DEPARTMENT OF NATIONAL RESOURCES

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

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Record 1978/81

Evaluation of proposed site
for disposal of radioactive waste,
West Belconnen, ACT, 1978

by

P.D. Hohnen, J.R. Kellett & G. Jacobson

BMR RECORD 1978/76

EVALUATION OF PROPOSED SITE FOR DISPOSAL OF RADIOACTIVE WASTE, WEST BELCONNEN, A.C.T., 1978

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P.D. Hohnen, J.R. Kellett & G. Jacobson

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		11

CONTENTS

APPENDICES

1. Logs of drillholes
2. Estimation of fracture opening
3. Cation exchange capacity of soil and rock samples

SUMMARY

A proposed site for the storage and disposal of low level radioisotopes produced in the A.C.T. has been evaluated by drilling, pump testing and infiltration testing. The site is underlain by several metres of clay soils beneath which is extremely to highly weathered, fractured, porphyry. The hydraulic parameters of the soil and rock indicate that the travel time for pollutants through groundwater to a possible discharge point 1 km away, would be about 20 years. The additional delays incorporated into the design of the facility are expected to enable the storage of radioisotope wastes with a half life of up to 5 years.

INTRODUCTION

At the request of the National Capital Development Commission a hydrogeological investigation of a proposed site for storage and disposal of radioisotope waste was carried out in 1978. The site is in the south-east corner of the West Belconnen landfill site (Fig. 1).

Proposals for disposal of low level radioisotopes produced in A.C.T. hospitals and research institutes have been developed by L.T. Frazer & Associates Pty Ltd (1977). The original proposal was for storage in large diameter boreholes to a depth of 7 m and it was on this basis that the hydrogeological investigation was undertaken.

Previous geological investigations in the area include studies of the geology of the landfill site by Vanden Broek (1971) and Jacobson (1978), and of the nearby Ginninderra sewer tunnel by Lang & Purcell (1976). During this investigation three boreholes were drilled by contractors, Stewart Bros Pty Ltd, and pump tests and infiltration tests were made to determine the hydraulic parameters of the aquifers. In addition, a dye tracing experiment is being conducted in conjunction with the Centre for Resource and Environmental Studies, Australian National University. Analyses of the cation exchange properties of drillhole samples were made by the CSIRO Division of Soils, Canberra, and groundwater samples were analysed by the Australian Mineral Development Laboratories, Adelaide.

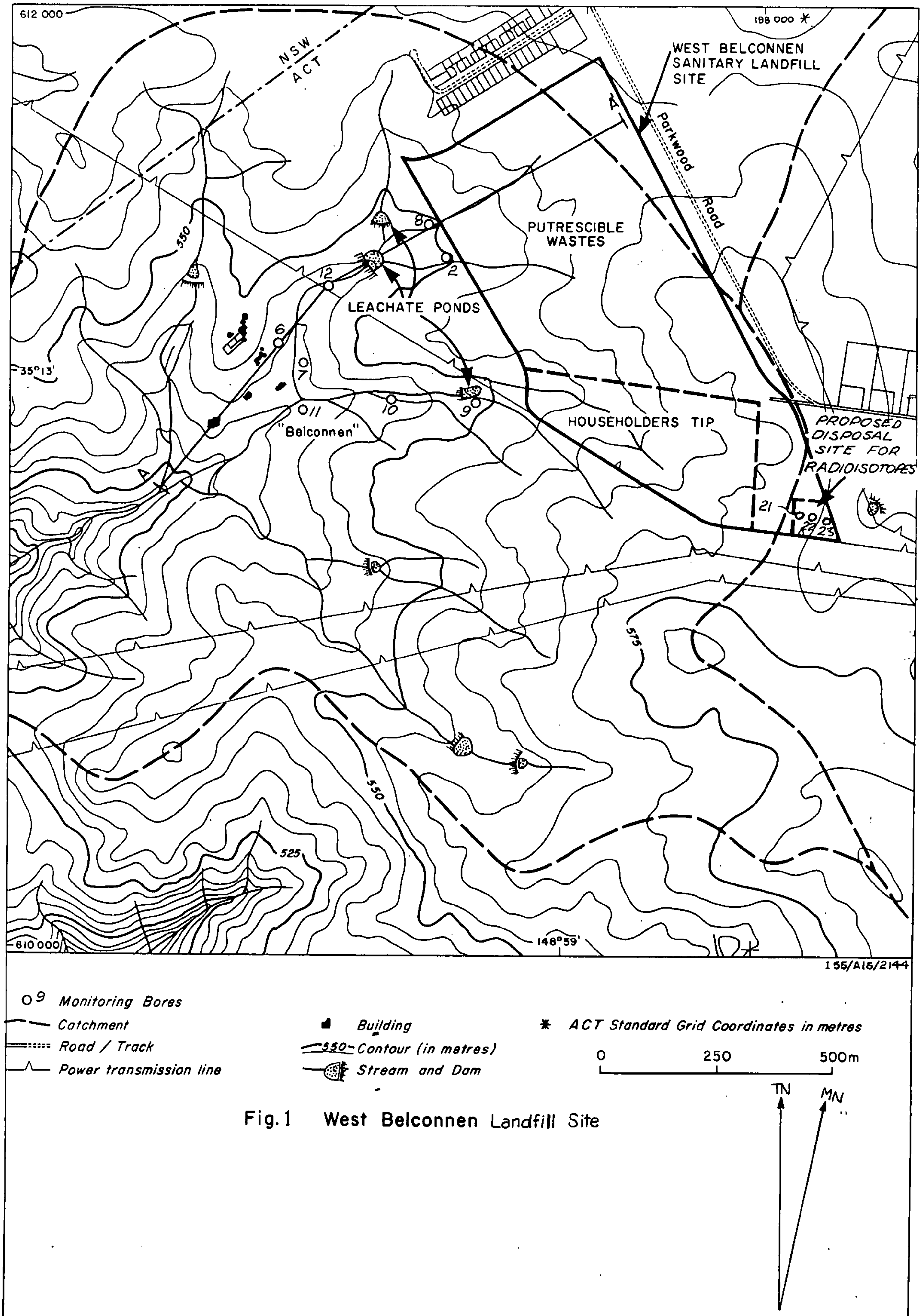


Fig. 1 West Belconnen Landfill Site

SOILS

Soil, including windblown sand that has been subjected to soil forming processes, and extremely and highly weathered rock, mantles the disposal site to depths of 5 to 9 metres. The windblown sand ranges in thickness from 2 to 4 metres and lies on the 'C' horizon of a truncated residual soil on dacitic or rhyodacitic porphyry, mapped as granite porphyry by Lang & Purcell (1976).

A red podzolic soil has formed on the windblown sand, which was probably a fine-grained red sand when it was first deposited. The podzolic soil profile consists of an 'A' horizon of about 10 cm of grey-brown sandy silt on a few centimetres of pallid silt, which overlies a 'B' horizon of 1-2 m of pisolitic, dark red-brown, heavy clay (CH). The pisolitic clay overlies, in places, a mottled zone of red, orange and grey heavy clay.

Where the windblown sand is thin, weathering and illuviation of clay have been extensive throughout the soil profile and there is no 'C' horizon within the windblown sand. Where the sand accumulated in greater thicknesses, there is a 'C' horizon of pale grey, streaked with red and yellow, fine sandy clay with manganese and limonite pisolites.

BEDROCK GEOLOGY

The illuviated windblown sand overlies highly to extremely weathered porphyry of granitic composition. The porphyry is of late Silurian age and intrudes volcaniclastic sediments including shale and sandstone, of early late Silurian age. At the disposal site, the porphyry is generally coarse-grained, inequigranular and holocrystalline, and component crystals range in diameter from 2 to 4 mm across. Component minerals in approximate proportions are kaolinised feldspar 70%, quartz 20%, biotite 10% and rare hornblende crystals which are up to 1 cm long.

Three test holes were drilled with tungsten carbide bits to a depth of 20 m; all were completed in moderately weathered porphyry (Fig. 2). To the depths drilled, the porphyry is closely jointed, with an average of 10 joints per metre of NMLC drill core. Most joints intersected were smooth and slightly open, and joint surfaces were commonly stained with manganese. At depths between 14 and 20 m, some joints were filled with red plastic clay. Detailed logs of the drillholes are given in Appendix 1.

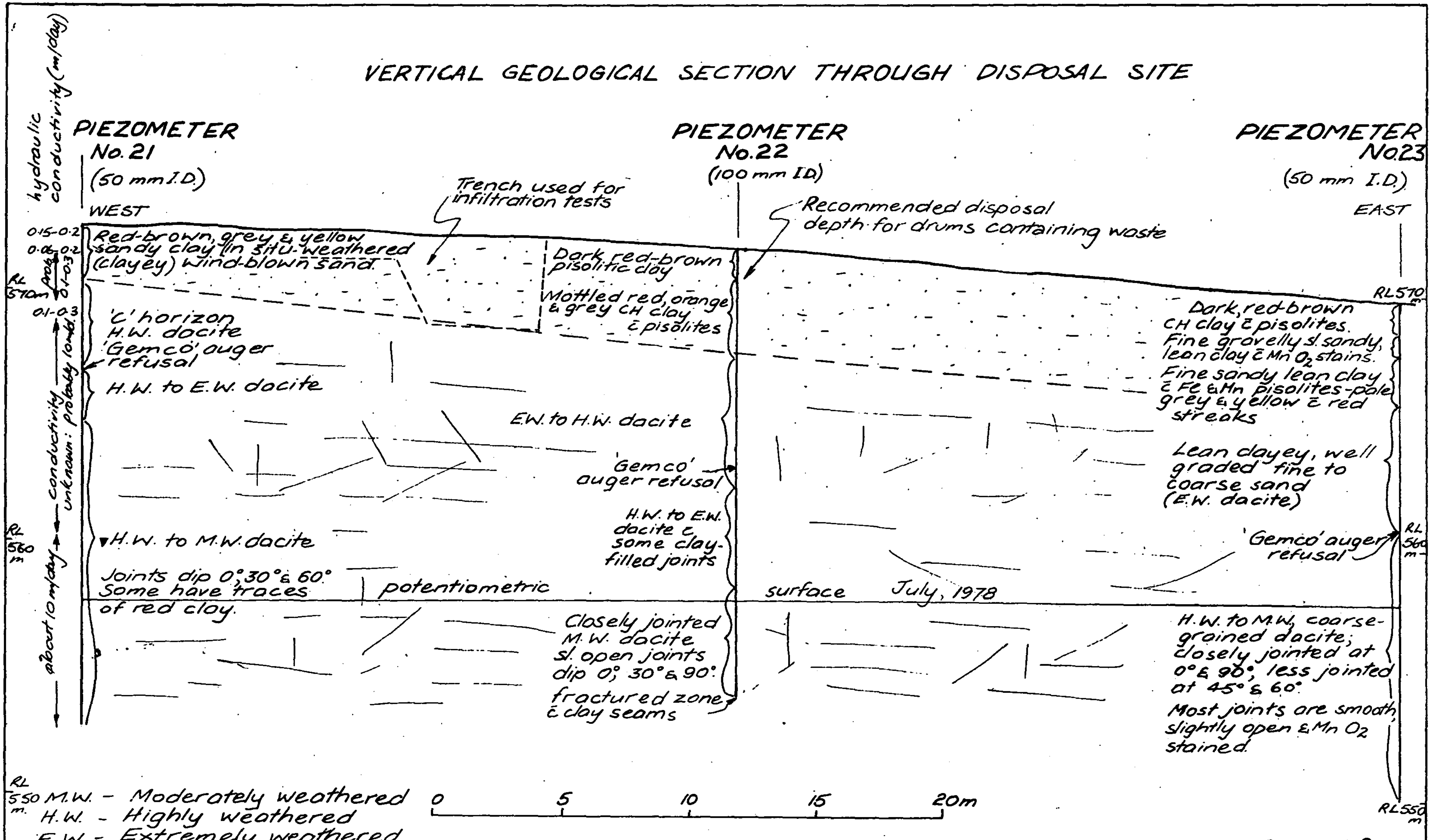
Geological logs of the nearby Ginninderra Sewer Tunnel show that at a depth of 50-65 m, joints are tight and are cemented with calcite; this has reduced the permeability of the rock mass to extremely low values along tunnel sections up to 100 m long.

HYDROGEOLOGY OF DISPOSAL SITE

FRACTURED ROCK AQUIFER

The fractured rock aquifer is unconfined, and the potentiometric surface coincides with the water table or phreatic surface, i.e. the aquifer is unconfined in this area. The phreatic surface, defined as the surface at which in situ groundwater is at atmospheric pressure, ranges in depth between 11 and 14 m below ground surface (Fig. 2). This means that the aquifer lies somewhere in the interval of 11 to 60 m below the surface, i.e. in the interval in which joints are possibly open. Figure 3 shows the likely schematic path of deep groundwater circulation in the fractured rock.

VERTICAL GEOLOGICAL SECTION THROUGH DISPOSAL SITE



I55/A16/2145 FIGURE 2

SCHEMATIC CIRCULATION OF DEEP GROUNDWATER IN FRACTURED-ROCK AQUIFERS

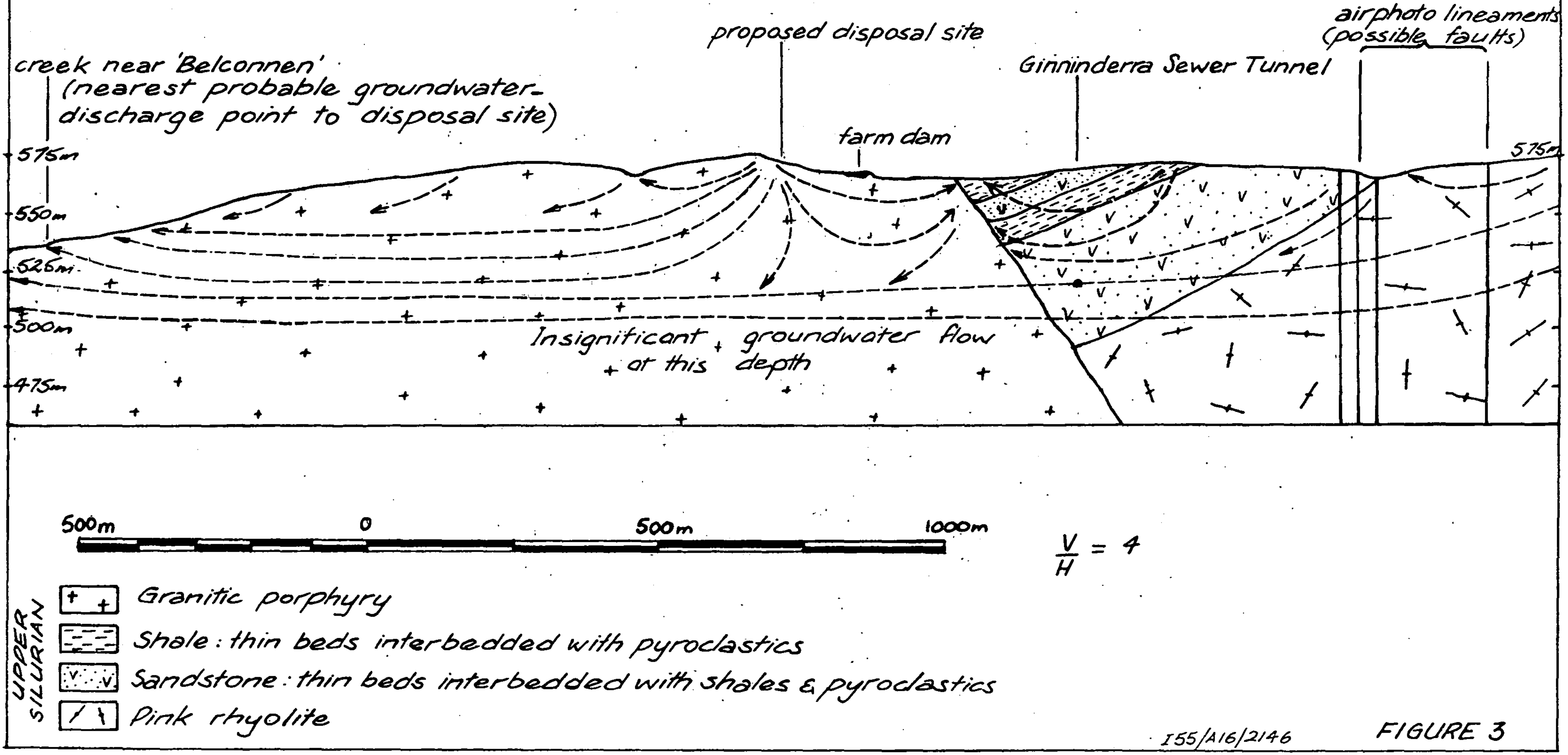


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FIGURE 3

Aquifer tests have been conducted on the assumption that groundwater in the fractured rock aquifer flows in accordance with Darcy's Law, which can be summarised as

$$Q = Aki$$

where A is the cross-sectional area of the aquifer, k is the hydraulic conductivity and i the hydraulic gradient. Thus the Darcy velocity of groundwater flow is given by

$$V_D = ki.$$

From the Darcy velocity, which is an abstract concept rather than a real flow rate, the mean pore velocity can be obtained as follows:

$$V_M = \frac{V_D}{\phi}$$

where ϕ = effective porosity of the aquifer.

The travel time t, for a tracer moving with the groundwater and discharging to the surface at distance L from its point of entry is given by $t = \frac{L}{V_M}$. A linear flow path is assumed for estimating travel time; the actual travel path for a pollutant would be more tortuous. This discrepancy results in calculation of a higher than actual groundwater velocity from point to point and hence a shorter travel time, thereby introducing a safety factor into the calculation to offset variables which cannot be estimated reliably. An example of such a variable would be the occurrence of a shear zone of high hydraulic conductivity occurring very close to the flow path, but not intersected by any of the three drill holes. If such a zone occurred it would reduce travel times below those calculated.

ESTIMATION OF HYDRAULIC PARAMETERS

The transmissivity of the fractured rock aquifer was estimated as follows:

(i) A 10-hour drawdown test was made on bore No. 22 (Fig. 2) using bores 21 and 23 as observation bores.

(ii) A residual drawdown test was carried out on the pumped bore on completion of pumping (Fig. 4).

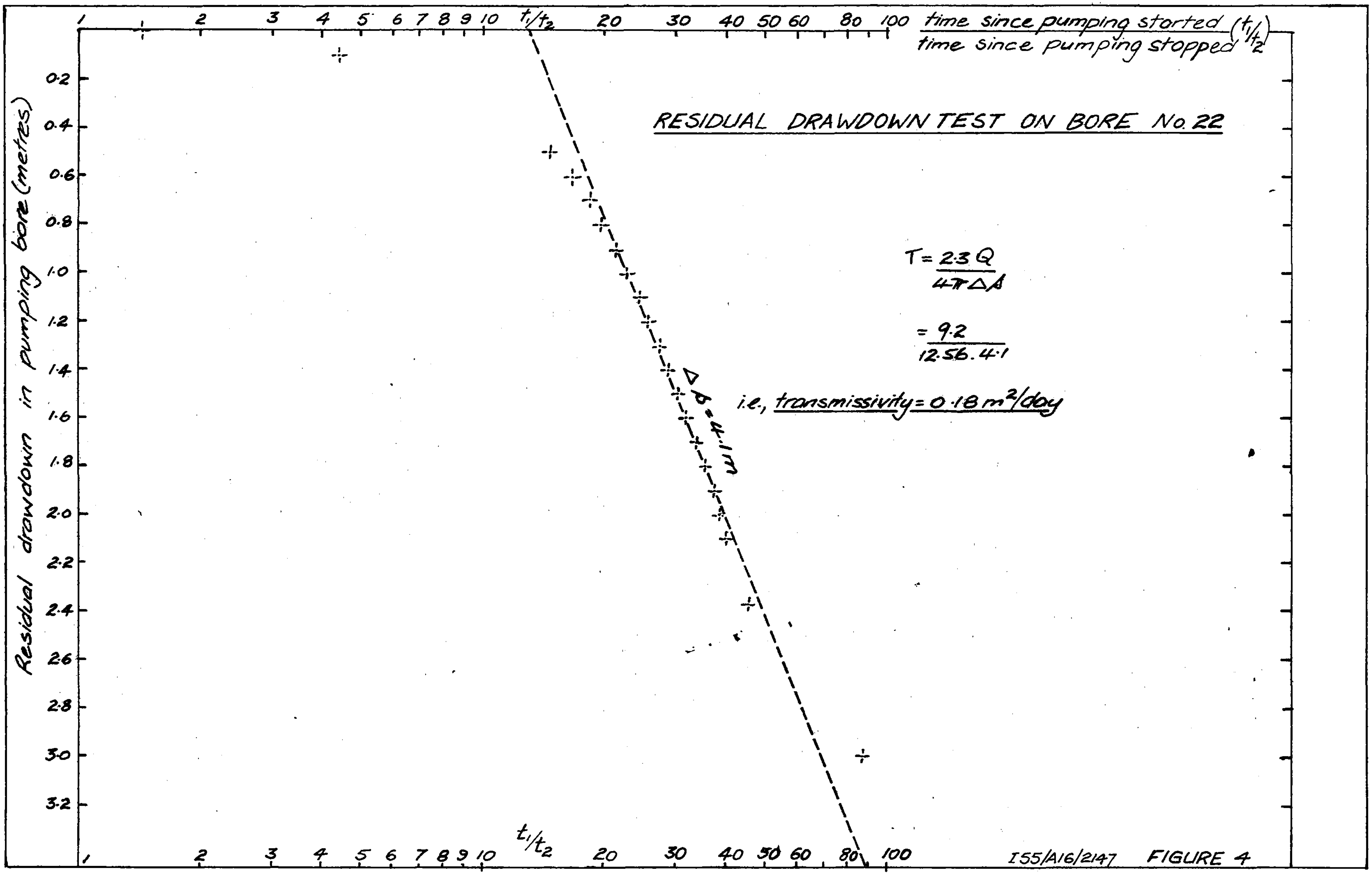
(iii) An instantaneous-head-change or 'slug' test was performed on the pumped bore (Fig. 5).

Results of these tests are summarised below:

TEST	TRANSMISSIVITY
Drawdown (observation bores)	Result invalid because the maximum drawdown was only 10 cm in one observation bore. Atmospheric pressure variations during test due to storm activity probably overprinted drawdown due to pumping.
Residual drawdown	0.18 m^3/day (see Fig. 4)
Instantaneous head change	0.12 m^3/day (see Fig. 5)

The mean transmissivity of 0.15 m^3/day was adopted as representative of the fractured-rock aquifer immediately surrounding the pumped bore.

To calculate the hydraulic conductivity of the fractures from the mean transmissivity, an assessment was made of the total fracture opening, as determined from drill-core fracture frequency and opening, from holes 21, 22 and 23. The fracture frequency was measured as 10 per metre, and the average drill core fracture opening was estimated to be about 0.25 mm. To check that the average drill core fracture opening is representative of the



RESIDUAL DRAWDOWN TEST ON BORE No. 22

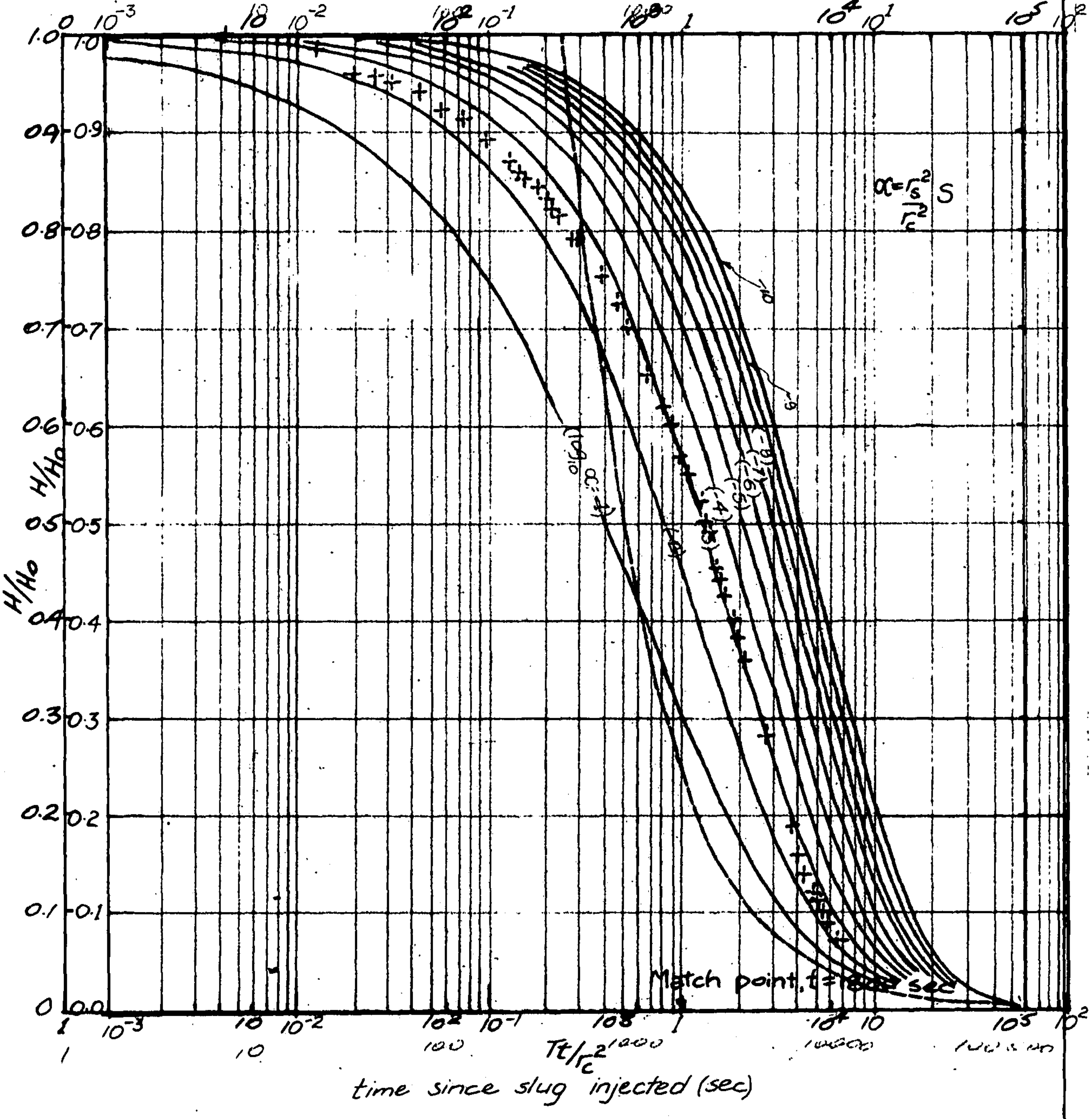
$$T = \frac{2.3Q}{4\pi\Delta s}$$

$$= \frac{9.2}{12.56 . 4.1}$$

i.e., transmissivity = 0.18 m²/day

I55/A16/2147 FIGURE 4

SLUG TEST AT WEST BELCONNEN FOR PROPOSED RADIOISOTOPE DISPOSAL



Type curves for instantaneous head change in a well of finite diameter

At match point, $\frac{Tt}{r_c^2} = 1.0$

$\therefore \quad T = \frac{r_c^2}{t}$

at match point, $t = 1800$ sec

radius of casing, $r_c = 5.0$ cm

i.e., $T = \frac{25}{1800}$

$= 0.139 \text{ cm}^2/\text{sec}$

i.e., <u>Transmissivity = 0.12 m²/day</u>

fracture opening in the rock mass, reference was made to published tables relating hydraulic conductivity to fracture frequency and fracture opening (Attewell & Farmer, Table 11.9, 1976; Hoek & Bray, Fig. 52, 1974). It was found that the estimate of fracture opening was consistent with measured hydraulic parameters (Appendix 2).

The horizontal groundwater-flow velocity was calculated by two methods which gave similar results. The first method was to calculate the mean hydraulic conductivity for the aquifer from the measured transmissivity and the saturated thickness of the aquifer that gave rise to the measured transmissivity. Thus,

$T = kb$ where $T = 0.15\ m^2/day$

and b, the saturated aquifer thickness = 7 m

$$\therefore\ k = \frac{0.15}{7}$$

$$= 0.023\ m/day.$$

The Darcy velocity, $V_D = ki$ where i, the hydraulic gradient = 0.014

$$= 0.023 \times 0.014$$

$$= 3.2 \times 10^{-4}\ m/day$$

Substituting this into the equation for mean pore velocity or apparent velocity, the rate of groundwater flow through the open fractures is obtained, i.e. $V_M = \frac{V_D}{\emptyset}$ where $\emptyset$, the effective porosity = 2.5×10^{-3}

$$= \frac{3.2 \times 10^{-4}}{2.5 \times 10^{-3}}$$

$$= 0.13\ m/day$$

Thus, the travel time for 1 km to the nearest probable discharge point would be 21 years.

The second method was to calculate the velocity of flow through the fractures. Using the relationship T = Kb, but substituting the total fracture opening for the aquifer thickness parameter, b, we derive

$$k(f) = \frac{T}{bNe} = \frac{0.15}{7x10x2.5x10^{-4}}$$

where T = transmissivity

N = fracture frequency

e = fracture opening

k(f) = hydraulic conductivity of fractures

Thus, the hydraulic conductivity of fractures is 9m/day.

Substituting the hydraulic conductivity for fractures into the equation for groundwater flow velocity, V = ki,

we get $V(f) = 9 \times 0.014 = 0.13$ m/day.

Thus, the velocity of flow through fractures is 0.13 m/day. The travel time for 1 km to nearest probable discharge point is then $= \frac{10^3}{0.13}$

= 7692 days

= 21 years

We conclude that the travel time for a pollutant in groundwater flow through the fractured-rock aquifer would be about 20 years.

INFILTRATION TESTS

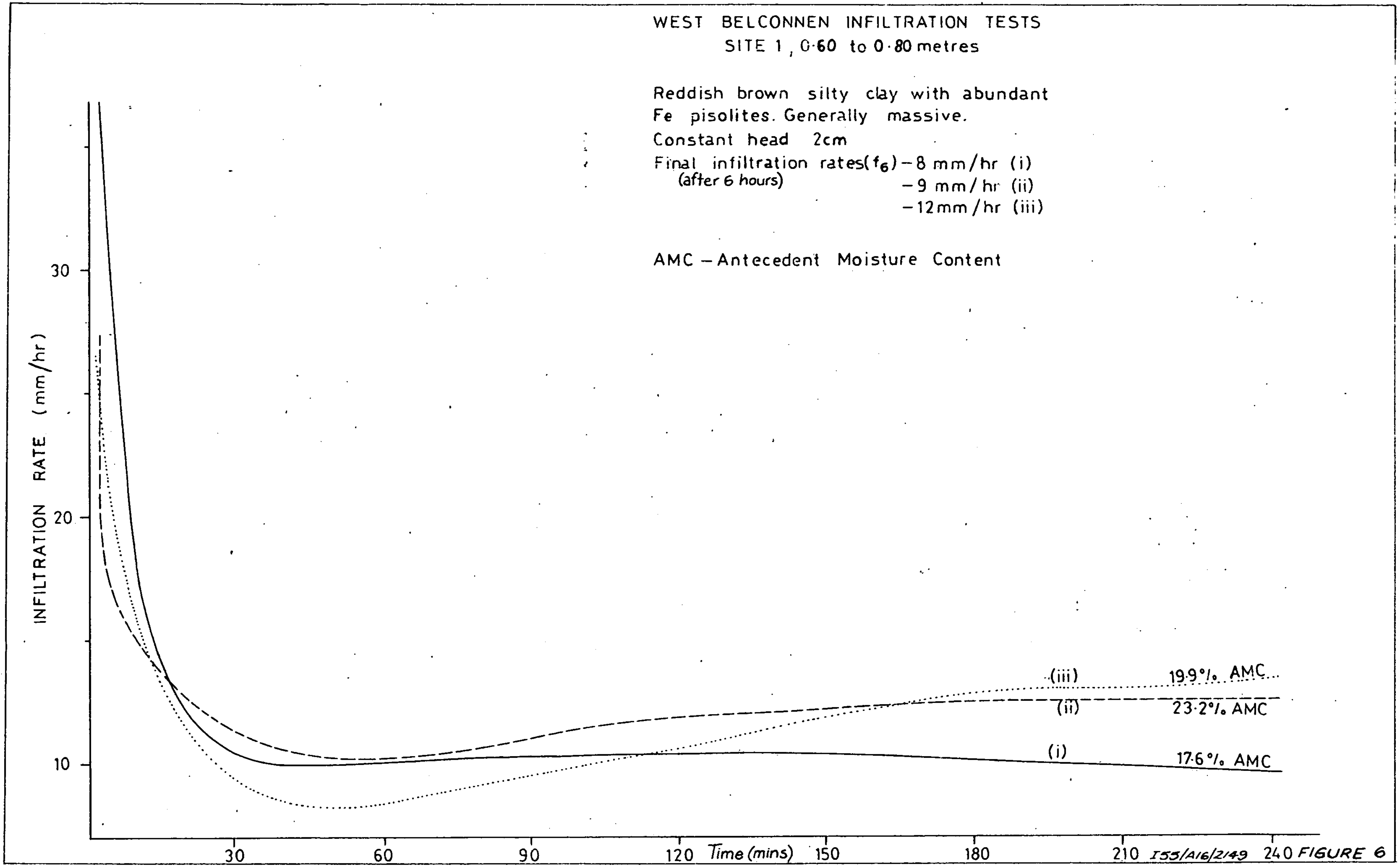
Infiltration testing of the soils was carried out at three different levels in a trench excavated by a backhoe. One dimensional infiltration capacities were determined by measuring the rate at which water flowed out of a permeameter in order to maintain a constant head of 1 to 2 cm in a 30 cm diameter ring. These tests were run for three different soil antecedent moisture contents.

The results for the first 4 hours are shown in Figures 6, 7 and 8. In site No. 1, the top of the ring was set at 60 cm below ground surface. The soil material was a reddish brown silty clay with numerous sesquioxide pisolites; structure was essentially massive with abundant, unconnected clay-coated megavoids. The antecedent moisture content for each run is shown on the respective curves (Fig. 6). An anomalous feature of the tests was the apparent increase in infiltration rate after about one hour following the initial sharp decline. It is thought that the mechanism responsible for this behaviour is that as the voids become progressively filled with water, entrapped air is compressed and temporarily restricts the progress of the wetting front. Apparently the delayed air expulsion takes between 30 minutes and 1½ hours, after which the measured infiltration rate settles down again and then decreases very slowly with time.

Site No. 2 was set at 85 cm below ground surface. The soil was similar in structure and texture to site 1, but the colour was yellow brown and clay content was slightly higher. At the lowest antecedent moisture content (Fig. 7) the phenomenon of delayed air expulsion was again experienced.

Site No. 3 (Fig. 8) was set at 3.5 m below ground surface in the pallid zone of the weathering profile. The clay content is generally lower than sites 1 and 2, with most of the clay occurring as clayskins around quartz grains and vein and plane fillings. Porosity of this horizon is higher (about 20%) with a significant proportion of planar voids. However, since most voids are clay-coated or filled, delayed air expulsion is also experienced in this horizon.

From extrapolation of the recession curves of the infiltration tests (Fig. 6), the apparent hydraulic conductivity after 24 hours between

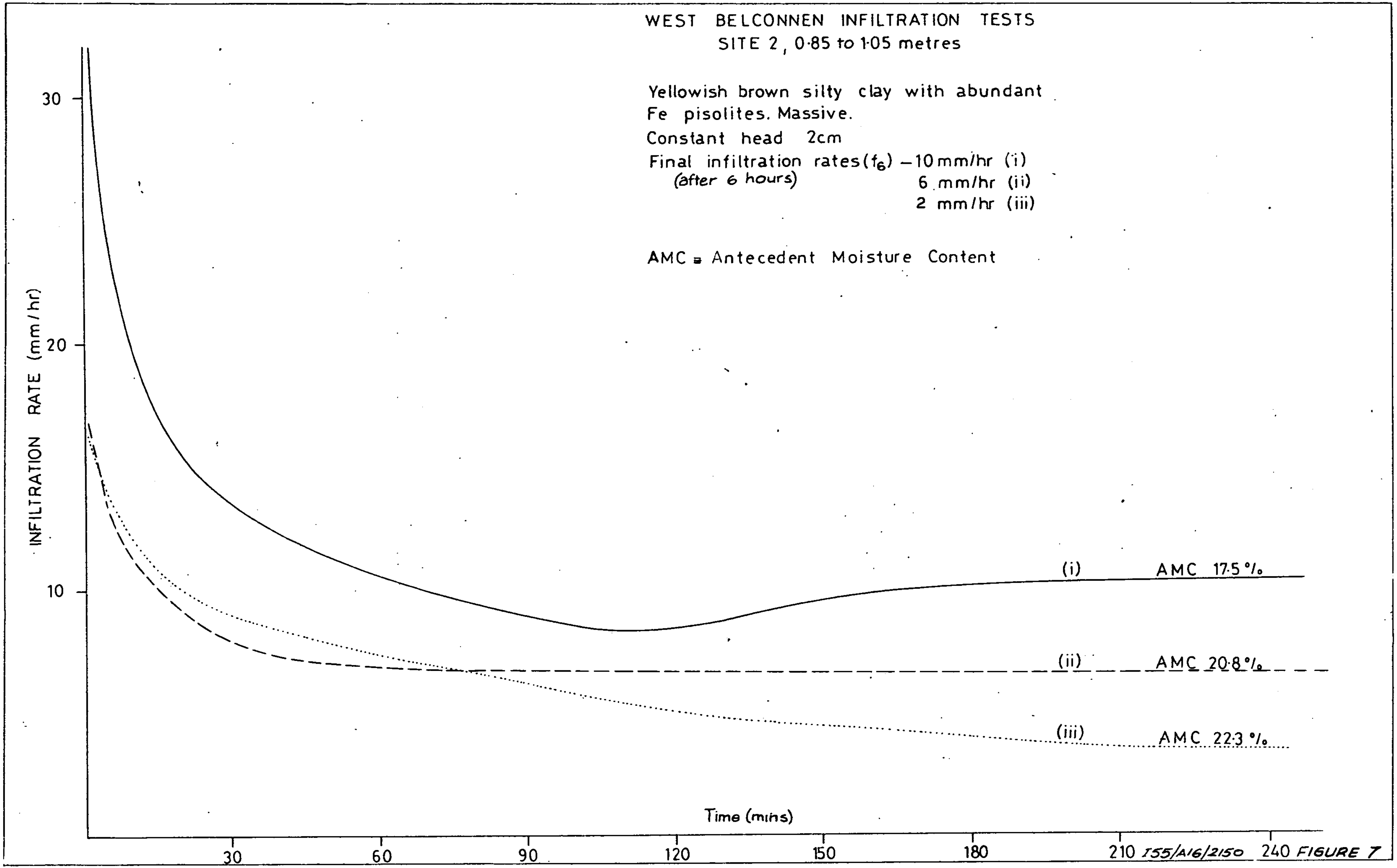


WEST BELCONNEN INFILTRATION TESTS
SITE 1, 0·60 to 0·80 metres

Reddish brown silty clay with abundant Fe pisolites. Generally massive.
Constant head 2cm
Final infiltration rates(f_6) – 8 mm/hr (i)
(after 6 hours) – 9 mm/hr (ii)
– 12mm/hr (iii)

AMC – Antecedent Moisture Content

I55/A16/2/49 FIGURE 6

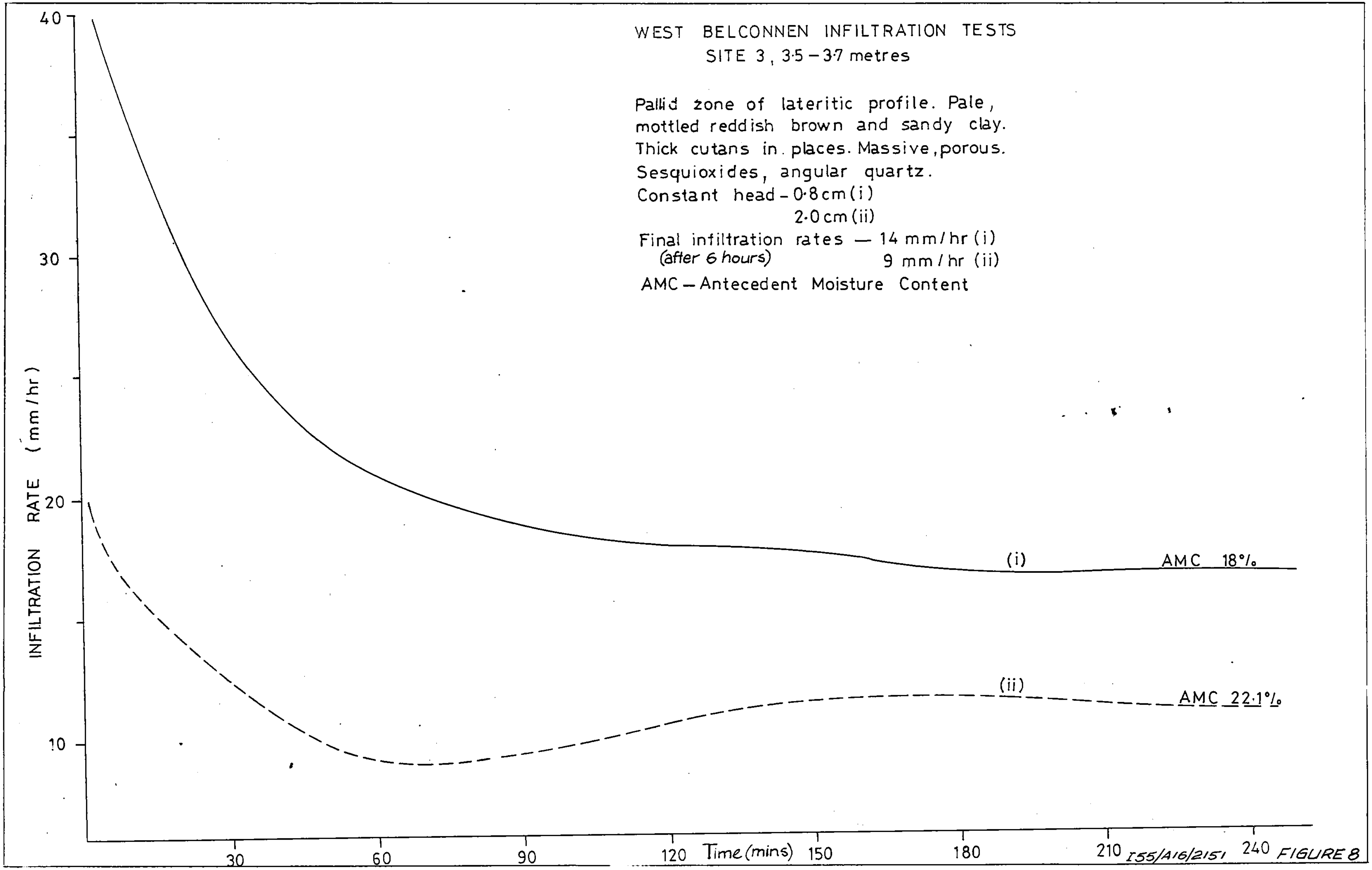


WEST BELCONNEN INFILTRATION TESTS
SITE 2, 0·85 to 1·05 metres

Yellowish brown silty clay with abundant Fe pisolites. Massive.
Constant head 2cm
Final infiltration rates(f_6) – 10 mm/hr (i)
(after 6 hours) 6 mm/hr (ii)
2 mm/hr (iii)

AMC = Antecedent Moisture Content

I55/A16/2150 FIGURE 7



WEST BELCONNEN INFILTRATION TESTS
SITE 3, 3·5 – 3·7 metres

Pallid zone of lateritic profile. Pale, mottled reddish brown and sandy clay. Thick cutans in places. Massive, porous. Sesquioxides, angular quartz.

Constant head – 0·8 cm (i)
2·0 cm (ii)

Final infiltration rates — 14 mm/hr (i)
(after 6 hours) 9 mm/hr (ii)

AMC – Antecedent Moisture Content

I55/A16/2151 *FIGURE 8*

60 and 80 cm varies from 0.03 m/day to 0.05 m/day, depending upon initial moisture content. From 85 cm to 105 cm (Fig. 7) the range is 0.001 m/day to 0.02 m/day, and from 3.5 m to 3.7 m (Fig. 8) the range is 0.10 m/day to 0.17 m/day.

Two infiltration tests were made at each level and the results varied by as much as 60%. This is attributed to the variability of the soils over short distances rather than any shortcomings in the technique. It should be noted that constant head tests over-estimate infiltration capacity from natural rainfall.

From the above results a minimum admittance time of about 14 days is required for a slug of water to travel from the ground surface to a static groundwater store at 12 m.

DYE-TRACING EXPERIMENT

A tracing experiment using a fluorescent dye, Rhodamine WT, is being undertaken in conjunction with Centre for Resource and Environmental Studies, Australian National University. About 400 gms of Rhodamine WT were injected into bore 22 on 2 May 1978 and the travel time to observation bores is being monitored. At the time of writing (7 August 1978) no dye had been observed in the closest observation bore 30 m away. The concentration of dye in the input hole is now about 400 micrograms per litre representing only a small fraction of the original dye input. The experiment will be continued until significant results are obtained, in an attempt to refine the estimate of pollution velocities.

CATION EXCHANGE CAPACITY

The cation exchange capacity of soil and rock in drillcore samples has been analysed by the CSIRO Division of Soils, Canberra. The results are given in Appendix 3, and schematically in a cross section of the site in Figure 9. The analyses show that the clayey soils near the top of the soil profile have a cation exchange capacity of 10-20 milliequivalents percent, whereas the weathered porphyry has a cation exchange capacity of about 5 milliequivalents percent. The clayey soils have a greater capacity for the ionic absorption of, and for ionic exchange with, pollutants than the weathered porphyry. Cation exchange capacity may not be relevant for the porphyry as pollutants would travel mainly in fractures in the porphyry.

HYDROCHEMISTRY

One full chemical analysis has been made of water from each of five monitored piezometers at the West Belconnen Landfill Site (Fig. 1), which includes the proposed radioactive-waste disposal site. The analyses, carried out by AMDEL (Jacobson, 1978) show a range of similar characteristics when their ionic proportions are plotted (see Fig. 10).

The analysis from Bore 9 (6.1 m deep) shows low ionic concentrations, and probably intersected perched groundwater in colluvial materials; sodium chloride is virtually the only salt present and is in a very low concentration. Water from Bore 2 (4.2 m deep) appears to have been derived from exclusively fractured-rock aquifers, and sodium chloride and sodium bicarbonate are present in relatively high concentrations (Table 1). Bores 8 and 22 (6.4 and 20 m deep respectively) appear to contain groundwater

WEST BELCONNEN RADIOACTIVE WASTE DISPOSAL SITE
CATION EXCHANGE CAPACITY (me %)
OF DRILLHOLE SAMPLES

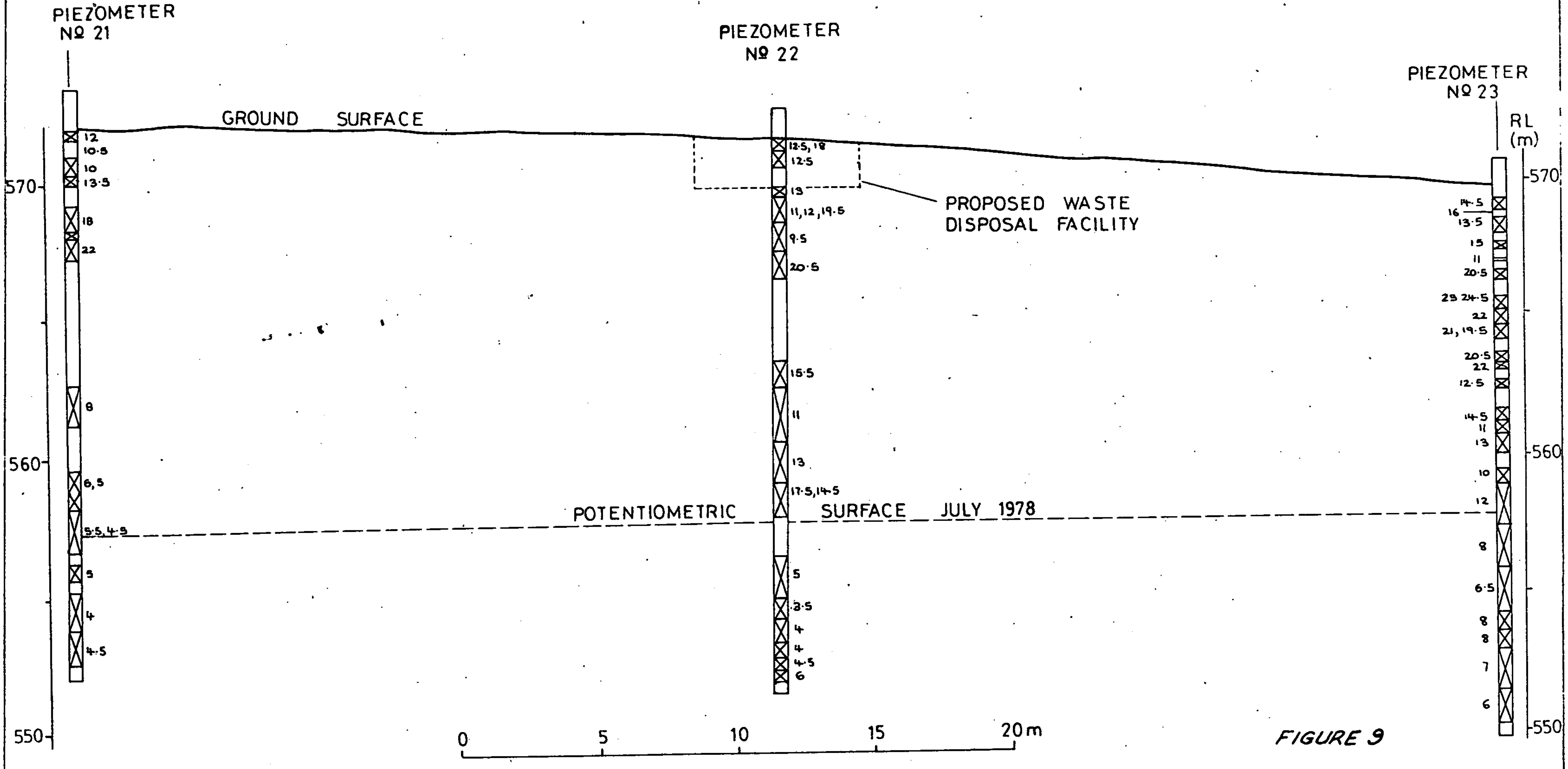


FIGURE 9

ANALYSES BY CSIRO DIVISION OF SOILS, APRIL 1978 I55/A16/2152 derived from both deeper fractured-rock aquifers and from shallow, perched aquifers in soil. Bore 12 (6.1 m deep) appears to have intersected almost wholly perched groundwater.

Bores 2, 8 and 10 have flowed at times during the period that they have been monitored. This is significant because they are close to seepage areas that have been attributed to groundwater from beneath the ridge that includes the radioactive disposal site.

Table 1 shows the theoretical concentrations of salts that are in solution in groundwater. The water sampled from Bore 22 at the proposed disposal site, apart from being quite saline, has a theoretical concentration of 100 mg/l of $MgCl_2$, which indicates that the groundwater would be slightly corrosive. The earlier proposal of disposing of wastes at depths of about 6 m in auger holes could have brought the containers into contact with aggressive groundwater at times of high phreatic surface.

TABLE 1 - COMPONENT SALTS OF GROUNDWATER IN FRACTURED-ROCK AQUIFERS AT DISPOSAL SITE.

	Bore 2 (mg/l)	Bore 8 (mg/l)	Bore 22 (mg/l)
$Ca(HCO_3)_2$	332	446	398
$Mg(HCO_3)_2$	256	139	95
$MgSO_4$	-	163	104
$MgCl_2$	-	24	101
NaCl	522	327	352
(K,Na) NO_3	-	95	54
$NaHCO_3$	571	-	-
Na_2SO_4	72	-	-
calculated T.D.S.	1334	969	910
pH	7.8	7.8	7.0

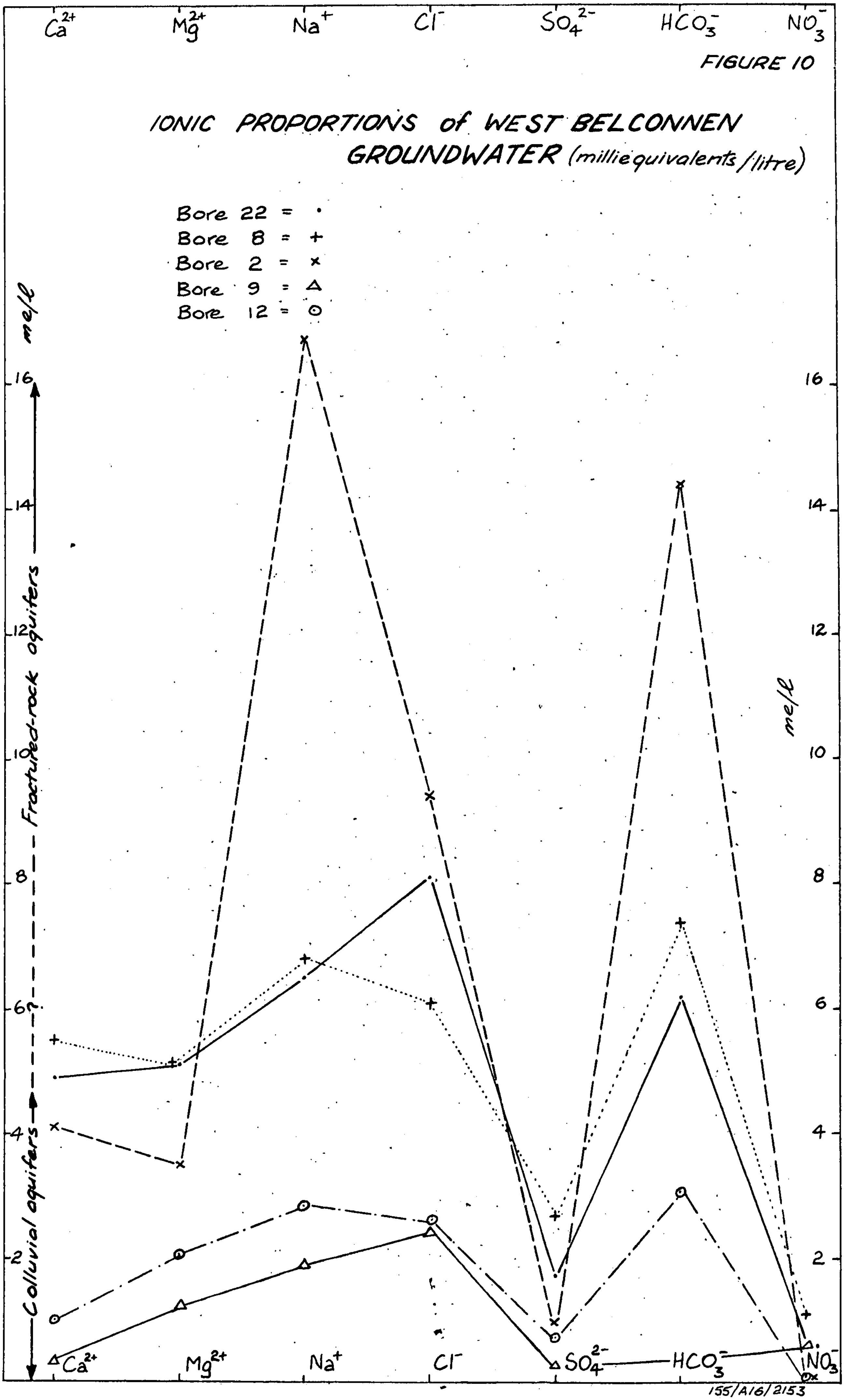


FIGURE 10

IONIC PROPORTIONS of WEST BELCONNEN GROUNDWATER (milliequivalents/litre)

155/A16/2153

BURIAL OF WASTES

The original proposal by the consultants, L.T. Frazer & Associates, was to bury radioactive wastes in large diameter auger holes at a depth of 6-7 m. Preliminary results of this investigation have led to a modification of the design, and it is now proposed that the wastes be stored in asbestos-cement cylinders extending from 1.5 m below ground surface to 2.5 m above it. The space surrounding the cylinders will be filled and the fill material will be waterproofed.

In the worst possible case of a container starting to leak immediately after disposal, then the pollution travel time is expected to be about 20 years, although the amount of pollutant will be diluted by an unknown factor. For complete radioactive decay, the material should be stored for 10 times its half life, by which time 0.1% of the original activity remains. At the West Belconnen site this means that material with a half life of up to 2 years could be buried in the ground with the expectation that decay would be virtually complete within the estimated travel time through the groundwater system.

The measures incorporated in the design, such as waterproofing the compound and the disposal of containers in cased holes, will delay movement of pollutants into the ground. The disposal of radioactive waste in stainless steel drums would introduce an additional major delay into the system. Drums containing liquid wastes should be packed in an absorbent material such as Kieselguhr. With these provisions, material with a half life of 5 years could be safely disposed of at this site.

CONCLUSIONS

The most significant delay in the passage of infiltrating water through the disposal site to the nearest discharge point, takes place in the saturated zone, i.e. within the fractured-rock aquifer system. The travel time is estimated at about 20 years for a distance of one kilometre. The infiltration component of the travel time is relatively insignificant, i.e. a delay of about 14 days. However, owing to the greater ionic adsorption potential per metre thickness of clay minerals in the unsaturated zone than in the fractured rock, the burial of wastes at a higher level in the unsaturated zone is preferred.

The study has not been sufficiently detailed to identify possible high transmissivity zones between the proposed disposal/storage site and likely discharge points. It is expected that the results of the dye test will show whether or not a fracture-zone with shorter groundwater travel times exists.

The measures incorporated in the design of the disposal system are expected to introduce a significant delay into the travel time of a pollutant. It is expected that material with a half life of 5 years could be safely disposed of at the site.

REFERENCES

ATTEWELL, P.G., & FARMER, I.W., 1976 - Principles of engineering geology. Chapman & Hall, London.

FRAZER, L.T. & ASSOCIATES PTY LTD, 1977 - Disposal of radioactive wastes in the A.C.T. Report prepared for the National Capital Development Commission, Canberra.

HOEK, E., & BRAY, J.W., 1974 - Rock slope engineering. Institute of Mining and Metallurgy, London.

JACOBSON, G., 1978 - The establishment of a leachate monitoring system at the West Belconnen landfill site, A.C.T., 1976-7. Bureau of Mineral Resources, Australia - Record 1978/

LANG, P.A., & PURCELL, D.C., 1976 - Geological investigations for the Ginninderra sewer tunnel, Belconnen. Bureau of Mineral Resources, Australia - Record 1976/44.

VANDEN BROEK, P.H., 1971 - Geological evaluation of the proposed Belconnen refuse disposal area, Canberra City district, A.C.T. Bureau of Mineral Resources, Australia - Record 1971/132.

APPENDIX 1

LOGS OF DRILL HOLES

BUREAU OF MINERAL RESOURCES, GEOLOGY & GEOPHYSICS

Geological Log of Auger Hole

Sheet 1 of 3

Project: West Belconnen Isotope Disposal Site Hole: 21 Date: 22-2-78 Logged by: P.D.H.

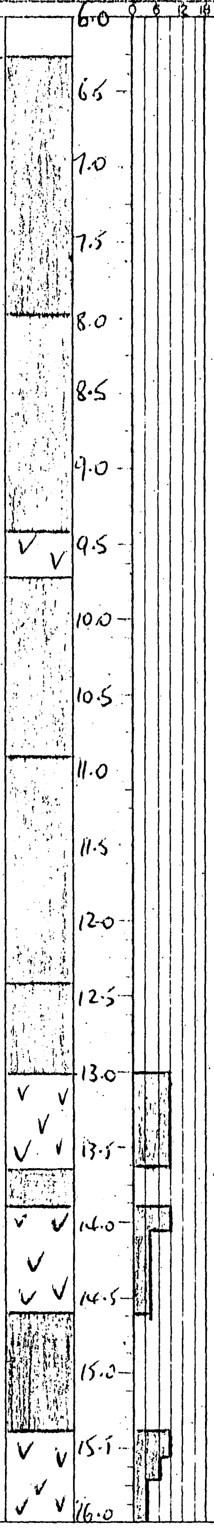
DEPTH (metres)	LOG	ENGINEERING SOILS DESCRIPTION (Text, plast)	Unified symbol	COLOUR Pale or dark Comb. col. R-B, Y-B	Moisture D, M>=<PL, W	Permeability (k) / Groundwater Observations	Structure Massive Porous Crumb etc.		Core Recovery (%)	GEOLOGICAL PEDOLOGICAL DESCRIPTION [Eolian Residual Alluvial Colluvial Decomposed rock Horizon A, B, C Buried soil]
		no core recovery plastic bag full of cuttings sampled from auger flights		pale orange	D		holle			fill & C.W. rock
1.0		silty, lean clayey fine sand	SC	pale yellowish brown	D	K ≈ 1.0 m/d	" (est)			in situ - weathered colluvium
		fine gravelly, sandy stiff clay	CL	mottled grey, yellow & red brown		K<0.1 m/d (est)	v. dense			
2.0		lean clayey sand	SC	mottled cream + pale orange	D	K<0.1 m/d	(est) massive friable			H.W. dacite 'C' horizon
3.0		well graded lean clayey sand and fine gravel	SC	"	D		"			"
		as above	SC	"	D		"			"
4.0										
5.0										
6.0		← auger refusal								

Driller: L. Jarvis Stewart Bros. Drill type: GEMCO ▓ No recovery Not sampled Checked by: P.D.H.

BUREAU OF MINERAL RESOURCES,
GEOLOGY & GEOPHYSICS
GEOLOGICAL LOG OF DRILL HOLE

PROJECT West Belconnen Isotope Disposal Site
LOCATION
ANGLE FROM HORIZONTAL (θ) 90° DIRECTION
COORDINATES R.L. OF COLLAR

HOLE NO 21
SHEET 2 OF 3



Rock Type and Degree of Weathering	Description Lithology, colour, strength, etc.	RQD	Structural Log	Structures Joints, veins, seams, fault, etc.	Water Level
	start of diamond drilling →				
H.W. to E.W. dacite	no core recovery - returning drilling water c̄ quartz, biotite + weathered felspars.				
	as above				
H.W. dacite	well graded sand quartz + biotite xtals ~2mm, feldspars up to 5mm across.				
M.W. dacite	only 2cm of core recovered in this interval				
				S.W.L. 28·2·78 —12·77m (joints)	▼ (B.T
H.W. rhyodacite	coarse-grained, equigranular dacite or rhyodacite - grainsize 2-4mm. c̄ biotite, kaolinised felspars, quartz (~20%), + rare hornblende to 10mm.			Fractures closely spaced at 2-5 cm - most are horizontal, some are sub-vertical. Some joints have thin red clay seams. Most common joint is subhorizontal: also a conjugate set at 30° + 60°. Joint surfaces are rough c̄ only traces of red clay.	
H.W. rh'd. M.W. rh'd.	as above			as above	

Drill type GOMCO
Feed
Core barrel type NLMC-3 tube
Driller L. Jarvis (Stewarts)
Commenced 22·2·78
Completed
Logged by P.D. HOHNEN
M(Pf) 221

Notes

Fracture Log — Number of fractures per 25cm of core. Zones of core loss blacked in.

Bedding & Joint Planes — Angles are measured relative to a plane normal to the core axis.

Water Level Measurements — ▼ Level when hole in progress at specified depth
▽ Level in completed hole on specified date.

Checked by

Core Photograph Negative No.		
Depth(m)	Black & White	Colour

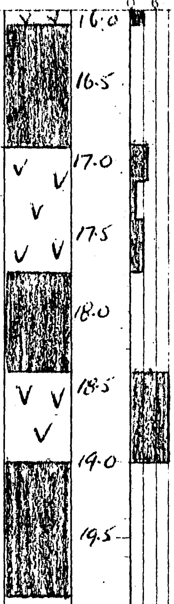
155/A16/

BUREAU OF MINERAL RESOURCES,
GEOLOGY & GEOPHYSICS

GEOLOGICAL LOG OF DRILL HOLE

PROJECT WEST BELCONNEN ISOTOPE DISPOSAL SITE
LOCATION
ANGLE FROM HORIZONTAL (θ) 90°
DIRECTION
COORDINATES
R.L. OF COLLAR

HOLE NO 21
SHEET 3 OF 3



Rock Type and Degree of Weathering	Description Lithology, colour, strength, etc.	Casing	Graphic Log	Depth and size of Core	RQD	Structural Log	Structures Joints, veins, seams, fault, etc.	Water Level
				16.0			Joints dip at 0°, 30° & 60°. Traces red clay.	
				16.5				
H.W. to M.W. rhyodacite				17.0			"	
				17.5				
				18.0				
5cm H.W., rest M.W. rhyodacite				18.5			"	
				19.0			Zone of H.W., friable rock for ~15cm at ~19.4m	
				19.5				
	END OF HOLE.			20.0			21m. of 50mm I.D. PVC casing installed	

Drill type GEMCO
Feed HYDRAULIC
Core barrel type NMLC
Driller L. Jarvis
Commenced 22.2.78
Completed " " "
Logged by P.D. HOHNEN

M(Pf) 221

Notes

Fracture Log – Number of fractures per 25cm of core. Zones of core loss blocked in.

Bedding & Joint Planes – Angles are measured relative to a plane normal to the core axis.

Water Level Measurements – ▼ Level when hole in progress at specified depth
▽ Level in completed hole on specified date.

Checked by

Core Photograph Negative No.

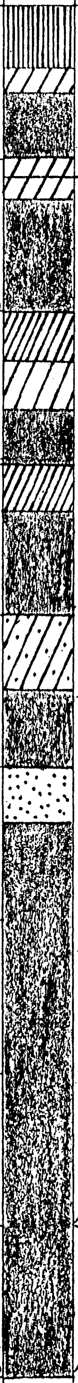
Depth(m)	Black & White	Colour

155/A16/

BUREAU OF MINERAL RESOURCES,
GEOLOGY & GEOPHYSICS

Geological Log of Auger Hole

Project: West Belconnen Isotope Disposal Site. Hole: 22 Date: 23.2.78 Logged by: P.D.H.



DEPTH (metres)	LOG	ENGINEERING SOILS DESCRIPTION (Text, plast.)	Unified symbol	COLOUR Pale or dark Comb. col. R–B, Y–B	Moisture D.M.>PL.W	Estimated Permeability (k) / Groundwater Observations	Structure Massive Porous Crumb etc.	Core Recovery (%)	GEOLOGICAL PEDOLOGICAL DESCRIPTION [Eolian Residual Alluvial Colluvial Decomposed rock Horizon A, B, C Buried soil]
		fine sandy silt; friable c̄ no clay.	ML	medium yellowish brown	D	high permeability	P		Aeolian
		v. stiff heavy clay c̄ abundant pisolites 2-3mm across.		dark red brown	D	very low k	M		
1.0		sandy heavy clay	CH	mottled red, orange & grey	D	" " "			
2.0		lean clay	CL	pale buff c̄ orange & red mottles.	D	low k			
		stiff, heavy clay c̄ pisolites	CH	mottled pale grey, orange & red.	D	v. low k			
3.0		lean sandy clay - lower 8cm stiff heavy clay	CL	fawn c̄ grey & red streaks & mottles → orange & grey mottled	sl. M	low k			
4.0		well graded sand c̄ some lean clay	SC	pale orange to buff, flecked c̄ cream feldspars		low to mod. k.			'c' horizon (extremely weathered porphyry)
5.0		well graded sand c̄ v. little lean clay	SW	orange, flecked c̄ cream		moderate k.	friable		"
6.0									
7.0		About 100 g of H.W. porphyry recovered							
8.0		10cm length of core recovered (E.W. porphyry)							
9.0		← 'Gemco' power-auger refusal.							

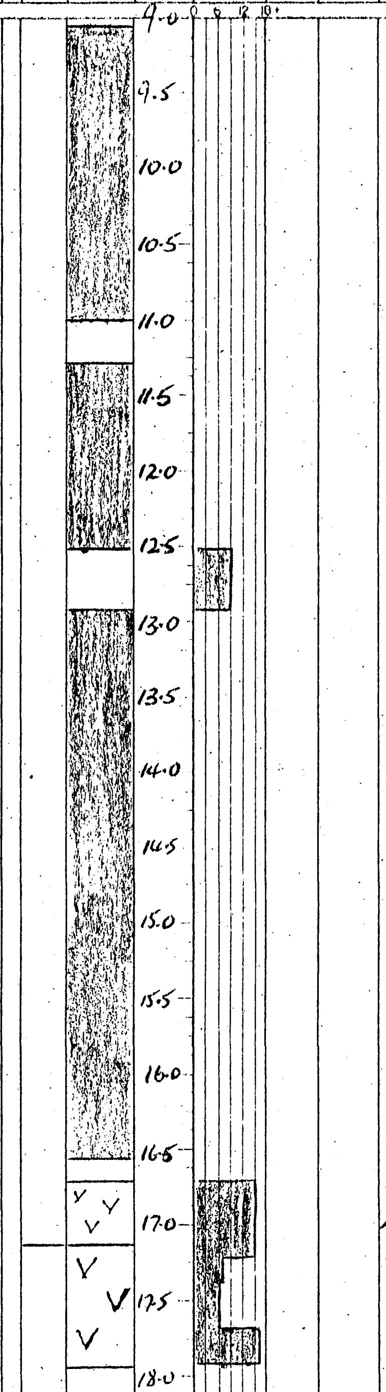
Driller L. Jarvis Drill type GEMCO ■ Not sampled = no core recovery Checked by: P.D.H.

BUREAU OF MINERAL RESOURCES,
GEOLOGY & GEOPHYSICS

GEOLOGICAL LOG OF DRILL HOLE

PROJECT WEST BELCONNEN ISOTOPE DISPOSAL
LOCATION BELCONNEN LANDFILL
ANGLE FROM HORIZONTAL (θ) 90° DIRECTION
COORDINATES R.L. OF COLLAR

HOLE NO 22
SHEET 2 OF 2



Rock Type and Degree of Weathering	Description Lithology, colour, strength, etc.	Structures Joints, veins, seams, fault, etc.	Water Level
C.W. dacite	start of diamond drilling.		▼ S. 28.2.
C.W.-H.W. dacite			▼ S.W. 30.5.78
c.w.-H.W. dacite		clay-filled joints dipping 60°.	
M.W. medium to fine grained dacite followed by coarse-grained, M.W. dacite at 17.1 m.		most joints are normal to the core axis; fewer occur at 30° to axis: one joint parallel to axis for ½ length of run. Top 44 cm of run is closely jointed at <2cm intervals - some fracturing due to drilling.	

Drill type GEMCO
Feed
Core barrel type N.L.M.C.
Driller L. JARVIS
Commenced
Completed
Logged by P.D.H.
M(PI) 221

Notes
Fracture Log – Number of fractures per 25cm of core. Zones of core loss blacked in.
Bedding & Joint Planes – Angles are measured relative to a plane normal to the core axis.
Water Level Measurements – ▼ *Level when hole in progress at specified depth*
▽ *Level in completed hole on specified date.*
Checked by

Core Photograph Negative No.

Depth(m)	Black & White	Colour

155/A16/

BUREAU OF MINERAL RESOURCES,
GEOLOGY & GEOPHYSICS

Geological Log of Auger Hole

Sheet 1 of 4

Project: West Belconnen Radioactive Isotope Disposal Site   Hole: 23   Date: 28.2.78   Logged by: P.D.H.

DEPTH (metres)	LOG	ENGINEERING SOILS DESCRIPTION (Text, plast)	Unified symbol	COLOUR Pale or dark Comb. col. R–B, Y–B	Moisture D.M.>< PL.W	Permeability (k) / Groundwater Observations	Structure Massive Porous Crumb etc.		Core Recovery (%)	GEOLOGICAL PEDOLOGICAL DESCRIPTION [Eolian Residual Alluvial Colluvial Decomposed rock Horizon A, B, C Buried soil]
0.35	⁞	loose silty and very fine sandy topsoil	SM	pale yellowish brown			Porous			windblown silt + fine sand
0.5 1.0	▨ ▓	V. stiff dense clay containing scattered pisolites to 0.6cm	CL	reddish brown grading down to dark brownish red.						B₀ horizon
	▨	pisolitic dense, stiff clay	CL	dark red						
1.5 2.0	▨ ▓	fine gravelly, slightly Sandy lean clay	CL	Irregularly mottled, pale grey, red & predom. yellow c̄ much MnO_2 staining.	V. Sl. moist		Crumbles readily on handling			B₁ horizon
2.5 3.0	▨ ▓	fine sandy lean clay with pisolites of Fe + Mn and small qz pebbles.	CL	predom. pale grey with scattered yellow + red streaks and mottles	V. Sl. moist		friable at top, sl. stiff + cohesive at bottom (prob. compacted by auger)			
3.5 4.0	▨ ▓	v. stiff Sandy lean clay grading to very highly compacted clay.	CL	predom. yellow c̄ grey mottles at top; pale grey c̄ yellow & red streaks in lower part.	Sl. moist		friable at top, very compact below.			
	▨	Sandy, v. stiff clay	CL	mottled grey + yellow	M					
4.5 5.0	▓	recovery of cuttings only of clayey sand (as loose crumbs, (SC)		pale orange						

Driller: L. Jarvis   Drill type: Gemco   ▓ No recovery Not sampled   Checked by: P.D.H.

BUREAU OF MINERAL RESOURCES,
GEOLOGY & GEOPHYSICS

Geological Log of Auger Hole

Sheet 2 of 4

Project: West Belconnen Radioactive Isotope Disposal Site Hole: 23 Date: 28-2-78 Logged by: P.D.H.

DEPTH (metres)	LOG	ENGINEERING SOILS DESCRIPTION (Text, plast)	Unified symbol	COLOUR Pale or dark Comb. col. R-B, Y-B	Moisture D. M> < PLW	Permeability (k) / Groundwater Observations	Massive Porous Crumb etc. Structure		Core Recovery (%)	GEOLOGICAL PEDOLOGICAL DESCRIPTION [Eolian Residual Alluvial Colluvial Decomposed Rock Horizon A, B, C Buried soil]
5.0	▨	lean clayey well-graded medium to fine sand	SC			pale orange with cream flecks (kaolinised felspars)	porous & crumbly when dry			'c' horizon
5.5	░									
6.0	▨	lean sandy clay grading down to lean clayey sand	CL		V.M	Sl. brownish yellow	low density			band of C.W. rock in 'c' horizon.
	▨	well graded very slightly clayey sand. decomposed dacite.	SC		sl.H	Orange c̄ cream flecks	friable			'c' horizon
6.5	░									
7.0	░	v. sl. clayey, well-graded fine to coarse sand. decomposed dacite	SW		sl.M	pale brownish orange/yellow	friable			C.W. dacite 'c' horizon
7.5	░	no recovery of core: cuttings sampled for ion adsorption								
8.0	░									
8.5	░									
9.0		← Power auger refusal								

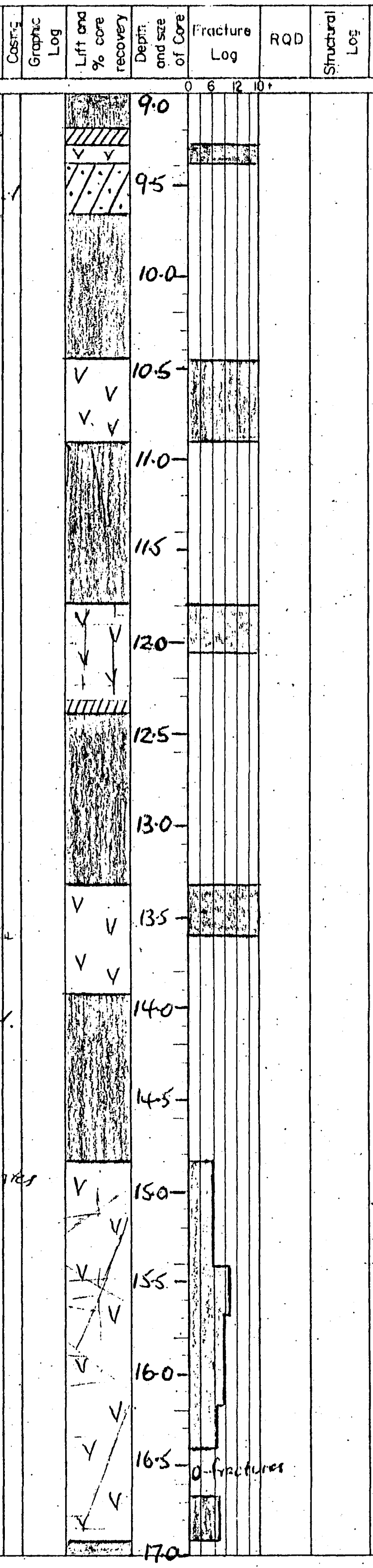
Driller: L. Jarvis Drill type: Gemco ▓ No recovery Not sampled Checked by: P.D.H.

BUREAU OF MINERAL RESOURCES, GEOLOGY & GEOPHYSICS

GEOLOGICAL LOG OF DRILL HOLE

PROJECT West Belconnen Isotope Disposal Site
LOCATION " "
ANGLE FROM HORIZONTAL (θ) 90° DIRECTION
COORDINATES R.L. OF COLLAR

HOLE NO 23
SHEET 3 OF 4



Rock Type and Degree of Weathering	Description Lithology, colour, strength, etc.	Structures Joints, veins, seams, fault, etc.
E.W. H.W. dacite E.W.	Sl. brownish yellow, lean, fine sandy clay. Coarse dacite - crumbles readily to coarse sand. lean clayey, well-graded sand. (brownish orange c̄ white flecks).	closely jointed and disaggregated. Joints at 0° & 90° to core axis.
H.W. dacite	dacite crumbles readily in hand to clayey, well-graded fine to coarse sand.	very closely jointed - disaggregates on gentle handling.
M.W. dacite grading to H.W., then E.W. for bottom 8 cm.	H.W. dacite which has disaggregated to well-graded sand. last 8 cm is lean, sandy clay.	M.W. dacite, very closely fractured in two directions (90° + 0° to core axis).
M.W. dacite H.W. - E.W. dacite	disaggregates on gentle handling to well-graded, clayey, fine to coarse sand.	closely fractured as above - MnO_2 - coated joints.
M.W. to H.W. dacite.	Some core disaggregates readily to clayey, well-graded sand.	closely jointed at 70° to 90° to axis. Disaggregates by moderate handling only locally.
M.W. dacite (100% recovery)	Grainsize of dacite 1 to 5 mm. Felspars break c̄ difficulty under HB pencil point. Core breaks more easily along joints than across unjointed core.	joints mostly at 75-90° to axis. Core breaks readily - only some breaks are along joints. Joints at 45° + 30° are also quite common. Most joints are smooth, have undulations of 0.5 cm over 5 cm & are MnO_2 coated.

Drill type GEMCO
Feed HYD.
Core barrel type NLMC-3 tube
Driller Stewart Bros. L. Jarvis
Commenced 1.3.78
Completed 1.3.78
Logged by P.D. HOHNEN

Notes

Fracture Log – Number of fractures per 25cm of core. Zones of core loss blacked in.

Bedding & Joint Planes – Angles are measured relative to a plane normal to the core axis.

Water Level Measurements – ▼ Level when hole in progress at specified depth

▽ Level in completed hole on specified date.

Checked by

Core Photograph Negative No.		
Depth(m)	Black & White	Colour

M(Pf) 221

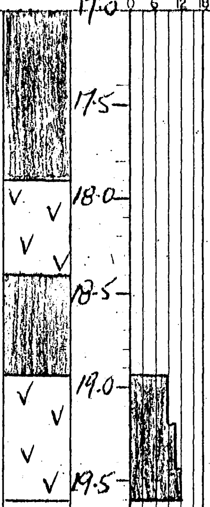
155/A16/

BUREAU OF MINERAL RESOURCES,
GEOLOGY & GEOPHYSICS

GEOLOGICAL LOG OF DRILL HOLE

PROJECT West Belconnen Isotope Disposal Site
LOCATION " "
ANGLE FROM HORIZONTAL (θ) 90° DIRECTION
COORDINATES R.L. OF COLLAR

HOLE NO 23
SHEET 4 OF 4



Rock Type and Degree of Weathering	Description Lithology, colour, strength, etc.	Casing	Graphic Log	Lift and % core recovery	Depth and size of Core	Fracture Log	RQD	Structural Log	Structures Joints, veins, seams, fault, etc.	Water Level
H.W. dacite	disaggregates on moderately gentle handling to well-graded, clayey, fine to coarse sand.				18.0				too weathered to log fractures - though these are probably closely spaced.	
M.W. dacite	apart from open joints (see fract. log) parts along v. tight, MnO2 stained, closely-spaced joints. Narrow zones of H.W. dacite				19.0				joints at 90° to core common, also 2 joint orientations at 20° to axis - these have strike diff. of 70°. Fewer joints at 45°.	

Drill type GEMCO
Feed HYD.
Core barrel type NMLC
Driller L. JARVIS
Commenced 1.3.78
Completed "
Logged by P.D. HOHNEN
M(Pf) 221

Notes

Fracture Log – *Number of fractures per 25cm of core. Zones of core loss blacked in.*

Bedding & Joint Planes – *Angles are measured relative to a plane normal to the core axis.*

Water Level Measurements – ▼ *Level when hole in progress at specified depth*

▽ † *Level in completed hole on specified date.*

Checked by

Core Photograph Negative No.		
Depth(m)	Black & White	Colour

155/A16/

APPENDIX 2

ESTIMATION OF FRACTURE OPENING

ESTIMATION OF FRACTURE OPENING

It is very difficult to assess the fracture opening in a rock mass from the joint separation evident in drill core, even when 100% recovery is achieved. To check that the assessed fracture opening was consistent with the assessed transmissivity, reference was made to tables relating hydraulic conductivity, fracture frequency and fracture opening (Attewell & Farmer, table 11.9, 1976; Hoek and Bray, Fig. 52, 1974 (Fig.52). By applying measured fracture frequency and various values of fracture opening to the tables, a range of values of hydraulic conductivity were obtained. These were checked by using the same values of fracture frequency and opening to calculate hydraulic conductivity by an iterative procedure, using the relationship $T = kb$, ... where k is the hydraulic conductivity, b is the sum of all fracture openings through the saturated thickness of the aquifer, and T has been determined empirically.

In this relationship the aquifer thickness, b, is a function of fracture opening (e), fracture frequency (N), and saturated thickness of the aquifer (b'), i.e.

$b = e.\ N\ .\ b'$ .... where N and b' are known, and b and e are unknown.

From Attewell and Farmer (1976) table 11.9, hydraulic conductivity (k), is proportional to the fracture frequency and the fracture opening,

i.e., $k \sim e.\ N$

and for any particular fracture opening, e,

$k = k'.e.N$ .... where k' is a constant

i.e., $k' = \dfrac{k}{e.N}$

Substituting this into the equation relating transmissivity, hydraulic conductivity and aquifer thickness we get:

$$T = k'.e.N.e.N.b'$$

$$\text{or} \quad e^{2} = \frac{T}{k'.N^{2}.b'}$$

where all the values to the right of the equation are known. Thus, various likely values of e can be selected and the corresponding value of k' determined from Attewell & Farmer (1976 Table 11.9) using constant fracture frequency, N, of 10/m. The values of k' so determined allow calculation of corresponding values of fracture opening. When a value of e is selected that agrees with the calculated value, then that fracture opening is the correct mean separation.

e.g. Assume $e = 0.25$ mm

$$\text{then } k'_{1} = \frac{10^{-4} \text{ x } 86.4 \text{ x } 10^{3}}{0.25 \text{ x } 10^{-3} \text{ x } 10}$$

$$\text{i.e., } k'_{1} = 34.56 \text{ x } 10^{2} \text{ days}^{-1}$$

$$\text{but } e^{2} \text{ also} = \frac{T}{k'.\ N^{2}\ {}^{2}.b'}$$

$$\text{i.e., } e^{2} = \frac{0.16}{34.56 \text{ x } 10^{2} \text{ x } 10^{2} \text{ x } 7}$$

$$\therefore e = \sqrt{7 \text{ x } 10^{-8} \text{m}} = 0.265 \text{ mm}$$

$\therefore$ estimate of e is correct.

Estimates of fracture opening, e, that are greater or less than 0.25 mm give calculated values for hydraulic conductivity that are widely different to the original estimate.

RELATIONSHIP BETWEEN JOINT SPACING & OPENING & HYDRAULIC CONDUCTIVITY

Table 11.9 (From Attewell & Farmer, 1976) : Comparison of pore and fissure sizes (*N* is the number of fissures per metre and δ is the fissure thickness) in porous and fissured materials having the same nominal permeability

Permeability (effective) coefficient m sec^{-1}	*2α (μm)*	*δ microns*		
		l/N = 1 m	*l/N = 0.10 m*	*l/N = 0.01 m*
10^{-1}	1426	5340	2480	1150
10^{-2}	452	2480	1150	530
10^{-3}	152	1150	530	250
10^{-4}	52	530	250	115
10^{-5}	16	250	115	53
10^{-6}		115	53	25
10^{-7}		53	25	12

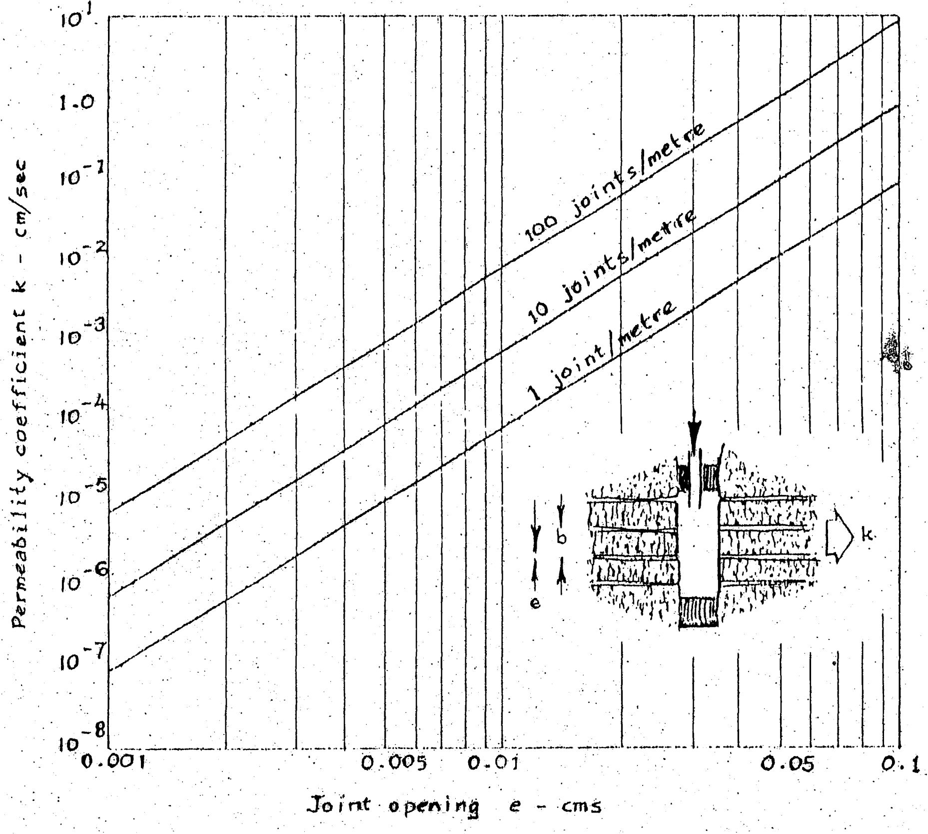


Figure 52 : Influence of joint opening e and joint spacing b on the permeability coefficient k in the direction of a set of smooth parallel joints in a rock mass.
(From Hoek & Bray, 1974)

APPENDIX 3

EXCHANGEABLE CATIONS AND CATION EXCHANGE CAPACITY OF DRILLHOLE SAMPLES

determined by

H.J. Beatty, CSIRO Division of Soils, Canberra

April 1978

EXCHANGEABLE CATIONS AND CATION EXCHANGE CAPACITY
(milliequivalents percent)

BOREHOLE 21

Depth (m)	pH	Ca	Mg	Na	K	CEC
0 - 0.3	6.3	1.9	0.93	0.89	0.23	12.0
1.0- 2.0A	6.9	2.2	2.4	0.40	0.16	10.0
3.8-4.8A	6.2	3.9	6.3	4.1	0.03	22.0
9.4-10.9	8.2	3.9	6.6	3.4	0.00	8.0
12.4-13.9A	8.6	3.2	3.6	1.8	0.00	6.0
13.9-15.4A	8.7	3.0	3.3	1.3	0.00	5.5
15.9-16.4	8.6	3.0	2.3	0.91	0.01	5.0
16.9-18.4	8.3	3.3	1.7	0.58	0.00	4.0
18.4-19.6	8.5	4.1	1.5	0.54	0.02	4.5
0.3- 1.0	6.4	3.4	1.8	0.22	0.18	10.5
1.75- 2.0	7.0	1.7	3.6	0.93	0.19	13.5
2.8- 4.0B	6.4	2.8	7.7	2.7	0.09	18.0
12.4-13.9B	8.6	2.8	3.0	1.9	0.00	5.0
13.9-15.4B	8.4	2.6	2.4	1.1	0.00	4.5

BOREHOLE 22

Depth (m)	pH	Ca	Mg	Na	K	CEC
0.5 - 1.0	6.8	4.6	1.8	0.14	0.43	12.5
1.75- 2.0	7.0	3.5	2.7	0.18	0.39	13.0
2.0 - 3.0A	6.6	3.0	3.2	0.28	0.19	11.0
3.0 - 4.0	6.2	2.3	3.1	0.40	0.11	9.5
4.0 - 5.0	6.3	6.0	6.4	0.86	0.07	20.5
8.0 - 9.0	6.5	6.4	6.1	0.83	0.19	15.5
9.0 -11.0	8.0	6.9	7.3	0.76	0.07	11.0
11.0 -12.5	7.4	9.2	7.7	0.76	0.05	13.0
12.5 -13.7	8.0	12.8	11.5	1.2	0.11	17.5
15.2 -16.7	8.0	6.3	3.3	0.73	0.00	5.0
16.7 -17.45	8.0	4.7	0.96	0.36	0.02	3.5
17.45-18.2	7.7	4.3	0.97	0.36	0.01	4.0
18.2 -18.95	7.7	4.4	1.1	0.26	0.00	4.0
18.95-19.34	8.1	6.0	0.87	0.33	0.00	4.5
19.34-19.7	8.1	7.4	1.1	0.40	0.02	6.0
0 - 1.0	6.5	4.2	1.6	0.09	0.38	12.5
2.0 - 3.0B	6.3	2.5	3.0	0.26	0.12	12.0
4.0 - 5.0	6.5	5.9	6.3	0.87	0.10	20.5
12.5 -13.7	7.9	10.8	9.0	0.86	0.08	14.5
0 - 1.0	6.5	6.7	5.6	0.86	0.12	18.0
2.0 - 3.0C	6.1	4.1	6.1	0.46	0.15	19.5

BOREHOLE 23

Depth (m)	pH	Ca	Mg	Na	K	CEC
0.5 - 1.0	6.6	4.7	1.2	0.02	0.38	14.5
1.0 - 1.1	7.1	5.3	2.0	0.07	0.55	16.0
1.1 - 1.7	7.1	3.5	2.2	0.18	0.30	13.5
2.0 - 2.25	6.2	3.1	2.9	0.39	0.28	15.0
2.25- 2.78	6.1	1.6	2.1	0.33	0.15	11.0
3.0 - 3.4	5.9	3.1	5.0	0.73	0.16	20.5
4.0 - 4.5	6.1	4.5	6.3	0.98	0.21	23.0
4.5 - 5.0	6.1	4.8	5.9	1.0	0.17	22.0
5.0 - 5.5	6.5	6.0	5.8	0.95	0.11	21.0
6.0 - 6.25	6.2	5.1	6.0	0.68	0.13	20.5
6.25- 6.4	6.4	6.5	6.2	0.98	0.13	22.0
7.0 - 7.25	7.4	9.3	5.7	0.91	0.08	12.5
8.0 - 9.0	7.8	8.6	6.0	0.89	0.08	14.5
9.12- 9.60	7.5	8.1	5.5	0.76	0.08	13.0
10.45-10.9	7.7	8.2	4.9	0.71	0.05	10.0
10.9 -12.4	7.9	9.2	5.1	0.78	0.05	12.0
12.4 -13.9	8.0	8.6	3.9	0.72	0.03	8.0
13.9 -15.4	8.0	8.0	2.4	0.65	0.00	6.5
15.4 -16.15	8.0	7.9	1.4	0.73	0.03	8.0
16.15-16.9	9.6	13.2	0.73	0.59	0.01	8.0
16.9 -18.4	8.5	8.2	1.7	0.60	0.06	7.0
18.4 -19.6	8.5	5.7	1.0	0.40	0.06	6.0
4.0 - 4.5	5.8	3.7	6.1	1.0	0.28	24.5
5.0 - 5.5	6.5	4.8	4.9	0.83	0.23	19.5
8.5 - 9.0	7.3	6.5	5.7	0.65	0.06	11.0