2- Geodynamics of Sedimentary Basins

2.1 Basins due to divergence
- Rifts
- Subsidence analysis
- Passive continental margins

Lakes Tanganyika & Victoria  Gulf of Suez & Red Sea  USA Atlantic Margin
2.1.1. Rifts

- a. stretching
- Subsidence analysis
- b. kinematics of rifting
- c. Rift basin architecture

a. Stretching

Extension $\Rightarrow$ deformation = stretching

![Diagram showing stretching and thinning](http://earth.imagico.de/main.php)

- Stretching factor ($\beta$): $l_{\text{final}}/l_{\text{initial}}$ (always $>1$)
- Thinning factor: $t_{h_{\text{final}}}/t_{h_{\text{initial}}}$ (always $<1$)
Lithospheric Stretching

- Stretching (extensional stress)
- a) Stretching => thinning
- b) Deformation = Normal faults in upper crust and uplift of Lithos/asthenos boundary
- c) N. Faults => initial subsidence
- d) LAB isotherm uplift => increased geotherm

Rifting and subsidence processes

- Cooling
- Stretching/thinning
- Loading

Rifting (lithosphere stretching and thinning) involves the 3 basic subsidences processes, simultaneously or successively.
Geological example of a rift: Viking Graben

- Postrift sequence
- Synrift sequence (initial subsidence)
- Thinned cont. Crust (lithosph. also affected)
- Moho

How does it work? -> the McKenzie model
= Subsidence Analysis

McKenzie, 1978
Computing the value of initial subsidence

\[ h \rho | = \rho | (h / \beta) + \rho_w S_i + \rho_a (h_l - h / \beta - S_i) \]

\[ S_i = \frac{(\rho_a - \rho_i)}{(\rho_a - \rho_w)} h_l (1 - 1 / \beta) \]

Sediment-fill = load => extra-subsidence

Subsidence without sediment

Subsidence with sediment

Extra Subsid. due to sediment load

local isostasy
Computing the subsidence due to Sediment-load

\[ h_{W}\rho_{W} + h_{S}\rho_{S} + h_{P}\rho_{P} = (h_{S} - S_{\text{load}} + h_{W})\rho_{W} + h_{P}\rho_{P} + S_{\text{load}}\rho_{a} \]

\[ S_{\text{load}} = \frac{(\rho_{S} - \rho_{W})}{(\rho_{a} - \rho_{W})} h_{S} \]

\[ S_{\text{load}} = 0.60 \text{ hs} \]

Subsidence in rift basins

<table>
<thead>
<tr>
<th>Temporal subdivision</th>
<th>Processes</th>
<th>Driving mechanisms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Syn-rift (instantaneous, initial)</td>
<td>Fault activity + Thermal recovery</td>
<td>Sediment load + Geodynamics (&quot;tectonic&quot;)</td>
</tr>
<tr>
<td>Post-rift (long-term)</td>
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</tbody>
</table>

True for any type of basin
Exercise: Viking Graben

- Considering a pre-rift crustal thickness of 35km, what is the total subsidence at points A, B, C?
- Same question, considering that Trias + U. Palaeozoic belong to pre-rift.
- What are the stretching and thinning factors at each point?

Subsidence evolution of sedimentary basins

Data Campos Basin

- 130My ago deposits at Surface
- Today, basement at 10km depth
Exercises: subsidence evolution of basins

Plot the total subsidence curve from different types of data

Measuring Subsidence in sedimentary basins

Subsidence: Amount of downward vertical movement of the sedimentation surface

Initial position must be known

Data from:
- borehole data (stratigraphic)
- seismic reflection or refraction
- sediment sections measured in the field

North Sea

Age (Ma) | Depth (km)
---|---
0 | 0.15
55 | 2.1
65 | 2.7
100 | 3.7
140 | 4.1
210 | 5.2
**Subsidence in rift basins**

- **Synrift**: fast subsidence
- **Post rift**: cooling of the lithosphere
- **Pre rift**: previously thinned

**Postrift subsidence = lithosphere thermal recovery**

Following rifting, the stretched mantle lithosphere gets cooler. As it gets cooler, the density increases, and subsides (principle of isostacy) = « thermal subsidence »

Subsidence due to sedimentary loading has been removed

**Exercise**: determine initial and thermal tectonic subsidence for a rift basin formed in Late Jurassic (considered instantaneous); Basin is 5km thick, Moho at 25km depth
Backstripping: Backstripping: geodynamics from total subsidence

Backstripping : 1D modeling softwares

Data for backstripping Chote well (W. Gulf of Mexico)

<table>
<thead>
<tr>
<th>Formation</th>
<th>Depth Base (m)</th>
<th>Age (Ma)</th>
<th>Sea level</th>
<th>Bathymetry</th>
<th>Top of formation</th>
<th>Base of formation</th>
<th>Formation physical properties</th>
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<tbody>
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<td>22</td>
<td>100 0.100 2.3 71.50 0  argi</td>
</tr>
</tbody>
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Computed « geodynamic » subsidence

Remove effect of sediment loading = backstripping

Basement burial = total subsidence
Backstripping

Burial history for each stratigraphic interval
Chote well (W. Gulf of Mexico)

Geodynamic subsidence = backstripped total subsidence computed

total subsidence = basement burial observed

Geodynamics subsidence
- Removal of Sediment load

2.1.1. Rifts

a. stretching
Subsidence analysis
b. kinematics of rifting
- Stretching in crust above stretching in the mantle,
- Postrift subsidence centred on the rift axis
- conjugate normal faults

- Offset of stretching in crust and in the mantle
- surface uplift above mantle thinning
- postrift subsidence offset
- Low-angle extensional detachment
- lower crust/mantle denudation

Assymetrical (Wernicke, 1981)

Symetrical (McKenzie, 1978)

uplift
- Geometry ?
- Synrift vs postrift ?
- Approx. thinning ratio ?
- Prerift?
c. Rift basin architecture

Tectonic-sedimentation relationships
- synrift sediment geometry
- Fault profile

Rift basin formation

Define prerift, synrift, postrift?

Parallel reflections
Divergent reflections
Horizontal, onlap reflections

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X'c. Rift basin architecture

Relationships between: fault profile and basin-fill geometry

Thin-skinned vs thick-skinned extensional tectonics
- Rift geometry
- Measurement of extension and consequences on crustal thinning
Active rift basin = Death Valley

Active rift basin - Nevada

Alluvial fan in the basin

Uplifted & eroded footwall

Small radius aggrading alluvial fans

Baseline or slab

wide radius prograding alluvial fans

axial drainage

basement erosion

www.marlimillerphoto.com
Fossil rift basin = Les Matelles

Sedimentary facies distribution ➞ syn-tectonic sedimentation
- Rapid facies change: proximal → distal
- Breccia along active faults - mudstone at rift axis
- Growth structures/ progressive unconformities

Benedicto, 1996

Architecture of rift basin infill

Downlap + thinning away from fault ➞ Proximal breccia → distal fine clastics

Define prerift, synrift, postrift?

Prosser, 1993
Tectonic-sedimentation relationships in rift basin

Rift initiation

- Migration and deposition of erosion sands controlled by interplay of regional winds and local structural topography
- Early riftwall catchments develop in easily eroded strata
- Aggradation of alluvial fan sourced from incipient riftwall catchments
- Fault scarp with incipient drainage catchments
- Tectonic–sedimentation relationships in rift basin

Gawthorpe & Leeder, 2000

Rift development

- Increased displacement rate and low sediment supply lead to lake development
- Rift initiation and interaction stratigraphy (Fig. 6a & 6b)
- Rift initiation and interaction stratigraphy (Fig. 6a & 6b)
- Large fan force axial river away from footwall
- Tectonic–sedimentation relationships in rift basin

Gawthorpe & Leeder, 2000

- Reversed drainage due to uplifting footwalls
- Large fan force axial river away from footwall
- Tectonic–sedimentation relationships in rift basin

Gawthorpe & Leeder, 2000
Tectonic-sedimentation relationships in rift basin

Fault scarp degradation causes major slides generating basin margin breaches

Area tectonics sourced from river basin slumps and axial fluvio-glacial deposits

Fluvial/coastal plain
Alluvial fan/sand delta
Marine basin
Rift initiation and interaction stratigraphy (Fig. 7a-7c)

Gawthorpe & Leeder, 2000

Rift climax

High subsidence results uplifts and fault supply, leading to deepening of basin and slope bypass

Reversed drainage due to uplift
Large catchments and fans mark breached segment boundaries
Sediment bypass on steep, sediment starved footwall scarps

Active rift basins: Gulf of Corinth

Acc << Sed
Acc ≤ Sed
Acc > Sed
Acc ≤ Sed

Rohais & al 2007
**Type sequence of a rift basin**

- **End of rifting**
  - postrift unconformity
  - Fluvial or littoral

- **Filling sequence**
  - Accom < Sedim
  - Lake delta
  - Lake turbidites
  - Lacustrine blackshales (anoxic => organic matter)

- **Rift climax**
  - Rift initiation (sediment against active faults)
  - Alluvial fan
  - Synrift unconformity

- **Starved basin**
  - Rift climax
  - Accom >> Sedim
  - Fluvial
  - Alluvial fan

**Model of an active rift basin**

- **Erosion in watershed**
- **Footwall**
- **Listric normal fault**
- **Footwall Rapid facies change**
- **Progressive unconformities = growth structures**
- **Roll-over**
- **Wide, thin, low accommodation alluvial fans above roll-over**
- **Narrow, thick, high accommodation alluvial fans close to border fault**
- **fluvial/lacustrine axial facies**
Geological example: Moray Firth

Architecture of post-rift basin infill

Geometry of post-rift sequence = « steer-head » (Porcupine Basin)