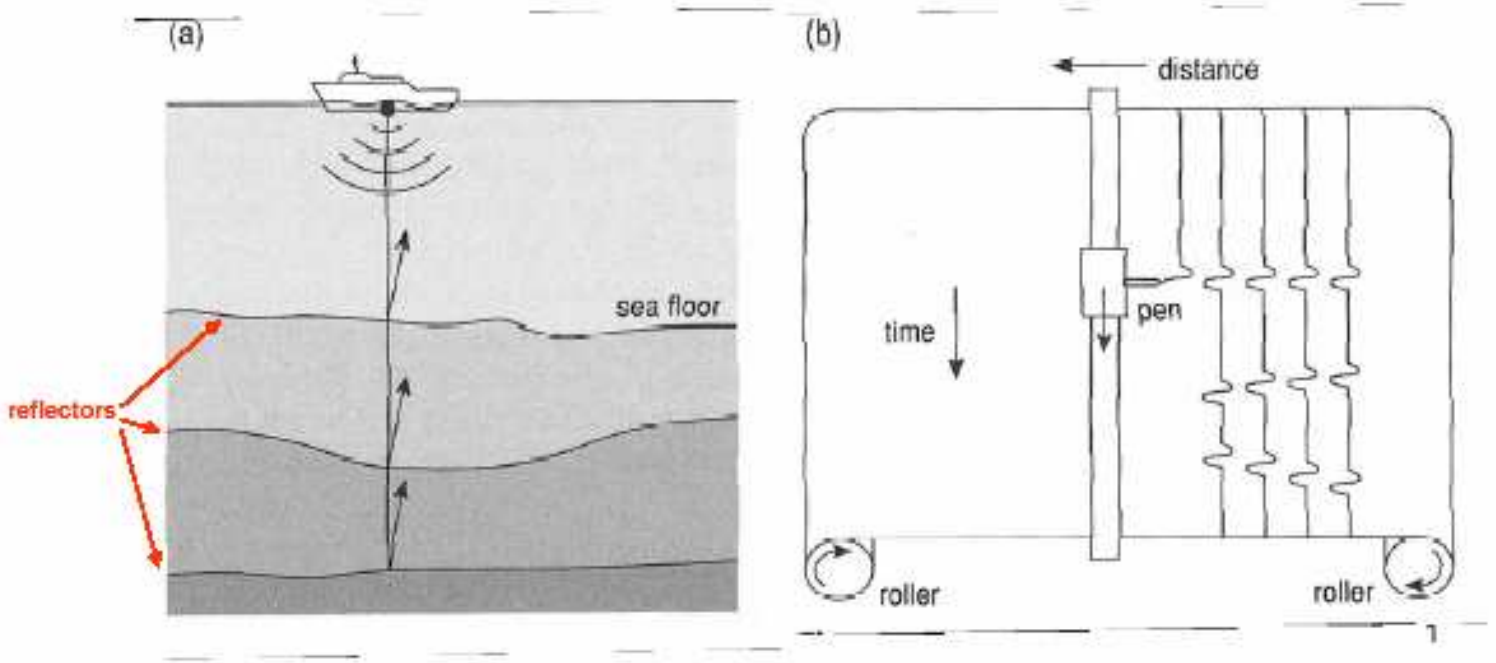


Reflection Seismology

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

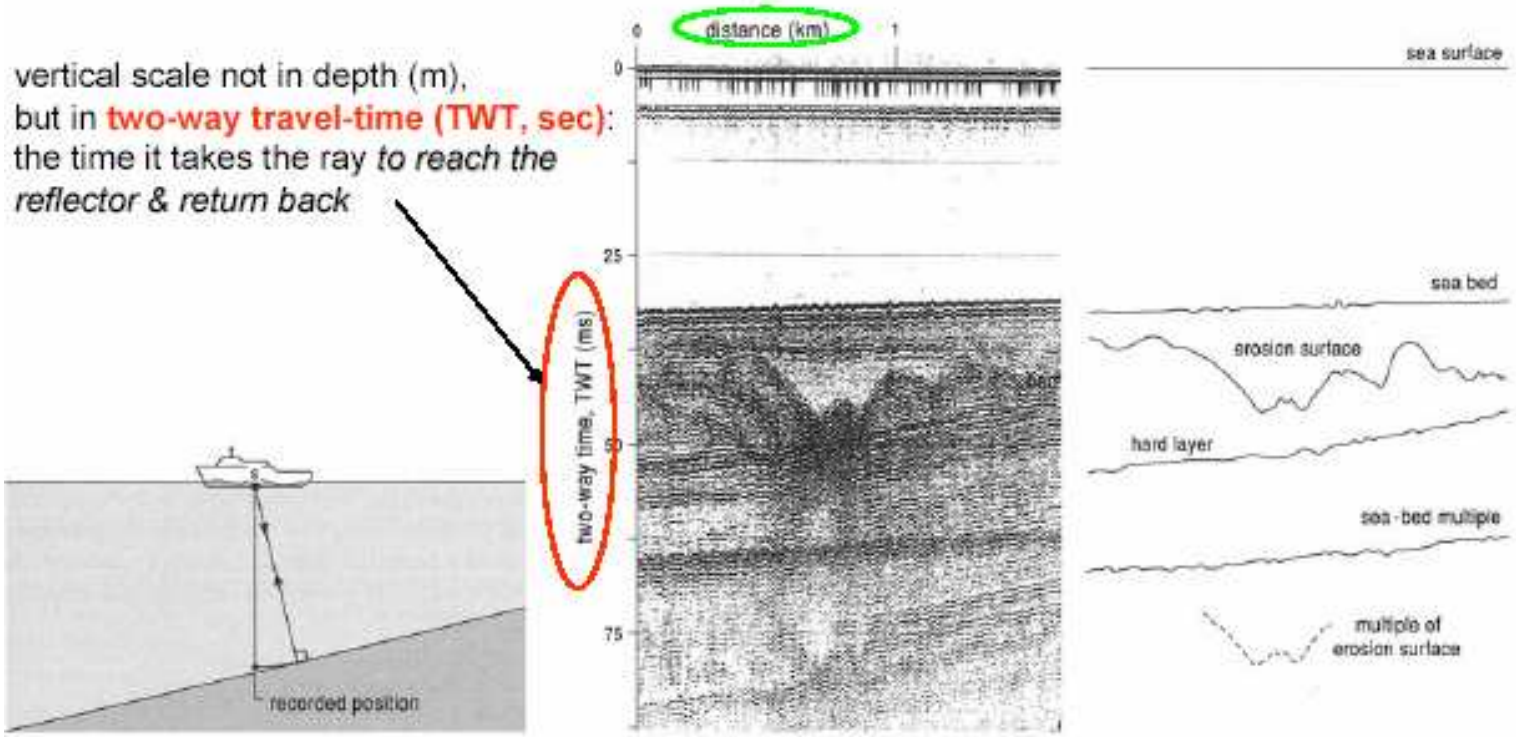
Reflection seismology can be considered as *echo or depth sounding* &
it is easier performed at **sea** than on **land**



Reflection Seismology

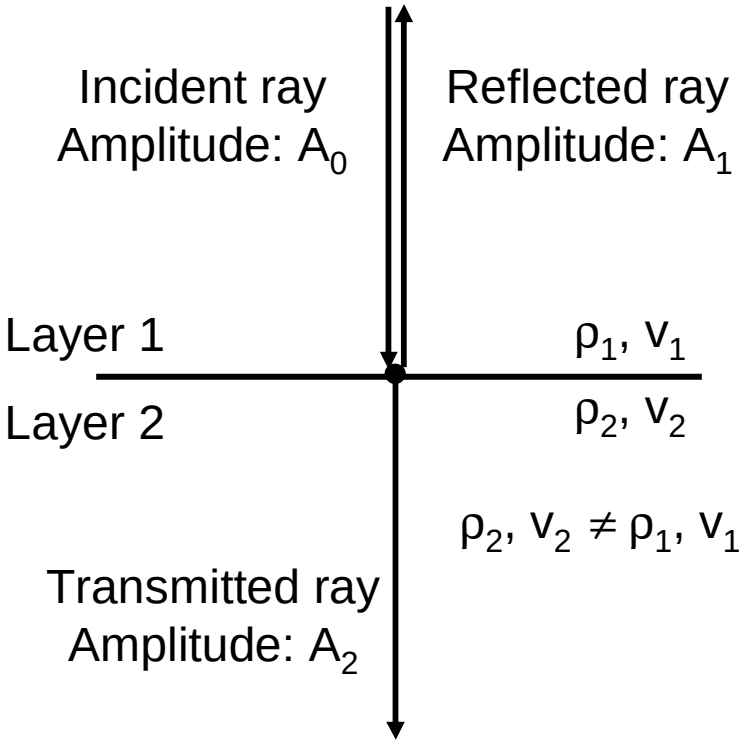
Reflection seismics output: seismic section (seismic reflection profile)

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



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

Reflection Coefficient: $R = A_1/A_0$

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

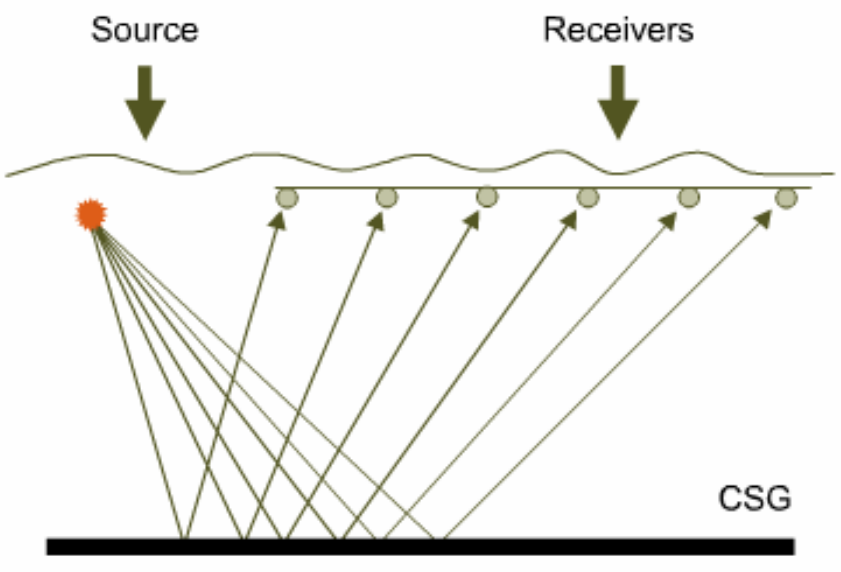
Transmission Coefficient: $T = A_2/A_0$

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

$-1 \leq R \leq 1$

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

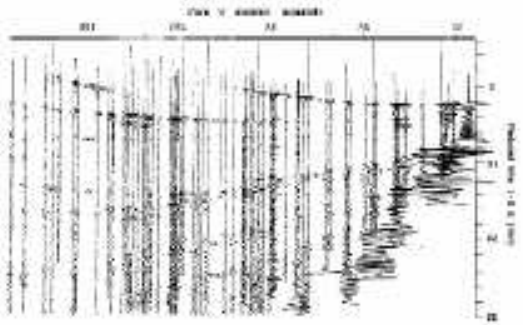


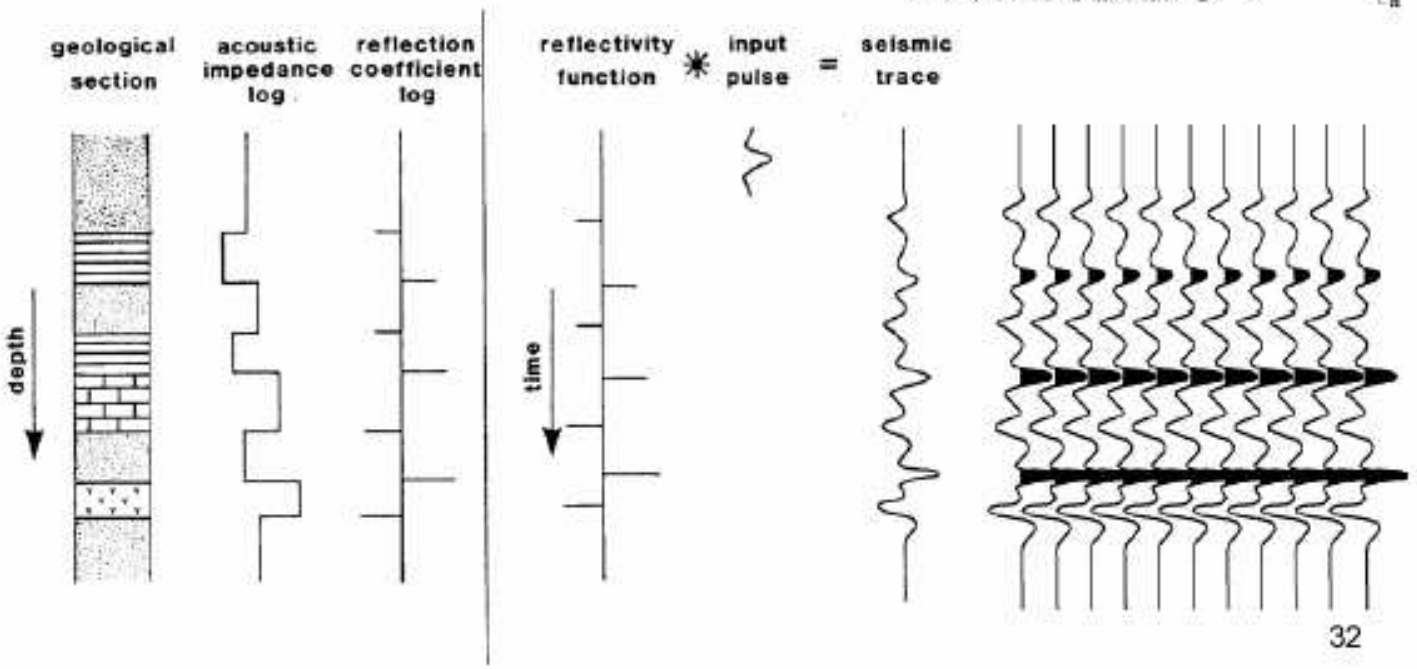
- Shotpoint interval 60 seconds
- 25-120 receivers
- Sampling rate 4 milliseconds
- Normal seismic line ca. 8 sTWT

Reflection Seismology

SEISMIC TRACE (REFLECTION SEISMOGRAM)

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



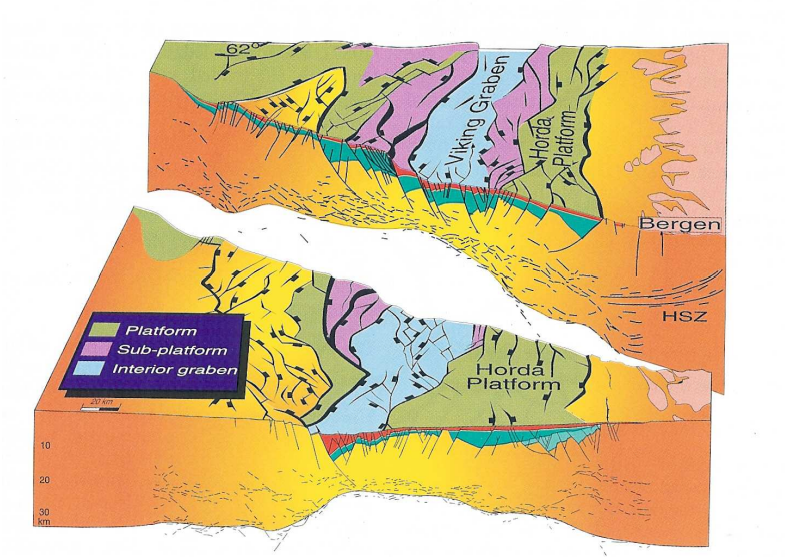


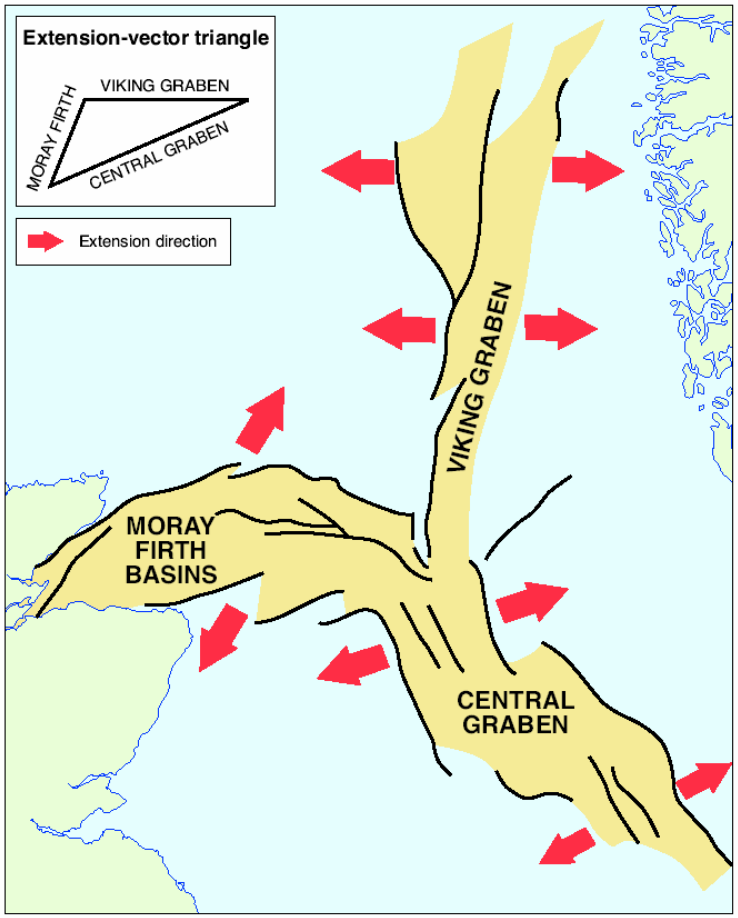
Sedimentary Basins

- Hydrocarbon provinces are found in sedimentary basins
- Important to know how basins are formed
- Basin Analysis
  - Hydrocarbon traps
  - Stratigraphy of
    - Source rock
    - Reservoir rock
    - Cap rock
  - Maturation of source rocks
  - Migration path-ways

Extensional Sedimentary Basins

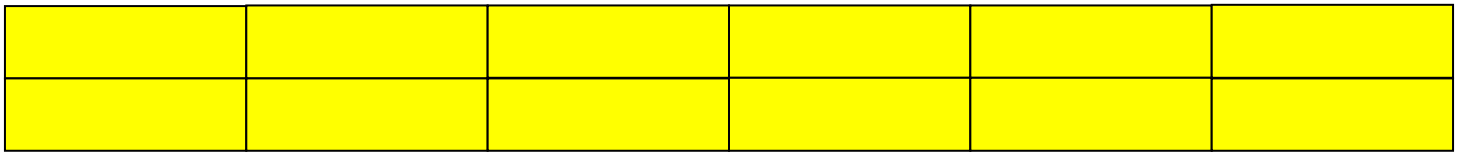
- **Offshore Norway – Viking Graben, Central Graben**
- **Late Jurassic – Early Cretaceous**
- **Mature Hydrocarbon Province**



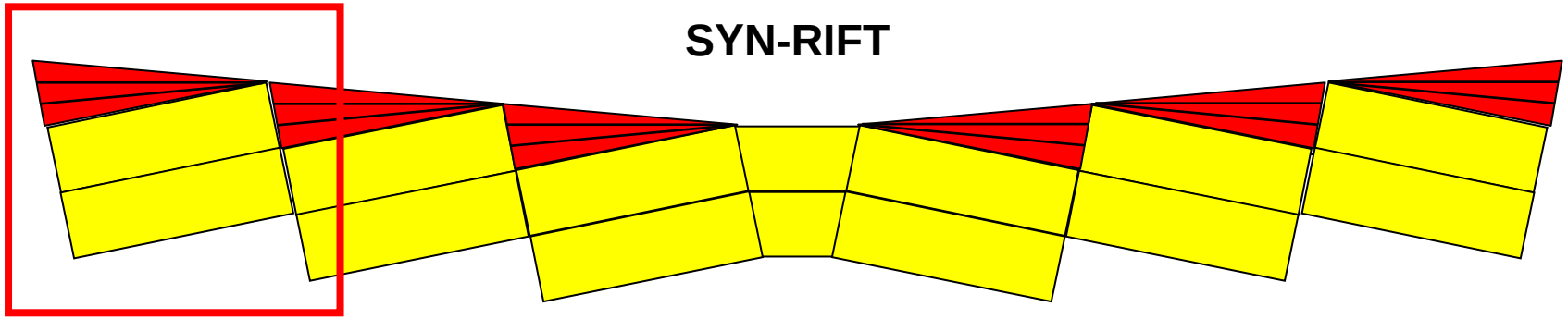


Basin Analysis

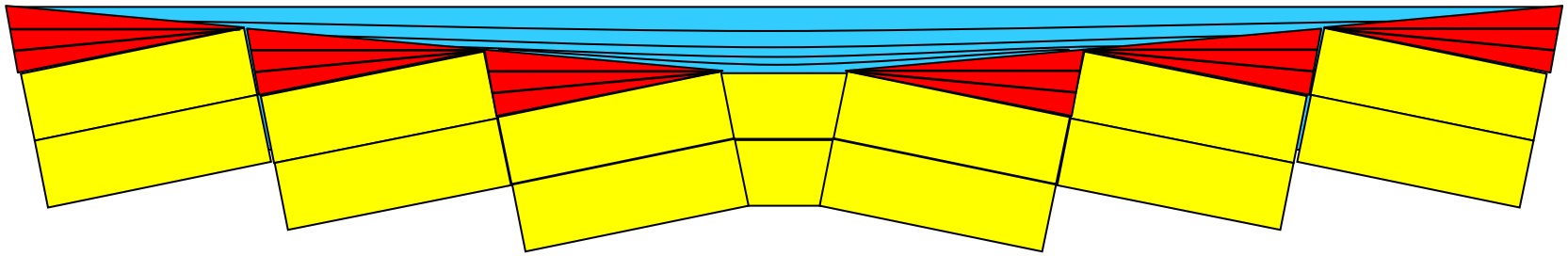
PRE-RIFT



SYN-RIFT

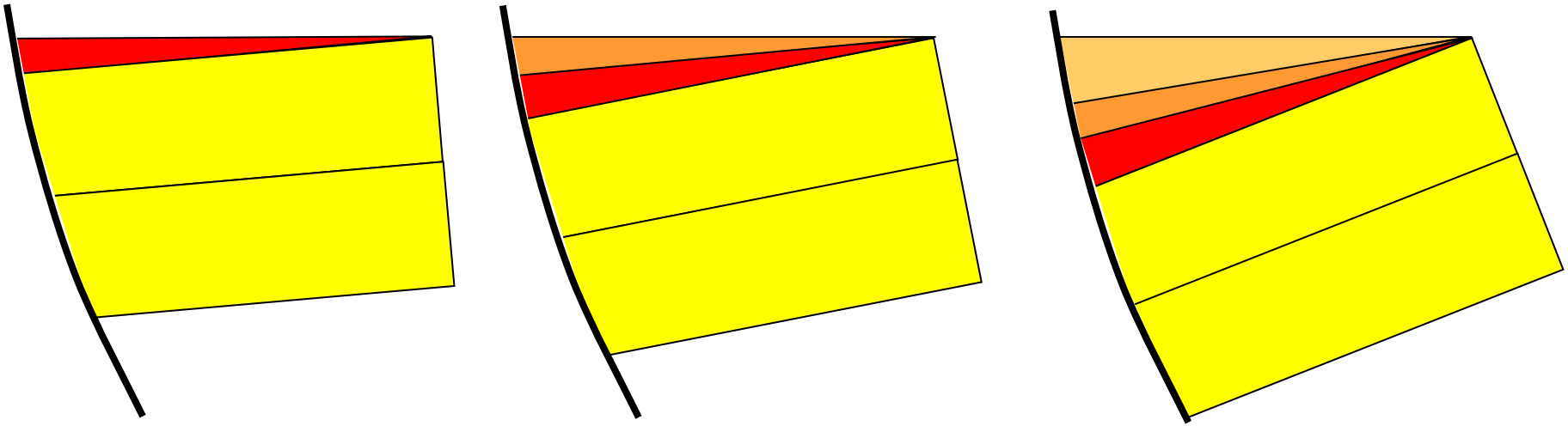


POST-RIFT



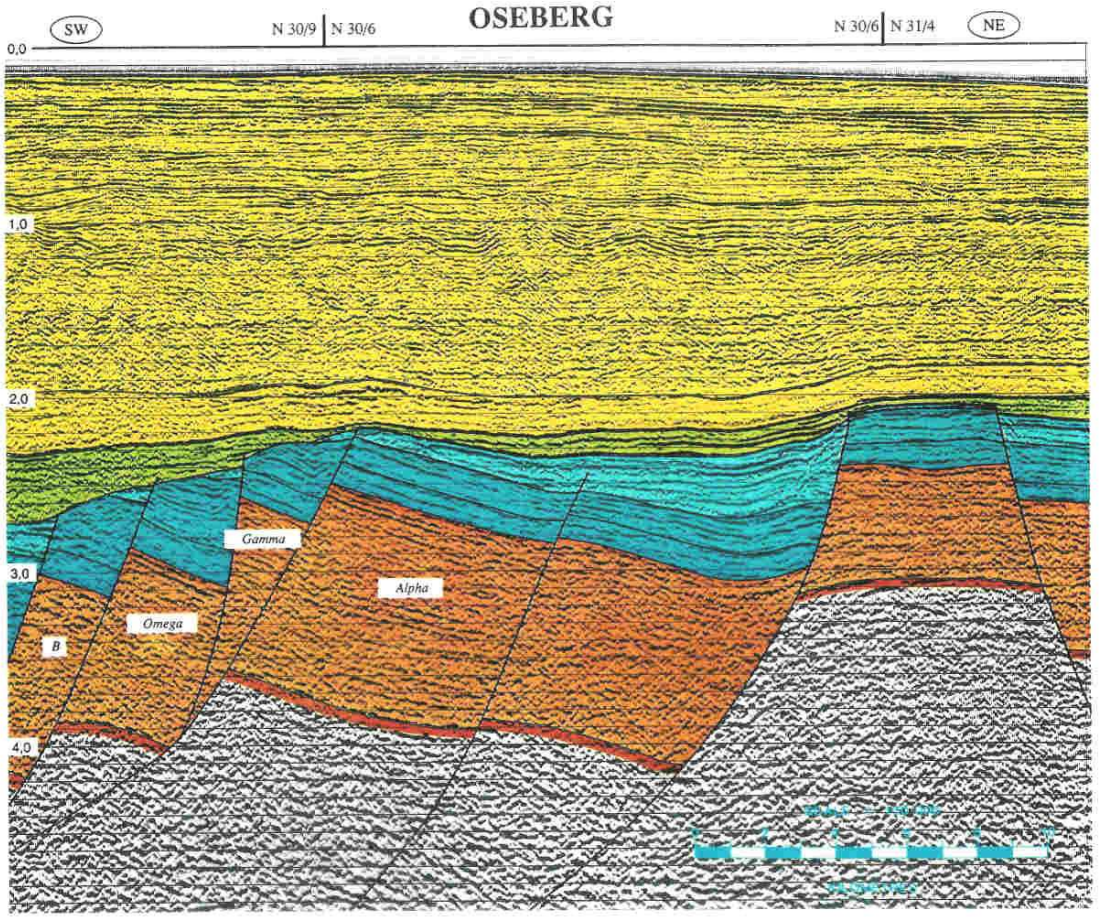
Syn-Rift

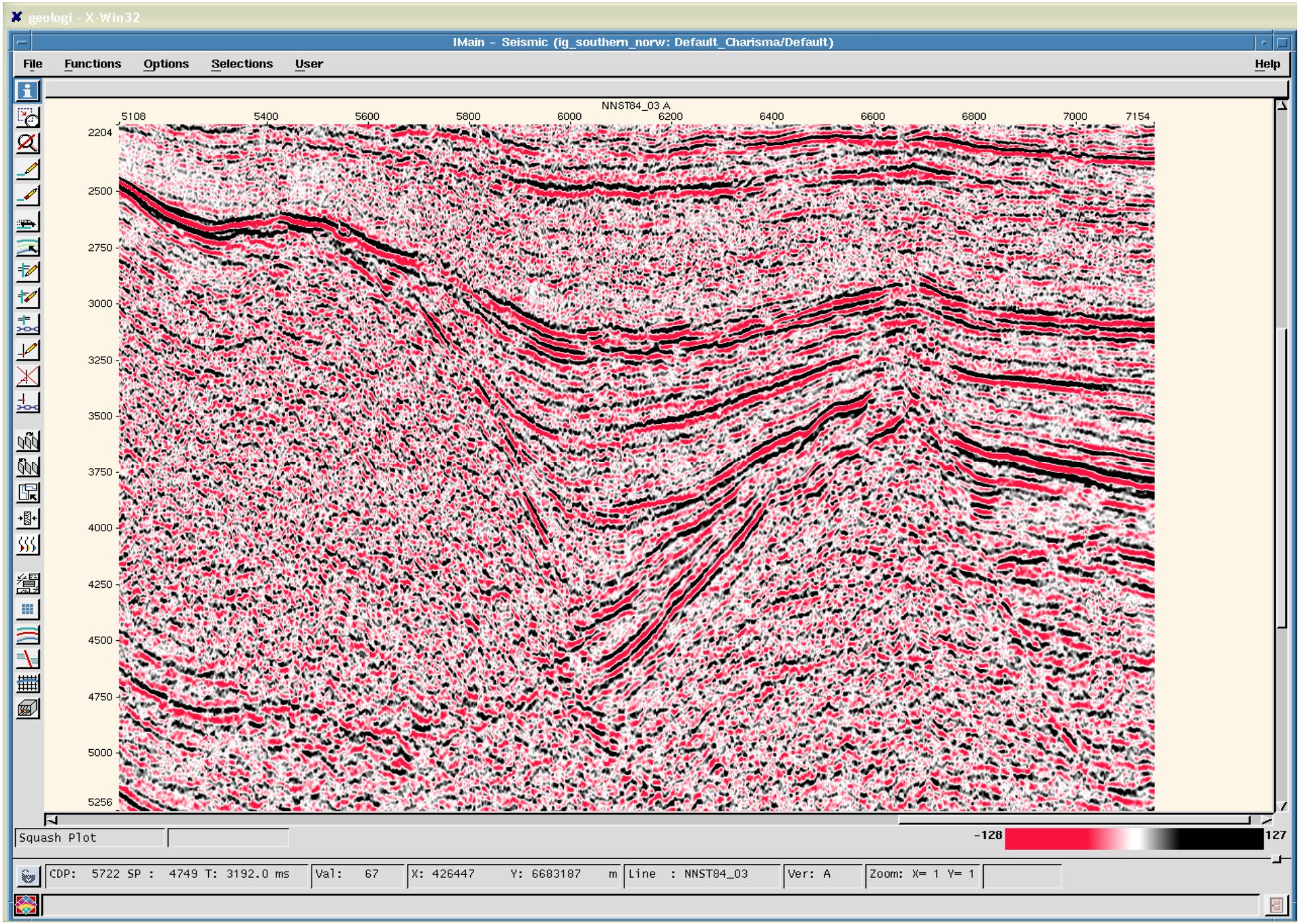
Rotated Fault Blocks



Increasing Fault Displacement

Seismic Signature of Extensional Sedimentary Basins

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File
Functions
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User
Help
NNST84_03 A
5108
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6400
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7154
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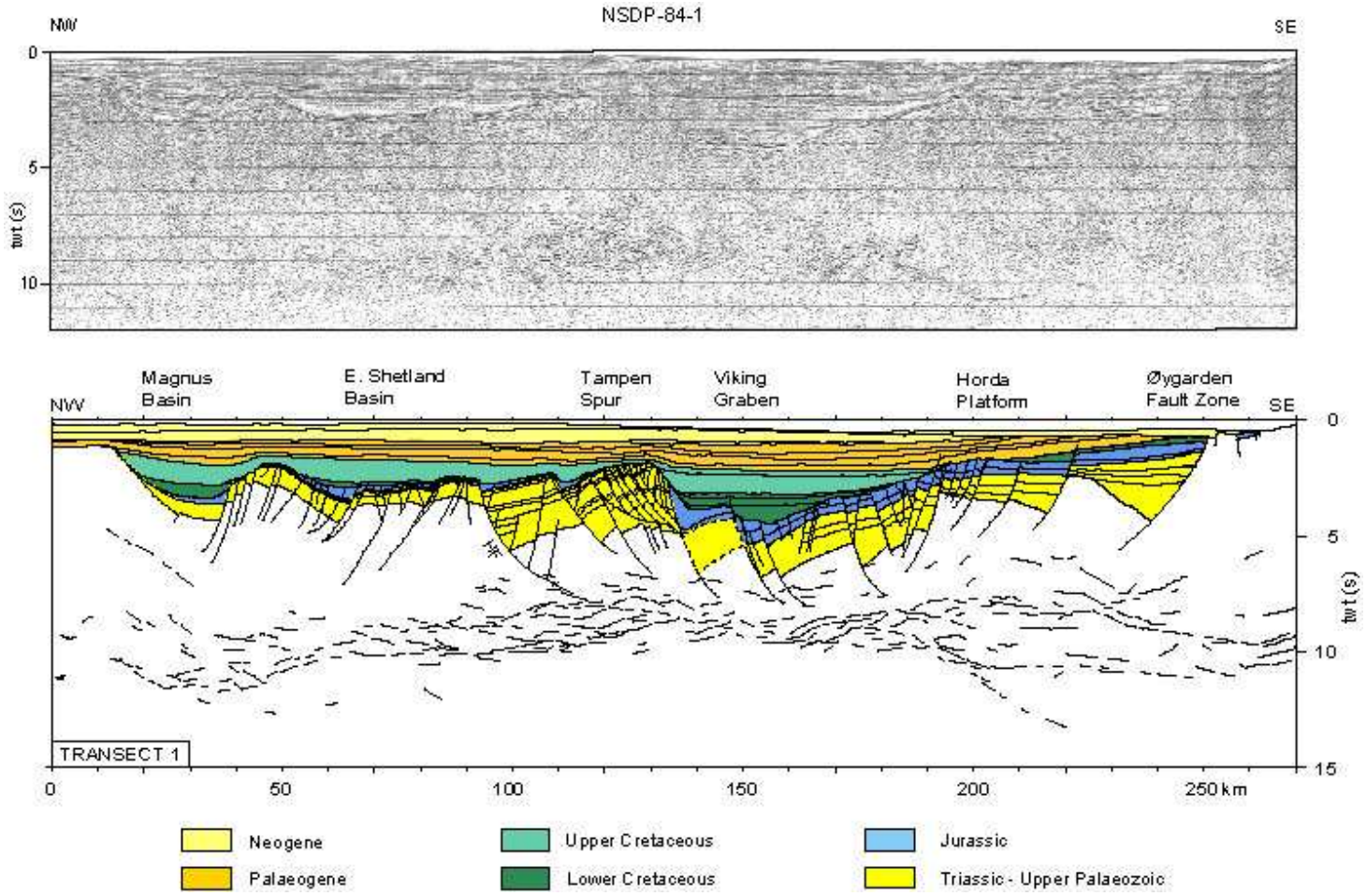
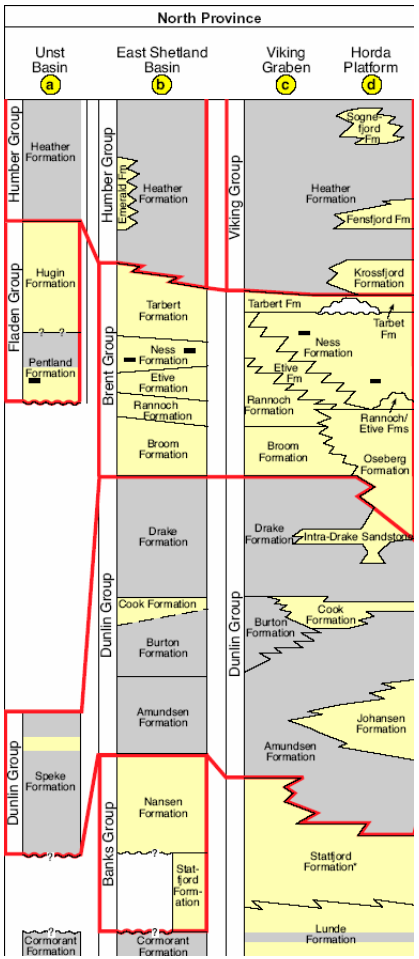
2500
2750
3000
3250
3500
3750
4000
4250
4500
4750
5000
5256
Squash Plot
-128
127
CDP: 5722 SP : 4749 T: 3192.0 ms
Val: 67
X: 426447 Y: 6683187 m
Line : NNST84_03
Ver: A
Zoom: X= 1 Y= 1

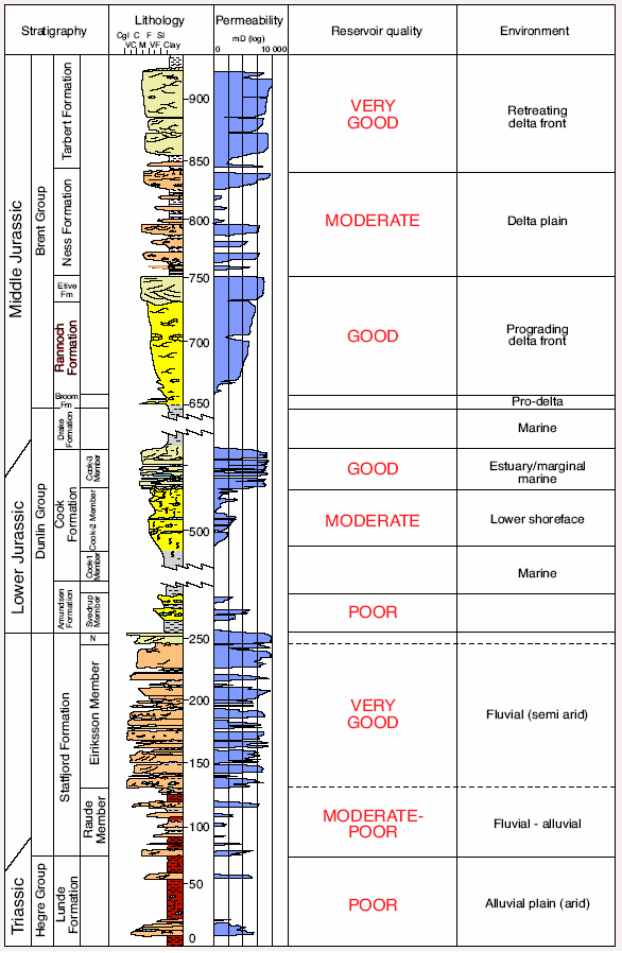
INTRODUCTION TO EXERCISE

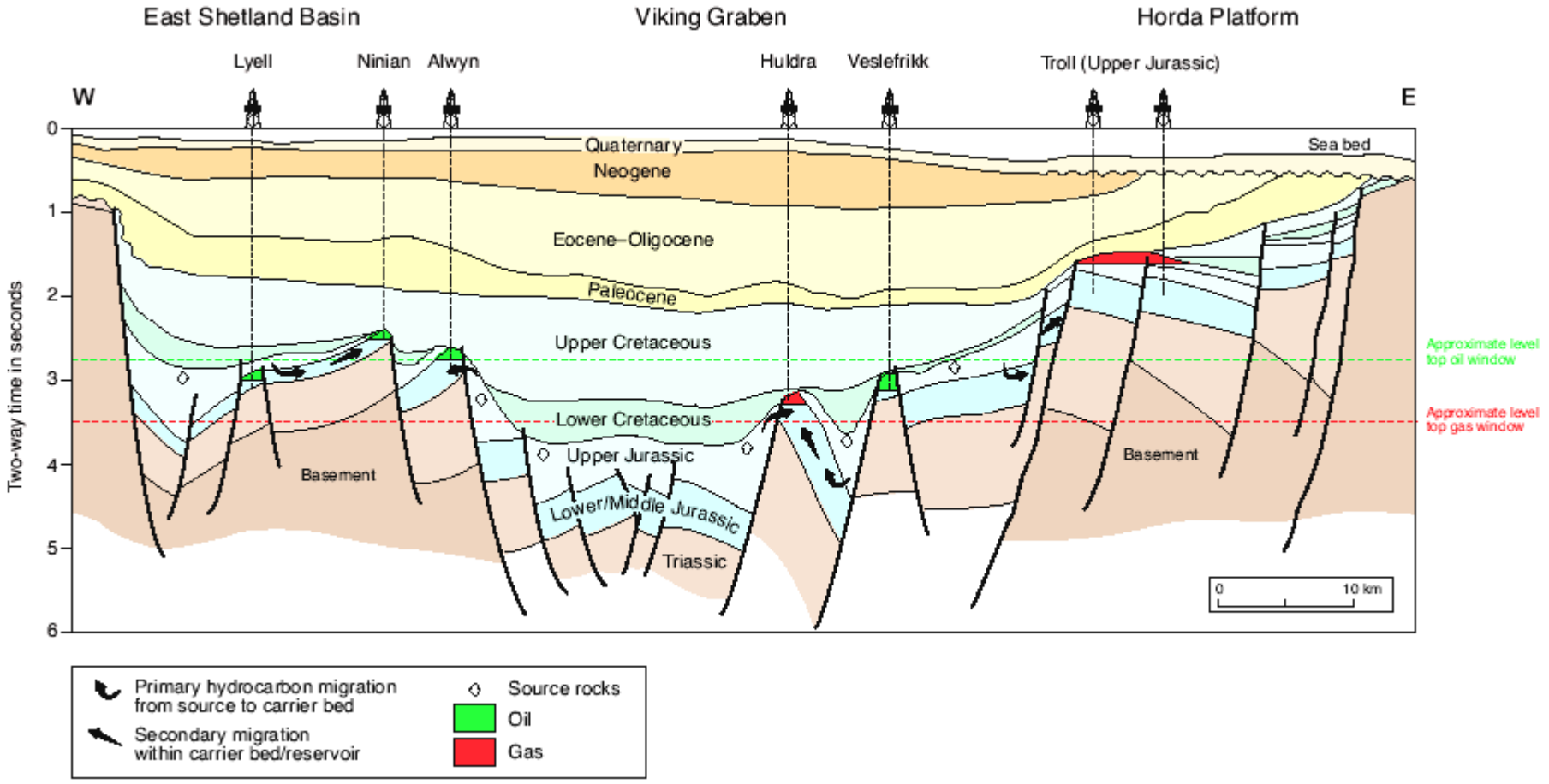
Seismic Signature of Extensional Sedimentary Basins – Offshore Norway



Stratigraphy – Offshore Norway






East Shetland Basin
Viking Graben
Horda Platform
Lyell
Ninian
Alwyn
Huldra
Veslefrikk
Troll (Upper Jurassic)
W
E
Two-way time in seconds
0
1
2
3
4
5
6
Quaternary
Neogene
Sea bed
Eocene–Oligocene
Paleocene
Upper Cretaceous
Lower Cretaceous
Upper Jurassic
Lower/Middle Jurassic
Triassic
Basement
Basement
Approximate level top oil window
Approximate level top gas window
0
10 km
Primary hydrocarbon migration from source to carrier bed
Secondary migration within carrier bed/reservoir
Source rocks
Oil
Gas

Summary Offshore Norway

- Main Rifting Event: Late-Jurassic – Early Cretaceous
- Structural Traps – Fault bounded
- Main Reservoir: Upper Triassic – Middle Jurassic, containing Tarbert, Ness, Rannoch, Cook, Statfjord and Lunde Fms.
- Source Rock: Upper Jurassic, Heather Fm
- Cap Rock: Early Cretaceous

Exercise

- Interprete seismic line NVGTI92-105
- Interprete pre-, syn- and post-rift sequences
- Interprete possible hydrocarbon traps
- Point out source-, reservoir, and cap-rock