Workshop & Lectures on Dam Engineering

TAILINGS STORAGE FACILITIES

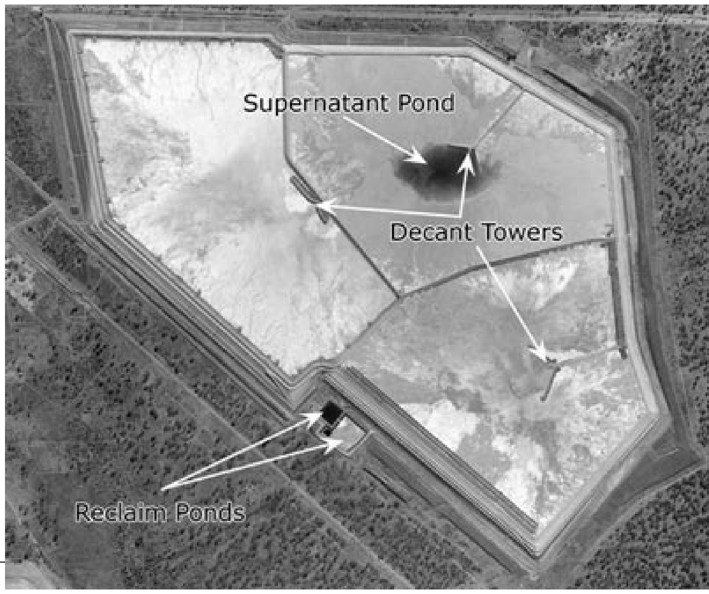
State of Art Tailings Storage

P.J. Burgess – Senior Principal – Coffey Geotechnics

coffey geotechnics
SPECIALISTS MANAGING THE EARTH

Sub-Aerial Disposal

coffey geotechnics
SPECIALISTS MANAGING THE EARTH



Modern sub-aerial Discharge

coffey geotechnics SPECIALISTS MANAGING THE EARTH

Case History - Merriespruit Tailings Dam Failure, Virginia, South Africa

coffey geotechnics SPECIALISTS MANAGING THE EARTH

Introduction

- The mining boom throughout Australia has resulted in mill tailings being produced at a greater rate than ever before in our history.
- Tailings Technology has expanded to address this boom but the degree of sophistication varies widely throughout industry.
- The larger companies are leading the way due to stricter enforcement of environmental requirements and because greater sophistication can yield greater financial rewards

coffey geotechnics
SPECIALISTS MANAGING THE EARTH

Scope of Session

- To present a summary of the techniques currently being used for tailings disposal and highlight the advantages and disadvantages of each method.
- Discussion will cover change from Tailings Dams to Tailings Storage Facilities, and to summarise the newer techniques being used.
- Case histories show application of some of the methods used.

coffey geotechnics
SPECIALISTS MANAGING THE EARTH

Reference

- 1. Guidelines on Tailings Dam Design, Construction and Operation" Australian National Committee on Large Dams (ANCOLD), 1999
- 2. Geotechnical Engineering of DamsFell, McGregor Stapledon & Bell, 2005

coffey geotechnics SPECIALISTS MANAGING THE EARTH

Tailings Processing

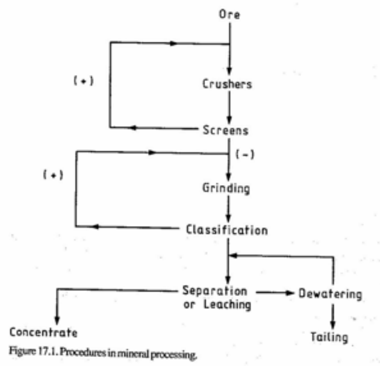


Figure 17.1. Procedures in mineral processing.

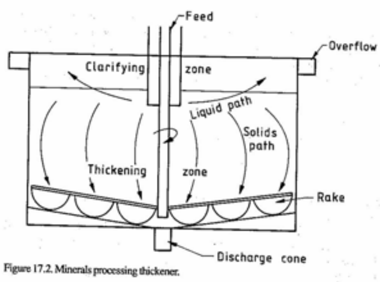


Figure 17.2. Minerals processing thickener.

coffey geotechnics SPECIALISTS MANAGING THE EARTH

Introduction - Regulations

- Australia mining regulations, are controlled by individual states.
- In Western Australia, the Department of Minerals and Energy (DME), through administering the Mining Act 1978, Mining Act Regulations 1981, Mines Safety and Inspection Act 1994 and Mine Safety and Inspection Regulations 1995, regulates safety and environmental aspects of tailings disposal in Western Australia (DME 2000).

coffey geotechnics
SPECIALISTS MANAGING THE EARTH

Introduction - Regulations

- In Victoria, the Minerals and Petroleum Division (MPD) of the Victorian Department of Primary Industries (DPI) is responsible for regulating the minerals, petroleum and extractive industries within Victoria and its offshore waters, including Commonwealth waters. The MPD manages the administration of the Mineral Resources Development Act 1990 and the Extractive Industry Development Act 1995 (DPI 2003).
- In Queensland, tailings storage facilities are regulated under the Environmental Protection Act 1994 (Robinson 1999).

coffey geotechnics
SPECIALISTS MANAGING THE EARTH

Introduction - Regulations

- In Tasmania a mining lease is required under the Mineral Resources Development Act 1995. Dam safety is handled under The Water Management Act 1999 which highlights in part 8, the regulations on dam construction maintenance and decommissioning. The Assessment Committee for Dam Construction (ACDC) manage this program and have to give their recommendations in any permit issued under the Environment Management and Pollution Control Act 1994 (EMPCA). Mineral Resources Tasmania (MRT) impose rehabilitation bonds on tailings projects as they progress. Environmental management plans are required for mines under (EMPCA) and waste handling, rehabilitation and discharge are covered under this Act (Grun 2005).
- There are no specific regulations or tailings management guidelines for tailings storage facilities in Tasmania.

coffey geotechnics
SPECIALISTS MANAGING THE EARTH

Introduction - Regulations

- In South Australia there are no specific regulations on tailings storage and guidelines for tailings impoundment construction and operation have been adopted from Western Australia and Victoria. South Australia, like many other mining regulators, is moving away from prescriptive regulations and more on to objective and risk management. This ultimately reduces the regulators exposure to risk in case of a project failure.

coffey geotechnics
SPECIALISTS MANAGING THE EARTH

Introduction - Regulations

- Australian tailings guidance manuals are commonly referred to by tailings personnel within Australia and internationally. The DME in Western Australia have produced two guidance manuals to improve tailings management. The Guidelines on the Safe Design and Operating Standards for Tailings Storage (DME 1999), are intended to provide a common approach to the safe design, construction, operation and rehabilitation of a tailings facility, and to provide a systematic method of classifying their adequacy under normal and worst case operating conditions (DME 1999).

coffey geotechnics
SPECIALISTS MANAGING THE EARTH

Introduction - Regulations

- All tailings storage facilities in Western Australia are designed and built to these guidelines (DME 2000). For the operational stage of a tailings facility the DME require a site-specific operating manual for every TMF (Anglo 2005). Each manual should be prepared in accordance with the Guidelines on the Development of an Operating Manual for Tailings Storage (DME 1998).
- It is a requirement to periodically review and update operating manuals as well as audit each tailings facility. The DME have another guideline document that reiterates their 1996 release. The Water Quality Protection Guidelines No.2 – Tailings Facilities (DME 2000) is designed to be used to manage the impacts that tailings storage has on the quality of the region's water resources (DME 2000).

coffey geotechnics
SPECIALISTS MANAGING THE EARTH

Introduction - Regulations

- The Environmental Protection Agency (EAP) of Australia produced a document in 1995 entitled, *Tailings Containment*. The document is part of a series of best practice in the mining industry aimed at protecting the environment and encouraging ecological sustainable development. *Tailings Containment* focuses on the design options of a TMF to reduce the long term environmental impacts, the need for monitoring during the operational stage and the overall objectives of tailings storage (EPA 1995). Martin et al. (2002) report that this document outlines key principles that contribute to tailings management operations within Australia.

coffey geotechnics SPECIALISTS MANAGING THE EARTH

Introduction - Regulations

- The Department of Primary Industries (DPI) in the state of Victoria has produced a comprehensive manual on tailings management. The document entitled, *Management of Tailings Storage Facilities* sets out regulatory policies and provides guidelines for tailings storage in the state of Victoria (DPI 2003). A clear and concise overview of tailings management throughout the life cycle of a tailings storage facility is presented. Statutory conditions are mentioned outlining what a mineral operator is required to achieve to fulfil the expectations of the regulators in the preliminary design through to closure of a TMF.

coffey geotechnics SPECIALISTS MANAGING THE EARTH

Introduction - Regulations

- The Ministerial Council on Mineral and Petroleum Resources (MCMPR) and the Minerals Council of Australia produced a document in 2003 entitled, Strategic Framework for Tailings Management. This document focuses on stewardship, stakeholder engagement, risk management, implementation and the closure aspects of tailings storage (MCMPR and MCA 2003).
- The document is not intended to provide a detailed set of guidelines on tailings management but compliment tailings regulations and other tailings guidance manuals implemented across all of Australia's jurisdictions. The goal of this document is to establish regulatory and industrial input to develop more consistent guidelines for tailings storage within Australia.

coffey geotechnics SPECIALISTS MANAGING THE EARTH

Introduction Development of Paste Technology

- In the last decade paste technology has progressed from a research based backfill idea to a widely accepted, cost effective backfill method with the potential to radically change the way tailings are disposed of on surface.
- Paste is simply dewatered tailings with little or no water bleed that are non-segregating in nature. It can be 'stacked' on surface and the risks associated with dam failure significantly reduces since there is no liquid containment and therefore no mechanism for the tailings to travel for tens of kilometres downstream in the event of a containment failure.
- The operating costs for the preparation and transportation of paste may be higher but life-of-mine cost analysis shows comparable costs to conventional disposal with significant environmental benefits. In addition, the eco-political impact of non water-retaining tailings dams could reduce permitting time considerably.

Paste – The Future of Tailings Disposal?
Phil Newman1, Roger White1, Alistair Cadden1
1Golder Associates (UK) Ltd., England

coffey geotechnics SPECIALISTS MANAGING THE EARTH

Paste Disposal

- Paste Disposal involves dewatering the tailings to a solids content of 70% to 85% (water content 30 – 15%) using high efficiency cone thickeners or conventional thickeners followed by partial vacuum filtration and paste mixing.
- Falls between thickened tailings and belt filtration
- High Pump Pressures,
- Angle of repose 3^0 to 10^0

coffey geotechnics
SPECIALISTS MANAGING THE EARTH

Paste Disposal – Advantages

- Less loss of water by evaporation
- Low permeability and limited capillary action to limit acid generation in sulphidic tailings
- Reduced groundwater pollution
- Minimal need for surrounding embankments,
- Possible elimination of liners,
- Usefule for underground backfill if cement added

coffey geotechnics
SPECIALISTS MANAGING THE EARTH

Paste Disposal – Disadvantages

- High Capital Cost
- High Operating Cost
- Performance inconsistencies
- High Pumping Costs particularly if long distances involved.

coffey geotechnics
SPECIALISTS MANAGING THE EARTH

Hazard Ratings

Hazard Ratings - Mine Tailings Storages (Adapted from DME(QLD) 1995 and DME (WA) 1996)

Type of Effect	HAZARD CATEGORY		
	HIGH	SIGNIFICANT	LOW
Uncontrolled Releases or Seepage			
Potential loss of human life	Contamination of a water supply likely to be consumed by humans is probable.	Contamination of a water supply likely to be consumed by humans is possible but not probable.	Contamination of water supply likely to be consumed by humans is not expected.
Potential loss of stock	Contamination of a water supply likely to be consumed by stock is probable.	Contamination of a water supply likely to be consumed by stock is possible but not probable.	Contamination of water supply likely to be consumed by stock consumption is not expected.
Environmental damage	Damage to an environmental feature of significant value is probable.	The significance of the environmental feature is less or damage is possible but not expected.	No environmental feature of significance or no damage expected.
Embankment Failure			
Loss of human life	Loss of life expected because of community or other significant developments.	No loss of life expected, but the possibility recognised. No urban development and no more than a small number of habitable structures downstream.	No loss of life expected.
Direct economic loss	Excessive economic loss such as serious damage to communities, industrial, commercial or agricultural facilities, important utilities, mine infrastructure, the storage itself or other storage downstream.	Appreciable economic loss, such as damage to secondary roads, minor railways, relatively important public utilities, mine infrastructure, the storage itself or other storages downstream.	No significant economic loss, such as limited damage to agricultural land, minor roads, mine infrastructure, etc.
Ongoing Economic Loss	Storage essential for services and repairs not practicable.	Repairs to storage practicable without major interruption to services.	Repair to storage practicable. Losses of services not significant.

coffey geotechnics
SPECIALISTS MANAGING THE EARTH

Hazard Ratings

Table 6.2

Design and Operating Requirements - Mine Tailings Storages (Adapted from DME (WA) 1996)

	HIGH HAZARD	SIGNIFICANT HAZARD	LOW HAZARD
Completion of Tailings Storage Data Sheet	Yes	Yes	Yes
Check Aftercare requirements	Probably State Government.	Probably State or Local Government.	Probably landowner.
Design	Report prepared in detail by Geotechnical/Engineering Specialist. Operations Manual required.	Report prepared by Geotechnical/ Engineering Specialist. Operations Manual required.	Notice of intent or Works Approval required including Operating Criteria.
Construction	Supervised by Geotechnical/ Engineering Specialist. Detailed construction report with as-built drawings.	Supervised by suitably qualified engineer. Brief construction report with as-built drawings.	Constructed by a suitably experienced contractor.
During Operations	Annual inspection and audit by Geotechnical/Engineering. Operation Manual reviewed.	Inspection and audit every 2 years by Geotechnical/Engineering specialist. Operation Manual reviewed.	Inspection and audit every 3 years by Geotechnical/Engineering specialist. Operating Criteria reviewed.
Risk Assessment	Yes	Preferred	Possible
Provision of Emergency Action Plan	Yes, based on a Dam Break analysis.	Yes	Yes
Routine daily inspection by site personnel	Yes	Yes	Yes
Rehabilitation Phase	Inspection and decommissioning report by Geotechnical/Engineering and other specialists depending on rehabilitation required. Formal handover to Aftercare Agency.	Inspection and decommissioning report by Geotechnical/Engineering and other specialists.	Inspection and decommissioning report by Geotechnical/Engineering specialist.

coffey geotechnics
SPECIALISTS MANAGING THE EARTH

Freeboard – Operating Dams

Table 6.3. Design Freeboard - Operating Dams

Hazard Category		Spillway/Freeboard Requirements	Additional Freeboard Required
HIGH	OR	PMF on highest pond level in normal year	None
		worst wet season on record less water returned to plant, plus 1 in 100 AEP storm plus waves	0.5m
SIGNIFICANT	OR	1 in 1000 AEP storm on highest pond level in normal year	0.3m
		worst wet season on record, less water returned to plant plus waves	0.3m
LOW	OR	1 in 100 AEP storm on highest pond level in normal year	0.3m
		worst wet season on record, less water returned to plant plus waves	0.2m

coffey geotechnics
SPECIALISTS MANAGING THE EARTH

Freeboard – at Closure

Table 6.4. Design Freeboard - At Closure

Hazard Category		Spillway/Freeboard Requirement	Additional Freeboard Required
HIGH		PMF on highest pond in normal year	None
	OR	worst wet season on record plus 1 in 1000 AEP storm plus waves	0.2m
SIGNIFICANT		1 in 10,000 AEP storm on highest pond level in normal year	0.2m
	OR	worst wet season on record plus waves	0.2m
LOW		1 in 1,000 AEP storm on highest pond level in normal year	0.2m
	OR	worst wet season on record	0.2m

coffey geotechnics
SPECIALISTS MANAGING THE EARTH

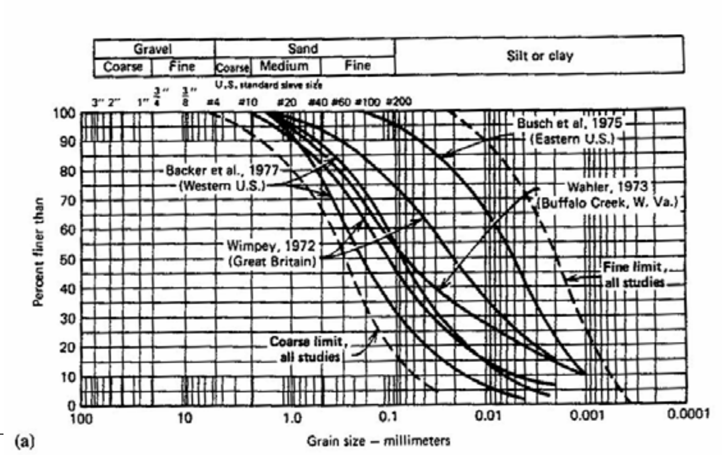
Acceptable Factors of Safety

Table 6.5. Acceptable Factors of Safety

Loading Condition	US Corps of Eng *(Note 1)*	Recommended Minimum for Tailings Dams (Note 2)	Shear strength to be used for evaluation Note 6)
Steady seepage at high pool level	1.5	1.5	Effective or total stress
Rapid drawdown from pool level	1.2	1.2 (Note 3)	Total stress, or effective stress
Earthquake (high pool for downstream slope, or at intermediate pool for upstream slope)	1.0	1.1 for pseudo- static analysis, (see Note 4 & Section 6.12)	Total stress or post liquefaction strength
Construction conditions, either slope	-	1.3 or 1.1 (Note 5)	Effective stress or total stress

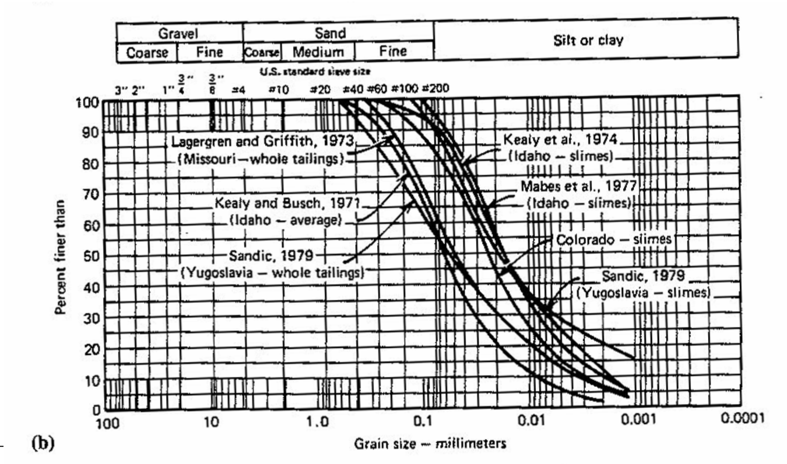
coffey geotechnics
SPECIALISTS MANAGING THE EARTH

Coal Washings PSD



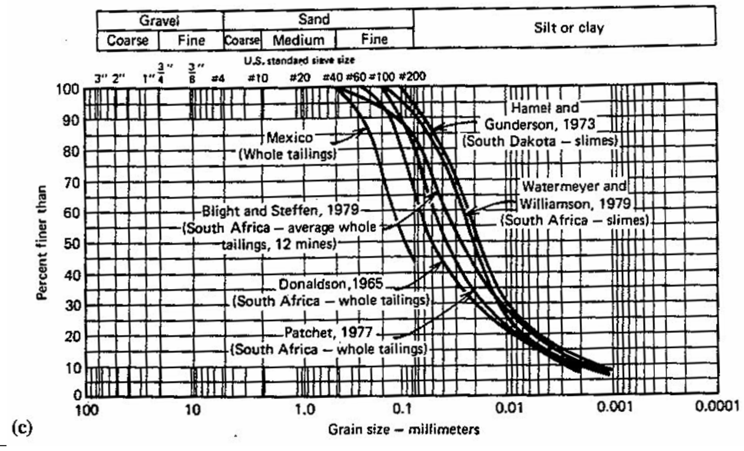
coffey geotechnics
SPECIALISTS MANAGING THE EARTH

Lead - Zinc PSD



coffey geotechnics
SPECIALISTS MANAGING THE EARTH

Gold Silver- PSD



coffey geotechnics
SPECIALISTS MANAGING THE EARTH

Tailings Properties

Table 19.3. Soil mechanics properties of some fine grained tailings.

Tailings	Water content (%)	Dry density (t/m³)	% solids	Soil particle density (t/m³)	Atterberg limits (%) Liquid limit	Plastic limit	Plasticity index	Particle size (%)[1] Sand	Silt	Clay[2]
Weipa 1	675	0.14	13	2.75	44	27	17	20	47	33
Weipa 2	362	0.25	22	2.85	43	26	17	15	45	40
Wambo	411	0.22	20	1.86	74	28	46	14	36	50
Riverside	250	0.32	29	1.74	44	28	16	16	50	34
Newman	192	0.46	34	3.70	33	22	11	20	60	20
Hamersley	169	0.50	37	3.50	30	21	9	5	55	40
North Kalgurli	71	0.94	59	2.81	28	21	7	Not available		
Broken Hill	462	0.20	18	3.05		Non plastic				

Notes: [1] Particle size with dispersant added as per AS1289; [2] percentage finer than 0.002 mm.

coffey geotechnics
SPECIALISTS MANAGING THE EARTH

Tailings Properties

Table 19.4. Typical in place densities and void ratio for non-desiccated tailings (adapted from Vick, 1983).

Tailings type	Specific gravity	Void ratio	Dry density (t/m^3)
Fine coal refuse			
Eastern US	1.5–1.8	0.8–1.1	0.7–0.9
Western US	1.4–1.6	0.6–1.0	0.7–1.1
Great Britain	1.6–2.1	0.5–1.0	0.9–1.35
Oil sands			
Sands	–	0.9	1.4
Slimes	–	6.0–10.0	
Lead–zinc slimes$^{(1)}$	2.9–3.0	0.6–1.0	1.5–1.8
Gold–silver slimes	–	1.1–1.2	
Molybdenum sands	2.7–2.8	0.7–0.9	1.45–1.5
Copper sands	2.6–2.8	0.9–1.4	1.1–1.45
Taconite sands	3.0	0.7	1.75
Taconite slimes	3.1	1.1	1.5
Phosphate slimes	2.5–2.8	11.0	0.25
Gypsum treated tailings	2.4	0.7–1.5	
Bauxite slimes	2.8–3.3	8.0	0.3$^{(2)}$

Notes: $^{(1)}$ For hard rock tailings; $^{(2)}$ low by Australian standards 0.5–0.9 t/m^3 more likely.

coffey geotechnics
SPECIALISTS MANAGING THE EARTH

Upstream Disposal - 1

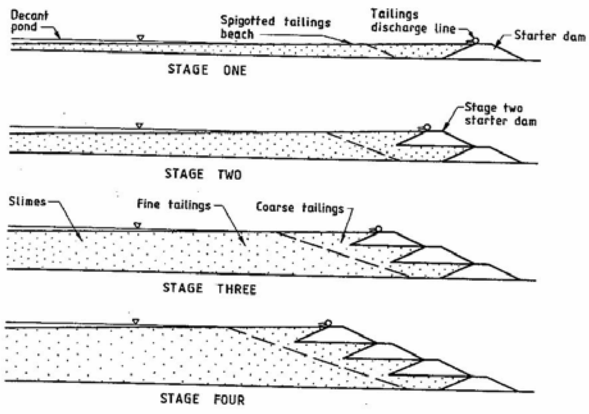


Figure 19.17. Construction of a tailings embankment using the upstream method.

coffey geotechnics
SPECIALISTS MANAGING THE EARTH

Upstream Disposal - 2

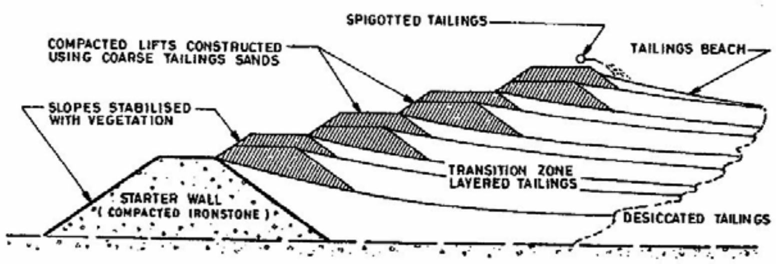


Figure 19.18. Section of bauxite tailings embankment at Weipa showing upstream construction (Minns, 1988, reproduced with permission of ASCE).

coffey geotechnics SPECIALISTS MANAGING THE EARTH

Centreline Disposal

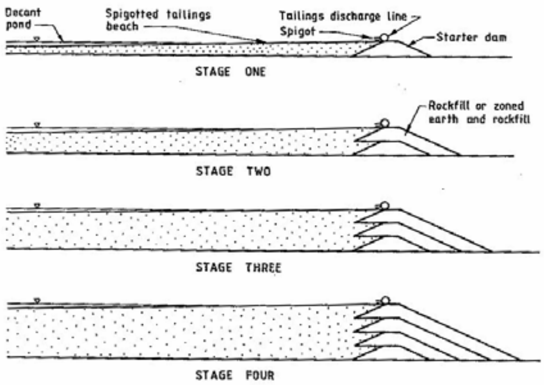
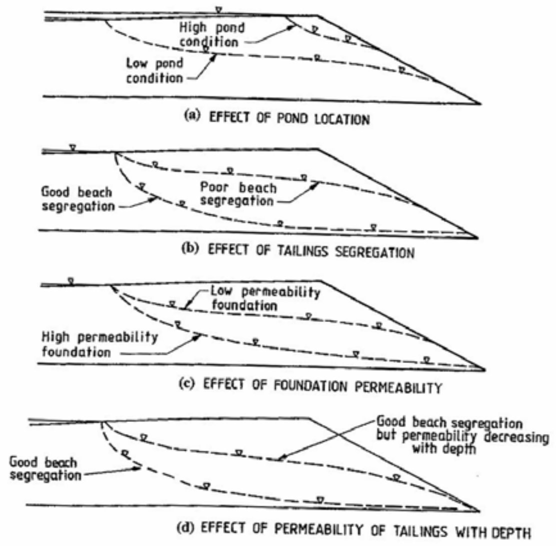


Figure 19.22. Construction of tailings embankment using the centreline method.

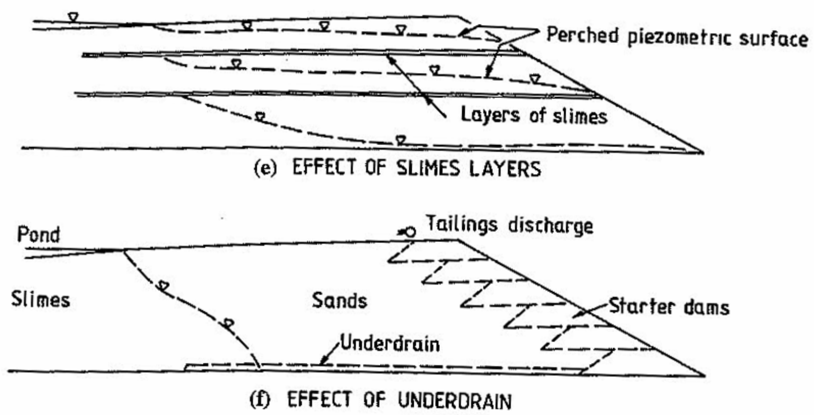
coffey geotechnics SPECIALISTS MANAGING THE EARTH

Drainage



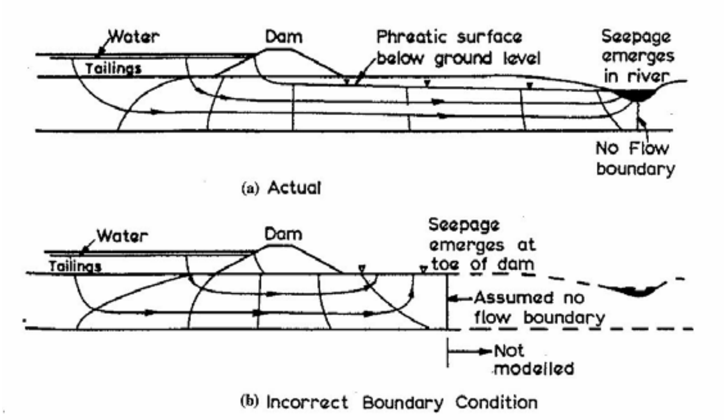
coffey geotechnics
SPECIALISTS MANAGING THE EARTH

Drainage



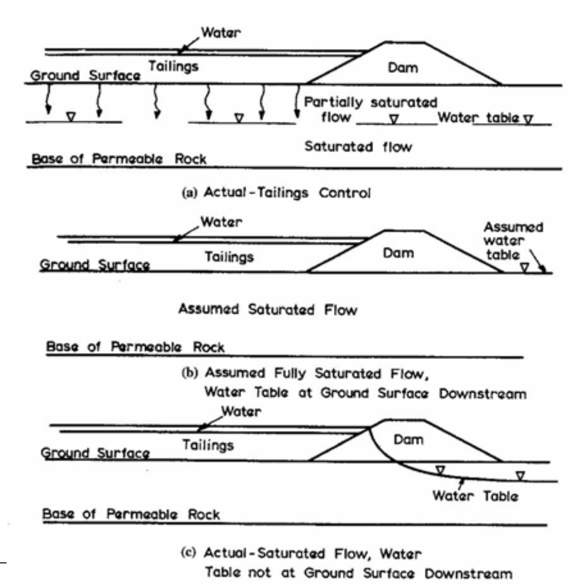
coffey geotechnics
SPECIALISTS MANAGING THE EARTH

Seepage



coffey geotechnics
SPECIALISTS MANAGING THE EARTH

Seepage



coffey geotechnics
SPECIALISTS MANAGING THE EARTH

Conventional Tailings Disposal – Containment Structures

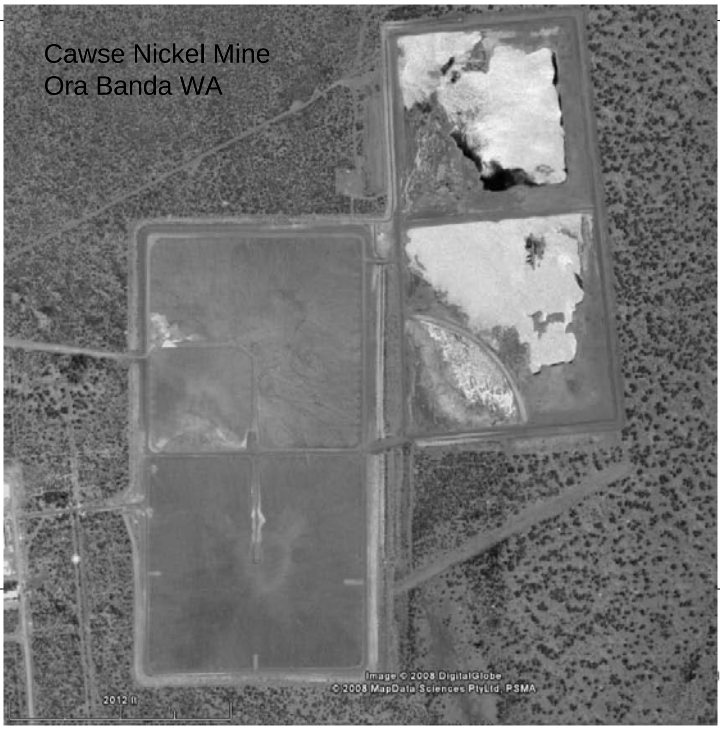
- Tailings Dams:
  - Upstream,
  - Centreline,
  - Downstream
- Lined Tailings Dams
  - Faced Embankments
  - Lined Paddocks

coffey geotechnics
SPECIALISTS MANAGING THE EARTH

Conventional Paddock Dams

- Earthfill embankments with managed tailings discharge – typically sub-aerial.
- Suited to semi arid climates
- Relatively simple to maintain water balance

coffey geotechnics
SPECIALISTS MANAGING THE EARTH


Cawse Nickel Mine
Ora Banda WA
Image © 2008 DigitalGlobe
© 2008 MapData Sciences PtyLtd, PSMA


Jubilee Mine
Kambalda WA
Image © 2008 DigitalGlobe
© 2008 MapData Sciences PtyLtd, PSMA
Google

Jubilee Mine
Kambalda WA

coffey geotechnics SPECIALISTS MANAGING THE EARTH

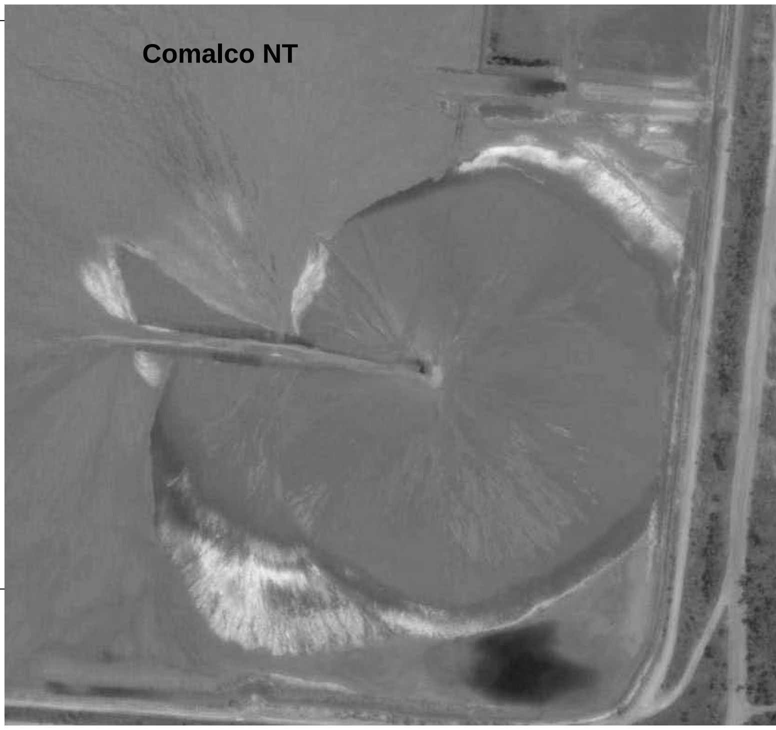
The Red Mud Problem

- Low density
- Highly Caustic
- Long Consolidation Times
- Highly Compressible

coffey geotechnics SPECIALISTS MANAGING THE EARTH


Comalco NT
2370 ft
Image © 2008 DigitalGlobe
Google
EARTH

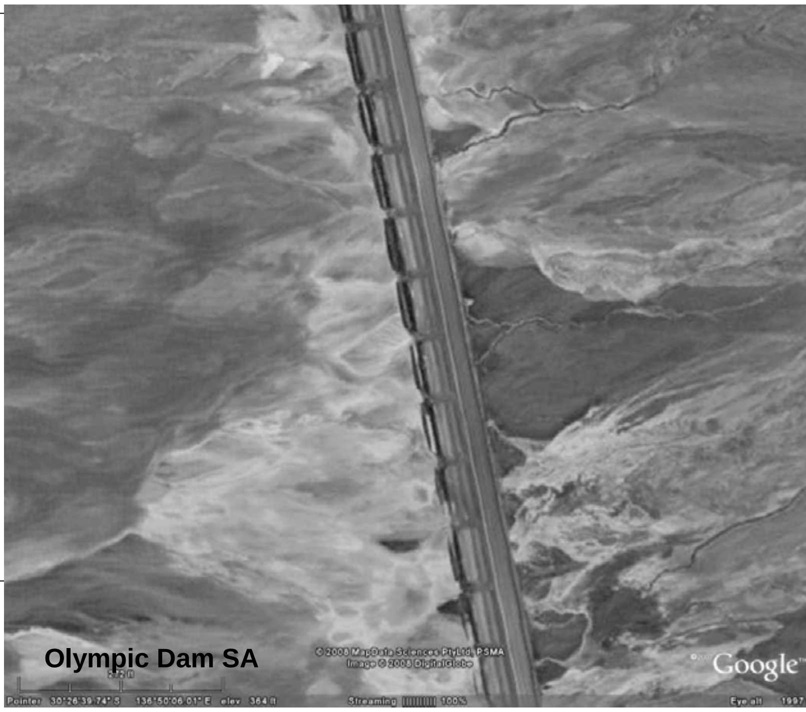

Comalco NT
831 ft
Image © 2008 DigitalGlobe
Google



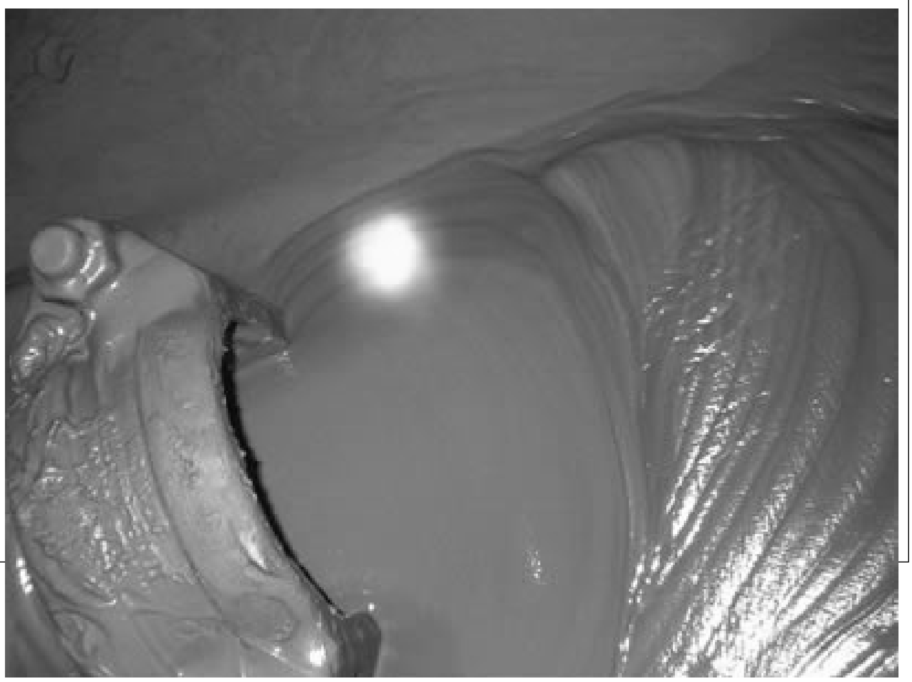
Complex tails Uranium Copper

- Olympic Dam SA


Olympic Dam SA
© 2008 MapData Sciences Pty Ltd, PSMA
Image © 2008 DigitalGlobe


Olympic Dam SA
© 2008 MapData Sciences Pty Ltd, PSMA
Image © 2008 DigitalGlobe

Stacked tailings
South America



Decant Barges

coffey geotechnics SPECIALISTS MANAGING THE EARTH

Decant Barges

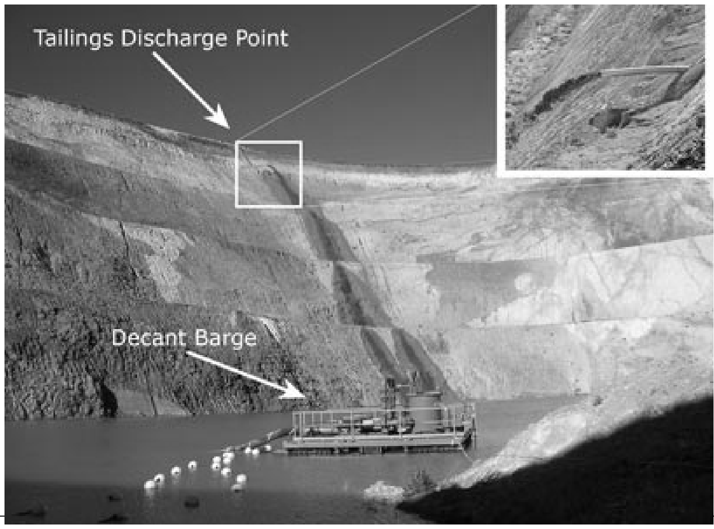
coffey geotechnics SPECIALISTS MANAGING THE EARTH

Decant System

coffey geotechnics
SPECIALISTS MANAGING THE EARTH

Decant System

coffey geotechnics
SPECIALISTS MANAGING THE EARTH



In Pit Disposal

coffey geotechnics
SPECIALISTS MANAGING THE EARTH

Lined Tailings Dam

coffey geotechnics
SPECIALISTS MANAGING THE EARTH

Lined Tailings Dam
- Construction

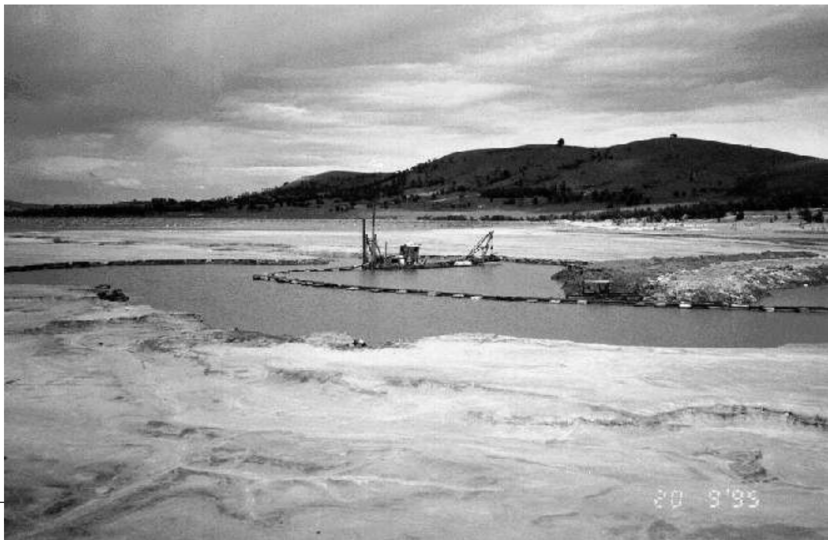
coffey geotechnics
SPECIALISTS MANAGING THE EARTH

Lined Tailings Dam

coffey geotechnics
SPECIALISTS MANAGING THE EARTH

Lined Tailings Dam

coffey geotechnics
SPECIALISTS MANAGING THE EARTH



Tailings dredging for re-processing

coffey geotechnics
SPECIALISTS MANAGING THE EARTH

Hydraulic Mining - Kaltails

coffey geotechnics
SPECIALISTS MANAGING THE EARTH

Hydraulic Mining - Kaltails

coffey geotechnics
SPECIALISTS MANAGING THE EARTH

Coal Tailings – More Problems

- Low Slurry Density

coffey geotechnics
SPECIALISTS MANAGING THE EARTH

Coal Co-Disposal

coffey geotechnics
SPECIALISTS MANAGING THE EARTH

Coal Co-Disposal

coffey geotechnics
SPECIALISTS MANAGING THE EARTH

Coal Co-Disposal

coffey geotechnics
SPECIALISTS MANAGING THE EARTH

Rock bridging on tailings

coffey geotechnics
SPECIALISTS MANAGING THE EARTH

Revegetation of Tailings dam

coffey geotechnics
SPECIALISTS MANAGING THE EARTH

Gravel Washery discharge

Gravel Washery discharge

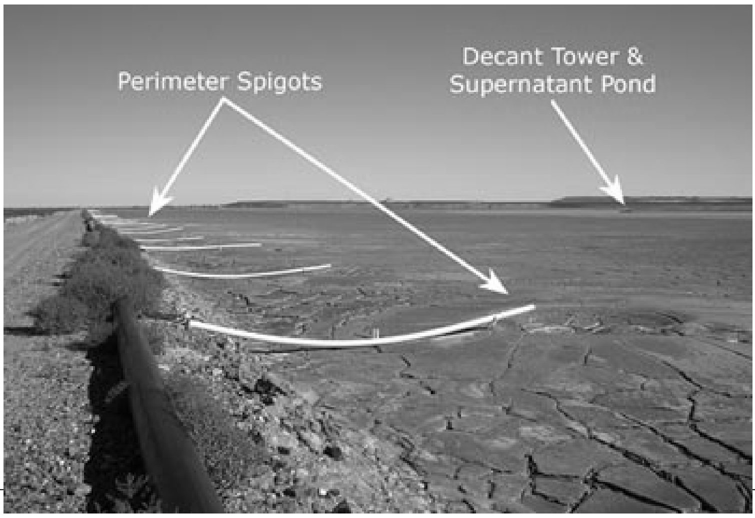
`

Central Thickened Discharge

coffey geotechnics
SPECIALISTS MANAGING THE EARTH

Sub-Aerial Disposal

coffey geotechnics
SPECIALISTS MANAGING THE EARTH



Sub-Aerial Disposal

coffey geotechnics
SPECIALISTS MANAGING THE EARTH

Central Thickened Discharge

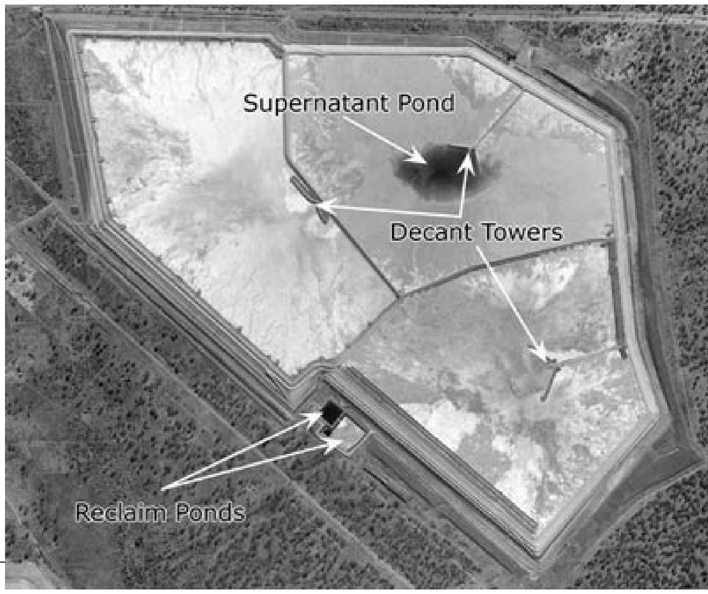
coffey geotechnics
SPECIALISTS MANAGING THE EARTH

Central Thickened Discharge

coffey geotechnics
SPECIALISTS MANAGING THE EARTH

Single point Discharge

coffey geotechnics
SPECIALISTS MANAGING THE EARTH



Modern sub-aerial Discharge

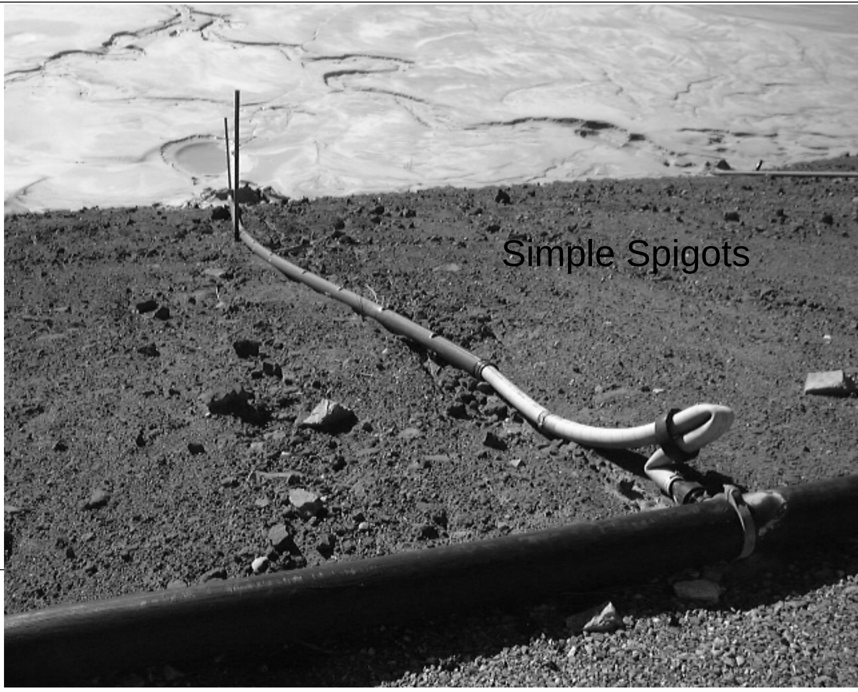
coffey geotechnics
SPECIALISTS MANAGING THE EARTH

coffey geotechnics
SPECIALISTS MANAGING THE EARTH

coffey geotechnics
SPECIALISTS MANAGING THE EARTH

Sub-Aerial Deposition

coffey geotechnics
SPECIALISTS MANAGING THE EARTH


Simple Spigots

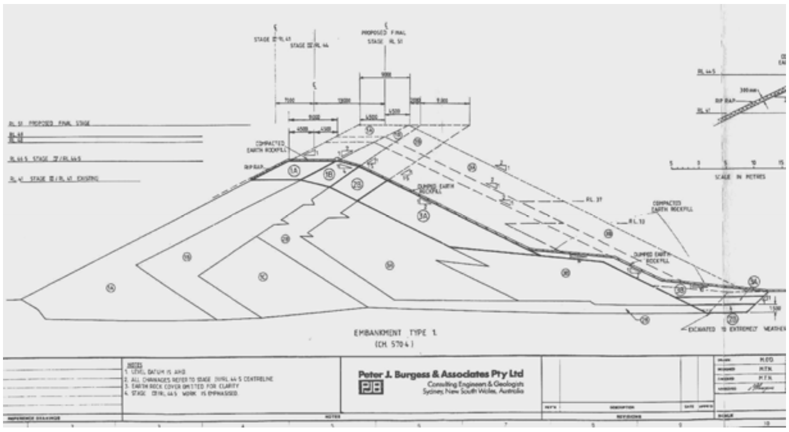

Simple Spigots

Quick Release Clamps

Sub- aqueous Disposal

- Uranium Mill tailings
- Ag Pb Zn Base metals

Water Retaining Dam



coffey geotechnics SPECIALISTS MANAGING THE EARTH

Sub-Aqueous disposal

Sub Aqueous Disposal

Sub-Aqueous disposal

coffey geotechnics
SPECIALISTS MANAGING THE EARTH

Tailings Deposition Issues to consider:

- Sedimentation for sub-aqueous deposition
- Beaching & segregation for sub-aerial deposition
- Immediate “settled density” & short-term water return
- Consolidation behaviour (time and amount)
  - final density & strength profiles
- Capping
  - revegetation?
- Erosion
  - outer wall protection, especially if constructed of tailings

coffey geotechnics
SPECIALISTS MANAGING THE EARTH

Tailings Consolidation – Issues to Consider

- Tailings consolidation is due to
  - self-weight
  - evaporation
- Self-weight consolidation without evaporation
  - in wet climate, or if tailings kept under water
  - effectiveness depends on base drainage condition
  - undrained base leads to *very poor* consolidation
  - drained base - slightly better
  - *time for consolidation* depends on d2 (drainage path length)
    - d for undrained base twice d for drained base: time increased by factor of 4
    - in-pit storage undrained base, d = 80 m, fine-grained tailings
      - CONSOLIDATION MAY CONTINUE FOR MANY DECADES

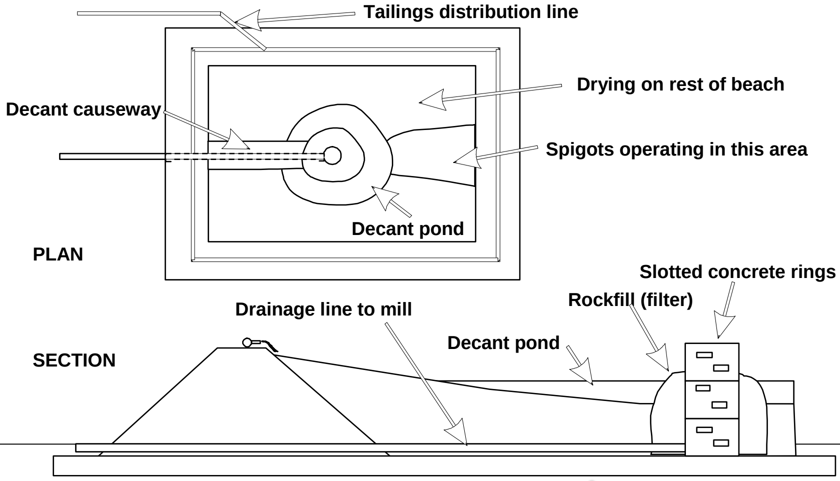
coffey geotechnics SPECIALISTS MANAGING THE EARTH

Tailings Consolidation

- **Self-weight consolidation not efficient because**:
  - weight not applied until material buried (remote from drained boundary), resulting in delayed consolidation
- **Evaporation "sucks" water from the surface**
  - consolidates the material on the surface, increasing the density
  - if sufficient drying, tailings are sufficiently consolidated that:
    - no further consolidation will occur due to weight of overburden material
    - maximum possible density achieved
    - maximum possible strength achieved (important for upstream construction)
    - maximum possible efficiency of the storage area
    - no settlement after filling ceases
    - strength sufficient for access to the surface for rehabilitation
    - no further downward flow of water (+ contaminants) into the groundwater

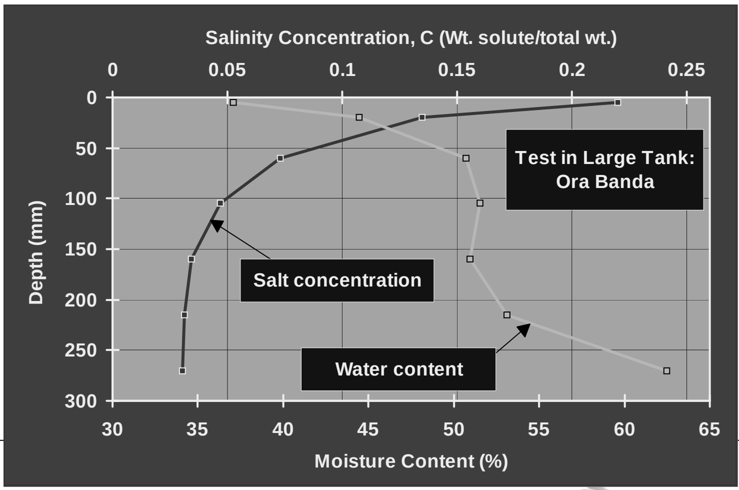
coffey geotechnics SPECIALISTS MANAGING THE EARTH

Basic Model for Paddock Placement



coffey geotechnics
SPECIALISTS MANAGING THE EARTH

Crusting of Tailings



coffey geotechnics
SPECIALISTS MANAGING THE EARTH

Tailings Storage

- "Storage" (long term), not "disposal"
- General requirements
  - no (minimal) direct impact on people, fauna, flora
    - stability against catastrophic failure
    - prevention of erosion "failure"
    - prevention of dust (especially toxic dust - cyanide, salt, radioactive)
    - prevention of groundwater contamination (acid, cyanide, salt etc)
  - acceptable visual impact
    - can landform be created identical to surrounding landforms (usually no)
    - what is acceptable?
- Economic requirements
  - provide safest, most cost-effective storage possible

coffey geotechnics
SPECIALISTS MANAGING THE EARTH

Environmental Factors

- Escape of leachate
  - tailings may contain cyanide, heavy metals, high salinity, radioactive components ……
- Dust from dry tailings can blow large distances
  - visual impact, and health impact (on plant and animals/humans)
- Acid generation ("Acid Mine Drainage")
  - capping, buffering, cleanup, neutralisation…..

coffey geotechnics
SPECIALISTS MANAGING THE EARTH

Current Tailings Disposal – Paste and Thickened Discharge

- Mine Pits:
- Underground Mines
- Sub- Marine Disposal

Thickened Tailings

coffey geotechnics SPECIALISTS MANAGING THE EARTH

Case History - Falconbridge - Kidd Creek Met Site, Timmins, Ontario, Canada

- The Kidd Creek Metallurgy site processes the copper/zinc ore from the Kidd Mine site located 7km away. The metallurgy site has a copper smelter and refinery, a zinc refinery, and indium and acid plants.

Case History - Falconbridge - Kidd Creek Met Site, Timmins, Ontario, Canada

- In 1973 the Falconbridge owned Kidd Creek Metallurgy Plant in the town of Timmins, Ontario, Canada was the first site to use thickened disposal of tailings. The theory was that instead of having a conventional impoundment involving embankments that are continually raised as more tailings are disposed of, there would be little or no embankments at all.
- The Kidd Creek thickened disposal site currently stores >100 million tonnes of base metal sulphide tailings and by the time the site is expected to close in 2023 >130 million tonnes will be stored. The radius of the conical pile is 1.2km and the height of the cone is 25m. The height of the cone increases by 0.2m/y and by closure the height is expected to be 29m.
- The reasons for thickened disposal at Kidd Creek instead of conventional impoundment storage are mainly due to the topography, hydrology and soil conditions of the area.
  - High dykes would be unsuitable for the area and the risk of instability would be increased due to the extremely poor soil conditions.
  - The tailings are finely ground (45µm) and imported materials would have to be used for dyke construction, thus increasing costs.
  - Predominantly cold climate conditions would only allow a short window for dam construction.
  - The site is situated on high ground surrounded on three sides by Porcupine River tributaries.

www.tailings.info

coffey geotechnics
SPECIALISTS MANAGING THE EARTH

Case History - La Coipa, Atacama Region, Chile, South America

- Dry stacking of tailings has been developed due to advancements in large capacity pressure and vacuum filters. The tailings are dried out to contain <20% water content (depending on the specific gravity) allowing them to be either trucked or by conveyor to the disposal site. The tailings are then spread out and compacted to increase the density of the stack. The deposit is much more stable than a paste disposal site.

Case History - La Coipa, Atacama Region, Chile, South America

Advantages

- The high density of the tailings reduces the overall volume of the storage facility required (less land required).
- Surface stability is much safer than conventional wet deposition and allows for quick plantation.
- The dry stack can be raised to heights which would not be economical with conventional impoundments.
- Groundwater contamination is reduced.
- Useful in arid climates where water conservation is an issue.
- For cold climates dry stacking prevents pipe freezes and frosting problems with conventional impoundments.
- Binders (cement) can be used to increase the stability of the deposit.
- Low seepage levels from the stack

Case History - La Coipa, Atacama Region, Chile, South America

Disadvantages

- Higher costs than conventional impoundment storage.
- Largely unproven technology and disposal method.
- Problems with dust and tailings becoming airborne.

Paste Technology

Future of Paste

- The increased utilisation of paste technology has improved the reliability and reduced the cost of preparation and transportation systems. This has led to the possibility of using paste for surface disposal.
- The final prize of such an endeavour is the introduction of virtually water-free surface tailings storage. This can eliminate the need for large water-retaining dams and remove the associated liability such structures pose to the environment.
- Such a step appears logical, as regulatory pressures become more demanding in Europe after recent high profile dam failures, increasing the permitting requirements for conventional tailings disposal.

Example of Paste

- The Bulyanhulu Mine in Tanzania, successfully commissioned in March 2001, is the first mine in the world to adopt a total paste solution for all its tailings. A portion will be used underground as backfill and the remainder will be ‘stacked’ on surface as paste.
- The advantages cited by Barrick Gold in their decision to develop the system
- include:
  - Reduced capital cost (no large starter dam required)
  - Water conservation (traditional disposal may have led to water scarcity and the need for a dedicated water pipeline from Lake Victoria, ~100 km)
  - Decreased footprint of tailings disposal site

Definition of Paste

- A paste can simply be defined as a mixture of solids and water that has little or no bleed water when idle.
- It must also, however, possess some yield stress such that when tested using a conventional concrete testing slump cone, it does exhibit slump.

Paste – The Future of Tailings Disposal?
Phil Newman1, Roger White1, Alistair Cadden1
1Golder Associates (UK) Ltd., England

coffey geotechnics SPECIALISTS MANAGING THE EARTH

Central Thickened Discharge

coffey geotechnics SPECIALISTS MANAGING THE EARTH

Slump 175 mm

Slump 250mm

Paste – The Future of Tailings Disposal?
Phil Newman1, Roger White1, Alistair Cadden1
1Golder Associates (UK) Ltd., England

coffey geotechnics
SPECIALISTS MANAGING THE EARTH

Paste Backfill

- Paste *backfill* is always placed cemented and the optimum slump that minimises transportation pressure losses and maximises strength gain is often found between 150 and 200 mm.

Future of paste

- The difference between 'backfill' paste and 'surface disposal' paste is subtle but impacts significantly on the preparation method and hence the cost of plant construction. At present, it is not possible to consistently manufacture a 'backfill' paste (i.e. a slump of <200 mm) without the use of mechanical dewatering (filtration). Improvements in dewatering technology have enabled the production of higher slump pastes to become possible for some tailings and this has opened up the possibility of low cost paste production, thus bringing environmentally beneficial paste disposal one step closer.

Environmental Advantages of paste

- The primary advantage is that there is very little free water available to generate leachate. In addition, the relatively low permeability of the poorly sorted full plant tailings limits infiltration, resulting in reduced seepage volume present in the deposited paste.
- Hydraulic conductivity values are not easy to determine for an uncemented paste but values have been determined for weakly cemented samples. These range between 10-7 and 10-8 m/s.

Additives

- The most commonly used additive for paste backfill is a pozzolanic binder such as cement, slag, flyash etc. These provide significant strength underground at addition levels of 3 – 6% by weight. For surface disposal, the cost makes them unattractive although tests have shown that 1 wt% cement addition can increase the neutralizing potential by an order of magnitude. It also raises the pH, which can lead to immobilisation of some metals through mineral precipitation.

Solids Content to form pastes

- The solids concentration (by mass) at which tailings exhibit paste properties can vary significantly and are a property of the fines content and the colloidal chemistry associated with such fines. For example, high clay content tailings such as aluminium tailings (red mud) can exhibit paste properties at ~45 wt% solids, (wt. Solids / (wt. Solids + wt. Water)). Base metal tailings, especially when combined with sand or waste rock can develop solids contents as high as 85 wt% solids and still be easily transported as a paste. Chemically altered tailings, e.g. from Uranium and Soda Ash processing, are pastes at very low solids content, 20-40 wt% solids.

Co-Disposal

- One of the most exciting opportunities for paste disposal is the wide range of co-disposal options that are available. The primary example is that of acid generating waste rock (a common occurrence for many mines) being sent to the same waste facility to be encapsulated' in tailings paste. This significantly reduces the oxidation risk and reduces the number of waste facilities requiring closure.

Paste – The Future of Tailings Disposal?
Phil Newman1, Roger White1, Alistair Cadden1
1Golder Associates (UK) Ltd., England

coffey geotechnics
SPECIALISTS MANAGING THE EARTH

Transportation of Tailings

- For paste backfill careful transportation design is required to ensure a full line which reduces hammer and wear, in turn reducing the risk of plugging the line. For surface disposal the transportation issues are more straightforward, normally related to finding a pump that can provide the necessary driving force with the required availability to operate 24 hours a day. Positive displacement pumps can provide the necessary pressure and capacity.

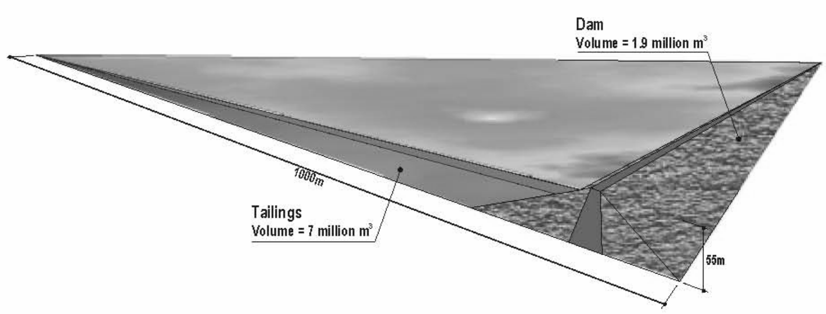
Acid Generating Tailings

- **Acid Generating Tailings**
- Reactive tailings need to be protected from oxidation and this is normally achieved through sub-aqueous disposal that inhibits oxygen contact with the tailings. Conventional sub-aerial disposal of reactive tailings as slurry results in segregation of the tailings that can result in accelerated oxidation leading to acid generation. Paste is homogenous and has a low permeability such that only a thin exposed layer can oxidise.

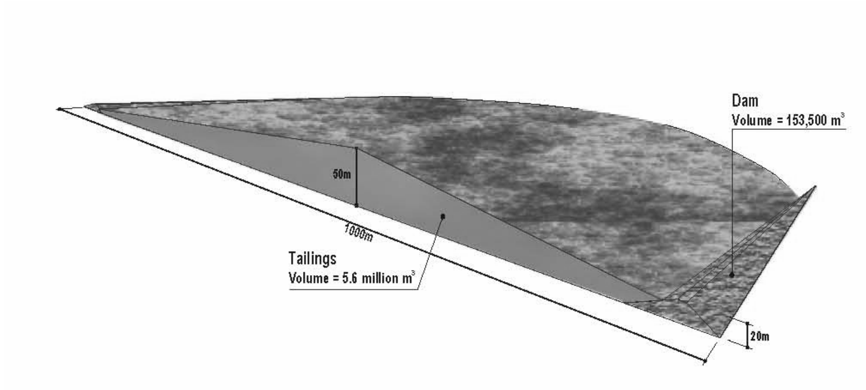
Tailings Placement to Exclude Oxidation

- Hence, a possible paste solution is to ensure that each layer of tailings is subsequently covered with fresh tailings before oxidation takes hold, effectively ensuring acid generation does not gain impetus. The practicalities of such a method have not been fully investigated and there are a number of questions that remain to be answered. However, the Kidd Creek Mine in Timmins, Ontario (Canada) stacks thickened tailings (very little segregation) and has found that as long as tailings are covered with a fresh layer within 12-18 months then acid generation does not become a problem.
- However, many tailings are much more reactive and covering of old tailings may have to be far more frequent and the issue of total coverage can become problematic.

Comparison Conventional vs Paste / Thickened



Comparison Conventional vs Paste / Thickened



Options for Placement

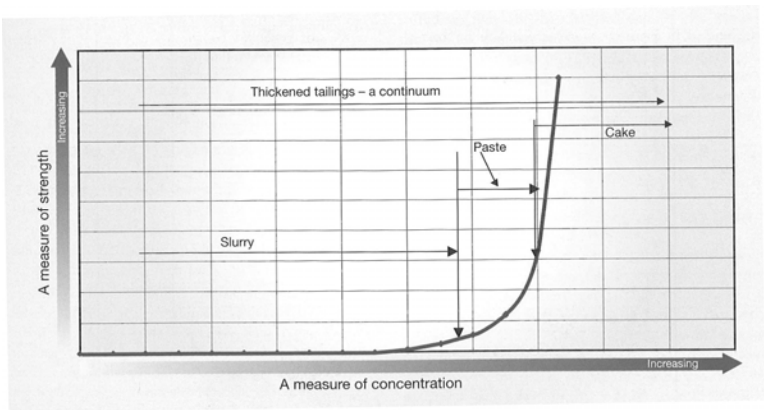
- The following additional advantages are not included in the cost analysis but are
- considered to be of significant value to the project:
  - elimination of a tailings 'dam' and the associated negative public perception of the dam
  - reduction in environmental disruption afforded through increased management of the facility and the use of concurrent rehabilitation of the site
- significantly reduced liability for the mine with respect to any TSF failure that may occur, this may impact on bond payments or insurance premiums
- possible co-disposal of other mine waste (notably acid generating waste rock) that reduces the number of waste areas requiring closure and monitoring
- possible additional revenue streams through the expansion of the paste facility to take other waste streams
- possible time saving from reduction in permitting constraints by the company adopting a more pro-

The Future

- Major mining companies such as Rio Tinto, Anglo and Billiton are committed to ever increasing environmental standards, pushing the bar higher in terms of compliance. It may appear that paste tailings disposal is the natural progression for this race for the moral high ground in an environmental sense. In Europe, regulatory pressure has increased significantly in recent years and many companies will have to adopt significantly more controlled waste management practices.

Paste – The Future of Tailings Disposal?
Phil Newman1, Roger White1, Alistair Cadden1
1Golder Associates (UK) Ltd., England

coffey geotechnics
SPECIALISTS MANAGING THE EARTH



Australian Centre for Geomechanics (ACG)
"Paste and Thickened Tailings – A Guide" 2006

coffey geotechnics
SPECIALISTS MANAGING THE EARTH