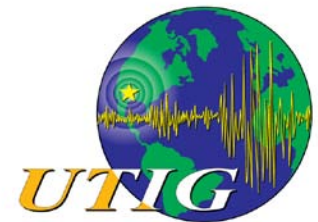# Geomechanical Modeling of Stresses Adjacent to Salt Bodies: Poro-Elasto-Plasticity and Coupled Overpressures*

Maria-Katerina Nikolinakou[1], Gang Luo[2], Mike Hudec[2], and Peter B. Flemings[2]

[1]Bureau of Economic Geology, University of Texas, Austin, TX (mariakat@mail.utexas.edu)
[2]Bureau of Economic Geology, University of Texas, Austin, TX

Abstract

We predict how stresses and pore pressures evolve in the sediments bounding a salt body using coupled geomechanical models. We show that salt relaxation alters the stress state in the wall rocks and can induce pore pressure perturbations that extend kilometers away into the sediments. The time scale of dissipation of these perturbations is on the order of millions of years, suggesting that pore-pressure anomalies should commonly be present in mudstones near salt systems. Because previous models have not coupled changes in the stress field to changes in the pore-pressure field, they are unable to predict the interdependence between pore pressure and stress. However, accurate estimation of both stresses and pore pressures is critical to well-bore design. We employ a poro-elastoplastic soil model (Modified Cam Clay) and study how different drainage conditions affect the changes in strain, stress and pore pressure. We show that in drained systems, stress perturbations can generate low least principal stresses and a small drilling window (the difference between least principal stress and pore pressure) beneath salt. In contrast, in undrained systems, underpressures can lead to a relatively large drilling window, coupled with a significant decrease in pore pressure. These results may provide insight into pressure perturbations that have been encountered in deepwater drilling near salt. Coupled poromechanical models such as the ones discussed have the potential to illuminate how deformation occurs and predict stress and pore pressures in salt systems around the world.

Reference

Hudec, M.R., 2008, Diachronous growth of fold limbs from the Mad Dog Anticline: implications for base-salt deformation in the Atwater Fold Belt: AAPG 2008 Annual Convention and Exhibition Abstract volume, 17, p. 94.

Hudec, M.R., and M.P.A. Jackson, 2006, Advance of allochthonous salt sheets in passive margins and orogens: AAPG Bulletin, v. 90/10, p. 1535-1564.

Rohleder, S.A., W.W. Sanders, R.N. Williamson, G.L. Faul, and L.B. Dooley, 2003, Challenges of an ultra-deep well in deepwater – Spa Prospect: SPE/IADC Drilling Conference, 19-21 February 2003, Amsterdam, Netherlands: SPE paper #79810, 15 p., DOI:10.2118/79810-MS.

Geomechanical Modeling Of Stresses Adjacent To Salt Bodies:
Poro-elasto-plasticity And Coupled Overpressures

Maria-Katerina Nikolinakou
Gang Luo
Mike Hudec
Peter Flemings

THE UNIVERSITY OF TEXAS AT AUSTIN
JACKSON
SCHOOL OF GEOSCIENCES

Acknowledgements

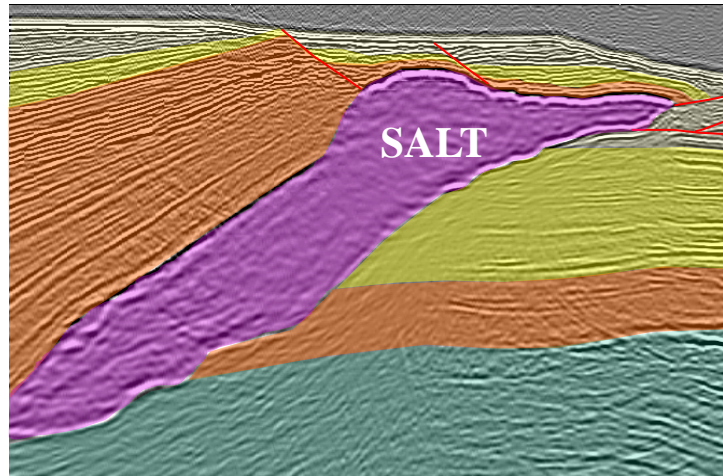# Estimation of stresses and pore pressures around salt
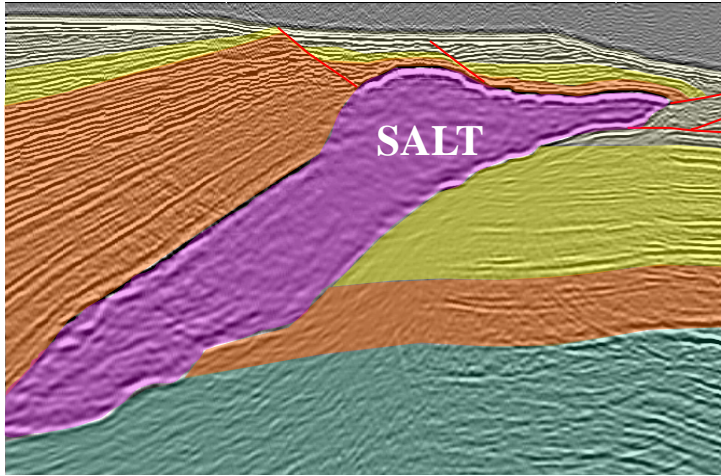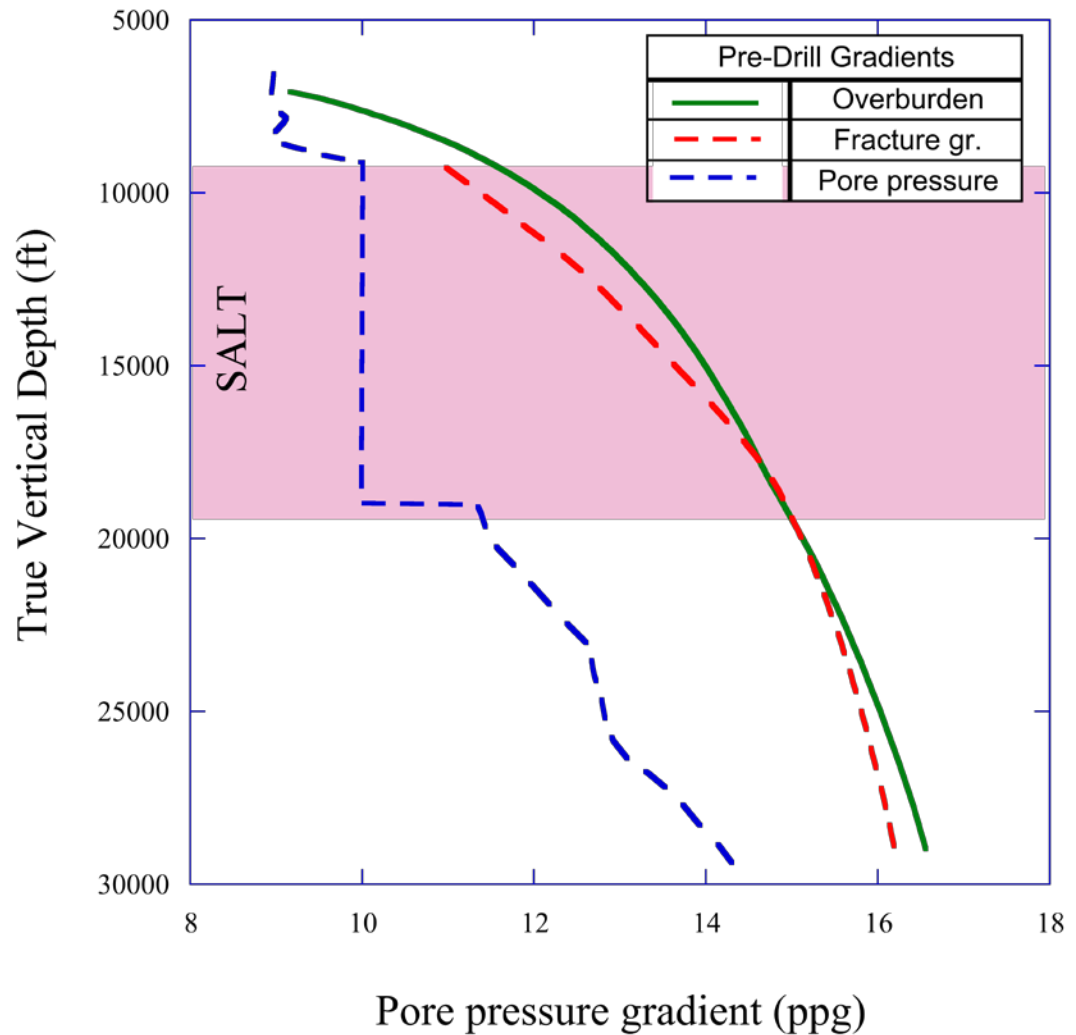
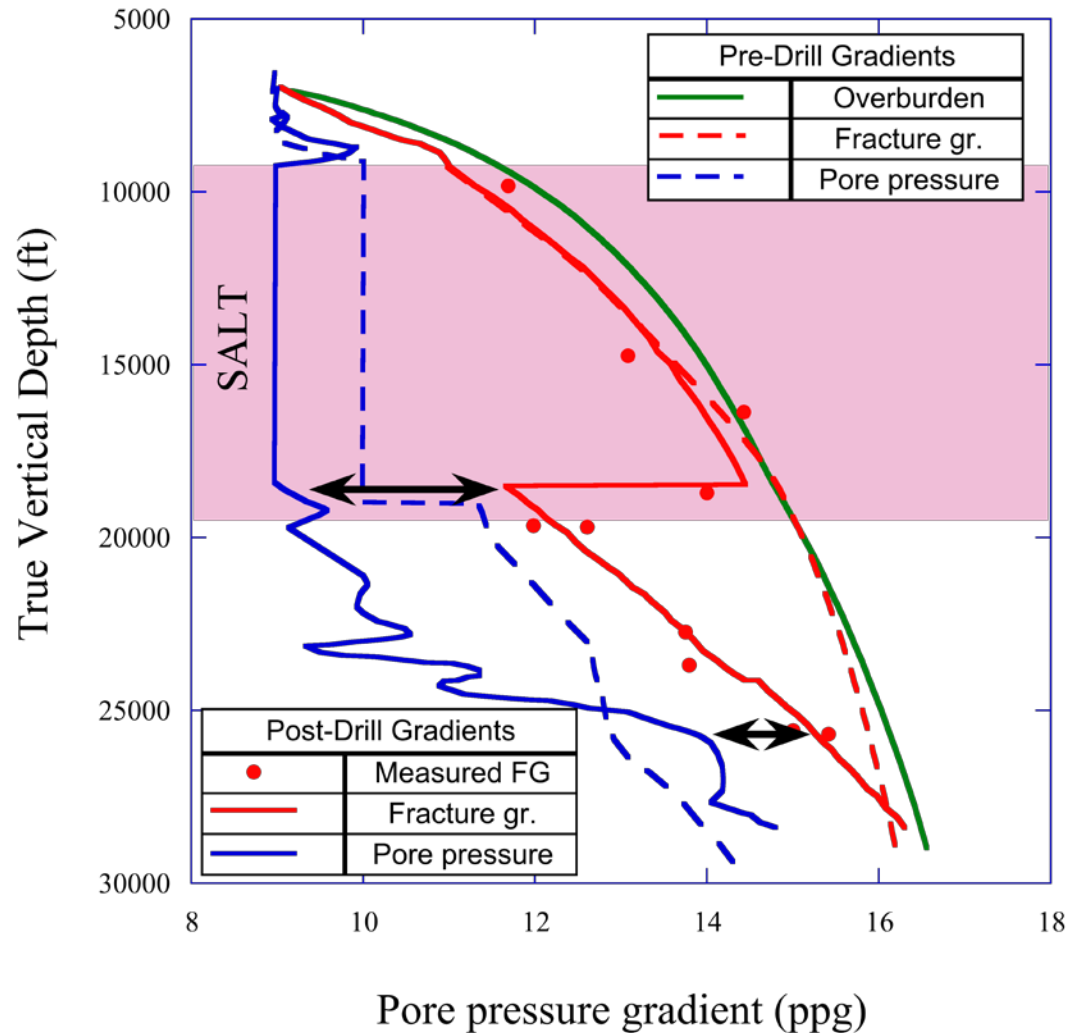Hudec & Jackson 2006

Rohleder et al., 2003

Estimation of stresses and pore pressures around salt

Hudec & Jackson 2006

Rohleder et al., 2003

Lower pore pressures

Drop in minimum principal stress

Narrow window between pore pressure and minimum principal

How to calculate stresses and pore pressures?

Usual assumptions:

Vertical stress:

Overburden
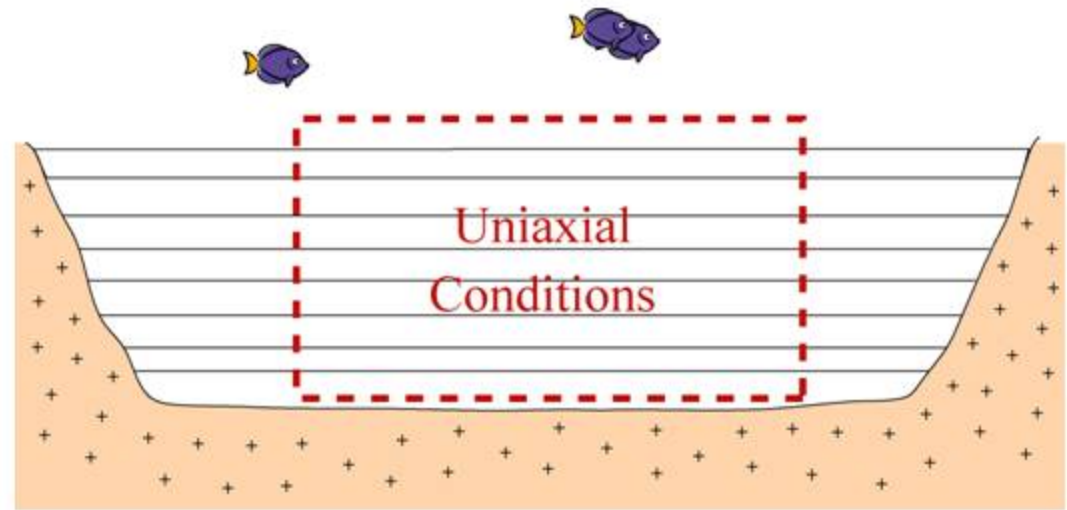
Horizontal stress:

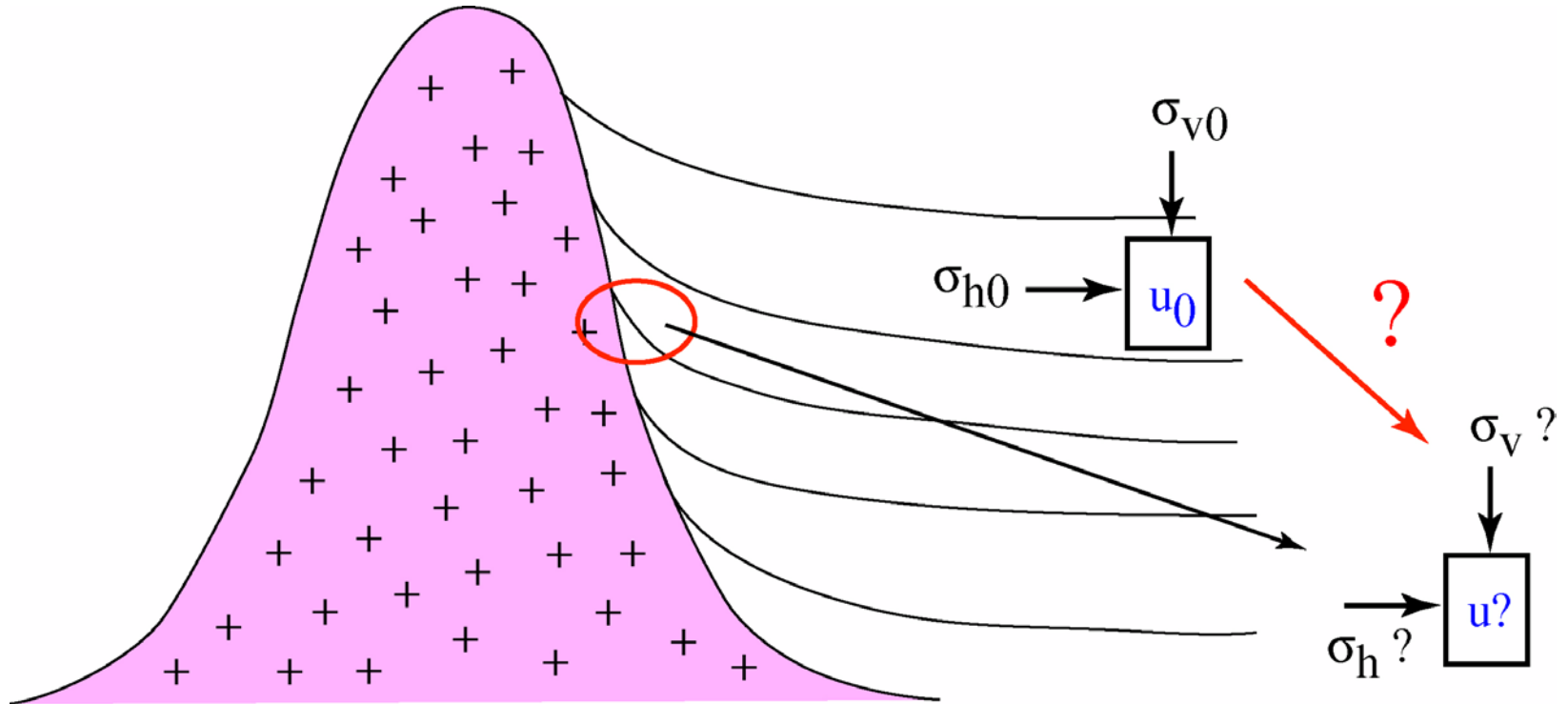Empirical ratio

Pore pressures:

Assume from analogous well

from seismic

from basin models

Material: Assume elastic

Uniaxial
Conditions

How to calculate stresses and pore pressures?

In this work:

More realistic sediments:

    Model pore space, permeability

    Elasto-plastic sediments

Stresses and pore pressures *calculated* through the *coupled* analysis

Why may pore pressures change?

Total stress, $\Delta\sigma$

Effective stress, σ'
(skeleton)

Pore pressure

=

+

Δu

Applied load shared between soil skeleton and pore fluid

Loading ➔ overpressures ➔ fluid flow ➔ back to hydrostatic

Duration of load application vs. time needed for dissipation:

- Loading much slower: pore pressures remain hydrostatic: *drained*

- Loading much faster: overpressures develop: *undrained*

Study: Porous geo-mechanical approach
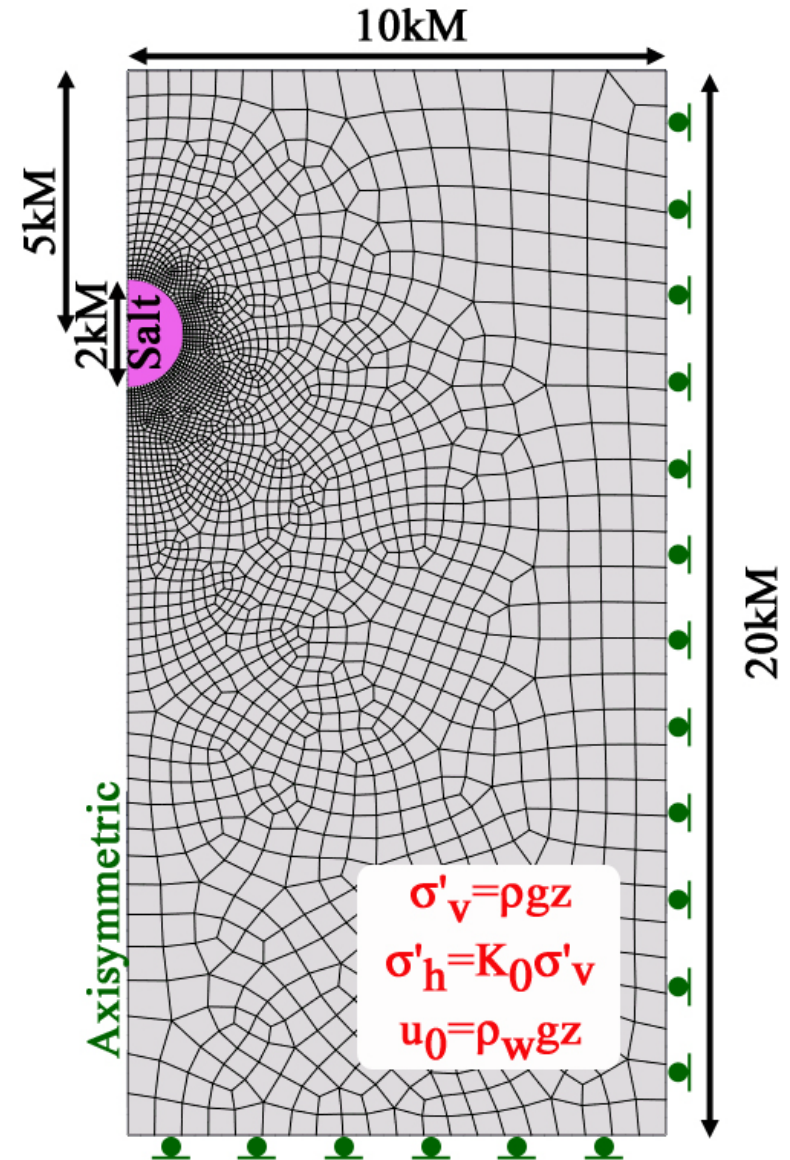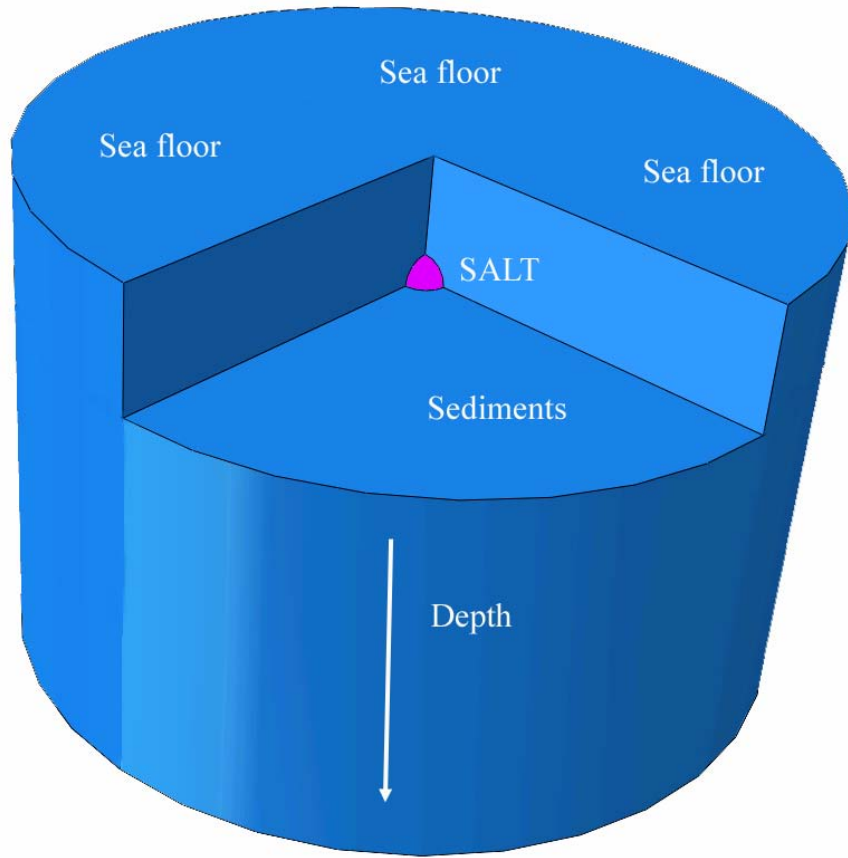
ABAQUS™

Axisymmetric model

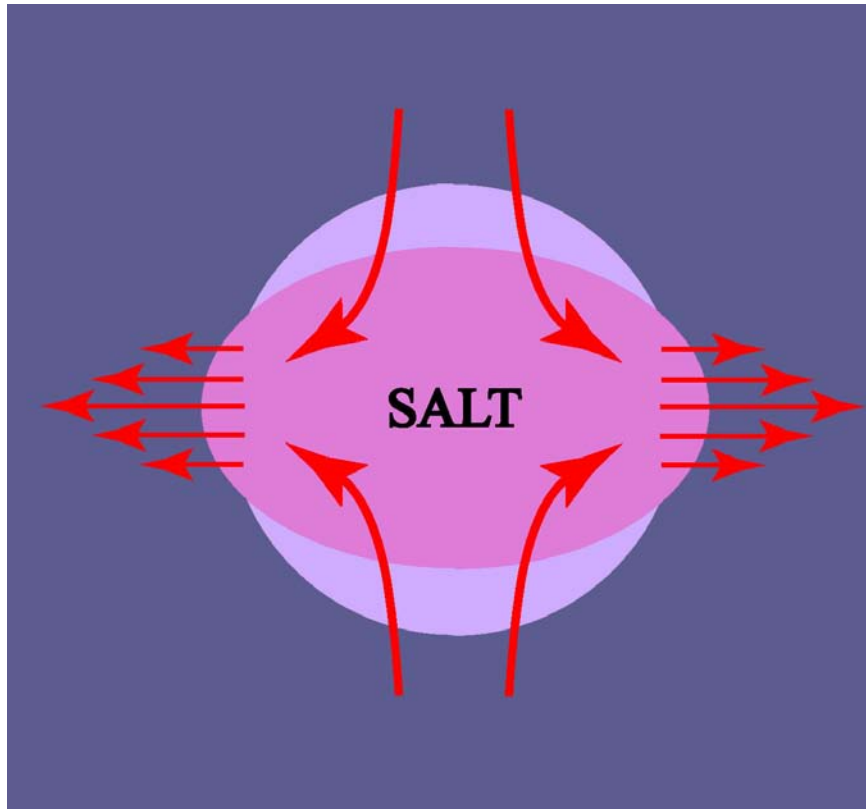Uniform far-field loading: $\sigma'_h = 0.5\sigma'_v$

Viscoelastic salt

Poroelastoplastic sediments (Modified Cam Clay)

Labels within figures:
- Sea floor
- SALT
- Sediments
- Depth
- 10kM
- 5kM
- 2kM
- Salt
- 20kM
- Axisymmetric
- $\sigma'_v = \rho gz$
- $\sigma'_h = K_0\sigma'_v$
- $u_0 = \rho_w gz$

Pore pressures remain hydrostatic

(Drained analyses)

Deformation pattern of relaxing salt
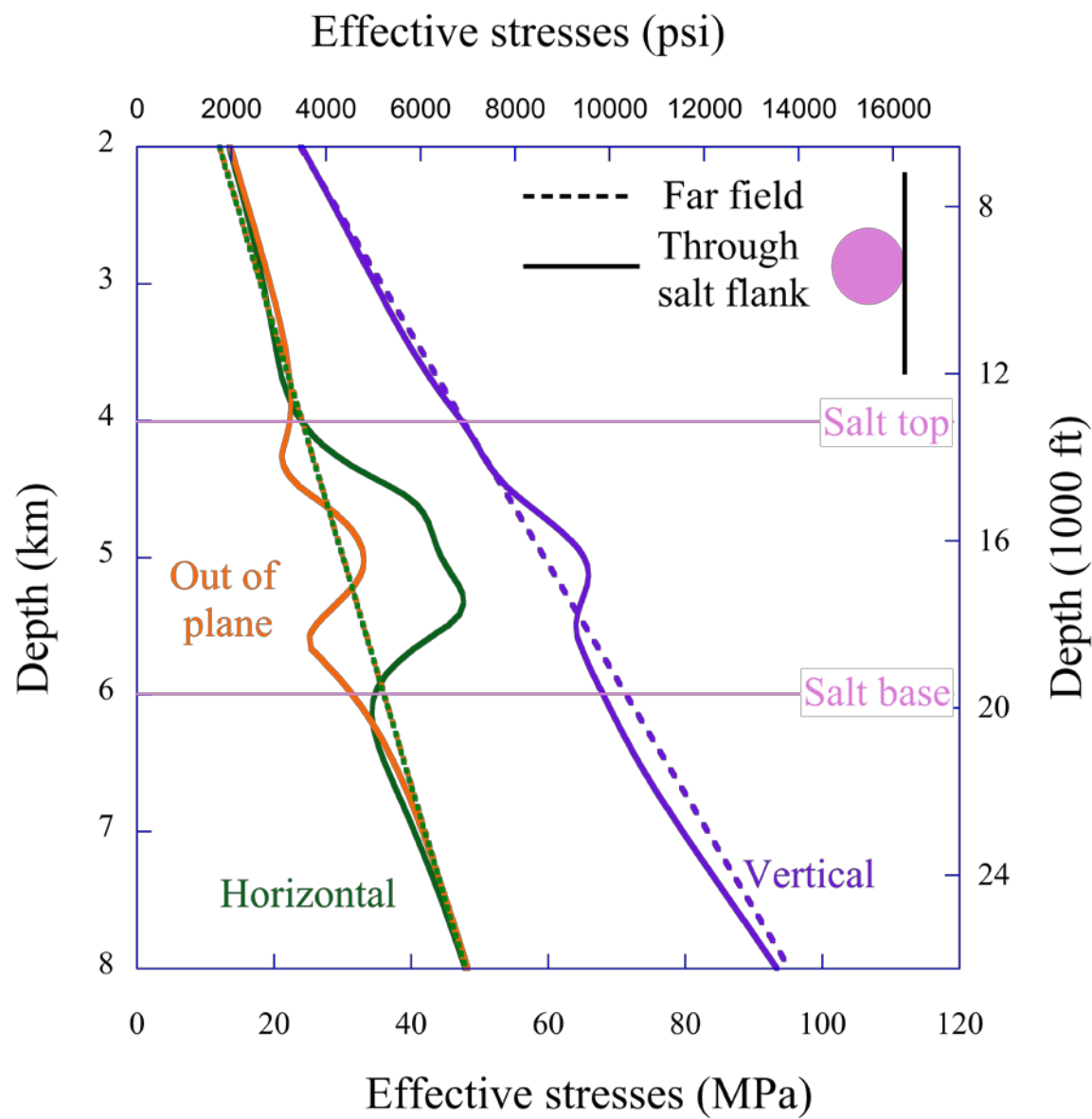
Salt deforming to achieve isostatic state

Change in mean stress relative to initial stress at flank
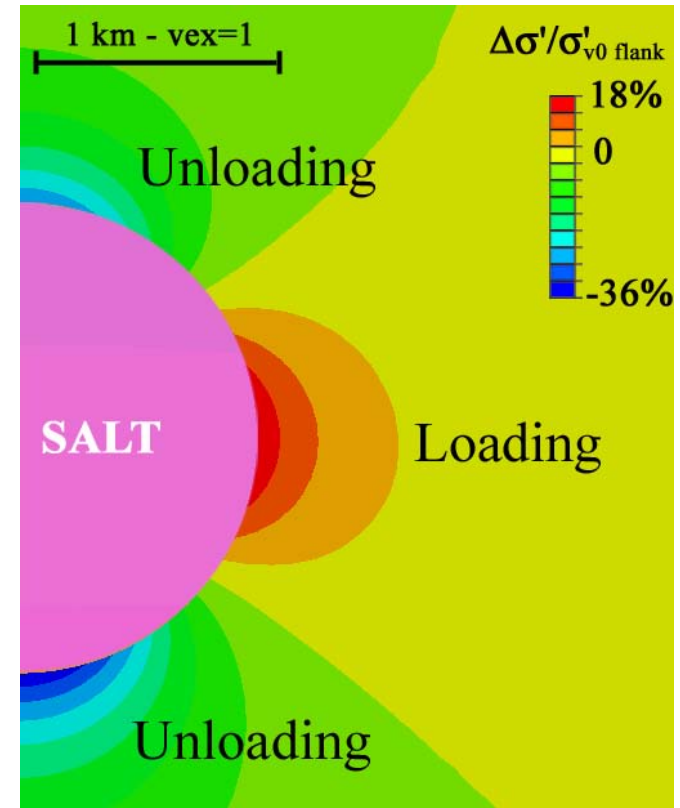
Spherical salt flattens and bulges at circumference

Significant changes in mean effective stress
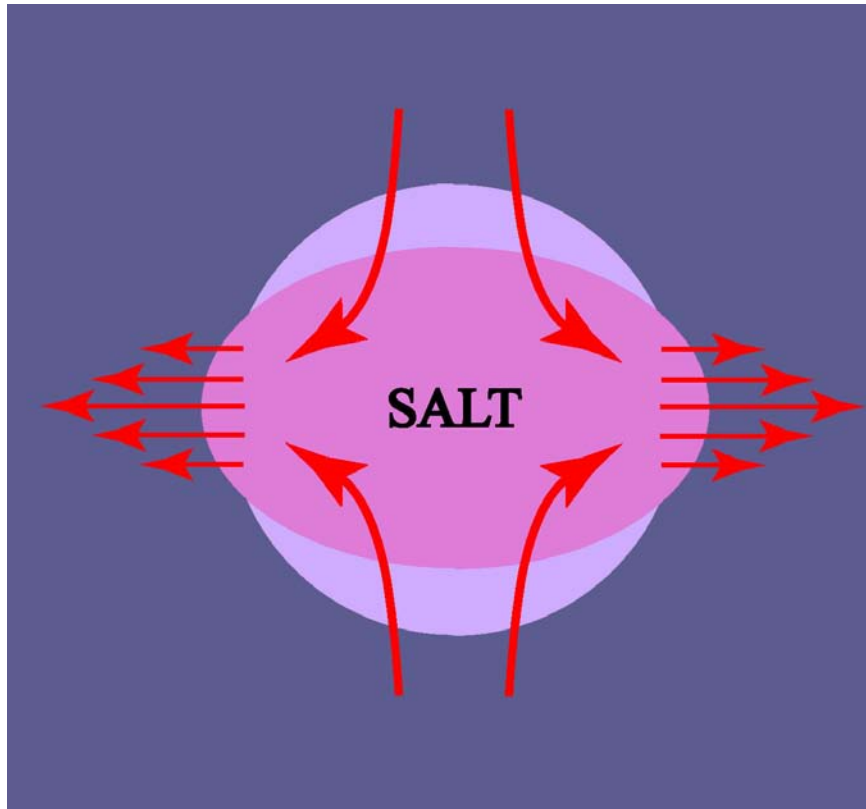
Stress changes around salt
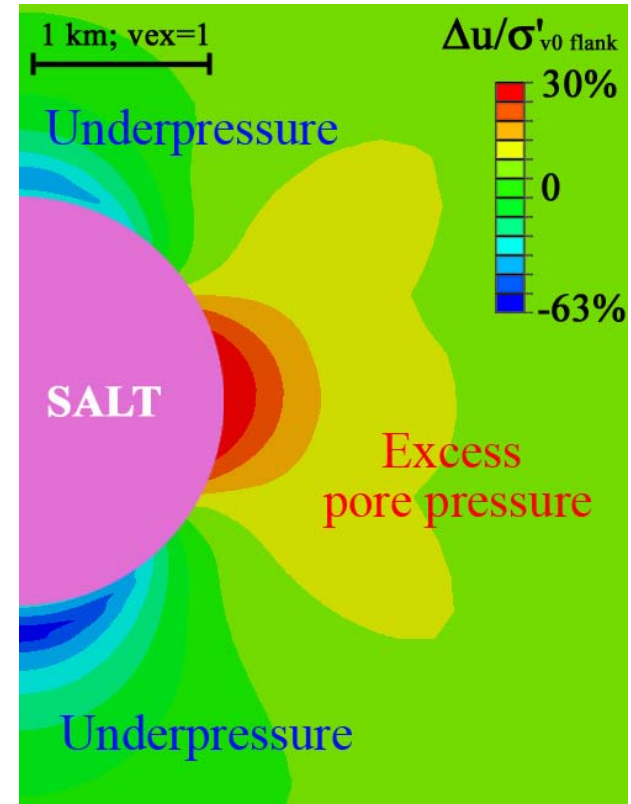

No empirical stress ratio can apply

Overpressures develop

(Undrained analyses)

Development of excess pore pressures

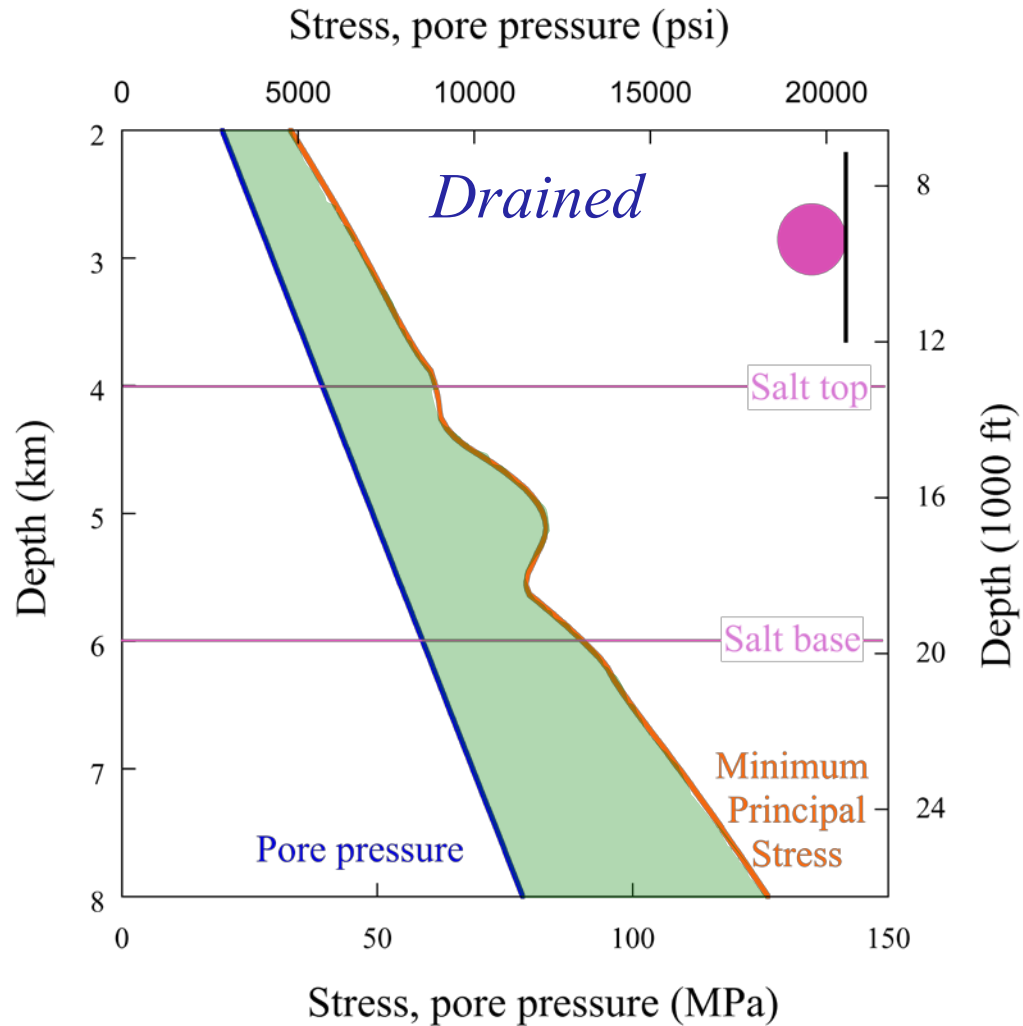*Salt deforming to achieve isostatic state*

Change in pore pressure relative to initial stress at flank

Pore pressure changes due to salt deformation:

Excess pressures at flank; Under-pressures above & below salt
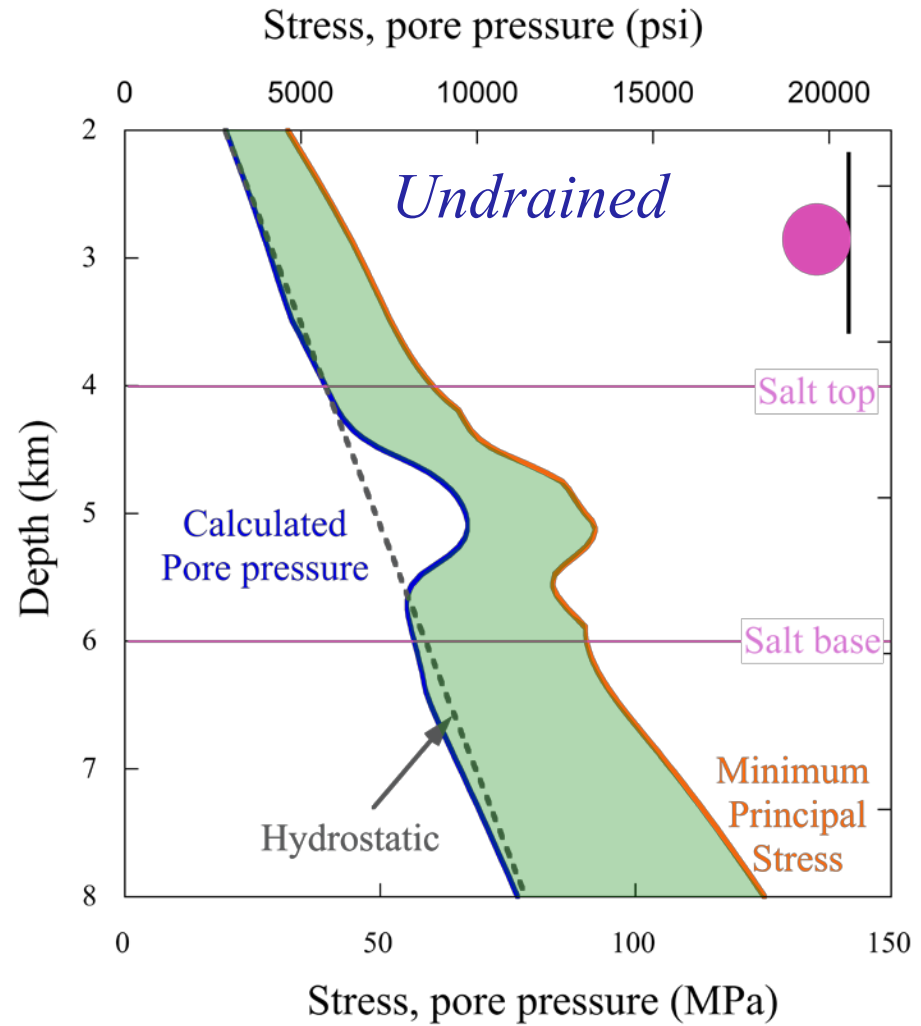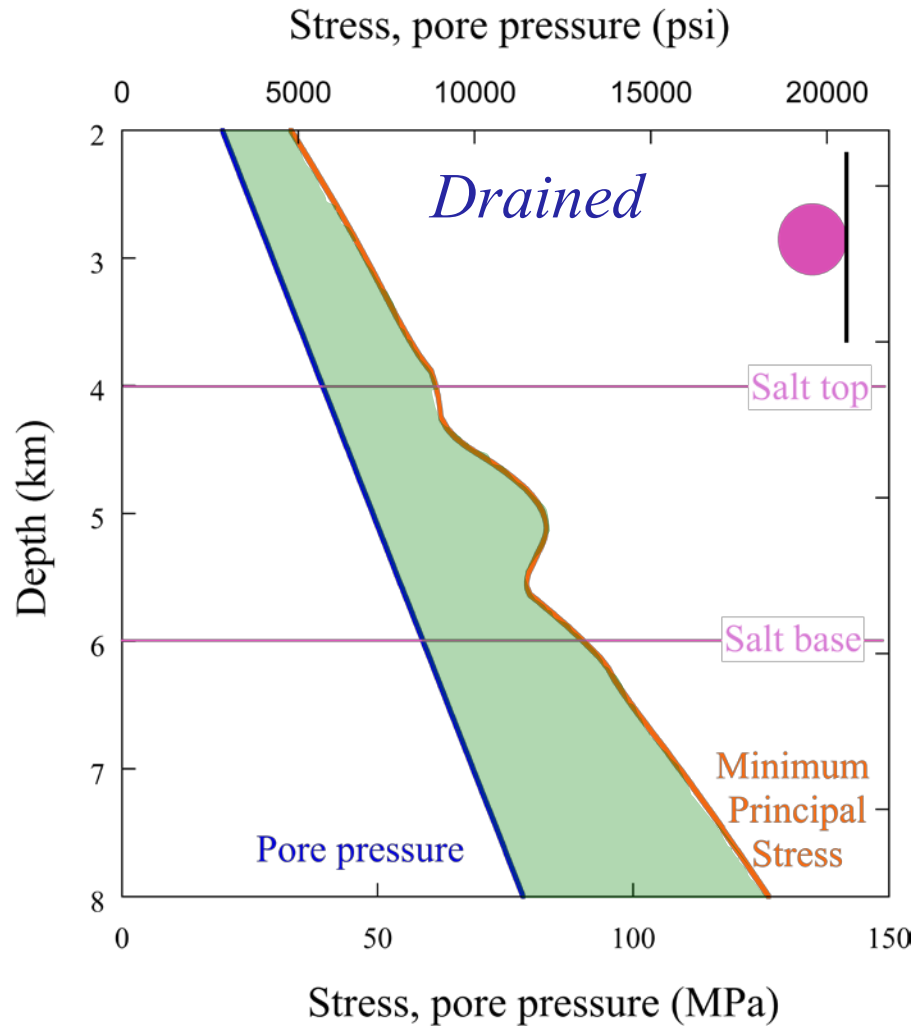
Pore pressure perturbations extend km into the sediments

Drilling implications: salt flank

Drained:

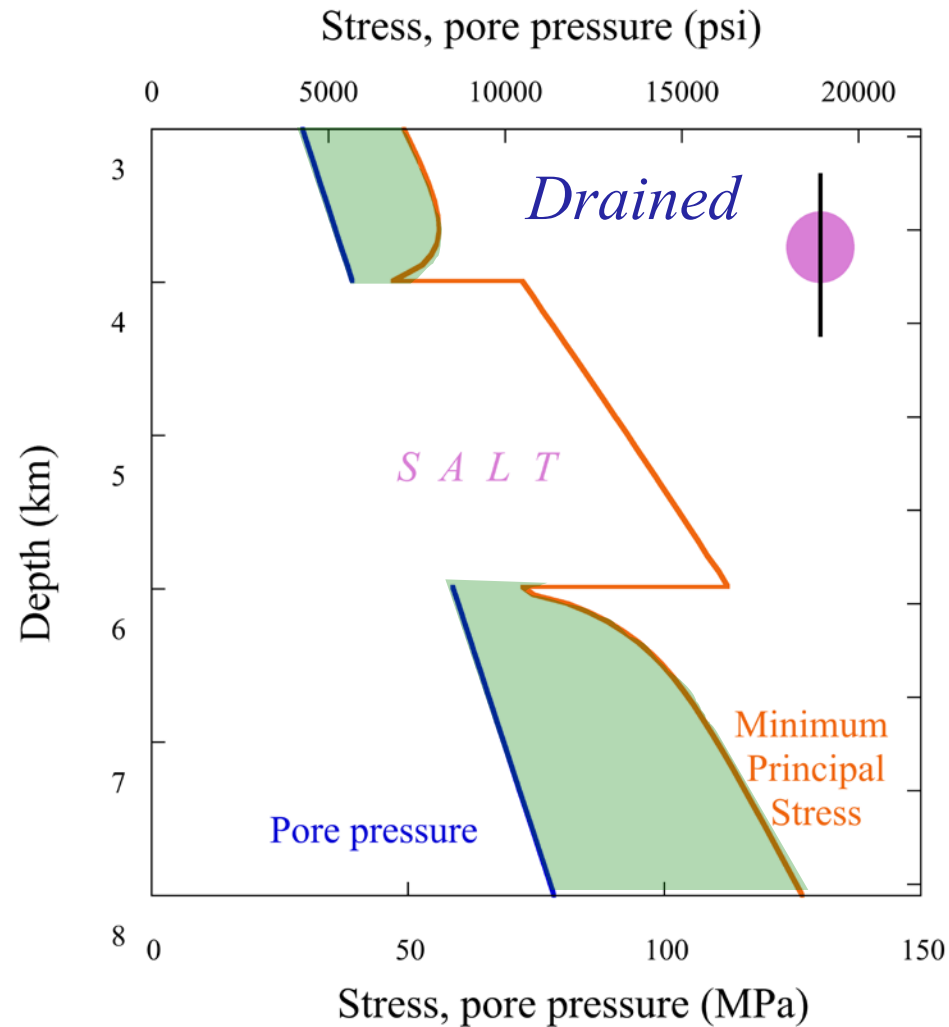Wider window between pore pressure and minimum principal stress

Drilling implications: salt flank

Drained (left plot)
Undrained (right plot)

Axes: Stress, pore pressure (psi) — top; Depth (km) — left; Stress, pore pressure (MPa) — bottom.

Labels: Salt top, Salt base, Minimum Principal Stress, Pore pressure, Calculated Pore pressure, Hydrostatic.

Undrained:
- Window narrows above and below salt flank
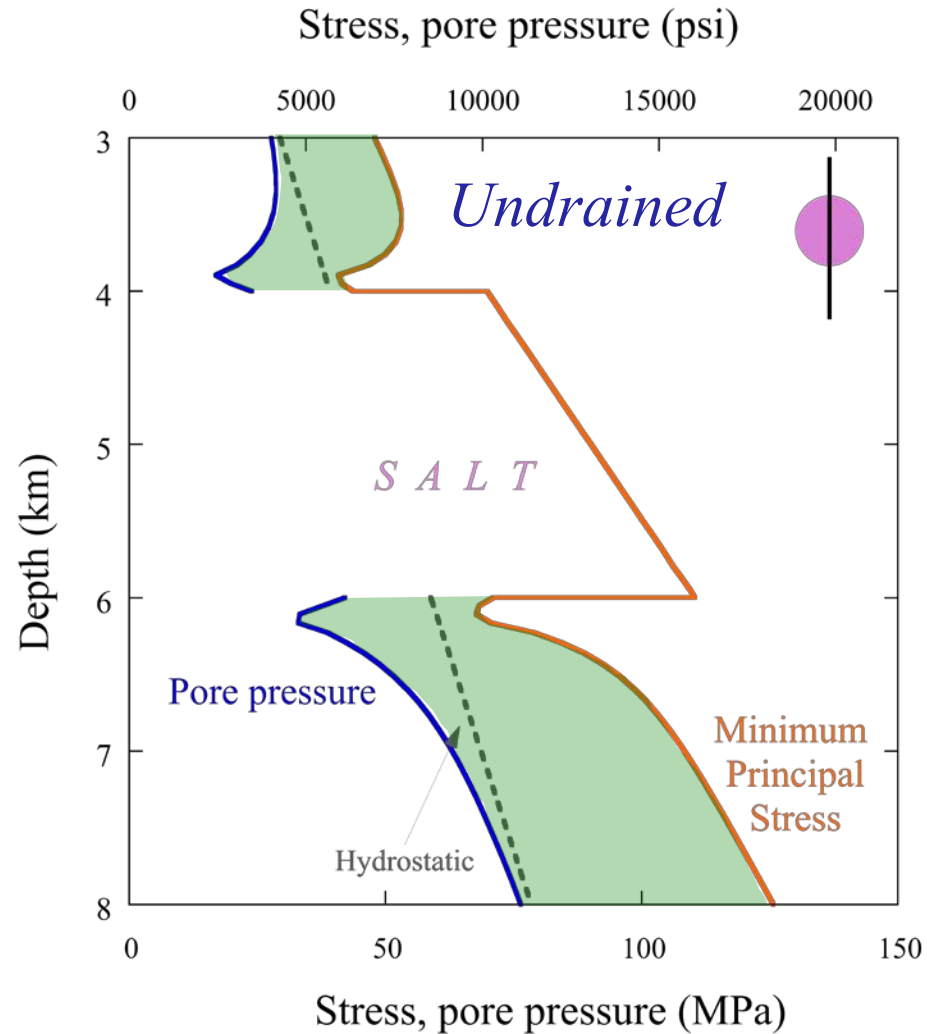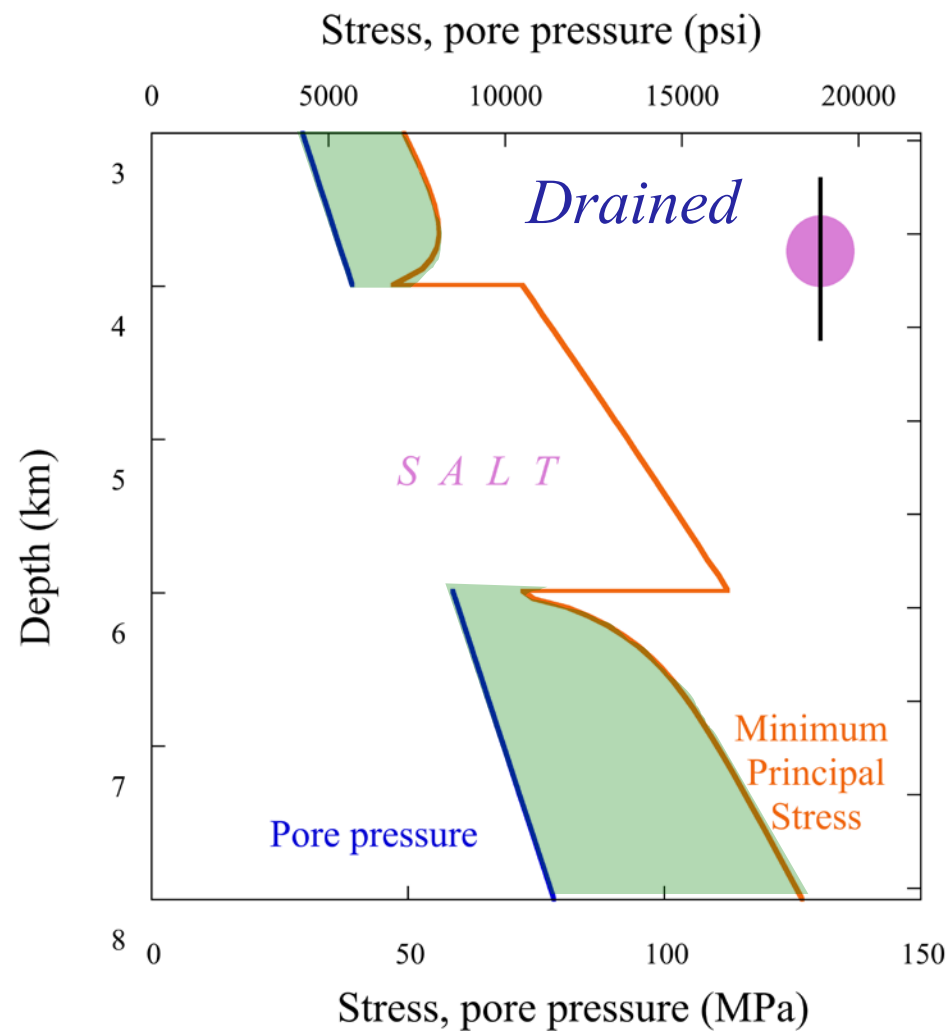- Window shifts at higher pressure levels (*Blow-out risk*)

Drilling implications: through center of salt

Drained:

Small window between pore pressure and minimum principal stress

Drilling implications: through center of salt

Undrained:

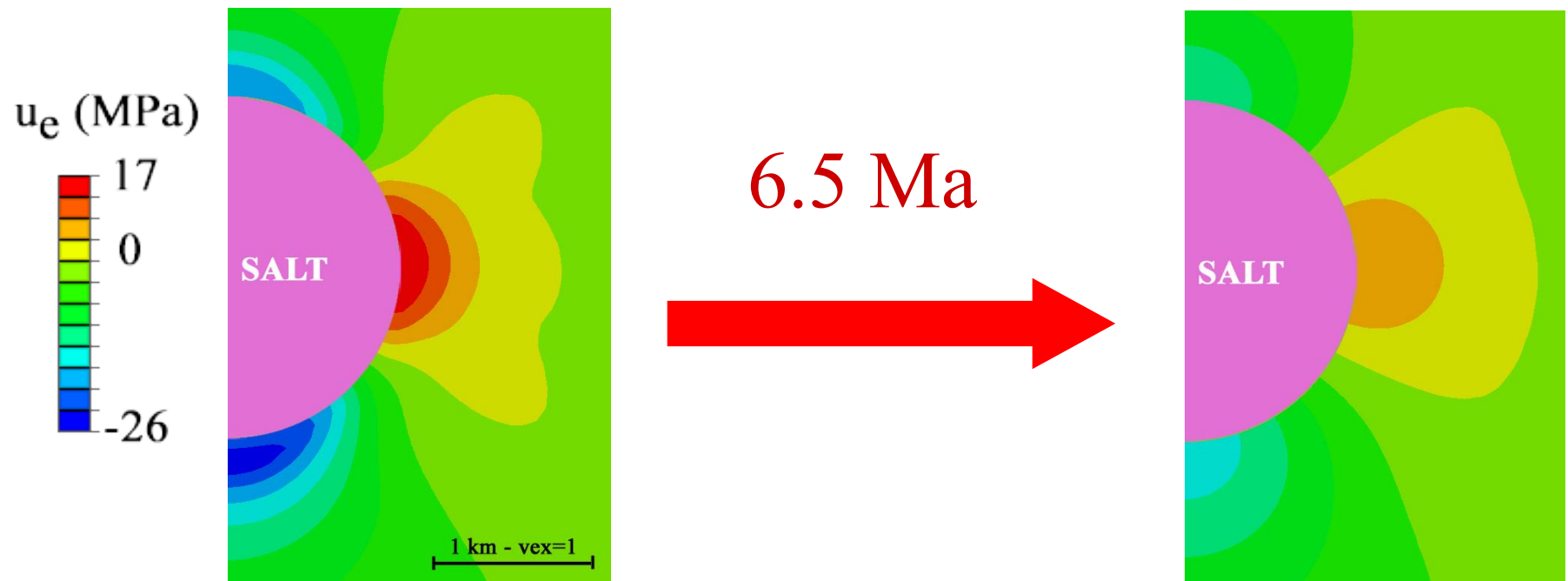Sudden pressure drop (*Lost circulation*)

Time required to dissipate from Undrained to Drained?

Drained and Undrained: two limits of behavior

Transient behavior from theory of consolidation

Characteristic material property: *coefficient of dissipation*

For basin sediments: $c_v = 10^{-8} \, \text{m}^2/\text{sec}$

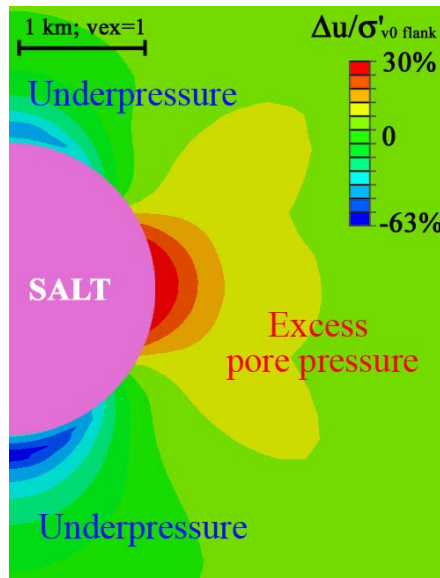Characteristic salt relaxation time: 10-100 years

Key points
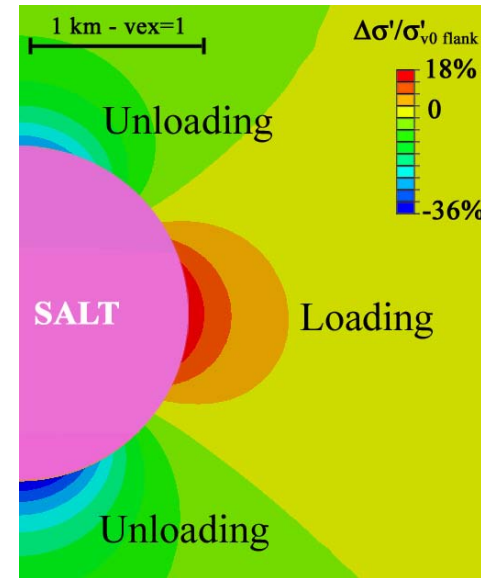
Key Points

Salt deformation

UNDRAINED ⟵ / ⟶ DRAINED

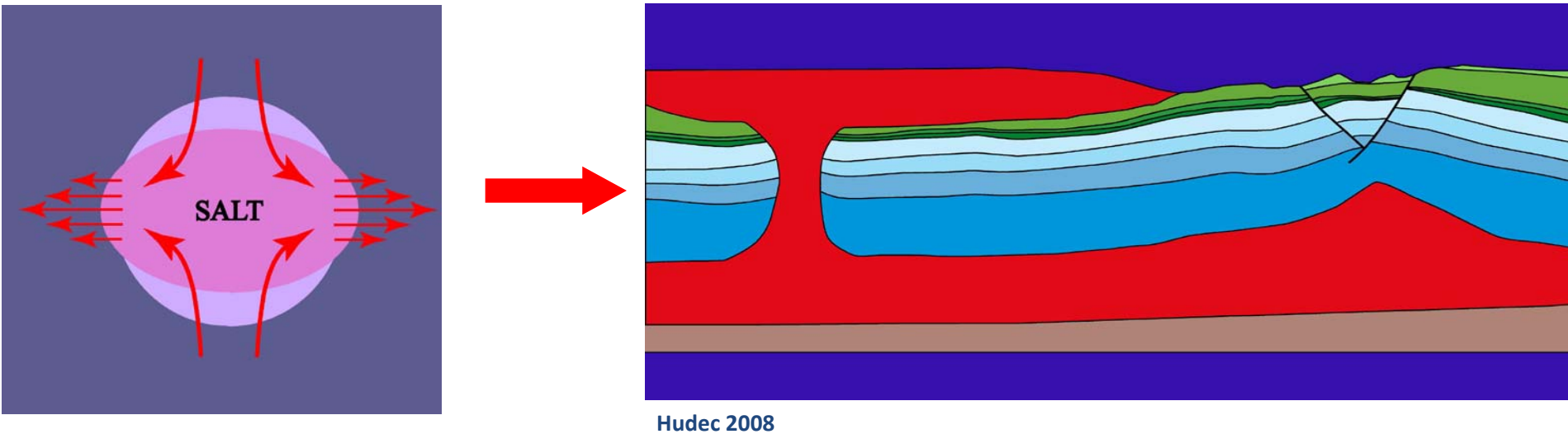Large pore pressure and stress changes

Million Years ⟶

Large stress changes

Extend km into the sediments

Overpressures result in:
- Shift of the safe mud window to higher pressures at the salt flank
- Sudden pressure drops at top and base of salt

Key Points

Hudec 2008

Simple geometry, loading due to salt relaxation:

    Component of pore pressure due to deformation

    Better insight into sediment behavior

Eventually, combine with pressures and stress states from basin
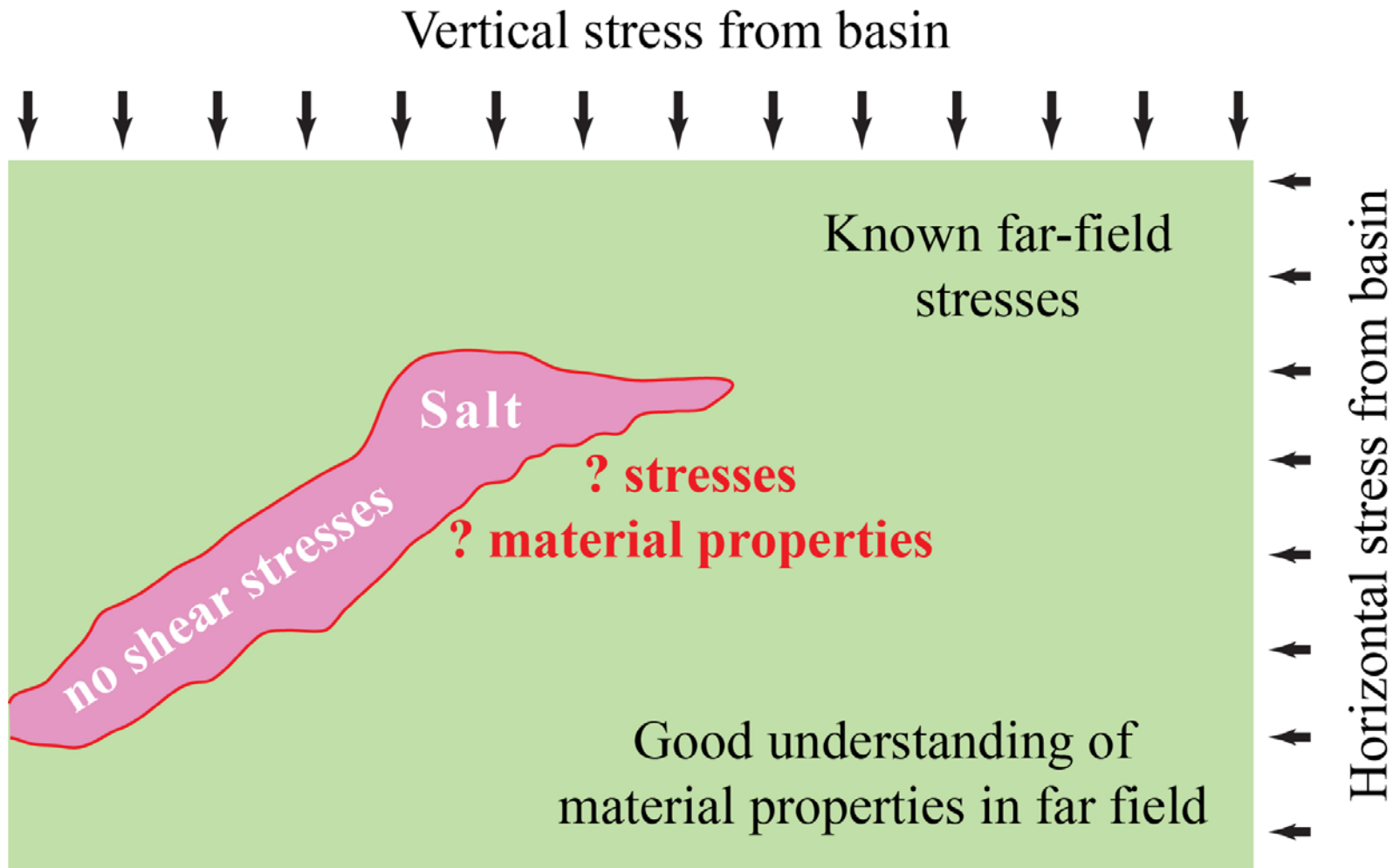   modeling and modeling of salt emplacement

Thank you!

Most common criticism:
A static model where system is relaxed does not represent the Earth

Vertical stress from basin

Known far-field stresses

Salt

? stresses
? material properties

no shear stresses

Good understanding of material properties in far field
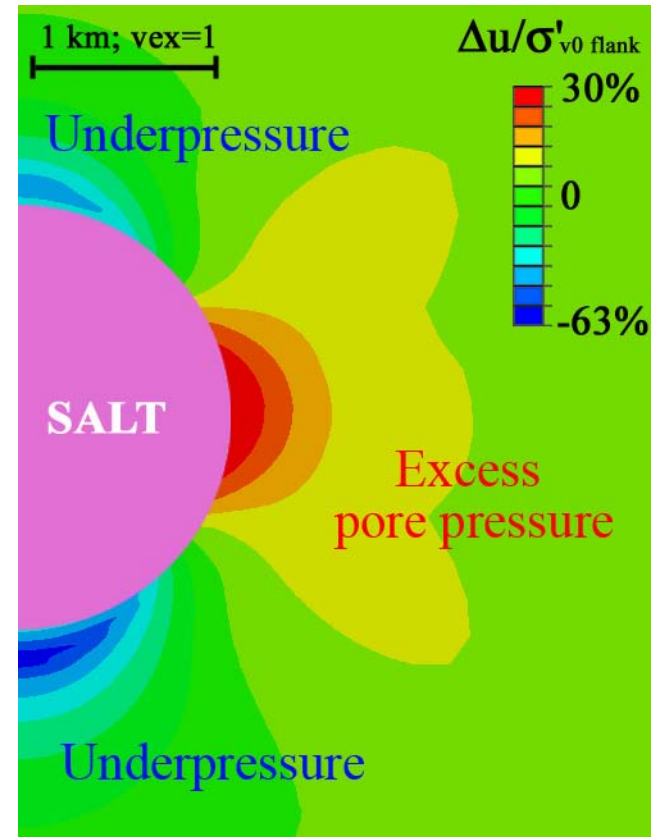
Horizontal stress from basin

From a mechanical point of view, stress/pressure changes due to deformation is one component of overall behavior

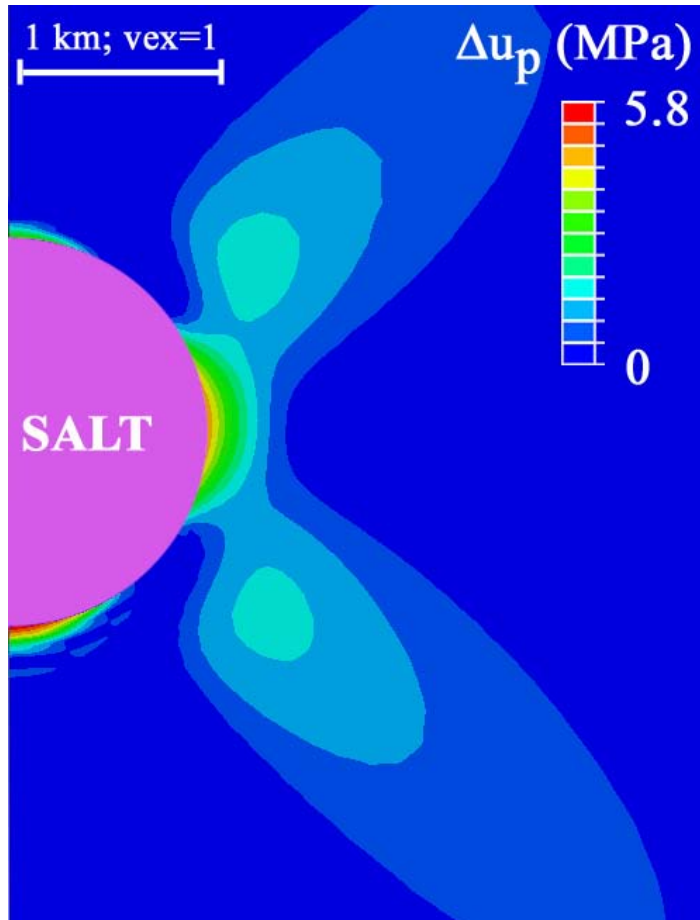# Development of excess pore pressures
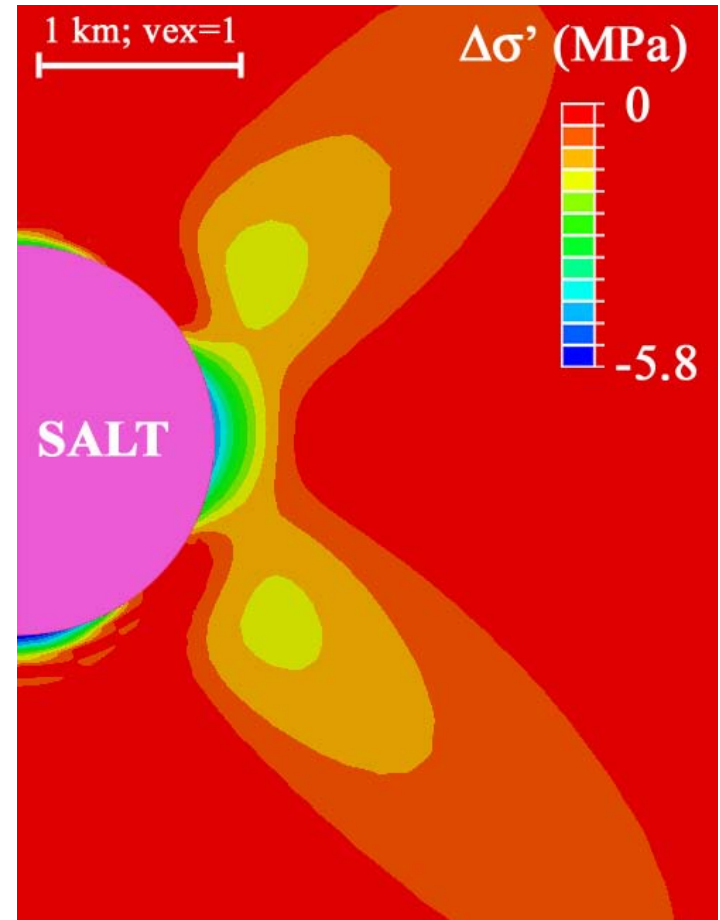
ELASTIC
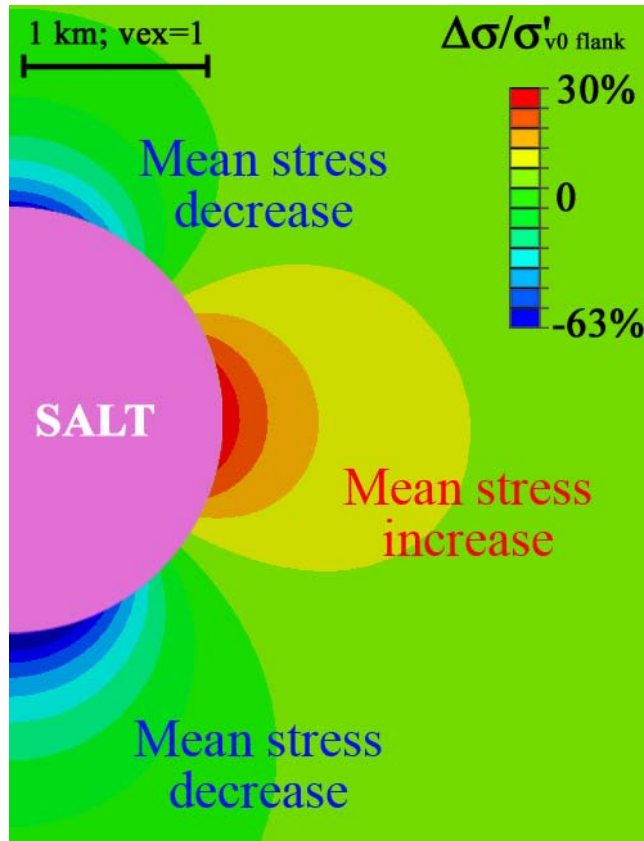
ELASTOPLASTIC

Development of excess pore pressures

Pore pressure – mean total stress

Change in mean effective stress

Elastic vs. elastoplastic stiffness