Landfill of Aluminium Smelter Waste at Wallaroo, NSW, Australia

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SYNOPSIS: Geotechnical investigations to assess the physical nature of the subsurface conditions, the geochemical properties of the soils and groundwater and the hydrogeological regime existing in an area proposed for the landfill disposal of Aluminium Smelter waste were undertaken to ensure safe and responsible management of this waste material was carried out.

The studies of the Wallaroo site have indicated the deeply weathered soil profile to have some useful characteristics for landfill disposal. The Permian rocks have been strongly and deeply weathered to a heavy clay that has a low permeability and the clay mineralogy has been established to have a significant adsorptive capacity for the waste chemistry.

A hydrogeologic model of the site was prepared using finite element computer techniques and correlated using monitored response from piezometers installed within some 90 boreholes drilled to evaluate the site. The groundwater level response and its sensitivity to variable infiltration rates and permeability parameters was then predicted using various model rainfall events.

Based upon the investigation data and the modelling results, a proposed "Waste Disposal Area" was selected. Two trial pits were constructed in this area, using sand to simulate the waste material. The area of these trial pits was extensively instrumented to assess rainfall infiltration to the pits and surrounding ground. The area was then subjected to extremely high simulated rainfall, using a spray irrigation system, and the performance assessed.

The effects of leachable fluoride and sodium and the high pH on the acidic clay have been studied in batch tests and distribution coefficients and maximum adsorption capacities measured. High concentrations of sodium and fluoride have also been passed through compacted clay core to study the effects on permeability and a decrease in permeability has been observed.

Following these extensive studies approval was granted for the disposal of wastes in the landfill on the basis of the inherent favourable geotechnical properties of the site together with the various safeguards provided by on-going monitoring and the favourable chemical interaction of the leachate with the surrounding natural clay. Initial disposal campaigns have now been conducted successfully.

1 INTRODUCTION

Potlining waste, the major waste from the aluminium smelting process has significant levels of leachable fluoride, cyanide and sodium and has a high pH. At the present time and into the foreseeable future there are major difficulties in treating this waste in an environmentally satisfactory way to remove the problem components.

In Australia the current practise at established smelters is to either store the waste above the ground, with collection and treatment of leachate, or landfill disposal of the waste. Similar waste management methods are used in USA.

A new smelter operated by Tomago Aluminium Company commenced production in September 1983 at Tomago which is situated 160 km north of Sydney. The smelter produces some 200,000 tonnes of aluminium a year and will produce about 10,000 tonnes per year of solid waste.

During the period 1983 to 1986 a detailed geotechnical investigation was carried out over a selected potential waste disposal site some 20 km north east of the smelter at Wallaroo. The location of the proposed waste disposal site is shown on Figure 1. The investigation techniques adopted were as follows:

- Terrain Evaluation, Regional Geology and
- Surface Hydrology studies
- Drilling of boreholes, soil sampling, installation of piezometers, field permeability testing and monitoring of groundwater levels
- Hydrogeologic modelling
- Soil structure and soil chemical analysis
- Trial disposal pit construction and monitoring

An area of some 200 ha was initially assessed and an area of 50 ha selected for detailed study. An area of about 0.5 ha per year is required for landfill disposal for a 3 m deep thickness of waste.

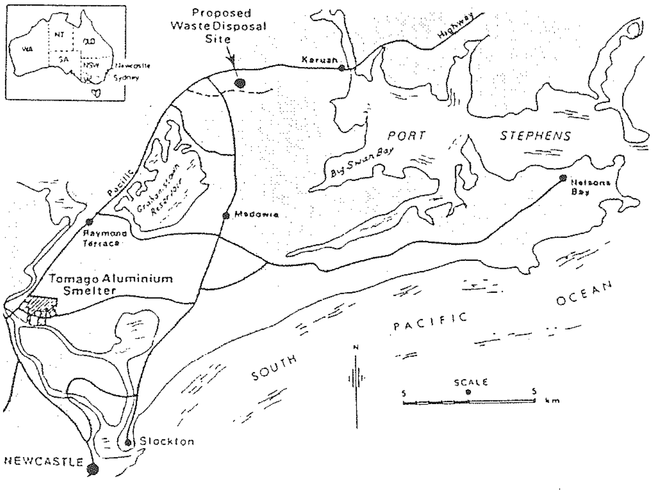

Figure 1 - Location of Landfill Site

2 TERRAIN, GEOLOGY AND HYDROLOGY

The proposed disposal area is situated on a flat to gently sloping topographic divide between the Port Stephens Estuary to the east and Grahamstown Reservoir to the south-west. The Estuary contains extensive commercial oyster leases and the Reservoir is a town water supply. The land is covered by a dry sclerophyll (open woodland) Eucalypt forest.

Beneath the forest there is a deeply weathered lateritic clayey profile developed on interbedded Permian siltstones, mudstones and clayey conglomerate beds to a depth of 20 to 40 m. At depth below the weathering zone beneath the proposed disposal site, there are gravelly strata overlying jointed rhyolite and ignimbrite volcanics.

Deep Tertiary lateritic weathering profiles are common in Australia and the age of major rock alteration has been dated elsewhere - Senior and Mabbutt (1979) as being mainly either Oligocene to Miocene (40-20 million years ago) when the climate was wetter than present. The weathering has chemically altered the rocks to aluminium and iron rich clay materials over depths of 20 to 30 m in a trough-like pattern that probably relates to a former Tertiary ground surface (Figure 2). This surface has undergone some change (erosion and deposition) in more recent times - Knight (1988).

3 SOIL CHARACTERISTICS

Over 90 boreholes and several test pits have revealed the soil characteristics. The acidic (pH 5.5) soils range from silty loams (slope deposit) to medium to high plasticity clays (in situ weathered rock) extending to 20 to 40 m depth with local zones of sandy and gravelly clays. Typical lateritic weathering patterns are present with reddish soils overlying a mottled zone passing down into a pallid zone and then to yellowish clays. The clays have a liquid limit ranging from 40 to 90 and plasticity index of 25 to 60. Natural moisture content is generally less than the plastic limit even below the water table confirming the highly overconsolidated nature of the clays. In situ permeability determined by insitu testing at some 50 locations indicated a mean value of 5×10^{-7} m/sec and ranged from 10^{-10} to 10^{-6} m/sec. A gravelly layer was found to exist 20 to 30 m below existing ground surface. permeability testing of this layer gave variable results the most permeable being 10^{-5} m/sec.

The clay composition is predominantly silica, aluminium and iron with lesser amounts of titanium, magnesium and potassium. Calcium is absent and sodium is very low which is typical of an extensively weathered and leached acidic profile of clay with low-cation exchange capacity.

4 HYDROGEOLOGIC REGIME

Monitoring of water levels within piezometer installations carried out during the early stages of the investigation revealed that groundwater levels beneath the south western (higher elevation) part of the site were quite sensitive to significant, but not abnormal, rainfall whereas the remaining area revealed quite minor response to natural rainfall.

This observation instigated a soil structure study of the upper 2 to 3 m of the soil horizon in the two areas which, in the responsive area, revealed the presence of vertical iron-rich tubular nodules down to 3 m which appeared vertically continuous and quite highly permeable and would allow the rapid passage of rainfall infiltration into the soil profile.

By comparison the soil structure in the less responsive area had a lesser proportion of iron-rich nodules with little apparent continuity.

The latter stages of investigation concentrated on the area which had relatively minor response to natural rainfall events. The phreatic surface in this area was generally 15 to 20 m below ground surface.

The piezometric surface within the underlying gravelly layer is quite insensitive to seasonal rainfall variation and has a very gentle hydraulic gradient down towards the north east.

4.1 Groundwater Modelling Study

A groundwater modelling study was carried out using Golder Associates suite of finite element groundwater programs to relate the properties of the soil profile to the observed patterns of groundwater response to rainfall. Initially a simplified vertical flow analysis was carried out to correlate the monitored response with inflow being a function of infiltration characteristics, permeability and storage coefficients. Outflow occurred via the underlying gravelly stratum.

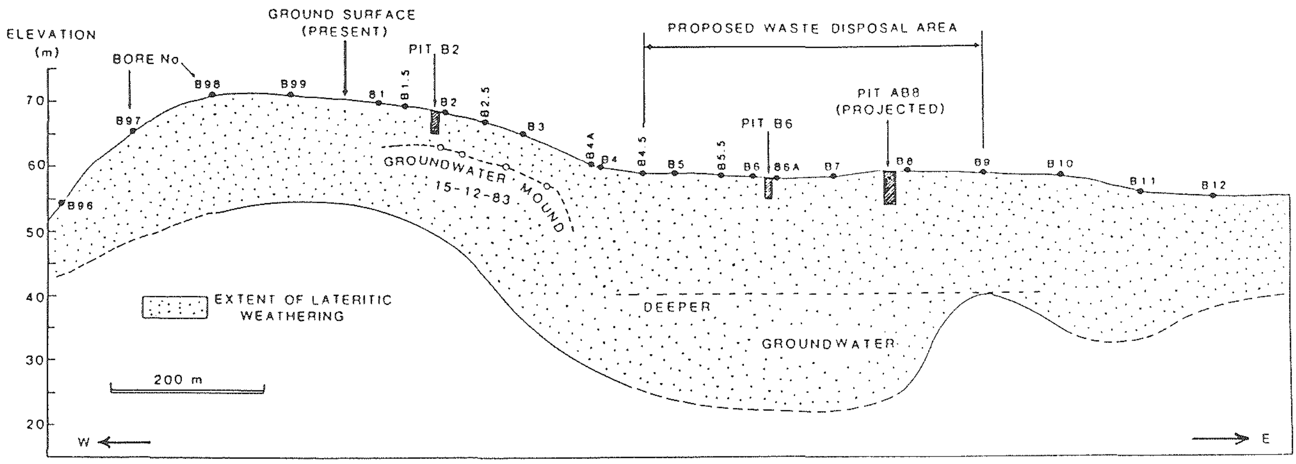

Figure 2 - East-West cross section through proposed Wallaroo waste disposal area showing lateritic weathering, groundwater, borehole and pit locations

A two dimensional analysis was then carried out modelling the observed water levels and recorded rainfall over a 9 month period with the infiltration factors determined earlier. After several trials a set of parameters were evolved which closely matched the observed data.

The calibrated model was then used to predict groundwater levels resulting from very heavy and very low seasonal rainfall situations. The infiltration characteristics were also varied to simulate the development of the site for its proposed waste disposal activity.

The modelling study was successful in mathematically assessing the sensitivity of the site to the effects of heavy rainfall however a more practical demonstration was considered appropriate to confirm the physical suitability of the site for waste disposal. Thus two substantial trial disposal pits were constructed.

5 TRIAL DISPOSAL PIT CONSTRUCTION

Two trial pits were excavated to a depth of about 5 m using large earthmoving plant. Pit A was excavated some 50 m long and 4 m wide with a central gently graded zone 10 m long and steeply graded access ramps at each end. The base of the pit had a 0.5 m thick local clay seal placed and compacted in thin layers. A 3 m thick layer of sand was placed over the central 10 m of the pit to simulate the waste and the ramp areas were built up with compacted clay. A clay surface seal 1.5 m thick was then placed over the simulated waste in thin layers each well compacted at slightly wet of optimum moisture content.

This trial pit was instrumented with piezometers and soil tensiometers at various depths within the upper clay seal, the simulated waste and the surrounding natural ground. Monitoring was then carried out at regular time intervals.

Following poor performance of Pit A under both natural and simulated rainfall, the upper clay seal was removed and extended at least 2 m beyond the plan extent of the simulated waste. Subsequently Pit B was constructed to a modified design which included a much wider excavation such that side walls of compacted clay were constructed to surround the waste. This pit was also comprehensively instrumented as shown on Figure 3.

5.1 Trial Pit Performance

A spray irrigation system was then installed to cover the areas of Test Pits A and B to provide a simulated rainfall. A rainfall intensity of at least 1.4 times the maximum weekly recorded rainfall for the area was applied over a period of two weeks. Regular monitoring of all piezometers and tensiometers was carried out during, and for several weeks following, the simulated rainfall event followed by periodic monitoring over a 12 month period.

The monitoring results indicate that rainfall very slowly infiltrates the upper 0.5 to 1 m of the upper clay capping; the tensiometers below 1.0 m indicating very minor moisture variation. No water entered Pit B however some water did enter Pit A and this was considered to have infiltrated the natural ground beyond the upper clay seal and then to have moved laterally towards the pit via microstructure and old tree roots within the natural clay and entered the walls of the pit. This microstructure was destroyed by the reworking of the clay in the walls of Pit B.

The satisfactory performance of Trial Pit B under the extreme rainfall events simulated was considered to demonstrate the effectiveness of an engineered clay capping. The comparison with the performance of Pit A indicates the necessity of compacted clay walls to ensure that no water can enter the waste material.

6 CHEMICAL BEHAVIOUR OF WALLAROO CLAY

The physical means of keeping water away from the waste, thus not generating leachate, were considered to be the primary means of managing the environmentally safe disposal of the waste.

As a secondary backup, should leachate be formed the chemical interactive behaviour of the leachate with the Wallaroo clay was also investigated. Detailed research findings have been discussed by Knight (1988).

6.1 Chemical Interaction Characteristics

The high level ground waters have very low salinity (100-200 mg/l) in equilibrium with kaolinite but salinity rises to 500 mg/l in the deeper clays where montmorillonite becomes significant and increases to

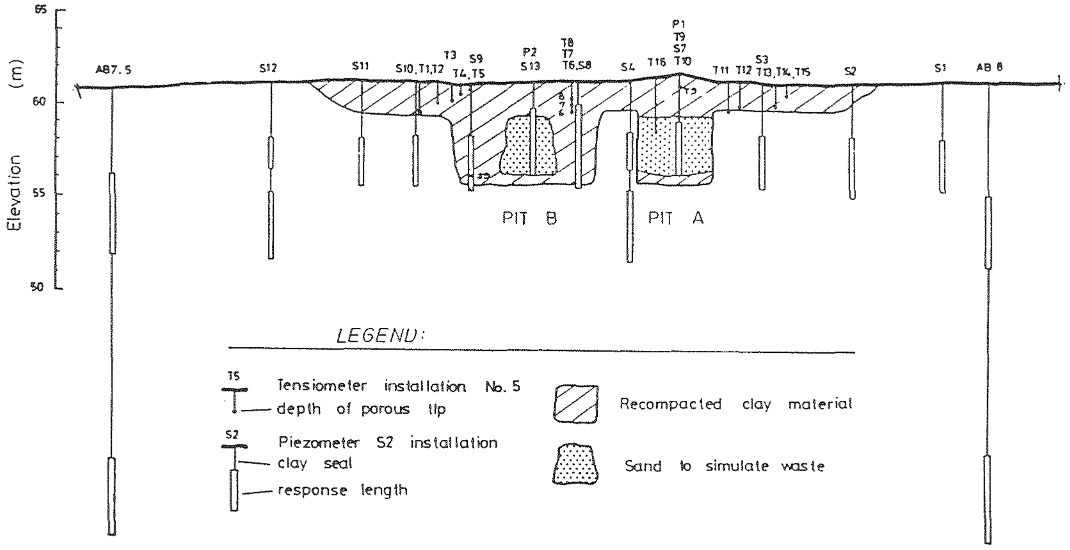

Figure 3 - Cross section through trial waste disposal pits showing pit geometry and instrumentation

1,600 mg/l in the underlying volcanics. Sodium and chloride are the dominant ions but are low (30, 60 mg/l respectively) in the upper 15 m leached zone, then increase with depth to 120 mg/l Na^+ and 250 mg/l Cl^-. If sodium should disperse from the disposal cells (5 m deep), it would be easily detected due to its low natural concentration in both groundwater and clay.

The acidic pH range of the waters (4-6) in the clays will have a significant buffering effect on any alkaline leachate (pH 12) formed from the waste.

6.2 Fluoride Adsorption

In order to simulate a fluoride leachate-clay interaction situation as closely as possible, batch tests using Wallaroo clay and sodium fluoride solutions were carried out within pH ranges (7-7.5 and 5-5.5), 4 concentrations of F (1 to 1,000 mg/l) with the soil solution ratio set at 2:1 and equilibriated over 10 days at 20°C. Polyethylene reaction vessels were hand shaken for 5 minutes each day and contrifuged to separate solid and liquid phases.

The variations in fluoride adsorption with time, pH and concentration fitted the Freundlich linear isotherm model and distribution coefficients (kd) were determined to be 3.3 ml/g (pH 7-7.5) and 3.1 ml/g (pH 5-5.5).

Other conclusions that may be drawn from this testing are:

- Most adsorption took place in 24 hours and by 10 days one could be confident that equilibrium had been achieved.
- An alkaline starting pH of 7-7.5 appears to result in equal or marginally better adsorption than the acid range 5-5.5
- Adsorption increases with concentration of F and at day 10, ranges from 1.7 mg F^-/Kg clay for 1 mg/l F solution to 2968 mg F^-/Kg clay for solutions with 1000 mg/l F^-.

Distribution coefficients from batch tests were used to estimate likely retardation factors that could be applied to vertically migrating fluoride fronts. An analysis using the proposed disposal design and soil properties suggested that 14 may be a reasonable retardation factor to apply to vertical flow velocities. In addition the maximum adsorption capacity was found to be useful in the evaluation of the site's ability to realistically adsorb the expected leachable fluoride.

6.3 Leachate effect on Permeability

A compacted core of Wallaroo clay was installed in a modified pressure chamber of a rock permeameter. The permeameter was initially filled with deionized water to establish stable baseline permeability. The deionized water was then replaced with NaF water at a concentration of 834 mg/l F and 1,020 mg/l Na^+. The pH of the solution was 6.3 and Eh + 208 mv. As the water discharged from the core it displaced an immiscible light oil up a burette which enabled discharge rates to be measured. Leachate samples were periodically pipetted from below the oil water interface. Fluoride content and sodium concentrations, Eh and pH were measured.

Permeability decreased with time by almost an order of magnitude over the 20 days of the test from 1.4 x 10^{-8} m/sec to 2.4 x 10^{-9} m/s at the end. The decrease appeared to be directly due to the Na interacting with the clay. The reduction in permeability is presented shown graphically on Figure 4.

The effect of NaF water on consolidation was examined using another sample of the clay in a standard consolidometer. Rigid filter ends and a static load of 100 kPa were used. The clay was compacted dry and presaturated with deionized water. A sharp decrease in void-ratio was observed when the NaF water was added to the clay that had achieved a stable consolidation using deionized water.

Consolidation in the field situation could occur where voids with pore pressures relatively lower than Na induced osmotic pressures did not exist and the effective overburden pressures are larger than the generated swelling pressures.

Though permeabilities of the consolidating clay were not measured, it seems reasonable that they would reduce during the process.

6.4 Retardation effects of NaF adsorption

Analysis of the sodium and fluoride break- through curves indicate that if the distribution coefficient (Kd) for fluoride determined in the clay core (1.91 ml/gm) was applied to a vertically migrating front at Wallaroo the flow velocity retardation factor is more likely to be 9 rather than the 14 estimated from the batch tests. The Na and F breakthrough curves are also presented on Figure 4.

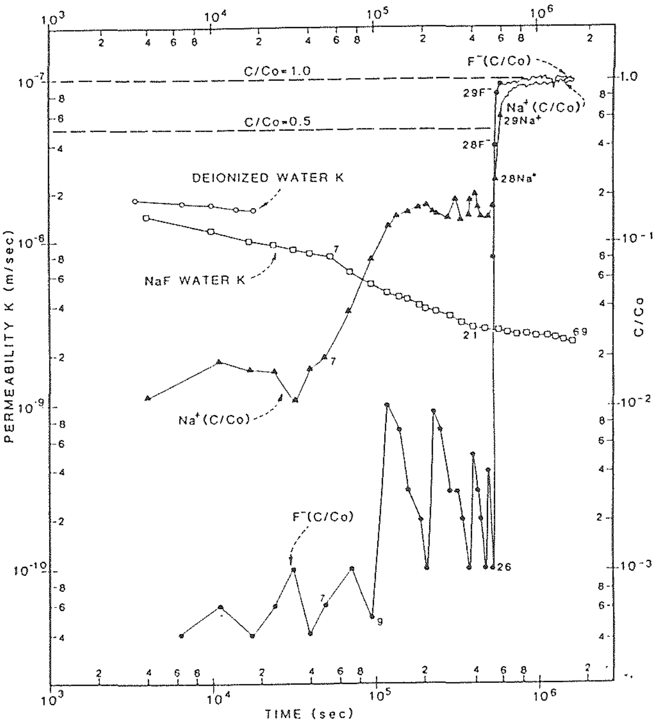

Figure 4 - Permeability (K) and sodium and fluoride relative concentrations of outflow with time - Knight (1988)

6.5 Spent Potliner Leachate - Clay reactivity

Samples of crushed potlining waste were used to form a leachate for clay reactivity studies. Some 25 g of the waste components were mixed in their approximate proportions found in a typical waste stream.

The 25 g of waste mix were added to 50 ml of deionized water and reacted over 6 days. Both hand and tumble shaking were used. Leachate is variable but is typically high in sodium, aluminium fluoride and iron and was extremely alkaline and reducing.

Leachate was reacted (shaken) with the clay in the proportions 5 g clay to 15 ml fluid over a 4-day period and then allowed to stand for 3 months. The reaction vessels were sealed in polyethylene tubes.

Dried leachate reacted clay and clay that had been in contact with deionized water were X-rayed at the end of the 3 month reaction time. The XRD traces show that a new mineral phase has formed. It is considered that the mineral is a type of sodium aluminium silicate possibly of the zeolite family.

6.6 Summary of Chemical Aspects

Based upon the chemical testing programme carried out it is considered likely that should aluminium potlining leachate be formed and leak into the natural clay formation it will cause a decrease in permeability of the kaolinitic lateritised clay by at least an order of magnitude as a result of sodium-clay dispersion and increases in expansive osmotic pressures. Additional consolidation occurring following dispersion is also likely to cause a permeability decline. Further decreases in permeability can be expected due to the formation in pore spaces of a new mineral phase arising from reactions between leachate and the clay.

Fluoride and sodium adsorption characteristics of Wallaroo clay are similar to each other and significant retardation of contaminant flow velocity has been forecast.

7 WASTE MANAGEMENT STRATEGY

7.1 Suitability of the Site

Based upon the detailed subsurface information available concerning the subsurface stratigraphy, permeability and groundwater levels, a suitable area of some 15 ha was selected for the buried waste disposal activity. This site has several natural security measures for waste disposal:

The primary attributes of the site are as follows:

- The area has an extensive deposit of clay soil extending 20 to 25 m depth overlying a more permeable gravelly stratum. The groundwater table within the clay profile, and the piezometric surface within the underlying gravelly layer, have been monitored for a period of 3 years and observed not to vary greatly in response to variable rainfall and to remain at least 15 m below the existing ground surface.

- Modelling using computer mathematical techniques indicated the groundwater level to remain at least 15 m below the surface in response to very heavy (extremely low frequency return) rainfall events.

- The permeability of the clay soils was determined at depth using field testing techniques to be very low with a mean value of 5×10^{-7} m/sec.

- The clay materials which would become available from disposal pit excavation are considered to be most appropriate to provide the necessary upper clay capping.

In addition the following chemical attributes are available as a secondary backup should leachate be formed in the pit.

- The natural clays' high potential to adsorb both sodium and fluoride. In addition the chemical reactions which take place are indicated to further reduce the permeability of the natural clay.

- The retardation factors in the passage of sodium fluoride through the clay which would result in any contaminant front moving at about one ninth the velocity of the leachate front.

The natural properties of the site should however be further enhanced by appropriate landfill waste disposal methodology.

7.2 Landfill Disposal

Engineered compacted clay covers over waste materials have generally only been partially successful as they tend to leak to some degree based upon North American and European performance evaluation. The two main reasons for this are considered to be:

Firstly clay covers are commonly quite thin (less than 1 m) and are quite susceptible to desiccation cracking, freeze - thaw and thermal expansion effects; the latter effects being major considerations in North America and Europe where most performance studies have been carried out, but of little relevance for the Wallaroo site which has a temperate climate.

Secondly the underlying waste materials are normally placed without good compaction and subsequent settlement causes fracturing of the capping layer. In addition, for putrescible waste facilities the build up of gas pressures can cause rupturing of the overlying clay cap.

In view of the poor performance of natural clay cappings (due to the above factors) in North America and Europe the trend in these countries is now towards the use of synthetic materials placed as a layer within a multi layer capping. This trend is now enforced by legislation in some countries, particularly the United States where standard designs incorporating synthetic liners are required above and beneath all hazardous waste disposal landfills.

Synthetic liners may also have deficiencies both in their purported fabric impermeability and also due to difficulties with installation - Haxo (1981).

The two main reasons for the non performance of natural clay capping in North America and European environments and experiences are not considered to be particularly relevant to the design of the Wallaroo Facility because:

- a thick clay cover is proposed, the upper 0.5 m or so being considered sacrificial to the unavoidable desiccation which will occur.

- The site is not subjected to freeze/thaw conditions.

- The waste for disposal at this site is not putrescible and it is proposed to thoroughly compact the waste material so that no subsequent settlement will occur, hence no cracking.

Based upon the above arguments the use of a thick engineered clay cover and base was considered appropriate for the Wallaroo Facility.

7.3 Legislative Requirements

New South Wales State Government Legislation to control chemical wastes was initiated in 1985 with the introduction of the Environmentally Hazardous Chemicals Act, 1985.

In accordance with this Act the State Pollution Control Commission (SPCC) of NSW issued a "Chemical Control Order in Relation to Aluminium Smelter Wastes Containing Fluoride and/or Cyanide" which prohibits the disposal of wastes containing leachable fluoride and/or cyanide; the definition of "leachable" being in the case of fluoride a leachate containing more than 150 mg/l and for cyanide a leachate containing more than 5 mg/l according to SPCC approved test procedures.

The Control Order also requires that a licence be issued for the keeping, conveying and disposal of wastes which have a leachable component less than defined above.

Licenses were issued to Tomago Aluminium for the disposal of "Approved Smelter Waste" in December 1986. This waste was considered to be non-hazardous in accordance with the above definition. Cyanide bearing wastes were excluded from the landfill disposal. The fluoride waste included meets the leachate criteria stated above.

7.4 Disposal Pit Design

The size selected for each pit is a function of the amount of material requiring disposal within each particular disposal campaign. Each campaign was expected to vary from 3,000 to 10,000 tonnes. The depth of disposal pits was selected as 5 m with a base compacted clay seal of 1.0 m thickness.

During each disposal campaign the base of each cell is graded smoothly to one corner where a shallow depression (sump) is excavated; and a layer of sand and gravel placed in this depression which forms the base of a monitoring well drilled after completion of the pit.

The waste material which arrives by covered truck is tipped directly in to the cell, spread and compacted in lifts by a heavy roller to a depth of 3 m within the 4 m deep pit. The surface seal is then placed, using the excavated clay spread in layers of about 200 mm and compacted to finally achieve about a 2 m thickness; the final ground surface being about 1 m higher than original, mounded to promote surface runoff then topsoiled and revegetated with shallow rooted species.

Upon completion of each cell a bore is drilled at the plan location of the previously excavated sump and a slotted PVC pipe installed through the waste. This installation will be used for detection of any leachate and which can be used for extraction should it be necessary.

A surface interceptor drainage system installed by grading shallow dish drains between each cell further minimizes the potential for infiltration through the clayey soil cover.

7.5 Monitoring Programme

An ongoing monitoring programme is part of the management strategy. This programme involves periodic water level measurement and sampling of installations within the natural clay formation in the vicinity of the waste disposal area. In addition the wells installed within each waste pit are regularly monitored for leachate. No problems have been experienced over the operational period (1986 to date).

8 CONCLUSION

The comprehensive geotechnical investigation programme carried out has provided the basis for convincing the regulatory authorities that the various natural attributes of the site together with an environmentally sound waste disposal procedure enable a natural clay site to be used for landfill disposal of most of the waste material from the Tomago Aluminium Smelter.

On-going monitoring will continue to ensure that the landfill does not adversely affect the surrounding environment.

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Data used in the paper has been drawn from unpublished reports over the period 1983 to 1986 by Golder Associates Pty Ltd and Knight M J.

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