Oil sands mine pit wall design and performance at Syncrude

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ABSTRACT
Empirical pit wall performance at Syncrude's Oil Sands North Mine is consistently better than can be calculated using conventional soil parameters. The steep pit wall design successes far outweigh the occasional, though problematic, occurrence of large movements, which also can be avoided with proper designs. Each aspect of the design is discussed with pictures of actual pit walls and cross-sections along with relevant field and lab data to indicate how the design basis was obtained.

RÉSUMÉ
La méthode empirique de calcul de stabilité des pentes développée par Syncrude pour la fosse « North Mine » s'avère généralement plus fiable que l'ensemble des règles et équations largement utilisées en mécaniques des sols, notamment, pour les déplacements en blocs. Chaque aspect du design y est présenté avec des photos, sections spécifiques et les paramètres de sols appropriés afin d'expliquer comment le model a été développé.

1 INTRODUCTION

Empirical pit wall performance at Syncrude's Oil Sands North Mine is consistently better than can be calculated using conventionally known soil parameters. Many of the soil parameters from the past were initially developed for overburden dump fills or tailings dam loading cases where high pore pressures and plastic movements often develop, that do not occur in the unloading pit wall scenario. To date, initial concerns of progressive failure of the clays leading to retrogressive pit wall failure have not occurred in the North Mine. Steep pit wall design successes far outweigh the occasional, though problematic, occurrence of large movements, which also can be avoided using proper empirical designs. Large shovels with operator cabs 10 meters above the bench floor, with their considerable reach, can safely manage single bench failure and slumping, but cannot tolerate multiple bench failures.

Over time, better parameters on both pore pressures and field shear strength for "unloading" cases need to be developed further, but this paper provides the latest update for Syncrude's North Mine.

Numerous actual mined walls are used as examples in this paper. Final pit walls and advancing pit wall designs are discussed, along with incorporation of haul roads, access ramps, contingency ore, ore inventory and final sloping. Design guidelines are included that provide a successful framework for pit wall design consideration through partially-saturated glacial sands, gravel sand tills, the high plastic Clearwater Formation Clays, the critical medium to high plasticity clay layers in the Upper Member McMurray Formation Marine oil sands, the Middle Member McMurray Formation Estuarine low plasticity clays and rich grade oil sand, the Lower Member McMurray Formation Pond Muds and the Waterways Formation Clays.

Not included in this paper are offset considerations for critical plantsite infrastructure, overburden dumps and tailings dams. Design parameter considerations for those are briefly discussed in a complimentary paper by McRoberts et al (2008) and must use calculated factors of safety. Those parameter inputs are considerably different than the ones discussed within this paper.

In the pit wall designs within this paper, extensive slope stability analyses were run with large ranges in the parameters. The ranges encompassed fully-drained to fully-saturated piezometric conditions, full-peak strength conditions to fully-softened peak conditions and finally down to residual shear strength conditions, and undrained shear strength considerations. It is the appropriate matching of these many possible theoretical considerations to the empirical conditions that requires continued work. This paper provides the latest update on pit wall design since the 1990 paper by Cameron and Ashton, and focuses on the empirical support, only citing the analytical information where appropriate.

2 DESIGN CONCEPT

Syncrude's pit wall designs start at what is called the "fixed ore point", which is based on either an economic ore limit for final pit walls or a set volume of ore for the annual wall advance. This "fixed ore point" is the desired crest location for the pit wall ore to be mined. When offsets from infrastructure, tailings dams, or dumps are involved, the design results in "equivalent fixed ore points" which are usually back-analyzed out of a design from the overburden crest down. Equivalent "fixed ore points" are not discussed in this paper.

For economic or volume style "fixed ore points", the main consideration is that both the overburden benches and the ore benches must be designed at the same time. This is one of the most critical learnings at Syncrude. This means that the mine pit wall benches must be designed from the original topography overburden crest down to the pit floor, all at the same time. If the lower ore limits and benches are not yet known, neither can the overburden benches above be known. At Syncrude, the concept is to design the overburden benches from the fixed ore point up and the ore benches from the fixed ore point down, with checks and considerations required for rich feed flow, the critical "Marine Clay Layers" within marine oil sand (which can occur within the overburden or the ore), and also the Pond Mud at the pit floor. Syncrude pit walls have had more failures and movement within "Marine Clay Layers" within marine oil sand than within Clearwater Formation.

The design concept also attempts to keep any potential overburden bench failure on top of the ore bench where it can be removed without contaminating the ore benches below. A critical difference between a mined out final pit wall and an advancing wall is that the final pit wall can be buttressed with overburden fill and/or mined and buttressed in segments, if required, whereas for an advancing ore wall, this is highly undesirable. Though it is geotechnically possible to have very steep advancing walls, from a risk-benefit approach, this is not necessarily the best approach. Consideration of one-time overburden push backs that, if maintained provide ore inventory for the life of the mine, can reduce the risk of overall pit wall failure. Steep overburden slopes can still be used while maintaining required haul roads and ramps between benches. This one-time pushback increases ore inventories and running surfaces as well as allowing for the large shovel mining inaccuracy and reduces both shovel walking time and impacts from shovel breakdowns. This is shown in the schematic in Figure 1a, where a steep "final" wall without a required haul road is compared to an "advancing" wall, shown in Figure 1b that incorporates some planning, productivity and risk tolerance requirements.

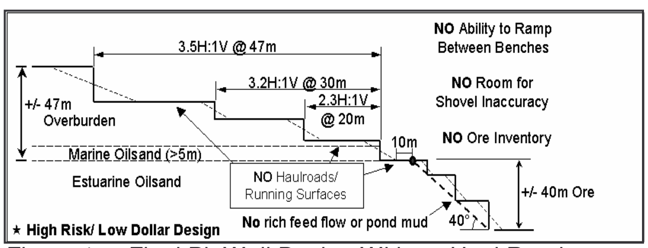

Figure 1a. Final Pit Wall Design Without Haul Road

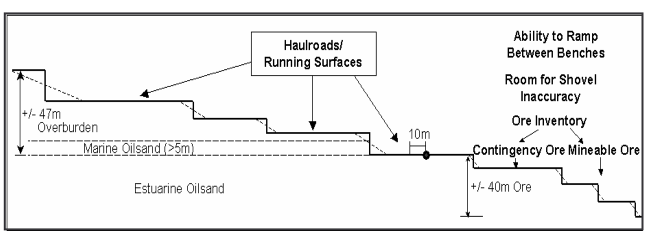

Figure 1b. Advancing Pit Wall Design With Haul Road

2.1 Design

The design methodology is shown in Figures 2 and 3 and will be explained in the considerations to follow, along with supporting evidence. The details shown are Syncrude-specific and are provided to allow understanding of where slope angles are measured. Others would have to determine their own specific slope considerations.

It is important to define what a "dig limit crest", an assumed "fall-down slope" and "overall slope" mean. A dig limit crest is a set of stakes that the shovel bucket will dig up to and generally should be regularly staked with operators being told to leave the stakes in place. An assumed "fall-down slope" is the angle a slope may be expected to fall down to after some time has passed. An "overall slope" is an approximation through multiple benches and may be measured from either a dig limit crest to a dug toe or, as is more common, from an assumed or actual fall-down crest to fall-down toe. It is important to refer to the figures when the term "overall slope" is being used to know which connotation is being used.

2.1.1 Consideration 1 – Obtain the Fixed Ore Point

Obtain the fixed ore point from the planning group. This will be provided as either a point at a certain geology section location or as a line in a plan view. The fixed ore point will be located at the economic top-of-ore elevation, as shown in Figure 2 (see #1).

2.1.2 Consideration 2 – Obtain the Planning Bench Heights Desired

Obtain the overburden and ore bench height elevations from the planning group and draw horizontal lines at these bench locations, shown as #2 on Figures 2 and 3. Calculate and show on the side the half bench height (bench height divided by two) for each ore and overburden bench.

2.1.3 Consideration 3 - Locate the Lowest Marine Clay Layers within Marine Oil Sand and Design Benches Above

From the area-specific geology location, locate the lowest elevation Marine Clay Layer in the wall area being designed. If the lowest Marine Clay layer elevation is not known, then use the bottom of the marine oil sand unit elevation.

For areas where the lowest Marine Clay Layer is within the overburden bench above the "fixed-ore point", as shown in Figure 2 (see #3), from a location 10m from the "fixed ore point" along the top of economic ore (#3a), draw an assumed "fall-down slope" at 2H:1V (#3b) (explained later). Where this 2H:1V line intersects the mid-point of the bench in which the Marine Clay Layer is located, draw a 72° line up and down to represent a shovel face for that bench. The 10m is a Syncrude

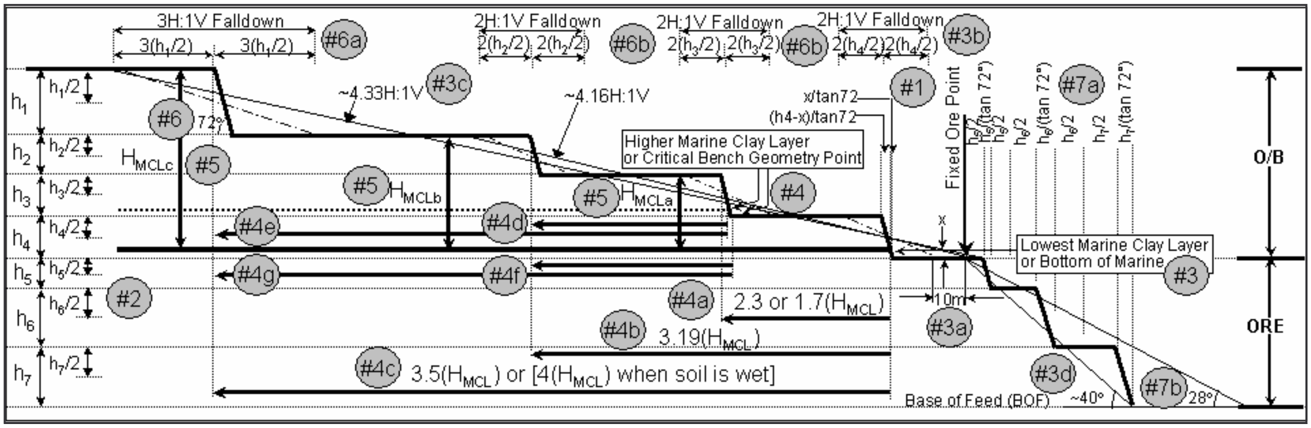

Figure 2. Pit Wall Design when Critical Lowest Marine Clay Layer or Bottom of Marine Occurs in Overburden

offset largely considering an overall overburden slope of 4.33H:1V (#3c) in this example, intersecting the 40° ore slope (#3d) up from the ore toe. Both will be explained further later. Others may wish an offset greater than 10m; this is a risk-benefit decision.

For areas where the lowest Marine Clay Layers occur within marine ore, as shown as #3 in Figure 3, it is critical that pit walls be designed more like the shallower overburden than the very steep oil sand ore pit walls. Historically, a cut-off depth of 7 to 10m into the oil sand was determined during Syncrude dragline mining operations where the high cross-bedded shear strength of the oil sand became difficult to shear and was termed a truncation depth. Therefore, pit wall designs at Syncrude currently use the deepest critical Marine Clay Layer, at no deeper than 7m into the ore, for checking ratios. When very deep marine oil sand occurs this truncation cut-off is helpful, but caution is still required if channel flank issues occur, if large backfilled sumps exist or if major jointing or faulting occur that could affect the otherwise strong cross-bedded oil sand strength.

To design areas where the lowest Marine Clay Layer occurs within marine ore, it is recommended to find a point on the Marine Clay Layer (no deeper than the 7m cut-off) vertically below the 1H:1V falldown limit of the uppermost ore bench, as shown as #3e on Figure 3. From this point, set dig limits back according to the required ratios in Table 1.

2.1.4 Consideration 4 – Locate Other Occurrences of Marine Clay Layers and Check Bench Designs

This consideration must not be missed. Though it is not necessary to check every Marine Clay Layer within the marine oil sand, it is necessary to check the uppermost and lowermost marine clay layers and any critical bench geometry daylight points, shown in Figures 2 and 3 (see #4). If the Marine Clay Layer locations are not known, then the top and bottom of the marine oil sand occurrence can be used and any critical bench geometry daylight point and dig limits need to be set for each ratio in Table 1, as shown as #4a, #4b #4c, #4d, #4e, #4f, #4g in Figures 2 and 3. This table is conservative for cases when the marine clay layers are included in the bottom of a high bench, like bench h3 in Figure 2. Do not pull dig limits forward as each design/check is made from the lowermost Marine Clay Layer upwards as pulling the dig limits forward would alter the ratios of the Marine Clay Layers below.

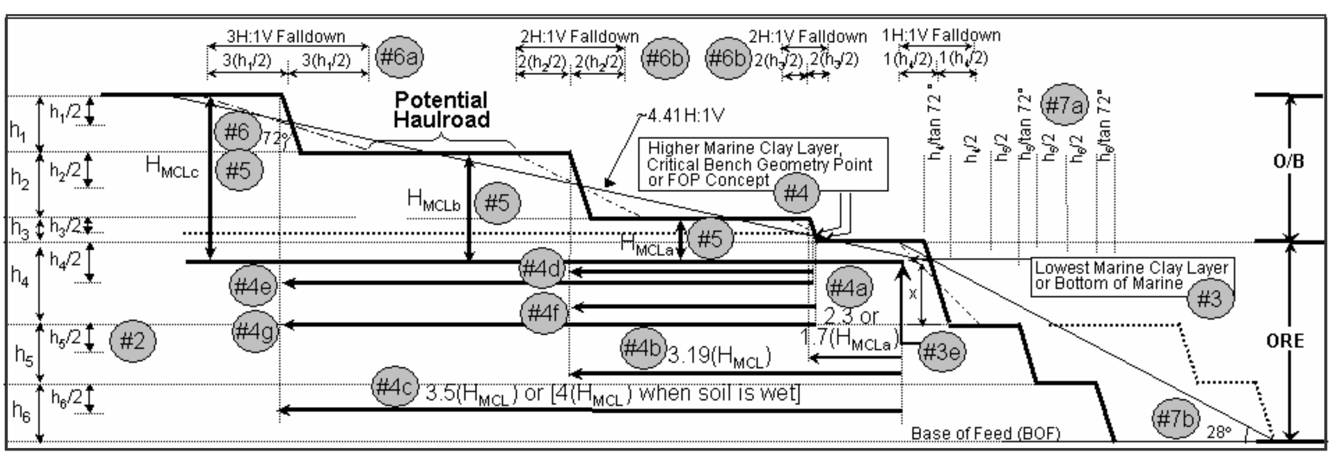

Figure 3. Pit Wall Design When Critical Lowest Marine Clay Layer or Bottom of Marine Occurs in Ore Oil Sand

Table 1. Minimum Slope Ratios for Heights above Critical Marine Clay Layers

Bench Height Above Critical Marine Layers (m)	Minimum Design Slope Ratio
0 to 15m	1H:1V
15 to 22m	1.7H:1V
22 to 25m	2.3H:1V
25 to 28m	2.6H:1V
28 to 35m	3.19H:1V
35 to 50m	3.5H:1V to 4H:1V
50m+	No Experience

Some slope ratio interpolation between 22 to 35m bench heights is possible when *in situ* conditions are favorable (not glacially affected)

2.1.5 Consideration 5 – History of Marine Clay Layers Within Marine Oil sand

The design calls for the height to be calculated for all the other benches above the lowest Marine Clay Layer (#5). The empirical basis, to date, supports setting bench dig limit crests at 72º shovel faces with the minimum slope ratios for benches above Marine Clay Layers in Table 1.

Syncrude has incurred numerous issues with these Marine Clay Layers. The most recent was in the G-Pit Area of Syncrude's North Mine where a 33.5m high triple-bench pit wall failure slid horizontally along the Marine Clay Layer. The area was aggravated by an incised glacial sand and gravel channel and so may represent a lower bound. The failed slope geometry and non-failed slope geometry directly to the south are shown in Figures 4a and 4b , respectively. For the two failed and non-failed geometries, the Marine Clay Layer properly back-calculated to a fully-softened peak strength of 19.5° and had a liquid limit, plastic limit, clay content and activity of 63%, 23%, 68% and 0.61, respectively. Up to this occurrence, previous experience with these Marine Clay Layers, like at the old Coke Cell 1 & 2 area, resulted in back-calculation of the Marine Clay Layer closer to the residual shear strength of $\phi_r = 9°$. By comparison, the mined out Coke Cell 1 & 2 areas, which had a failure during mining with dimensions of 200m long and 67m wide, as shown in Figures 5a, 5b, and 5c, had generally a lower liquid limit, plastic limit, and clay content at 58%, 23.5%, and 54.5%, respectively, and a similar activity at 0.65.

The key difference between these two areas is the marine clay layer depth below overall topography during glacial drag movement. The marine clay layer at 19m depth in the Coke Cell 1 & 2 area is suspected of having been reduced close to residual strength by glacial drag, whereas the 44.5m depth to Marine Clay Layer in the G-Pit triple bench failure area was not. Other work not presented here indicates the actual drag cut-off could be between the depths of 27 to 31m and there may also be a consideration of distance to the Athabasca River or other open face and to the amount of Clearwater Formation clay shales above.

Other notable cases with marine clay layers within the Marine Oil sand that were also shallow and so expected to have been affected by glacial drag movement are:

- Syncrude's Base Mine NE pit wall *in situ* trimmed at 4H:1V, which cracked and was re-sealed numerous times,
- Syncrude's Base Mine SE pit wall *in situ* trimmed at 5.2H:1V, that failed and slid 20m horizontally onto a haul road,
- Syncrude's Base Mine west side pit wall where numerous windrow failures during dragline mining either failed towards conveyors or out the pit wall and had to be managed by either pile heights or offsets, respectively.

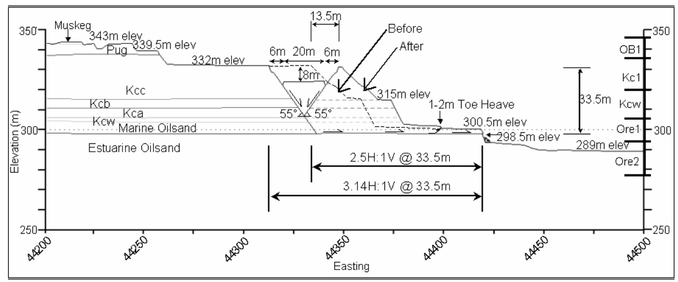

Figure 4a. Failed Slope Geometry of G-Pit Triple Bench Failure

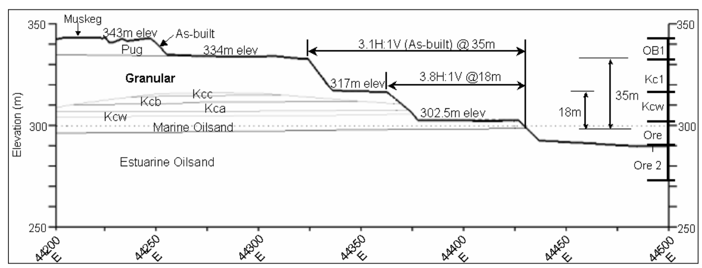

Figure 4b. Non-Failed Slope Geometry North of G-Pit Triple Bench Failure

It should be noted that, when comparing the trimmed slopes noted to those in Table 1, one would have to divide the *in situ* trimmed slopes by 2 and shallow them out slightly. This is because an *in situ* trim has some greater overall net strength issues over the shovel-dug fall-down type slopes.

At Syncrude, there is an example of some very steep pit walls with marine oil sand in the SW Quadrant of the Base Mine, shown in Figure 6a and in the schematic in Figure 6b.

However, this pit wall was mined over a span of 6 years with the oil sand also mined over many years and so considerable drainage and slow stress relief would be expected. Also, no critical Marine Clay Layers were observed within the marine oil sand for this area.

Therefore, when pit walls stand steeper, it is still consistent within the context presented here.

Figure 5a. Coke Cell 1&2 Failure Plan View

Figure 5b. Coke Cell 1&2 Failure Buttress Fill

Figure 5c. Coke Cell 1&2 Failure Oil sand Shearing

Another issue to note in these figures is the deliberate "stair step look" to the benches and that there is a larger bench separating the overburden benches from the ore benches. Benches that have consistent heights and consistent bench widths and have wider separation between overburden and ore are characteristics of well performing walls at Syncrude. When the top benches are very high and the lower benches are of lower height but still meet the ratios, this is not ideal and, in extreme cases, these guidelines may not be sufficient.

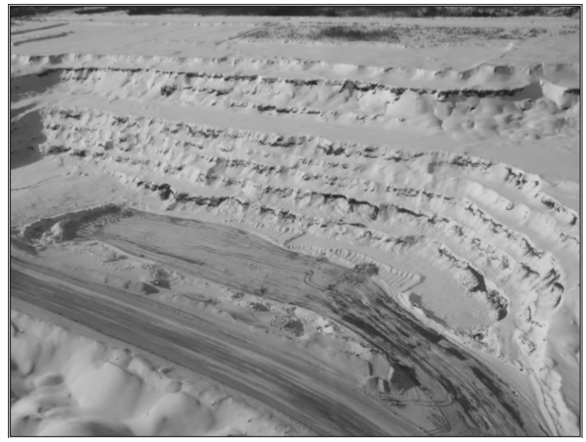

Figure 6a. Syncrude's Base Mine SW Quad Pit Wall

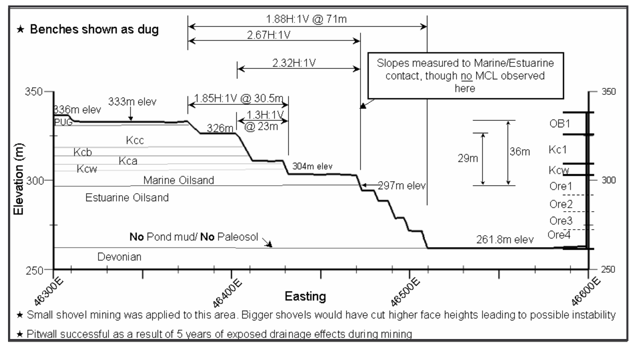

Figure 6b. Schematic of Syncrude's Base Mine SW Quad Pit Wall

2.1.6 Consideration 6 – Assumed Overburden Fall-down Limits

After addressing considerations 3, 4 & 5, the final overburden dig limits should have been determined by meeting all ratios for all critical layers for all benches. Since these are dig limit crests, 72° shovel excavation faces are drawn down from these crest points in Figure 2 or 3 (see #6). Now it is important to check and consider realistic overburden fall-downs of shovel faces.

The top mining bench at Syncrude is often comprised of Pleistocene-age clays, partially-saturated sands, gravels and tills overlying Clearwater Formation high plastic clays. In Syncrude's Base Mine, the Pleistocene-age units, when very wet, would slide off the Clearwater Formation unconformity surface at 4.8H:1V on the Base Mine east side and at 4H:1V on the drier Base Mine west side. This was determined in a study by Van de Brand and Van Wieren (1989) when slumping of this overburden was filling in ditches. However, generally 3H:1V and 2H:1V occurred, for the wet and dry areas, respectively, but in ditch cleaning it was the 30% that fell flatter that caused the problem. An internal study by MacNabb between 1998-2001, for the North Mine, showed 72° shovel-dug faces fell down to 2.7H:1V, 3.3H:1V and 4H:1V for various 10m and 15m high top-bench overburden face heights. For a few years, some areas stood 2H:1V, but more recently at the Panel 17 area of North Mine, slumping down to 3H:1V resulted in a shovel having to go back and mine more overburden to make room for the haul road. Figure 7 shows a double bench failure of some granular material from a mostly dewatered Pleistocene-age channel and indicates how caution is required when the Pleistocene-age material occurs below the top bench. As an initial guideline, all top bench and other benches with Pleistocene age units in them should use 3H:1V as the assumed fall-down and, as shown on Figures 2 and 3 (#6a), this should be shown dashed onto the design through the midpoint of the 72° dug face for the top overburden bench containing Pleistocene-age overburden.

The second, third and sometimes fourth benches in the overburden are most often comprised of the Clearwater Formation high-plastic clays. In North Mine, the Clearwater Formation is commonly very thick, upwards of 40m in places. This Clearwater Formation generally tends to be dry of the plastic limit, though some exceptions occur in low-density layers.

Piezometers 50m behind a recently excavated pit wall showed the Kcc Clearwater Formation clay to have no pore pressure versus its usual r_u = 0.45 and the Kca to have an r_u = 0.16 equivalent to its 0.16 normal pore pressure ratio for this area. Fall-down slopes for the short term can likely be considered at 2H:1V (see #6b) and, for the longer term, may have to be considered at 3H:1V pending support by future mine infilling. Weaker Clearwater in wetter areas, like around flanks of glacially incised channels, should be designed with 3H:1V falldowns and confirmed over time.

Table 2 shows previous work by Isaac and Lord (1987) where 19m high unweathered *in situ* Clearwater Formation high plastic clay shales can exist for up to 2 years at steeper than 2H:1V and after 3 years had only 20% fall down to 2.7H:1V.

Work in 1990 on pipeline river crossings showed fall-down slopes of 4.4H:1V and 4.7H:1V for natural river valley slopes with upwards of 70m of Clearwater Clays and 150m high overall slopes. This indicates slopes in this order can be stable for very long periods of time. Nicol's (1991) and Dewars (1996) work on the McKay River reported slopes ranging from 2H:1V to 9H:1V with the average considered around 6H:1V.

Another consideration is to ensure the bench fall-downs expected do not overlap the bench fall-down of the bench below. If this does occur, the bench above needs to be pushed further back. When moving benches, the ratios in Table 1 must still be maintained. At no time should room for haul roads or running surfaces lead to stacking of benches beyond the criteria noted within as this is one of the greatest causes of pit wall failure. The second greatest cause of pit wall failure is overburden being left behind (not dug back to limits) when a shovel is needed for ore production and doesn't get back to mine out what seems to be a minor amount of overloading. A slight underdug limit for one bench with a slight overdug limit on the bench below can quickly lead to oversteepening of multiple benches. This is especially true when considering that dig limit style mining geometries are already half of what a normal equivalent trimmed slope would be, essentially magnifying errors by two times on each bench. Haul roads and safety berms, when required, would have to be placed on the bench between fall-down limits and all upper benches shifted to create enough space.

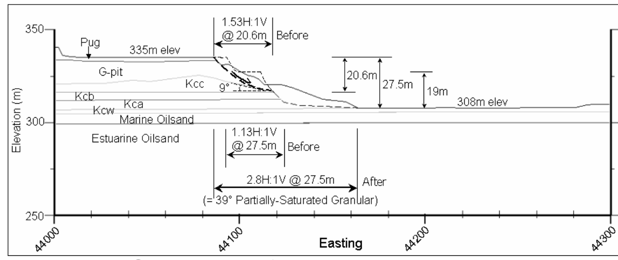

Figure 7. Schematic of Pleistocene-age Double Bench Failure

Table 2. Shovel Overburden Slope Angles – Modified from Isaac & Lord (1987)

ACTIVE FACE	PLEISTOCENE AND WEATHERED CLEARWATER FM.		UNWEATHERED CLEARWATER FM.	
Excavation - 6 hours	85° (steep as possible)		85° (steep as possible)	
NON-ACTIVE FACE				
1 - 3 months	40% - 85°		95% - 85°	
	40% - 50°		5% - 50°	
	10% - 40°		(local slumping)	
	10% - 30°			
3 - 12 months	80% - 50°	*(0.8H:1V)*	90% - 85°	*(0.1H:1V)*
	10% - 40°	*(1.2H:1V)*	10% - 50°	*(0.8H:1V)*
	10% - 30°	*(1.7H:1V)*	(local slumping)	
1 - 2 years	60% - 40°	*(1.2H:1V)*	70% - 85°	*(0.1H:1V)*
	40% - 30°	*(1.7H:1V)*	20% - 50°	*(0.8H:1V)*
			10% - 30°	*(1.7H:1V)*
2 - 3 years	100% - 20°	*(2.7H:1V)*	50% - 85°	*(0.1H:1V)*
			30% - 50°	*(0.8H:1V)*
			20% - 20°	*(2.7H:1V)*

Syncrude reduces the maximum bench height to 12m for its largest shovels in special circumstances, like when mining close to incised channel flanks, with the flanks being the Clearwater high-plastic clays, when it is not possible to directionally mine the flank. This is to reduce the impact of flank failures, as shown in Figures 8a, 8b, and 8c, for a bench that had already been reduced to 14m high. This is also considered in jointed flank areas where jointed block slides occur, as shown dropped in Figure 9.

In the case of Syncrude's North Mine, many slopes will be buttressed in the future with overburden and tailings storage. Longer-term slopes will be flattened to more appropriate long-term slopes, if not buttressed to full height and so it is still possible to consider the 2H:1V and 3H:1V fall-down slopes in the design of pit walls for the short-term.

Figure 8a. Flank Failure (Crest)

Figure 8b. Flank Failure (Toe)

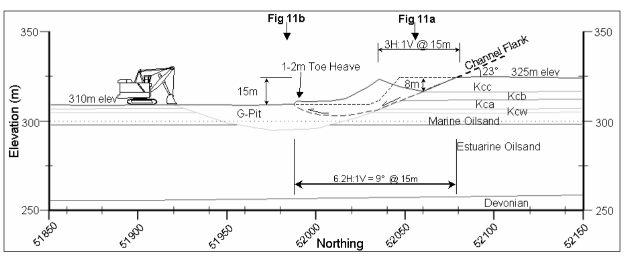

Figure 8c. Flank Failure Schematic in Clearwater Near Incised Glacial Channel

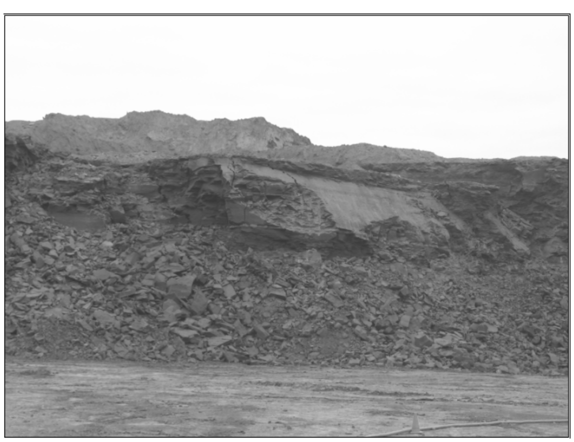

Figure 9. Jointed Block Slide

2.1.7 Consideration 7 – Ore Design and Fall-down Slopes

If the critical Marine Clay Layers in the marine oil sand exist within the overburden and the bitumen grade of the oil sand is less than 12.7%, then the final wall ore benches are as shown in Figure 2. Generally, from the “fixed ore point” you must add h/2 for the bench below to get the dig limit crest and then calculate the shovel face at 72° from this location for that bench. Each bench below, thereafter, has a bench width that is composed of ½ of the bench height above plus ½ of the bench height below between the 72° toe of the bench above and the 72° crest of the bench below (see #7a). In general, this leads to each individual bench falling down to 45°, leaving a small catchment area for material spalling from above, and results in an overall ore slope between 37° to 45°, depending on the ore depth (shown as 40° on Figure 2 as #3d). This design relies on the reach of large shovels owned by Syncrude and that the shovel operator cab is 10m above the bench floor. Operations personnel, on foot, and small equipment are not allowed closer than 1.5 times the height of the operating bench.

Other considerations, like blockslides, are discussed in a paper by Cameron and Ashton (1991). The main point on blockslides is to avoid mining directly into steep dips and avoid dozer trimming in the direction of like dips. This is not discussed in detail here as fewer incidents occur in the truck and shovel operations than in the dragline operation due to the greater time period for drainage and slower wall stress relief with shovel mining resulting in greater pore pressure dissipation. In Syncrude’s North Mine, the majority of all mining is with the dip direction to the north, which is a favorable mining direction for these dips.

Rich feed (generally considered greater than 12.7% and greater than 15m thick) flow below steep estuarine dips and Marine Clay Layers in the marine oil sand can be an aggravating factor leading to pit wall failures. Figures 10 and 11 show both, respectively. It is very important that shovel operators know not to mine ore that is flowing to the shovel once the dig limit has been first met. Sometimes rich feed will continue to flow towards the shovel and if the shovel keeps mining it, the rich feed will keep flowing. However, this leads to “bailing”, which is a term for removing the support from under the other benches above.

For final walls, rich feed flow may have to be buttressed with overburden to support the final wall or else oil sand may have to be left behind. For a final wall with rich feed flow concerns initially leaving a 100m wide final rich feed bottom bench for a month to allow for gas exsolution to occur (i.e. allows dissolved gas to vent out of the oil sand) and then mining will reduce the amount of oil sand fabric breakdown maintaining the oil sands natural high strength.

The delay in mining the final bench in rich feed areas also allows slower wall relaxation and so less *in situ* fabric/structure breakdown. This final 100m may have to be mined in segments and replaced with 15m to 20m high overburden fill to maintain overall pit wall stability.

Figure 10. Rich Feed Flow Below Steep Estuarine Dips

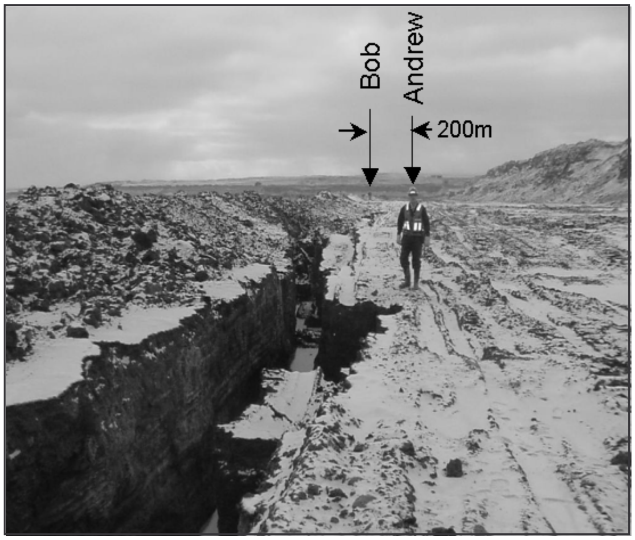

Figure 11. Rich Feed Flow Below Marine Clay Layers in the Marine Oil sand

For advancing walls, with rich feed, the minimum temporary slope from the mined ore toe to the fixed ore point should be less than 28° up from horizontal, since buttressing this ore is not an option. An example is shown in Figure 3 (see #7b).

Pond Muds on the pit floor have been encountered in the Base Mine and North Mine during mining and generally do not pose a problem unless major joints or faults are involved, if rich feed gas exsolution is allowed to occur quickly in the ore above weakening the oil sand structure, or if shovel operators "bail" the rich feed. Care must be taken to maintain overall pit wall slopes (dig limit crest of topography to dig limit toe at pit floor) to no less than 3H:1V when Pond Muds exist and no steeper than 1.88H:1V when no Pond Muds are present. Oil sand ore has been mined at slope angles between 37° and 45° and up to 45m high, with movement on the Pond Muds occurring, but not leading to slope failure. Still, precautions are required (like delayed mining of the last bench) to control any effects that lead to premature breakdown of the oil sand cross-bedded shear strength. If significant risks occur in the surrounding area, be it dam construction requiring an un-cracked pit wall abutment or to infrastructure located above, then this low factor of safety approach in regards to the Pond Muds is not warranted.

The Waterways Formation clays have not posed a pit wall problem to date but currently only limited exposure to the weakest surficial clay has occurred.

3 CONCLUSIONS

Many of the pit walls can be steep empirically, but the steeper the walls are, the less room for error and the greater the impact of failure. Since odd circumstances like shovel accuracy, incised Pleistocene channels, joints, fractures/faults, wetter areas, higher piezometric level areas, gas exsolution, and speed of mining can impact slope performance, some all-encompassing design framework is required. Failed areas, even when relatively small and not impacting shovel safety, can affect ore volumes available and can lead to productivity reduction to below 50% when having to mine through failed areas. For "advancing" walls, planning reasons alone such as ore inventory, haul road requirements, running surface requirements, and ramping accesses should lead to flatter slopes than required for geotechnical stability. Problems occur when such issues are forced into a stable slope without accommodating additional width. Balancing the risk of steep advancing walls that have to be maintained and managed for a 30 year mine life to the cost of one time push backs of advancing walls leading to safer and more productive day to day pit walls is required Final walls can often be buttressed and often have fixed haul road needs and so are not subject to the same upfront cost versus productivity and risk concerns as advancing walls.

Overall, the overburden portions of Syncrude's North Mine pit walls have actually ranged between 4H:1V to 5H:1V, due to haul roads or timing of top-bench pushbacks.

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