Gravitational Salt Tectonics Triggered by Deposition of Turbiditic Lobes: a New Experimental Modeling Approach with Applications to Salt Tongues in the U.S. Gulf of Mexico*

Nicolas Sellier¹ and Bruno C. Vendeville¹

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¹Laboratoire Geosystemes- CNRS 8157, Universite de Lille 1, Villeneuve d'ascq, France. (nicolas.sellier@ed.univ-lille1.fr)

Abstract

So far, there have been two drastically different approaches at modeling the effects of deposition of clastic sediments wedges along passive margins. First, the stratigraphic approach models sediment transport and deposition, focusing on the resulting stratigraphic architecture, but neglecting the impact of syndepositional deformation. Many flume experiment simulating turbidity deposits were designed to understand the stacking patterns of deep-sea turbiditic fan systems. But most experiments did not account for syndepositional deformation. Second, there has been some extensive experimental and numerical work by structural geologists on deformation of sediment wedges above weak substrates (salt or shale), but using rather crude and simple ways of sedimentation processes (by adding episodically one sediment layer uniformly, regardless of the potential influence of the bathymetric relief on depositional patterns).

We designed a new tectono-stratigraphic modeling tank that comprises a channel connected to a main basin. The basin can be filled with different kind of substrates either rigid (sand) or viscous (silicone polymer, simulating a salt layer of varying length and thickness). A mixture of fine-grained sand powder and water (50 to 150 μm in diameter) were released, then channeled into the basin.

We investigated the effect of depositing several consecutive turbiditic lobes on the deformation of a viscous salt body. The dynamics of turbidity currents lead to deposits whose thickness varied laterally: thick in the proximal area, and thinning progressively distally, thus creating a gentle regional surface slope. In addition, salt’s response to even minor local differential loading was vigorous. In models, lobe deposition generated sub-marine dunes sub-millimetric in scale. The underlying salt immediately subsided beneath each
sedimentary ridge, and rose passively in between the dunes. Furthermore, with growing maturity of the sedimentary lobe, regional spreading/collapse of the entire overburden started. Spreading induced shortening at the distal salt basin’s edge and radial extension in the proximal area, which generated multidirectional grabens and normal faults, in a ROHO fashion, and associated salt ridges that evolved into piercing diapirs.

We also conducted a series of systematic experiments varying the length and thickness of the salt body, as well as the sediment input. The outcome varies from ROHO-like structures to counter-regional faults.

**Selected References**


Vendeville, B.C., 2005, Similarities and differences between salt and shale tectonics, in Abstracts; NAPE and AAPG West Africa deepwater regional conference, p. unpaginated.

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Nicolas Sellier and Bruno C. Vendeville
Laboratoire Géosystèmes
Université de Lille 1, France
• What is the mutual influence between sedimentation and gravitational salt tectonics?
Outline

- Introduction
- New experimental approach and set up
- Salt response to local differential loading
- Salt response to regional differential loading
- Conclusions and perspectives
INTRODUCTION

Two different ways for modeling the effects of deposition of turbiditic sediments wedges along passive margins:

- Turbidity current deposits modeling (Flume experiments)
- Classic (sandbox) physical modeling

Baas et al., 2005
Turbidity current modeling (Flume)

Flume experiments have focused mainly on:
• Flow properties
• Stacking pattern and lobe switching (Parsons et al., 2002)
• The geometry of sediment bodies (Baas et al., 2004)

Lobes with proximal channel-levee system:
• Structureless sediments filling in the channel and lobe’s centre
• Laminated levee bodies and lobe fringe

Baas et al., 2004
However, most flume experiments have not combined sediment transport and deposition with synsedimentary deformation.
Numerical and experimental models (Ings et al., 2004; Vendeville, 2005) demonstrate that deposition of successive sediment wedges onto a weak substratum (salt or shale) triggers:

- Vertical collapse of the sedimentary wedge.
- Lateral spreading of the lobe.

Vendeville (2005)
But this approach is strictly tectonically oriented:

- deposition of each lobe is crudely modeled by adding a new layer uniformly, regardless of the influence of bathymetric highs or lows on the depositional pattern.
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A new experimental approach

Aim of the study:
To design a new tectono-stratigraphic tank that combines modeling:

- Turbiditic transport and deposition
- Salt-related deformation
Experimental set-up

Main tank

Channel 150 cm

65 cm

130 cm

Sellier and Vendeville (2008)
**Experimental set-up**

**Deforation tank:**

- can be filled with various substrates:
  - Rigid (sand)
  - Viscous (silicone polymer, simulating mobile salt layer)

Sellier and Vendeville (2008)
Experimental set-up

Mixing Container:

Filled with a 10% per Vol. fine powder in suspension (50 to 150 µm).
Experimental set-up

Turbiditic episode

Valve

Sellier and Vendeville (2008)
Side View

Head

Tail

Sellier and Vendeville (2008)
Side View

Sellier and Vendeville (2008)
Side View

Head

Tail

Sellier and Vendeville (2008)
Head
Rapid deposition (a few seconds)
Results

We conducted several consecutive turbiditic episodes.

Dynamics of turbidity currents leads to differential deposition:

- Each lobe is thick in the proximal area (5 mm)
- Thins progressively towards the distal area (<1 mm)

➡️ Building of a very gentle bathymetric slope

Side view of a non-deformed turbiditic fan (19 turbiditic events)
Experimental approach

Each turbiditic fan was deposited onto a viscous layer of silicone polymer (mobile salt).

We investigated the effect of depositing several consecutive lobes on mobile salt.
One experiment, two different responses at two different scales

One experiment

Differential loading

Local scale
Regional scale
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Results: Salt response to local differential loading

In the model, lobe deposition generated sub-marine sedimentary ridges (sub-millimetric in height)

The ensuing differential loading was low.
Deformation of the underlying salt was fast, the sand ridges subsided rapidly.

The bathymetry was inverted:
- What used to be a high has become a low.

Results: Salt response to local differential loading.
The salt rose passively beneath the inter ridge segments (thinner overburden).

Crestal grabens formed.
Results: Influence of salt structures on *local* sedimentation (asymmetric deposits)
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Progressively, a gently-dipping fan forms.

Sellier and Vendeville (2008)
Sellier and Vendeville (2008)
Radial spreading and collapse of the fan

Sellier and Vendeville (2008)
Radial spreading and collapse of the fan

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Sellier and Vendeville (2008)
Turtle structures and multidirectional crestal grabens

Sellier and Vendeville (2008)
Vertical exaggeration: 3
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Conclusions

The tectono-stratigraphic approach demonstrates that:

1. **Swift salt movement can occur in response to low local differential loading**

2. **Gravity spreading and collapse can occur, even with a very gentle bathymetric slope (~ 1°)**
Gentle slope in the presently active part of the U.S. Gulf of Mexico

Worrall and Snelson (1989)
Perspectives

We are investigating the effect of depositing several consecutive lobes on salt bodies having various shapes: salt tongue to salt stock.
Perspectives (preliminary results)

Roho style

Counter-regional fault
THANK YOU
Example of early deformation: Gulf of lions (Western Mediterranean)