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Case study – bauxite residue management at Rio Tinto Alcan Gove, Northern Territory, Australia ©

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Abstract

The operations of Rio Tinto Alcan Gove are located on the Gove Peninsula in the north-east part of the Arnhem Land in the Northern Territory, Australia. They consist of bauxite mining and refining which converts bauxite into alumina. Bauxite residue is a byproduct in the Bayer process to extract alumina from bauxite ore. The residue is alkaline and, as such, required to be disposed of and managed in a safe, economical and environmentally friendly manner. Rio Tinto Alcan Gove has gone through a number of changes and has spent tremendous efforts and resources to improve the sustainability of the residue management since the start of the operations.

This paper describes the sustainable changes with emphasis on mud thickening in the refinery and mud farming in the residue disposal area.

1 Introduction

The operations of Rio Tinto Alcan Gove are located on the Gove Peninsula in the northeast part of the Arnhem Land in the Northern Territory, Australia. The Gove Peninsula is approximately 650 km east of Darwin. The operations consist of bauxite mining and refining which converts bauxite into alumina. Bauxite residue is a byproduct in the Bayer process to extract alumina from bauxite ore. The residue is alkaline and required to be disposed of and managed in a safe, economical and environmentally friendly manner.

Since the start of refining operation in 1972, Rio Tinto Alcan Gove has spent tremendous efforts and resources to improve the sustainability of the residue management. Some of the step changes include:

- Deep cone washers were introduced in 1991 and high rate thickeners in 2006, to produce high underflow densities.
- Central discharge and dry stacking in 1992, to improve in situ residue density and thus increase the storage efficiency of the residue disposal process.
- Mud farming in 1998, to maximise evaporation and improve drainage to further improve residue density and to enable upstream raising.
- High temperature double digestion to reduce residue production and development of seawater neutralisation technology to neutralise supernatant liquor and residue in recent years.

This paper describes the above step changes with emphasis on mud thickening in the refinery and mud farming in the residue disposal area. Over the years, geotechnical field investigations including borehole drilling and cone penetration test (CPT) probing, and laboratory testing have been carried out to characterise the deposited residue. The results of those geotechnical investigations demonstrate that mud thickening and mud farming have led to high efficiencies and improvements in storage and environmental protection.

2 Operations and residue disposal area

2.1 Gove operations

Bauxite in Gove was discovered in 1949 and the special lease for the operations was granted in 1965. The refinery operations commenced in 1972 and the alumina production rates have been increased over the years. After the third stage expansion has been completed, the alumina production will be increased to 3.8 Mtpa. Due to the global financial crisis, the full capacity has not yet been fully utilised and the alumina production was 2.5 Mtpa in 2009.

Bauxite at Gove is mined by open cut methods and transported to the refinery 19 km by overland conveyors. Bauxite residue (red mud) is separated from the alumina and pumped approximately a few kilometres to the residue disposal area (RDA), as shown in Figure 1.

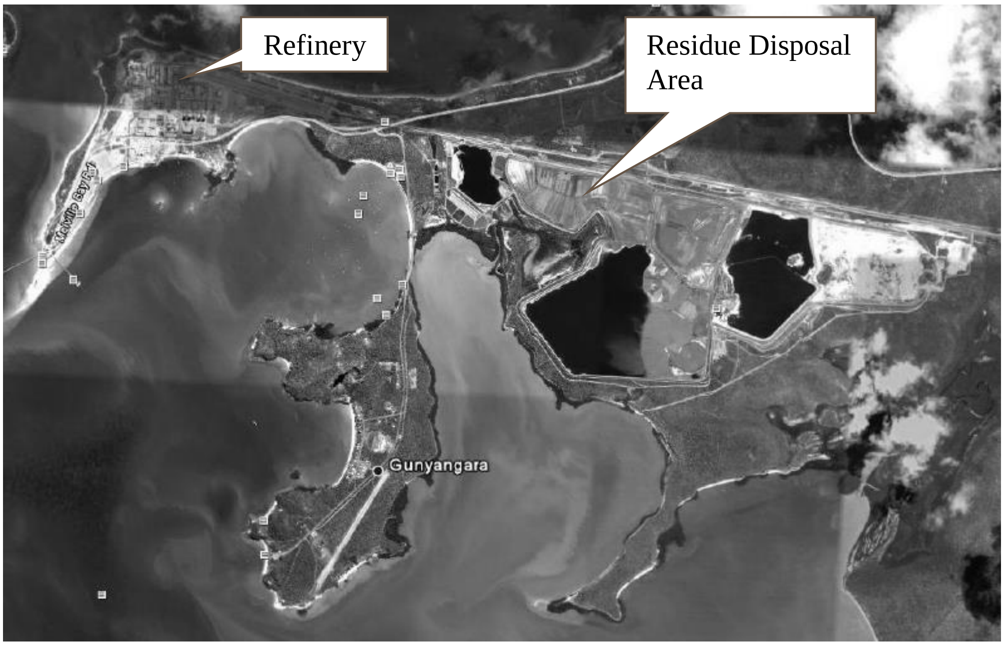

Figure 1 Gove Alumina refinery and residue disposal area

2.2 Residue disposal area

The residue disposal area comprises 10 “ponds”: Northern Pond, Pond 2, Pond 3, Pond 3/4, Pond 4, Pond 5, Pond 6, Pond 6S, Pond 7 and Pond 8. Except for Pond 8, which is under construction, all of the ponds are shown in Figure 2. Among the ponds, the Northern Pond was revegetated many years ago, and Ponds 3 and 3/4 were covered by HDPE and top soils in 2008 and in 2009.

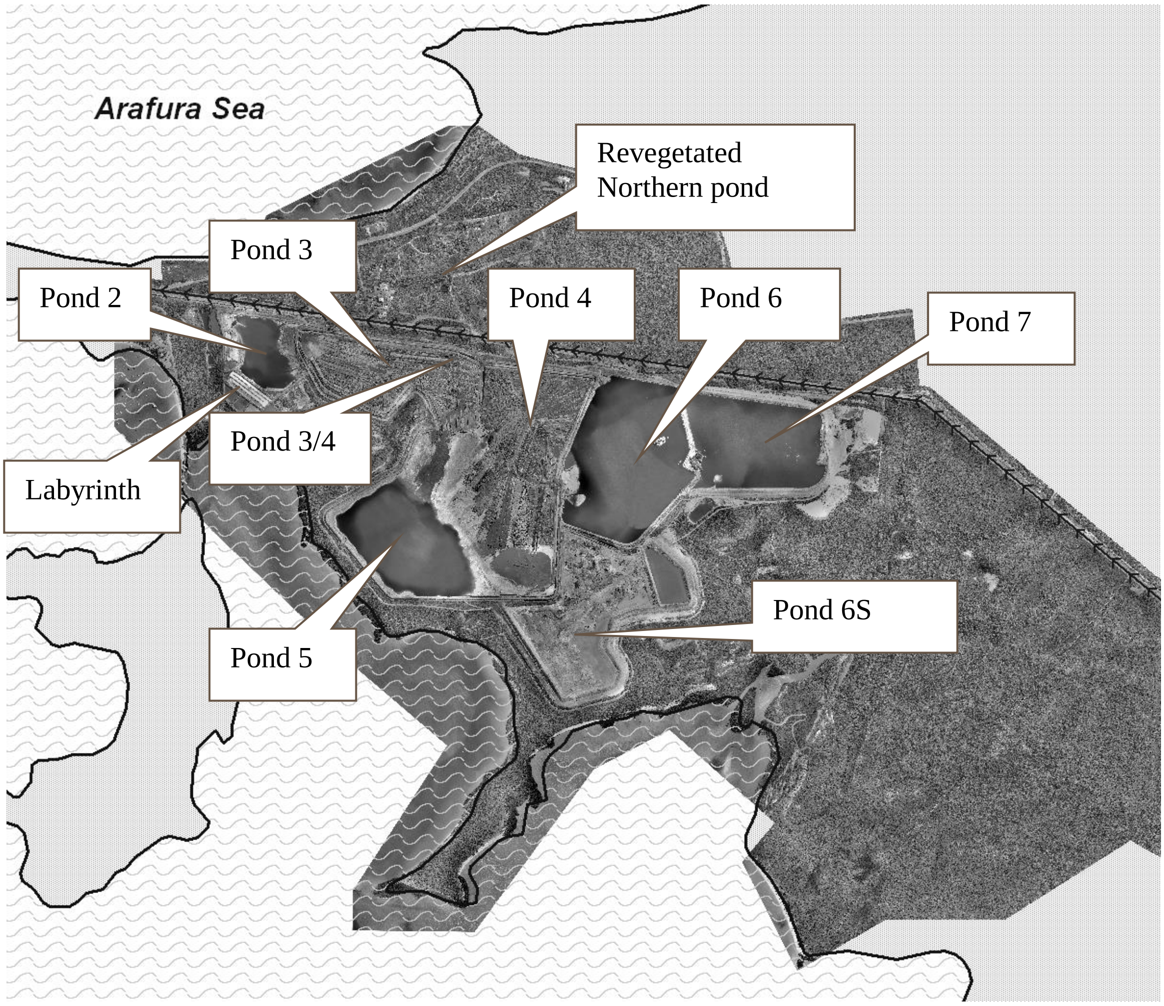

Figure 2 General layout of RDA at Gove, with Pond 8 under construction and not included

3 Digestion and thickening

3.1 High temperature double digestion

The Rio Tinto Alcan Gove refinery was expanded in 2006. The digestion circuit was modified from the original low temperature digestion (LTD) to incorporate a high temperature, double digestion circuit. The basic concept of double digestion (DD) for the extraction of alumina from bauxite has been around for many years but Rio Tinto Alcan has significantly improved the technology especially with the addition of the pressure decantation technology.

Bauxite at Gove contains the alumina minerals gibbsite and boehmite. In the Bayer process for alumina production, bauxite is digested with caustic liquor at elevated temperature/pressure to extract the alumina into solution. After flash cooling the slurry is decanted and the clarified overflow, or pregnant liquor, is sent for alumina recovery by precipitation. The solid from the decantation step is then further processed through high temperature digestion (HTD).

DD provides a more energy efficient means to extract the gibbsite and boehmite from the bauxite and results in a lower specific bauxite consumption (bauxite/alumina product by weight) of ~9% (Kumar et al., 2008) and a lower mud factor (mud/alumina product by weight) of 10–15%, compared to LTD. The improved efficiency results in a reduction in operating cost compared to alternative technologies. Importantly, the higher extraction of alumina from the bauxite means that less mud is produced per tonne of alumina.

3.2 Bauxite residue deep cone washers

The bauxite residue from digestion is removed as slurry, which also contains caustic liquor. It is both economically, and environmentally, imperative to recover the caustic from the bauxite residue and recycle it back into the Bayer process. To achieve this recovery the bauxite residue is washed in a counter-current wash train to recover caustic and alumina. The washing is performed using condensate that is recovered elsewhere in the Bayer process.

At Rio Tinto Alcan Gove the washing was originally performed in conventional flat bottomed tanks of six washer stages. A modification was made in 1991 to install the Rio Tinto Alcan design of deep cone washer at the end of this washer train. This produced a high density underflow paste, suitable for dry stacking.

During the expansion of Rio Tinto Alcan Gove in 2006, the bauxite residue washing area was modified. The washing is now performed using deep cone washers (DCWs) in series to produce a high solids concentration bauxite residue paste that is suitable for dry stacking and/or treatment by sea water neutralisation. The underflow solids concentration from the last DCW is 750–800 g/L (45–51%w/w).

The Gove DCWs are an above ground design with a diameter of 24 m. The tanks have an internal rake that is designed to improve mud dewatering in the cone and help to prevent areas of inactive mud. The production of high solids paste concentration means that only four DCWs are required in series to process 350–400 t/d of residue solids, or a specific throughput of ~20 $t/m^2/day$.

The high solids concentration also results in a high viscosity residue that can be difficult to deliver to the pump, particularly if there is a period of very high solids such as during an over-flocculation event. The underflow slurry stream typically has yield stress of ~100 Pa at 45–47%w/w. The Gove DCWs feature the Rio Tinto Alcan design (US Patent 6,340,033) to allow recirculation of a portion of the underflow back into the mud bed and shear-thin the slurry. This technique results in slurry that is pumpable to the downstream positive displacement pump, while still maintaining a high underflow solids concentration.

4 Residue disposal and mud farming

4.1 Brief history of residue disposal

1972–1975	Residue was discharged in the Northern Pond. The initial solids content was low.
Wet disposal 1975–1990	Residue was discharged in Pond 2, Pond 3, Pond 4 and Pond 5. Initial solids content was low. The average solids content was approximately 24% by weight and settled residue in the ponds was found to be in the order of 55% solids content (Massey et al., 1990).
Dry stacking 1991–1997	Deep cone washers were introduced, and high initial solids content residue produced. Initially multi-central discharges were applied, with targeted settled solids content of 60%. Residue was discharged in Ponds 3, 3/4, 4 and 5. The Labyrinth was constructed in the early 1990s and seawater neutralised supernatant liquor (SNL) was allowed to be discharged to the bay.
Mud farming since 1998	Mud farming was introduced in 1998. Both amphirol and swamp dozers are used. Achieved in situ solids content 72%.
Recent developments	New deep cone washers were installed in 2006. Ponds 3 and 3/4 were covered with HDPE and top soils. Seawater neutralisation plant is being developed.

4.2 Pumps and residue distribution systems

Gove has four positive displacement pumps, with three types, for transporting the residue to the residue disposal area. The first two pumps are the same type and were installed in 1992. The third pump, second type but very similar to first type, was installed in 2001. The fourth pump (third type), intended for seawater neutralized SNL, was installed in 2007 and was brought into operation only in 2009. The design pressure for the pumps is 130/157 bar, enabling pumping thickened residue with solids of 720 g/L (46%w/w).

Residue at Gove is distributed through pipe spigot system and small mud header channels where necessary to direct mud to farming bays. The header drains are constructed by excavators to a size and gradient adequate for the red mud to flow. Excavators are used to block the mud flow in the mud header drains and direct mud to flow into the bays where required. It has an advantage over a pipe spigot system in that it is less restrictive to pouring bay location and allows mud to be distributed more evenly and has been found to be less machinery intensive in keeping channels maintained and clear. Small Mud headers are used to distribute mud across the top of the bay, as shown in Figure 3.

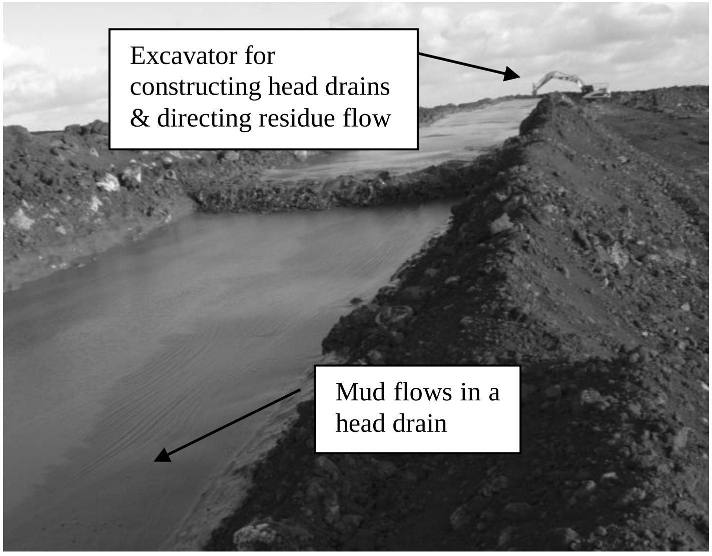

Figure 3 Head drain for distributing residue

4.3 Mud farming

Mud farming is the best practice for bauxite residue disposal in the alumina industry and has been successfully employed in Gove and several other bauxite residue disposal sites in Australia. It has at least three advantages: increased storage efficiency, increased stack stability and readier accessibility for rehabilitation. It is a process where thickened mud is distributed in layers and then turned over or ploughed to increase deposited density through the promotion of solar drying, water drainage and compaction.

At Gove, it started as a bulldozer operation but technology has moved to an amphirol basis.

Mud farming includes establishment of farming bay and farming operations. The dimensions of a drying bay depend on mud characteristics, mud production rate and the size of the mud storage area. The length of a bay depends on the yield stress of the mud. The optimum length is about 600 m, but bays up to 1,400 m long were made to work.

Farming operations include surface preparation, mud deposition, mud curing and drying and mechanical working.

Surface preparation: this is to prepare the floor to ensure it has an appropriate slope and it is firm so that residue can be distributed evenly in a bay, bleed water can drain quickly and a high farming productivity rate can be achieved. If the residue have not been adequately dried and compacted or there are soft spots, the Amphirolle that works in subsequent layers will be slowed down and the productivity will be reduced. It should be noted that surface preparation doesn't need to be smooth - in fact better to be a bit rough and help the residue 'stick'. The slope consistency is extremely important, and the cross section needs to be levelled to get maximum filling. This can have a high impact on farming efficiency.

Residue deposition: residue is deposited in layers in the drying bays. The thickness of a layer depends on the residue drying characteristics, production rate, climatic conditions, etc. At present, the thickness of a layer is approximately up to 900 mm and 400 mm for amphirols and swamp dozers, respectively.

Curing and drying: after deposited, residue is allowed to be "cured" for a certain time, so that bleed water can drain away and mud undergoes sedimentation, consolidation and solar drying. Once the targeted solids content is achieved, the next layer of residue can be deposited or mechanical working can commence.

Mechanical working: this is to use machines to plough, scarify, dry and compact the residue. The machines that have been used include swamp dozers and Amphirolles. An Amphirolle, as shown in Figure 4, is a specialised equipment for mud farming that:

- breaks up the surface crust that is the primary inhibitor for solar drying
- roughens the surface to increase the evaporative surface area
- provides better drainage for the bleed and squeeze the water to the surface. The drainage channels that are created by the amphirolles also significantly reduce the impact of rain as it runs straight off and does not delay the drying time except for just the period of the rain
- provides a compactive force that densifies the residue (like a road construction roller).

Figure 4 Amphirolle (preparing a new mud farming area)

5 Geotechnical properties

There have been many geotechnical investigations carried out to characterise the residue for the past 40 years or so. Some results of a few more recent investigations are shown in Figures 5–7. Figures 5 and 6 and Table 1 were produced based on the results of geotechnical investigations for Ponds 3, 3/4 and 4 (GHD, 2005). Figure 7 was extracted from the factual report by RTA (2008). These figures and table show that the geotechnical properties are quite different for the farmed and wet disposed residue.

Figure 5 shows the changes of solids content with depth and it can be seen from the figure that except for a few samples, farmed residue has higher solids content than the wet disposed. Table 1 below provides average values of solids content, moisture content (geotechnical definition), bulk and dry density for farmed and wet disposed residue. The residue has dry densities of 1.49 t/m^3 and 1.15 t/m^3 for the farmed and wet disposed, respectively. Based on this dry density data, compared to the wet disposal, mud farming has reduced the storage requirement by approximately 23% in volume. Moreover, with low moisture content, farmed residue will not have significant seepage issue.

Table 1 Engineering properties of farmed and wet disposed residue

Residue	Solids Content (%)	Moisture Content (%)	Bulk Density (t/m^3)	Dry Density (t/m^3)	Sample Number
Farmed	72.0	38.9	2.07	1.49	15
Wet disposed	63.4	57.7	1.80	1.15	33

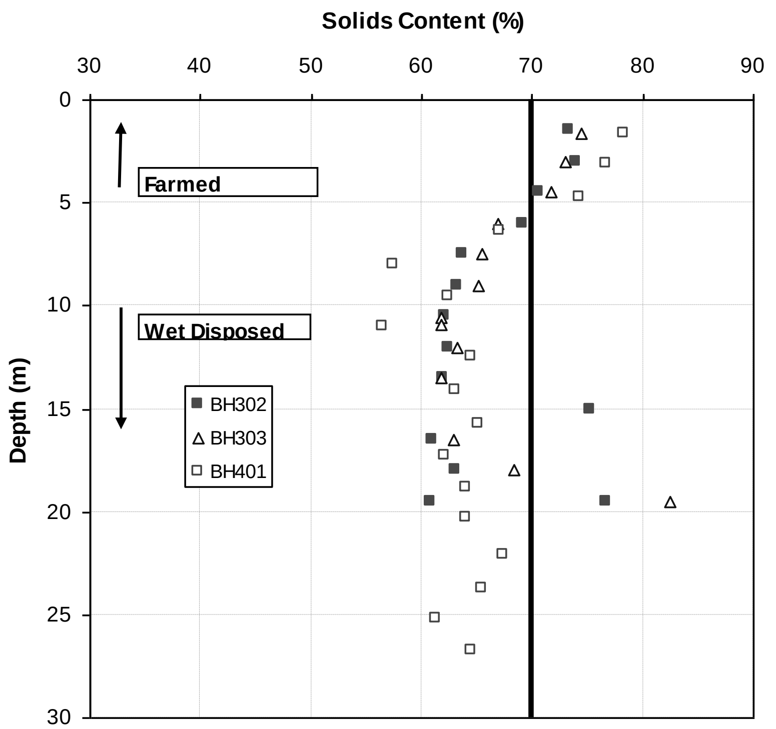

Figure 5 **Changes of solids content with depth for farmed and wet disposed bauxite residue, based on the results of 2004 geotechnical investigations (GHD, 2005)**

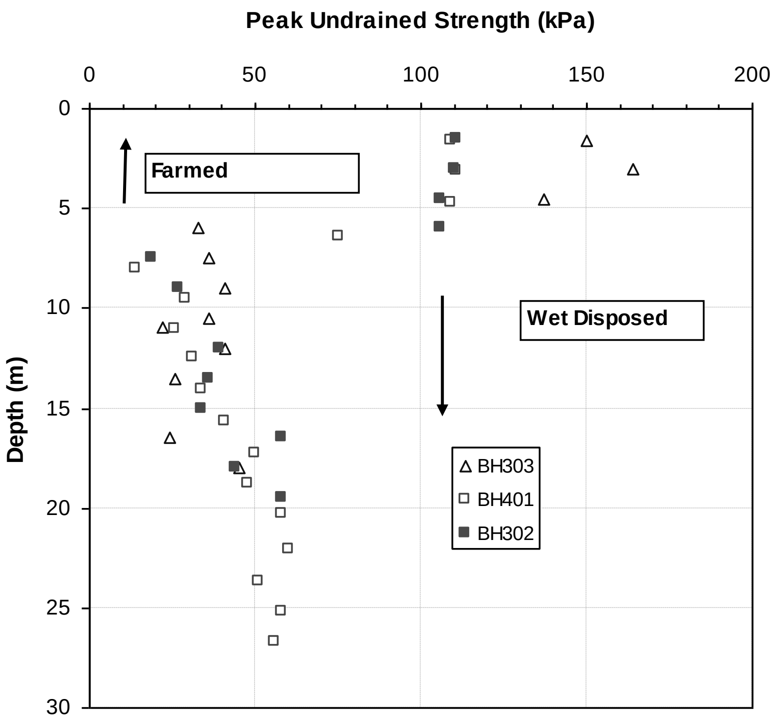

Figure 6 **Changes of peak undrained strength with depth for farmed and wet disposed bauxite residue, based on the results of 2004 geotechnical investigations (GHD, 2005)**

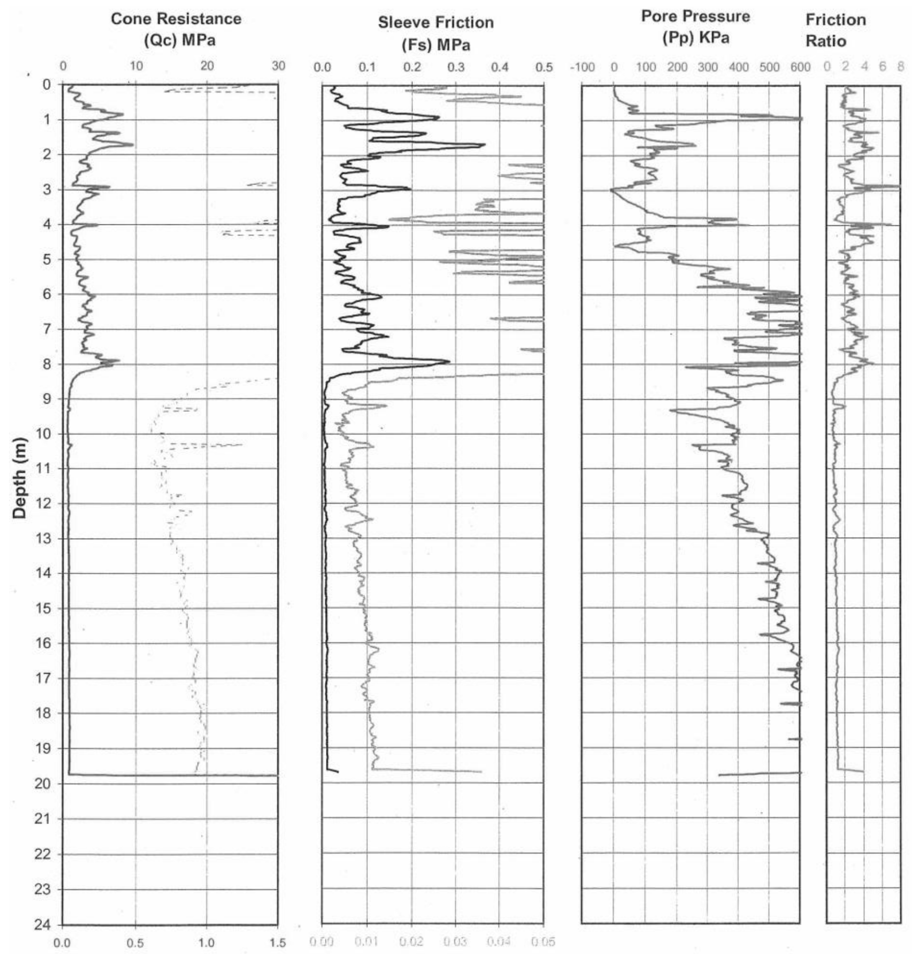

Figure 7 Typical Piezocone testing results at Gove RDA (RTA, 2008)

Figure 6 shows the changes of peak undrained strength with depth. The vane tests were conducted on the base of retrieved U50 samples using a 19 mm vane with an approximate embedment in to the base of the sample of 100 mm. It can be seen from the figure that farmed residue has much higher strength than the wet disposed.

Figure 7 shows a typical piezocone testing results for the bauxite residue at Gove. It can be seen that the residue on the top 8 m, which has been mud farmed, has much higher tip resistance and sleeve friction than the residue in the lower part, which was wet disposed.

Clearly, with high tip resistance, high sleeve friction and high strength, the farmed residue will not only significantly increase the slope stability but also significantly reduce or eliminate some other risks, such as liquefaction.

6 Seawater neutralisation

To significantly reduce the inventory of SNL, Rio Tinto Alcan is carrying out a SNL Neutralisation project. The objective of the project is to neutralise supernatant liquor so that it can be discharged to the environment (Melville Bay). The neutralisation rate is inversely proportional to the soda concentration.

A number of methods to neutralise the SNL were investigated. Many were uneconomical in terms of either capital expenditure or operating cost. This was predominantly due to the high neutralisation rate of SNL over about 10 years. The method finally chosen involves mixing a large volume of seawater and a small amount of bauxite residue with the SNL. This lowers the pH and binds the heavy metals in a precipitate that is then disposed of with the neutralised residue. The clean liquor from the process can then be discharged to Melville Bay within the current discharge licence conditions. This method takes advantage of the refinery location next to a source of seawater.

7 Conclusions

Since the operations commenced in 1972, Rio Tinto Alcan has continued developing and adopting new technology for sustainable disposal and management of the bauxite residue at Gove. Today Rio Tinto Alcan are using the following best available technologies:

- Double digestion – this results in a lower mud factor (mud/alumina product by weight of 10–15% as compared to the conventional low temperature digestion.
- Deep cone washers – to produce high density underflow residue that enables dry stacking residue disposal, and/or treatment by sea water neutralisation.
- Mud farming – This results in high in situ solids contents of more than 70%. Compared to wet disposal, mud farming has reduced volumetric storage requirement by more than 20%. Moreover, it enhances slope stability and significantly reduces the risks of ground water contamination and liquefaction.

Acknowledgements

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