# Performance Of Mine Waste Earth Fill Dumped Into Deep Standing Water

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ABSTRACT
An inflow of saline groundwater from a deep aquifer beneath the Albian Sands Muskeg River Mine pit required construction of dykes to contain the saline water and isolate it from the active mining area. Large volumes of mine waste earth fills were dumped and pushed into the saline water pond to raise the water level in order to reduce the hydraulic gradient and the inflow rate, and to ultimately provide a seal to prevent further water ingress or future reverse flow. The saline water was then pumped out of the pond to medium-term storage, to provide room for in-pit tailings storage. Detailed procedures were required to safely advance the fills into deep standing water. A geotechnical investigation program was performed to determine the properties and verify the integrity of the seal. Observations of the material behaviour during backfill placement into the pond, and the controlled slumping of the outer shell of the containment dyke that occurred during pond drawdown, provide insights into the behaviour of the lean oil sand fills.

RÉSUMÉ
Un afflux d'eau souterraine saline provenant d'un aquifère profond sous la fosse de la mine Muskeg River à Albian Sands a nécessité la construction d'une digue pour isoler l'eau de la zone d'exploitation active de la mine. Des stériles ont été déversés et poussés dans la fosse pour élever le niveau d'eau afin de réduire le gradient hydraulique et le débit d'eau venant de l'aquifère et, ultimement, sceller le fond de la fosse. L'eau saline a ensuite été pompée hors de la fosse pour créer l'espace necessaire aux résidus miniers. Des procédures détaillées ont été nécessaires pour faire avancer en toute sécurité la construction du remblai dans l'eau accumulée au fond de la fosse. Une étude géotechnique a été complétée pour déterminer les propriétés du remblai et vérifier son étanchéité. Les observations du comportement des stériles miniers pendant la construction du remblai et lors de l'affaissement contrôlé de la couche externe de la digue de confinement donnent une idée du comportement géotechnique des remblais faits de stériles miniers de sables bitumineux.

## 1 INTRODUCTION

An inflow of saline groundwater from a deep aquifer beneath the Albian Sands Muskeg River Mine (MRM) pit that started in October 2010 required construction of dykes to contain the water and isolate it from the active mining area. During construction of the containment dyke, large volumes of mine waste earth fills were dumped and pushed into the saline water pond to raise the water level in order to reduce the hydraulic gradient and the inflow rate, and to ultimately provide a seal to prevent further water ingress or future reverse flow.

The inflow was in Cell 2a of the mine pit, which had been designated for in-pit tailings storage prior to the inflow. The structures providing containment in Cell 2a were In-Pit Dyke 2 (IPD 2) to the south, IPD 3S to the west, IPD 2i to the north, and the pit wall to the east. The inflow prevented use of Cell 2a for tailings storage, since the highly saline groundwater could not be mixed with water normally recycled to the oil sand extraction plant from tailings deposits. Figure 1 shows Cell 2a shortly after the start of the inflow.

This paper specifically addresses the program to backfill over the inflow locations, initially to create a pad for drilling investigation holes to determine the source of the inflow and to raise the water level in Cell 2a to reduce the inflow rate, and in a second phase to increase the thickness of the seal over Cell 2a to prevent further inflow as the saline water was pumped out for long-term storage. Once the saline water was removed, fluid fine tailings (FFT) was transferred into Cell 2a.


Figure 1. Satellite image from November 4, 2010 showing saline water inflow locations (within red circle)

## 2 GEOLOGY

Relevant aspects of the geology of MRM are described from the ground surface down, with the approximate top elevations in the vicinity of Cell 2a (Stoakes, 2014):

- Holocene and Pleistocene soils (285 m)
- Cretaceous McMurray Formation oil sand (280 to 285 m)

- Devonian Waterways, Slave Point and Watt Mountain Formations: shales, limestones, mudstones, anhydrites (180 m to 230 m)
- Prairie Evaporite Formation halites, anhydrites and dolomites that onlap against and over reefs and basin margins (108 to 166 m)
- Keg River Formation porous dolomites, comprising a lower ramp and an upper reef (54 to 105 m)
- Devonian Contact Rapids Formation shales and siltstones (14 to 39 m)
- Precambrian Basement granitic gneiss (-24 to -9 m)

An aquifer was previously known to be present in the lower Devonian, however, it was commonly viewed that the intervening caprock would prevent any inflow to oil sand mine pits. However, after the Cell 2a inflow, a geologic investigation found that conduits can exist through the caprock. The characteristics of the bedrock between the aquifer and the base of the pit were investigated with a series of deep core holes around the MRM site, and three shallow angled (25° below the horizontal) core holes drilled from the pad to the west of the inflow. A series of downdropped faults was identified as shown in Figure 2.

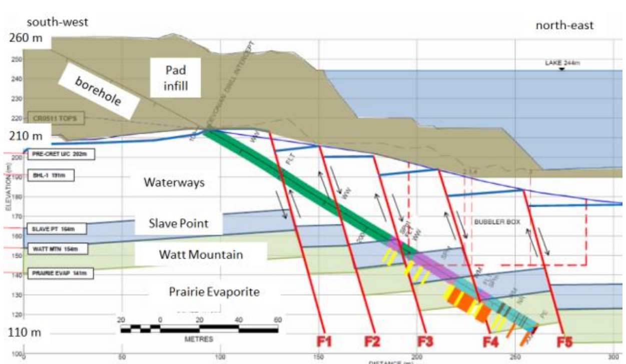


Figure 2. Schematic section through inflow location showing angled borehole and fault blocks (F1-F5)

Dissolution of the halites in the upper Prairie Evaporite Formation took place in response to an influx of fresh waters, primarily introduced into outcropping units along the basin margin to the east. The dissolution front advanced from east to west in multiple phases in areas where the Keg River reef was absent. This resulted in broad areas of collapse of the overlying rock and the formation of high angle faults through the overlying Devonian caprock. Interbedded dolomite units in the lower intact Prairie Evaporite Formation became de-dolomitized by the passage of calcium-charged water, and provide the laterally extensive aquifer that fed the saline water inflow. The high-angle faults through the Devonian caprock are mostly tightly sealed and did not display measureable permeability during borehole testing, however, in some discrete locations these faults may have been the source mechanism for upward forming karst and chimney development, which appears to have created the conduits through the caprock for the Cell 2a inflow (Stoakes, 2014). This type of karst, referred to as hypogenic karst, can occur where fresh water is introduced laterally, from the basin margin, but beneath an intact overlying caprock. This is in contrast to epigenic (top down) karst, which is the result of the downward percolation of waters from the surface (Stoakes, 2014). A conceptual karst propagation model is shown in Figure 3.

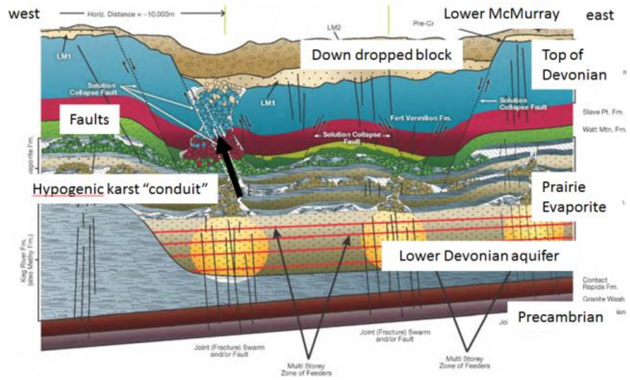


Figure 3. Conceptual karst propagation model (Albian Sands, 2014)

## 3 INFLOW EVENT

In mid-October 2010, Cell 2a was being prepared for tailings storage as mining was nearly complete in the area. Mining had terminated at the Pre-Cretaceous unconformity exposing the Devonian aged Waterways Formation at an elevation of approximately 188 m, resulting in the removal of about 100 m of material.

On October 16, 2010 an inflow of saline water occurred from discrete seepage points on the southwest side of Cell 2a. A satellite image from November 4, 2010 clearly shows two main inflow locations and two possible additional locations (Figure 1).

The initial inflow rate was approximately 4,000 $m^3$/hour based on records of the water level rise in the pond. The water chemistry indicated that the source was an aquifer associated with the Prairie Evaporite Formation, located approximately 90-130 m beneath the bottom of the mine pit. Total dissolved solids were measured at 38,000 mg/L (saline). The total saline hydraulic head in the Prairie Evaporite aquifer at that location prior to the inflow was approximately 260 m, or 70 m above the base of the pit.

### 3.1 Initial Response

The initial response was two-fold:

- Construction of IPD 3S and IPD 2i was advanced rapidly to maintain containment in Cell 2a; IPD 2 was already constructed to a higher elevation.
- Fill was pushed from the upstream of IPD 3S (west to east) (Figure 4) in an attempt to cover the inflow location with mine waste backfill using 797 haul trucks and D11 dozers. However, a combination of the high inflow rate and high unbalanced water pressure in the aquifer caused the backfill to wash away faster than it could be placed. This initial tactic was therefore abandoned in late 2010.

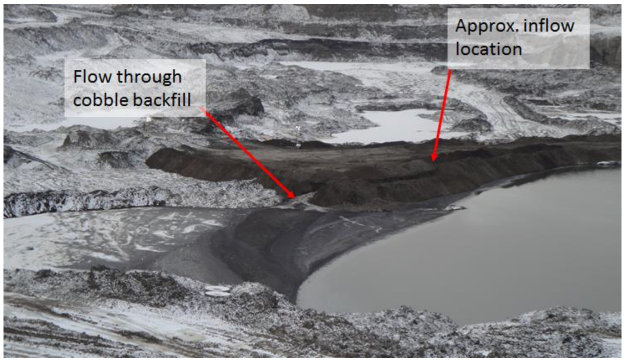

Figure 4. Erosion of initial backfill placement

## 4 PAD CONSTRUCTION – PHASE 1

During the initial active flow period, grouting through boreholes into bedrock at the base of the conduit(s) was proposed as an option to reduce the inflow. A pad of dumped lean oil sand mine waste material (overburden and interburden soils) was therefore advanced into the pond in 2011 with three objectives:

- Form a platform over the inflow locations for conducting grouting operations
- Raise the water level to reduce the hydraulic gradient between the underlying aquifer and the mine and therefore reduce the inflow rate and the total accumulated water volume
- Utilize the Cell 2a space for mine waste storage

At the time the Phase 1 construction started in August 2011, the pad that had been placed for initial water containment comprised a submerged lower bench at elevation 220 m, with the pad crest at 240 m. As the water level rose, the pad was raised in 5 m increments to maintain a minimum of 5 m above the water level.

### 4.1 Construction and Safe Work Practices

It was anticipated that cracking and slumping would occur along a semi-rotational surface as the crest of the pad was loaded, causing the toe of the slope to displace into the pond and the pad to advance into the pond. The factor of safety along a potential slip surface increases with distance from the crest of the slope. For reasonable assumptions of the material parameters for the fill and the below-water slope angle, a setback distance of 20 m was adopted for operational safety. Manned equipment was kept outside of this setback.

Since the pad would be advancing into deep water, the fill placed into the water would be un-compacted and vulnerable to undrained shearing. There was significant uncertainty as to how the lean oil sand fills would behave, including the scale and rate of slumping. To protect the safety of personnel, the following safe work practices were followed:

- Full-time monitoring of cracking and deformation of the fill slope using qualified geotechnical spotters
- Controlled equipment entry in the 20 m setback area; trucks were required to dump fill outside this offset
- Limited visibility of the 797 haul truck drivers required them to come in with cab side towards the dozer so that the lift in front was always visible to the operator
- Only remote controlled dozers were used for this phase of fill advance
- Dozers pushed two loads, perpendicular to the advancing crest, so that the second load acted as the safety berm
- Work stopped every 2 hours for an inspection of the advancing crest
- Full time $H_2S$ monitoring, since the initial inflow contained minor concentrations of dissolved $H_2S$
- A minimum 5 m freeboard between the crest and pond
- A maximum of 5 m advance of the crest into the pond per day along any cross-section
- The active dump platform was shut down for a 24-hour period upon observing crack(s), more than 3 m from the safety berm, and exceeding 100 mm in a vertical or horizontal direction in a 12-hour period.

Real time survey monitoring tools were utilized to measure the crest movement using techniques such as laser scan of the dump face and GPS measurements at specific stake locations. Underwater slope angles of the pad fill were measured twice monthly using remotely operated sonar boats until pond freeze-up. Daily construction reports were prepared with photographs of the crest taken from the same location to assess its progress with time.

### 4.2 Results

From August 2011 and January 2012, mine interburden waste was placed from the west and south into the Cell 2a pond. The pad crest initially advanced into the pond as placement proceeded. The crest advance in Phase 1 was about 30-40 m, over a bench 20 m below the advancing crest at elevation 220 m, and up to 15 m below the water line. The advancing underwater profile had two components, with a steeper fill depositing in up to about 10 m water depth and then a flatter toe building beyond that in a hockey-stick shape, which had the effect of shallowing the local water depth so that more fill could be built out at the steeper slope. However, when the toe of the advancing slope reached the crest of the submerged bench in November 2011, the water deepened significantly and no further crest advance occurred (Figure 5).

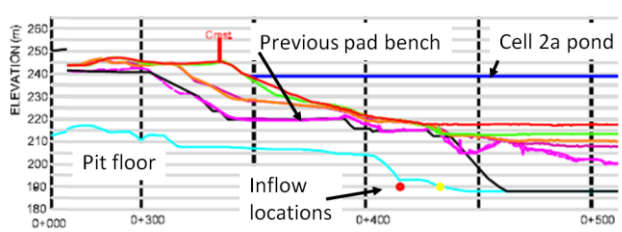

Figure 5. November 2011 section of crest advance profiles over previous pad.

Further fill that was pushed over the crest fell through a significant depth (15-30 m) of water before reaching the pond bottom, forming highly mobile slurry. The fill ceased to accumulate at the toe of the pad slope, but rather flowed into the interior of the pond, even reaching the pit slope on the far side of the pond, 300 m from the placement area, successively raising the floor of the pond but not advancing the crest further. An overall concave profile formed with progressively shallower slopes at a greater distance from the dump point and pond depth.

Some cracking and slumping of the advancing pad occurred while the pad was advancing over the submerged 220 m bench (Figure 6). Once the crest advance ceased, further fill placement into the water by dozers pushing fill over the edge of the crest resulted in no further cracking or slumping of the pad.

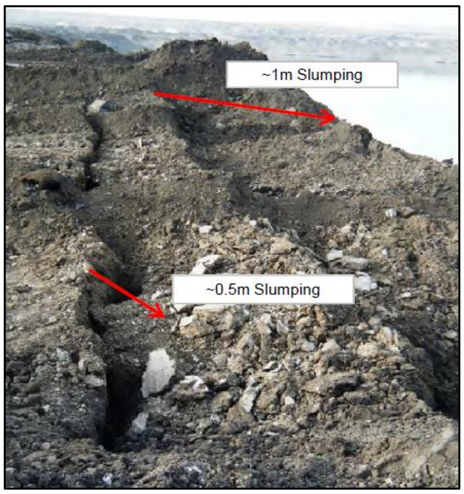


Figure 6. Pad slumping during construction – cracks observed ~ 2m behind the crest, August 2011

In late November to early December 2011 the pad was raised 6 m from elevation 244 to 250 m. The pit floor had been at roughly elevation 210 m under that area, for a fill thickness of approximately 34 to 40 m. The fill was typically placed in thick lifts (5-6 m), spread by D11 dozers and compacted with 797 haul trucks. Settlement of the pad was due to a combination of settlement of the existing fill due to the weight of the recently placed material, and self-weight settlement of the new material. Two precision GPS installations were placed 50-70 m from the crest of the pad to monitor settlement in anticipation of the shallow horizontal drilling program to check if ongoing settlement of the pad fill would excessively deflect the drill casing. A plot from one of the GPS monuments is shown in Figure 7, and settlement data from both monuments are summarized in Table 1. It was not possible to apportion the measured surface settlement between the total fill thickness and the incremental thickness, so both values are given as a percentage in Table 1 to bound the range. Most settlement occurred within one month of construction. Piezometers placed in the fill showed that the advance of the saturation front from the pond was very slow, and so the fill in the area of the settlement monitoring was likely partially saturated at the time, and the measured settlements would have been a combination of elastic settlement and consolidation.

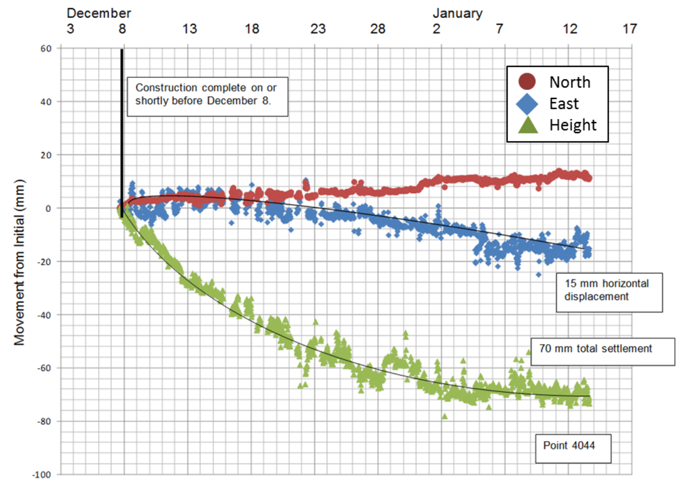


Figure 7. Pad settlement data from a 5 m lift

Table 1. Settlement Data from 250 m Elevation Raise

| Site | Settlement at one Month | | | Rate[1] (mm/day) |
|---|---|---|---|---|
| | Absolute (mm) | % of Total Fill Thickness | % of Incremental Fill Thickness | |
| 1 | 70 | 0.2% | 1.2% | 0.4 |
| 2 | 120 | 0.3% | 2.0% | 1.4 |

[1]ongoing settlement rate after one month

Standard Penetration Tests (SPTs) were completed at 5 locations on the constructed pad and vibrating wire piezometers were installed in two holes. The majority of SPT N-values were in the compact to very dense range (blow counts of 30-50+), despite placement of uncontrolled 5 m thick lifts of mine waste, indicating the influence of compaction from the large haul trucks. The top 5 m was compact with the density increasing proportionally with depth as shown in Figure 8.

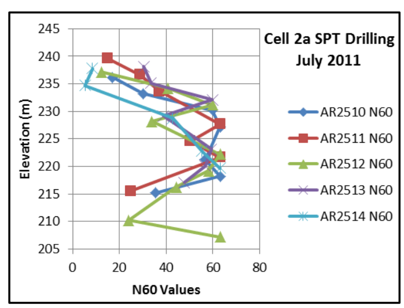


Figure 8. SPT results from 5 boreholes in the pad fill

Pad construction halted in January 2012 when it was apparent that the combination of the fill placement over the inflow location at that time (approximately 40 m), the increased water level in the pond, and lateral squeezing of the conduit due to the high fills placed immediately to the west, had halted any measurable inflow. The final below-water slope profile at the end of Phase 1 construction is shown in Figure 9. The typical below-water slope angles are summarized in Table 2.

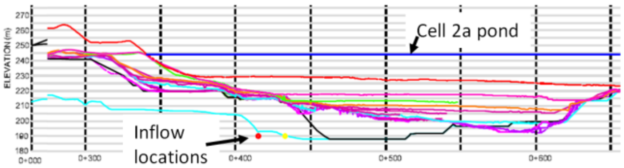


Figure 9. Multiple sonar profiles showing material flow across pond bottom during Phase 1 infilling, representing conditions at the start of Phase 2 infilling. Uppermost (red) line is June 2012 sonar.

Table 2. Phase 1 Typical Below Water Slope Profile

| Water Depth (m) | Distance from Water Edge (m) | Slope (xH:1V) | Slope (degrees) |
|---|---|---|---|
| Above water | n/a | 1.3 - 1.5 | 37° - 34° |
| 0 – 5 | 0 | 1.5 - 1.7 | 34° - 30° |
| 5 – 10 | 8 | 2 - 4 | 26° - 15° |
| 10 – 20 | 40 | 6 - 11 | 10° - 5° |
| More than 20 | 100 | 30 - 70 | 2° - 1° |

The pad construction was not successful in creating a platform for drilling over the inflow locations because the crest remained approximately 140 m west of its intended target. The plan was therefore revised to drill inclined wells (Figure 2) to reach to the vicinity of the conduits.

After waste dumping ceased in mid-January 2012, the water level remained constant at approximately elevation 244 m until Phase 2 fill placement started in January 2015, with no further measurable inflow.

No cracking or slumping of the 2011-2012 fills occurred and the pad remained stable throughout the period January 2012 to January 2015, with above-water slopes at the 37° angle of repose. This angle is consistent with other unsaturated mine waste fills at Albian.

At the end of Phase 1, approximately 4.5 $Mm^3$ of mine waste had been placed into Cell 2a from the south and west sides of the pond.

## 5 SALINE WATER STORAGE

Several options were considered to temporarily or permanently store the saline water that could not be used in the bitumen extraction process. One option was to fill the pond in with coarse tailings sand (CST) that had been drained of the transport water, so that the saline water would be stored in the void space of the CST. With a ratio of 4 $m^3$ of CST to store 1 $m^3$ of saline water, it would require 28 $Mm^3$ of CST to store all the saline water.

A geotechnical investigation of the mine waste fills that that flowed across the pond was performed in August – September 2013 with three primary objectives:

- Assess the capacity of the Pond Bottom Material (PBM), the mine waste soil that had flowed across Cell 2a to the far pit wall, to act as a long-term seal against further flow
- Assess the capacity of the PBM to support CST infill for saline water storage
- Estimate future settlement of the PBM that could expel additional saline water that would require storage

### 5.1 Pond Bottom Material Investigation

An amphibious carrier (barge) on the surface of the Cell 2a pond was used to conduct a geotechnical field investigation program in August and September 2013. The investigation consisted of a total of 16 Cone Penetration Tests (CPT) with Pore Pressure Dissipation measurements along five transect lines through Cell 2a. Ten CPTs were advanced through the full depth of PBM to the pit floor while six met refusal at shallower depths. Ball Penetrometer Tests (BPT) were performed at 14 locations to characterize the shallow slurry in more detail and field Vane Shear Tests were performed at three locations. Sonar soundings were performed to measure the surface of the PBM. The sampling program consisted of collecting 83 samples of slurry and water from above competent pond bottom, with 37 disturbed samples and 21 undisturbed samples from the PBM.

The PBM consisted of a slurry zone that was 0.5 to 1.0 m thick with an undrained strength of less than 2 kPa. The slurry zone was underlain by more competent soil that transitions within about a 1 m interval to an undrained strength of about 10-20 kPa and contains zones or blocks of material with a strength around 100 kPa. Within the soil column the typical lower bound strength was about 10 kPa, and the rate of strength gain with depth followed a mean trend of approximately $Su/\sigma_v'=0.4$, and a minimum trend of $Su/\sigma_v'=0.2$, with the high values influenced by the sand content of the fill. The transition zone from the slurry to more competent PBM is evident from the CPT and BPT data in Figure 10, which also shows the mudline from the sonar and gamma-CPT results that corroborate the transition from slurry to solid material. Photos of samples taken throughout this transition zone are shown in Figures 11 and 12.

The PBM soil was predominantly low plastic, silty sand with typical liquid limits of 20-26%. Two zones of soil gradation were evident: an upper zone up to 7 m depth with 20-90% fines (44 μm) and 5-40% clay, and a lower zone with 20-60% fines and 5-15% clay content.

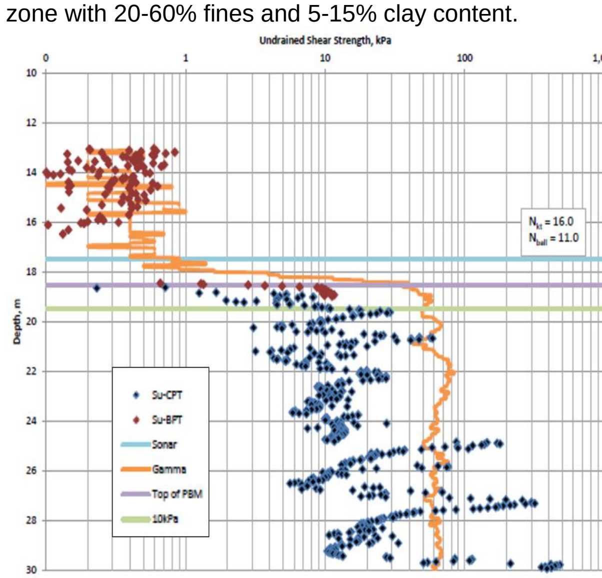


Figure 10. Typical BPT and CPT profile showing transition from mudline to solid PBM

Figure 11: Saline Water (1 m above mudline) and slurry (1 to 2 m below mudline)

Figure 12: Transition from slurry to PBM (2 to 3 m below mudline) and PBM (7 m below mudline)

The observation of a thin slurry zone with a strength of less than 2 kPa matches the interpreted mode of deposition of the PBM in sheets flowing out from the dumping locations. To flow at the very flat grades of 30-70H:1V, the undrained strength of this slurry would have been in the range of 0.3-0.6 kPa. Once each successive layer was buried, these layers rapidly gained strength, as shown on the CPT profiles.

The permeability of the soil, estimated from CPT pore pressure dissipation tests and laboratory consolidation tests, typically ranged from $1x10^{-7}$ to $1x10^{-9}$ m/s.

## 6 PAD CONSTRUCTION – PHASE 2

Although the PBM investigation concluded that the PBM would support CST deposition into Cell 2a for saline water storage, it was determined that the process of manufacturing approximately 28 $Mm^3$ of semi-drained sand would take several years, so a decision was made to transfer the 7 $Mm^3$ of saline water out of Cell 2a so that the 40 $Mm^3$ volume of Cell 2a could be available for tailings storage earlier.

To ensure that pumping down the pond would not re-initiate inflow, it was decided to resume constructing the pad using dumped mine waste fill in the area of the inflow to raise the pond bottom in this area to a minimum elevation of 245 m, later increased to 260 m. Whereas in Phase 1, construction occurred along the entire west and south sides, for Phase 2 placement was limited to the area immediately over the inflow locations. The starting condition for the Phase 2 construction is shown in Figure 9.

Phase 2 pad construction started in January 2015. By this time, the surrounding dykes had been constructed sufficiently high to contain the increased water level that would result from further placement into the water.

The initial step was to ramp down from the 260 m pad so that there was 5 m difference between the pond elevation and the pad crest, as shown in Figure 13.

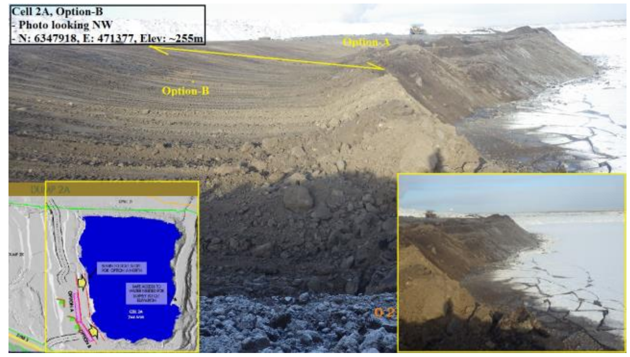


Figure 13: Pad ramp-down and safety berm

### 6.1 Safe Work Practices

- Haul trucks were restricted initially to a 50 m distance from the safe work limit (location of furthest cracks). After further experience with the mode of slumping, this was reduced to 20 m, increasing dozer efficiency.
- Manned dozers were used for Phase 2, in lieu of the remote dozers used for Phase 1.
- Regular geotechnical inspections were done, staking the location of the most recent cracking for visual tracking of the safe dozer push limits.
- Safety berms (~2 to 3 m high) were maintained at the crest of the fill. They also acted as surcharge load, to facilitate crest slumping.
- Dozers were GPS equipped, with an alarm if the blade passed the safe work limit by 2 m to ensure that the tracks were within the safe work limit.
- After an area had cracked or slumped, work in the slumped area was halted until the movement subsided. Dozers then pushed down material from behind the slump onto the slump block until no further cracking was noted. The next lift was then permitted to cover this area. The trucks always dumped from behind (west of) the location of recent cracking.

### 6.2 Results

During the Phase 2 pad construction into the Cell 2a pond, the crest advance behaved significantly differently than in Phase 1, where no further crest advance occurred after November 2011. The Phase 2 infill operation was successful in advancing the crest approximately 110 m further to the east to cover the inflow locations. Although no further crest advance had occurred at the end of the Phase 1 construction, it is hypothesized that sufficient soil had built up across the base of the southern portion of the pond that when the Phase 2 construction started, the pond depth in that area was only about 15 m, which allowed the pad to build up before the soil falling through the water column lost the majority of its strength (similar to the early crest advance during the Phase 1 construction, before the toe advanced over the edge of the bench). This would likely have also happened had the Phase 1 construction not been halted at that time.

During Phase 2 infilling, extensive cracking and slumping of the newly placed fill occurred. This permitted the fill to advance by displacing more competent fill below the slump zone, rather than having the new fill be pushed over the dump edge and free-falling through the water column. As the material behind the pad slumped between 1 to 6 m vertically, this displaced material below the toe of the active lift outwards into the pond, advancing the toe under water and maintaining a shallower zone in front of the lift to build out on. The slumping was predominantly vertical, with little or no rotation, and in a single block without the formation of grabens. The typical below-water slope profiles are shown in Table 3.

During Phase 2, cracking and slumping was typically within 3 to 15 m from the advancing crest, but there was occasionally slumping up to 25 m and cracking 75 m from the advanced crest. During the early stages of Phase 2 fill advance, the cracking alignment was mainly concentrated very close to the initial crest line established at the end of Phase 1 construction (Figure 14). Essentially no cracking occurred to the west of the January 2012 crest, indicating that the cracking and slumping was due to the weak PBM that the new fill was stepping out onto. A larger slump is shown in Figure 15. A minimum 5 m thickness of fill was maintained above the water level, to reduce the risk that a slump block would become submerged in the pond before any equipment could back up behind the slump zone. Throughout the operation, no rapid slumps occurred that would have endangered equipment or operators. Slumps as shown in Figure 15 took several hours to progress.

Table 3. Phase 2 Typical Below Water Slope Profile

| Water Depth (m) | Distance from Water Edge (m) | Slope (xH:1V) | Slope (degrees) |
|---|---|---|---|
| Above water | n/a | 1.3 - 1.7 | 37° - 30° |
| 0 – 5 | 0 | 1.7 – 2.0 | 30° - 26° |
| 5 - 15 | 10 | 5 - 7 | 12° - 8° |
| 15 - 20 | 50 | 11 - 20 | 5° - 3° |
| More than 20 | 150 | flat | Flat |

The water elevation was 245 m at the start of Phase 2 and the fill placement into the pond increased the water level to 254.6 m by August 15, 2016 when the pad construction was completed. The crest was advanced approximately 110 m beyond the 2012 limit, with up to 30 m of fill placed over the previously placed PBM.

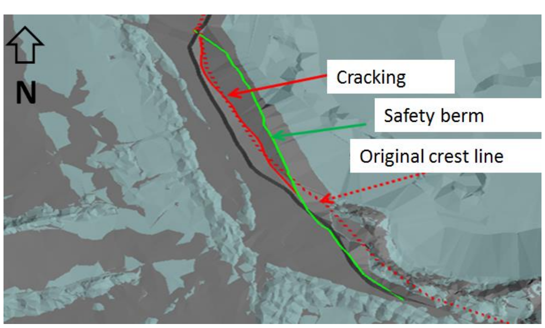


Figure 14. Slumping during Phase 2 backfill, showing safety berm (crest) location and slumping behind crest

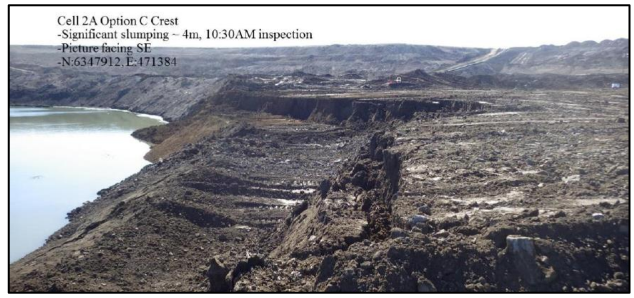


Figure 15. Slumping was typically preceded by cracking, and the slumping occurred slowly. Note the 4 m drop with significant extents. Photo from May 2015.

## 7 POND DRAWDOWN

By mid-August 2015 the pad had been advanced to the east beyond the inflow locations, which were covered by the pad fill with a thickness of 70 m. An aerial photo and cross-section of the pad immediately prior to the start of water transfer, with the inflow locations shown as coloured dots, are shown in Figures 16 and 17 respectively. The section location shown in Figure 16 is common for all sections in this paper, with the section marks delineated from station 0+300 to 0+600.

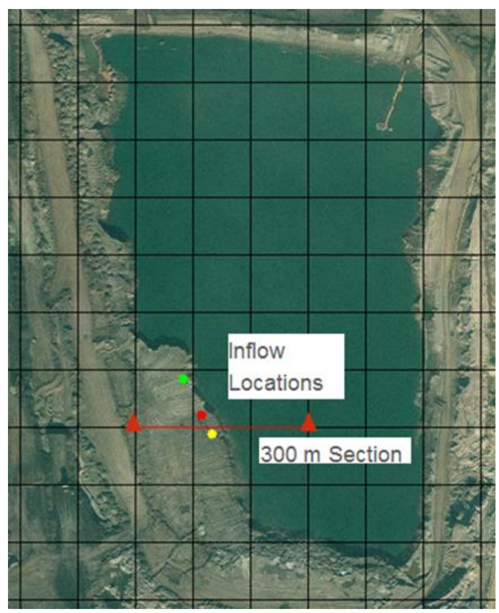


Figure 16. Cell 2a prior to water transfer, showing original inflow locations and cross-section location

Transfer of the saline water from Cell 2a to two lined storage ponds started on September 21, 2015 and continued for 3 months until December 20. During this time, the pond level was drawn down from elevation 254.6 m to 236.3 m, for an average rate of 0.2 m vertically per day. Of the approximately 7 $Mm^3$ of saline water in Cell 2a, the operation successfully transferred out all but 38,000 $m^3$, which was trapped in isolated depressions at the base of the cell.

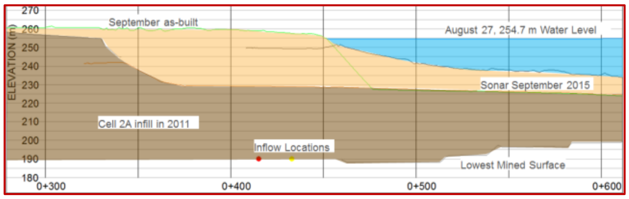


Figure 17. Pad profile prior to water transfer

Slumping of the recently placed pad fill started shortly after the initiation of the pond drawdown and by the time the drawdown was complete, significant slumping extended about 30 m behind the final constructed crest, with cracking up to about 100 m behind the final crest (Figure 18). In the area of significant slumping, the vertical displacement was up to 10 m. The cracking extended the majority of the way back to the previous 2012 crest limit, through the recent fill that was placed over the PBM.

A back analysis of the post-slumping surface indicated that the material deposited into the standing water near the dump face could be characterized by an undrained strength ratio $Su/\sigma_v'=0.2$ with a minimum undrained strength of 20 kPa. As found in the PBM investigation, the material distant from the dump face also had a lower bound $Su/\sigma_v'=0.2$, but without a minimum undrained strength.

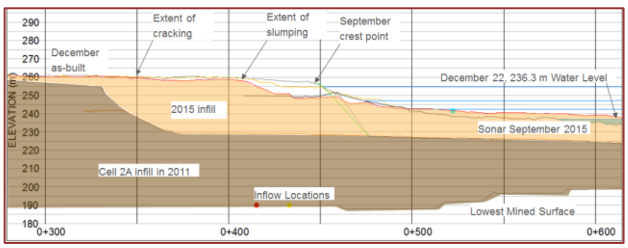


Figure 18. Progression of water drawdown and slumping

Several mud boils were observed during drawdown and slumping. These were interpreted to be from undrained shearing of the loose fills that were placed into the standing water. A typical mud boil is shown in Figure 19. In a final phase of fill placement in January 2016, after the saline water was pumped out of the pond, the pad was again extended to cover these boils to prevent them from partially compromising the integrity of the seal.

Figure 19. Mud boil during drawdown

During drawdown, safety watches were in place whenever personnel were working on the pump barge, in case of a rapid slump that could cause large waves in the pond. However, no rapid slumping occurred and no waves were generated.

## 8 PERMEABILITY TESTING

The objective of the Phase 2 pad placement over the inflow locations was to prevent further seepage either into Cell 2a from the deep Devonian aquifer, or out of Cell 2a to the aquifer once the pit was infilled with tailings above the elevation of the hydraulic head in the aquifer. To confirm that the 70 m thickness of mine waste fill over the inflow location would provide a suitable seal to limit seepage, two standpipe piezometers were installed for slug testing in coreholes through the pad in November 2016, approximately 100 m to the south-west of the inflow locations. The wells were screened below the pond water elevation in pad fill with a similar gradation and had been placed into standing water, similar to the fill that was placed directly over the inflow locations. Static water levels in both wells were above the top of the well screens, at about elevation 246 m. The holes were set 100 m away from the inflow locations to avoid becoming conduits for seepage.

Inflow and outflow slug tests in the two wells indicated a range of permeability of $4x10^{-8}$ m/s to $1x10^{-9}$ m/s, with a geometric mean of $5x10^{-9}$ m/s. Based on this very low permeability, together with the 70 m thickness of pad fill, the leakage rates across the pad fill will be extremely low.

## 9 CONCLUSIONS

The program to advance fill over the Cell 2a inflow and seal these against future flows was safely executed and ultimately successful. In the process there were many observations about the behaviour of lean oil sand fills placed into standing water that can input to predictions of fill behaviour in similar circumstances.

## 10 ACKNOWLEDGEMENTS

The safe and successful sealing and infilling of the Cell 2a pond was due to the work of a large, multidisciplinary team at the Albian Sands mine and various supporting consultants. Key contributors beyond the authors of this paper included Robert Mahood, Matthijs Verhoef, Andrew Conran, Stoakes Consulting Group, Golder Associates, BGC Engineering, Norwest Corporation, BARR Engineering, ConeTec, SarPoint Engineering, and others.

## 11 REFERENCES

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