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AUSTRALIAN NUCLEAR SCIENCE AND TECHNOLOGY ORGANISATION

LUCAS HEIGHTS RESEARCH LABORATORIES

RADIUM AND HEAVY METAL TRANSPORT BENEATH AN ABANDONED URANIUM TAILINGS DAM

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ABSTRACT

An abandoned uranium tailings dam at Moline in the Northern Territory of Australia was the site of a study to assess the movement of potentially toxic elements from tailings into subsoil. The tailings at Moline were first laid down in 1959 and have since been leached by prevailing rainfall. Sixteen sampling sites were selected to give a good representation of the dam. At each site, a trench was excavated through the tailings and into the subsoil, then samples of subsoil were taken at 10 cm intervals down to a depth of 50 cm. A sample of the tailings overlying the tailings-subsoil interface was also taken. Samples were analysed for radium, uranium, copper, zinc, and lead. At most sites there was only minor accumulation of these elements in the 0-10 cm subsoil layer immediately below the interface, with concentrations typically one or two orders of magnitude less than the concentrations in overlying tailings. Below 10 cm, the concentrations were typically at or close to background concentrations.

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ABANDONED SITES; COPPER; DAMS; EXPERIMENTAL DATA; LEAD; LEACHING; MILL TAILINGS; NORTHERN TERRITORY; ORE PROCESSING; RADIONUCLIDE MIGRATION; RADIUM; SOILS; URANIUM; URANIUM DIOXIDE; WATER; ZINC

EDITORIAL NOTE

The Australian Nuclear Science and Technology Organisation replaced the Australian Atomic Energy Commission on 27 April 1987. Reports issued after April 1987 have the prefix ANSTO with no change of the symbol (E, M, S or C) or numbering sequence.

CONTENTS

1. INTRODUCTION

Tailings are a major waste product from the processing of uranium dioxide (yellowcake). Typically, tailings constitute 95-99 per cent of the weight of ore processed and have the consistency of fine sand. They contain some radioactivity and heavy metal elements such as copper, zinc, cadmium and lead are often present. Given the toxicity of these elements it is essential that tailings are managed in ways that minimise their release to the environment.

At present in Australia, it is normal practice to dispose of tailings by impounding them in specially constructed dams. Such dams are usually lined to minimise water seepage and contaminant release. However during the 1950s and 1960s, the two uranium processing mills operating at Rum Jungle and Moline in the Northern Territory discharged tailings directly onto land adjoining the mills with only minimal site preparation. There were no clay liners to prevent seepage and only crude earthen bunds were used at Moline to retain the tailings. These bunds were often breached during the monsoonal rains.

In a study of chemical profiles beneath the Rum Jungle tailings, Evans *et al.* [1987] found that thirty years after tailings disposal had commenced there were significant increases in the concentrations of radium and copper in only the first 20 cm of subsoil beneath the tailings-soil interface. At 50 cm below the interface, the concentrations of these two elements were generally at background values. They concluded that the extent of transport of radium and copper was quite small; even in areas of the dam where the subsoil remained saturated for much of the year, and in areas where the subsoil remained mostly unsaturated, there was no significant transport.

A study has been made of the abandoned uranium tailings dam at Moline. These tailings were laid down almost thirty years ago and hence are representative of some of the oldest uranium tailings in Australia. The main purpose of this study was to assess the extent of heavy metal and radionuclide transport from tailings into underlying soil and, if possible, to elucidate mechanisms limiting contaminant transport. The study was carried out in a manner similar to that done on the Rum Jungle site [Evans *et al.* 1987].

2. STUDY SITE

The abandoned tailings dam at Moline is located to the East of Pine Creek in the Northern Territory (**figure 1**). The Moline mill, formerly known as Northern Hercules, was commissioned in 1959 and operated for 13 years, treating ore from a number of small mines in the area [NTDME 1982]. Various ores were treated including uranium (130 000 t), copper (51 000 t), and lead/zinc/silver (81 000 t).

Tailings from the mill were discharged to a shallow gully running northward from the mill. Earthen bunds were initially used to contain the tailings near the head of the valley but these were frequently breached by rains during the wet season. It is estimated that 246 000 t of tailings was discharged to the dam before the mill closure in 1972.

It would appear that no attempt was made to stabilise the tailings after mill closure. Tailings continued to erode from the dam surface and deposit further down the valley. A survey of the site was made in 1980 by the Northern Territory Department of Mines and Energy to determine the limits of tailings dispersion [NTDME 1982]. It was found that tailings extended about 1100 m down the valley and covered an area of about 18 ha (**figure 2**). Cull *et al.* [1986] also reported significant erosion of the tailings into Eureka and Bowerbird Creeks which drain the Moline site.

When the site was visited in May 1986, a gold extraction plant was being constructed to reprocess the Moline tailings. The plant, operated by Pacific Goldmines NL, was commissioned in June 1986. Reprocessed tailings from this plant have since been stored in a new tailings dam adjacent to the old dam on which this study was based.

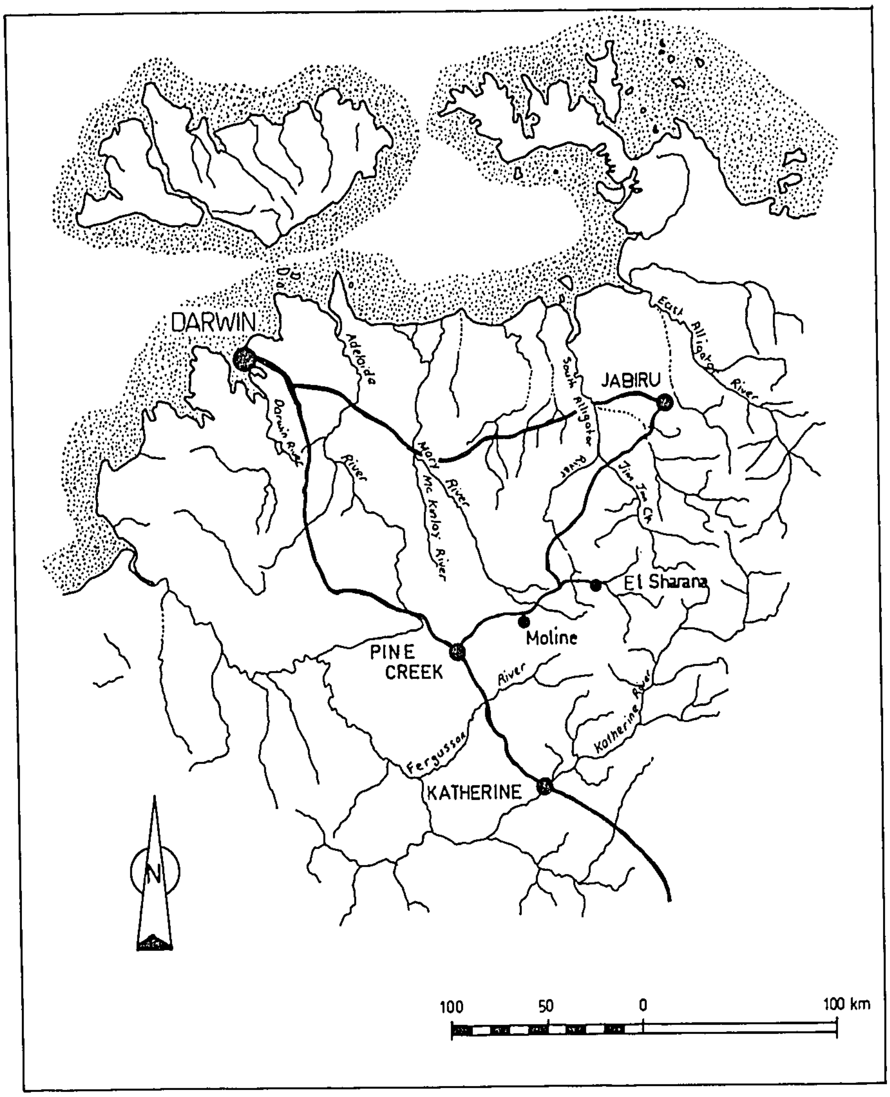

Figure 1 Locality map for Moline tailings dam

3. EXPERIMENTAL PROCEDURES

3.1 Sediment Sampling and Analysis

Tailings and subsoils were sampled at sixteen sites (**figure 3**). Trenches were dug by backhoe down through the tailings and into the subsoil then a section of one of the exposed faces was trimmed and photographed. A visual description of the profile was also recorded.

The subsoil profile was sampled in 10 cm intervals, down to a depth of 50 cm below the tailings-subsoil interface. The tailings were sampled immediately above the tailings-subsoil interface, and at selected depths throughout the profile. Approximately 500 g of sample was taken in each case, using a small trowel; the sample was then sealed in a plastic bag for transport to the laboratory.

A background soil sample was also taken about 0.5 km east of the tailings dam. This area appeared to be undisturbed by mining and processing activities and was covered by vegetation. A topsoil layer was initially discarded to avoid contamination from dust that may have settled in the area, then the underlying soil was sampled.

On return to the laboratory, the samples were air-dried and passed through a 2 mm mesh sieve to remove gravel and other coarse materials. The acid-extractable metals were determined by extraction with hot concentrated acid [Evans *et al.* 1987]. A 10 g subsample of the minus 2 mm fraction was digested in 50 mL of 10 HCl at 110°C for two hours. The digest was filtered and the filtrate made up to volume (100 mL) for analysis of heavy metals, uranium, and radium.

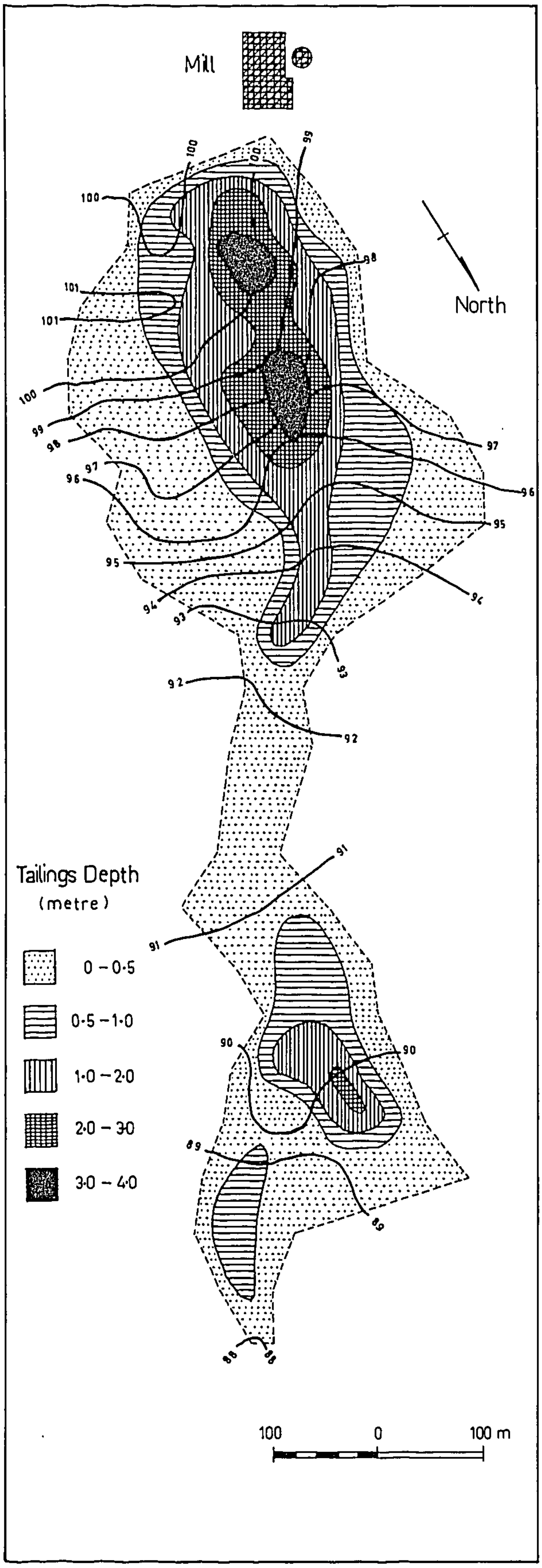

Figure 2 Topography and depth of Moline tailings dam

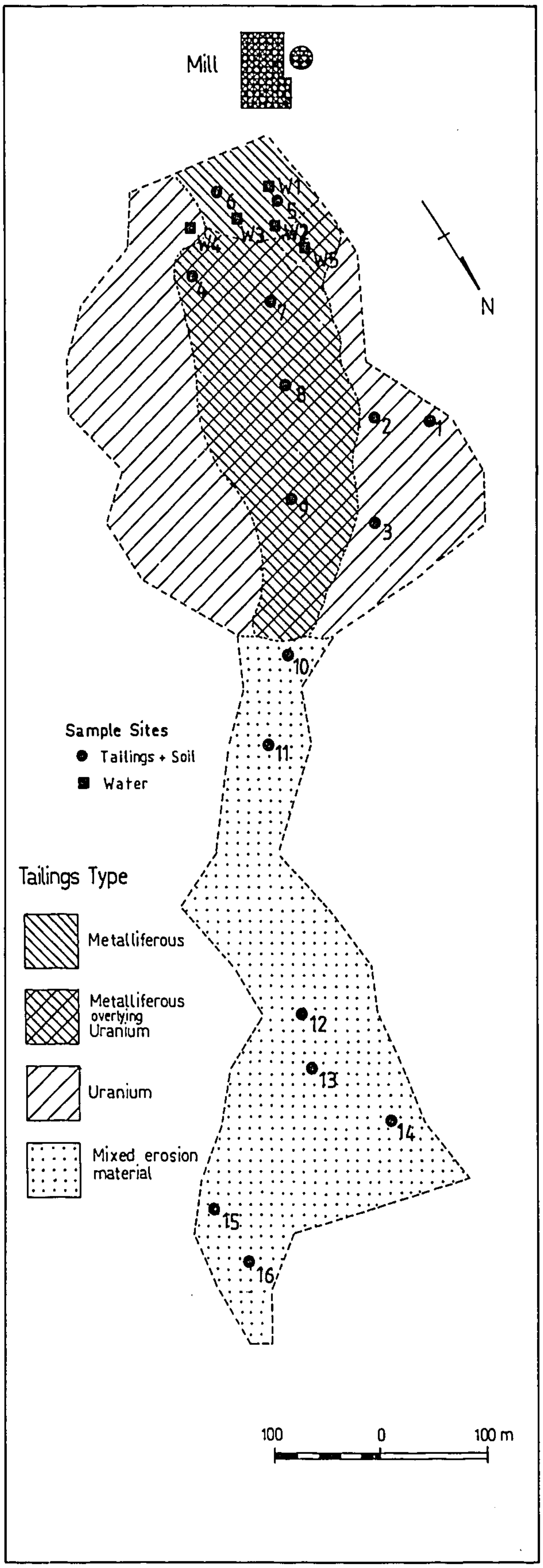

Figure 3 Tailings and subsoil sampling sites and tailings classification

Copper, cadmium, lead and zinc in the filtrate were measured directly by atomic absorption spectroscopy. Analysis for radium-226 was by a radon emanation method using liquid scintillation [Cooper and Wilks, 1981]. A 5 mL aliquot of the filtrate was adjusted to pH 1-2 with NaOH, diluted to 10 mL with distilled water, then purged with N_2 to remove radon. Ten millilitres of scintillant solution (2,5,diphenlyoxazole in toluene) was added, then the vials were sealed and allowed to stand for 14 days before counting with a Packard liquid scintillation counter.

The uranium content of some of the tailings and subsoil samples was measured by a delayed neutron method. Ten g of sample was sealed in a plastic cell and irradiated within the Moata reactor (operating at 88 kW) for one minute. The samples were then transferred to a detector outside of the reactor and delayed neutrons counted for one minute. Sample counts were calibrated against pure uranium standards with a natural isotopic abundance of ^{235}U.

3.2 Water Sampling and Analysis

Two types of waters were sampled and analysed:

(a) surface water that had collected in depressions on the dam surface, and

(b) pore waters extracted from within the tailings or subsoil.

In the latter case a sample of tailings or soil was placed in an hydraulic press and squeezed at pressures up to 20 MPa (3000 psi). Pore water was collected in a plastic syringe fitted to a port in the base of the press.

All the surface waters were collected at the southern end of the dam adjacent to the old mill (**figure 3**). One surface water sample (*i.e.* W4) was taken from a large, shallow pool (*i.e.* about 10 m in diameter and 10 cm deep) on the tailings surface; the other samples were taken from small puddles in shallow erosion channels.

The pH of water samples were measured at the time of collection. Samples were then acidified with a few drops of concentrated hydrochloric acid and sealed in glass vials for transport to the laboratory. Subsequently the samples were analysed for radium, cadmium, copper, lead, zinc, iron manganese, and aluminium. Some were also analysed for sulphate by ion chromatography.

4. RESULTS

4.1 Tailings

The content of radium and heavy metals in tailings varied widely between sampling sites and also at different depths at the same site. **Table 1** gives the range of measured concentrations in tailings immediately overlying the tailings-subsoil interface (refer to **appendix A** for a complete listing of results). The variability in tailings composition reflects the different ore types that were treated at the mill and the placement of the various tailings types within the disposal area.

TABLE 1
COMPOSITION OF TAILINGS AND BACKGROUND SOIL

Element	Unit	Mean	Range	Background
Cu	mg kg^{-1}	140	22 - 1110	11
Pb	mg kg^{-1}	650	71 - 2320	18
Zn	mg kg^{-1}	220	13 - 4100	40
U	mg kg^{-1}	450	3 - 900	19
Ra	Bq g^{-1}	15	0.02 - 159	0.15

The dam can be roughly divided into four regions on the basis of the composition of the overlying tailings (**figure 3**). The four regions are

(a) uranium tailings,

(b) metalliferous tailings,

(c) metalliferous tailings overlying uranium tailings, and

(d) mixed erosion material.

In the latter case, the tailings are a mixture of all tailings types that have eroded from the southern end of the dam and deposited in the northern end. At the southern end of the dam, it is mainly uranium tailings which cover the tailings-subsoil interface. This is logical since uranium ores were the first to be treated at the mill. Most of the metalliferous tailings appear to have been deposited in the centre of the southern end of the dam.

4.2 Subsoil

Subsoil analyses for a typical site in each of the four tailings regions mentioned in **section 4.1** are given in **figures 4** to **7**. A complete list of results is given in **appendix A**. With few exceptions, it would appear that radium and heavy metals have not been transported far into the subsoil. Some minor accumulation of copper, lead, zinc, radium and uranium has occurred in the 0-10 cm subsoil layer immediately below the tailings-subsoil interface, but concentrations in subsoil layers below 10 cm were at or close to background concentrations. Even in the 0-10 cm subsoil layer the concentrations of radium and heavy metal were typically one or two orders of magnitude less than the concentrations in tailings.

There were two exceptions. At site 5 there was significant movement of zinc to a depth of at least 50 cm. There were also elevated concentrations of copper in the 30-40 and 40-50 cm depth intervals. Although natural leaching of these elements cannot be ruled out, it may also be significant that this site was at the head of the dam, very close to the process mill, so it is possible that some localised disturbance (*e.g.* tailings-subsoil mixing, chemical spillage, etc.) may have contributed to the leaching of the heavy metals. Similarly, at site 11 there were elevated concentrations of the heavy metal elements in the 30-40 and 40-50 cm depth intervals. This site was located in the narrow gully joining the southern and northern areas of the dam. Again, it is not possible to ascertain whether these elevated concentrations resulted from vertical leaching of the heavy metals or whether some form of soil disturbance (*e.g.* gully erosion caused by the channelling of surface water through the gully) may have been responsible.

4.3 Surface Waters

The Moline site was visited in May, which is well into the region's 'dry season', and very little surface water remained on the tailings dam. The largest pool (*i.e.* site W4) was lying atop of pink uranium tailings. The water was moderately acid, it contained some radium, but had low concentrations of heavy metal elements (**table 2**). Waters sampled at the other four sites (*i.e.* sites W1, W2, W3 and W5) were lying atop of grey metalliferous tailings. They were of very low pH, rich in iron, and had a brown colouration. They also contained significant amounts of the heavy metal elements (**table 2**).

TABLE 2
COMPOSITION OF SURFACE WATERS

Sample	pH	Ra ($Bq\ L^{-1}$)	Al	Cd	Cu	Fe ($mg\ L^{-1}$)	Mn	Pb	Zn
W1	2	0.04	1970	4.2	190	18020	68	3.0	850
W2	2	1.8	3240	1.2	300	16060	14	1.2	310
W3	2	0.7	1290	0.6	90	13360	63	1.7	160
W4	3.5	2.9	13	0.04	4	0.8	1.3	0.2	6
W5	1.5	0.8	4460	2.0	350	27400	154	0.5	1490

4.4 Pore Waters

Most of the tailings in the dam at the time of sampling were quite dry but a few sites were located where moisture remained at lower depths. The yield of pore water during a typical one hour compaction was about 20-30 mL per 500 g of tailings. The composition of pore water varied with the type of tailings (**table 3**). Samples removed from grey metalliferous tailings were acid and similar in composition to the surface waters described in **section 4.3**. In contrast, pores waters from pink uranium tailings were near neutral in pH, contained very little iron, and negligible amounts of heavy metals.

TABLE 3
COMPOSITION OF PORE WATERS REMOVED FROM TAILINGS

Site No	Sample Depth (cm)	Tail Type*	pH	Ra (Bq L^{-1})	Cu (mg L^{-1})	Fe (mg L^{-1})	Mn (mg L^{-1})	Zn (mg L^{-1})	SO$_4$ (mg L^{-1})
5	120	Met	3.6	-	<0.3	16 620	520	740	-
6	65	Met	1.5	<0.004	101	8580	6.7	74	52 040
	130	Met	3.6	<0.004	1.1	30 720	310	850	-
9	25	Ur	6.9	5.2	<0.3	2.8	0.4	92	1630
	55	Ur	5.4	<0.004	0.3	58	4.1	72	1990
	120	Ur	6.4	1.0	0.4	1.4	8.3	23	-
14	45	Mix	6.8	0.9	<0.3	1.5	0.2	3	2480
	65	Mix	7.3	-	<0.3	0.6	1.4	11	-
	75	Mix	6.8	-	<0.3	<0.1	0.7	5	-
16	55	Mix	5.5	-	<0.3	-	-15	-	
	65	Mix	7.0	-	<0.3	0.7	0.2	2	1320
	115	Mix	6.9	0.9	<0.3	0.6	0.3	2	-

*Met = metalliferous, Ur = uranium, Mix = mixed erosion material

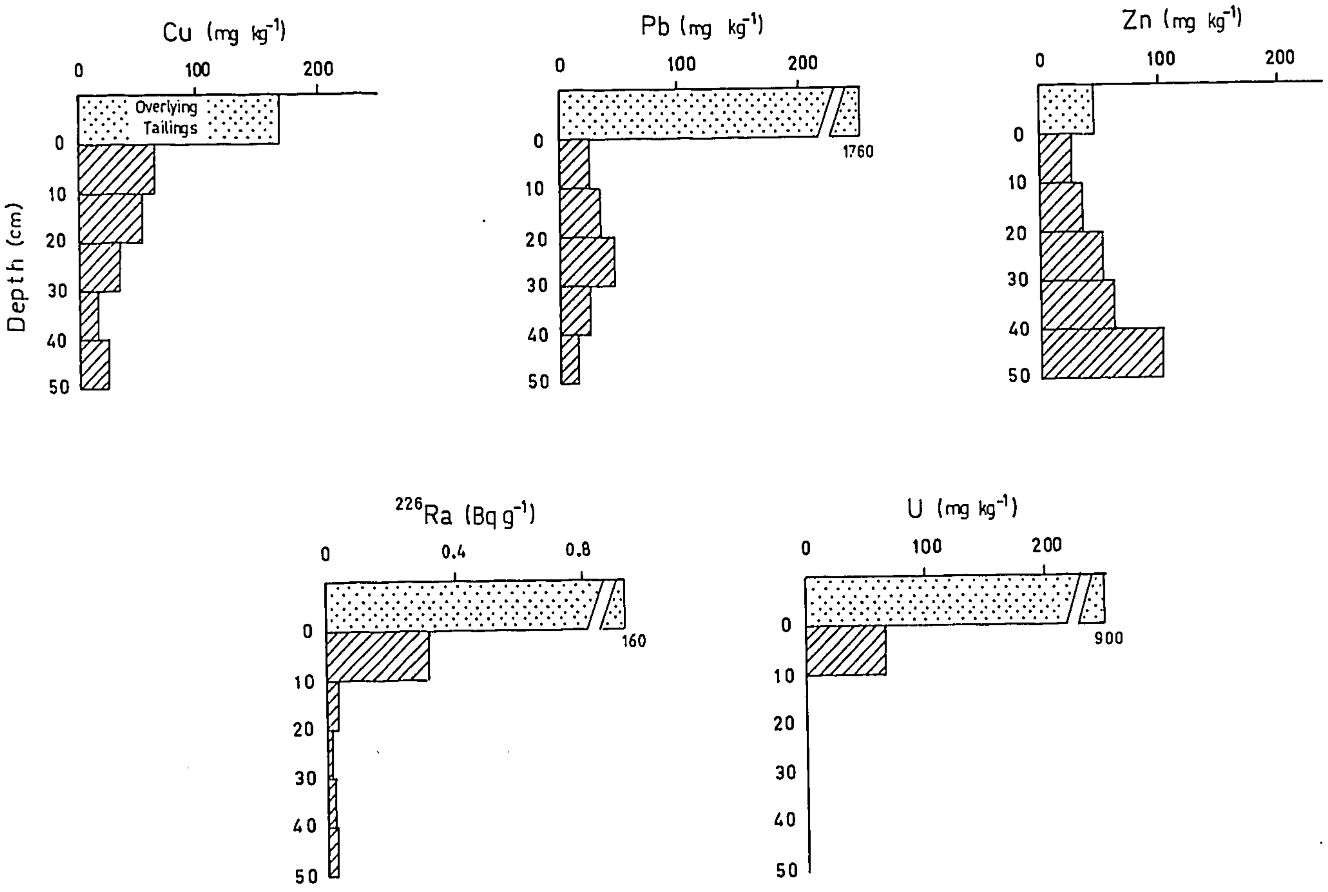

Figure 4 Composition of subsoil and overlying tailings (uranium) at site 2

5. DISCUSSION

The most important finding of this study is that as was the case with the Rum Jungle study by Evans *et al.* [1987] there appears to have been very little leaching of heavy metals and radioisotopes from the Moline tailings into the underlying subsoil. This is despite the fact that there was virtually no site preparation at Moline before tailings were discharged to the surrounding area.

Over most of the dam it appears that only the first 10 cm of subsoil beneath the interface has been affected by the tailings to any significant extent. Furthermore, given that there has been little accumulation of contaminants below 10 cm from the tailings-subsoil interface it would seem very unlikely that there has been any leaching to depths greater than the 50 cm limit used in this study. The strong affinity of heavy metals for clay surfaces is such that if there had been significant contaminant transport across the tailings-subsoil interface, then there should have been elevated concentrations throughout the 0-50 sampling zone. Clearly this was not the case.

We can postulate on the mechanisms limiting contaminant transport at the Moline site. The transport of elements such as heavy metals in soils is related to the movement of water and to the geochemistry of the particular elements. In respect to the latter, most heavy metal elements have a close affinity with the solid phase, either through precipitation or through adsorption onto soil surfaces (*i.e.* clays). As such, their movement through a soil is usually retarded in relation to the movement of water. Conditions that favour adsorption, such as high pH, also enhance the retardation of heavy metal transport.

The mixed erosion tailings at the northern end of the dam were only slightly acid (sediment pH typically 5 to 6) and had low concentrations of soluble heavy metals in their pore waters (**table 3**). Hence the potential for contaminant leaching from this type of tailings would appear to be small. On the other hand, the grey metalliferous tailings located at the southern end of the dam were more acidic (*i.e.* typical sediment pH was around 4) and there was evidence of high concentrations of soluble heavy metals in the pore water (**table 3**) and especially in surface waters lying atop of grey tailings (**table 2**). One might infer from this that there was at least the potential for heavy metal leaching from metalliferous tailings. The fact that minimal leaching of heavy metals had occurred at the southern end of the dam may be due to a layer of uranium tailings that overlaid most of the tailings-subsoil interface at the southern end. These uranium tailings were only moderately acid (*i.e.* pH of 4 to 5) and had low heavy metal contents, hence conceivably they may have acted as a barrier to the movement of contaminants from the highly acid surface horizons down into the subsoil.

The relatively small increases in radium content of the subsoil beneath uranium tailings can possibly be attributed to the low solubility of radium in the tailings. For example, the highest measured radium concentration in pore water from uranium tailings was 5.2 Bq L^{-1} with most values being around 1 Bq L^{-1} (**table 3**). Assuming an annual vertical flux of water in the dam of 750 mm (*i.e.* roughly half the annual rainfall), the maximum rate of leaching of radium would be 0.39 Bq $cm^{-2}\ y^{-1}$ if the radium moves unhindered through the tailings-subsoil interface. At such a rate it would take 180 years to increase uniformly the radium content of the top 50 cm of subsoil by 1 Bq g^{-1}.

There is also a possibility that a lack of water movement either through the tailings or down into the subsoil may have limited contaminant transport. Very little is known of the hydrology of the Moline tailings dam. It is a complex system, in part because of the different types of tailings that have been placed in the dam, but also because of the tendency for tailings to stratify into layers of slimes and sands. In a recent study [Jeffery, ANSTO, unpublished results] of tailings from the Rum Jungle mine it was found that the saturated hydraulic conductivity of tailings slimes was about two orders of magnitude less than the conductivity of tailings sands. In effect, the layers of tailings slimes act as very low permeable barriers to the vertical movement of groundwater. Comparable data for Moline tailings are not available but the variations in texture observed with Moline tailings were similar to those reported for the Rum Jungle site.

The only hydrological data available for the Moline dam consist of a number of surface infiltration measurements that were made during the site visit using double ring infiltrometers according to the method of Bertrand [1965]. The measured rates varied widely, even for one given tailings type. For example, after one hour, the rates of infiltration varied from 0.04 to 0.09 cm min^{-1} for uranium tailings, 0.01 to 0.2 cm min^{-1} for metalliferous tailings, and 0.006 to 0.05 cm min^{-1} for mixed erosion material. This variation highlights the variable nature of the dam surface which, in some areas, appears as a hardened shale-like crust, but elsewhere as expanses of coarse sand.

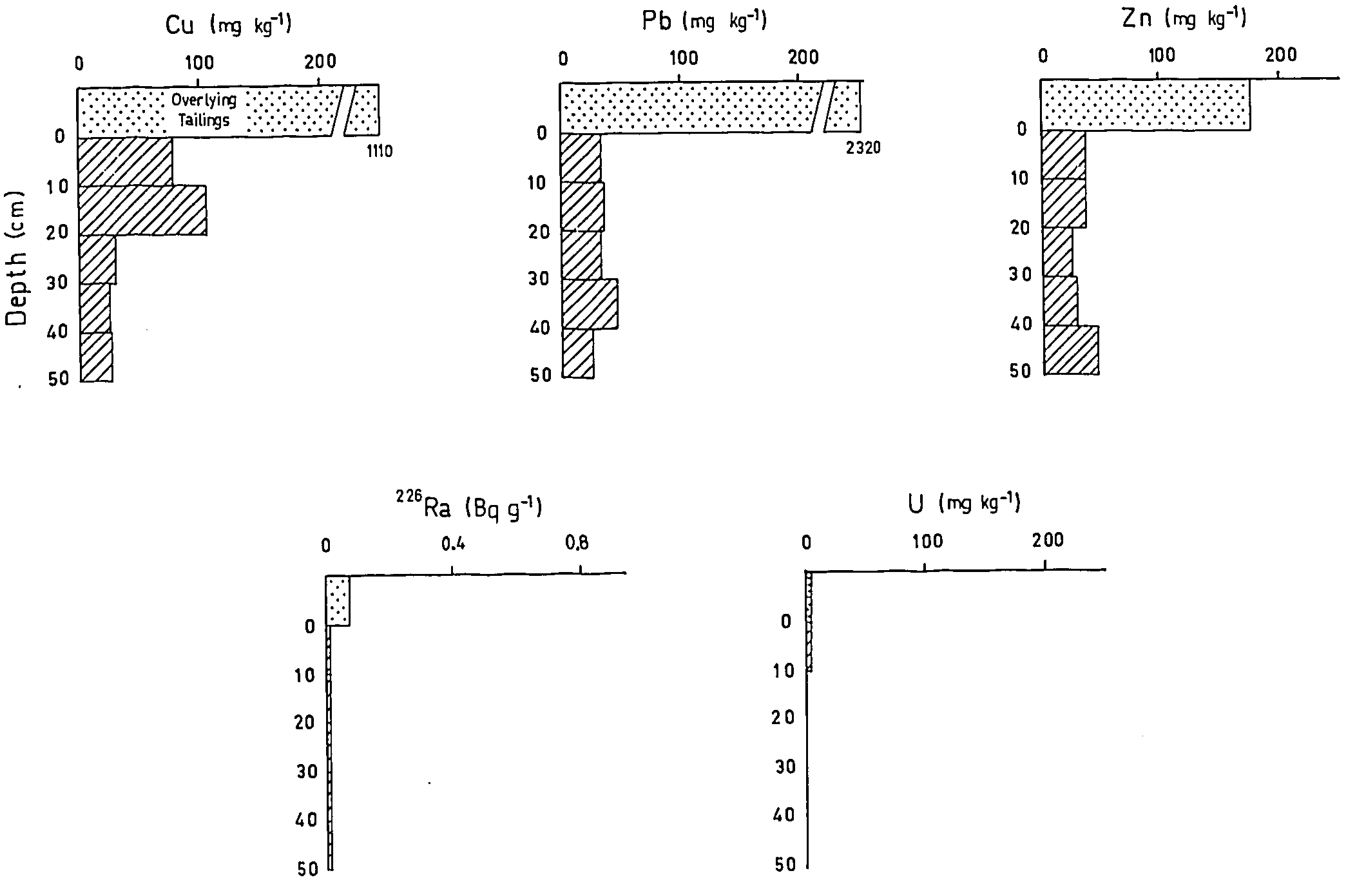

Figure 5 Composition of subsoil and overlying tailings (metalliterous) at site 6

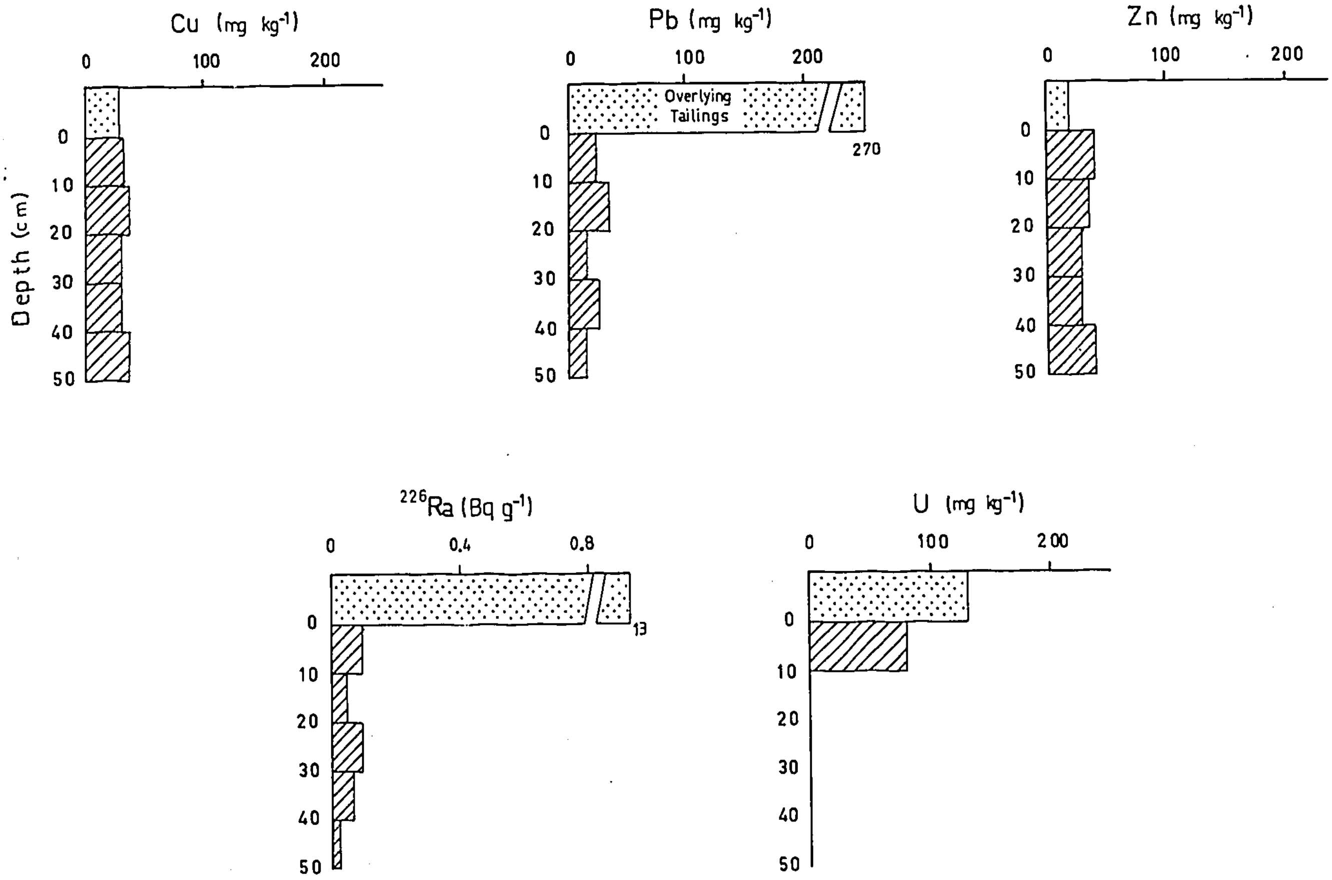

Figure 6 Composition of subsoil and overlying tailings (metalliferous/uranium) at site 8

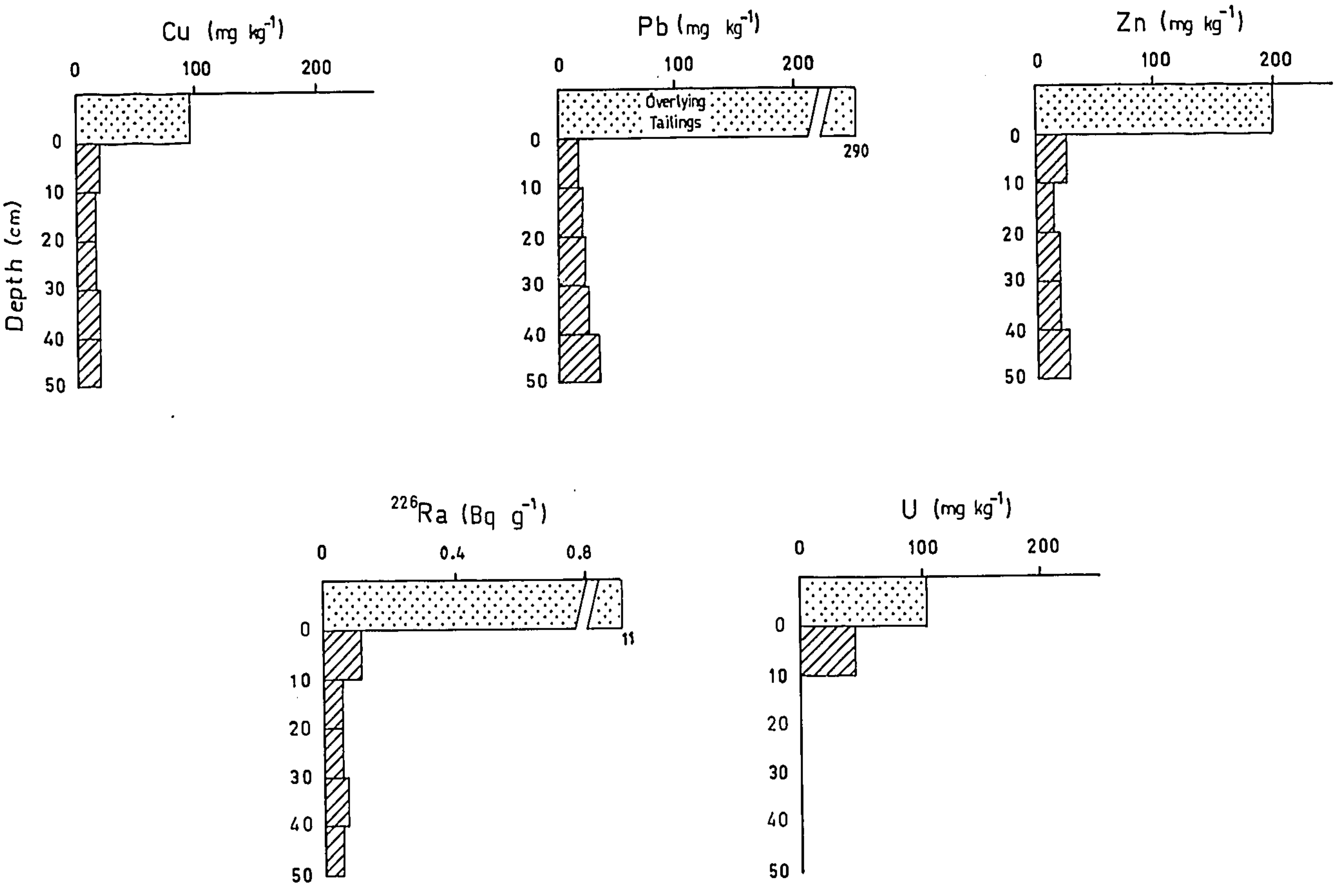

Figure 7 Composition of subsoil and overlying tailings (mixed erosion material) at site B

6. CONCLUSIONS

The tailings at Moline were laid down between 1959 and 1974. After nearly 30 years of leaching only minor transport of radium, uranium, copper, lead and zinc into subsoil has occurred. Transport has largely been confined to less than 10 cm below the tailings-subsoil interface. Factors limiting contaminant transport have been discussed. Pore water analyses indicate a low chemical solubility in uranium tailings (which constitute the bulk of tailings in the dam), and the hydraulic conductivity of all tailings is limited by stratification of sands and slimes.

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APPENDIX A
COMPLETE TAILINGS AND SUBSOIL ANALYSES

Site No	Depth	Colour	Texture	< 2 mm Fraction (%)	pH	E.C. mS	U mg kg^{-1}	Ra Bq g^{-1}	Cu mg kg^{-1}	Pb mg kg^{-1}	Zn mg kg^{-1}	Cd mg kg^{-1}
1	T1	pink	sand	100	4.3	0.03	177	10.7	30	422	18	0.3
	T2	pink	slime	100	4.5	0.04	155	11.2	29	415	20	0.3
	S1	yellow/brown	clay	60	3.7	0.09	39	0.026	51	17	30	<0.2
	S2	yellow/brown	clay	61	3.7	0.09	-	0.030	36	15	31	<0.2
	S3	yellow/brown	clay	56	3.9	0.07	-	0.022	32	14	28	<0.2
	S4	yellow/brown	clay	57	4.2	0.09	-	0.022	28	13	34	<0.2
	S5	yellow/brown	stoney clay	27	4.5	0.06	-	0.033	17	12	49	<0.2
2	T1	pink	sand	100	4.2	0.12	840	152	158	1700	37	0.3
	T2	pink	slime	100	4.1	0.09	900	159	167	1760	43	0.2
	S1	mottled yellow	clay	46	4.1	0.11	69	0.30	65	25	28	<0.2
	S2	mottled yellow	clay	40	4.1	0.10	-	0.022	53	31	36	<0.2
	S3	mottled yellow	clay	32	4.3	0.11	-	0.004	33	45	50	<0.2
	S4	mottled yellow	clay	38	4.6	0.11	-	0.026	17	26	60	<0.2
	S5	mottled yellow	clay	28	4.9	0.09	-	0.033	22	15	102	<0.2
3	T1	pink	sand	100	5.2	2.3	323	0.78	117	700	198	0.7
	T2	pink	slime	100	4.5	0.52	320	16	95	901	37	<0.2
	S1	mottled yell/brown	clay	65	4.2	0.26	39	1.2	33	70	32	<0.2
	S2	mottled yell/brown	clay	73	4.3	0.23	-	-	31	45	41	<0.2
	S3	mottled yell/brown	clay	52	4.6	0.24	-	0.37	23	32	40	<0.2
	S4	mottled yell/brown	clay	46	4.5	0.26	-	0.44	21	47	49	<0.2
	S5	mottled yell/brown	clay	49	4.7	0.25	-	0.011	18	35	44	<0.2
4	T1	dark brown	slimes	100	4.9	0.37	129	1.6	31	437	30	<0.2
	T2	light brown	slimes	100	4.7	0.17	96	3.3	32	256	14	<0.2
	S1	yellow	clay	42	4.1	0.27	21	0.18	21	40	23	<0.2
	S2	yellow	clay	48	4.2	0.28	-	0.030	46	10	29	<0.2
	S3	yellow/brown	clay	27	4.2	0.28	-	<0.004	42	7	36	<0.2
	S4	yellow/brown	clay	56	4.2	0.28	-	0.022	36	8	34	<0.2
	S5	yellow/brown	clay	45	4.1	0.31	-	0.022	38	8	40	<0.2
5	T1	grey	sand	100	4.1	3.2	35	0.48	830	1404	5452	401
	T2	grey	slimes	100	4.2	3.2	12	0.11	240	1075	2297	6.5
	S1	yellow	stoney clay	35	3.6	1.3	3	0.004	31	119	1150	<0.2
	S2	yellow	stoney clay	21	3.6	1.5	-	0.007	36	126	1149	<0.2
	S3	yellow	stoney clay	25	3.6	1.6	-	0.030	80	51	707	<0.2
	S4	yellow/brown	clay	51	.5	1.9	-	<0.004	635	38	741	<0.2
	S5	yellow/brown	clay	53	3.4	2.1	-	<0.004	260	30	611	<0.2

Continued

APPENDIX A (Continued)

Site No	Depth	Colour	Texture	< 2 mm Fraction (%)	pH	E.C. mS	U mg kg^{-1}	Ra Bq g^{-1}	Cu mg kg^{-1}	Pb mg kg^{-1}	Zn mg kg^{-1}	Cd mg kg^{-1}
6	T1	grey	sand	100	3.9	3.7	7	0.048	1016	1900	2998	30
	T2	brown	ash	100	3.3	2.8	3	0.078	1114	2318	175	3.2
	S1	yellow	stoney clay	19	-	-	4	<0.004	77	31	37	<0.2
	S2	yellow	stoney clay	27	3.3	1.9	-	<0.004	105	36	37	<0.2
	S3	yellow/brown	clay	47	3.4	2.2	-	<0.004	30	31	25	<0.2
	S4	yellow/brown	clay	37	3.6	2.1	-	<0.004	24	44	29	<0.2
	S5	yellow/brown	clay	40	3.9	1.7	-	<0.004	27	25	44	<0.2
7	T1	pink	laminated	100	4.0	0.28	85	15	25	158	10	0.3
	T2	pink	laminated	100	4.0	0.25	103	13	28	169	13	0.2
	S1	brown	stoney clay	23	3.8	0.43	47	0.35	61	24	15	<0.2
	S2	brown	stoney clay	25	3.8	0.40	-	0.34	51	31	21	<0.2
	53	brown	stoney clay	22	3.8	0.61	-	0.10	47	22	17	<0.2
	S4	yellow-brown	stoney clay	18	3.7	0.56	-	0.10	61	33	18	<0.2
	S5	yellow-brown	stoney clay	13	3.8	0.50	-	0.09	70	29	16	<0.2
8	T1	pink	sand	100	5.1	1.9	85	2.1	25	205	27	0.2
	T2	pink	sand	100	4.2	0.64	131	13	29	267	19	<0.2
	S1	yellow	stoney clay	32	4.2	0.65	80	0.10	31	23	38	<0.2
	S2	yellow	stoney clay	33	4.3	0.60	-	0.048	35	35	36	34
	S3	yellow	stoney clay	42	4.3	0.58	-	0.096	30	17	29	<0.2
	S4	yellow	stoney clay	32	4.2	0.73	-	0.067	30	24	29	<0.2
	S5	yellow	stoney clay	36	4.1	0.91	-	0.011	35	14	39	<0.2
9	T1	purple	sand	100	5.6	0.35	85	9.3	17	138	69	1.0
	T2	purple	sand	100	4.7	0.18	65	4.1	37	390	32	0.2
	S1	yellow	stoney clay	47	3.5	0.46	3	0.13	16	66	12	<0.2
	S2	yellow	stoney clay	44	3.5	0.42	-	0.41	25	122	25	<0.2
	S3	yellow	stoney clay	27	3.7	0.30	-	0.24	16	68	17	<0.2
	S4	yellow	stoney clay	18	3.9	0.37	-	0.24	63	284	22	<0.2
	S5	yellow	stoney clay	19	3.8	0.43	-	0.59	64	302	28	<0.2
10	T1	purple-red	slimes	100	5.4	1.1	112	2.2	35	303	53	0.4
	T2	purple	sand	100	5.5	2.3	134	3.7	48	605	181	1.5
	S1	yellow/brown	clay	73	4.0	1.1	21	0.24	33	37	46	<0.2
	S2	yellow/brown	clay	85	3.9	0.95	-	0.12	25	29	44	<0.2
	S3	yellow/brown	clay	87	4.0	0.63	-	0.085	23	12	36	<0.2
	S4	yellow/brown	clay	70	3.8	0.39	-	0.14	22	42	32	<0.2
	S5	yellow/brown	clay	88	3.7	0.27	-	0.16	29	45	30	<0.2

Continued

APPENDIX A (Continued)

Site No	Depth	Colour	Texture	< 2 mm Fraction (%)	pH	E.C. mS	U mg kg^{-1}	Ra Bq g^{-1}	Cu mg kg^{-1}	Pb mg kg^{-1}	Zn mg kg^{-1}	Cd mg kg^{-1}
11	T1	red-brown	sand	100	5.7	0.22	42	1.3	867	6524	8527	43
	T2	brown	slimes	100	5.0	0.22	43	0.52	52	71	36	<0.2
	S1	yellow/brown	stoney clay	40	4.0	0.18	22	0.085	42	132	54	<0.2
	S2	yellow/brown	stoney clay	21	4.1	0.26	-	0.16	77	79	69	<0.2
	S3	yellow/brown	stoney clay	29	4.1	0.19	-	0.15	132	328	83	<0.2
	S4	yellow/brown	stoney clay	58	4.4	0.11	-	0.16	249	1767	261	2.3
	S5	-	-	-	-	-	-	-	-	-	-	-
12	T1	pink	laminated	100	5.6	0.08	91	7.2	202	192	15	<0.2
	T2	black	interface	100	5.0	0.10	131	15.7	88	301	17	<0.2
	S1	green-yellow	clay	76	4.3	0.09	48	0.41	32	18	10	<0.2
	S2	yellow	clay	80	4.2	0.10	-	0.17	29	20	14	<0.2
	S3	yellow	clay	71	4.0	0.16	-	0.070	32	20	18	<0.2
	S4	yellow/brown	stoney clay	34	3.9	0.17	-	0.10	33	36	30	<0.2
	S5	yellow/brown	stoney clay	40	3.8	0.18	-	0.056	28	36	38	<0.2
13	T1	pink-brown	sand	100	5.5	0.05	74	4.1	19	204	188	1.5
	T2	black	interface	100	5.6	0.11	105	11	93	291	199	2.1
	S1	orange/brown	clay	84	5.3	0.06	48	0.11	19	15	23	<0.2
	S2	orange/brown	clay	76	5.4	0.06	-	0.059	14	21	13	<0.2
	S3	orange/brown	clay	76	5.4	0.08	-	0.063	13	22	18	<0.2
	S4	orange/yellow	clay	69	5.2	0.14	-	0.074	16	25	19	<0.2
	S5	orange/yellow	clay	56	4.3	0.20	-	0.059	17	32	21	<0.2
14	T1	purple	slime	100	5.4	0.23	144	8.0	45	505	94	0.6
	T2	grey	sand	100	5.4	0.20	21	6.6	28	157	4100	4.3
	S1	yellow	clay	59	4.5	0.16	42	0.56	20	43	39	<0.2
	S2	yellow	clay	42	4.4	0.22	-	0.12	24	44	35	<0.2
	S3	yellow/brown	clay	46	3.9	0.28	-	0.11	21	27	25	<0.2
	S4	yellow/brown	clay	45	3.9	0.28	-	0.007	23	29	23	<0.2
	S4	yellow/brown	clay	51	3.8	0.28	-	0.093	24	27	24	<0.2
15	T1	purple	sand	100	4.9	0.05	64	2.1	13	58	32	0.5
	T2	purple	slimes	100	5.3	0.83	202	7.5	22	879	192	3.0
	S1	yellow	clay	93	4.6	0.67	13	0.37	69	362	148	<0.2
	S2	yellow	clay	83	4.2	0.17	-	0.23	17	54	23	<0.2
	S3	yellow	clay	76	4.1	0.15	-	0.20	16	41	27	<0.2
	S4	yellow/brown	clay	80	4.0	0.16	-	0.25	13	32	26	<0.2
	S4	yellow/brown	clay	75	4.0	0.16	-	0.16	14	33	25	<0.2

Continued

APPENDIX A (Continued)

Site No	Depth	Colour	Texture	< 2 mm Fraction (%)	pH	E.C. mS	U mg kg^{-1}	Ra Bq g^{-1}	Cu mg kg^{-1}	Pb mg kg^{-1}	Zn mg kg^{-1}	Cd mg kg^{-1}
16	T1	brown	sandy soil	100	3.9	0.10	13	1.1	44	160	38	<0.2
	T2	brown	sandy soil	100	3.9	0.30	13	0 022	96	480	67	0.5
	S1	brown	clay	82	4.1	0.07	7	0.16	19	32	24	<0.2
	S2	brown	clay	73	3.9	0.12	-	<0.004	16	36	20	<0.2
	S3	yellow/brown	stoney clay	51	4.0	0.12	-	0.17	16	66	20	<0.2
	S4	yellow/brown	stoney clay	27	3.9	0.13	-	0.27	16	75	23	<0.2
	S5	-	-	-	-	-	-	-	-	-	-	-