

## Observations on SAGD Caprock Integrity

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### Summary

Caprock integrity assessments have become a key element in the design and operation of SAGD projects and a critical element in the selection of a maximum steam injection operating pressure. By necessity, these caprock integrity assessments involve geotechnical engineering principles and have generally lead to more use of reservoir-geomechanical simulations (one way coupled or sequentially coupled) in the establishment of what is termed “safe” maximum steam injection pressures. Almost without exception, all current SAGD development applications must submit as part of their regulatory approval submissions, an assessment of caprock integrity. In general, these caprock assessments have included geological framework studies for the caprock, in situ stress determination, constitutive property characterization and numerical simulations all designed to ensure the design steam injection pressure does not pose a threat to the confinement of the steam chambers. While these elements of SAGD projects were always considered in the regulatory due diligence process, increased attention was brought to bear on this issue with the catastrophic release of steam that occurred in May 18 2006 at the Joslyn Creek thermal in situ oil sands scheme, located about 60 kilometers north of Fort McMurray.

Caprock assessments conducted to date have incorporated varying levels of detail and complexity in each of the major elements of the study. This presentation will focus on observations concerning two elements of a caprock study: material property or constitutive properties and reservoir-geomechanical numerical simulation studies. The current effort underway by the ERCB to understand the complex geological framework of the units overlying (and underlying) the oil sands will provide valuable input to future caprock studies. As well, the procedures and techniques for conducting and interpreting in situ stress tests in the caprock, and for that matter, the oil sands, has evolved rapidly over the last several and while it remains a critical element in the assessment process, for sake of time, will not be discussed in this presentation.

For the majority of caprock assessments, it is the constitutive properties of the Clearwater Formation and the Wabiskaw Formation that have received the most attention. Recently, increased attention has focused on the properties of the intraformational shales within the McMurray Formation to better understand their role as baffles/barriers to steam flow and to perhaps “decipher” a way to control the properties of these units to enhance steam chamber development. The presentation will highlight the stress-strain behavior, the role of pre-consolidation stress determined from oedometer testing, the process of thermal consolidation that occurs within the shales, the influence of stress path during testing and the permeability of these units. For a geological perspective, this constitutive behavior has implications for the stress history of the material, and whether it should be treated as a continuum or discontinuum (i.e. fissures present or not). All these elements associated with the constitutive behavior are intimately linked to the assumptions chosen for numerical modeling studies aimed at SAGD process optimization and caprock integrity assurance.

Reservoir-geomechanical simulations have become a key component of caprock integrity assessments and are generally the method by which maximum steam injection pressures are chosen, at least from a caprock integrity perspective. It is recognized of course, that many other issues are embedded in steam injection operational strategies. Numerical simulation techniques have ranged from one-way coupled (or uncoupled) where pressure and temperature from a thermal reservoir simulation are passed to a geomechanical simulator with no feedback to iteratively coupled where thermal reservoir simulation results are fed to a geomechanical simulator at time step intervals and geomechanically induced changes, primarily permeability, are updated in the thermal reservoir simulator prior to the next time step iteration. Much has been written on this subject and it is not the intent of this presentation to review the merits of these techniques. What this presentation will focus on however, is the choice of material model chosen for each major unit for these simulations: oil sands, shales and underlying carbonates. The choice of material model can have a profound impact on the results of reservoir-geomechanical simulations. In particular, the presentation will focus on the prediction of “caprock” failure and what this means relative to material model selection. Clearwater Formation shales, for instance, are very heavily overconsolidated and as a result of this stress history, generally contain epigenetic features (e.g. fissures) that will influence how this class of materials behaves as failure conditions are approached. It is argued that in some cases, the use of continuum models will provide over-conservative estimates of the caprock resistance to geomechanical strains associated with increased pore pressure and thermal stress changes during steam injection into the oil sands.

As a way of summarizing the results from numerical simulations, it has been suggested that a “factor of safety” approach be adopted to provide more tangible method of communicating the margin of safety present in any setting and any given steam injection pressure(s). The concept of factor of safety for both tensile and shear failure is reviewed from the context of geotechnical engineering. The dynamic nature of the “factor of safety” will be highlighted showing that careful attention to how the steam chambers develop in time can impact how the tensile and/or shear failure conditions can develop over time.