Back Analysis of Joslyn Steam Release Incident Using Coupling Reservoir Geomechanical Model*

Alireza Khani[1], Nathan L. Deisman[2], and Rick Chalaturnyk[2]

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[1]Civil and Environmental Engineering, University of Alberta, Edmonton, Alberta, Canada (khani1@ualberta.ca)
[2]Civil and Environmental Engineering, University of Alberta, Edmonton, Alberta, Canada

Abstract

At Joslyn Creek, about 5:15 a.m. on May 18, 2006, the caprock (Clearwater Formation) which was supposed to be a barrier for steam inside the bitumen reservoir breached and caused a 125 by 75 meter surface disturbance, hurling rocks and trees, and leaving large craters. Joslyn Creek steam assisted gravity drainage (SAGD), at that time, was operated by Deer Creek Energy Limited, a subsidiary wholly owned by Total E&P Canada Ltd. (Total). Long time after steam release, Total and Energy Resources Conservation Board (ERCB) released 1140-page and 177-page reports about this phenomenon respectively. Total and others have provided several scenarios for steam release and so far nobody knows what exactly has caused the failure in this shallow reservoir during a short time of operation. Total's report states that “further work is needed especially to improve the quality of the geomechanical data (stresses and mechanical properties) and achieve two way coupling between the reservoir simulator and the geomechanical simulator”. It is challenging to simulate the behavior of unconventional reservoirs in an accurate manner when several physical models like geomechanics are not properly considered. Because of this fact, the geomechanical properties of the reservoir such as in situ stress, deformation, porosity, and compressibility change during operation and their values are completely different compared to the original; thus, a reliable geomechanical model is needed in the conventional reservoir simulator. In traditional geotechnical engineering, back analysis of failed slopes or earth structures are used to test the models used to predict the factor of safety and the accuracy of laboratory testing. For the Joslyn Creek event, this is one of the only cases for SAGD where the Factor of Safety of the reservoir was unity (i.e. the applied forces where equal to resisting forces), therefore this presents a unique opportunity for a back analysis. This paper presents the initial work on creating the geomechanical and flow models and the coupled reservoir geomechanical simulation approach which will be used for the

back analysis. The model includes Discrete Fracture Network modeling, discontinuum modeling, and coupling with CMG-STARS as a reliable representative for complicated geometry of fractured media. This approach may provide an opportunity to model real complex systems of a heterogeneous and anisotropic reservoir systems.

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Reservoir Geomechanics Research Group [RG]^2
Foundation CMG Industrial Research Consortia in Reservoir Geomechanics
for Unconventional Resources

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AAPG, Calgary, June 2016

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Outline

- ✓ Motivation for This Study
- ✓ Oil Sands in Canada and Location of Joslyn Creek
- ✓ Why Joslyn Steam Release is Important?
- ✓ Reports on Joslyn Release Incident and Postulated Potential Mechanisms
- ✓ Coupled Reservoir Geomechanical Simulation
  - Stratigraphy and Geological Model for Joslyn
  - Continuum and Discontinuum Modeling
- ✓ Reassess the Possible Causes of the Failure Forensically
- ✓ Using POST Failure Monitoring Data to Calibrate the Numerical Model

Motivation

Total as Operator in Joslyn:

"Further work is needed especially to:

a. Improve the quality of the geo-mechanical data (stresses and mechanical properties).
b. Achieve the two ways coupling between the reservoir simulator and the geo-mechanical simulator.
c. Investigate the long term integrity and contribute to monitoring implementation and interpretation."

Mike Carlson (Applied Reservoir Enterprises Ltd.):

"There is very little material on the issue and virtually nothing from an engineering perspective on the caprock failure at Joslyn."

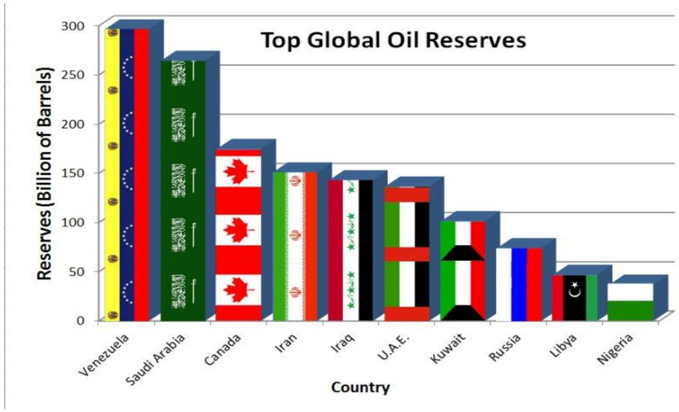
M. Uwiera-Gartner (SPE 148886):

"Post-failure analyses of the causes for caprock failure at Josyln Creek are not entirely conclusive."

In Conclusion:

We need to model full failure process including the behaviors of Caprock and Reservoir simultaneously

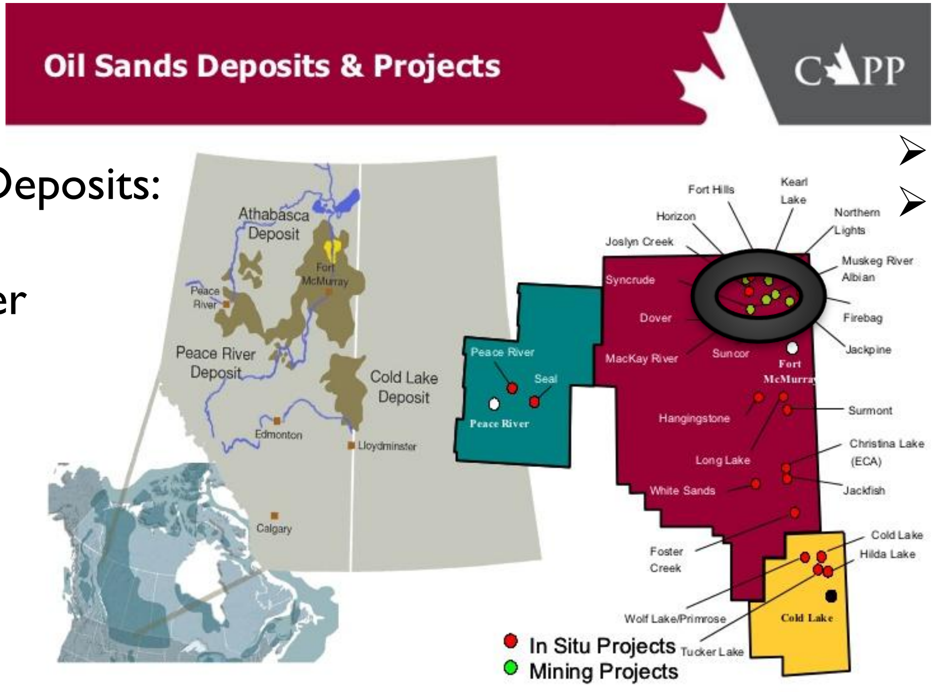
Oil Sands in Canada and Location of Joslyn



- ❑ Canada has the third largest oil reserves in the world
- ❑ 97% of those reserves are in the oil sands

Three Main Deposits:

- ❖ Athabasca
- ❖ Peace River
- ❖ Cold Lake



Source: Dave Collyer

- ➢ 20% Surface Mining (Depth<70m)
- ➢ 80% Insitu Recovery (Depth > 70m)
  - CSS
  - SAGD

- about 60 km north of Fort McMurray
- estimated 7.5 billion barrels of bitumen

Joslyn Failure

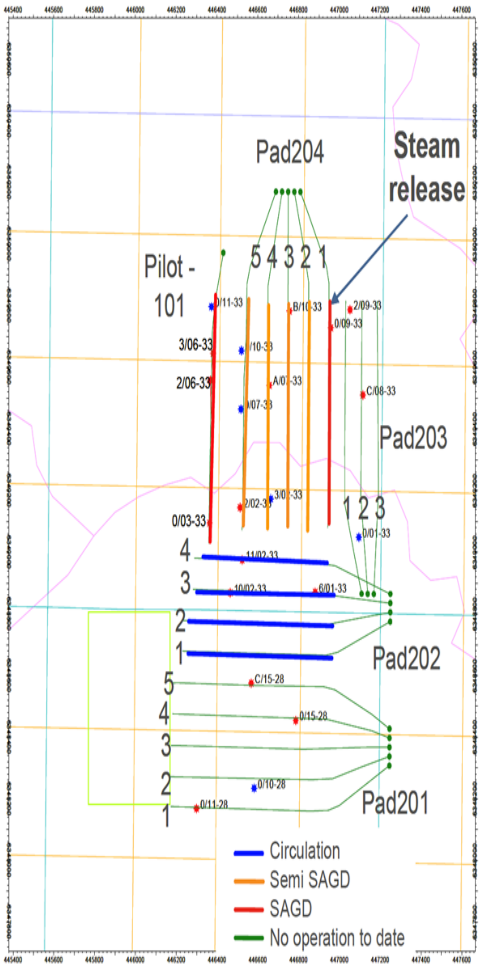


Figure 2 Well Location and Status Map (@ time of steam release)

Joslyn Failure

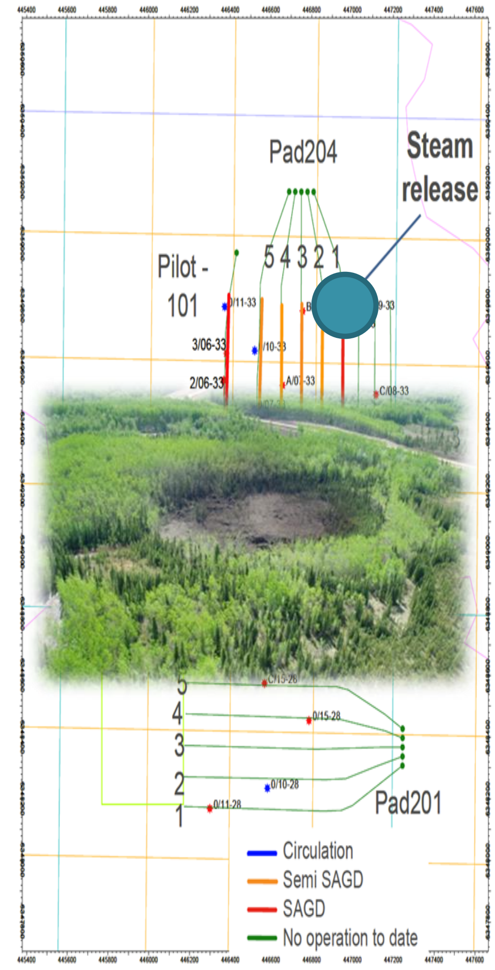


Figure 2 Well Location and Status Map (@ time of steam release)

Joslyn Failure

- On May 18th 2006, Steam released to surface
- The release created a crater and disturbed an area of 165 m by 65 m.
- At the time of the release, the associated wellpair was just starting to produce, following a lengthy circulation phase to heat up the bitumen
- The release happened just after about 5 months from the beginning of the project
- This incident is regarded as <u>the Most Important Known Caprock Failure in the 30 Years of SAGD Operations</u>
- It continues to have a significant effect on the approval process of future SAGD projects

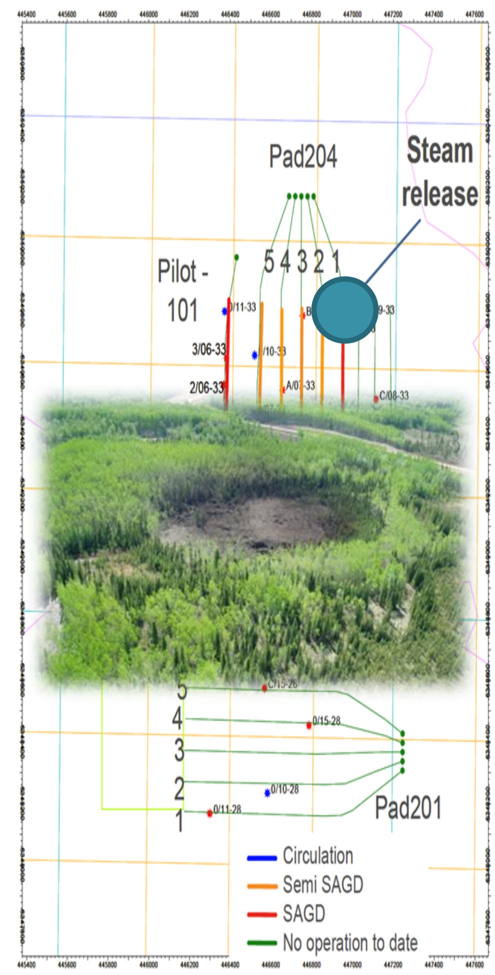


Figure 2 Well Location and Status Map (@ time of steam release)

Reports on Joslyn Failure

Very Long Report From Total as the Operator (2007,2008)

- **A fast, gravity-driven local development of steam chamber or "chimney" to the top of the SAGD pay zone, probably involving sand dilation.**
- **Lateral extension of the pressurized area below the first major shale barrier in the Upper McMurray.**
- **Shear failures on the edges of the pressurized area that allowed the steam to breach within the Wabiskaw reservoir.**
- **Significant storage of water and steam in the localized SAGD chamber and fracture system.**
- **Catastrophic shear failure of the Clearwater caprock, leading to steam release at surface on May 18, 2006.**

Reports on Joslyn Failure

Energy Resource Conservation Board (ERCB, now AER) Report (2010)

- "Staff believes it is **unlikely** that a dilation chimney would develop during the 4-month circulation period of well pair 204-I1P1 and provided arguments to support this view."
- "Staff agrees with Total that the explosive nature of the steam release required storage of steam and hot water below the caprock. Therefore, the steam release did not likely occur as a single fracturing event from the wellbore to surface on May 18, 2006. This is supported by pressure and injection data that indicate an initial fracturing event on April 12, 2006."
- "Staff believes that Total's geomechanical modeling was reasonable and showed that shear failure of the caprock could have occurred due to pooling of high-pressure steam and water in porous and permeable zones beneath the Clearwater shale."

Observations from Reports

A number of potential mechanisms were postulated

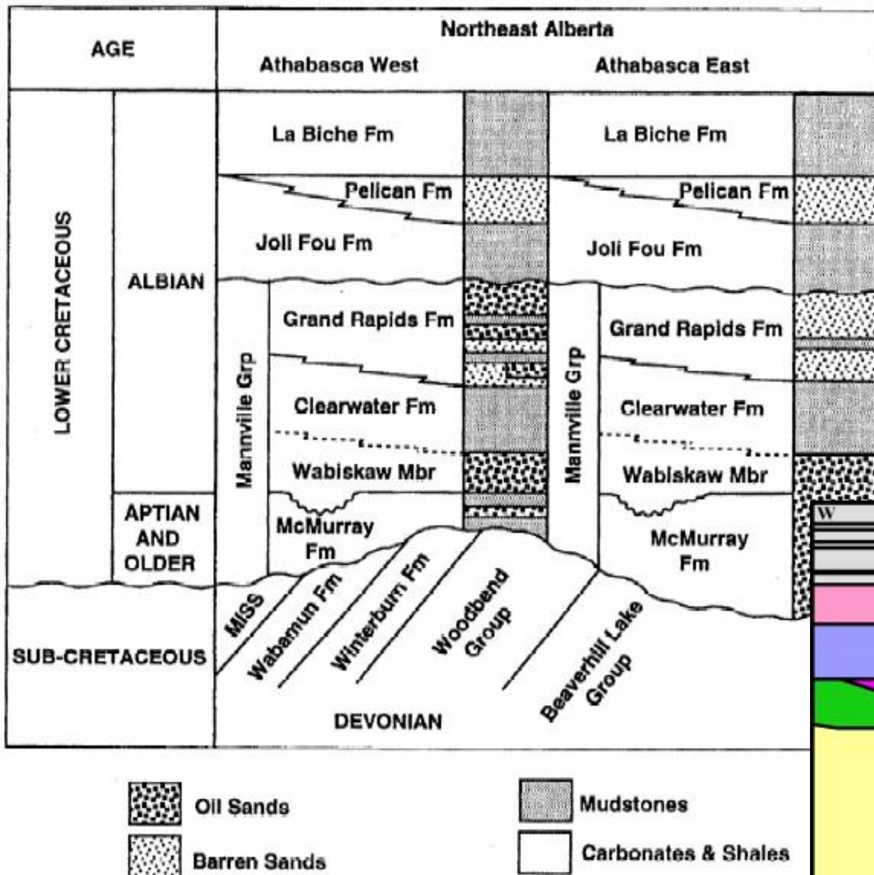
No definitive resolutions….

Lack of Coupling Reservoir Geomechanical Simulation in these reports…

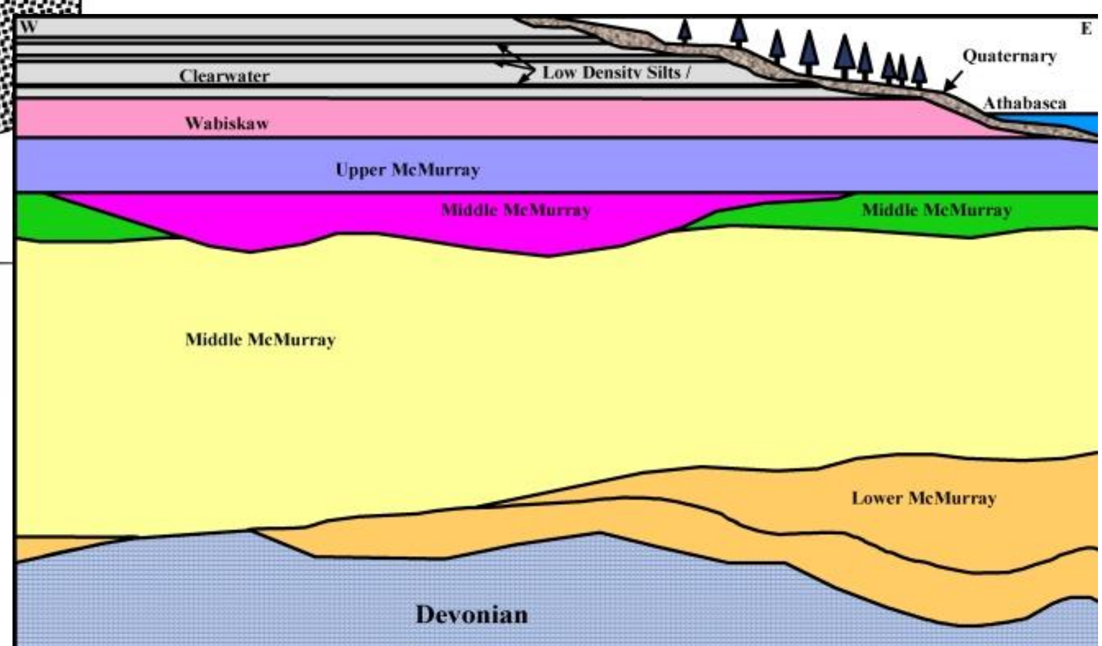
A comprehensive study for caprock integrity includes **a good representative for geology of caprock and reservoir** *and* **a coupled reservoir geomechanical simulation resulting steam injection**

Stratigraphy and Geological model

➢ **Stratigraphy**:



- Main pay zone is the middle member of the McMurray formation
- Wabiskaw member is oil saturated in some locations
- Caprock is provided by the Clearwater shales
- Devonian carbonates are the base on which the McMurray sands were deposited



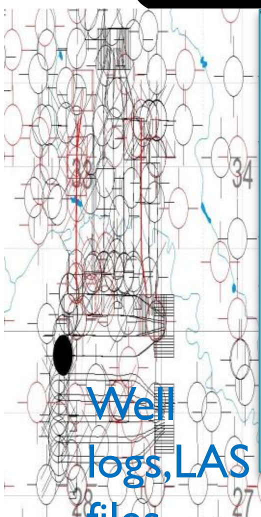
Building Geological Model

DATA

More detailed data → Less uncertainty in the model

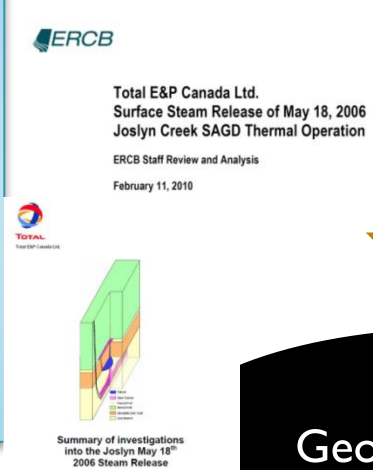
Public data:

GeoScout | Reports | AER | Papers



Well logs,LAS files

Available Public data


ERCB

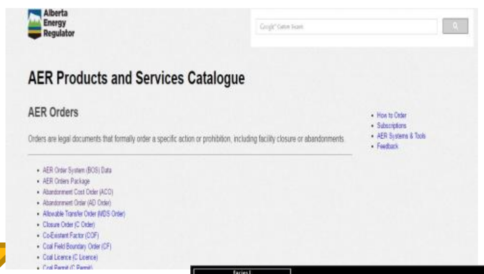
Total E&P Canada Ltd.
Surface Steam Release of May 18, 2006
Joslyn Creek SAGD Thermal Operation

ERCB Staff Review and Analysis

February 11, 2010

Summary of investigations into the Joslyn May 18th 2006 Steam Release

Gocad SKUA


Alberta Energy Regulator

AER Products and Services Catalogue

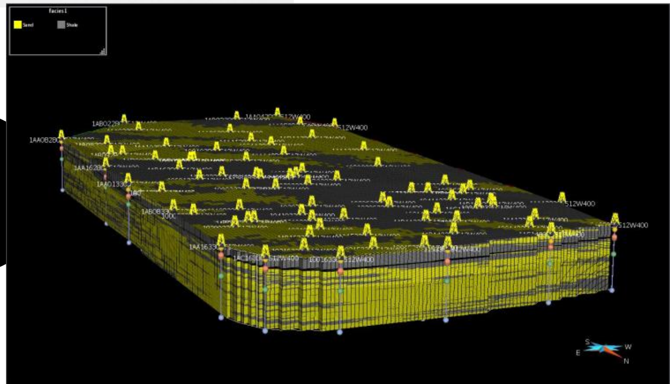
AER Orders

Orders are legal documents that formally order a specific action or prohibition, including facility closure or abandonments.

- AER Order System (BOS) Data
- AER Orders Package
- Abandonment Cost Order (ACO)
- Abandonment Order (AD Order)
- Allowable Transfer Order (MDS Order)
- Closure Order (C Order)
- Co-Existent Factor (COF)
- Coal Field Boundary Order (CF)
- Coal Licence (C Licence)

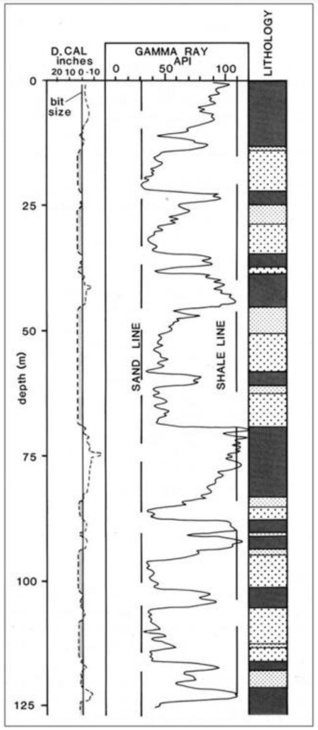
- How to Order
- Subscriptions
- AER Systems & Tools
- Feedback

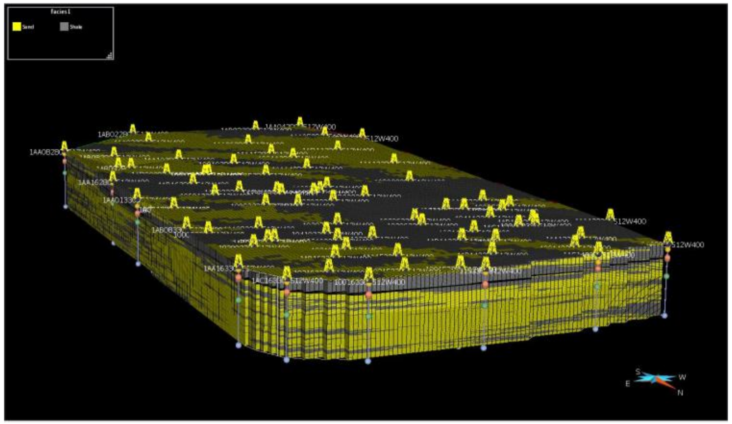
Geological Model



Creating Geological Model

- ✓ **Defining cut-offs for facies generation:**
  - **Quality of well logs**
  - **Local cut-off values for facies**
  - **No specific method for interpretation**
- ✓ **Facies have significant role on the result**
- ✓ **Then a geological model with a reasonable uncertainty is prepared to use in the Flow and Geomechanical codes**

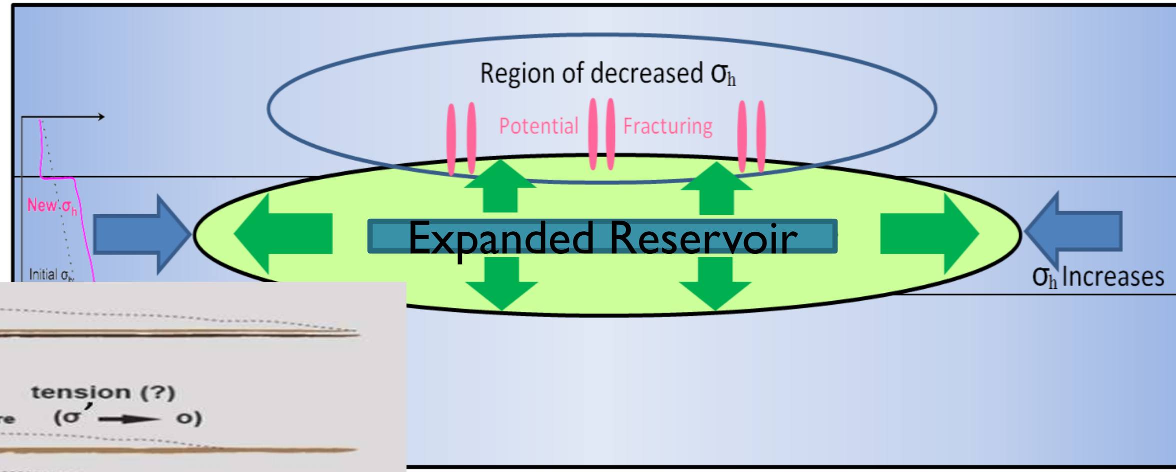


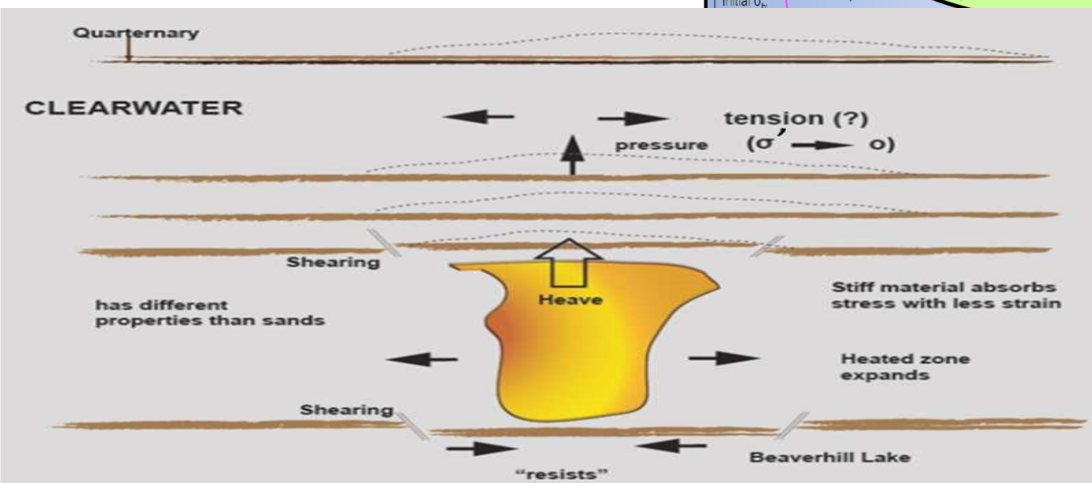


models for:
- Rock type
- Porosity
- Saturation
- Permeability

Stress Transfer in a Caprock-Reservoir System for an Injection Scenario

- **State of problem:**





- **Types of coupling:**
  - Two-way
    - Full coupling: FLOW & MECHANICAL variables SOLVED TOGETHER
    - Partial/Sequential coupling: SOLVED SEPARATELY and then ITERATED
  - One-way

    flow variables (P & T) are fed unidirectionally to the geomechanical simulator

Simple Geomechanical Simulation

Total:

	Young's Modulus	Poisson's ratio	Friction angle	Dilation angle	Cohesion
Reservoir	500 MPa	0.25	45°	35°	0
Cap rock	500 MPa	0.4	30°	20°	0

Table 1 Mechanical parameters used in the Geo-mechanical model

Insitu Stresses:
The vertical stress gradient = *21 KPa/m.*
The horizontal minimum stress gradient = *24 KPa/m*
The maximum stress gradient = *31.5 KPa/m*

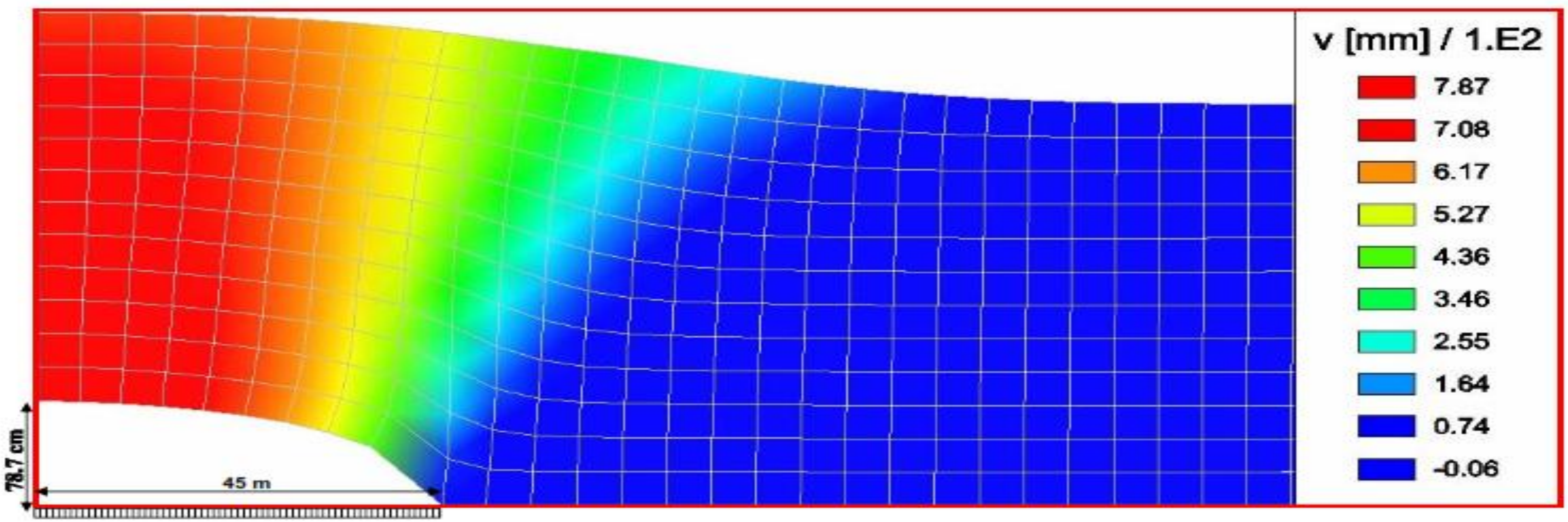
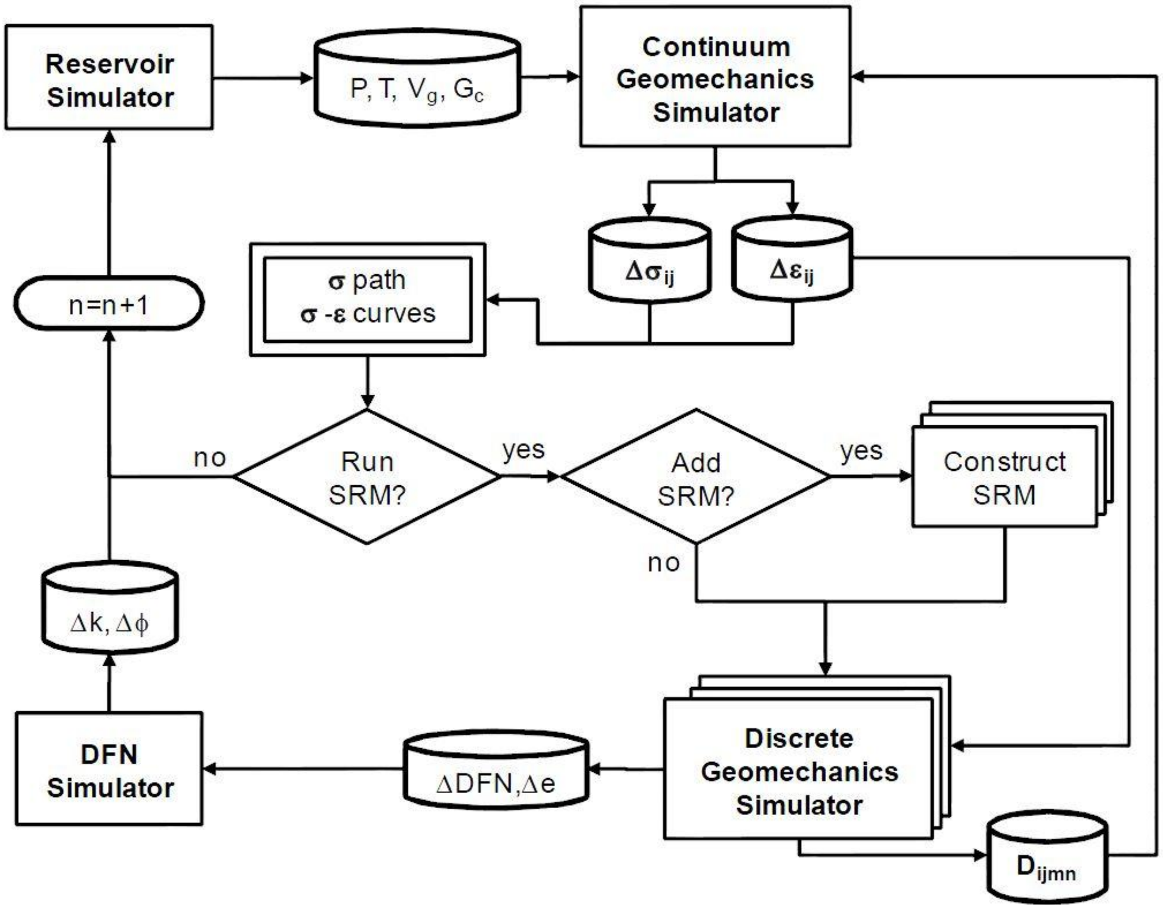


Figure 17. Vertical displacement inside a 60 m thick overburden when a pressure of 1800 kPag is applied on a zone of 45 m radius at its bottom.

The ground rises up almost 80 cm?!

Coupling Geomechanical modeling and Reservoir Simulation

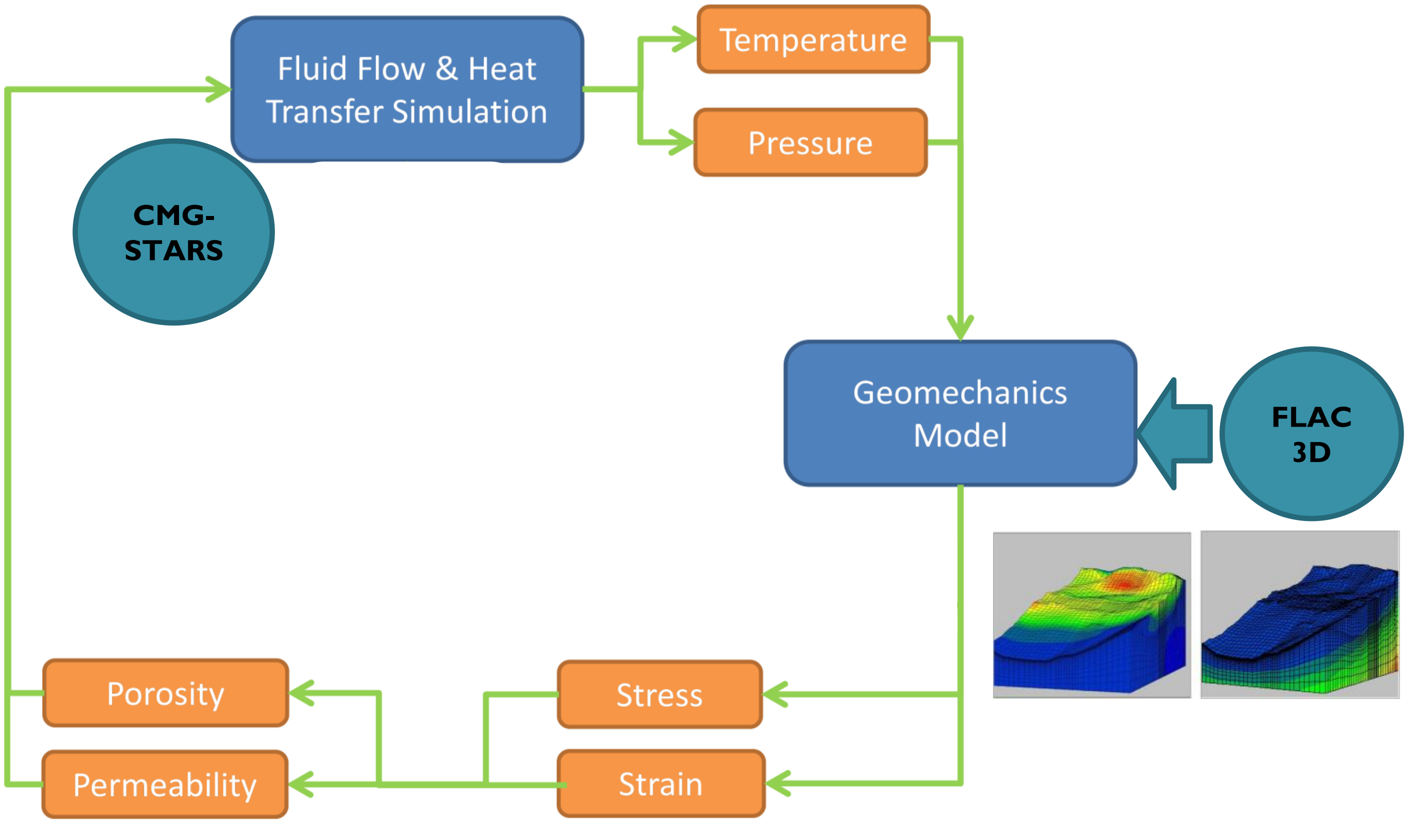


Pseudo Adaptive Reservoir Continuum Discontinuum workflow

Source: Deisman Nathan et al. SPE 2009

Coupling Geomechanical modeling and Reservoir Simulation

- The first stage will be 3D sequentially coupled reservoir geomechanical continuum analysis to model initial behavior till the fractures are developed



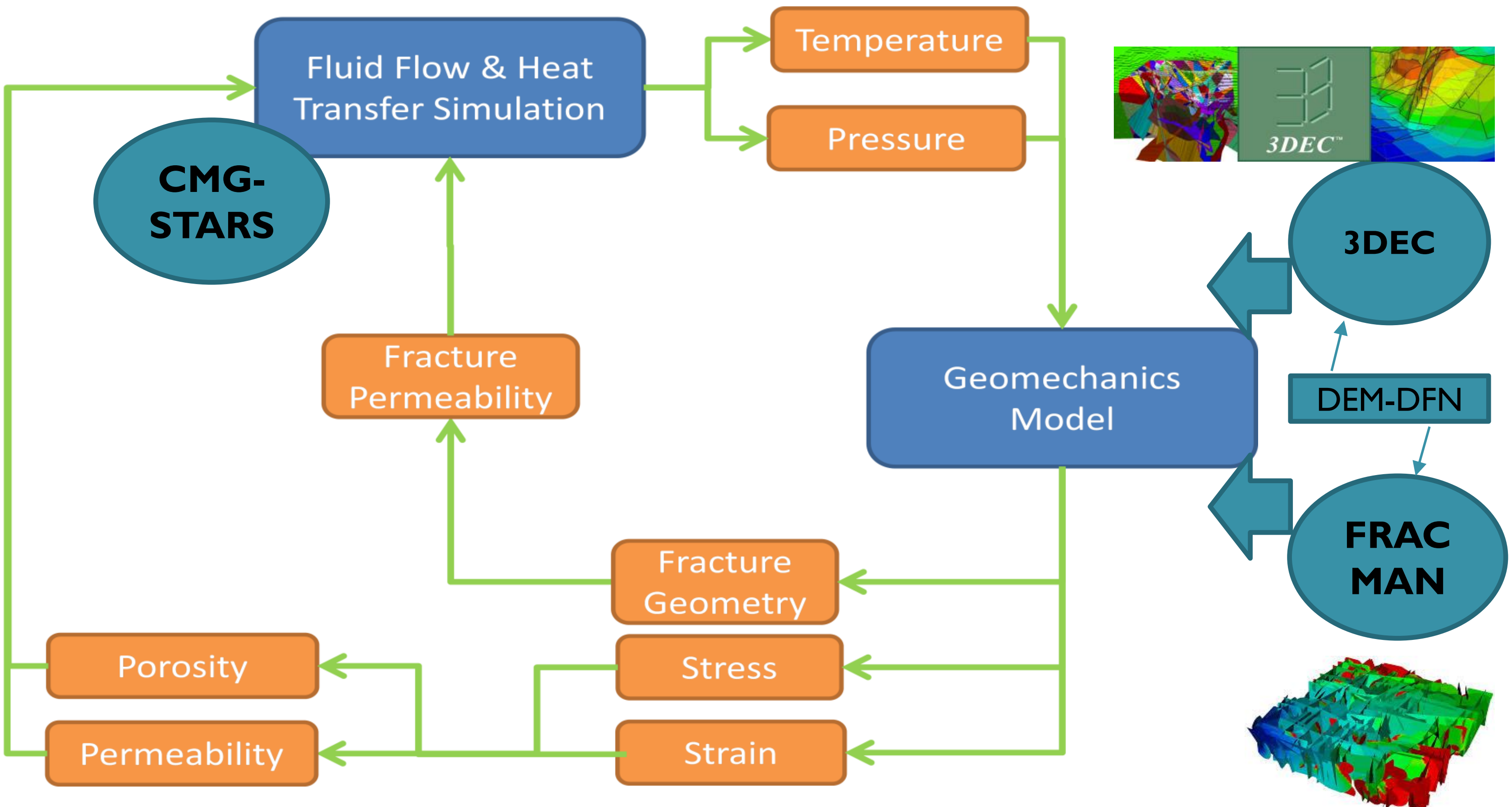
Coupling Geomechanical modeling and Reservoir Simulation

- The first stage will be 3D sequentially coupled reservoir geomechanical continuum analysis to model initial behavior till the fractures are developed

- Second stage will be 3D sequentially coupled reservoir geomechanical discontinuum analysis to model the upper caprock failure

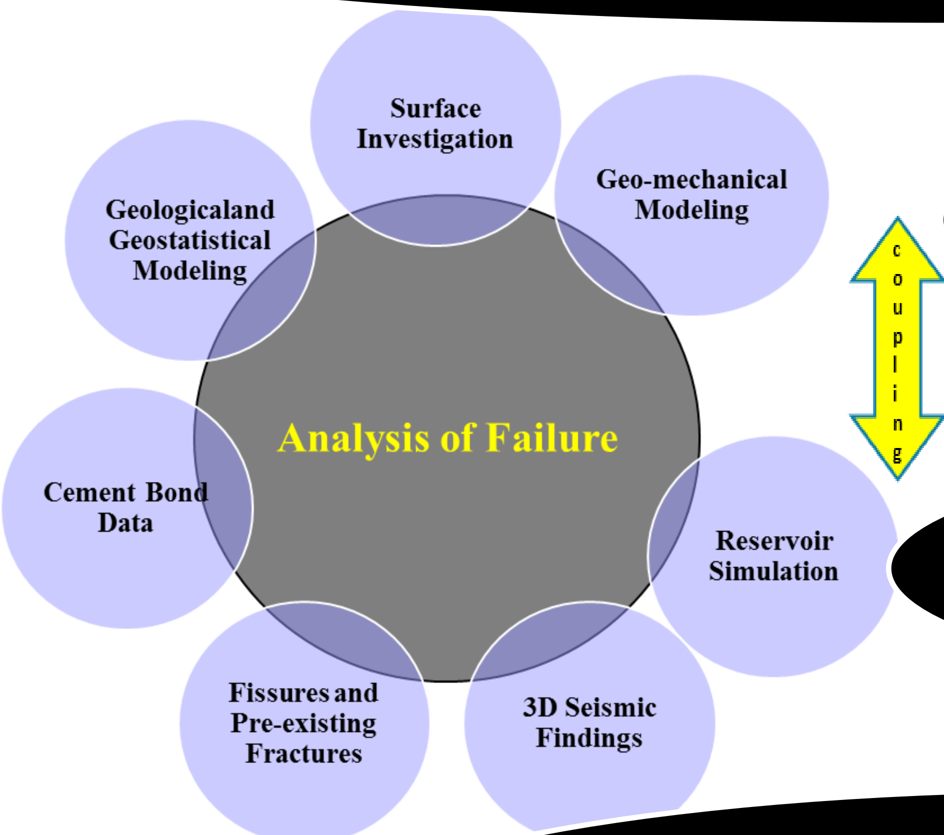
Coupling Geomechanical modeling and Reservoir Simulation

- The first stage will be 3D sequentially coupled reservoir geomechanical continuum analysis to model initial behavior till the fractures are developed
- Second stage will be 3D sequentially coupled reservoir geomechanical discontinuum analysis to model the upper caprock failure



Need to Re-Assess the Possible Causes of the Failure

Using models and available data from adjacent wellpairs after steam release in 2006



Most Likely Steam Release Scenarios

Forensic Engineering Analysis

Consider the Assessments to Constrain the Requirements to Establish *Factor of Safety* against Tensile and Shear Failures

Thank you for your attention

Alireza Khani
Khani1@ualberta.ca