# PSNumerical Modeling of the Deformation and Displacement of Salt Bodies with Embedded Carbonate or Anhydrite Stringers*

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## Abstract

Large carbonate or anhydrite inclusions are embedded in many salt bodies (so-called rafts, floaters or stringers) and these respond to the movements of the salt in a variety of ways, including displacement, folding and fracturing. The movement and deformation of those embedded carbonate or anhydrite bodies is a process which is not fully understand yet. No numerical study yet has investigated the brittle deformation of individual stringers during the initial phases of salt tectonics. We presented numerical models of the deformation of a salt body with embedded stringers using a case study from the South Oman Salt Basin. We investigated by Abaqus package (finite element models) how differential displacements of the top salt surface induces salt flow and the associated deformation of brittle stringers (including both brittle and viscous material properties).

In our research, the main work was to use and develop techniques in Abaqus to make models of rheological behaviour of salt tectonics and brittle or ductile behaviour of carbonate stringers embedded in salt. A series of techniques were used in order to make successful models. We simplified the geometry from seismic data, define carbonate or anhydrite and rocksalt material, model passive tectonic processes through applying boundary conditions, model large displacement through adaptive remeshing technique and python script, and model brittle fracture through iterative scheme for stringer breaking and adaptive remeshing techniques. The simplified model offers a practical method to investigate complex stringer motion and deformation. Models suggest that brittle stringers can break very soon after the onset of salt tectonics. The extension can make brittle stringers to

boudinage and fracturing and compression can make brittle stringer bending and thrusting. Models suggest that viscous stringers have folding and extension deformation. Results also show the internal structure of salt body and stringer fracturing or deformation is strongly dominated by the geometry or material properties of models.

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# Numerical modeling of the deformation and displacement of salt bodies with embedded carbonate or anhydrite stringers

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# Content

**Question:**

Large carbonate or anhydrite inclusions are embedded in many salt bodies (so-called rafts, floaters or stringers) and these respond to the movements of the salt in a variety of ways, including displacement, folding and fracturing. The movement and deformation of those embedded carbonate or anhydrite bodies is a process which is not fully understand yet.

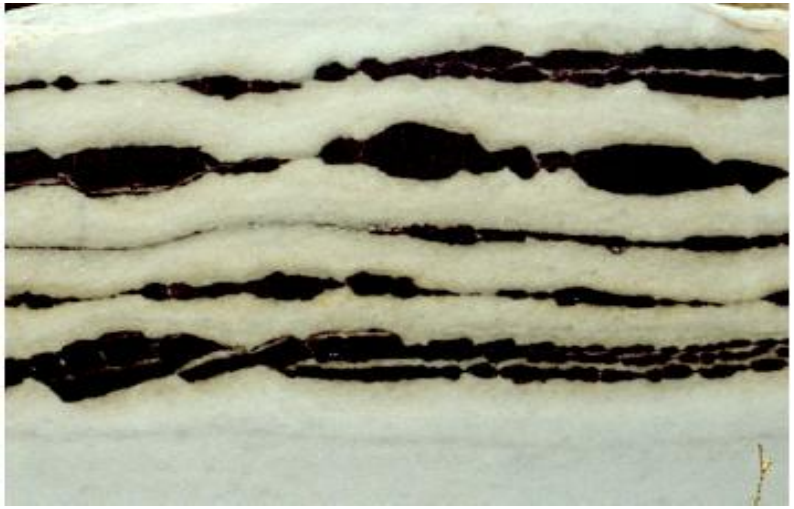


Fig 1: Brittle Stringers are embedded in ductile medium

## Question:

The main question is how the displacement and deformation of the embedded inclusions (stringers) is influenced by deformed salt bodies.

1 From the perspective of geological research, the deformation and displacement of the embedded inclusions are closely relevant to the internal dynamics of salt structure.

2 From the perspective of engineering application, one reason is that the carbonate or anhydrite inclusions may cause potential drilling hazards because they are overpressured.

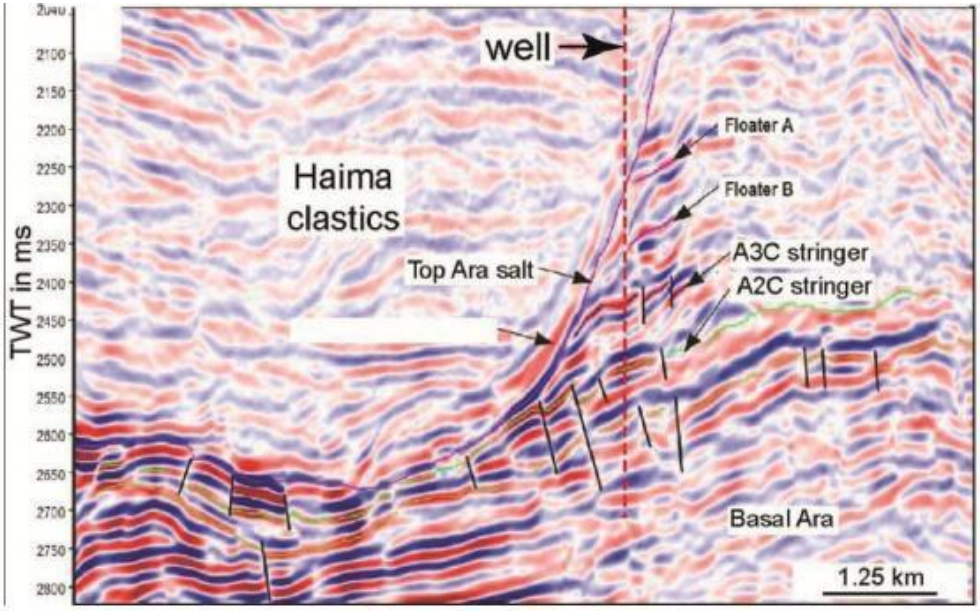



Fig 2: Seismic cross section of an Ara salt diapir

## Geological setting:

In general, the study area is situated in the south western part of the South Oman Salt Basin (SOSB), in the south of the Sultanate of Oman. The salt tectonic evolution of the study area was studied from seismic lines supplied by PDO Exploration.

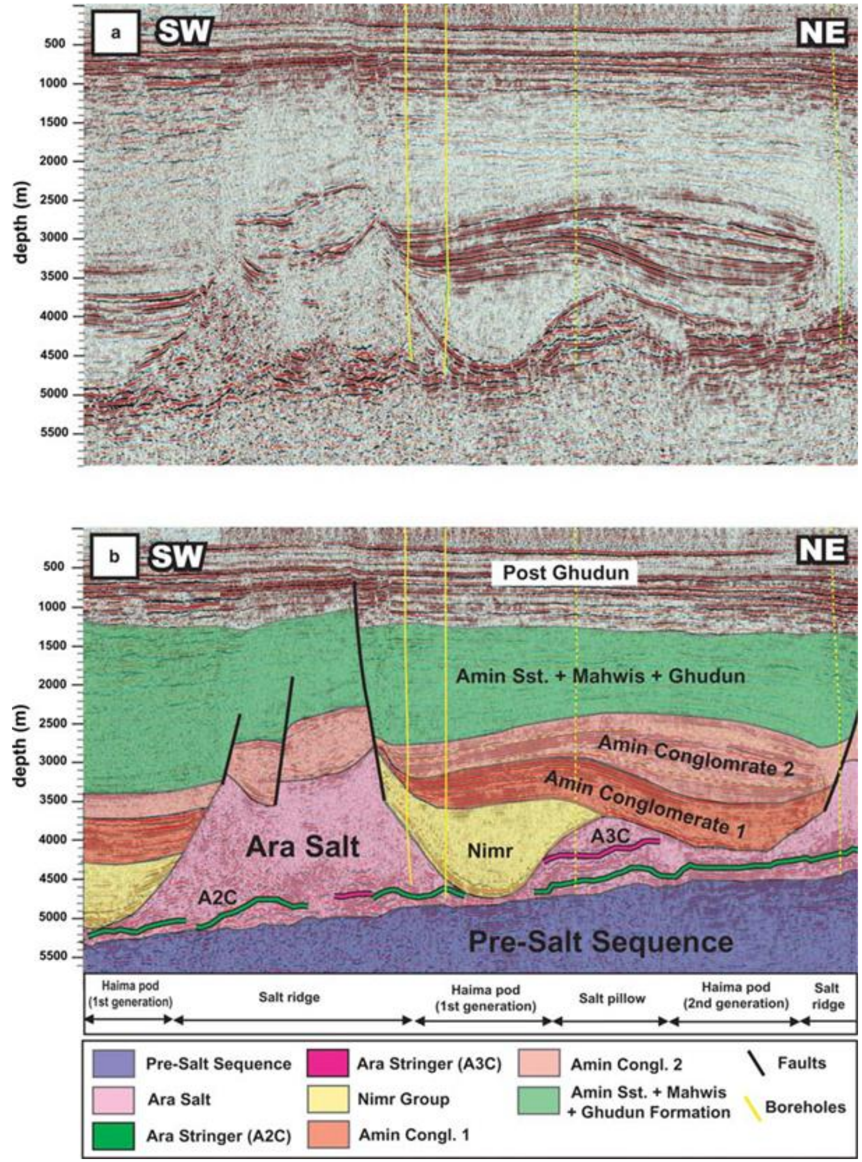



Fig. 3. (a) Uninterpreted seismic line crossing the study area. (b) Interpretation of the seismic line shown in (a). The formation of salt pillows and ridges is caused by passive downbuilding of the siliciclastic Nimr minibasin leading to strong folding and fragmentation of the salt embedded carbonate platforms. (Kukla et al., 2011)

# Methods and Models

We establish an assumed symmetry model (Fig. 4) with two sediment pods and we restrict the computational domain to the area between the centers of the pods. The down-building is not modeled directly but a deformation is imposed on the top salt surface instead.

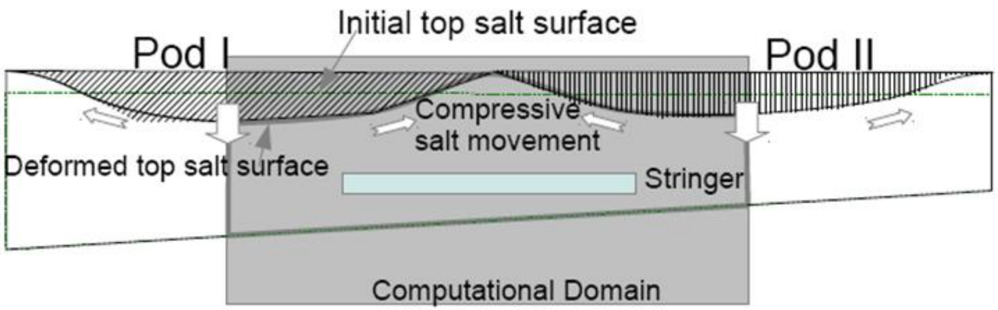



Fig. 4 Conceptual Model Geometry

In this study we used the commercial finite element modelling package ABAQUS for our modelling, incorporating power law creep, elastoplastic rheologies and adaptive remeshing techniques, and we used improved iterative scheme to model frequent stringer breaking (Li et al., 2012).

# Methods and Models

We present a numerical model for the compression case which means that the brittle stringer deforms in a compressive environment. The model setup includes geometries and imposed deformation patterns of the top salt surface (brittle stringer deformation models).

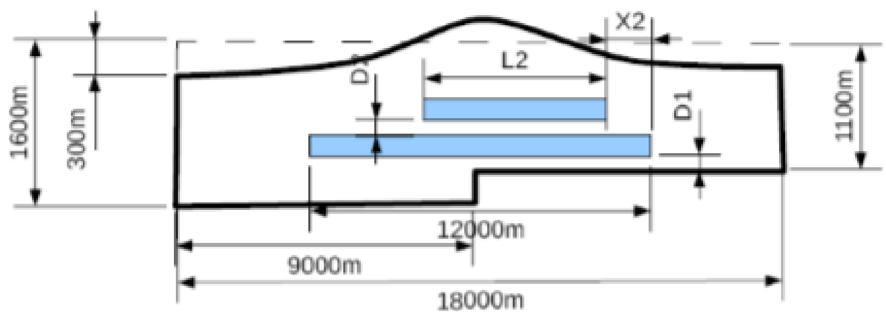



Fig. 5 Simplified standard model set-up in Model (stringers paralleling to the basement)

Fig.6 The top stringer is located at right alignment, central-right side and central part of the model. The length of top stringer ranges from 3000 to 9000m. The basement has stepped configuration in the center of the model.

# Methods and Models

- Case No. 1

We present a numerical model for the compression case which means that the brittle stringer deforms in a compressive environment.

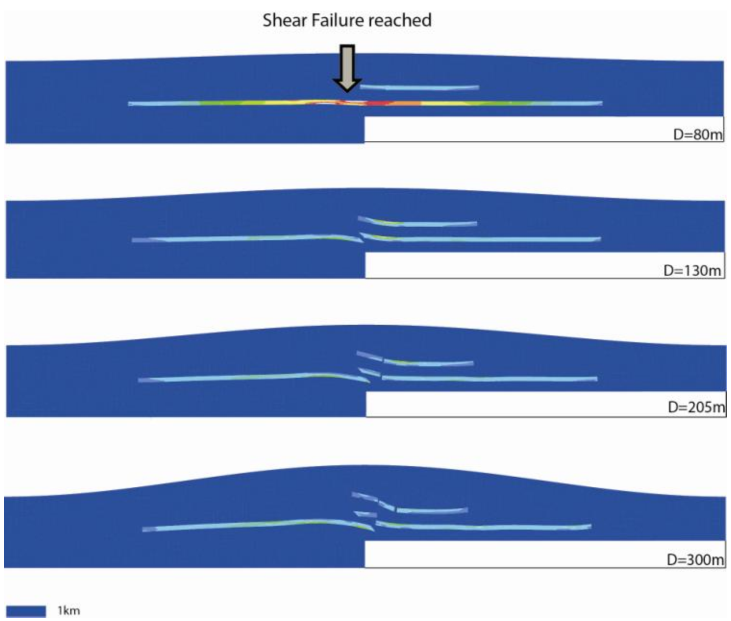
| Parameter | Value |
| --- | --- |
| Width of salt body (W) | 18000m |
| Height of salt body (H) | 1600m |
| Stringer thickness (h) | 80m |
| Stringer length (l) | 12000m |
| Salt density | 2040kg/m$^3$ |
| Stinger density | 2600kg/m$^3$ |
| Salt rheology | A=1.04×10$^{-14}$MPa $^{5}$s$^{-1}$ , n=5 |
| Salt temperature | 50°C |
| Stringer elastic properties | E=30Gpa,υ=0.3, c=35MPa, T=25MPa |
| Basement elastic properties | E=50Gpa, υ=0.4 |
| Basement density | 2600kg/m$^3$ |
| Calculation time | 3.8 Ma |

- Case No. 2

We present a numerical model for the compression case which means that the ductile stringer deforms in a compressive environment.

| Parameter | Value |
| --- | --- |
| Width of salt body (W) | 18000m |
| Height of salt body (H) | 1600m |
| Stringer thickness (h) | 80m |
| Stringer length (l) | 12000m |
| Salt density | 2040kg/m$^3$ |
| Stinger density | 2600kg/m$^3$ |
| Salt rheology | A=1.21×10$^{-13}$MPa$^{-1}$s$^{-1}$ , n=1 |
| Salt temperature | 50°C |
| Stringer viscous properties | A=1.21×10$^{-16}$MPa$^{-5}$s$^{-1}$ , n=1 |
| Basement elastic properties | E=50Gpa, υ=0.4 |
| Basement density | 2600kg/m$^3$ |
| Calculation time | 3.8 Ma |

# Results



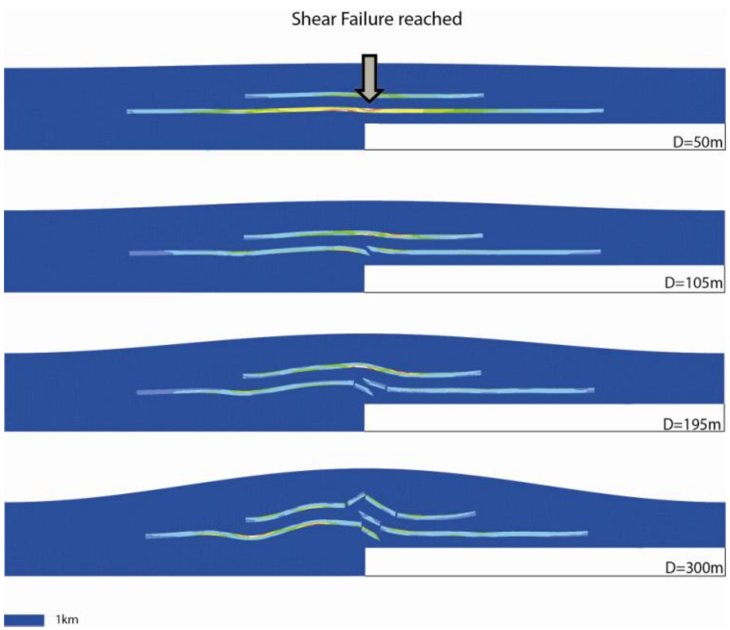
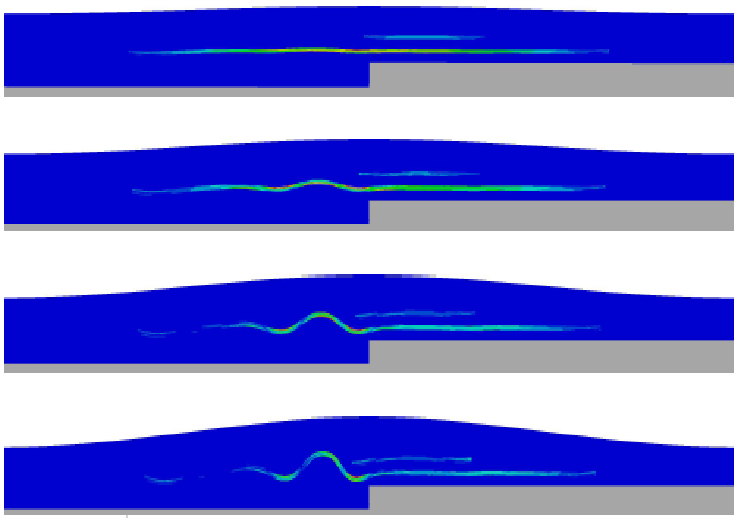




Fig. 7 shows two brittle stringers (top stringer 1/4 times longer than bottom one) and the initial shear break occurs in the centers of the bottom stringer. Further bending breaks occur in the right (up) stringer fragments. The top stringer has only bending break because it is 1/4 times longer than bottom one and it is located in the right side of salt.

Fig. 8 shows two brittle stringers (top stringer 1/2 times longer than bottom one) horizontally located. In this model, multiple fractures and complex final situation are observed.

# Results



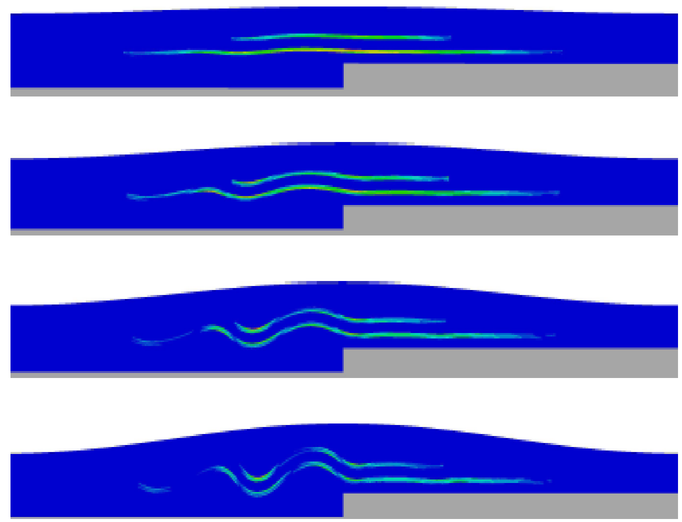
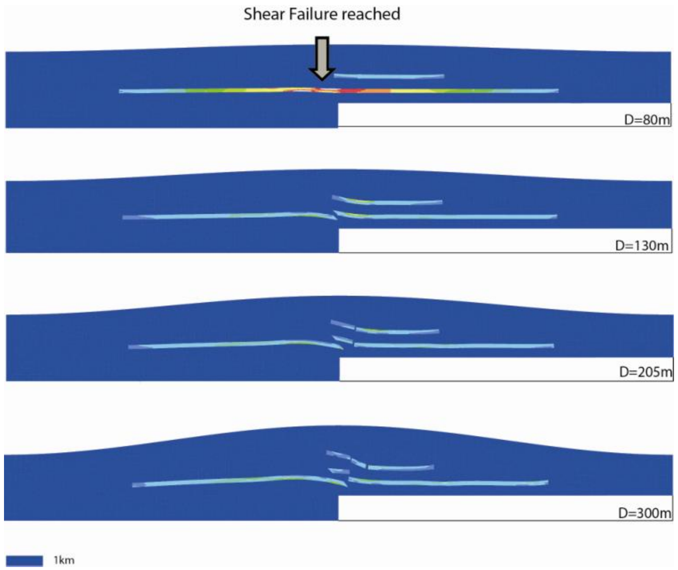
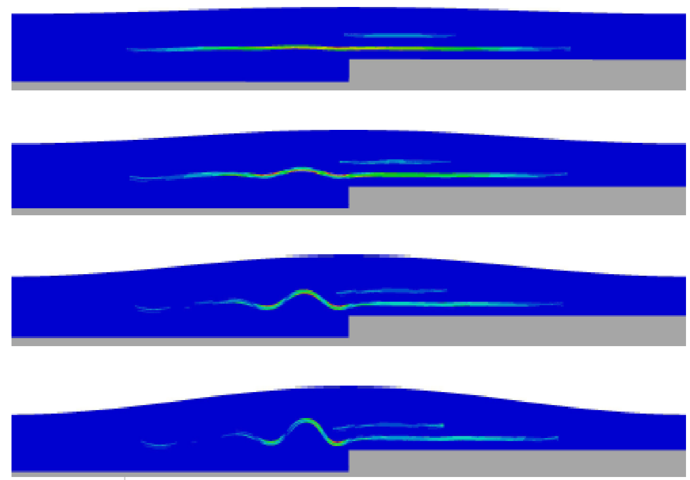


Fig. 9 shows two ductile stringers and strong folding in the left part. The top stringer has no obvious folding because it has ¼ of total length of the bottom one and located in the right part where the compression is not as strong as the central part. The peak stress in the bottom stringer is 10MPa and in the top stringer is 5MPa.

Fig. 10 shows two ductile stringers. the strong folding of both top and bottom stringers in the left part. The folding in the top stringer is obvious because there is enough space around it in the left half part of the model. The peak stress occurring in the top stringer is 15MPa.

# Results



Brittle stringer : Top stringer has higher number of breaks than the bottom due to its closer position to the top salt surface. Some stringer fragment has large rotation because in the center of the model the top surface deformation causes strong compression.

Viscous stringer : The top stringer has no obvious folding because it has 1/4 of total length of the bottom one and located in the right part where the compression is not as strong as the central part. The observed wave length of the folded stringer is compared with the wavelength theoretically expected from the Biot-Ramberg theory of viscous folding.

**Conclusions**

1 The simplified model offers a practical method to investigate complex stringer motion and deformation.

2 Models suggest that brittle stringers can break very soon after the onset of salt tectonics. The compression can make brittle stringer bending and thrusting.

3 Models also suggest that viscous stringers have folding deformation. The viscosity contrast results in harmonic and large folding of stringers deforming in the central part of salt body. The internal structure of salt body and stringer fracturing or deformation is strongly dominated by the geometry or material properties of models.