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HYDROGEOCHEMICAL EVOLUTION OF AN EXPERIMENTAL THICKENED TAILINGS
PILE OF PYRITIC URANIUM TAILINGS

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Hydrogeochemical Evolution of an Experimental Thickened
Tailings Pile of Pyritic Uranium Tailings

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ABSTRACT

Hydrogeochemical investigations were conducted on a 10,000 tonne experimental mini-pile of thickened (65-70% solids) pyritic uranium tailings at the Denison Mine site in Elliot Lake, Ontario. The pile was completed in 1982 to investigate the feasibility of in situ coning of such tailings and their placement as a 'cap' on inactive tailings as a decommissioning option. The results showed that there was segregation between coarse and fine fractions, and the majority of the pile consisted of unsaturated tailings which were completely acidified to the maximum depth.

INTRODUCTION

Environmental concerns associated with the long-term management and decommissioning aspects of pyritic uranium tailings are those of pyrite oxidation, subsequent generation of acid and release and migration of contaminants. One 'close-out' alternative which was investigated by Denison Mines Ltd. in Elliot Lake, Ontario, was the placement of a cap of thickened tailings (1-5) during the final stages of tailings deposition in currently active or inactive management areas. Laboratory experiments have shown that by discharging tailings at relatively high solid concentrations, the slope of the deposited tailings can be increased to about 5%, thereby increasing surface run-off, minimizing infiltration, and providing good surface drainage for future vegetation establishment for surface stability.

An experimental 10,000 tonnes mini-research pile of thickened pyritic

uranium tailings was established at the Denison Mine's tailings site to investigate the feasibility of in situ coning and effects of run-off, seepage flow, pyrite oxidation and migration of contaminants. The work on the pile commenced in 1979, and after initial operational difficulties associated with mechanical components, was finally completed in June 1982. The final layer of thickened tailings incorporated limestone and grass seeds and was deposited at approximately 70% solids, creating a slope of approximately 3.4%. Following completion of the pour, thickened tailings quickly formed a dry hard surface crust. The limestone added to the pile formed a surface crust at places. Initially during construction, and then for two continuous years post completion the pile was monitored for its physical, chemical and biological characteristics (3,4). The present investigation was undertaken to complement the previous studies and to observe and review how the pile has evolved geochemically over the past eight years or so.

Principles of Thickened Tailings Disposal

Thickened tailings disposal consists of discharging tailings with a relatively thick consistency such that the tailings form a cone. When the tailings are thickened, segregation (in which the coarser fraction settles out near the discharge point) does not occur, instead the heavy slurry flows down the outside of the cone without effective sorting until it stops.

Some of the possible advantages of the thickened tailings system in relation to the close-out of pyritic uranium tailings (5) are:

- 1) Increased slopes will enhance run-off and reduce infiltration into the tailings;
- 2) The segregation of coarse grained and fine grained solids which occurs at lower solids contents is inhibited;
- 3) Dusting is minimized;
- 4) Erosion from run-off is reduced due to the uniform distribution of fine particles which act as a 'binder';
- 5) Since the thickened tailings slopes should remain saturated due to capillary rise in the fine fraction of the tailings, both radon emanation and any pyrite oxidation should be reduced;
- 6) The above advantages are in addition to the increased storage capacity of the tailings basin because the tailings are discharged at high solid rates (~70%), compared to conventional slurry discharged at (20-30% solids) which requires large storage space prior to dewatering.

Although there are no fixed slopes for thickened tailings, a 6% slope has been commonly recommended.

DESCRIPTION OF THE PILE

The experimental pile was constructed on an operationally inactive tailings area, some 500 m south of the Denison Hydrometallurgical Mill. The circular embankment for the cone was constructed in 1979. It measured 100 m in diameter and incorporated a 10 mm thick PVC membrane across the base in order to simulate the conditions of pouring the thickened tailings onto slimes, i.e., condition of no downward drainage. The site was instrumented with a total of 9 twin head piezometers along two axes of the cone and 4 stand pipes installed at positions removed from the pour point, as shown in Figure 1.

Although the laboratory tests indicated that an extremely high percent solids was required for the desired slope (73-75% solids), the uranium tailings come off the secondary drum filters within the Denison mill at 80% solids. Suitable modifications were carried out within the mill to isolate the tailings from one of the secondary drum filters. These unclassified thickened tailings were then pumped to the site through a 7.5 cm diameter plastic pipe.

The deposition of the tailings was intermittent due to mechanical breakdown and operational problems, and extended over three periods:

December 1979 to January 1980	- 2,400 dry tonnes
May 1980 to June 1980	- 2,400 dry tonnes
June 1981 to July 1981	- 6,000 dry tonnes.

The final cover was poured partly in November 1981 and completed in June 1982. It incorporated a mixture of 0.2 kg/tonne of grass seeds and 9 kg/tonne of limestone, and was deposited at approximately 70% solids, creating a final slope of approximately 3.4%.

Both physical and chemical characteristics of the pile were measured during the construction phase and regularly thereafter until 1984 (3,4). Since then the pile has been left unattended. These parameters were re-examined during the summer 1988 to spring 1989 period in order to determine how the pile has evolved geochemically over the extended period of time.

Detailed vegetation growth and survival surveys were conducted regularly during the period 1982 to 1984, and are given in reference (4). In 1988-89 sampling, no vegetative cover surveys were conducted.

SAMPLING AND ANALYSIS

Earlier sampling and analytical methods for tailings cores, porewater, surface run-off water and pore gas are described in detail in references (3,4).

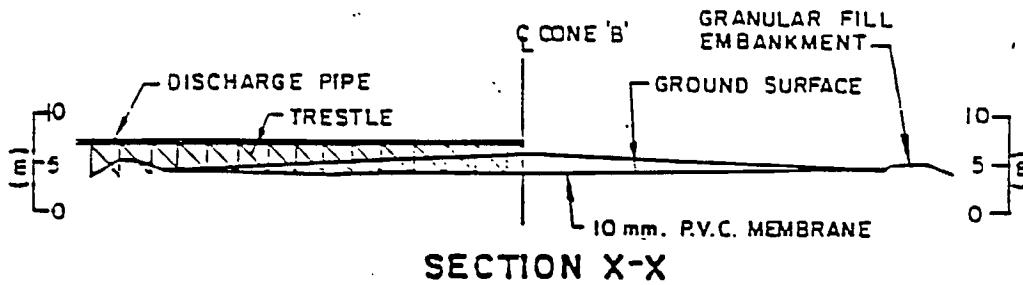
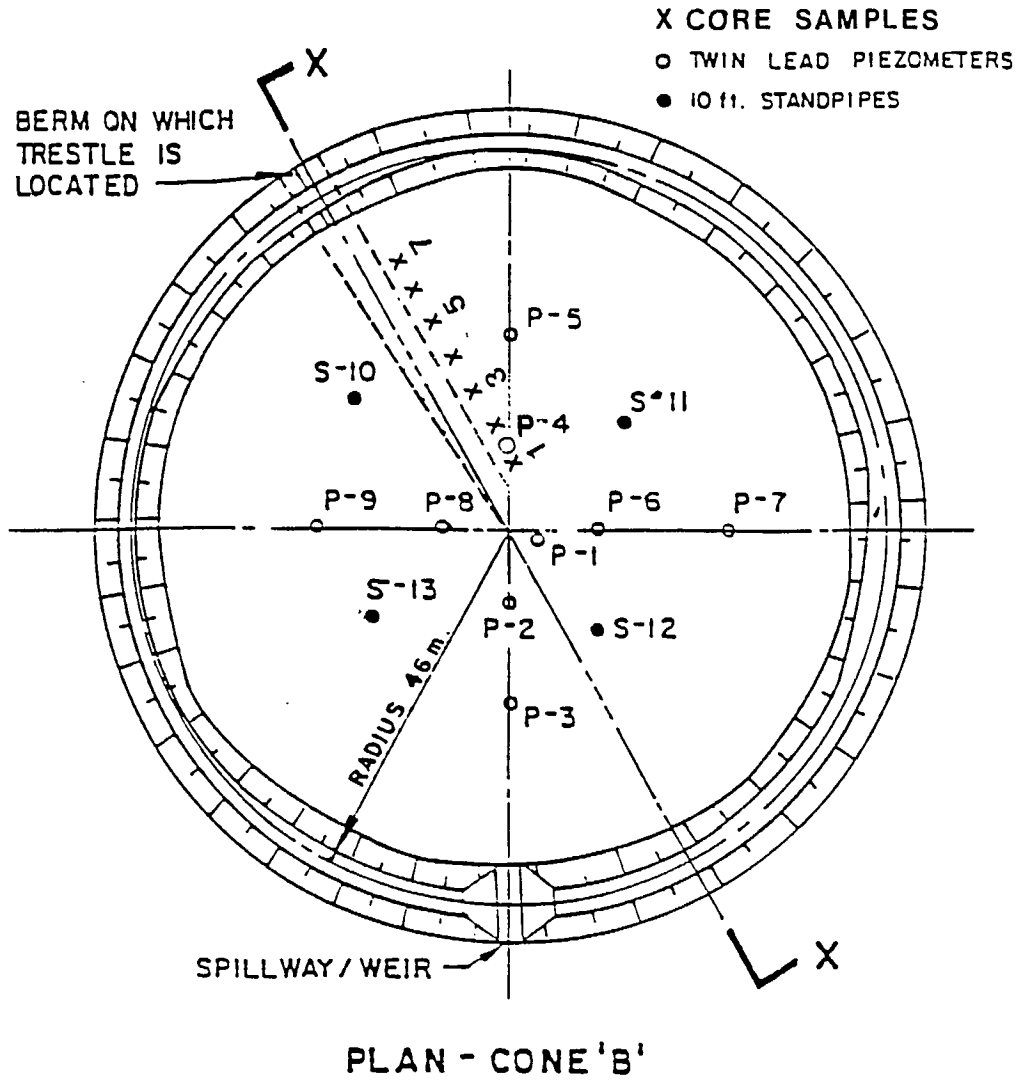


Fig. 1 - Plan and section of 10,000 tonne mini experimental pile.

In 1988-89 sampling, the tailings core samples were obtained by driving an aluminum tube 2 mm thick, and 75 mm diameter, through the entire pile and pulling the sample cores out with the tube. As soon as the tube was pulled out the ends were flushed with compressed nitrogen and sealed air tight with plastic bags in the field. The core samples were then transported to the laboratory where the ends were further sealed by dipping into hot wax.

For each location the cores were sectioned at an interval of 15 cm, where the alternate samples were used for physical and porewater chemical profiles, respectively. The physical parameters measured were grain density, moisture content, wet and dry bulk densities, screen size analysis, porosity and moisture saturation.

Porewater samples were obtained by hydraulic squeezing of the cores (6), using paraplex liquid wax to displace porewater. The porewater so obtained was filtered through a 0.45 μm membrane filter, its pH, Eh and electrical conductance 'Ec', measured and was acidified for the determination of metals and sulphate. A direct current plasma (DCP) emission spectrophotometer was used for measuring total dissolved Fe, Ca, Mg, Al, Si, U, Th, and Pb. Total dissolved sulphate concentrations were measured using a radiochemical tracer technique (7).

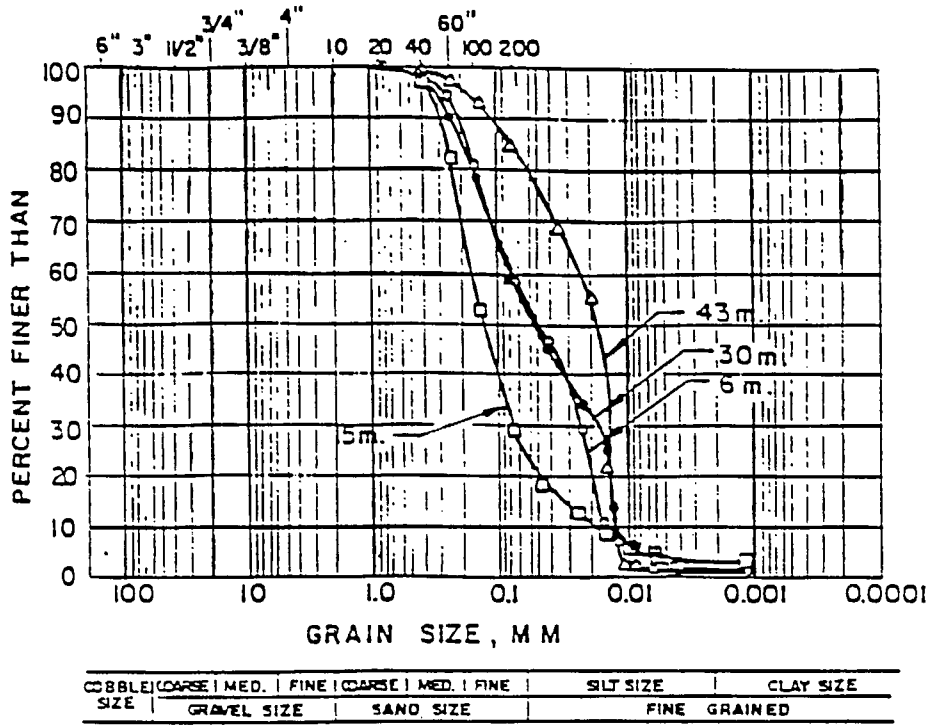
For pre-gas sampling, the original array of stainless steel gas sampling probes installed at various elevations, and at three locations (4) were cleaned, re-installed and used initially. Sampling difficulties were encountered at areas containing fines, and at greater depths because of the leakage of atmospheric oxygen into the meter. The gas sampling probes were then modified to include a gas sample reservoir with inlet and outlet sample tubes. Prior to sampling, the reservoir was purged with compressed nitrogen. A suction was then applied from the top and the two ends sealed for it to come in equilibrium with the pore gas. Following a few hours of equilibrium period, the two sampling ports were connected to suction and exhaust manifolds of the oxygen meter. The pore gas oxygen concentration was thus measured by recirculating the gas through the meter and reservoir without creating appreciable negative pressure for air leakage.

RESULTS AND DISCUSSION

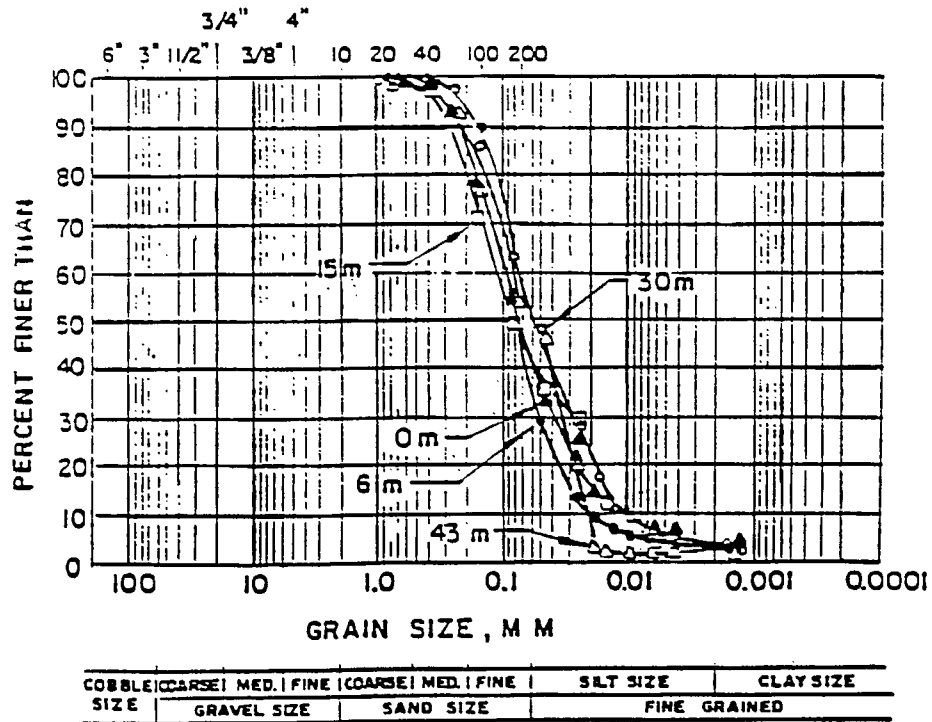
For brevity, results and discussion in this report will be limited to three near surface locations: apex, middle, and perimeter of cone 'B' (see Figure 1). Detailed results will be published elsewhere.

Particle Size Distribution

During the initial pour of the thickened tailings, it was observed that the tailings were segregating markedly. It was found that although the tailings were being discharged at 70 to 75% solids from



a) JUNE 1981 - 63 PERCENT SOLIDS TAILINGS SEGREGATING



b) AUGUST 1981 - 70 PERCENT SOLIDS UNIFORM TAILINGS

Fig. 2 - Gradation analysis at varying distances from centre of cone, 1981.

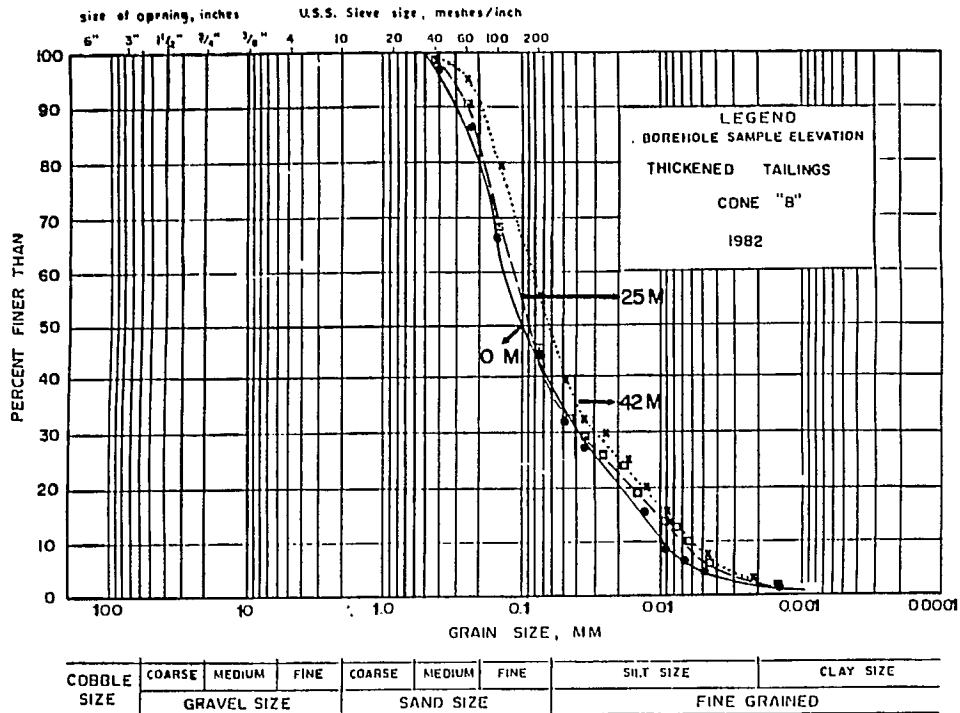


Fig. 3 - Gradation analysis at varying distances from centre of cone, 1982.

the agitator overflow, they were reaching only 63% solids at the outface because of dilution with the gland water of the pump. After modifications to the pump, and depositing tailings at about 70%, the solids held to an essentially uniform deposition within the cone (Figure 2).

During 1982, 1984 and 1989 gradation analyses, the results generally indicated a fairly well graded material throughout, being sand size with some silt and clay size fractions. Materials tended to be coarser near the apex with fines contents increasing towards the perimeter. However, along the perimeter of the cone, the material increased in sands content at the spillway weir (Figures 3, 4 and 5). At most locations the 1989 results indicated a substantial drop in fine-grained material, confirming 1984 results of migration of fines through the cone (Figure 5).

Moisture Profiles

With the initial pour at 25 to 37% moisture by weight (63 to 75% solids), the surface of the tailings slowly dried with time. The moisture contents near the surface varied from 26% at the apex to 43% at the perimeter in 1982, to 9.5 and 34.6%, respectively, in 1984, indicating a faster drying out near the apex where the tailings were coarse. In 1989, the average moisture content of the pile was $13.1 \pm 5\%$ by weight ($61 \pm 26\%$ saturation by pore volume) which indicated that about half the initial water has been lost to evaporation and

M.I.T. GRAIN SIZE SCALE

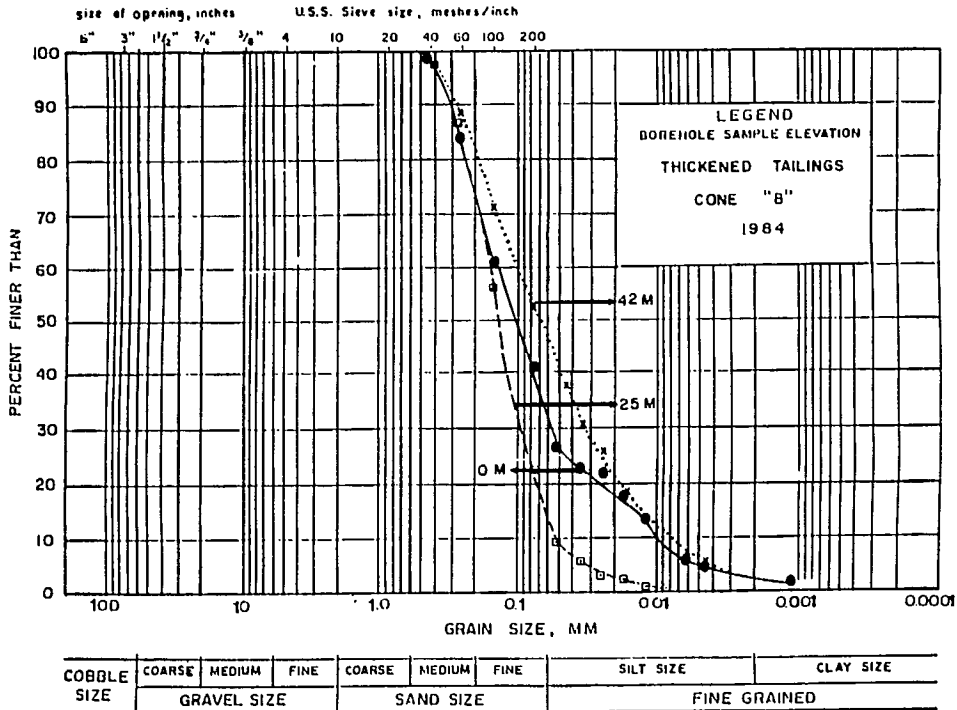


Fig. 4 - Gratation analysis at varying distances from centre of cone, 1984.

M.I.T. GRAIN SIZE SCALE

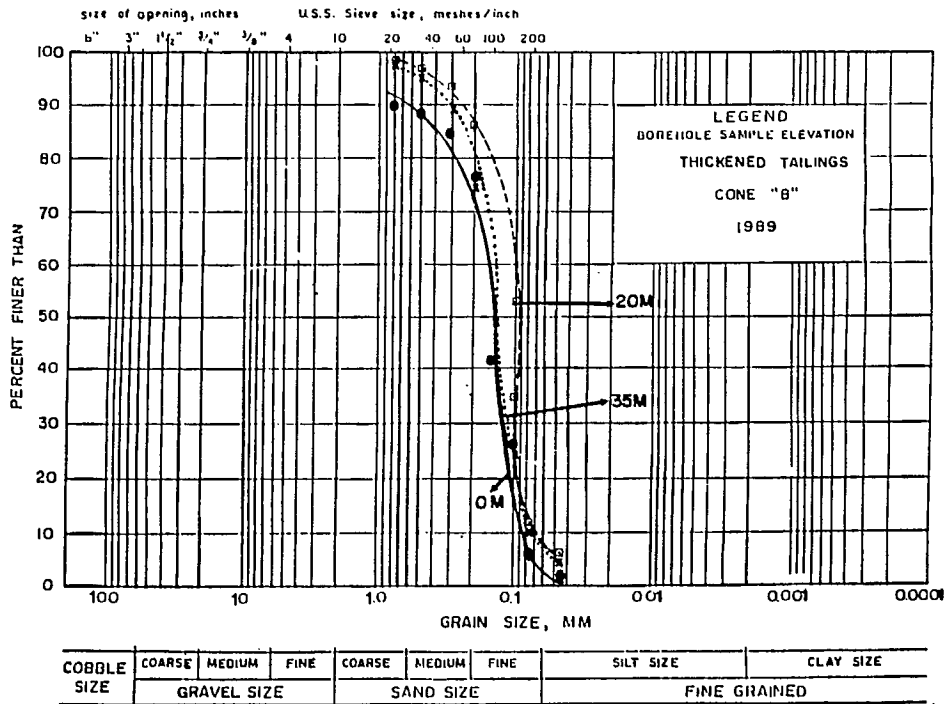


Fig 5 - Gratation analysis at varying distances from centre of cone, 1989.

drainage. Figures 6 and 7, and Table 1 show moisture profiles with depth at various locations. These results clearly indicated that although there were local fluctuations, the overall pile was in a state of unsaturation without any phreatic surface. The average grain density, wet and dry bulk densities and porosity were 2.63 ± 0.1 , 1.81 ± 0.2 , 1.57 ± 0.2 kg/L, and $39.9 \pm 7\%$, respectively.

Because of the absence of a saturated zone, piezometric pressures or water levels were unobservable at any of the locations.

Poregas Oxygen Profiles

Poregas sampling probes were originally installed in 1983 as an array of seven stainless steel probes at 15 cm depth intervals and at three locations (4). The earlier data (1983-84), showed that although difficulty was encountered in monitoring poregas oxygen in areas containing fines, in coarse areas the oxygen readily decreased from atmospheric concentration of 20% to almost nil within 0.5 m. In 1989 sampling these probes were cleaned and re-installed, but the sampling difficulty remained in areas, and at depths, where the oxygen meter operated under a sufficient negative pressure or suction. The meter used was designed for sampling oxygen in flue gases where a positive pressure existed. In cases where a suction was created while sampling from greater depths or fines where the passage resistance was high, a check-valve in the sampling port of the instrument opened allowing the entry of atmospheric air in the system to break the vacuum. The measured oxygen concentrations were thus erroneous.

With the modified oxygen probes, where a gas reservoir was installed at the desired depth with inflow and outflow tubes to break the negative pressure, the measured oxygen concentrations were 20, 14 and 9% at depth of 30, 40 and 50 cm, respectively.

Porewater Chemical Profiles

The chemical characteristics of porewater and surface run-off water monitored in 1983-84 sampling are given in Table 2. Results of the detailed sampling program in 1989 are shown in Tables 3 and 4, and Figures 8 to 13. At locations where the tailings were coarse, the pile has completely oxidized to a depth of 50 cm, and where near surface iron and sulphate concentrations were as high as 26,000 and 84,000 mg/L, respectively. Areas which contained predominantly fines were also being oxidized, but at a reduced rate. With the migration of oxidized products within the pile, the latter has been completely acidified with pH ranging from 1.3 to 1.9 near the surface to 2.1 to 3.3 at intermediate and bottom elevations. Dissolved metal concentrations were high throughout the pile such that the observed profiles were characteristic of unsaturated zone oxidation, similar to those observed at other locations in the area where the tailings were discharged conventionally at 20 to 30% solids (6). These results were consistent with the measured oxygen profiles.

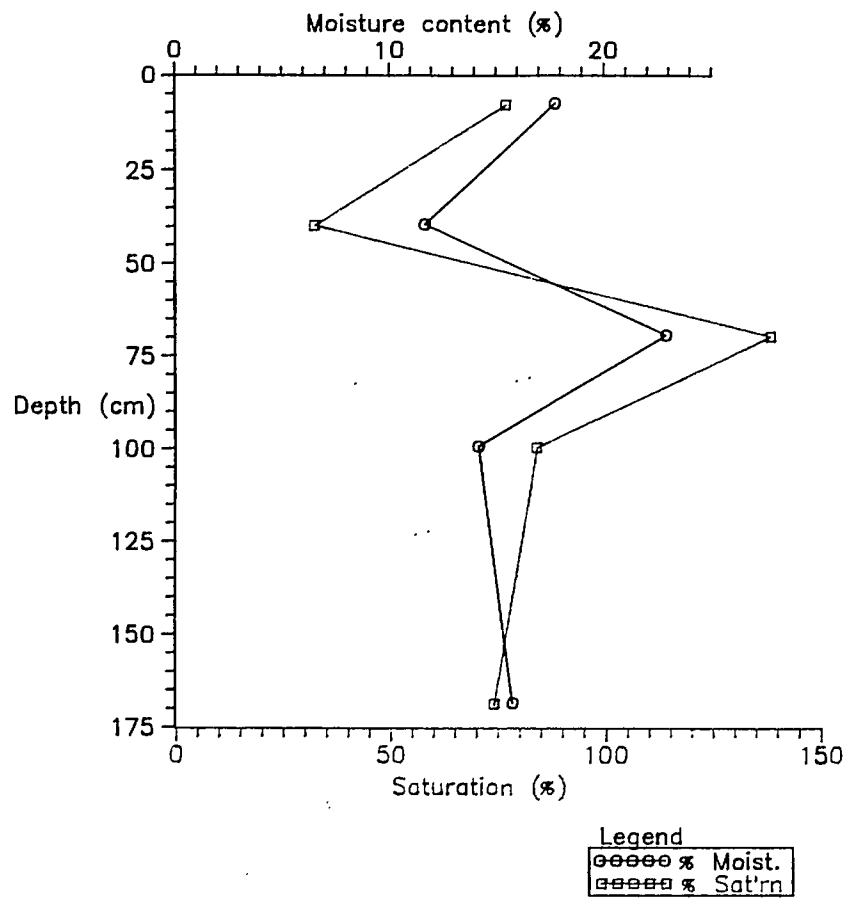


Fig. 6 - Moisture profile with depth at the centre of the pile.

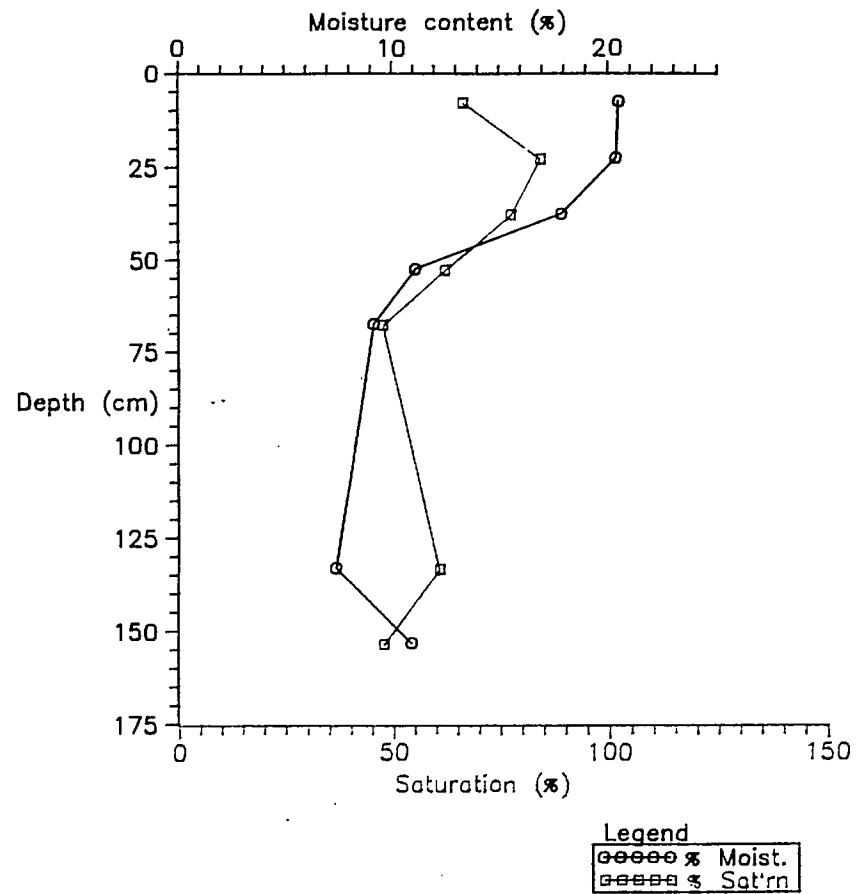


Fig. 7 - Moisture profile with depth at 10 m from the centre.

TABLE 1 -- Thickened tailings density analysis

Site	Sample Depth (cm)	Gd (g/mL)	Wet Density	Dry Density	Moisture Content (%)	Porosity (%)	Moisture Saturation (%)
1	7.50	2.57	1.82	1.49	17.75	41.88	76.97
	39.50	2.61	1.43	1.26	11.65	51.65	32.17
	69.50	2.68	2.21	1.70	22.83	36.42	138.39
	99.50	2.53	1.97	1.69	14.13	33.19	83.84
	168.50	2.59	1.86	1.57	15.72	39.57	73.89
2	22.50	2.70	1.80	1.44	20.33	43.52	84.23
	52.50	2.67	1.94	1.73	11.06	34.61	62.04
	133.13	2.43	1.99	1.84	7.31	24.00	60.62
	153.25	2.72	1.77	1.58	10.86	40.55	47.49
	7.50	2.58	1.62	1.29	20.48	50.04	66.31
	37.50	2.57	1.81	1.49	17.85	41.90	77.32
	67.50	2.67	1.87	1.70	9.10	36.03	47.37
3	22.50	2.57	1.79	1.55	13.62	39.64	61.52
	67.50	2.63	1.97	1.76	10.95	33.10	65.28
	98.25	2.81	2.10	1.87	10.97	33.45	68.71
4	22.50	2.61	1.89	1.68	11.40	35.65	60.57
	52.50	2.64	1.76	1.61	8.79	38.73	40.03
	79.50	2.81	1.73	1.69	2.34	39.83	10.17
5	37.50	2.60	1.82	1.56	14.29	29.62	65.62
	85.75	2.79	1.42	1.32	6.73	52.62	18.12
6	7.50	2.55	1.61	1.34	16.89	47.34	57.50
7	7.50	2.60	1.58	1.36	14.05	47.72	46.42

TABLE 2 -- Porewater chemical characteristics, 1982-84.

	Pore water	Run-off water
pH	6.5	2.9
Acidity mg/L (as CaCO ₃)	24.5	94
Alkalinity mg/L (as CaCO ₃)	24	0
TDS mg/L	2250	790
Ca mg/L	571	167
Fe mg/L	1.5	26.1
NH ₃ mg/L (as N)	<1	<1
NO ₃ mg/L (as N)	18	17
SO ₄ mg/L	1730	510

TABLE 3 -- Thickened tailings pore water chemical analysis (a) 1989

Site	Depth (cm)	Temp. F	Ec. μ S	Eh \pm Mv	pH mg/L	Aluminum mg/L	Calcium mg/L	Iron mg/L
1	22.50	75.3	38000	371.0	1.91	4310	735	26400
	54.50	75.4	16520	282.5	3.07	1290	588	9010
	114.50	76.1	12370	305.5	3.20	1460	525	4080
	129.50	76.8	10180	327.5	2.95	1220	474	2140
	144.50	76.6	9600	349.1	2.42	1050	476	1390
	157.50		8000	318.3	3.16	1010	499	1120
2	7.50	74.9	38800	372.4	1.95	3160	549	28250
	22.50	70.5	31800	516.7	1.28	361	572	22400
	37.50	77.4	16870	321.4	2.59	1840	525	6780
	52.50	75.9	6910	312.8	2.79	217	464	2200
	97.50	77.2	8460	296.5	3.33	1710	450	618
	133.13	76.0	10630	331.9	2.41	1580	489	1770
164.00	76.3	9980	338.7	2.14	890	496	1210	
3	7.50	75.0	12990	198.4	2.76	1360	515	5020
	82.50	76.4	10230	204.4	3.60	625	483	4040
4	37.50	75.9	1390	246.2	2.58	2780	551	3450
5	22.50	75.5	8520	474.6	2.43	1480	502	1130
	52.50	79.5	15050		2.38	1170	181	1070
6	22.50			300.8	2.70	2330	514	887
7	22.50	74.4	14390		3.06	3360	487	3000

TABLE 4 -- Thickened tailings pore water chemical analysis (b) 1989

Site	Depth (cm)	Magnesium mg/L	Lead mg/L	Thorium mg/L	Silicon mg/L	Uranium mg/L	Sulphate mg/L
1	22.50	182.0		27.10	62.40	17.80	83633.89
	54.50	161.0	4.0	5.25	63.30	10.90	22185.42
	114.50	70.6	4.01	2.40	48.60	3.32	14254.81
	129.50	60.9	2.73	3.74	56.40	2.41	9980.00
	144.50	48.1	4.35	2.78	74.20	2.41	8689.64
	157.50	54.4	3.73	1.05	53.60	1.59	6874.50
2	7.50	187.0	3.47	28.40	54.30	17.90	64319.07
	22.50	257.0	3.68	57.30	20.20	9.80	55192.32
	37.50	179.0	3.41	132.00	77.50	15.00	24681.73
	52.50	164.0	5.68	37.40	67.40	5.69	5474.21
	97.50	35.8	3.14	1.57	43.60	1.61	11145.38
	133.13	45.1	3.57	4.61	73.40	2.42	13253.67
	164.00	33.1	3.52	3.14	72.60	1.05	7670.84
3	7.50	115.0	1.23	12.60	57.90	3.55	16834.22
	82.50	115.0	10.20	0.60	47.40	1.87	8730.21
4	37.50	112.0	1.26	13.80	86.40	3.83	21855.63
5	22.50	110.0	0.86	15.40	67.00	2.66	10589.85
	52.50	60.6	3.01	5.82	7.32	1.46	7878.26
6	22.50	103.0	1.16	8.37	70.80	2.23	15869.72
7	22.50	141.0	1.39	16.40	69.00	2.96	25199.97

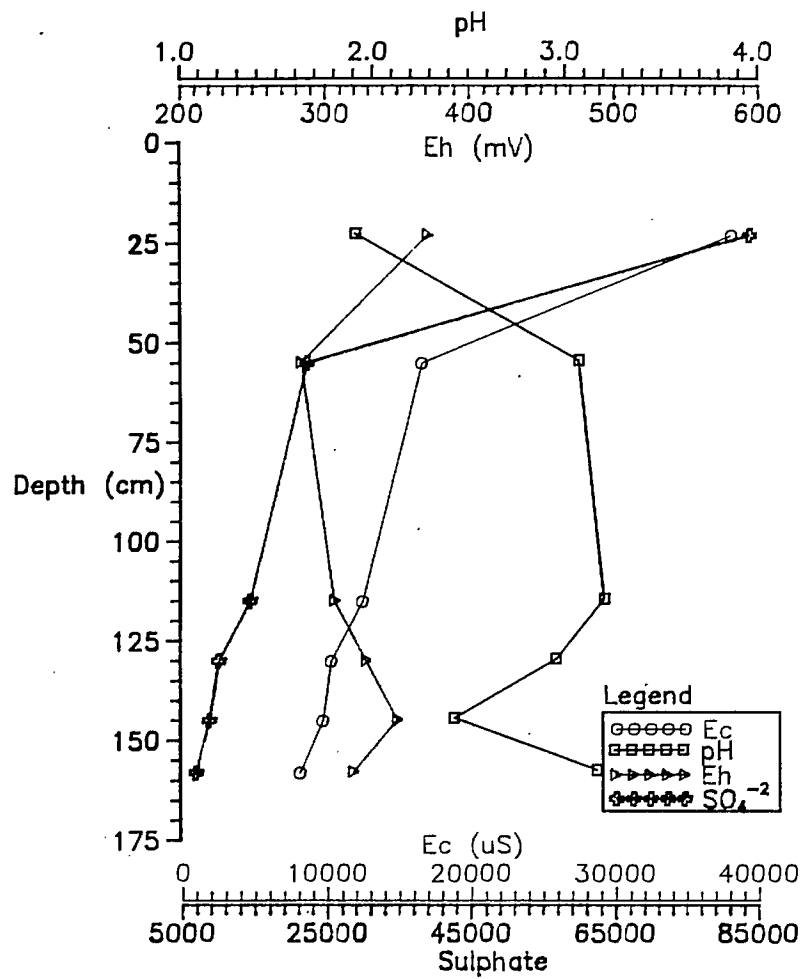


Fig. 8 - Porewater chemical profile, pH, Eh, Ec, and SO₄⁻² at centre of the pile.

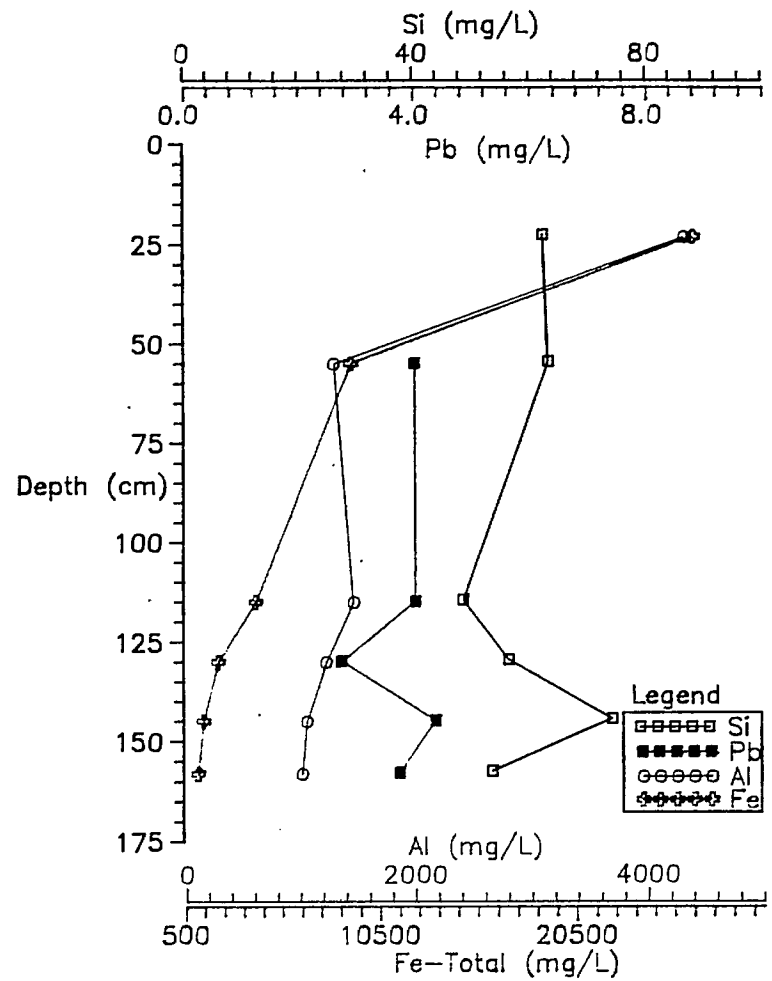


Fig. 9 - Porewater chemical profile, Fe, Al, Pb, and Si at the centre of the pile.

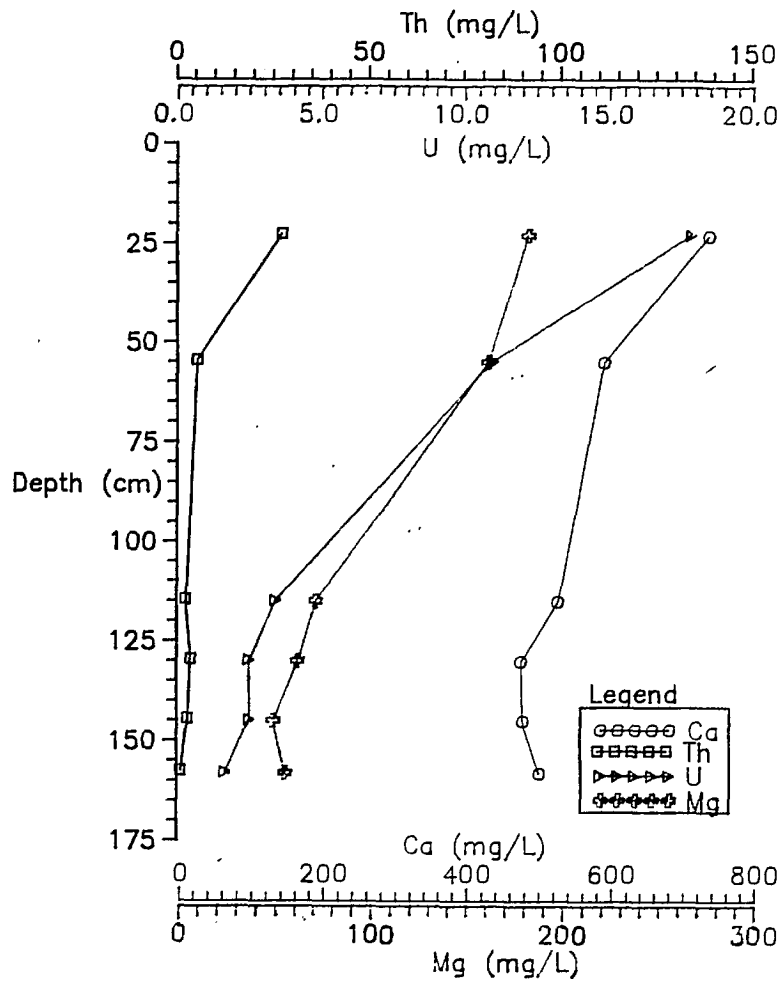


Fig. 10 - Porewater chemical profile, Ca, Mg, U and Th at centre of the pile.

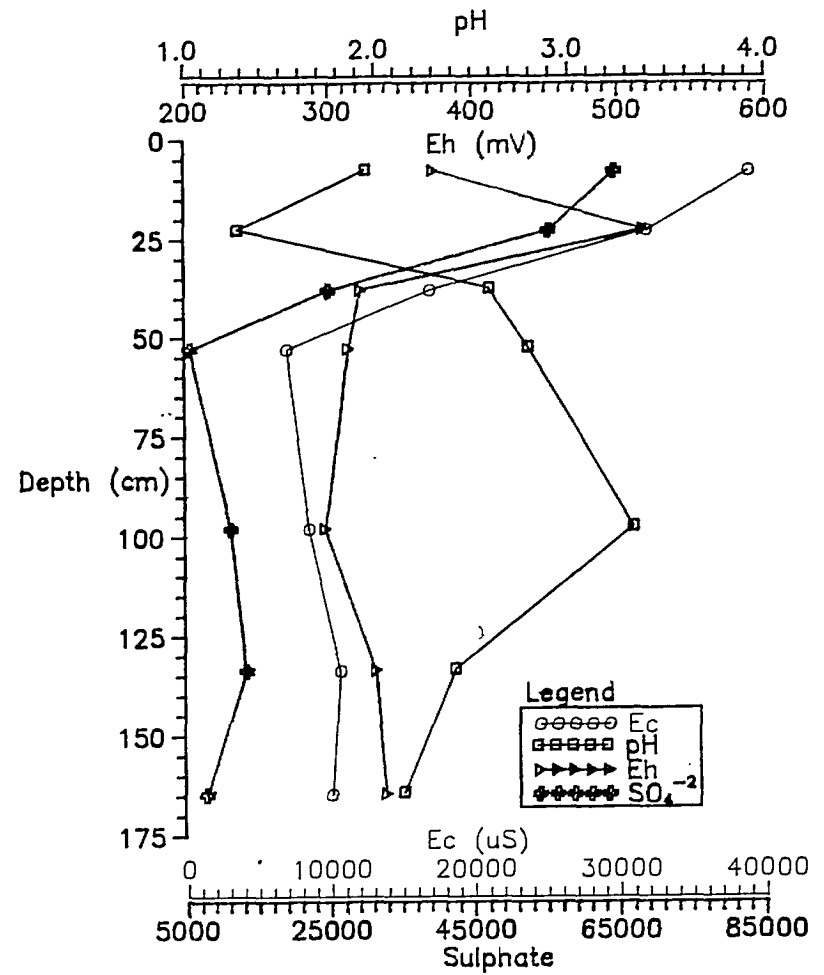


Fig. 11 - Porewater chemical profile, pH, Eh, Ec and SO_4^{2-} at 10 m from the centre.

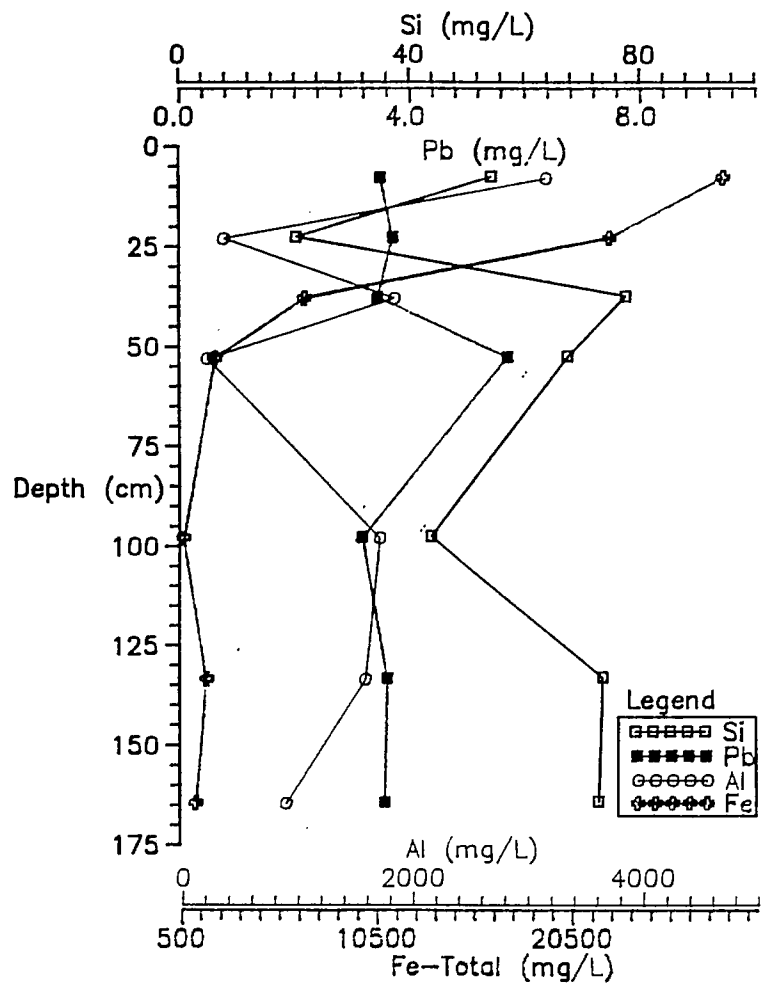


Fig. 12 - Porewater chemical profiles, Fe, Al, Pb and Si at 10 m from the centre.

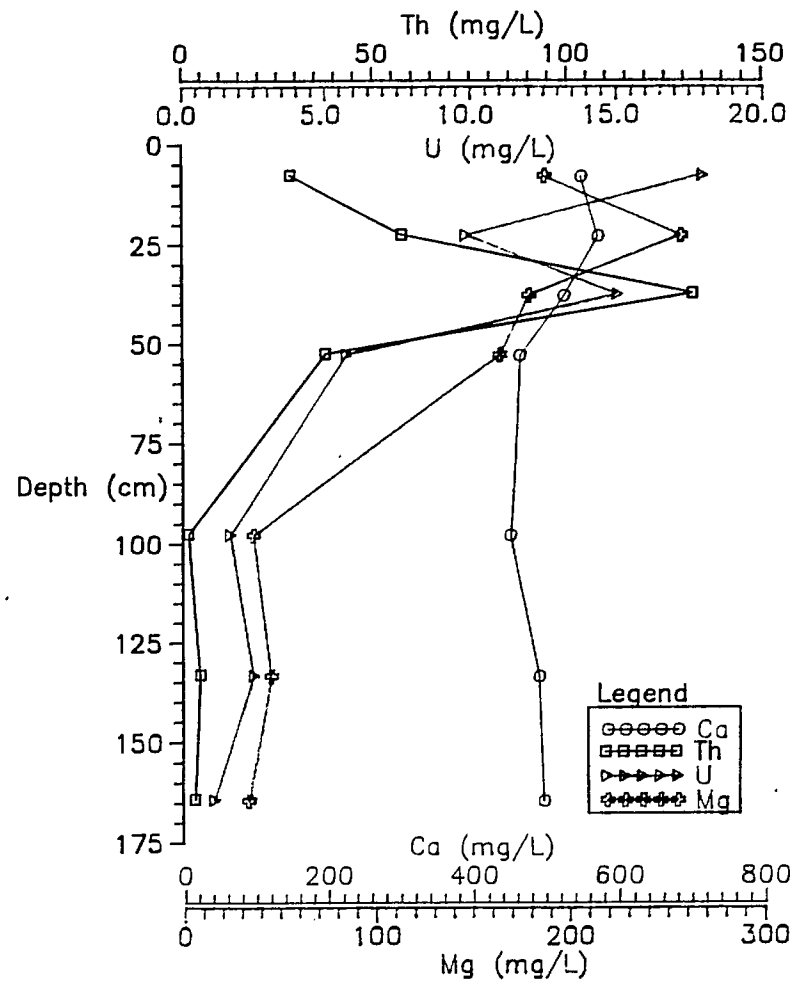


Fig. 13 - Porewater chemical profiles, Ca, Mg, U and Th at 10 m from the centre.

Summary

The present results have clearly indicated that with time the thickened tailings pile has developed segregation of coarse and fine fractions, has lost moisture, and is in a state of unsaturation. With the loss of saturation conditions, the pile has completely weathered and the top layer, as deep as 50 cm, has been completely oxidized. The migration of oxidation products has acidified the pile completely to represent a typical unsaturated zone scenario producing acid mine drainage. Based on the experimental thickened tailings pile data, such a pile cannot be considered as a final cover for 'close-out' for the control of acid generation and migration of contaminants.

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