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LOWER GRAND RAPIDS BITUMEN POOLS AT COLD LAKE, ALBERTA – VARIATIONS IN STRATIGRAPHIC SETTING AND DEPOSITIONAL ENVIRONMENTS

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Summary

Mannville Group strata in the Cold Lake Oil Sands area host immense heavy oil and bitumen reserves, which are being produced using both cold and thermal recovery processes. Most thermal operations to date have focused on shallow marine and transitional sandstones of the Clearwater Formation. Substantial resources also exist in the Grand Rapids Formation, but our stratigraphic and reservoir knowledge of the Grand Rapids is not as advanced, and there are only two producing thermal operations.

Our goal for this presentation is to characterize producing Grand Rapids reservoirs at Wolf Lake and Tucker Lake, and to compare stratigraphic boundaries and depositional settings with the Grand Rapids reservoir mapped by OSUM Oil Sands at Taiga (see adjacent Core Conference presentation by Quinn and Willmer).

Regional Setting

The Grand Rapids Formation lies above marine shales and lowstand shoreface sandstones of the Clearwater Formation, and beneath thick Joli Fou shales. Cant and Abrahamson (1997) interpreted Grand Rapids internal stratigraphy as: "falling and lowstand sea level deposits which offlap from surfaces equivalent to updip unconformities. Six allostratigraphic units defined on the basis of regressive surfaces of erosion cut at the bases of shorefaces and transgressive surfaces at their tops have been defined. Each offlapping allostratigraphic unit consists in the south of thin channel and crevasse-splay sands grading northward into major shoreface sands."

Maynard et al. (2010) demonstrated that a complex sequence stratigraphic architecture, building on the principles of the Cant and Abrahamson model, comprising nearshore marine facies punctuated by incised valley fills can be mapped in the Grand Rapids of the Cold Lake area. The current study area lies at the position of the arrow in Fig. 1, where the lower part of the Grand Rapids consists primarily of stacked deltaic to shoreface facies, while the upper part comprises marginal marine strata cut by flooding surfaces and estuarine valley fills at several levels. Reinforcing this placement, Beynon et al. (1988) established that Grand Rapids strata exhibit a well-developed brackish water ichnofauna in the Cold Lake area.

Wolf Lake Lower Grand Rapids Pool

Canadian Natural Resources Ltd. (CNRL) produces bitumen from a lower Grand Rapids sandstone body in Twp 65 and 66, Rge 5W4, using SAGD wells drilled from four pads. The primary lower Grand Rapids reservoir at Wolf Lake is a laterally-continuous sandier- and coarsening-upward succession interpreted as a delta strandplain to shoreface. The core from well 16-4-66-5W4 shows a well-

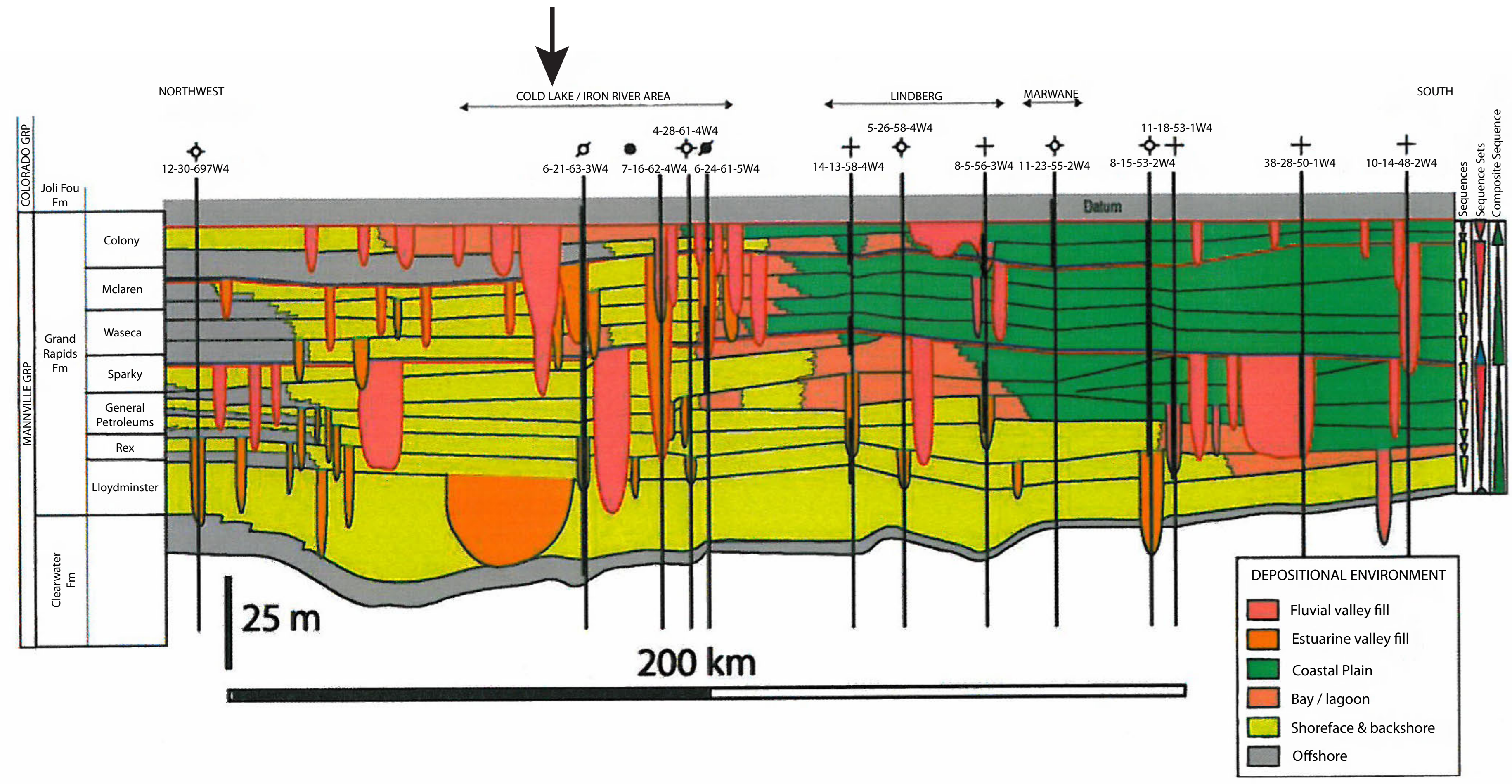

Figure 1. Schematic regional cross-section relating Mannville Group stratigraphy in east-central Alberta. Area indicates approximate position of Wolf Lake/Tucker Lake pools.

developed shoreface succession, grading up from heterolithic interbedded light grey muds and bitumen-stained sandstones, to massive bitumen-saturated sandstones in the upper several metres (Fig. 2). Bitumen saturation obscures sedimentary structures in clean sandstone sections, although large-scale low-angle planar lamination can be observed in places. Mudstone beds grade from mm scale where scarce, to cm and dm scale toward the base of the succession, where they can make up as much as 40-50% of the gross rock volume. While burrowing is neither diverse nor intense, there are isolated mud-filled burrows preserved within sandstone beds, and sand-filled burrows breaking mudstone beds. Grain size variation is limited, ranging generally from lower very fine to upper fine-grained.

The Wolf Lake shoreface is capped by a thin transgressive marine shale, correlative throughout the entire study area (and eastward through Tucker, to Taiga, as discussed below). There was no evidence noted of exposure, such as rooting or soils, at the top of the shoreface succession and beneath the transgressive shale marker. However, the shale marker has been eroded beneath younger channel deposits in some wells, particularly along the southeastern margin of the pool.

Stratigraphic well log cross-sections demonstrate the continuity of the Wolf Lake shoreface through the study area, and in particular the continuity of the capping marine shale marker (Fig. 3). Two to three sandier-upward successions, interpreted as older lower Grand Rapids shorefaces, are seen to be regionally correlative between the Wolf Lake shoreface and the regional Clearwater Shale. Above the Wolf Lake shoreface, at least four regional flooding intervals are recognized and correlated within the upper Grand Rapids.

The Wolf Lake shoreface is bounded along its southeastern margin by a younger incision event, while to the northwest it grades to more distal shoreface deposits with significant interbedded mudstones that degrade reservoir quality (Fig. 3). Net pay thickness in the developed area generally ranges from 12 to 15 metres, and the pay section features average porosity of 33% and average oil saturation of 75%, according to the operator. Reservoir sandstones are fine-grained sublitharenites that can be characterized fairly clearly on logs. Some uncertainty in net pay determination occurs in more distal facies with mudstone laminae, and additional bitumen volumes could be attributed to the pool by adopting less conservative net pay cutoffs.

Tucker Lake Lower Grand Rapids Pool

Husky Energy produces bitumen from a lower Grand Rapids sandstone in Twp 64, Rge 4W4, using a single SAGD pilot well pair, although additional drilling activity took place in 2013. The reservoir is interpreted to occur within an estuarine valley-fill complex. Cores from well 00/10-32-64-4W4 show a thick, homogeneous bitumen-saturated sandstone, fining upward from upper fine to lower medium at the base of the cored section to lower to upper fine-grained at the top. The entire cored section is within the valley fill, so there are no contact relationships to be examined. Bitumen saturations obscure sedimentary structures and other features, but pervasive low-angle large-scale cross-lamination can be seen toward the base of the core, as well as a couple of thin mud layers (clasts?) where saturations are lower.

At 00/13-32-64-4W4, we see a section dominated by finely-laminated sandy mudstones and muddy sandstones, broken by the abrupt introduction of bitumen-saturated sandstones at the base of Core #2; unfortunately the contact appears to have been lost at the core break (Fig. 4). Large angular mud clasts dominate the basal 1.5 m of the sandstone succession, above which laminated cm- to dm-scale mudstone beds are common, with the uppermost substantial bitumen-saturated sandstone occurring above 6.5 m below the top of Core #1. The section is dominated by physical structures, with little burrowing. Low-angle large-scale lamination is most common, but finely-interbedded intervals show current ripples and climbing ripples highlighted by thin bitumen-stained sandstones. Small-scale soft-sediment faulting is evident in places. A stratigraphic cross-section (Fig. 5) shows 13-32 to be within

Figure 2. Core photos, Wolf Lake shoreface section, BP PCI 00/16-4-66-5W4.

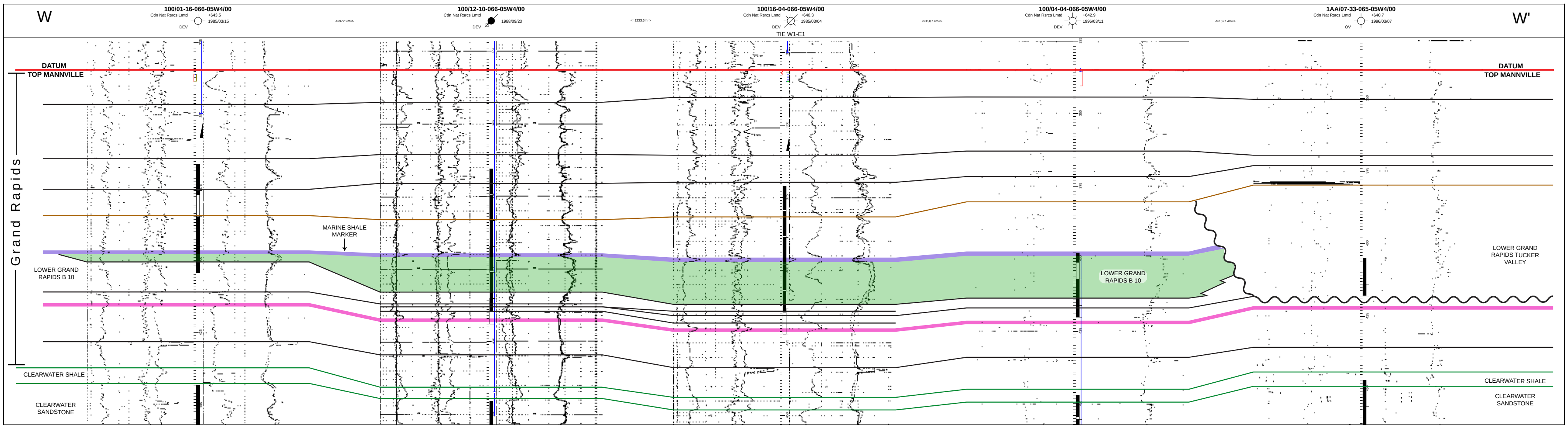

Figure 3. Stratigraphic cross-section W-W’, Wolf Lake pool.

Top

Husky EOR C11 Cold Lake
00/13C-32-64-04W4

Base

Intra-Valley Scour Marked by Sandstone and Mud Clasts

Near Top Valley Fill?

Tucker Valley Fill
(Non-Reservoir Facies)

Figure 4. Core photos, Tucker Lake valley fill section, Husky 00/13C-32-64-4W4.

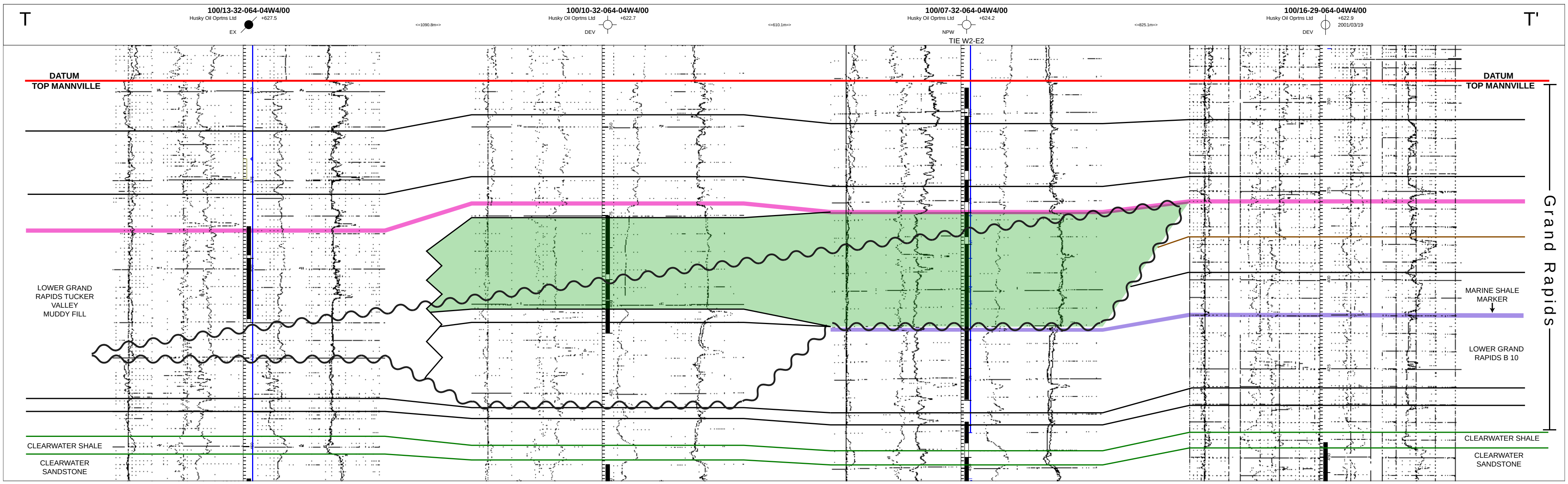

Figure 5. Stratigraphic cross-section T-T',
Tucker Lake pool.

the Tucker Valley fill unit, and so we interpret this section as a mud-dominated valley fill, interrupted by a high-energy event depositing sandstone in an overall muddier-upward succession.

Reservoir sandstones at Tucker are fine-grained litharenites containing substantial proportions of feldspars. While clean reservoir sandstones can be characterized reasonably well on logs, it is more difficult to distinguish facies with abundant mud laminae or clasts, partly because of “hot” gamma log signatures in the feldspathic sands. There is also relatively little contrast in resistivity values, making net pay determinations and picking of oil/water contacts difficult. Bottom water is thick and continuous along thick sand fairways in the south and east.

Where the valley incision is thin or absent, we see a similar regional succession as at Wolf Lake – a continuous Wolf Lake shoreface sandstone capped by a transgressive shale marker, overlain by a channelized unit. While the Wolf Lake shoreface is generally wet, the overlying unit shows good bitumen saturations in many places, and may represent an additional bitumen resource.

Correlation to Taiga Area

Regional cross-section A-A’ (Fig. 6) illustrates stratigraphic correlations from the CNRL Wolf Lake lower Grand Rapids pool in the west, eastward through the Husky Tucker Lake lower Grand Rapids pool, ending in the east at OSUM’s Taiga project area in Twp 65, Rge 2W4, which is highlighted in the Core Conference display by Quinn and Willmer. The Grand Rapids is readily picked between the top Mannville and Clearwater shale markers. Several intervals can be picked more or less continuously within the Grand Rapids, including the Wolf Lake/B10 shoreface and its capping transgressive shale.

OSUM’s well AA/13-26-65-2W4 shows a bitumen-saturated Wolf Lake shoreface succession virtually identical to that observed at Wolf Lake. At 13-26, however, we see coaly clasts and a 12 cm coal bed in place at the top of the succession, suggesting preservation of capping shoreline/washover facies beneath the sharp transgressive surface at the base of the overlying marine shale marker. This shoreface sand is the primary reservoir unit in the lower Grand Rapids at Taiga.

The stratigraphy in the Taiga area also includes incisions from the same marker as at Tucker, and from higher in the section (e.g., wells 1AX/1-7-65-3W4 and 1AA/12-30-65-2W4, Fig. 6). All these valleys contain sandy facies; however, the Tucker-age valley is entirely water-saturated. Relatively clean gamma log values and high resistivities at 12-30 suggest a smaller lithic-feldspathic component than in the valley at Tucker Lake.

References

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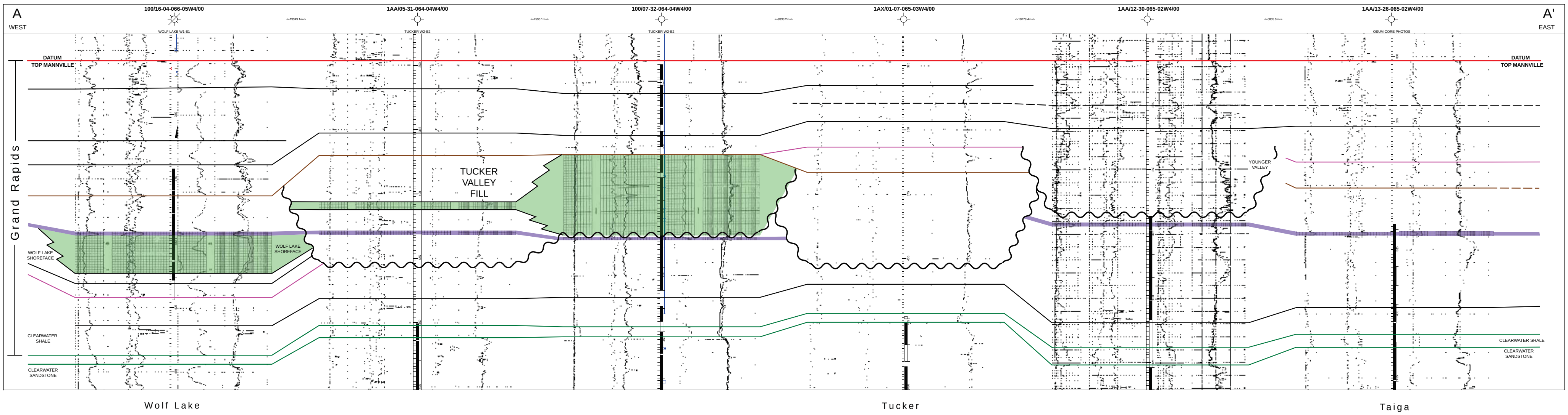

Figure 6. Regional stratigraphic cross-section A-A', linking Grand Rapids oil accumulations at Wolf Lake, Tucker Lake, and Taiga.