Draft Caprock Criteria and Information Requirements for Steam-Assisted Gravity Drainage Schemes in the Shallow Thermal Area

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1 Introduction

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 to contain the steam and heated reservoir fluids. This document defines the shallow thermal area for the Wabiskaw-McMurray deposit in the Athabasca Oil Sands Area and the associated draft caprock criteria and information requirements for steam-assisted gravity drainage (SAGD) schemes.

2 Shallow Thermal Area

The shallowest bitumen resource in the Athabasca Wabiskaw-McMurray deposit is adjacent to the surface mineable area. In this area, the overburden for the Wabiskaw-McMurray deposit may consist of Quaternary strata, thin sections of the Grand Rapids Formation, or the Clearwater Formation. Based on the criteria discussed in the following section, the Quaternary strata and Grand Rapids Formation do not contain caprocks, whereas the Clearwater Formation does contain caprocks. However, these caprocks may be partially or completely eroded at depths shallower than 150 metres (m). 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, potentially resulting in a catastrophic surface release. Therefore, the shallow thermal area, as shown on figure 1, is defined where the Lower Clearwater shale is either shallower than 150 m at its base or completely eroded and the net bitumen pay in the Wabiskaw-McMurray deposit is greater than zero.

Outside the shallow thermal area the overburden is relatively thick, there are zones above the caprock that contain potential barriers to the upward flow of fluids, and there are porous intervals that can act as pressure and temperature sinks. As a result, if there is a caprock breach the probability of steam reaching the surface is low. In the absence of a surface release of steam, the consequences of a caprock breach may be serious, but are unlikely to pose a safety risk.

3 Draft Caprock Criteria for the Shallow Thermal Area

A caprock in the shallow thermal area must meet the following criteria:

a) be a minimum of 10 m thick,

b) be composed of clay-rich bedrock of the Clearwater Formation with a gamma-ray value greater than 75 API units, and

c) be laterally continuous across the in situ project area.[1]

[1] Alberta Energy Regulator (AER) *Directive 023: Oil Sands Project Applications* (May 2013 draft edition) defines an in situ project area as the boundaries within which bitumen recovery may occur over the life of the project.

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 contain steam and heated reservoir fluids within the reservoir but do not meet the above criteria. Requests to calculate the maximum operating pressure at the base of these units will be considered by the AER at the project application stage. However, the Lower Clearwater shale would still have to be present and meet the above criteria.

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, shown on figure 1, there is no caprock that meets the 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.

Figure 2 is a log from a reference well that illustrates the Lower Clearwater shale, Wabiskaw A shale, and Wabiskaw D mudstone.

The following provides the basis for the caprock criteria.

Minimum 10 m thickness

In areas where the Lower Clearwater shale is at least 10 m thick, there is a high degree of confidence that the unit is laterally continuous and that the probability of caprock shear failure is minimal.

Clay-rich bedrock with a gamma-ray value greater than 75 API units

Bedrock in the shallow thermal area consists of sediments from the Cretaceous Period.[2] Clay-rich bedrock with a gamma-ray value greater than 75 API units has a sufficiently low permeability to prevent steam and heated reservoir fluids from escaping through porous media flow. A 10 m thick caprock can include small amounts of tight streaks and organic-rich material with gamma-ray values less than 75 API units.

Continuous across the in situ project area

To ensure that steam and heated reservoir fluids are contained within the reservoir over the life of the project, the caprock must be laterally continuous across the project area.

4 Limitations of Non-bedrock Glacial Deposits for Reservoir Containment

There are regions of the shallow thermal area where the Lower Clearwater shale has been eroded and unlithified Quaternary strata, in the form of glacial deposits, sit directly on the Wabiskaw-McMurray

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[2] Prior, G.J., Hathway, B., Glombick, P.M., Pana, D.I., Hay, D.C., Schneider, C.L., Grobe, M., Elgr, R., and Weiss, J.A., (2013): Bedrock geology of Alberta; Alberta Energy Regulator, AER/AGS Map 600, scale 1:1 000 000, URL: <www.ags.gov.ab.ca/publications/abstracts/MAP_600.html>

deposit. These glacial deposits consist of diamict (heterogeneous mixture of silt, sand, gravel, and clay) deposited as till, glaciolacustrine, glaciofluvial, and loess sediments. The highly variable lithological properties make glacial deposits anisotropic and nonuniform.[3]

Throughout much of the shallow thermal area, particularly outside the surface mineable area, many wells have cased-hole logs of the glacial strata. Casing obscures the log response, making it difficult to distinguish lithology. Consequently, there is limited data on the upper part of the geological section where glacial deposits are encountered.

Based on currently available information, glacial deposits are not considered suitable for containing steam and heated reservoir fluids for the reasons below.

- Silt and clay-rich glacial deposits may have sufficiently low permeability to contain steam and heated reservoir fluids on a local scale. However, the glacial depositional environment is very complex and the continuity of silt and clay-rich units can be unpredictable due to facies variability, resulting in preferential flow pathways.[4] For instance, the presence of a glacial channel filled with porous sand that has incised a silt or clay-rich unit can increase the overall hydraulic conductivity and act as a flow pathway from the reservoir to the surface. These glacial channels can be as small as hundreds of metres wide and up to hundreds of metres thick and may be difficult to accurately delineate with typical wellbore spacing and seismic.
- Near-surface glacial deposits have been affected by glacial stresses applied after deposition. Glacial melting and retreat releases the weight of the overlying ice on the underlying strata. This results in isostatic rebound of the earth’s crust and subtle expansion of the glacial sediments, potentially creating a network of fractures. Fractures can increase the permeability[4] of the glacial deposits and reduce their ability to contain steam and heated reservoir fluids. In addition, glacier movement can induce thrusting, thereby compromising the integrity of the underlying glacial strata.[5] Glacial thrusts are expressed as either extracted masses of displaced bedrock that are moved a short distance or as faults and folds associated with glacial shear planes.
- Fine-grained glacial deposits that have been subjected to the weight of several kilometres of glacier ice can exhibit consolidation. However, the relatively young age of glacial deposits means that they have not been subjected to adequate pressure, temperature, and cementation to be sufficiently lithified and indurated.

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[3] Stephenson, D.A., Fleming, A.H., and Mickelson, D.M. (1988): Glacial deposits; The geology of North America, Hydrogeology, v. O-2. The Geological Society of America.

[4] Cherry, J.A. and Parker, B.L. (2004): Role of aquitards in the protection from contamination: A “state of the science” report. Awwa Research Foundation.

[5] Andriashek, L.D. (2002): Quaternary geological setting of the Athabasca Oil Sands (in situ) Area, northeast Alberta. EUB/AGS Earth Sciences Report 2002-03, URL: <www.ags.gov.ab.ca/publications/abstracts/ESR_2002_03.htm>

5 Limitations of McMurray Inclined Heterolithic Strata for Reservoir Containment

The McMurray Formation can be subdivided into the Upper, Middle, and Lower McMurray. The estuarine Middle McMurray has both a fluvial and marine influence and is dominated by point-bar deposits. Middle McMurray estuarine point bars consist of sandstones at the base that fine upwards into a thick (up to 30 m) package of interbedded sandstones and silty mudstones, commonly called inclined heterolithic strata (IHS). There are regions in the shallow thermal area where the only strata between the bitumen reservoir in the McMurray Formation and the overlying glacial deposits are IHS.

IHS are not considered suitable for containing steam and heated reservoir fluids for the reasons below.

- Changes in lateral and vertical facies associated with point-bar deposits make predicting the occurrence and continuity of mud beds within IHS successions difficult, even with good-quality log and core data for wells that may be spaced only tens to hundreds of metres apart.[6] In addition, channel migration creates erosional surfaces that may deposit higher-permeability sandstone adjacent to silty mudstone IHS.
- Interbedded sandstones and silty mudstones within the McMurray IHS can be inclined up to 12 degrees.[7] The inclined higher-permeability sandstone interbeds may provide a pathway for vertical fluid migration.

6 Draft Caprock Information Requirements for the Shallow Thermal Area

For SAGD scheme applications in the shallow thermal area, the following requirements must be met. All isopach, structure, and depth maps must incorporate three-dimensional (3-D) seismic, be annotated with well data, and be at a scale that shows the project area.

1) Describe how the caprock meets the shallow thermal area caprock criteria, supported by logs from representative wells that illustrate the caprock, formation tops, and 75 API unit cutoff on the gamma-ray log.

[6] Fustic, M., Bennett, B., Huang, H., MacFarlane, B., Leckie, D., and Larter, S. (2011): Bitumen and heavy oil geochemistry: a tool for distinguishing barriers from baffles in oil sands reservoirs; Bulletin of Canadian Petroleum Geology, v. 59, p. 295–316.

[7] Labreque, P.A., Hubbard, S.M., Jensen, J.L., and Nielsen, H., (2011): Sedimentology and stratigraphic architecture of a point bar deposit, Lower Cretaceous McMurray Formation, Alberta, Canada; Bulletin of Canadian Petroleum Geology, v. 59, p. 147–171.

2) Describe the information used to delineate the caprock in the project area, supported by

   a) a map with the location of evaluation wells, cored wells, and wells with fracture imaging logs; and

   b) a map showing where 3-D and two-dimensional (2-D) seismic data have been acquired.

3) Describe the geology of the caprock, supported by

   a) the lithology and mineralogy of the caprock, including available particle size and mineralogical analysis;

   b) structure maps of the caprock top and base;

   c) a map of the depth to base of caprock in metres true vertical depth;

   d) an isopach map of the caprock; and

   e) representative log cross-sections illustrating the thickness and continuity of the caprock, including formation tops and the 75 API unit cutoff on the gamma-ray log.

4) Acquire 3-D seismic data for the entire development area[8] and for any future expansions to the development area to identify faults, incising channels, and localized subsidence features that may not be identified by evaluation wells or 2-D seismic data, and provide the following information:

   a) a description of the 3-D seismic data acquisition parameters and the methods used to process the data;

   b) representative depth-converted seismic sections tied to well logs that are annotated with formation tops;

   c) structure and isopach maps of the Prairie Evaporite Formation, Paleozoic Era, Wabiskaw Member, and Clearwater Formation; and

   d) a description of any faults, incising channels, and localized subsidence features in the project area, supported by

      i) a map that illustrates the location of these features,

      ii) a discussion of the strata containing these features,

      iii) a discussion of the impacts on the caprock of these features, and

      iv) an explanation of how the proposed development strategy mitigates the possible impacts of these features on caprock integrity over the life of the project (e.g., setbacks and operational strategies).

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[8] *Directive 023* (2013 draft) defines a development area as the boundaries within the project area approved for specific placement of drainage patterns for the recovery of bitumen.

5) Acquire representative caprock core and fracture imaging logs for wells with caprock core for the development area and for any future expansions to the development area and provide a description of the caprock fracture occurrence, supported by

   a) depth-corrected photos for all caprock core, and

   b) a comparison of fractures identified in core and fracture imaging logs, with examples from each.

6) Acquire representative diagnostic fracture injection tests (DFITs) for the caprock and the reservoir in the development area and for any future expansions to the development area and provide the following information:

   a) the raw test data;

   b) a discussion of the operational procedures for the tests;

   c) the test intervals in metres true vertical depth;

   d) an interpretation and analysis of the test results, supported by

      i) the estimated fracture closure gradient for the reservoir and caprock,

      ii) a description and justification of the analysis techniques and interpretation, and

      iii) the identification of any unexpected or unusual test results and a discussion of possible causes;

   e) the criteria used to determine the locations of the DFITs; and

   f) a discussion of any geological features that could affect the DFIT results.

7) Describe the continuity, thickness, porosity, and permeability of all porous intervals between the bitumen reservoir top and the base of caprock, supported by data from representative wells and isopach maps of the intervals.

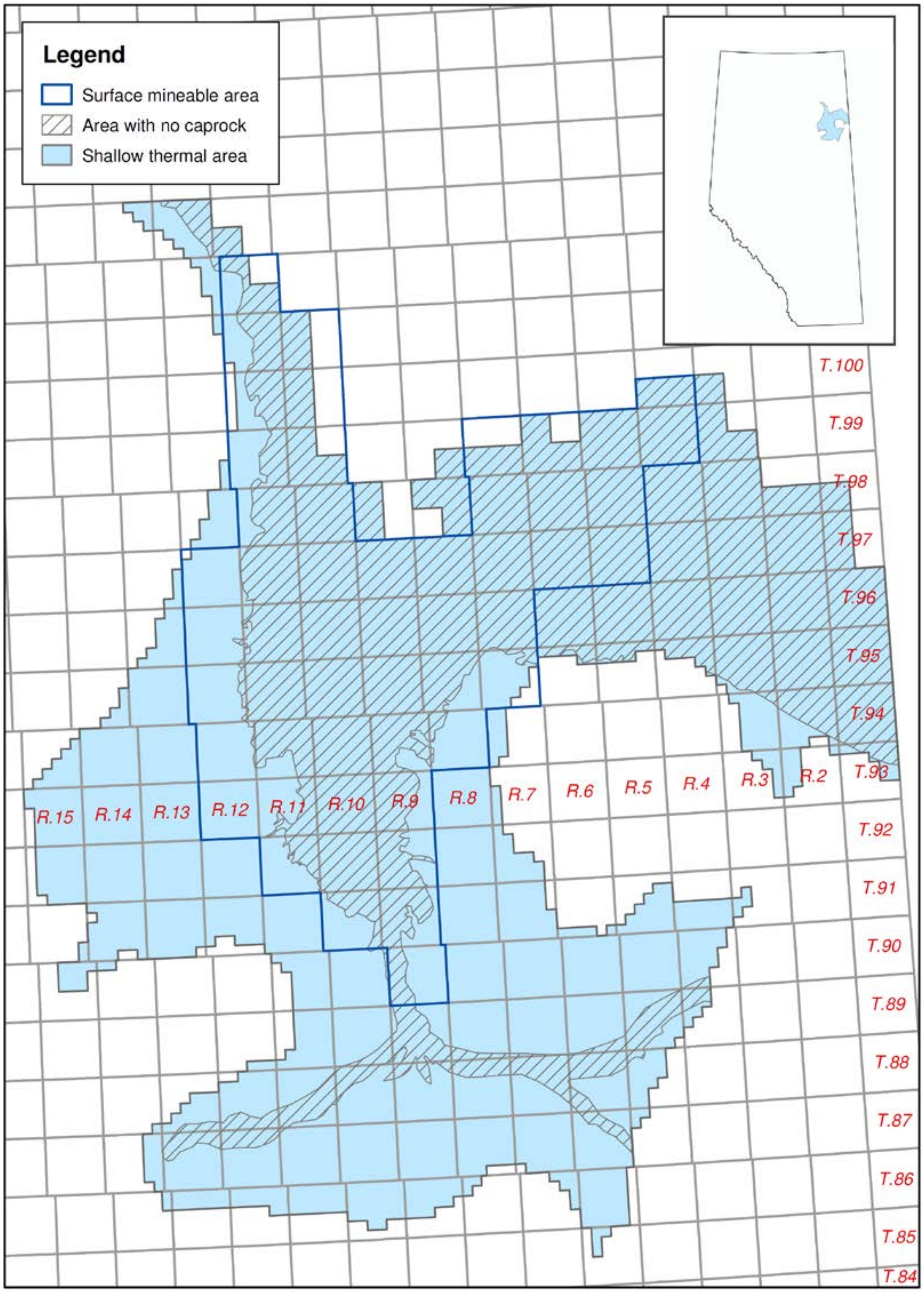

Figure 1. Shallow thermal area

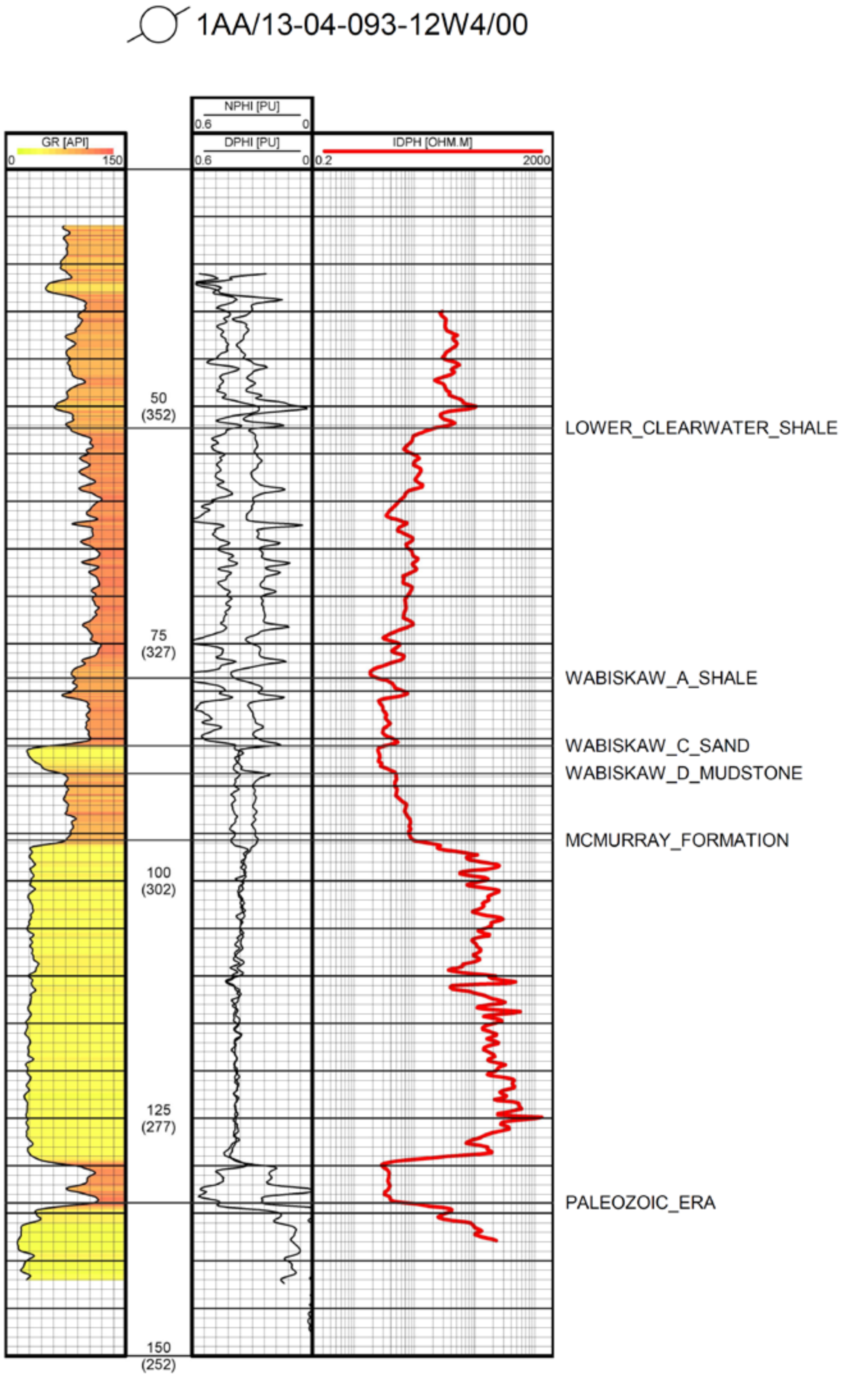

Figure 2. Reference well log