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Orthogonal geometrics of lower McMurray Formation sand complexes: effects of salt dissolution collapse-subsidence across the northern Athabasca oil sands deposit

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Summary

Lower McMurray strata distributed across the northern one-third of the Athabasca oil sands deposit filled cross-cutting troughs that formed a giant orthogonal lattice. This pattern of lineament pair bound troughs on the sub-Cretaceous paleotopography was configured by underlying Middle Devonian salt dissolution-collapses. The western segment of the giant 50 km long V-shaped Bitumont trough overlies the 5-10 km wide Middle Devonian salt scarp, which was further dissected by continued dissolution along lineament pairs during the lower McMurray period. There was a more complete removal of at least 100 m of salt beds underlying the eastern trough. Salt removals during the pre-Cretaceous and lower McMurray periods fragmented the overlying Upper Devonian strata into fault blocks that floored these giant cross-cutting troughs and resulted in Devonian block containers that differentially subsided and compartmentalized the lower McMurray deposits. These container fills were mostly coarser sand aggradations across the western trough in contrast to structurally lower heterolithic flood plain deposits to the east. The container fills inherited orthogonal geometrics contiguous with the underlying salt dissolution lattice pattern.

Introduction

Widely accepted pre-Cretaceous salt structuring is reinterpreted to have continued into the Aptian contemporaneous with lower McMurray deposition across the northern Athabasca deposit. A new interpretation is presented for the lower McMurray Formation strata distribution across the northern Athabasca oil sands deposit, which filled giant salt dissolution collapse-subsidence troughs on the underlying sub-Cretaceous paleotopography. A giant lattice pattern (Figure 1) with tens of kilometers long cross-cutting troughs is interpreted as an overprint of a similar, but now obliterated, reticulated pattern of dissolution troughs that formed within the substrate of Middle Devonian halite salt beds. Dissolution of more than 100 m of salt beds was initially directed along this orthogonal lattice of NW-SE and NE-SW oriented lineament pairs that dissected the 10 km wide Middle Devonian salt scarp as it migrated westward (Figure 1). Continued dissolutions between the lineament pairs resulted in collapse-subsidence troughs of the overlying Upper Devonian strata that now floor the Athabasca oil sands deposit. The unusually low 1:2 to 1:3 thickness ratios of halite salts to overlying strata resulted in the Upper Devonian strata collapse into underlying dissolution troughs being more cataclysmic during this earlier phase of salt removal. The slower but complete salt dissolution phase that followed removed the remaining salt beds between the earlier troughs. This resulted in more gradual subsidence of the overlying Upper Devonian strata, but also obliterated the earlier Middle Devonian intra-salt bed lattice pattern of giant cross-cutting dissolution troughs.

Interpretation

The western segment of the giant Bitumont trough developed extensive collapse-subsidence displacements during the Aptian contiguous with lineament B westward of the main paleovalley (Range 9), but not eastward (Figure 1). The western Bitumont trough floor fragmented into NW-SE and NE-SW oriented fault blocks at the 1-5 km scale with 10-20 m elevation differences. The largest and longest sag was a linear chain of fault blocks that extended southeast for 10-15 km along the western Bitumont trough floor. As a result, the trough floor of Devonian fault blocks was a composite of pre-Cretaceous and Aptian block movements that differentially subsided as the underlying salt scarp was dissected by the linear dissolution trends. This resulted in a reticulate mosaic of 1-5 km scale containers that differentially filled with lower McMurray clastics. These fills adopted orthogonal geometrics oriented NW-SE and NE-SW contiguous with the containers and underlying salt structuring. A sand distribution map (Figure 2) with a relatively high quality cut-off (Vsh<10%) emphasizes the orthogonal geometrics of these compartmentalized container fills across the western Bitumont trough floor. These sand (Figure 2) and mud (Figure 3) distribution maps have similar NW-SE and NE-SW orthogonal geometrics (lattice overlays) for a wide range of map parameters cutoffs. Similar orthogonal geometric patterns developed with heterolithic to muddy flood plain deposits that filled eastern Bitumont trough, in contrast to the mostly sand filled western trough containers. Although all of these lower McMurray deposits have a common orthogonal geometric pattern with NW-SE and NE-SW orientations, some areas emphasized dominant northwest orientations, whereas other areas had northeast alignments.

Lower McMurray sand accumulations initiated as a braidplain across both western and eastern trough areas. The relative instability of the western trough during lower McMurray deposition favored braided channel aggradations. These containers variously filled as fluvial channels switched between active and inactive subsidence block depocenters. The drainage favored actively subsiding containers with movements contiguous with the lineament B chain of fault block collapses. Up to 60 m thick sand aggradations filled these containers, and were capped by thickened coal beds.

Mosaics of reticulated containers also developed with more subtle movements across the eastern Bitumont trough floor and other eastward areas with advanced to complete salt removal at depth. The structurally lower eastern areas underlain by mostly pre-Cretaceous salt dissolution collapse areas accumulated thinned, water saturated, gravely sands as basal lower McMurray beds. These passed up into widespread heterolithic and muddy flood plain deposits (Figure 3). The braidplain of the more structurally stable eastern areas passed upwards into an anastomosing channel network. The eastward containers imparted reticulate fill patterns similar to those of the western trough, but mostly with heterolithic sands and muddy flood plain deposits, in contrast to coarse gravely sand fills of the western trough. The orthogonal fault block terrain across the eastern trough areas mostly resulted from pre-Cretaceous structuring. These eastward areas were less impacted by significant underlying fault block movements tied to Aptian salt dissolutions, excepting more localized sinkhole collapses over smaller fault block displacements at the tens of meters scale. This resulted in markedly less, but not absent, capacity for lower McMurray syndeposition. Larger kilometer scale rectangular containers were subdivided into reticulate patterns of over bank deposit fills at the hundreds of meters scales. These eastward areas had structurally stable channel banks with levee builds and over bank flood deposits that were frequently preserved in contrast to the western trough areas.

Bitumen saturated lower McMurray sand complexes are mostly distributed along the structurally elevated western segment of the Bitumont trough, areas at the junction of the northern E valley and the northeastern Bitumont trough, and small scattered patchy areas across the southeastern study area. The largest and thickest lower McMurray bitumen sand (BWB>8%) trend filled the western Bitumont trough (Figure 4). This study interprets bitumen saturated sands at all grade cutoffs to have reticulated

NW-SE and NE-SW oriented geometric patterns inherited from the underlying sand complex patterns. Similar lattice geometrics are observed for the smaller and thinner lower McMurray bitumen sand trends that accumulated elsewhere across the study area.

Conclusions

This new interpretation of salt dissolution collapse-subsidence structuring during lower McMurray deposition provides insights on how differing salt removal phases resulted in braidplain channels in some places and anastomosing channels elsewhere, but all with allegiances to a single underlying salt dissolution induced orthogonal structural framework. These sands were later saturated by oil migrations into the area, then biodegraded into bitumen. Orthogonal patterns inherited from the underlying sand complex geometrics controlled the bitumen thicknesses and grade variations. This counterbalance between a western braidplain and eastern anastomosing channel networks is a new interpretation for the lower McMurray fluvial architecture.

Acknowledgements

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Figures

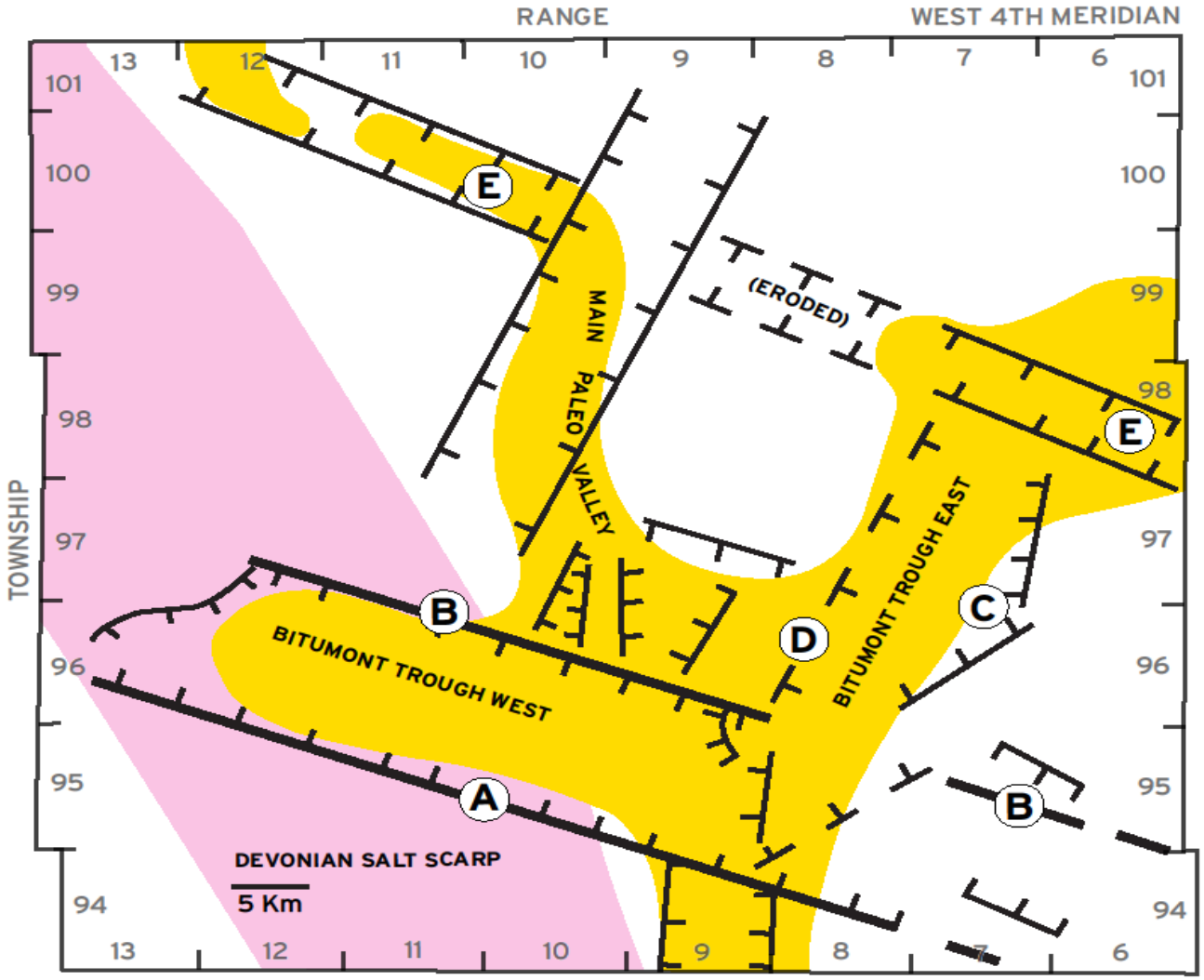

Figure 1. Structural interpretation of the northern oil sands deposit as a giant orthogonal lattice of cross-cutting salt dissolution collapse-subsidence troughs developed on the sub-Cretaceous paleotopography. The Middle Devonian salt scarp (pink) underlies the western Bitumont trough. These troughs filled with lower McMurray clastics (yellow).

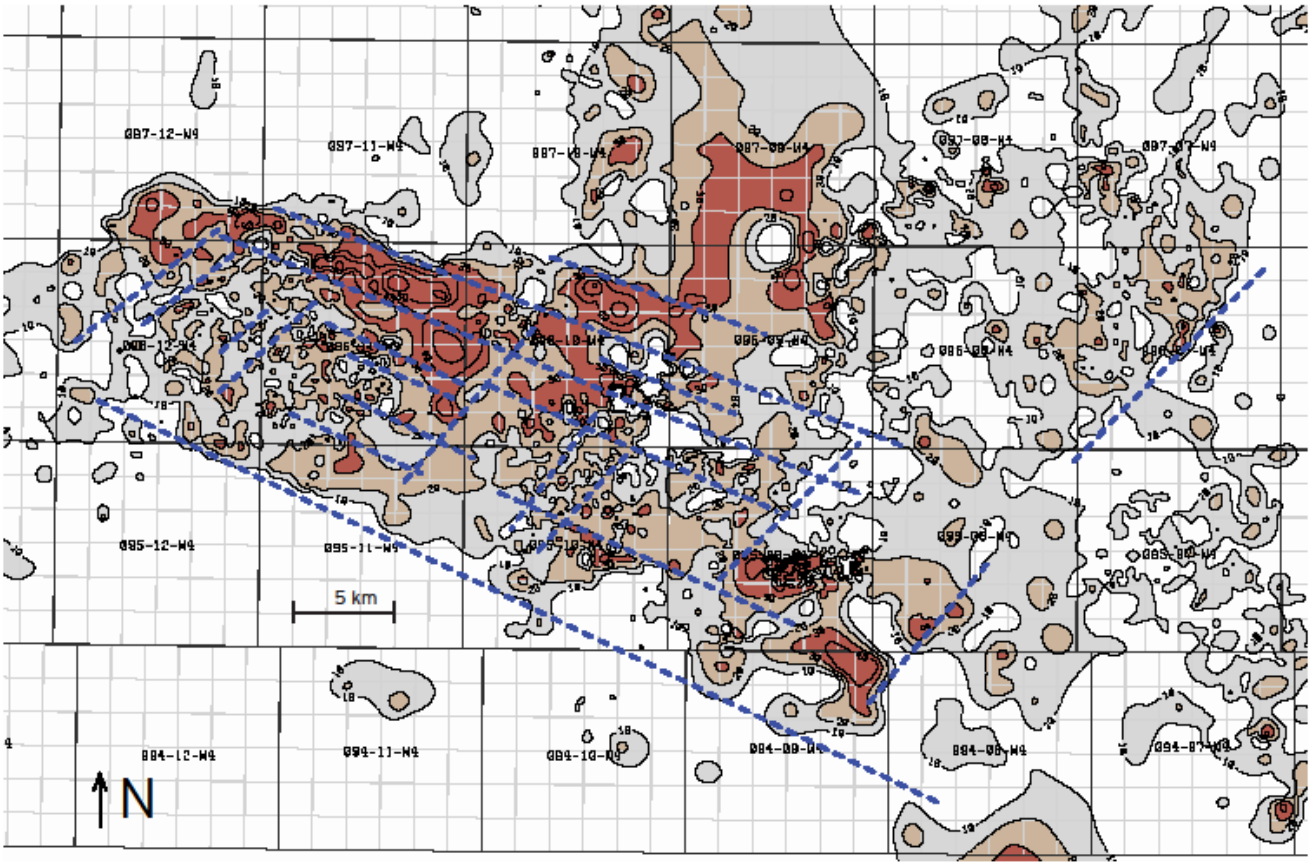

Figure 2. Devonian blocks compartmentalized lower McMurray sand fills (Vsh<10%) accumulated along the western Bitumont trough. The container fills have NW-SE and NE-SW orthogonal geometrics (lattice overlay) at the 1-5 km scale inherited from the underlying salt dissolution structural lattice.

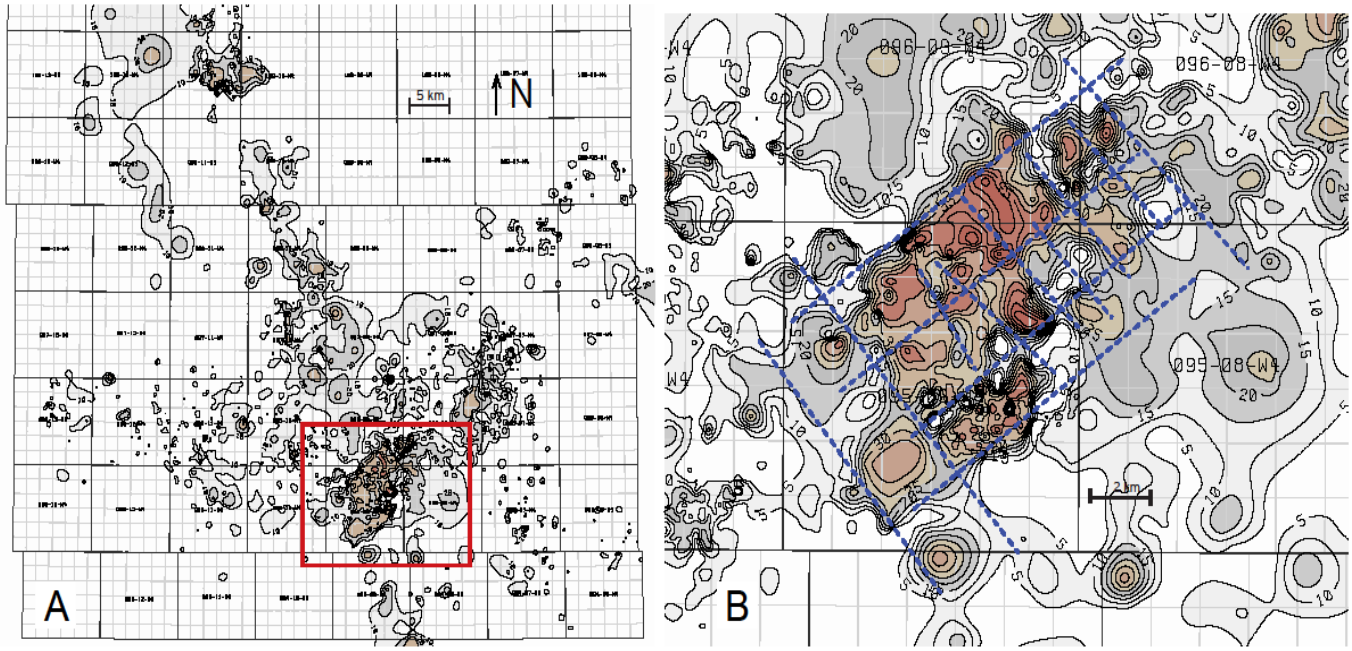

Figure 3. Compartmentalized heterolithic and muddy flood plain deposits (Vsh>25%) dominate the eastern Bitumont trough (A). These deposits filled a large container and sub-container areas (B) across the south-central Bitumont trough, eastward of the salt scarp edge. The reticulate pattern (lattice overlay) of these container fills developed as anastomosing channel deposits accumulated contiguous with underlying orthogonal lattice of salt dissolution collapse-subsidence lineaments.

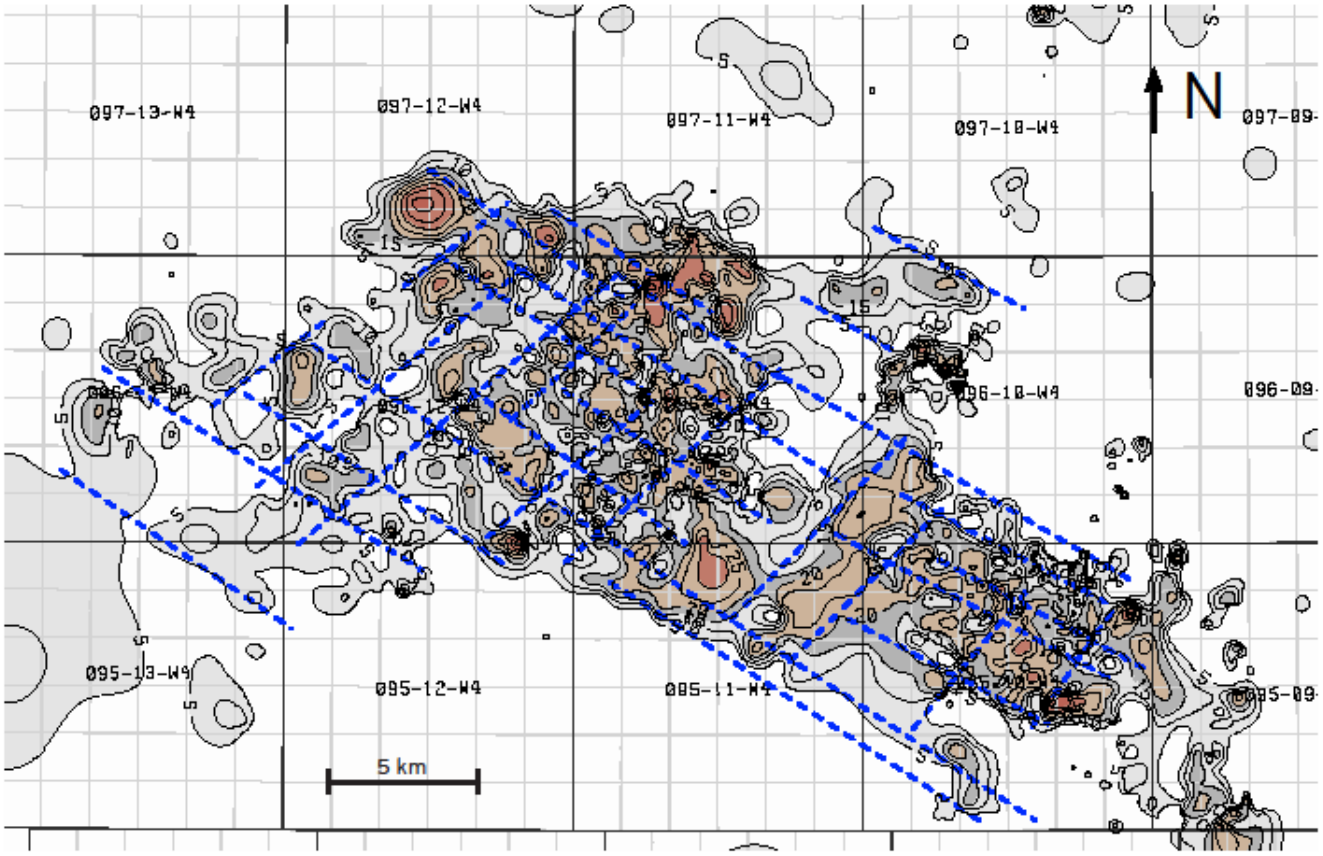

Figure 4. Bitumen saturated lower McMurray sands (BWB>8%) filled the western Bitumont trough containers, but were mostly wet eastward. The compartmentalized distribution pattern (overlay) was inherited from orthogonal geometrics of the sand complex container fills.