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 exercise
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

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


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 acceleration 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:
  \[ F = \frac{G \times M \times m}{R^2} = mg \rightarrow g = \frac{G \times M}{R^2} \]

- \( G = 6.67 \times 10^{-11} \text{ m}^3\text{kg}^{-1}\text{s}^{-2} \)
- \( R \) 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
$g_{\text{av}} = 9.81 \text{ m/s}^2$

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

$g_{\text{min}} = 9.78 \text{ m/s}^2$ (equator)
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\( \times 10^7 \)
Magnetics

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

- Magnetic anomaly = regional - residual
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

one of the problems: 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

Incident ray
Amplitude: $A_0$

Layer 1

Reflected ray
Amplitude: $A_1$

Layer 2

$\rho_1, v_1$

$\rho_2, v_2$

$\rho_2, v_2 \neq \rho_1, v_1$

Transmitted ray
Amplitude: $A_2$

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 $(180^\circ)$ 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)

- geological section
- acoustic impedance log
- reflection coefficient log
- reflectivity function
- input pulse

\[ \text{seismic trace} = \text{reflectivity function} \ast \text{input pulse} \]
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
INTRODUCTION TO EXERCISE
Seismic Signature of Extensional Sedimentary Basins – Offshore Norway
Stratigraphy – Offshore Norway
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