GEL2150: Field course and methodology in geology and geophysics

Introduction to exercise

Geophysical Part
Objective

- Introduction to seismic interpretation
- Introduction to interpretation of potential field data
- In the field, impression of seismic principle and scale in comparison to the real geology
Contents of this lecture

• Geology of the Oslo Rift (Oslo + Skagerrak grabens)
• Stratigraphic logging in the field
• Synthetic seismograms
• Introduction to determination of acoustic impedance in the field
• Correlation between stratigraphy and seismic
• Report
Oslo Graben

- Active between c. 320 – 240 Ma
- Preserved Cambro-Silurian (≥ 1700m)
- Upper Carboniferous Asker Group (70-80m)
- U-Carb. – Permian igneous rocks (basalts/RP & intrusives)
- Permian sediments
## Lower Paleozoic

<table>
<thead>
<tr>
<th>Epoch</th>
<th>Rock type</th>
<th>Stage</th>
<th>Formation/Group</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cambrian</td>
<td>Mostly Sandstone (*&quot;Ringerike Sandstone&quot;)</td>
<td>10</td>
<td>Sundvollen</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Ringerike Group</td>
</tr>
<tr>
<td></td>
<td>Mostly limestone</td>
<td>9a-g</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>8c-d</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Shales/Sst</td>
<td>8a-b</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Mostly limestone</td>
<td>7c</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>7a-b</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Shales with thin layers of limestone</td>
<td>6a-c</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Calc. Sst</td>
<td>5b</td>
<td></td>
</tr>
<tr>
<td>Ordovician</td>
<td>Shales with Lst nodules; *&quot;Knollekalk&quot;</td>
<td>5a</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>4b-d</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Shales Some Lst.</td>
<td>4a-b</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Alum shales Sst. Cgl.</td>
<td>3a-c</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>2a-e</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>1c-d</td>
<td></td>
</tr>
<tr>
<td>Silurian</td>
<td></td>
<td>1b</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Shales/Sst</td>
<td>6a-c</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Mostly limestone</td>
<td>5b</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>4b-d</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>4a-b</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>3a-c</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>2a-e</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>1c-d</td>
<td></td>
</tr>
</tbody>
</table>

- **Cambrian:**
  - Marine transgression over Precambrian peneplain
- **Lower-Middle Ordovician**
  - Fairly stable marine conditions; changing oxygen content
- **Late Ordovician**
  - Erosional products; sea-level drops
- **Silurian**
  - Caledonian Orogeny
  - Foreland basin in-fill
Fig. 7. Palaeotectonic/palaeogeographic maps of the East European Craton. Legend: 1 = continental sands; 2 = continental sands and shales; 3 = tills (Early Vendian); 4 = alluvial-deltaic and shallow-marine, mainly sands; 5 = alluvial-deltaic and shallow-marine sands and shales; 6 = shallow-marine sands and shales; 7 = alluvial-deltaic and shallow-marine sands and shales (for Precambrian and earliest Cambrian only); 8 = shallow-marine sands, shales and carbonates; 9 = shallow-marine carbonates and shales; 10 = mainly carbonates; 11 = carbonates, mainly coral and/or algal; 12 = carbonates and evaporites; 13 = mainly evaporites; 14 = deeper-marine carbonates, clays and siliceous shales; 15 = deeper-marine clays and siliceous shales; 16 = deeper-marine clastics and/or carbonates; 17 = turbidite series, flysch; 18 = plateau basalts; 19 = acid volcanites and clastics; 20 = granite intrusions (for Early Riphean); 21 = oceanic basin; 22 = active fold belts; 23 = inactive fold belts; 24 = cratonic highs; 25 = boundaries of the craton and main tectonic units; 26 = major active faults; 27 = spreading axes; 28 = subduction zones; 29 = inversion axes; 30 = dyke systems (Precambrian); 31 = continental slope; 32 = rifts; 33 = highly stretched continental or oceanic crust; 34 = active major thrusts; 35 = boundaries of lithological zones; 36 = erosional edge of mapping interval; 37 = directions of elastic influx; 38 = orogenic volcanism; 39 = basaltic volcanism; 40 = unknown continental terrane.
Upper Paleozoic sediments

- **Asker Group**
  - Deposited on a eroded peneplain (20° North)
  - Continental deposits (rivers, deltas)

- **Kolsås Fm**
  - Red shales; some sst and lst; 15m

- **Tanum Fm**
  - Sst and Cgl; lst as cement; 15m
  - 1m thick marine lst

- **Skaugum Fm**
  - Red shales and sst; volcanic detritus; 20m
Upper-Carboniferous – Permian lavas and sedimentary rocks
Graben Formation

Pre-rift phase
- 312-285 Ma
- Deltaic deposits in wide depression, sill intrusions, minor volcanism

Composite Stratigraphic Column from Central Area of the Oslo Graben

- Lava flow
- Distal and proximal volcanoclastic alluvial fan deposits in front of lava escarpments
- Fluvial dominated delta prograding into a brackish water basin
- Tidal influenced braid delta prograding and retrograding within a shallow marine basin
- Fluvial dominated delta prograding into a shallow but widespread lacustrine basin

"Pre Upper Carboniferous"
Graben Formation
Graben Formation
Thick volcaniclastic alluvial fans banked against the master fault
Graben Formation

4 Syn-rift phase II
- 275-265 Ma
Central volcanoes (basaltic)
Caldera collapse

5 Batholith emplacement phase
268-255 Ma
No supracrustal rocks
Correlation between Oslo Graben and Skagerrak Graben

- **Oslo Graben:**
  - Surface geology
  - Stratigraphy
  - No information on depth

- **Skagerrak Graben**
  - Below sea-level
  - Seismic sections
  - Depth information
  - No control on geology
Seismic line OG-7
Potential Field Data
How to correlate OG and SG

- Logging stratigraphic section
- Divide section into seismic sequences
- Define acoustic impedance of seismic sequences
- Calculate reflection coefficient
- Construct synthetic seismogram
- Correlate with seismic
Stratigraphic logging

SCALE?
## Seismic scale

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

<table>
<thead>
<tr>
<th>Age of rocks</th>
<th>VERY YOUNG</th>
<th>YOUNG</th>
<th>MEDIUM</th>
<th>OLD</th>
<th>VERY OLD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depth of target</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Formation Velocity (m/s)</td>
<td>1600</td>
<td>2000</td>
<td>3500</td>
<td>5000</td>
<td>6000</td>
</tr>
<tr>
<td>Predominant Frequency (Hz)</td>
<td>70</td>
<td>50</td>
<td>35</td>
<td>25</td>
<td>20</td>
</tr>
<tr>
<td>Wavelength (m)</td>
<td>$\lambda$</td>
<td>23</td>
<td>40</td>
<td>100</td>
<td>200</td>
</tr>
</tbody>
</table>

**LIMIT OF SEPARABILITY**

<table>
<thead>
<tr>
<th>Visibility Limit</th>
<th>Poor S/N</th>
<th>Moderate S/N</th>
<th>High S/N</th>
<th>Outstanding S/N</th>
<th>e.g.</th>
<th>e.g.</th>
<th>e.g.</th>
<th>e.g.</th>
</tr>
</thead>
<tbody>
<tr>
<td>V/S/L Visibility</td>
<td>Water sand poor data</td>
<td>Water or oil sand fairly good data</td>
<td>Gas sand good data</td>
<td>Gas sand excellent data</td>
<td>$\lambda/8$</td>
<td>$\lambda/12$</td>
<td>$\lambda/20$</td>
<td>$\lambda/30$</td>
</tr>
<tr>
<td></td>
<td>$\lambda/4$</td>
<td>6</td>
<td>10</td>
<td>25</td>
<td>50</td>
<td>75</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

units are meters
Seismic scale
Vertical resolution

Wavelength increases with depth
Frequency decreases
Reduced vertical resolution

<table>
<thead>
<tr>
<th></th>
<th>f</th>
<th>ν</th>
<th>λ</th>
<th>λ/4</th>
<th>z</th>
</tr>
</thead>
<tbody>
<tr>
<td>100 Hz</td>
<td>2 km/s</td>
<td>20 m</td>
<td>5 m</td>
<td>~250 m</td>
<td></td>
</tr>
<tr>
<td>40 Hz</td>
<td>4 km/s</td>
<td>100 m</td>
<td>25 m</td>
<td>~2250 m</td>
<td></td>
</tr>
</tbody>
</table>
Seismic sequences

Composite Stratigraphic Column from Central Area of the Oslo Graben

Lava flow

Distal and proximal volcanoclastic alluvial fan deposits in front of lava escarpments

Fluvial dominated delta prograding into a brackish water basin

Tidal influenced braided delta prograding and retrograding within a shallow marine basin

Fluvial dominated delta prograding into a shallow but widespread lacustrine basin

"Pre Upper Carboniferous"

SCALE
ACOUSTIC IMPEDANCE

SQ 1
SQ 2
SQ 3
SQ 4
SQ 5
SQ 6
WHAT IS A REFLECTOR: HOW CAN IT BE DEFINED (how strong it is)?

**Normally Incident Seismic Rays**

- incident ray amplitude $A_0$
- reflected ray amplitude $A_1$
- transmitted ray amplitude $A_2$

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

**Acoustic Impedance**

$$Z = \rho v$$

**Reflection Coefficient**

$$R = \frac{A_1}{A_0} = \frac{A_{\text{refl}}}{A_{\text{incid}}}$$

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

- $-1 \leq R \geq +1$
- $R = 0$ → all incident energy transmitted ($Z_1 = Z_2$)
- $R = +1$ or $-1$ → all incident energy reflected
- $R < 0$ → phase change $\pi$ ($180^\circ$) in reflected ray

**Transmission Coefficient**

$$T = \frac{A_2}{A_0} = \frac{A_{\text{trans}}}{A_{\text{incid}}}$$

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

30
The energy in a seismic wave encountering an interface with different acoustic impedance above and beneath, is divided in an up going - and a down going wavefield.

\[ T = \frac{At}{Ai} \quad T_{P1,2} = \frac{APt}{API} \]
\[ R = \frac{At}{Ai} \quad R_{P1,2} = \frac{APt}{API} \]

Ai: amplitude of incoming wave.
At: amplitude of transmitted wave.
Ar: amplitude of reflected wave.

Expressions are for vertically incoming pressure waves.

**Acoustic impedance: \( \rho v \)**

Acoustic impedance is the product between the wave velocity and the density of the medium. \( l = \rho v \)

The reflection and transmission coefficients express the amplitude of the waves.
SEISMIC TRACE (REFLECTION SEISMOGRAM)

Seismic trace: amplified oscillographic recording of each detector (geo-/hydro-phone)
<table>
<thead>
<tr>
<th>Rock Type</th>
<th>Density g/cm³</th>
<th>Vp km/s</th>
<th>Vs km/s</th>
</tr>
</thead>
<tbody>
<tr>
<td>water</td>
<td>1.0</td>
<td>1.5</td>
<td>0.0</td>
</tr>
<tr>
<td>sea water</td>
<td>1.03</td>
<td>&quot;</td>
<td>&quot;</td>
</tr>
<tr>
<td>oil</td>
<td>0.90</td>
<td>&quot;</td>
<td>&quot;</td>
</tr>
<tr>
<td>coal</td>
<td>1.2-1.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>sand, clay, soil (dry uncon)</td>
<td>1.4-2.0</td>
<td>2-4</td>
<td>1.5-3</td>
</tr>
<tr>
<td>marine seds. (unc.)</td>
<td>1.2-2.2</td>
<td>~2.5</td>
<td>less than 1.5</td>
</tr>
<tr>
<td>Sandstones</td>
<td>2.0-2.5 (up to 2.7)</td>
<td>2-5</td>
<td></td>
</tr>
<tr>
<td>salt (rock salt)</td>
<td>2.1-2.45</td>
<td></td>
<td></td>
</tr>
<tr>
<td>limestone, chalk</td>
<td>2.3-2.8</td>
<td>3-6</td>
<td></td>
</tr>
<tr>
<td>Gneiss</td>
<td>~2.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Basalt</td>
<td>2.5-3.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- extruded basalt</td>
<td>2.5, pillows 2.8+, compacted</td>
<td>3.5-6.0, layer II 6.0-6.7, layer III</td>
<td>2-4, layer II ~4, layer III</td>
</tr>
<tr>
<td>- basalt rubble</td>
<td>2.1-2.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Granite</td>
<td>2.5-2.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gabbro</td>
<td>2.8-3.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diabase</td>
<td>2.5-3.2 2.8+, typical</td>
<td>~8.2 under Moho</td>
<td></td>
</tr>
<tr>
<td>Top of mantle</td>
<td>3.2-3.4</td>
<td>~8.2 under Moho</td>
<td></td>
</tr>
<tr>
<td>Lithospheric mantle</td>
<td>7-11</td>
<td></td>
<td>3.5-4.6</td>
</tr>
</tbody>
</table>
Field Trip

• Departure: 8.30 from the institute
• Arrival: c. 16.00 at the institute
• What to bring with you:
  – Lunch
  – Field book
  – Pencil and color pencils (do not use pens)
  – Clothing relative to weather
  – Light footwear (mainly roads and dirt roads)
• Other equipment is provided by us
GEL2150
Field course and methodology in geology and geophysics

Stratigraphic logging
Identification of seismic boundaries

Scale: 1:15000
UTM Zone 32
Datum: ED50
Exercise

• Make a stratigraphic log, emphasize seismic units/sequences
• Create NW-SE profile
• Calculate thickness of the stratigraphic column using profile
• Convert stratigraphic column to synthetic seismic trace (so you need velocity and density estimates of the lithologies present - literature)
• Correlate your seismic trace with seismic from the Skagerrak
• Interprete OG-7 using what you have learned during this exercise
• **Introduction**
  – Shortly about the approach to the problem
  – Figures: Location of the research area
• **Geological Framework**
  – Short introduction to the geology of the Oslo Region
  – Figures: Map
• **Procedure**
  – What did you do to get the results
  – Figures: up to you
• **Results and discussion**
  – Compare the field results with the seismic from the Skagerrak
  – Figures: stratigraphical column, ”synthetic seismogram”, interpretation of seismic.
• **Conclusions**
  – Main results – what have I learnt….?
• **References**