Are Relay Ramps Pathways for Turbidity Currents?

A study combining analog sandbox experiments and numerical flow calculations

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(http://www.fault-analysis-group.ucd.ie/gallery/relay.html)
Outline

• background
  • relay ramps?
  • role in sediment routing?

• relevance/aim

• approach/method
  • sandbox modeling
  • numerical modeling

• results

• conclusions/wrap-up
Relay Ramps?

• common feature at continental margins, associated with extensional tectonics

• transfer zones consisting of reoriented bedding between two synthetic normal faults that overlap in map view

• develop in normal fault zones through propagation of en-echelon faults

• dimensions of up to tens of kilometers in width, length

• transient features!

Athmer et al., 2008
Anatomy of a Relay Ramp

Athmer et al., submitted
Formation stages

formation: different stages, with different morphology

stages A, B:
relay ramps unfaulted
continuous path upthrown to downthrown block

stage C:
continued extension, overlapping fault link, ramp becomes breached

Gawthorpe and Collela, 2000
Field-Scale Examples

Canyonlands Grabens, Utah

![Canyonlands Grabens, Utah](image by Bruce Trudgill: http://geology.mines.edu/faculty/btrudgil/trudgill25.jpg)

Arches NP, Utah

![Arches NP, Utah](image by Michael Strugale: http://www.flickr.com/photos/strugale/2933812701)
Role in Sediment Routing

large-scale relay-ramps:

- influence transport of sediments towards basins
- large-scale: several kilometers width, 10s of kilometers length

documented examples from subaerial settings

- East African Rift (Soreghan et al., 1999)
- Suez Rift (Gupta et al., 1999; Young et al., 2002)
- Gulf of Corinth, Greece (Gawthorpe and Hurst, 1993)
Submarine Setting?...

relay-ramps in **submarine setting** (lakes, oceans):

- role in sediment routing less clear
- no convincing evidence yet published

- current status: **speculative**

  - “RRs may act as conduits for river-sourced submarine gravity flows in the Danish North Sea” (Bruhn and Vagle, 2005)
  - “flow constraining by channelization and tilting of RRs might help direct flows down the ramp” (Soreghan et al., 1999)
Relevance/Aim

deep-marine turbidite systems:

major exploration targets on many passive continental margins (e.g. offshore Norway, West Africa, Brazil)

role of RRs in sediment routing of great relevance to predict location of reservoirs

AIM: investigate the influence of relay ramps on

1. pathways of turbidity currents from shelf to basin
2. distribution of deep-marine sediments in/around rifted-basin margins
Approach

combination of **Analog** and **Numerical** modeling:

**A.** sandbox modeling: realistic rift basin bathymetries (incl. RR)

**N.** process-based model: turbidity-current flow & sedimentation

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A. sandbox modeling: realistic rift basin bathymetries (incl. RR)

N. process-based model: turbidity-current flow & sedimentation

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**Analog model** (Athmer et al., 2008)

Direction of extension

Relay ramp (between two normal faults with same dip-direction)

Upscaled discretized bathymetry
Sandbox Modeling

Athmer et al., submitted

19 June 2009
Numerical Model

FanBuilder: simulates evolution of fan stratigraphy in 3D
         : each flow & sedimentation modeled separately

classification: process-based (2-DH model Parker and co-workers)
               : hydrodynamics, sediment transport
               : erosion, deposition, water entrainment

input: flow velocity, concentration & height, sediment volume, recurrence interval, bathymetry

output: thickness, grain size
        : geometry of deposits (shape, size)
        : erosive contacts

validation: laboratory data (Groenenberg et al., 2007, 2009)
Configuration sketch

Groenenberg, 2007
Numerical Experiments

variables: - ramp geometry
- inflow angle
- on-ramp confinement

ramp geometry : width, incline, tilt
inflow angle : angle of incidence between streamwise flow direction at entrance and ramp incline
confinement : no confinement vs. channel-like

flow properties : defined at entrance

- flow depth : 40m
- velocity : 5 ms\(^{-1}\)
- density : 1092 kgm\(^{-3}\) (4%)
- grain size : 125 \(\mu\text{m}\) (fs)
Results: Perpendicular Inflow

width : 4.55km
ramp incline : 6.0°
basinward tilt : 1.7°
Results Oblique Inflow (1)

width : 4.55km
ramp incline : 6.0°
basinward tilt : 1.7°
Results: Ramp Geometry

*larger width, incline, smaller tilt “facilitate” down-ramp flow
Results: Oblique Inflow & Confinement

width : 4.55km
ramp incline : 6.0°
basinward tilt : 1.7°
channel depth : 45m, decreasing monotonically
Results: Oblique Inflow & Landward-Tilt

- width: 4.55 km
- ramp incline: 5.2°
- basinward tilt: -1.5°

* modified: experimentally obtained relay ramps all slightly tilted basinward.
Conclusions

most influential factor : ramp tilt

observations:

- massive spill-over down the fault directly into basin for all basinward-tilted ramp experiments
  *basinward tilt common feature of all but largest-scale RRs

- on-ramp confinement results in funneling down the ramp

- flow has great difficulty in turning in the direction of ramp incline
  reacts “sluggish” to gradient change in upper reaches of ramp

Athmer et al., submitted
Wrap-up

other important considerations:

• location of sediment source (shelf edge, delta) morphology of RR such that their incline is perpendicular to shelf-edge

• RRs transient features, open-stage morphology is transient, requires that timing of sediment supply is synchronous with open-stage phase

Are relay ramps pathways for turbidity currents?

Answer: Questionable...