Water Disposal in the Upper Elk Point Carbonates under the Athabasca Oil Sands Area, N.E. Alberta*

Michael B. Rogers[1]

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[1]Nexen Inc., Calgary, Alberta, Canada (Mike_B_Rogers@nexeninc.com)

Abstract

Water disposal is an essential part of any SAGD project. Understanding the reservoir characteristics is a vital part of drilling, completing and long-term usage of any disposal well. The Upper Elk Point Group carbonates in NE Alberta are suitable water disposal targets but their long and complicated history means that a thorough geological understanding is required to make a successful project. The core display will present a depositional facies model and show examples of subsequent diagenetic overprints that ultimately affect the success of water disposal schemes in the Upper Elk Point Group carbonates.

Introduction

The Wabiskaw-McMurray deposit of the Athabasca Oil Sands Area contains over 140 billion barrels of recoverable bitumen of which about 75% is too deep to mine under current economic conditions (E.R.C.B. 2011). The bulk of this deeper resource will be extracted using some form of in-situ thermal method. In current and projected in-situ extraction schemes, very large volumes of water are used. Although most of this water is recycled, the unrecyclable water amounts to significant volumes. This water is typically injected into deeper underground formations for disposal, which must be conducted safely and economically.

The ideal disposal formation has three main attributes:

1. Excellent near-wellbore permeability, in carbonates this is often a result of natural fractures
2. Large regionally connected pore volume
3. Vertical and lateral containment for long term storage

The Middle Devonian aged Upper Elk Point Carbonates meet these three criteria only in select locations. Consequently, a regional and locally detailed knowledge of the sedimentology, structural history and diagenesis is essential for planning a long-term water disposal program in this interval.

Approximately 200 to 400m below the bitumen-bearing McMurray Formation lie the regionally pervasive carbonates of the Middle Devonian aged Upper Elk Point Group. This carbonate unit was deposited as a regional platform carbonate to the south-west passing northeastward into an open marine basin in which isolated biogenic mounds developed. In the inter-mound areas, basinal algal laminites formed.

Subsequent to carbonate deposition, the basin became evaporitic creating an environment ideal for dolomitization. During this period, the majority of the original limestone was converted to dolomite by shallow reflux dolomitization, which resulted in the development of excellent porosity and permeability. As the salinity in the basin increased, anhydrite and halite formed between and over the mounds and platform blanketing them in a regionally extensive evaporite unit.

Later Paleozoic deposition buried the Elk Point Group to a depth in excess of 1500m. The middle Mesozoic transition to a foreland basin caused uplift and erosion, which lead to the introduction of fresh water to the system. This fresh water influx caused extensive dissolution of the evaporites and massive changes in pore geometry.

The core presentation will introduce a new sequence stratigraphic history of the Upper Elk Point Group and use that interpretation to discuss the impact on the diagenetic fabrics of the different facies present. This will be related to geological factors that need to be addressed when targeting disposal wells in the Upper Elk Point Group and during subsequent evaluation, testing and monitoring of disposal wells in the unit.

Geology

Regional mapping confirmed that the Upper Elk Point Group of N. E. Alberta was deposited in and around extensions of the La Crete and Saskatchewan sub-basins with stratigraphy more consistent with that described in the Saskatchewan part of the basin (Figure 1). Consequently, the terminology used in the presentation is based mainly on the Saskatchewan table of formations (Reinson et al. 1972, Zhang et al. 2004).

Middle Devonian Depositional History

The underlying Lower Elk Point Group was deposited on a highly eroded and irregular Precambrian and Lower Paleozoic surface. Deposits of primarily continental red beds and evaporites filled the depressions resulting in a vast inland plain. Deposition of the Upper Elk Point Group began with the Middle Devonian Kaskaskia eustatic transgression. The basin began to fill with a broad, flat deposit of evaporitic coastal plain sediments of the Contact Rapids Formation. Sea level continued to rise initiating a rapid flooding of this coastal plain. During this event, it is estimated that sea level rose by as much as 100m and flooded open marine water across Western Canada from N.E. British Columbia to North Dakota. This rapidly deepening event is represented by the Lower Keg River Formation and culminates in an organic rich laminated wackestone with abundant *Tentaculites*.

The perimeter of this very large basin was then partially infilled by a prograding carbonate ramp deposited in moderately deep water. In the centre of the basin, biogenic carbonate mounds formed. The fauna of the ramp facies and the basal parts of the mounds are rich in several types of algae and corals that seemingly stabilized the deep water carbonate muds and allowed the growth of frame-building biota.

Growing in relatively deep water, but still within the photic zone, codiacean algae formed the material that constitutes the bulk of the lower 2/3 of the mounds (Martindale et al. 1989). In the upper, shallower parts of the mounds, which grew to sea level, Chaetetid sponges, red algae, bryozoa, corals and stromatoporoids become the dominant biota (Martindale et al. 1991). Pelloidal grainstones, presumably stabilized by algae, bryozoa and other filamentous organisms, make up a significant portion of the mound facies. The isolated mounds in the centre of the basin reach a maximum height of about 100m. Meanwhile, the margins of the basin evolved from a ramp to a platform on which formed a variety of shallow water carbonates including patch reefs, pelloidal grainstone shoals, lagoonal muds and occasional intertidal flats deposits.

At that point in time, far to the north-west, reef growth became so prolific that a line of reefs stretching from the Peace River Peninsula to the northeast coast of the basin coalesced to form the Presqu'ile Barrier. Water flow through the barrier was restricted and being in an arid environment, the basin became evaporitic. Evaporitic drawdown of the basin subaerially exposed the mounds resulting in characteristic vadose and phreatic diagenetic textures. Meanwhile during the resulting regression off the basin-margin platform, a thin Sabkha deposit developed followed by a subaerial exposure surface. During this period, the majority of the original limestone was converted to dolomite by shallow reflux dolomitization, which resulted in the development of excellent porosity and permeability in much of the carbonate units.

As the water level in the basin continued to drop as a result of evaporitic drawdown, the salinity increased. Anhydrite and algal laminated dolomite began to be deposited around the basinal mounds. At the same time, an anhydrite alteration zone formed within the mounds. Unfortunately, during this phase, a portion of the porosity in the dolomite was filled by anhydrite. Eventually the seawater became supersaturated with respect to NaCl causing halite to precipitate from the water between the mounds. The halite formation occurred both on the sea floor as vertically aligned halite chevrons and as a rain of surface generated smaller halite crystals. The inter-mound basins became almost completely filled with the Lower Prairie Evaporite (Whitkow) Salt.

After a significant period of subaerial exposure, sea level began to rise again, inundating the Presqu'ile Barrier. Initially, less saline brines flooded back across the basin depositing the Quill Lake Dolomite. However, renewed reef growth re-established the Presqu'ile Barrier as an effective barrier to marine water influx. A vast inland basin, a few metres below sea level, was created that slowly filled with evaporites in shallow salinas. The first deposit was the Shell Lake Anhydrite gradually passing up into the Middle Prairie Evaporite Salt as NaCl saturation re-established itself. The Middle and Upper Prairie Evaporite Salts were deposited over the entire study area enclosing the underlying carbonates in a thick blanket of evaporites.

Post-Depositional History

After a long period of moderate burial, these deposits were uplifted in association with development of the Mesozoic foreland basin. This uplift resulted in erosion of the overlying Devonian sediments exposing gradually older rocks in a SW to NE direction. As the Upper Elk Point Group sediments came closer to the surface, they were subjected to the introduction of fresh groundwater circulation that began the process of dissolution of the evaporites.

The dissolution process proceeded from the outcrop area to the NE in a SW direction in three stages:

1. Dissolution of halite
2. Conversion of anhydrite to gypsum
3. Dissolution of gypsum

Dissolution is a critical part of the water disposal story as it re-opened evaporite plugged vuggy porosity and fractures. Areas with less dissolution may experience more challenges when it comes to establishing suitable disposal sites within the Elk Point carbonates.

Core Display Features

Because the Upper Elk Point Group contains a large number of depositional facies and diagenetic features, multiple wells are required to tell the whole story. For this reason, small-cored sections from a number of widely distributed wells will be used.

Cores will be shown that highlight depositional and diagenetic facies including:

Open Marine Carbonates

Transgressive Deepening Facies
Tentaculites Laminated Facies
Carbonate Ramp Facies
Prograding Platform Facies
Pelloidal Grainstone Facies
Biogenic Mound Facies

Evaporite Environments

Coastal Sabkha Facies
Evaporitic Mudflats Facies
Sub-aqueous Halite Facies
Salina-type Halite Facies

Diagenetic Fabrics

Vadose and Phreatic Diagenetically-modified Facies
Dissolution Facies

Conclusions

The Elk Point Carbonates of NE Alberta are an attractive target for water disposal from SAGD projects in the Athabasca Oil Sands but the complicated geology needs to be understood to ensure success. A combination of depositional facies analysis and understanding of subsequent early and late diagenetic events are critical for establishing both well bore capability and long-term storage capacity.

Acknowledgements

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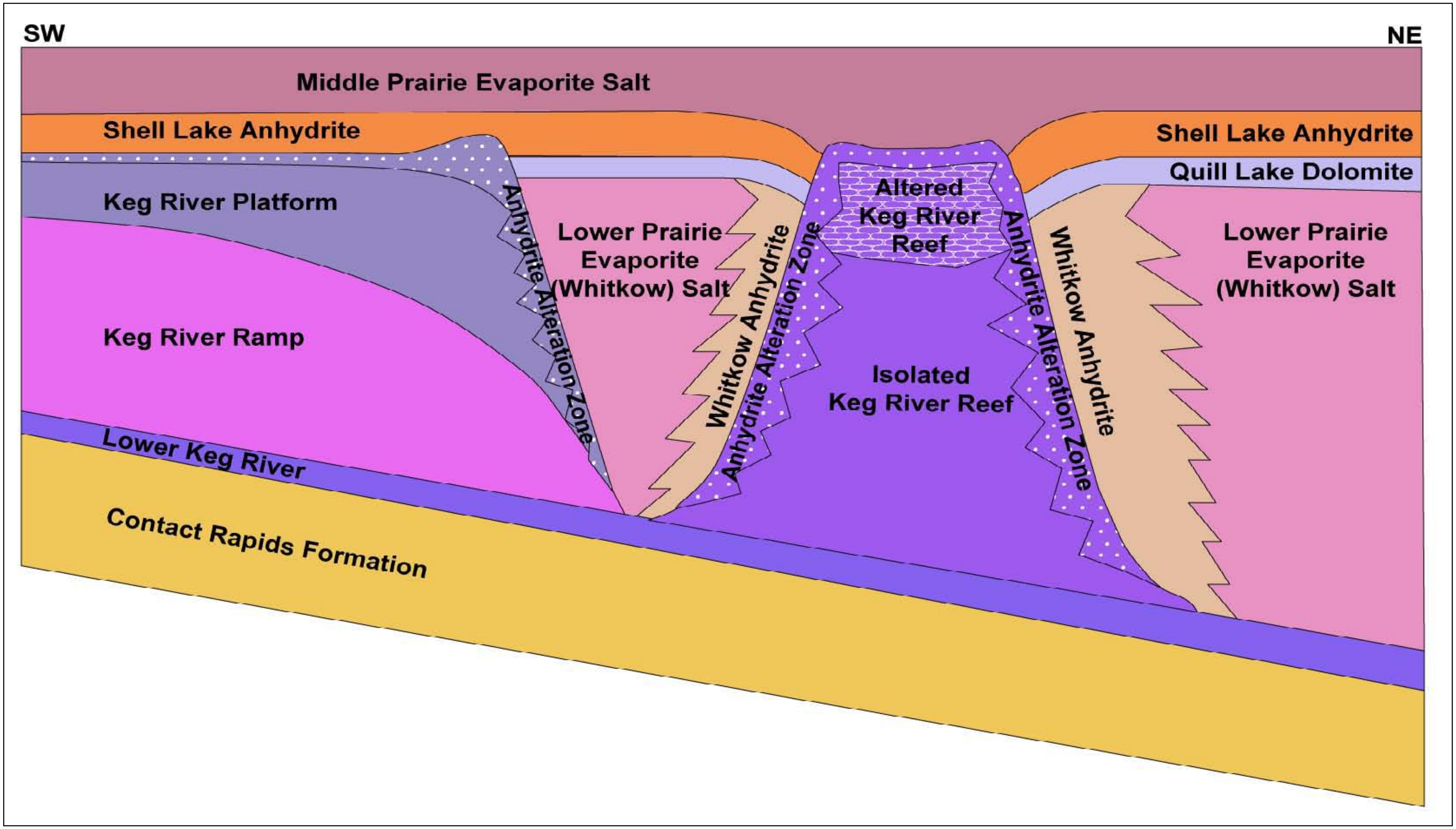

Figure 1. Table of formations and depositional model.