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Geomechanical Modeling of Stresses Adjacent to Salt Bodies: Uncoupled Models*

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Search and Discovery Article #40777 (2011)

Posted July 26, 2011

*Adapted from oral presentation at AAPG Annual Convention and Exhibition, Houston, Texas, USA, April 10-13, 2011

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Abstract

We have explored and compared four approaches to geomechanical modeling of stresses adjacent to salt bodies. These approaches are distinguished by their use of elastic or elastoplastic rheology for the sediments surrounding the salt, and by the way that they treat fluid pressures in the modeling. In all cases the fluid pressures are assumed (hydrostatic), rather than calculated during the modeling; thus fluid pressures and stresses are uncoupled. The four approaches are: (1) simulate total stresses in an elastic medium, and then subtract an assumed pore pressure after the calculations are complete, (2) simulate effective stresses in an elastic medium by using the assumed pore pressure during calculations, (3) simulate total stresses in an elastoplastic medium, either ignoring pore pressure or approximating its effects by decreasing the internal friction angle, and (4) simulate effective stresses in an elastoplastic medium by using the assumed pore pressure during calculations. We evaluate these approaches by comparing stresses generated by stress relaxation of a salt sphere. In all cases, relaxation causes the salt sphere to shorten vertically and expand laterally, producing extensional strains above and below the sphere, and shortening against the sphere flanks; mean stress is dropped above and below the salt sphere, and minimum principal stress is lowered everywhere around the salt sphere. Elastic models of sediments may induce unrealistically large shear stress and unrealistically low minimum principal stress at salt boundaries. In contrast, elastoplastic models of sediments, placing an upper limit on shear stresses due to plastic yield of sediments, can predict smaller stress perturbations and better simulate stresses around salt than elastic models. Our model of an irregular salt sheet shows that mean stress within the salt converges to the far-field vertical stress and that minimum principal stress is lowest where the salt is thick. These results and comparisons provide insights into stresses around salt bodies, and give interpreters a basis to evaluate and compare stress predictions.

References

Fredrich, J.T., D. Coblenz, A.F. Fossum, and B.J. Thorne, 2003, Stress Perturbations Adjacent to Salt Bodies in the Deepwater Gulf of Mexico: Society of Petroleum Engineers (SPE), SPE paper #84554, 14 p., Web accessed 14 July 2011, <http://www.onepetro.org/mslib/servlet/onepetropreview?id=00084554&soc=SPE>

Nikolinakou, M.A., Luo, G., M. Hudec, and P.B. Flemings, 2011, Geomechanical Modeling of Stresses Adjacent to Salt Bodies: Poro-Elasto-Plasticity and Coupled Overpressures: Search and Discovery Article #90124, Web accessed 14 July 2011, <http://www.searchanddiscovery.com/abstracts/html/2011/annual/abstracts/Nikolinakou.html?q=%2BtextStrip%3Anikolinakou>

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Acknowledgements

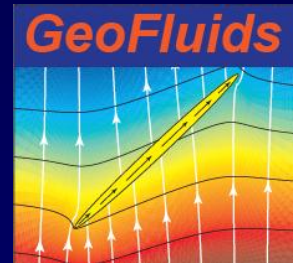
➤ **Applied Geodynamics Laboratory (AGL) consortium**

Anadarko, BHP Billiton, BP, CGGVeritas, Chevron, Cobalt, ConocoPhillips, Ecopetrol, ENI, ExxonMobil, Fugro, Global Geophysical, Hess, IMP, INEXS, ION Geophysical, Maersk, Marathon, Mariner, McMoRan, Murphy, Nexen, Noble, Pemex, Petrobras, PGS, Repsol-YPF, Samson, Saudi Aramco, Shell, Statoil, TGS-NOPEC, Total, WesternGeco, and Woodside.



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➤ **Jackson School of Geosciences, UT-Austin**



OUTLINE

1. Model approach

- Elastic sediments
- Elastoplastic sediments

2. Results for different salt geometries:

- Sphere
- Irregular sheet

3. Key results

Model description

1) Some models (e.g., Fredrich et al., 2003)

- Assume hydrostatic pore pressure
- No development of pore pressure
- Elastic sediments

2) Some models (e.g., Nikolinakou et al., last talk)

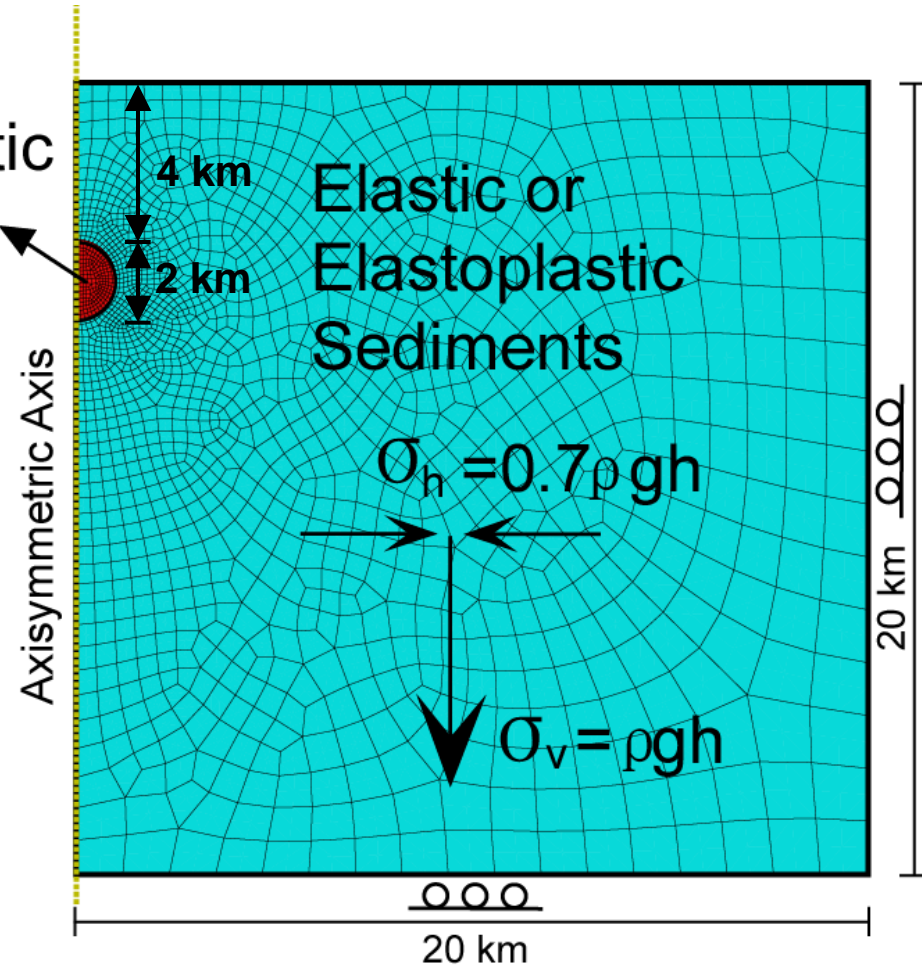
- Calculating development of pore pressure
- Elastic or elastoplastic sediments

3) This talk

- Assume hydrostatic pore pressure
- Differences between elastic and elastoplastic sediments
- Different salt geometries

1. Model approach

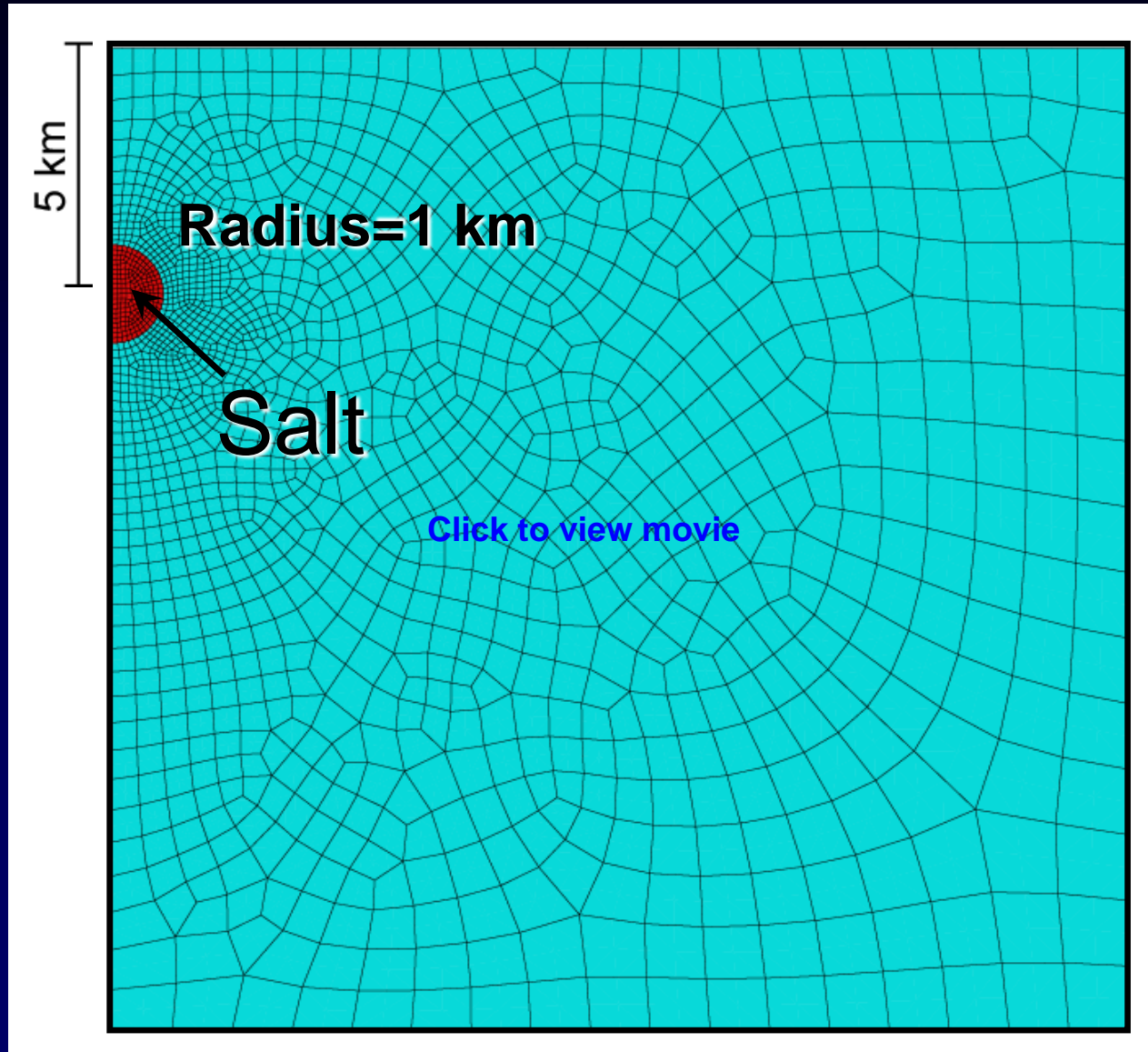
- Axisymmetric model.
- Stress-Strain relations:
 - ✓ Viscoelastic salt;
 - ✓ Elastic or elastoplastic sediments;
- Initial geostatic stress:
 $\sigma_V = \rho gh$; $\sigma_H = 0.7 \times \rho gh$
- Boundary conditions:
 - ✓ Rollers at right and bottom boundaries;
 - ✓ Axisymmetric left boundary.



(Software: Abaqus)

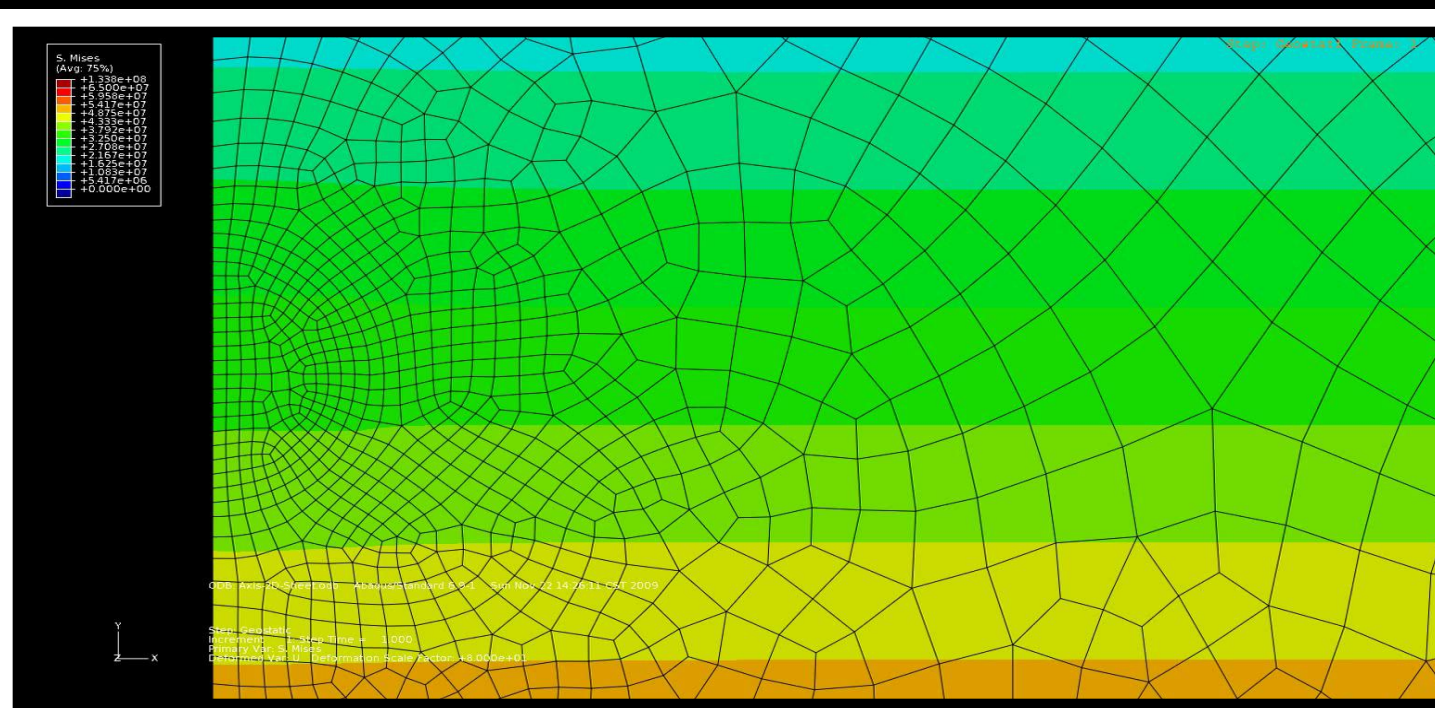
2. Results

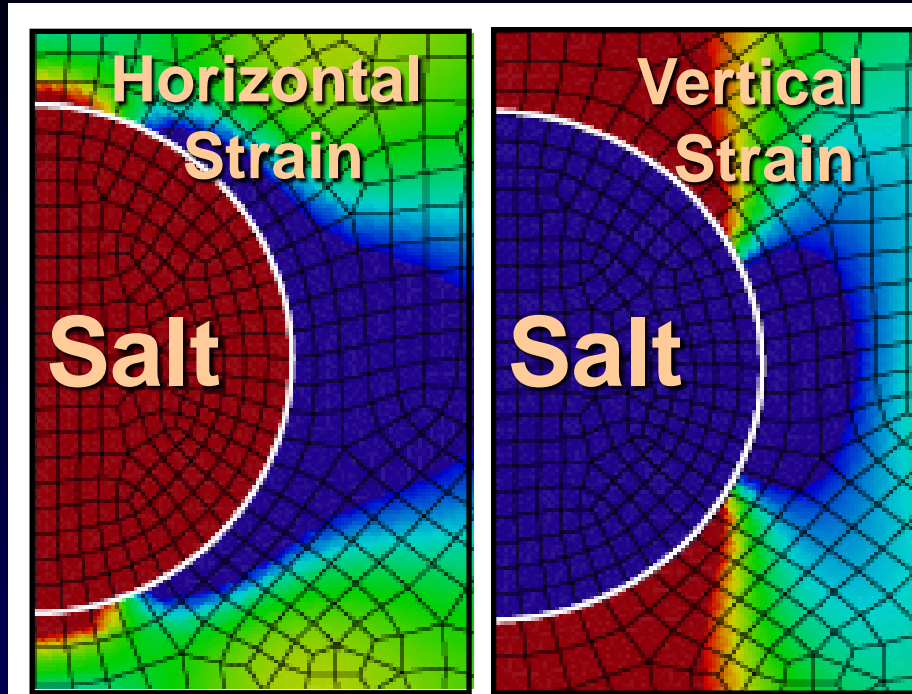
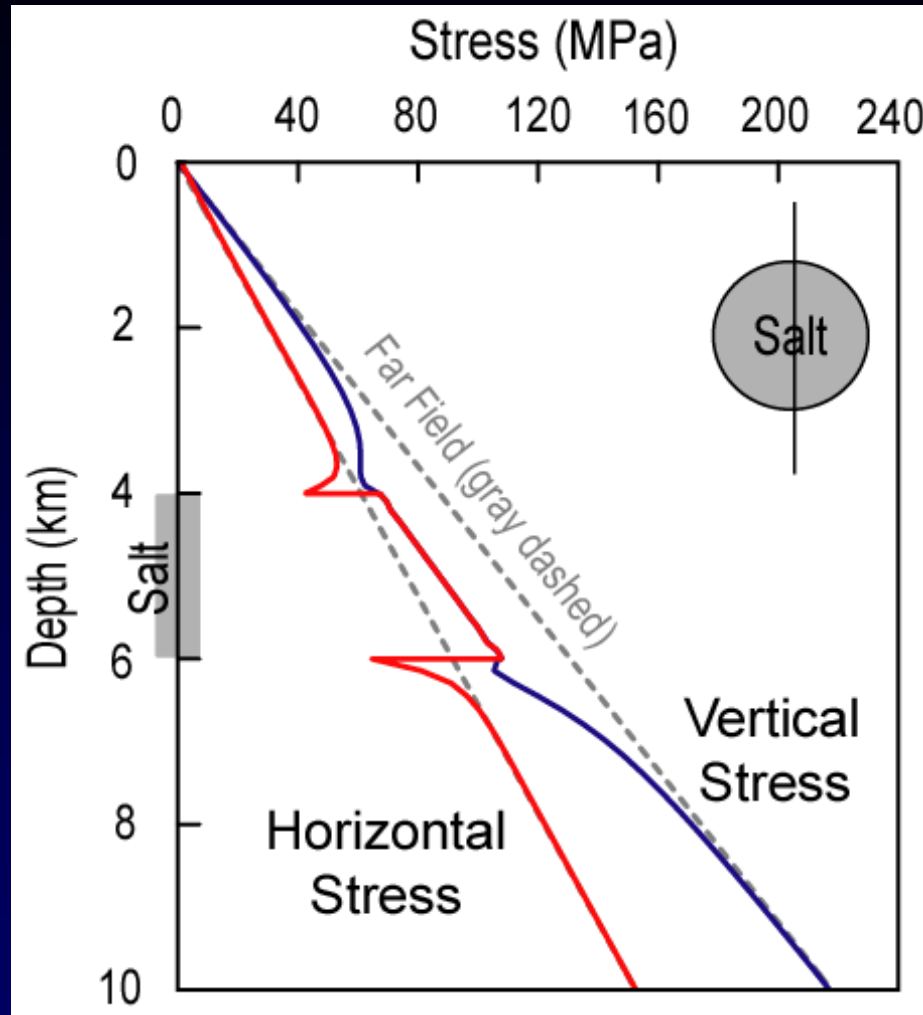
(1) Sphere



Deformation and Evolution of von Mises Stress

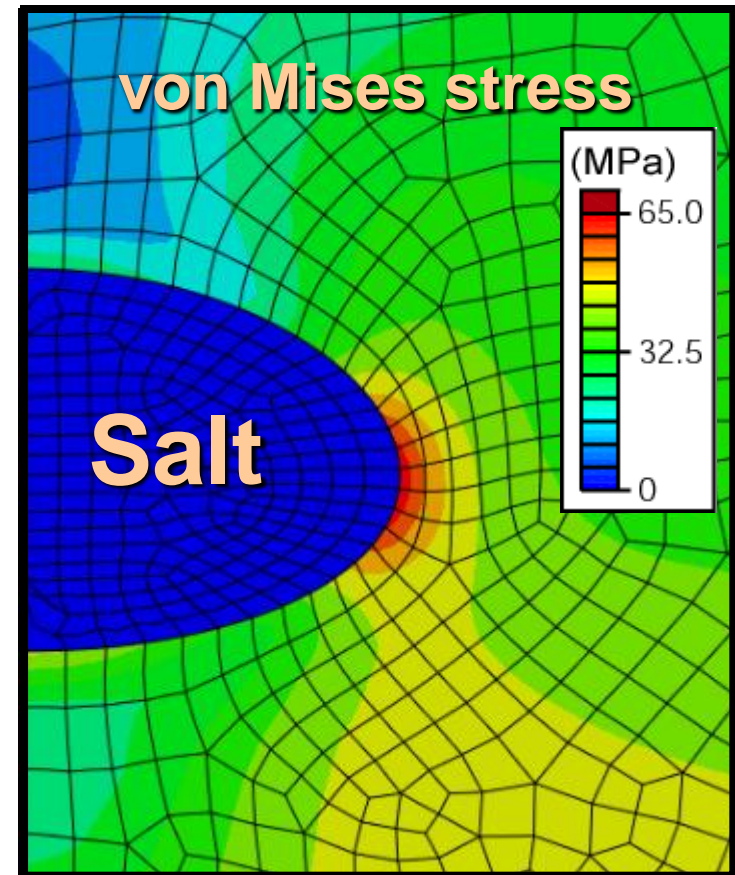
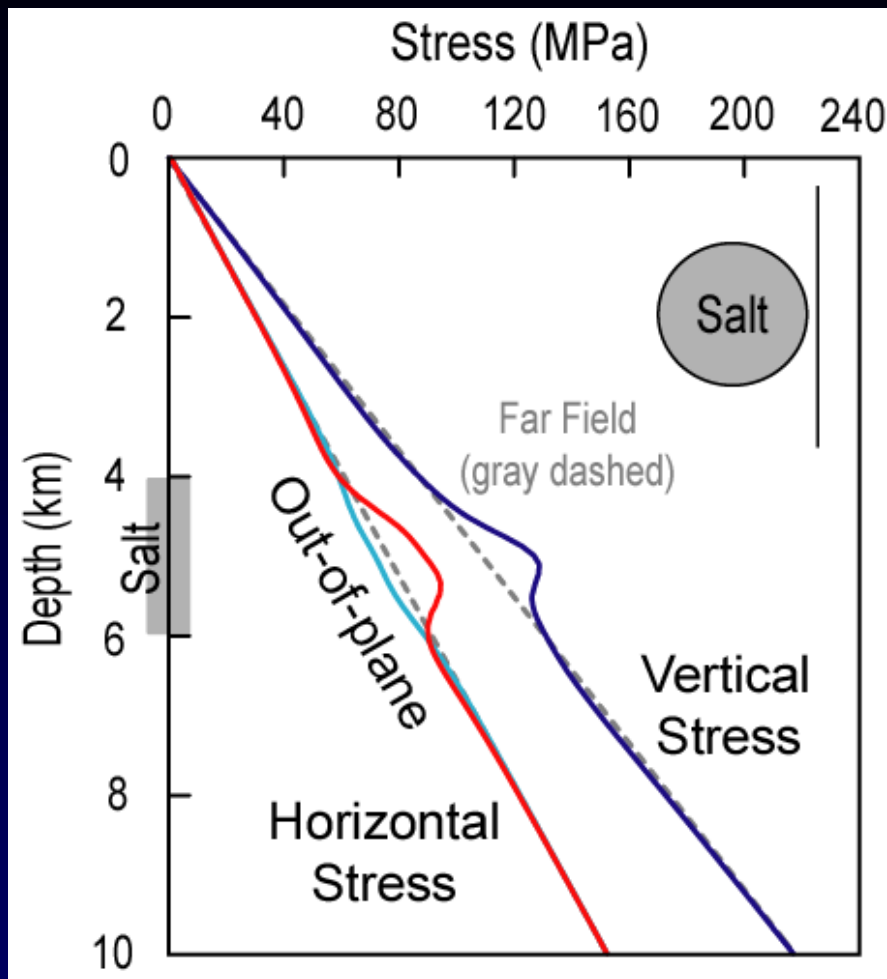
(Deformation is highly exaggerated)





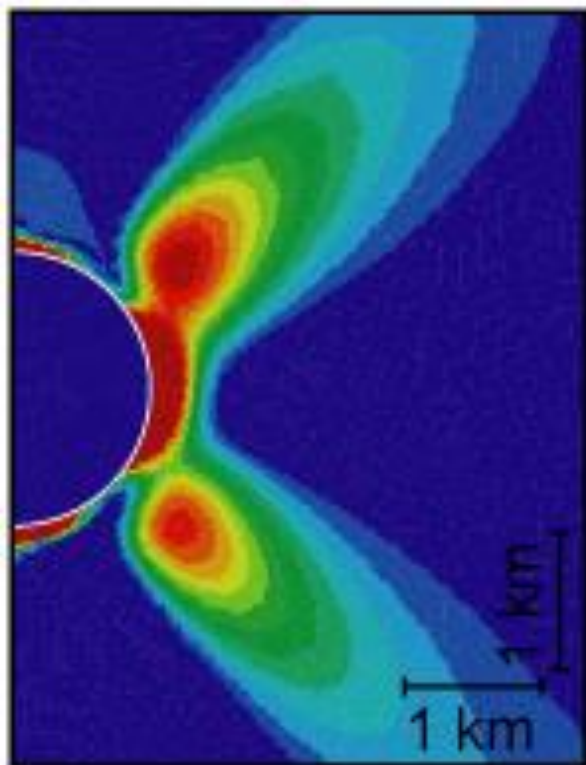
Red: extension
Blue: shortening

- Horizontal and vertical stresses above and below salt decrease.
- Horizontal and vertical stresses within salt converge to an intermediate value. No shear stress within salt.



(Deformation is highly exaggerated)

- Horizontal and vertical stresses increase, but out-of-plane stress decreases.
- Shear stress (von Mises stress) increases.



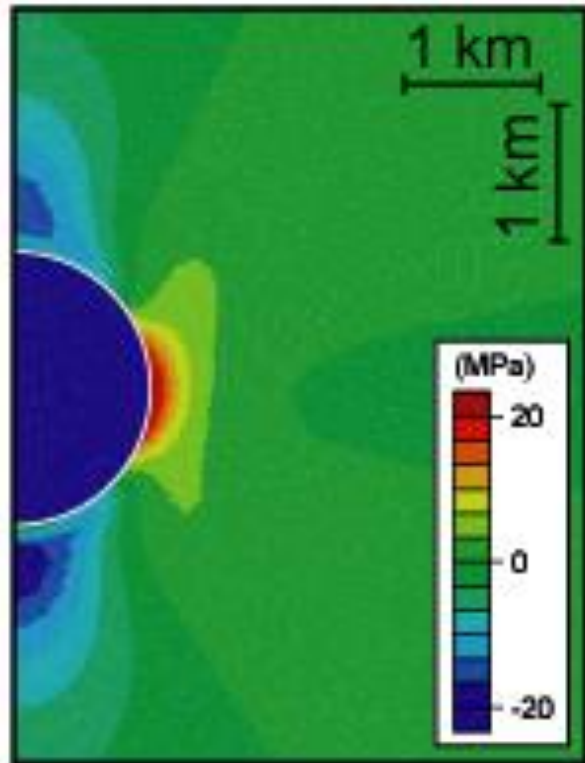
Plastic strain

$$\varepsilon_{Plastic} = \sqrt{\frac{2}{3} [(\varepsilon_1^{pl})^2 + (\varepsilon_2^{pl})^2 + (\varepsilon_3^{pl})^2]}$$

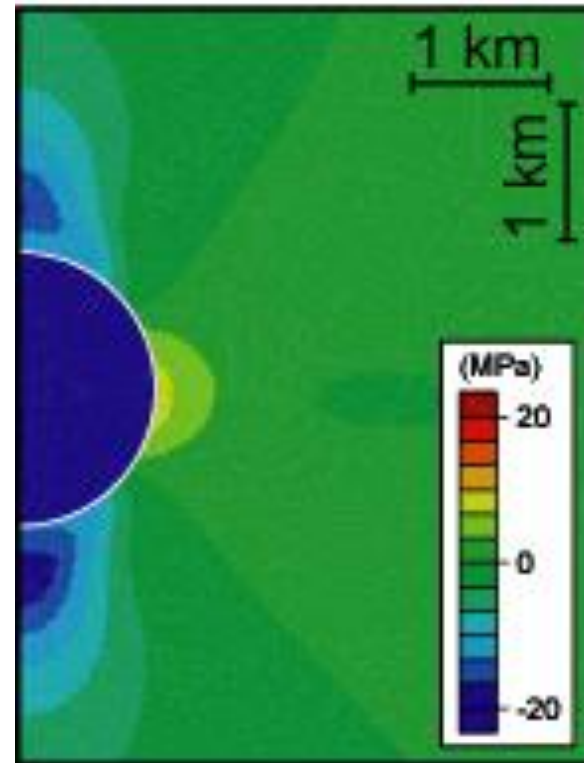
$(\varepsilon_1^{pl}, \varepsilon_2^{pl}, \varepsilon_3^{pl})$: **Principal components of plastic strain**)

- Hydrostatic pore pressure is assumed.
- Drucker-Prager inner-circle plastic criterion.
- Plastic strain occurs around the salt.

Δ Shear stress, Elastic

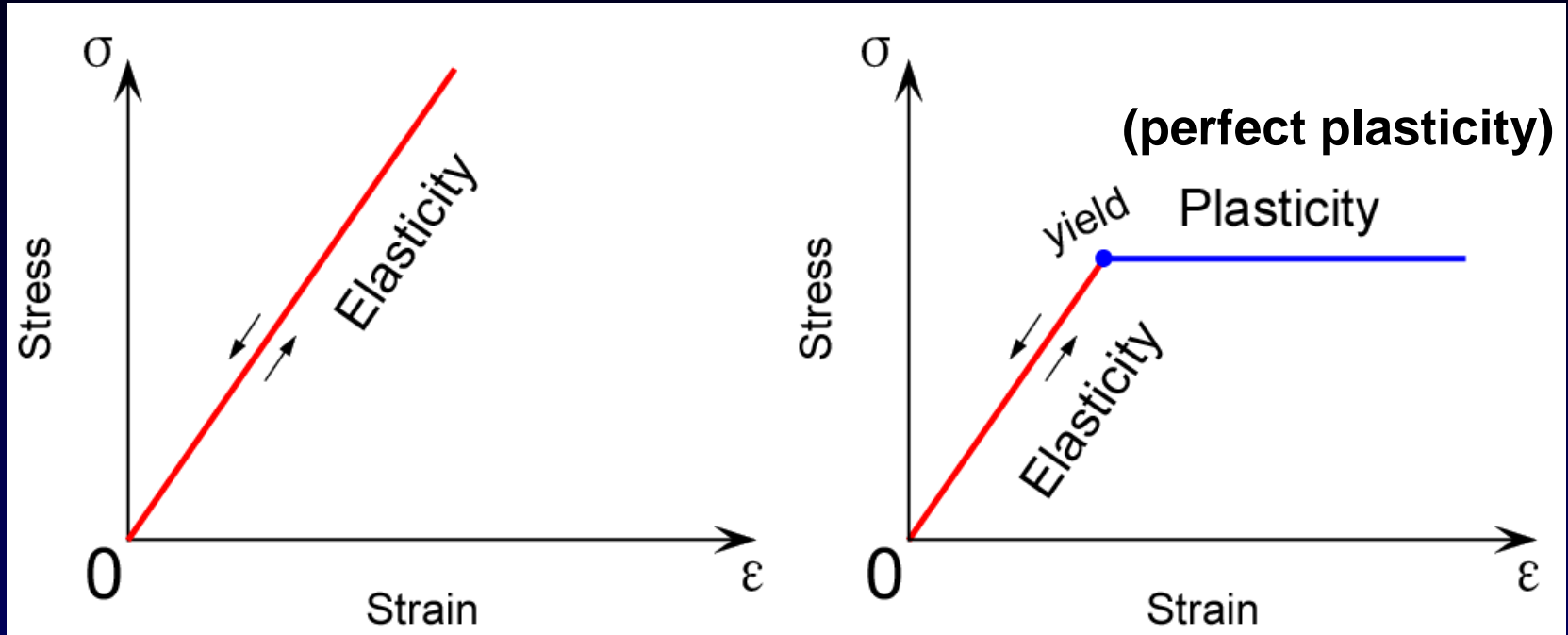


Δ Shear stress, Elastoplastic



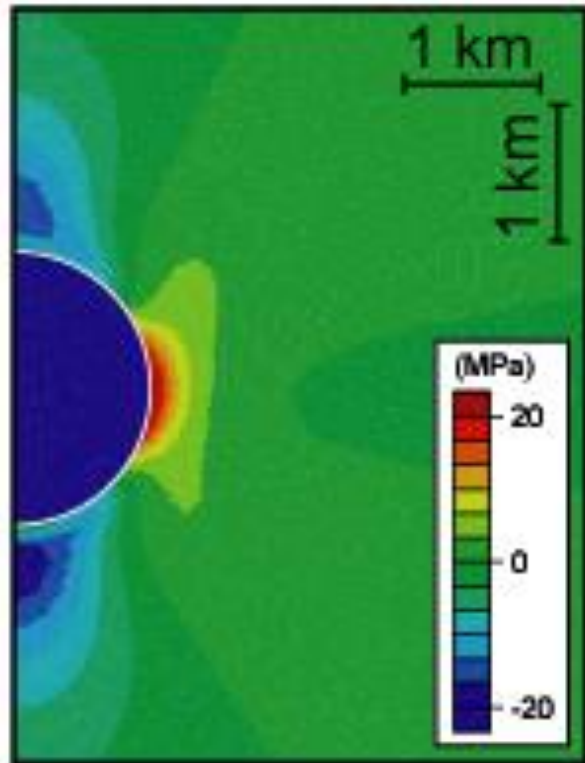
- Concentration of shear stress is reduced, when plasticity is included.

Comparison of elastic and elastoplastic models

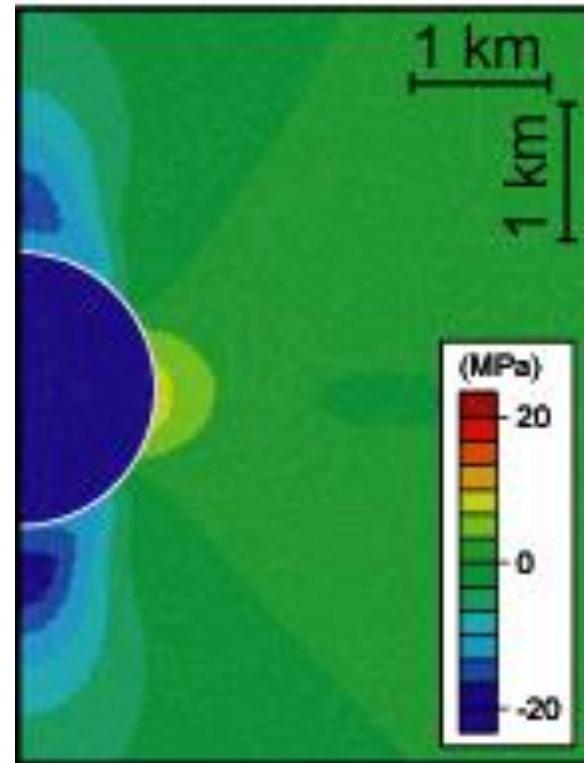


- Elastic models have no yield: shear stress can increase to infinity.
- Plasticity has a yield criterion, puts limit to shear stress, and constrain magnitude of shear stress.

Δ Shear stress, Elastic

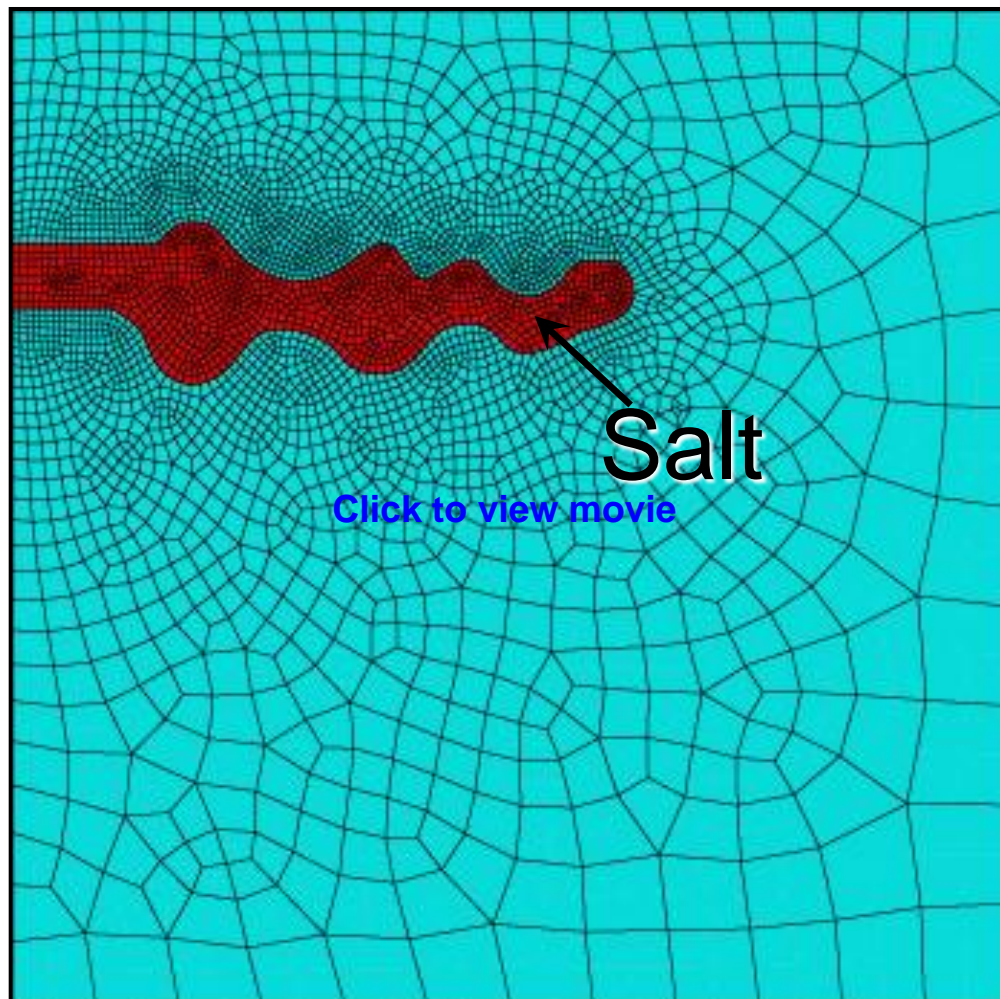


Δ Shear stress, Elastoplastic



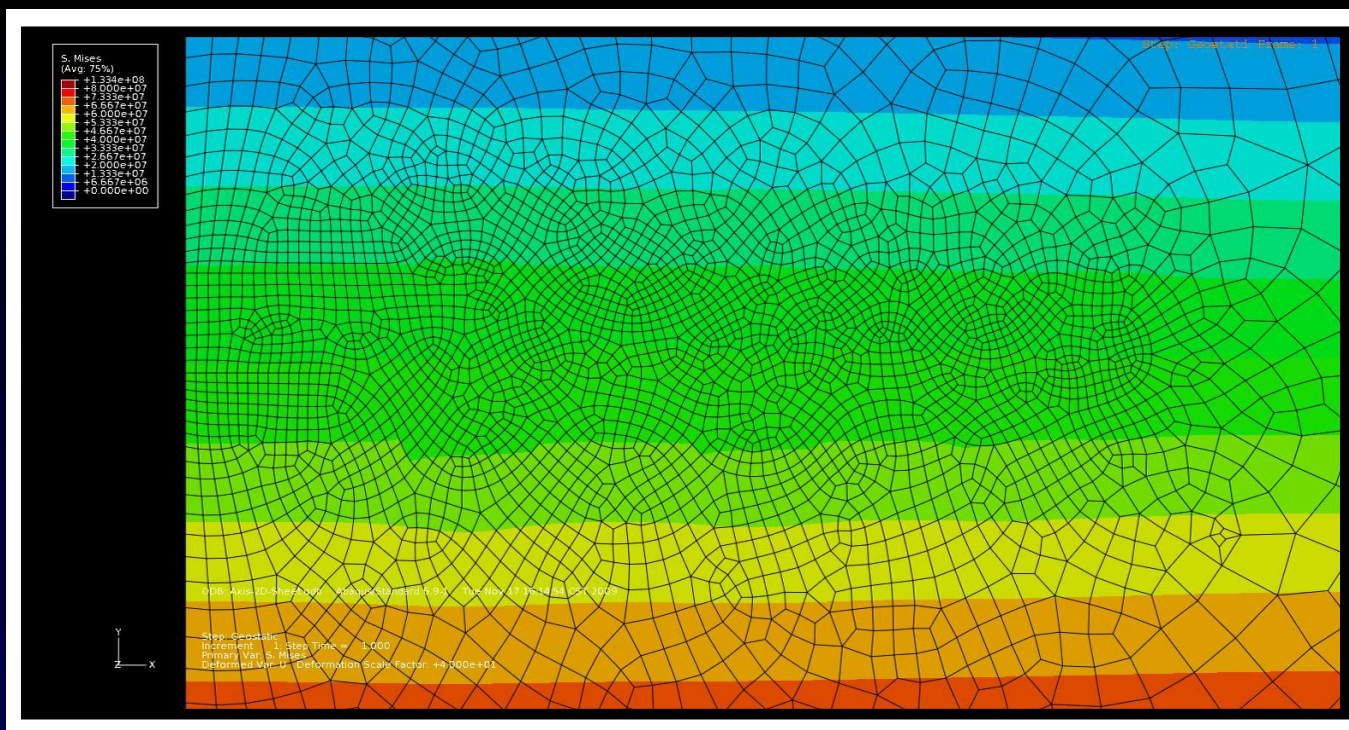
- Concentration of shear stress is reduced, when plasticity is included.

(2) Irregular Sheet

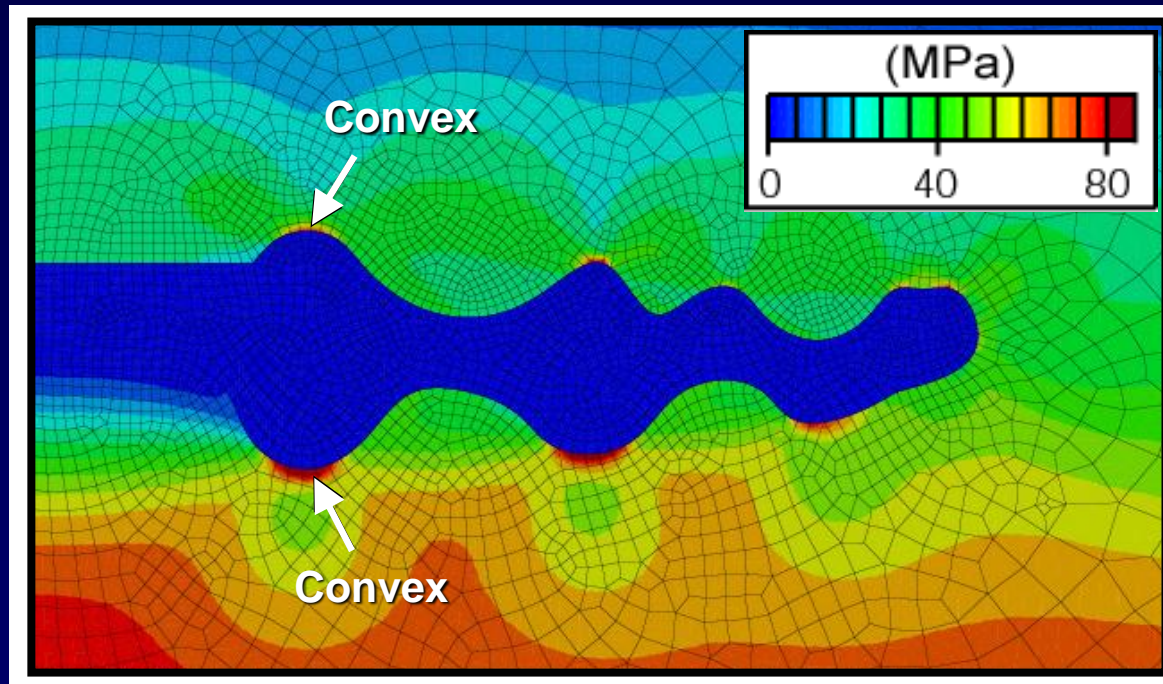


Deformation and Evolution of von Mises Stress

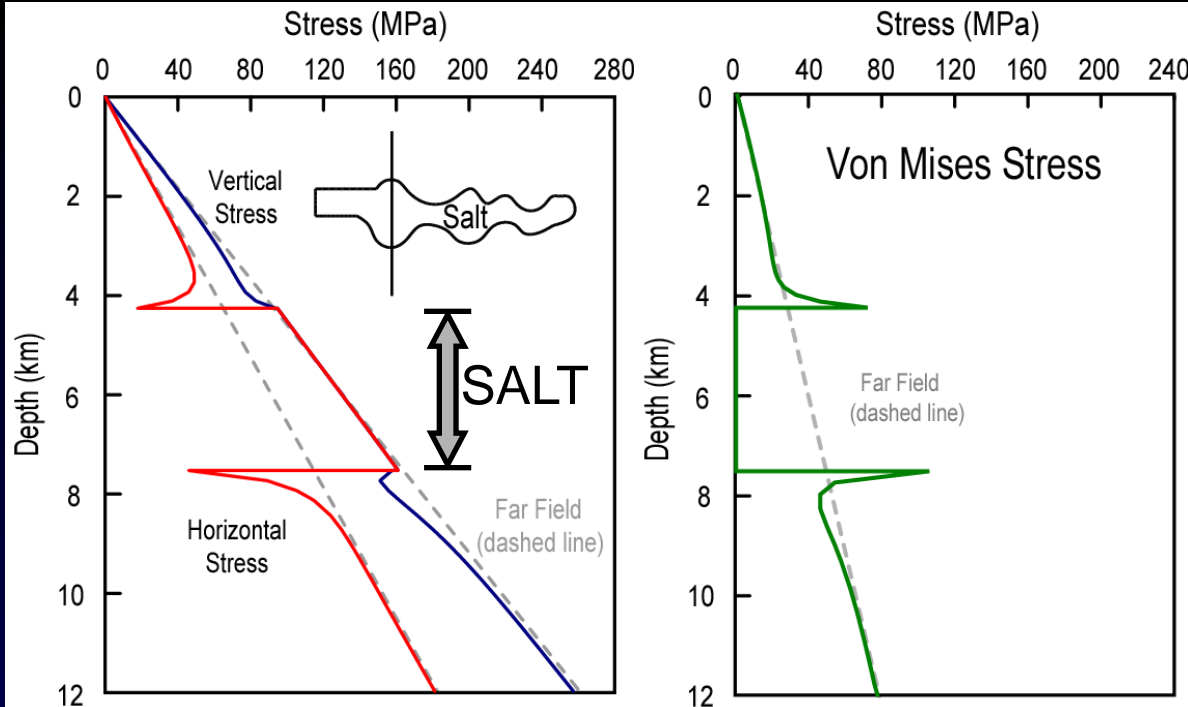
(Deformation is
highly exaggerated)



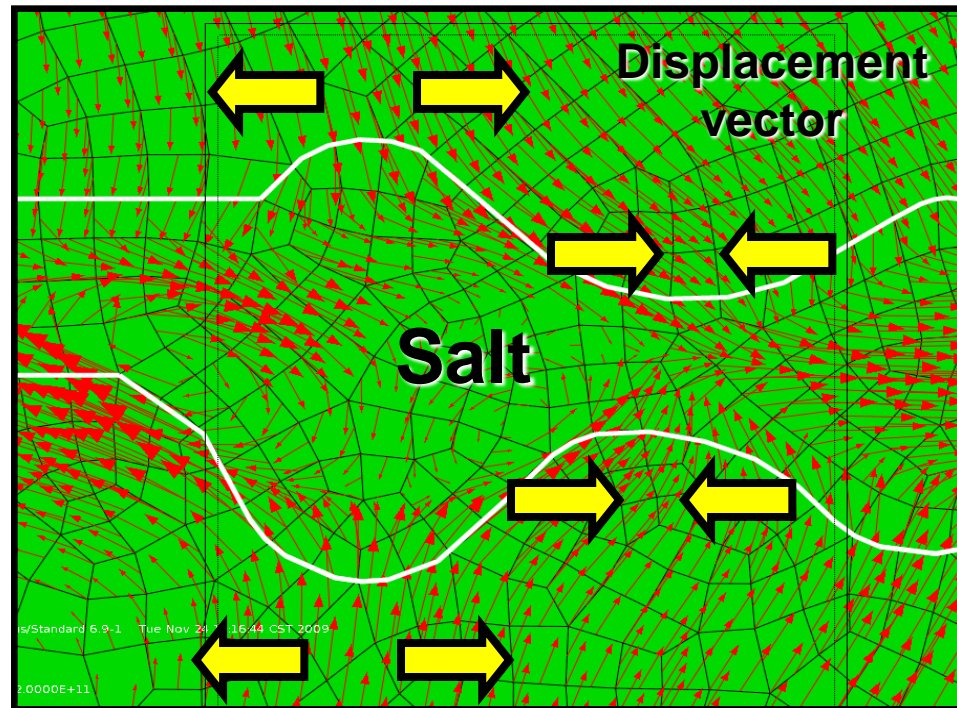
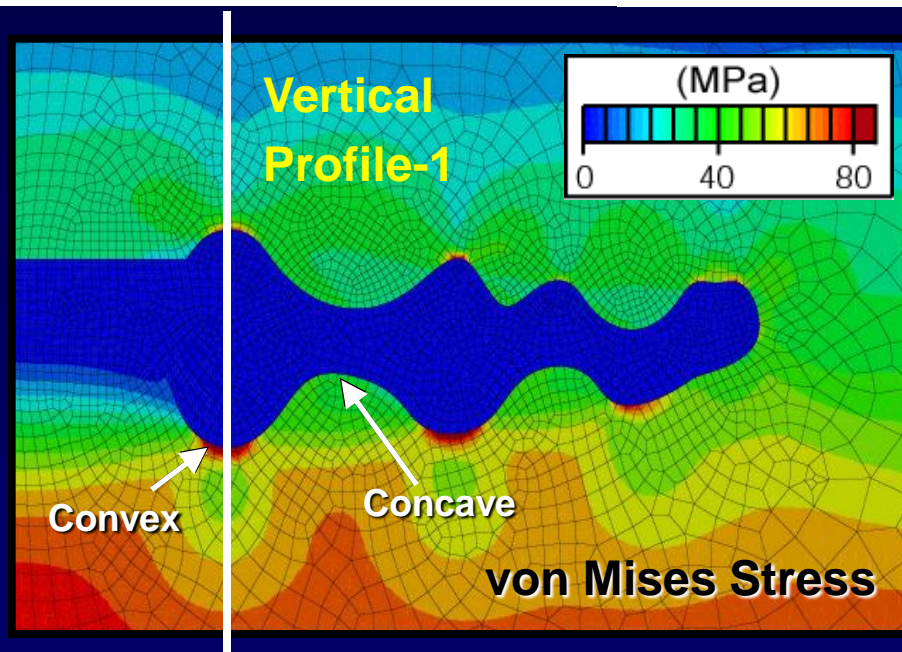
Final von Mises Stress



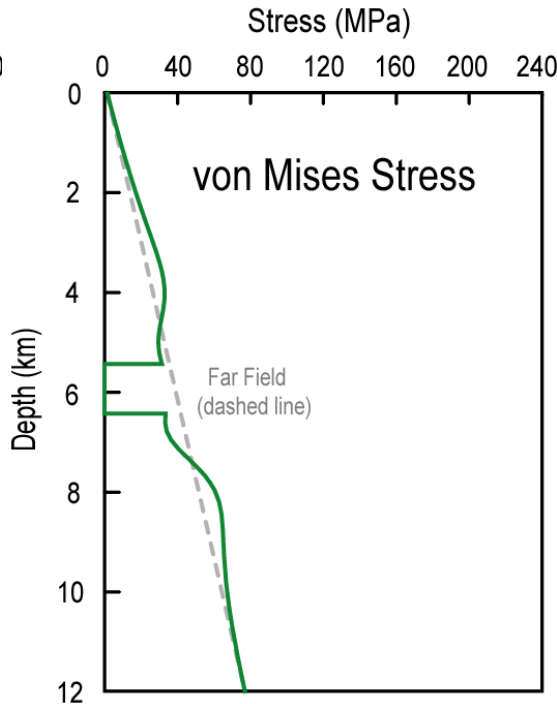
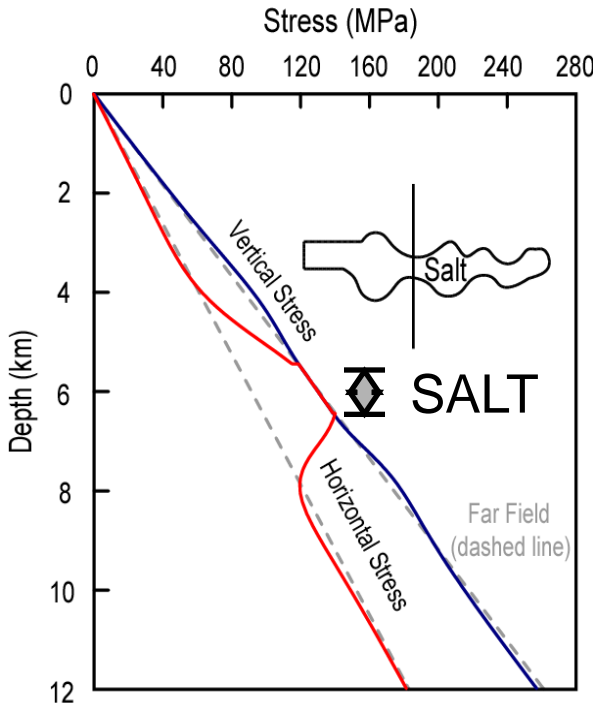
Elastic sediments



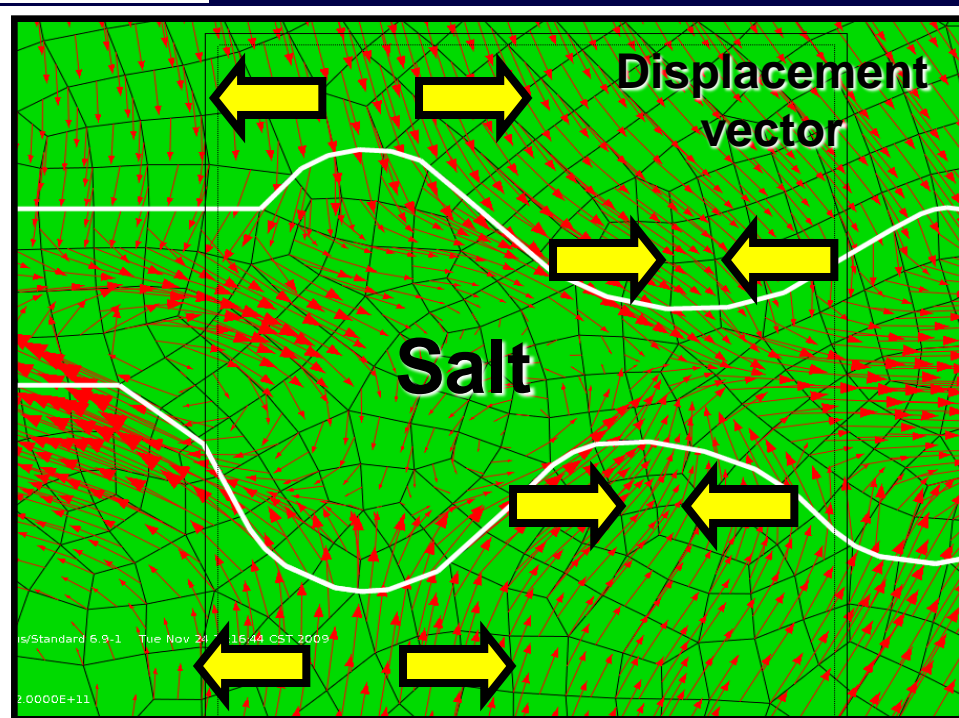
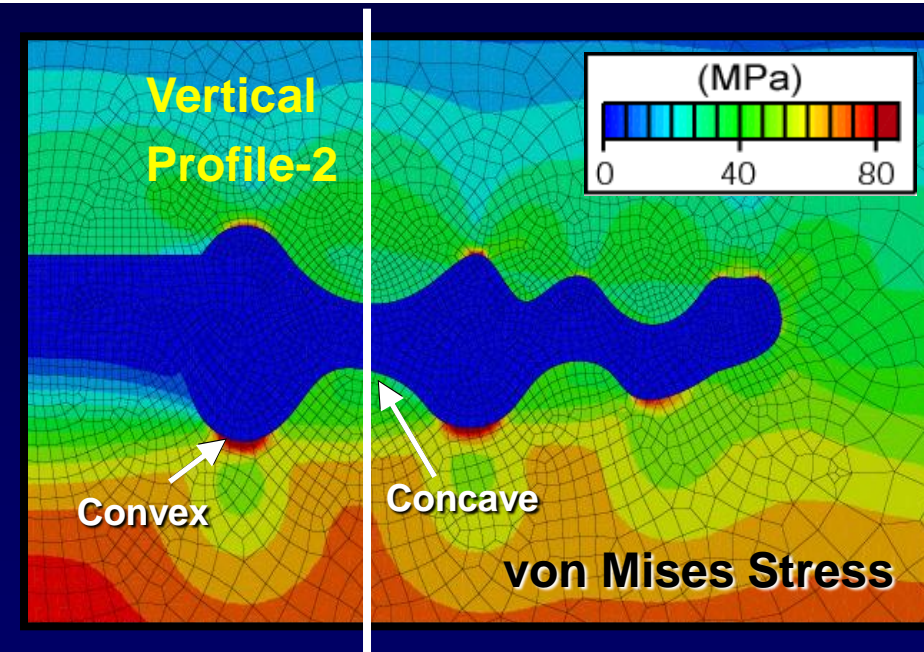
- Why are von Mises stresses high adjacent to convex salt?
- Because vertical stress changes little, but horizontal stresses above and below salt are strongly reduced.
- Convex portions of top and base salt are bad places to drill.



Elastic sediments

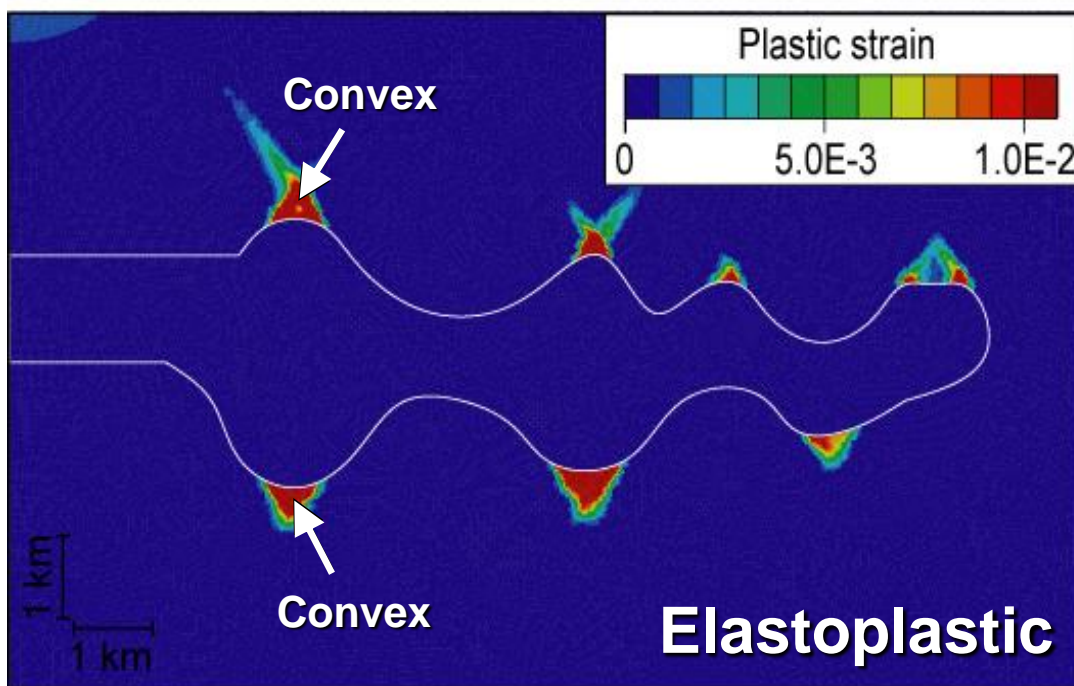


- Why are von Mises stresses low adjacent to concave salt?
- Vertical stress changes little, but horizontal stresses above and below salt increase.
- No shear stress concentration above and below salt.
- Concave top and base salt are good places to drill from a shear-stress perspective. Pore pressure is another issue!



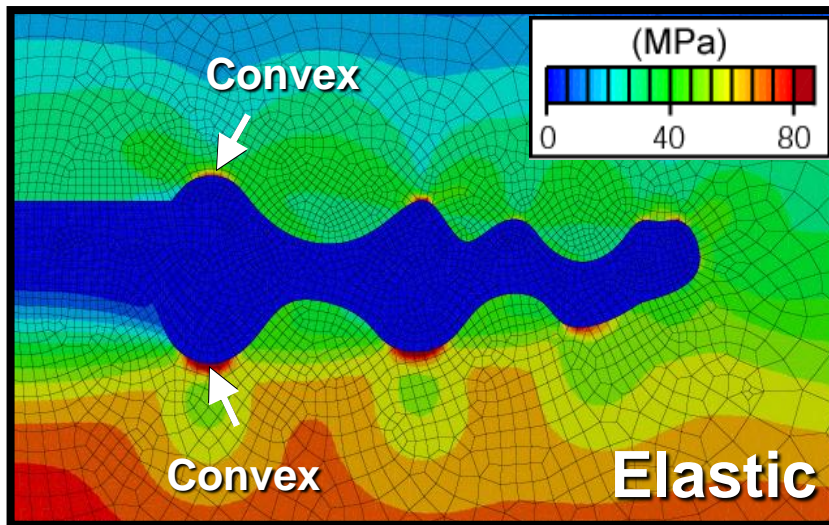
Elastic sediments

Plastic strain $\varepsilon_{Plastic}$

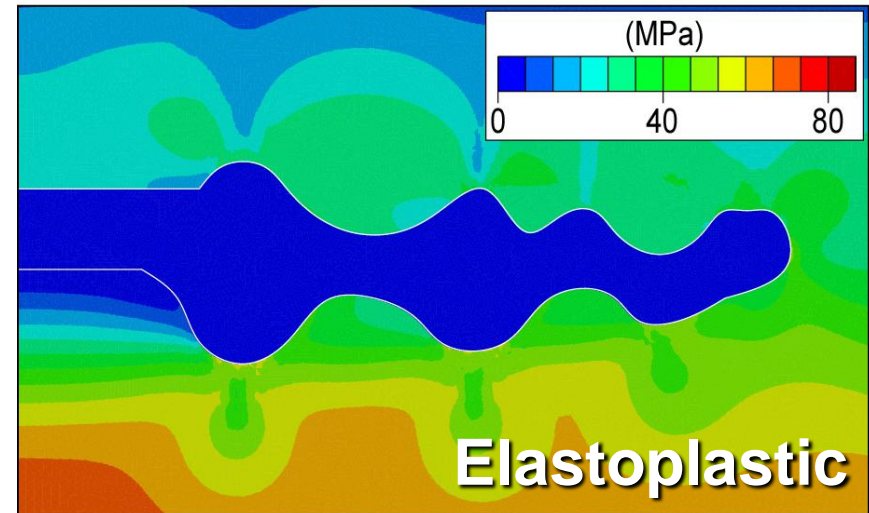


- Hydrostatic pore pressure is assumed.
- Mohr-Coulomb plastic criterion.
- Plastic strain occurs at convex curves.

von Mises stress



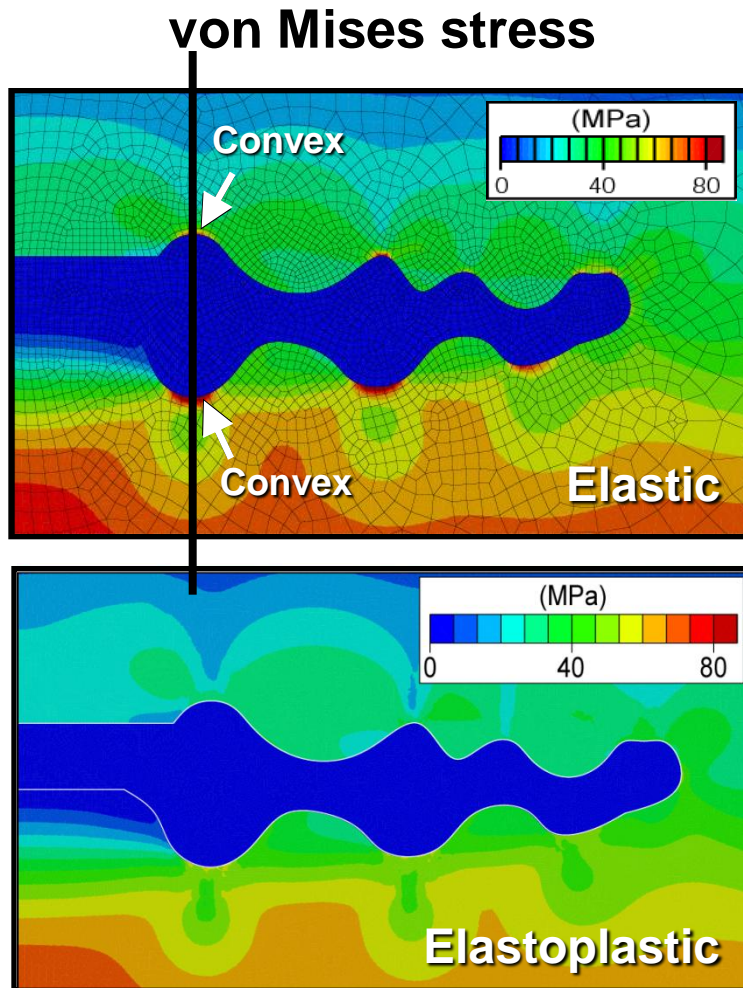
von Mises stress



- Concentration of shear stress at convex curves is suppressed, if plasticity is included.

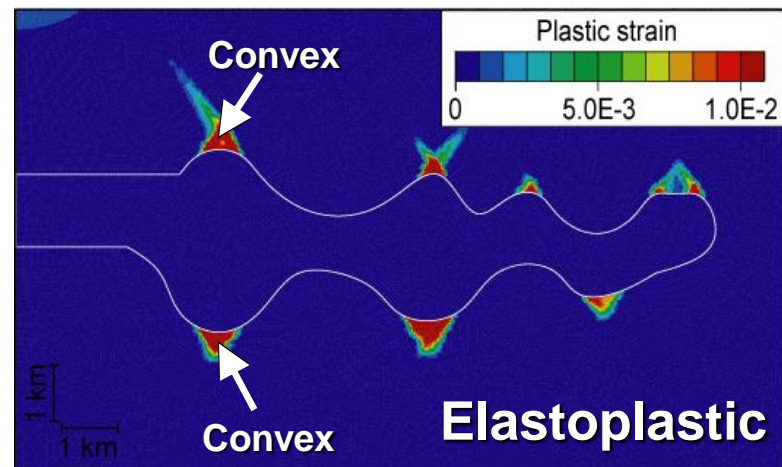
3. Key results- Summary

(1) Plasticity changes stresses, and may give different prediction from elastic models.



(2) Plasticity introduces plastic yield zones.

Plastic strain $\epsilon_{Plastic}$

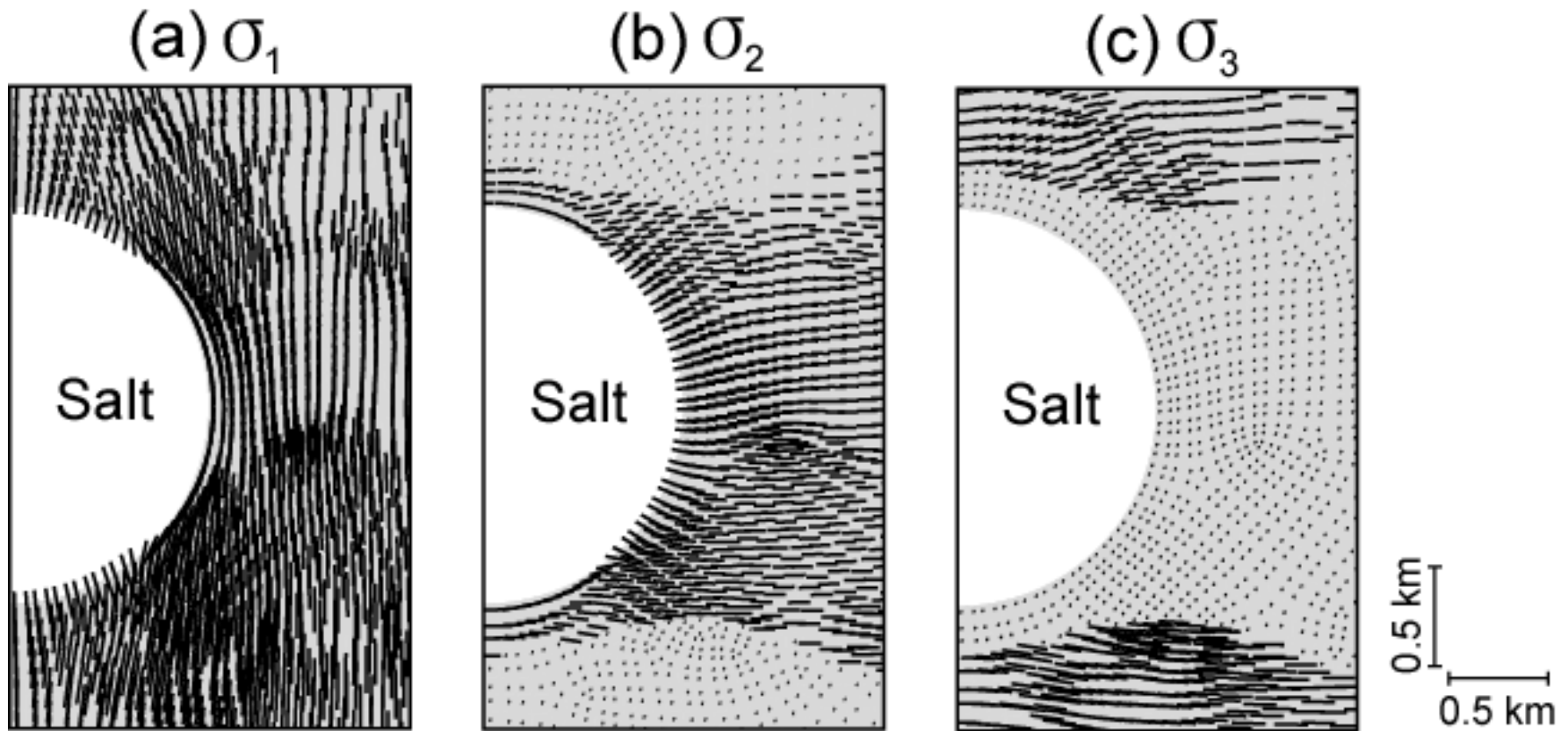


Thank You!

References

Fredrich et al., 2003, Stress Perturbations Adjacent to Salt Bodies in the Deepwater Gulf of Mexico, *SPE* 84554, P1-14.

Nikolinakou et al., 2011, Geomechanical Modeling of Stresses Adjacent to Salt Bodies: Poro-Elasto-Plasticity and Coupled Overpressures, AAPG annual meeting, 2011, April, Houston.



Model predicted orientations of three principal stresses shown by bars in this profile and dots for out-of-plane orientation.