Summary of Conclusions from the Reservoir Containment Project for Steam-Assisted Gravity Drainage Schemes in the Shallow Thermal Area

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Alberta Energy Regulator
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1 Introduction

In July 2011, the Alberta Energy Regulator (AER) started the reservoir containment project to investigate caprock integrity and maximum operating pressure (MOP) for thermal in situ oil sands schemes and to develop regulatory requirements for these schemes. The project is being done to manage the risk of a caprock being breached at a thermal scheme. The project has been divided into two phases: the first phase deals with shallow steam-assisted gravity drainage (SAGD) schemes, where there is a higher risk to safety; the second phase will deal with deeper thermal schemes. Until regulatory requirements are developed for deeper thermal schemes, the AER will continue to evaluate reservoir containment on an application-by-application basis. The AER's current practice regarding reservoir containment is to require detailed caprock integrity studies for all new thermal in situ oil sands schemes and, in the case of SAGD schemes, to specify an MOP based on a formula.

A caprock breach at shallow depths poses a potential safety risk because a likely consequence is a surface steam release, which in the worst case could result in a catastrophic release, such as the incident that occurred on May 18, 2006, at the Joslyn Creek SAGD scheme. For deeper schemes, there are additional barriers to the steam rising if the primary caprock is breached, and there are porous intervals that can act as pressure and temperature sinks, which make a surface steam release much less likely. Shallow SAGD schemes may be uneconomic or marginally economic unless they are operated at pressures close to the caprock tensile and shear failure thresholds. Therefore, applicants for shallow SAGD schemes may request MOPs that are higher than those that the formula or shear modelling would allow. In addition, at shallow depths, the impact of faults, incising channels, or localized subsidence features on caprock integrity can be more critical.

2 Shallow Thermal Area

A caprock base of 150 metres (m) has been selected as the depth to differentiate between shallow SAGD schemes and deeper thermal schemes in the oil sands areas. In the shallow thermal area, the overburden for the Wabiskaw-McMurray deposit may consist of Quaternary strata, thin sections of the Grand Rapids Formation, or the Clearwater Formation. The Quaternary strata and Grand Rapids Formation do not contain caprocks, but the Clearwater Formation does. However, at depths shallower than 150 m, a completely uneroded section of the Lower Clearwater shale may not be present. The existing erosion increases the risk that steam and heated reservoir fluids would not be contained within the reservoir and high-pressure steam may flow to surface.

The shallow thermal area is shown in figure 1. This area is where the Lower Clearwater shale is either shallower than 150 m at its base or is absent and where the net bitumen pay in the Wabiskaw-McMurray deposit is greater than zero.

3 Draft Caprock Criteria and Information Requirements

Most bitumen that is recoverable by in situ methods requires the use of steam injection. Steam injection requires a caprock with low permeability, sufficient integrity, and lateral continuity in order to contain the steam and heated reservoir fluids.

In the shallow thermal area, the caprock must be

- a minimum of 10 m thick,
- composed of clay-rich bedrock of the Clearwater Formation with a gamma-ray value greater than 75 API units, and
- laterally continuous across the in situ project area.

The Lower Clearwater shale is the deepest caprock overlying the Wabiskaw-McMurray deposit that meets the above criteria. On a local scale, the Wabiskaw A shale and Wabiskaw D mudstone may be able to contain steam and heated reservoir fluids but not meet the above criteria. Therefore, at the application stage, the AER will consider requests to calculate the MOP at the base of the Wabiskaw A shale and Wabiskaw D mudstone, but in these situations the Lower Clearwater shale must still be present and meet the above criteria. Non-bedrock glacial deposits or McMurray inclined heterolithic strata are not considered to be suitable for containing steam and heated reservoir fluids.

There are regions of the shallow thermal area where the Lower Clearwater shale has been completely eroded or is less than 10 m thick. In this area, which is shown in figure 1, there is no caprock that meets the above criteria. However, it should be noted that the majority of this area is within the surface mineable area, which is more amenable to bitumen recovery through mining rather than in situ methods.

To ensure that the caprock criteria for shallow SAGD schemes are met, the AER has developed draft minimum information requirements, which are detailed in the report *Draft Caprock Criteria and Information Requirements for Steam-Assisted Gravity Drainage Schemes in the Shallow Thermal Area*. Of particular significance, caprock integrity can be affected by the location and nature of faults, incising channels, or localized subsidence features that partially or completely penetrate the caprock. Identifying these features is essential in determining the integrity and continuity of a caprock. Since these features may not be identified by wellbores or two-dimensional seismic, three-dimensional seismic information is required for the development area of shallow SAGD schemes.

4 MOP Formula for SAGD Schemes

The MOP formula was developed to ensure that the bottomhole injection pressure would be below the caprock tensile failure pressure throughout the life of a project. As a result, no matter what pathway the steam follows, or how quickly it rises in the reservoir, tensile failure of the caprock should not occur.

The MOP formula is:

$$MOP_{(bottomhole)} = \text{Safety factor of } 0.8 \times \text{Caprock fracture closure gradient} \times \text{Depth at shallowest base of caprock}$$

The 0.8 safety factor is intended to ensure that the steam injection pressure is below the estimated fracture closure pressure of the caprock and to account for potential errors and uncertainties in the estimate of the fracture closure pressure. A 0.9 safety factor has historically been used in setting MOPs for conventional waterfloods and water disposal schemes. As there are more unknowns and potentially more severe consequences of a caprock failure in high-temperature, high-pressure, high-compressibility SAGD schemes, a more conservative safety factor is required.

The fracture closure gradient is used in the MOP formula rather than the fracture propagation gradient. Although a steam injection pressure above the fracture closure pressure would not always lead to the propagation of fractures, the fracture closure gradient is used because it would preclude any pre-existing natural fractures from propagating. The AER will use what it considers to be the lowest valid caprock fracture closure gradient obtained from representative diagnostic fracture injection tests.

The MOP is calculated at the shallowest base of the caprock rather than at the well depth to ensure that the steam chamber pressure will always be less than the caprock tensile failure pressure. This approach eliminates the uncertainty in trying to determine where the steam chamber is in all parts of the reservoir at all times and the need to reduce the pressure as the steam chamber rises. If the steam were to find a pathway ahead of the main steam chamber, the MOP formula ensures that the pressure at the base of the caprock would still be below the tensile failure pressure.

The pressure calculated by the MOP formula has not been decreased to account for the horizontal stress reduction in the caprock that occurs prior to the caprock being heated. Such a reduction would only be required if the following conditions were met, which is unlikely:

- steam reaches a caprock that is still at or near its initial temperature;
- caprock stress reduction is high enough to reduce the horizontal stress below the vertical stress, thereby reducing the tensile failure pressure; and
- steam injection pressure is equal to or greater than the stress-reduced tensile failure pressure.

5 Limitations of Geomechanical Modelling for Determining MOP

Coupled reservoir and geomechanical models have been used to assess tensile and shear failure of caprocks. Following is a summary of the limitations of currently used geomechanical models for determining an MOP for shallow SAGD schemes:

- A rock mass is a difficult material to accurately represent mathematically in numerical modelling.
- Half-symmetry or quarter-symmetry models assume rock deformations will be identical on both sides of the symmetry boundary. This may underestimate the potential for tensile failure.
- Currently used geomechanical models do not have rock constitutive laws that are capable of accurately modelling oil sands dilation.
- Currently used geomechanical models do not take into account the difference between the unloading and loading Young's modulus of the caprock. This may underestimate the potential for tensile failure.
- Industry practice is to use one-way, explicitly coupled or two-way, iteratively coupled geomechanical and reservoir models rather than fully coupled models. Fully coupled models would give more accurate MOPs.
- Using rock properties derived from small-scale laboratory tests tends to underestimate the potential for tensile failure.

Considering the limitations of geomechanical modelling, the MOP formula provides a more acceptable level of risk with respect to tensile failure by ensuring that the steam injection pressure is 80 per cent of the caprock fracture closure pressure at the shallowest base of the caprock.

The potential for caprock shear failure is more difficult to analyze than tensile failure. Notwithstanding the limitations of geomechanical modelling, modelling is the only available method that can provide insight into the complex factors contributing to caprock shear failure. Therefore, the AER proposes that applicants for shallow SAGD schemes be required to conduct geomechanical modelling to assess shear failure of the caprock and provide the data used for the modelling, the source of the data, and a discussion of the results.

6 Use of Monitoring to Justify a Higher MOP

Until recently, monitoring technologies have typically been used to better understand and improve the SAGD process, and not to safeguard against a possible caprock breach. Some applicants have proposed monitoring as a mitigation measure to justify MOPs higher than those calculated by the MOP formula.

Current technologies may not be able to effectively detect the movement of steam and heated reservoir fluids everywhere within the reservoir and in real time. Even technologies that have the potential to provide total coverage over the development area and respond in pseudo real time, such as tiltmeters, are largely untested in the Alberta oil sands.

In addition to the technological challenges, monitoring requires strict adherence to a series of protocols for responding to any anomalies identified. At all times, even years after scheme start-up, the field operators must be prepared to take action if monitoring detects an anomaly. This introduces the potential for human error.

Even if both the technological challenges and risks of human error were minimized, for shallow thermal schemes there is a risk that detection and intervention may not occur in time to stop a caprock breach. In contrast, the purpose of the MOP formula is to significantly reduce the probability of a caprock breach by limiting injection pressure to 80 per cent of the caprock fracture closure pressure at the shallowest base of caprock.

Considering the above factors, the AER will not rely on monitoring to allow steam injection pressures for shallow SAGD schemes that are greater than the pressures calculated by the MOP formula or determined from shear modelling.

The report *Monitoring Reservoir Containment in Thermal EOR*[1] provides a detailed review of monitoring techniques for reservoir containment at thermal schemes.

[1] EOR: enhanced oil recovery.

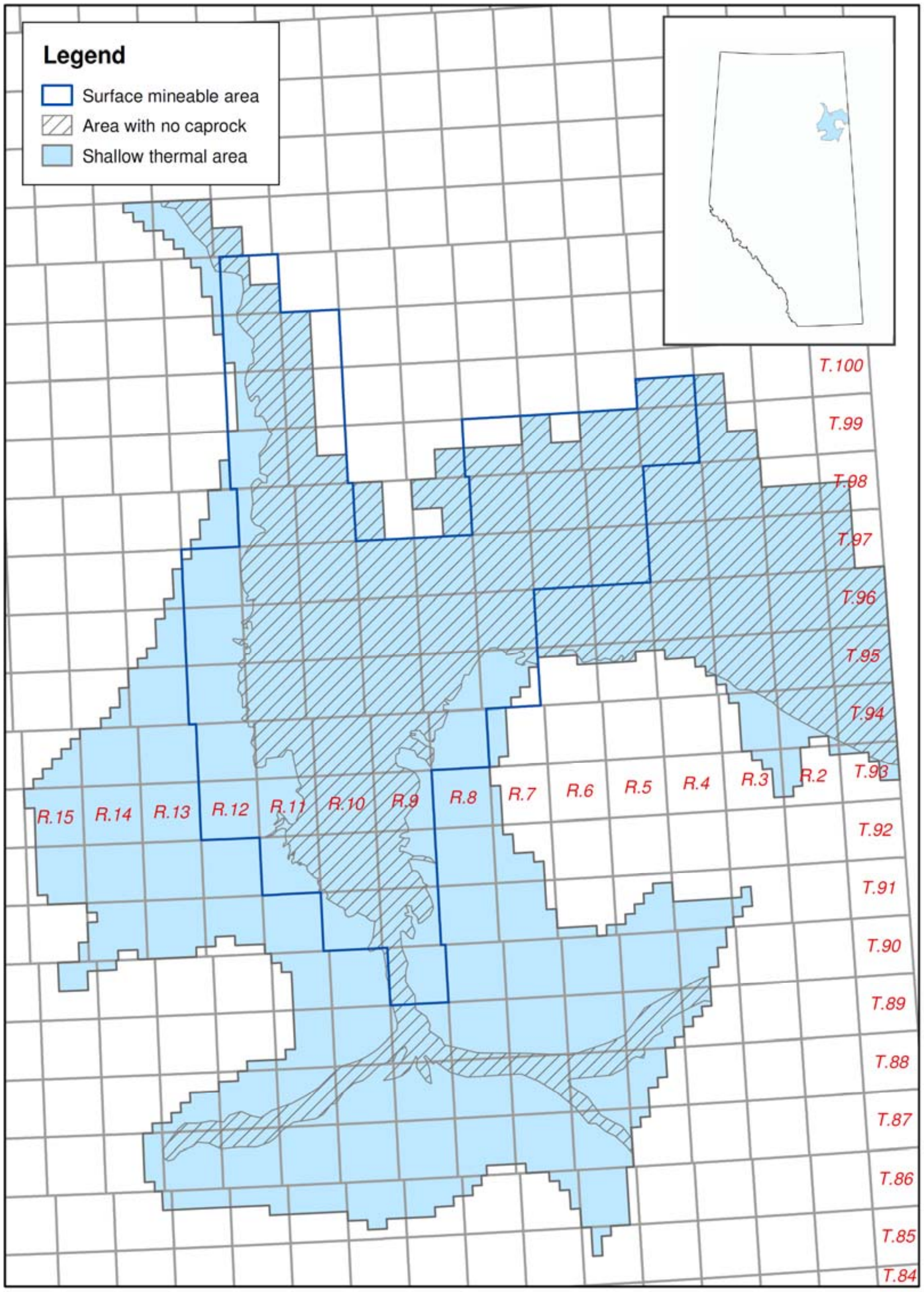

Figure 1. Shallow thermal area