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RESEARCH ESTABLISHMENT

LUCAS HEIGHTS

THREE BASELINE STUDIES IN THE ENVIRONMENT
OF THE URANIUM DEPOSIT AT YEELIRRIE, WESTERN AUSTRALIA

by

A.J. BROWNSCOMBE
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PAPER I

THE DISTRIBUTION OF SOME NATURALLY OCCURRING ELEMENTS IN THE ENVIRONMENT OF THE YEELIRRIE URANIUM DEPOSIT, WESTERN AUSTRALIA

by
A. R. WILLIAMS

PAPER II

GROUNDWATER QUALITY IN THE GENERAL AREA OF THE YEELIRRIE URANIUM DEPOSIT

by
M. S. GILES

PAPER III

ENVIRONMENTAL LEVELS OF RADON-222 AND ITS DAUGHTERS

by
A. J. BROWNSCOMBE
D. R. DAVY

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PAPER III URANIUM ORES; GEOLOGIC DEPOSITS; WESTERN AUSTRALIA; YEELIRRIE DEPOSIT; DAUGHTER PRODUCTS; RADON 222; NATURAL RADIATION; EARTH ATMOSPHERE; GROUND WATER; RADON; QUANTITY RATIO

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ERRATA

PAPER I

Page (ii) Contents	line 12	samphite	SHOULD READ	samphire
	27	*burkitti*	SHOULD READ	*burkittii*
	31	*aneura*	SHOULD READ	*stowardii*
Page 3	line 30	[1970]	SHOULD READ	[1978]
Page 12	line 15		DELETE	and total
Page 24	line 3 (in KEY)	Cunya land system SHOULD READ Cunya waterway system		
Page 34	line 6	*burkitti*	SHOULD READ	*burkittii*
Page 35	line 5	*aneura*	SHOULD READ	*stowardii*
Page 40-41	line 1-3 (table heading)	THE EXTREME RIGHT HAND SIDE COLUMN SHOULD HAVE THE HEADING pH Ash/dry (wt %)		

PAPER III

Page 8	line 25		INSERT) AFTER	^{226}Ra
Page 14	line 16		INSERT) AFTER	$0.015\ cm^2s^{-1}$

FOREWORD

The work reported in the three papers contained in this volume was carried out under contract to Western Mining Corporation Ltd. Decisions on the scope of each study, the location of sampling sites and the type of analyses performed on samples were reached by consensus of the opinions of AAEC staff involved and representatives of WMC (Meagher and Le Provost, Australian Groundwater Consultants Pty Ltd, Maunsell and Partners) together with WMC staff.

Because the role of the AAEC was limited to the gathering of baseline information on the Yeelirrie environment before the commencement of mining operations, a minimum of interpretation has been given to the data presented.

THREE BASELINE STUDIES IN THE ENVIRONMENT OF THE URANIUM DEPOSIT AT YEELIRRIE, WESTERN AUSTRALIA

PAPER I

THE DISTRIBUTION OF SOME NATURALLY OCCURRING ELEMENTS IN THE ENVIRONMENT OF THE YEELIRRIE URANIUM DEPOSIT, WESTERN AUSTRALIA

by

A. R. WILLIAMS

ABSTRACT

The distribution of Cu, Pb, Mo, V, Sb, As, Se, U, ^{226}Ra and ^{210}Pb in soils, plants and animals associated with the Yeelirrie uranium deposit was examined. The data were summarised to provide estimates of the background metal distributions in the area before commencement of the mining operation.

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NOTES

1. INTRODUCTION

The purpose of this work was to measure the distribution of metals in the vicinity of the Yeelirrie uranium deposit, Western Australia, (Figure 1), before commencement of mining operations, in order to provide base-line data for the assessment of the environmental impact of the proposed operation.

The survey was based on a preliminary study of the mining proposals, the local environment, and previous experience in the mining and milling of uranium ores, carried out in consultation with Western Mining Corporation (WMC) management, its environmental consultants, and officers of the Australian Atomic Energy Commission.

The objectives of the present study were:

- to select a range of elements likely to be important, from the known mineralogy of the ore deposit and the milling process, and to analyse all samples for these elements;
- to locate a series of sites in the vicinity of the orebody which are most likely to be influenced by the mining operation, and to take soil and plant samples from these sites; and
- to collect animal samples, where possible, to provide background data on human diet.

2. THE MINING PROPOSAL

2.1 Operations Statement

The geology of the uranium deposit described elsewhere by WMC [1978] can be summarised as follows. The major mineral present is carnotite ($K_2(UO_2)_2(VO_4)_2.3H_2O$; no other minerals have been identified) which has been deposited from groundwater onto aggregated calcrete. The calcrete has been deposited from groundwater also and forms a massive body in the valley floor, which was once the bed of the stream draining the local watershed. Mineralisation occurs largely below the present groundwater table, $\sim$ 3 m from the surface, and extends down to $\sim$ 9 m. The location of the deposit is shown in Figure 2.

The proposed development which has been outlined elsewhere by the WMC [1970] consists of the following essential points. The deposit will be opencut and the ore and overburden will be stripped by ripping and scraping. The ore will be crushed to - 48 mesh and the uranium extracted by a hot caustic leaching process. Uranium will be precipitated from pregnant liquor with sodium hydroxide. Tailings and barren liquors will be disposed of to a fully contained tailings dam. The working pit will be fully dewatered to allow a close control of ore grade to be maintained, and this water will be disposed of by evaporation from the tailings dam. The mine zone will be fully flood-bunded at the

beginning of operations; this bund will be retained throughout the life of the mine and after operations cease. The mill and tailings dam will be located well above the maximum probable flood level.

2.2 Possible Effects of the Operation

Contaminants from any mining operation may exert some influence on the surrounding air, surface and subsurface water, soils and organisms. The proposed Yeelirrie operation will have two zones of influence. One is in the immediate vicinity of the excavations, dumps, roads and plant, and the other is at some unspecified distance from the operation site as determined by wind and water transport of contaminants. The zone of influence of wind transport will be radial from any point source, but individual transport events will be rather unpredictable; water transport will follow the surface topography downstream of the source. To cover the major zones of influence, therefore, sample sites should be located in the orebody zone, immediately downstream and upstream of the orebody, and at some distance downstream.

3. THE ENVIRONMENT

The survey program and, in particular, the detailed selection of sites were based on the following environmental information.

3.1 Climate

Arnold [1963] analysed the climate in the Wiluna-Meekatharra area to the north of Yeelirrie: the following summary is derived from this analysis and available Yeelirrie records.

Annual rainfall averages ∿ 250 mm with a 95 per cent confidence interval of 5-490 mm. Rain can occur at any time but the long-term pattern shows more rain in summer than in winter, with winter rain being more likely than summer rain. Rain is least likely to occur in spring. The distribution and intensity of rainfall is such that no more than one growth period exceeding four weeks in duration can be expected per year, and one year in every three will receive no 'drought-breaking' rains at all. Sufficient rainfall to produce streamflow in the main waterway has not yet been recorded in the area, although one such event has been recorded to the south in the Laverton district.

Temperatures are characteristic of an inland continental arid zone with extreme diurnal and seasonal variations. Frosts can be expected on ∿ 10 days of the year, whereas temperatures will exceed 40°C on ∿ 20 days.

Evaporation is of the order of 2500 mm per year, ranging from ∿ 350 mm per month in summer to ∿ 50 mm per month in winter.

3.2 Flora

Yeelirrie lies within the Eremaen botanical province described by Burbidge

[1968] . The three main formations at Yeelirrie are:

(a) *Mulga woodland* dominated by low trees of *Acacia aneura*, with an understory of either small shrubs or perennial grasses. This formation occurs along the waterways and tributary run-on zones.

(b) *Spinifex grassland* dominated by large tussocks of *Triodia basedowii* with a sparse, low tree layer. This formation occurs on sand plain adjoining the mulga zone.

(c) *Halophyte shrubland* consisting of low shrubs ($\leq$ 1 m) of various species including *Maireana*, *Atriplex*, *Frankenia* and *Arthrocnemum*. This formation occurs on salt flats, lake margins and alluvial plains within the mulga formation.

All formations carry a large seed store of annual species which proliferate when rainfall is sufficient. Prominent among the annuals are forb species of the *Asteraceae* and *Amarantaceae* and the grasses *Aristida contorta* and *Stipa scabra*.

The orebody occurs as a calcrete outcrop within the mulga woodland formation along the waterway zone and carries a small area of halophyte shrubland, surrounded by a taller woodland of *Eucalyptus* and *Casuarina* and a distinctive *Acacia burkittii* shrub layer.

3.3 Geomorphology

Topographical relief in the Yeelirrie area is very low. Along the valley where the ore deposit occurs, slope varies from 0 to 1:1500, whereas the slope from the valley to the nearest 'breakaway' averages 1:250.

The land surface is very old; the following brief history of its development is based on Mabbutt [1963]. Basement rock in the ore zone is Archaean granite and the oldest existing surface layer (the 'old plateau' of the interfluve zone) was developed as a lateritised peneplain during the Cretaceous period. Stable, moist conditions accompanied laterite formation and were followed by a rejuvenation of drainage (by recession of sea level?) which began the 'new plateau' formation during the Tertiary period. This process was interrupted by a reduction of rainfall so that competent streamflow ceased and the trunk valleys became filled with alluvium, and devolved into a series of internal drainage systems terminating in salt lakes. As water erosion ceased, wind erosion continued and some areas adjoining Yeelirrie give evidence of dune formation. Following dune formation, the climate must have improved somewhat as the dunes have become vegetatively stabilised.

During the Quaternary period, and possibly right up to the present, calcium carbonate deposits have been forming within the trunk valleys and around the

salt lakes as a hard, porous 'calcrete' material. It developed in discrete masses and increased significantly in volume such that at present it outcrops in ridges above the surrounding lake and valley floors.

3.4 Land Use

The Yeelirrie property is a pastoral lease and before 1972 was used for wool production for about 45 years. It is on the eastern fringe of the arid pastoral zone and, within the present economy, it is envisaged that the land use, after mining ceases, will be either continued pastoral production or a return to wilderness.

To maintain the pastoral land use option, the two most important features to conserve are the quantity and quality of potable groundwater and the integrity of the waterway land system, which contains the most productive vegetation units, in terms of sheep fodder, on the property.

3.5 Ecological Mapping

The orebody zone, and the upstream and downstream waterway, were mapped from aerial photographs for features of vegetation and geomorphology likely to be of use in sample site selection. Eight land units were defined. Their major features of soil topography and vegetation are set out in Table 1; they are also illustrated in Plates 1-11, their distributions are mapped at key points on Figures 3, 4, 5 and 6 and the locations of these mapped areas are shown in relation to one another on Figure 2. A schematic transect through the lake zone is given in Figure 7; this shows the relationship of topography, lithology and vegetation between the land units.

One topographic feature which is not illustrated is the depression referred to as a 'pan' (see Plate 11). These depressions are very common throughout the waterway, but appear to be confined to it. They range in size from 10 - 100 m diameter, are generally oval or circular in shape, and have a relief differential of $\sim$ 0.5 m. There are two main types of pan, one having a bare scalded surface with little or no vegetation on it, the other carrying a dense mixed growth of trees. They usually retain some water after rain, since they have a less pervious bottom than the surrounding sandy soils, and so are of interest as potential foci for contaminated surface water.

3.6 The Expected Pattern of Waterflow

The watershed to which the main Yeelirrie waterway belongs once flowed in a south-easterly direction into the sedimentary basin now known as the Nullarbor Plain [Beard 1973]. Since that time the rainfall has decreased and the whole system has devolved into a series of local watersheds terminating in salt lakes. Erosion channels in the Yeelirrie area leading into the main

waterway, suggest that competent streamflow still occurs where the stream gradient is large enough. However there is no evidence of streamflow in the main waterway which suggests that such events are very rare, non-existent or, when they do occur, the velocity of water movement is very low. It has been assumed in the present study that such streamflow is possible, but with a rather long expected return period. An estimate of the size and frequency of possible flood events has been carried out by Binnie International (Aust.) Pty Ltd.

It has been assumed that when surface flow does occur in the main channel the flow will terminate at the first salt lake that it encounters. Therefore, as long as the proposed mine and mill sites remain within the main watershed, all contaminated surface drainage will be retained within the existing property boundaries and will flow via the lowest stratum of the valley floor; this is shown in Figure 7 to be land units 4 and/or 5.

Access of surface water to the groundwater will be rather variable. On calcrete outcrops there is a generally porous surface with some karst-type holes through which water would penetrate rapidly. In other parts of the waterway the surface soil is generally underlain by a ferricrete hardpan. In the mine zone, surface waters will mix with the ground waters because of the bund walls and the excavation.

The movement of groundwater will also be variable, with the possibility of rapid movement in calcrete zones but low transmissivity in inter-calcrete zones. The surface soils of the waterway outside of the lake zones show no accumulation of salt so it has been assumed that solutes do not normally transfer between the groundwater and the surface. In the lake margin zone, there is a fine sand which shows surface accumulation of salt and a moist profile from the surface down to the watertable. This suggests that solute transfer from groundwater to surface does occur in this narrow zone, hence contamination of groundwater would find surface expression in such an area. However, movement of contaminated groundwater through the 30 km from the orebody area to the lake zone would take a very long time.

4. THE SURVEY PROGRAM

4.1 Aim

The aim of the present survey was to identify locations where contamination of soils, plants and/or animals might occur as a result of the proposed mining operation, and to measure the concentration of metals most likely to be associated with such contamination.

4.2 Methods

4.2.1 Site selection

Section 2.2 gave an overview of the possible effects of the mining operation and, therefore, of the basic principles of site location. Section 3.5 and the maps showed the major features of the environment to which these principles are to be applied, and Section 3.6 outlined the waterflow pattern which provides an estimate of the direction and possible frequency of contamination events. This information has been combined to formulate a soil and plant sampling program.

In situ contamination may occur in and around the orebody zone, so sites were selected on calcrete ridges upstream and downstream of the orebody. This area carried an open low shrubland of *Acacia burkittii* with an annual ground cover of the grasses *Stipa scabra* and *Aristida contorta*. The *Acacia* was in good condition and was sampled at each site; the grasses were dead and so only a composite sample of the *Stipa* was collected. The collection sites were CA (Figure 3), CB (Figure 4), CD (Figure 5) and CC (Figure 6); a typical site is illustrated in Plate 8.

Short-distance surface water transport of contaminants would influence the valley floor below the orebody, so the first large pan and halophyte plain zone to the lower end of the orebody were sampled. The halophyte plain site (AT, Figure 5, Plate 6) carried *Maireana pyramidata* and *Cratystylis subspinescens* shrubs in good condition so these were sampled, but the ground cover was very sparse, and only a collection of depauperate *Bassia sp.* was possible. The pan (site AP, Figure 5, Plate 11) carried a dense low tree cover of several species, but only the major trees *Acacia stowardii, A. tetragonophylla, Grevillea sp.* and the shrubs *Eremophila longifolia* and *Ptilotus obovata* were sampled. Ground cover was sparse but there were tussocks of *Eragrostis* present; unfortunately these had been closely cropped by kangaroos which did not leave enough material to be sampled. A search was made for a control site to correspond to sites AT and AP on the upstream side of the orebody. This was not achieved, but a pan was located (CP, Figure 3) in which soil and *Acacia stowardii* were collected.

Long-distance surface water transport was assumed to end up in the salt lakes south-east of the homestead. Two types of lake were encountered - a clay soil, saltbush-dominated type and a loam soil, samphire-dominated type. Both types were sampled through the centre (sites L1 and L2, Figure 6, Plates 1 and 2) and around the margins (L1M, L2M Figure 6, Plates 3, 4 and 5). The saltbush lake margin (L1M) was the only place where groundwater found surface

expression, so this site was analysed for that effect also. A control for the latter site was located on the same vegetation and soil type in the Altona waterway (site AC, Figure 2).

Individual plants which occurred naturally on the orebody were sampled to estimate pre-operational orebody zone surface metal levels. Among these were *Maireana pyramidata, Cratystylis, Ptilotus, Acacia stowardii, A. tetragonophylla, A. burkittii, Eremophila* and *Melaleuca* (sites 01-05, CB, Figure 4). *Maireana pyramidata, M. sp.* and *Ptilotus* were found growing on high grade ore dumps and sampled to estimate maximum ore exposure levels (sites 06-08). *Maireana pyramidata* found growing on the edge of a pan to which slot water had been discharged was sampled to estimate possible contamination from this source (site SP, Figure 4).

In the animal sampling program, unlike the plant/soil situation, it was not possible to relate organ samples to food sources, so a different approach was used. Two animals, Merino sheep (*Ovis aries*) and red kangaroo (*Megaleia rufa*) were selected because of their size and abundance; these were taken from known mineralised areas and unmineralised areas. Four wethers (ages - SW1 2 y, SW2 1.5 y, AD1 5 y, AD2 2 y) were taken from the lakes area near Snake Well and the adjoining paddock at Albion Downs, classified as a mineralised grazing zone. Two wethers (Y1 3 y, Y2 2y) were taken from spinifex country on nearby Yakabindi station, classified as an example of an unmineralised zone. Two female kangaroos (SL1, SL2 - mineralised) were taken while drinking at the slot on the orebody and a female and male (ND1, ND2 - unmineralised) were taken from breakaway country near Never Despair bore.

A summary of the sites sampled, giving the site and sample numbers, the soil and land unit type, species names and the purpose of each site location, is given in Appendix A.

4.2.2 Sampling procedures

The plant species were selected by ranking according to dominance (quantitative visual assessment), palatability to stock, resistance to drought, and grazing. The number of species per site was then selected on the basis of a balance between replication and number of analyses allocated to the program.

The portion to be sampled was defined as the outermost 15 cm of vegetative material available on the plant at sampling time, as cut with grass shears or secateurs and packed unwashed into new polythene bags. This definition was adopted because:

(a) Such portions were most accessible to grazing animals.

(b) No definition of leaf-to-stem ratio applied to all plants. The samphires

and *Acacia*, for example, had no leaves on their modified stems, whereas the *Grevillea* and *Eremophila longifolia* samples were nearly all leaf.

(c) Some plants (*Acacia* and *Grevillea*) had large fruiting bodies, which were not included. However, the small fruits of the halophytes were included.

The soil was sampled by digging a small trench 5 cm wide by 10 cm deep, with one smooth face. A 1 cm thick slab was chipped down the smooth face from the surface to 10 cm depth and then scraped from the hole. This method was adopted when the standard coring devices failed to sample the dry, loose soil adequately.

All plant and soil samples consisted of between five and ten subsamples and were replicated either by systematic linear transects or, where this was not possible, in nearest neighbour clusters. Soil was taken as near as practicable to the corresponding plant sample.

In the animal sampling program, replicates of two animals per site were used; the whole liver and kidneys were taken from each animal together with the flesh and long bone from both back legs, making four items per animal.

4.2.3 Sample preparation and analysis

All sample preparation was done by the Analytical Chemistry Section at the AAEC Research Establishment, Lucas Heights. Pre-drying preparation was as follows. Soils were sieved to -2 mm if necessary and the gravel was discarded. Plants were not touched. Animal organs were cut with a carbon steel knife, then frozen in liquid nitrogen and pulverised while enclosed in a plastic bag.

All samples were weighed straight from the original polythene bag for fresh weight. They were then oven-dried at 80°C and subsamples were ashed at 450°C in porcelain containers.

Uranium, ^{226}Ra and ^{210}Pb were determined at the AAEC Research Establishment, some ^{226}Ra was determined by Radiation Management Corporation (RMC) of the USA and all other metals were determined by the Australian Mineral Development Laboratory (Amdel), South Australia. The analytical procedures for the individual metals are listed in the following table.

Element	Soil		Plant		Animal	
	Ash	Dry	Ash	Dry	Ash	Dry
As,Se,Sb		2,3,9		3,9		3,9
Pb,Mo,Sb	4,2,9		4,2,9		1,9	
^{226}Ra	2,5		1,5		1,5	
^{210}Pb		2,6		1,6		1,6
U	7		7		1,8	
Others	2,9		1,9		1,9	
pH		10				

Key: 1 acid dissolution; 2 acid dissolution including HF; 3 acid dissolution including $HClO_4$ followed by hydride evolution; 4 X-ray fluorescence; 5 emanation method; 6 determine ^{210}Po by deposition on silver and calculate ^{210}Pb by assuming equilibrium; 7 neutron activation analysis; 8 spectrophotometry; 9 atomic absorption spectrophotometry; 10 glass electrode in 1:5 soil solution in water.

4.2.4 Data analysis

To display the data in a form which reflects their underlying pattern of variation, the CSIRO programs MULCLAS [Lance & Williams 1967] and POLYDIV [Williams & Lance 1975] were used to classify each set of sample types. These programs compute the similarity between each sample and every other sample and then sort those samples into groups that are most like one another.

The soil, plant and animal data sets are presented in their own classifications in Appendices B-D. Replicates can be identified either by their serially numbered site symbols, or by the numbers given in Appendix A. Group averages have been computed for each class, using either the mean of a symmetric distribution or the median of a skewed distribution. In some cases, these group values may be of assistance in estimating the parameters of metal distribution in a particular sample medium.

4.3 Results

4.3.1 Soil

The soil data are presented in Appendix B; these are classified into groups which bear some relation to identifiable environmental influences.

The 'lake bed' and 'lake margin' soils are as defined on the ecological maps (Figures 4, 6) and the profile diagram (Figure 7). The 'water influenced soils' form a mixed group dominated by the series of samples taken from the

soil to which slot water was discharged; the relationship between this group and the lake margin L2M soil is unclear, but it was observed that when groundwater was discharged to the surface, a change in the soil structure occurred, so it is not surprising that the chemistry changed also, to become more like that of the lake soils. The 'dry valley fill' soils consist of all those not belonging to the lake or calcrete groups; they are largely sandy soils with variable amounts of loamy material, depending on their exposure to water-borne fines. The 'calcreted valley fill' soils are similar to the latter except that they have somewhat more calcium, owing to the presence of calcrete gravel; they consist of all the soils collected on calcrete outcrops. The mineralised calcrete differs from the surface calcreted soils mainly in U, Ra, ^{210}Pb and V content.

The availability of metals to the soil solution is given in Table 2, which lists the water soluble, ammonium acetate exchangeable, dilute nitric acid leachable and total fractions for each major soil type. The concept of availability is based upon the chemical state of an element in the soil. If it is bound in silicate minerals, it is entirely unavailable to plants; if it is bound in a chemical form that is subject to weathering or microbial attack, then it may become available for plant use; if it is mobilised by water or dilute solutions, then it will be readily available to plants. If a soil has been contaminated by metals in solution, then the 'available' fraction would increase more rapidly than the total soil content, and so is a more sensitive indicator of contamination.

The effect of groundwater discharge to the surface soil is illustrated by the SD series of samples (4076-4083; see Appendix A) which were taken in an area of 'calcreted valley fill' soil to which slot water had been discharged. The levels of Na, K, Mg, Cu, Pb, As have increased in the contaminated soil (SD1, SD2) and Ca and U have decreased (although the high U in SD4 is possibly due to mineral occurrence). There seems to be no difference between the top 1 cm and the lower 19 cm of the contaminated surface, which suggests that distribution is even in the top 20 cm of soil.

A further effect of groundwater discharge to the surface is illustrated in sample SP (4088; see Appendix A) which was taken from a pan to which slot water had been discharged. These results may be compared with an uncontaminated pan CP (4084, 4085) above the orebody, and another AP (2212-2214) below the orebody. The most significant difference between these is in Ra content which is 15 times higher in SP than in CP; the corresponding differences in U and ^{210}Pb are 3 and 1 respectively. This suggests that Ra is highly accu-

mulated by the surface of the pan.

The deposition of solutes from uncontaminated surface runoff is illustrated by samples from the pan site CP (4084-4085; see Appendix A) where separate 0-1 and 1-10 cm samples were collected. There is no difference between these samples which shows that there is no accumulation of the measured metals from this natural source.

It was observed that in the halophyte plain zone near Snake Well, and at some other sites, a crust of algae occurred on the surface of the soil. The AS series of samples were taken from two crusted patches (AS1: 4104, 4105; AS3: 4108, 4109) and two adjacent non-crusted patches (AS2: 4106, 4107; AS4: 4110, 4111; see Appendix A). Analysis showed that the algal crust contains higher levels of Cu, Pb, Mo, V, Se, U than either its underlying soil or its neighbouring non-crusted areas. This suggests that such algal growth may be a more sensitive indicator of metal contamination than is the soil itself.

4.3.2 Vegetation

The vegetation classification is presented in Appendix C and shows that, in general, variation between species is greater than variation within species. This means that, in most cases, plant uptake depends more on the species than it does on the amount of metal present. Exceptions to this rule occur in plants that grow in both mineralised and non-mineralised areas and show large differences in V, U, Ra and/or ^{210}Pb levels.

The uptake of elements by plants from soil is a complex process which varies with plant species, soil type, condition of the soil, chemical form and properties of the element and the properties of other elements present. There are several ways of characterising the transfer process: for example, the total amount of element in the plant tissue can be measured meaningfully for it must all derive from the soil; however, only a fraction of the element in the soil phase is available for transfer to the plant, and this fraction will vary with the soil type and degree and type of contamination. It is also possible to express the transfer in other ways, such as in proportion to the total fresh weight, to the total dry matter content, to the total mineral content or to some part of the mineral content chemically related to the element in question.

It is important to be able to characterise the transfer properties of a particular element in a particular plant species, as this identifies the species that will be the most sensitive indicator of contamination in the soil. The usual method is to calculate a 'transfer coefficient', being the plant content divided by the soil content. Values > 1 indicate active uptake, values

of ∿ 1 indicate passive uptake and values < 1 indicate active discrimination against uptake. This interpretation is only correct, however, if the plant concentration is related either to the total mineral metabolism of the plant or to some well defined portion of it (*i.e.* expressed on an ash weight basis or on the weight of chemical analogues also present); the soil concentration should be expressed in terms of either the total available mineral content or the same well defined portion of it.

Exact specification of transfer characteristics is therefore difficult to achieve.

In the present work the best method of approximation to the true situation is to calculate concentration factors from the total contents of the plant and the acid leachable fraction of the soil, expressed on an ash weight basis. This calculation has been made in Table 3 and the estimated best 'indicator' species for each element are as follows:

Copper	-	*Cratystylis subspinescens*
Lead	-	*Melaleuca sp.*
Molybdenum	-	*Acacia tetragonophylla*
Vanadium	-	*Arthrocnemum leiostachyum*
Arsenic	-	*Acacia burkittii*
Selenium	-	*Cratystylis subspinescens*
Uranium	-	*Atriplex sp.*
Radium-226	-	*Arthrocnemum leiostachyum*
Lead-210	-	*Melaleuca sp.*

The question of plant response to increased soil levels of metals has also been addressed in the sampling program. Six species have been sampled in both mineralised and unmineralised soil, for which the data are included in Table 3. This shows that in general the response is variable both between species and between metals within species.

The identification of plant species sampled during this program has proved a little difficult and the names in Appendix A are given to the limit of confidence for the material collected. Staff of the Western Australian Herbarium have suggested further names as follows:

Arthrocnemum leiostachyum		individuals are also associated with an undescribed species
Atriplex sp.	=	*A. bunburyana - A. rhagodioides hybrid*
Grevillea sp.	=	*G. pyramidalis*
Melaleuca sp.	=	*M. cymbifolia*

However, these names cannot be verified with the material collected. A complete collection of specimens was retained by the author at Lucas Heights.

4.3.3 Animals

The animal data are presented in Appendix D. The outstanding feature of this classification is that the main grouping is by species and organ rather than by site, which means that metal accumulation is influenced more by species differences than by site differences. One exception is the sheep viscera in which lead, chromium, arsenic and selenium are higher at the exposed sites than the unexposed sites. A large difference in copper metabolism between sheep and kangaroo is demonstrated in the liver samples.

The kangaroo data suggest that there is no difference between the orebody and the interfluve zone as a source of metals in forage and drinking water. This is possibly influenced by the kangaroo's drinking habits. It was thought that, at the orebody where the two animals were taken, they were drinking directly from the saline groundwater exposed in the slot. However it was later noticed that they were actually drinking from small holes they had scraped, about 20 cm away from the water's edge, and just deep enough to allow about 2 mm of water to enter. We assume, therefore, that this water is of potable quality even though the adjacent water is highly saline. An interesting anomaly in the kangaroo data is the extraordinarily high levels of lead and antimony in the viscera of animal SL 2. These values have been checked and they appear to be quite genuine.

From the point of view of human diet, the significance of the pre-mining levels of heavy metals and radiation in these animal samples can be assessed by comparing these data with Australian or international standards (*e.g.* radiation assessment guidelines given by the International Commission on Radiation Protection [1959] and IAEA [1971]), but no such assessment has been attempted in this report.

4.4 Summary

It is not possible to predict in detail the precise effect of the mining operation on the local environment; however, by examining the operation statement, the climate, the vegetation and the topography it is possible to give a broad definition of areas of influence and the type and frequency of possible contamination events.

Surface water transport of contaminants from the mine site will be a very rare event, but its areas of influence can be easily defined. In monitoring such events, the analysis of soil samples should yield more reliable results than the analysis of plant or animal samples because, in this arid environment, organism abundance and distribution is very variable.

The best use of organism analysis is in gauging the extent of the influence of a pollution event on the organisms themselves. Among the organisms, some accumulate certain metals more than others so it would be wise to select carefully both the metal being analysed as well as the organism being sampled, so that maximum sensitivity is achieved.

Transport of contaminants by groundwater is likely to be a very slow process so it would be more efficiently monitored through direct borehole water sampling. Transport of contaminants by wind or vehicle will be less predictable at this stage, but the samples taken in the calcreted orebody zone provide a measure of metal levels where activity will be most concentrated.

When comparing these data with some future monitoring data, the sample groupings presented here may be used to estimate the population parameters of metal distribution and therefore provide a basis for assessing the statistical significance of any differences found.

5. ACKNOWLEDGEMENTS

I would like to thank the staff and consultants of Western Mining Corporation for initiating this project and helping in its achievement; the Manager of Yeelirrie Station, and his family, for their hospitality; the Curator and Staff of the Western Australian Herbarium, for identification of some of the botanical specimens; Mr George Gardiner of the W.A. Department of Agriculture, for field advice; Dr R.J. Knight of the AAEC Research Establishment for his capable administration, and Mr D.R. Davy, also of the AAEC, for his planning and oversight of the field work, and comments on the manuscript.

6. REFERENCES

Arnold, J.M. [1963] - Climate of the Wiluna-Meekatharra area. In Lands of the Wiluna Meekatharra Area, Western Australia, 1958, CSIRO Land Research Series No. 7, Melbourne.

Beard, J.S. [1973] - The elucidation of palaeodrainage patterns in Western Australia through vegetation mapping. Occasional Paper No. 1. Vegetation survey of Western Australia, Vegmap Publications, Applecross.

Burbidge, N.T. [1968] - The phytogeography of the Australian region. *Aust. J. Bot.* 8:75-211.

IAEA [1971] - Disposal of radioactive wastes into rivers, lakes and estuaries. International Atomic Energy Agency, Safety Series No. 36, Vienna.

International Commission on Radiation Protection [1959] - Report of Committee II on Permissible Dose for Internal Radiation. Pergamon Press, New York (Table 12).

Lance, G.N. & Williams, W.T. [1967] - A general theory of classificatory sorting strategies 1. Hierarchical systems. *Comput. J.* 9, 373-380.

Mabbutt, J.A. [1963] - Geomorphology of the Wiluna-Meekatharra area. In Lands of the Wiluna-Meekatharra Area, Western Australia, 1958, CSIRO. Land Research Series No. 7, Melbourne.

WMC [1978] - Draft environmental impact statement - Yeelirrie uranium development. Western Mining Corporation Ltd, Perth.

Williams, W.T. & Lance, G.N. [1975] - POLYDIV: A divisive classificatory program for all - numeric data. *Aust. Comput. J.* 7, 144.

NOTES

TABLE 1

A DESCRIPTION OF THE LAND UNITS DEFINED IN THE ECOLOGICAL MAPPING PROGRAM

Land Unit		Surface Soil Type	Topography	Dominant Vegetation
No.	Name			
1	Saltbush lake	Friable red clay	Flat	*Atriplex* halophyte shrubland
2	Samphire lake	Hard-setting, yellow-red, silty loam	Flat	*Arthrocnemum* halophyte shrubland
3	Lake margin	Yellow fine sand with surface crust	Gently sloping	Several types (mainly *Frankenia*) of halophyte shrubland
4	Halophyte plain	Coarse red sand	Flat, some depressions	Mixed halophyte shrubland
5	Alluvial valley-fill	Coarse red sand	Wide valley floor with numerous depressions	*Acacia aneura* woodland, *Danthonia* and *Triodia* perennial grass understorey
6	Calcrete complex	Red sandy loam with gravel	Emergent ridges, some depressions	Several types of woodland
7	Sand plain	Coarse red sand	Flat	*Triodia basedowii* savannah grassland
8	Run-off zones	Coarse sand	Gently sloping with runnels	*Acacia stowardii*, woodland with low shrubs and annual grasses

TABLE 2

AVAILABILITY OF METALS TO THREE MODES OF EXTRACTION

FROM THE MAJOR SOIL TYPES

Soil Type	Na	K	Ca	Mg	Cu	Pb	Mo	V	Sb	As	Se	U	^{226}Ra	^{210}Pb
WATER SOLUBLE														
C1	42	4	4	< 1	< 1	< 10	< 40	< 2	< 7	< 1	< 20	< 1	< 1	< 1
C2	78	9	33	2	< 1	< 10	< 20	< 2	< 7	< 1	< 20	< 1	1	< 1
C3	22	1	2	2	< 1	10	< 50	< 6	<20	< 1	< 30	1	< 1	< 1
C4	2	1	1	2	1	24	< 30	< 2	<10	< 1	< 30	2	< 1	< 1
C5	2	1	2	1	< 1	15	< 50	< 4	<20	< 2	< 50	37	< 1	2
C6	35	6	3	4	< 1	< 25	< 40	<10	<20	< 2	< 25	18	13	2
EXCHANGEABLE TO A 1 M AMMONIUM ACETATE SOLUTION														
C1	58	15	67	2	< 1	< 10	< 40	< 2	< 7	< 1	< 20	1	25	< 1
C2	79	14	79	3	< 1	< 10	< 20	< 2	< 7	< 1	< 20	4	9	< 1
C3	25	3	22	12	< 1	< 10	< 50	< 6	<20	< 1	< 30	2	18	< 1
C4	3	4	58	9	< 1	< 6	< 30	< 2	<10	< 1	< 30	3	30	1
C5	2	3	25	4	< 1	< 10	< 50	< 4	<20	< 2	< 50	17	6	2
C6	36	7	11	4	< 1	< 25	< 40	<10	<20	< 2	< 25	40	19	7
LEACHABLE IN 5% NITRIC ACID														
C1	67	16	73	32	< 1	< 10	< 40	< 1	< 7	< 1	< 20	16	38	< 1
C2	79	16	92	63	15	18	< 20	1	< 7	1	< 20	50	100	< 1
C3	27	5	26	37	23	50	< 50	9	<20	< 1	< 30	54	100	3
C4	3	7	61	28	24	35	< 30	4	<10	< 1	< 30	74	100	1
C5	3	7	91	60	23	23	< 50	4	<20	< 1	< 50	49	27	7
C6	36	7	10	19	13	< 25	< 40	9	<20	17	25	100	100	50

The figures given are expressed as a percentage of the total for complete acid dissolution.

Soil Types:

C1 - saline clay, composite of site L1;
C2 - saline clay loam, composite of site L2;
C3 - loamy sand, composite of site AT;
C4 - clay loam, composite of site AP;
C5 - loam, composite of sites CA-CD;
C6 - saline fine sand, from site L1M.

TABLE 3

METAL CONCENTRATION FACTORS FOR PLANT SPECIES FROM SOIL

Species	Na	K	Ca	Mg	Cu	Pb	Mo	V	Sb	As	Se	U	Ra-226	Pb-210
Acacia stowardii	48	160	470	34	14	< 0.8	28	0.1	< 40	600	16	0.3	0.1	15
Acacia burkittii	750	180	30	12	16	< 0.7	23	0.6	-	800	15	0.6	0.2	40
Acacia tetragonophylla	140	200	400	61	19	1.2	92	0.1	< 40	560	36	0.5	0.7	25
Eremophila longifolia	48	330	200	43	27	0.8	33	< 0.1	< 40	440	10	0.3	0.5	4
Grevillea sp.	290	170	330	70	13	1.6	20	0.1	< 40	480	39	1.4	0.2	32
Ptilotus obovatus (a)	240	260	220	84	7.5	1.6	14	0.1	< 40	333	26	0.9	1.9	9
(b)	33	310	2	1	20	< 1.7	0.4	2.3	-	110	4	0.8	1.5	2
Arthrocnemum leiostachyum	29	21	2	0.7	5.3	< 1.1	3.4	15	< 57	10	5	1.7	29	5
Atriplex sp. (a)	57	97	12	1	320	< 2.3	4.6	2.9	< 38	83	15	4.3	0.6	0.3
(b)	240	100	5	2	410	< 1.8	6.2	5.2	-	29	29	0.4	1.8	4
Atriplex bunburyana	2200	120	14	3	2	< 0.7	5	< 0.5	-	2	3	0.1	1.8	2
Cratystylis subspinescens (a)	410	210	370	65	22	< 0.4	10	0.8	< 40	110	46	0.5	1.3	7
(b)	180	100	7	1	1500	< 1.8	41	4.2	-	21	36	0.3	2.8	48
Maireana pyramidata (a)	710	130	140	92	11	< 0.4	2	0.5	< 40	110	14	0.4	1.2	9
(b)	2600	170	0.5	0.4	16	< 1.7	0.6	0.1	-	88	3	0.1	0.2	0.1
Maireana sp.	1800	75	0.6	0.2	3	< 1.7	1	0.02	-	42	3	0.003	0.1	0.1
Bassia sp.	510	68	130	92	4	1.0	4	0.3	< 40	48	8	1.5	1.5	3

TABLE 3 (continued)

Species		Na	K	Ca	Mg	Cu	Pb	Mo	V	Sb	As	Se	U	Ra-226	Pb-210
Melaleuca sp.	(a)	50	68	7	3	380	6.8	15	2.5	57	110	8	1.6	3.0	140
	(b)	140	58	8	2	460	1.8	25	1.0	>110	390	11	0.5	2.6	0.4
Frankenia sp.1	(a)	12	57	11	29	7	4.0	1	2.2	-	8	4	1.1	5.0	12
	(b)	28	17	19	7	7	4.0	6	0.4	8	4	10	0.9	1.3	8
Frankenia sp.2		1200	24	62	4	3	1.1	8	0.5	-	32	9	0.5	4.2	2
Stipa scabra		42	60	4	4	6	3.6	5	9.4	-	190	9	1.1	5.5	13
Maximum		2600	330	470	92	1500	6.8	92	15	>110	800	46	4.3	29	140
Median		180	100	14	4	14	1.6	6.2	0.5	< 40	110	10	0.5	1.5	7
Minimum		12	17	0.5	0.2	2	0.4	0.4	0.02	8	2	3	0.003	0.1	0.1

Note: Concentration factors were computed by dividing the average plant value by the acid leachable proportion of the average soil value. Where mineralisation occurred the low mineral group (a) was calculated separately from the high mineral group (b).

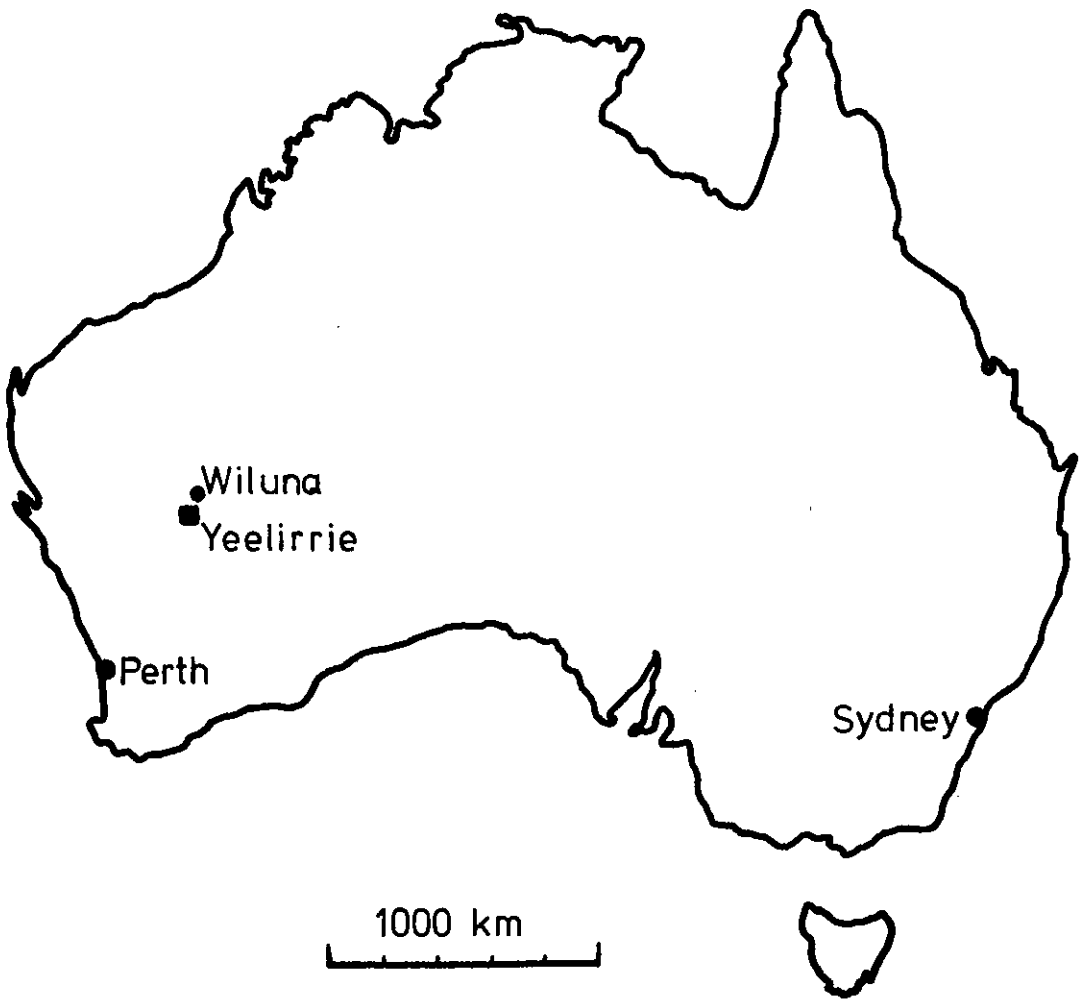

FIGURE 1. LOCATION OF YEELIRRIE

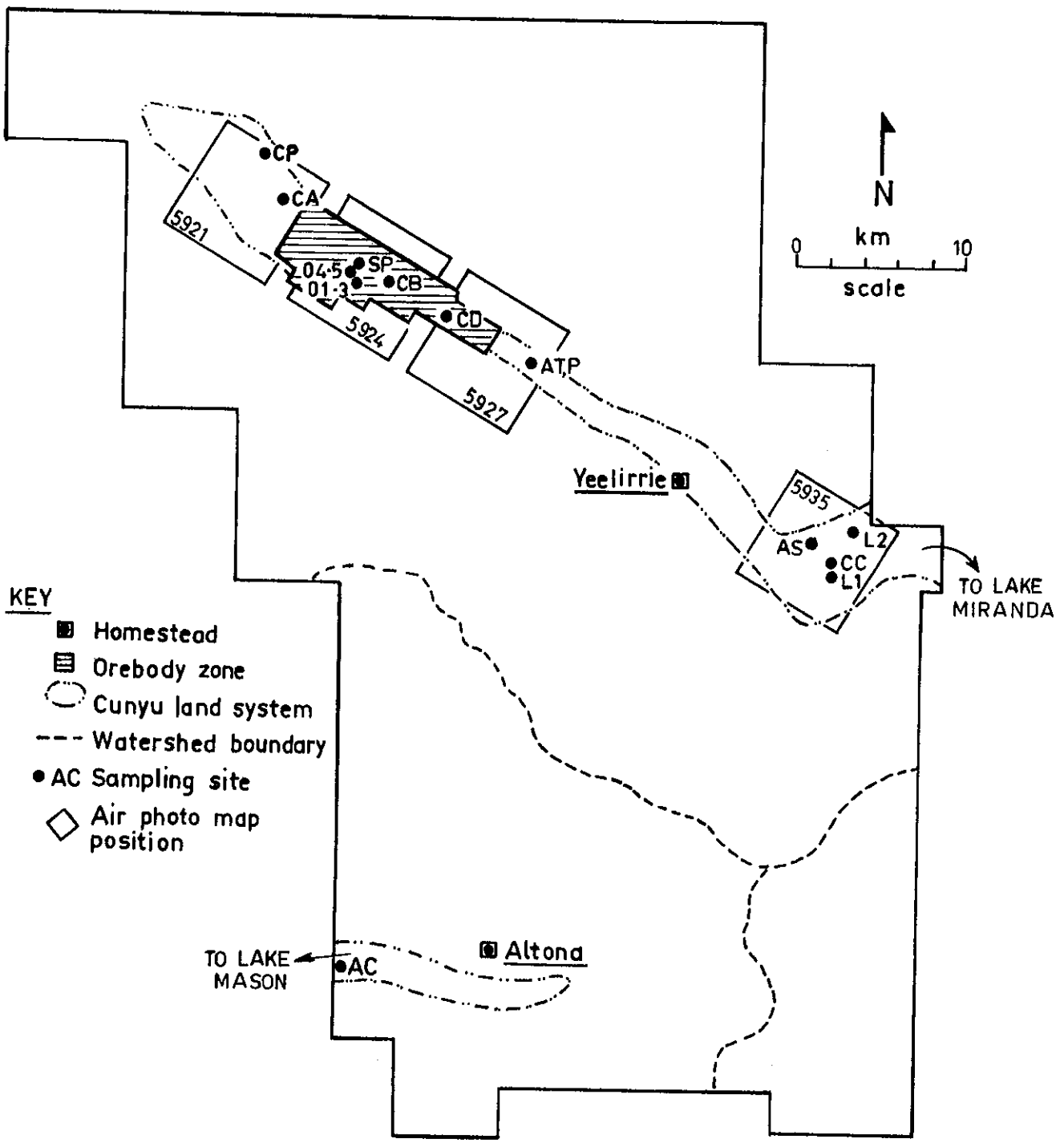

FIGURE 2. YEELIRRIE STATION, SHOWING SAMPLE SITES IN RELATION TO THE OREBODY AND THE WATERSHED

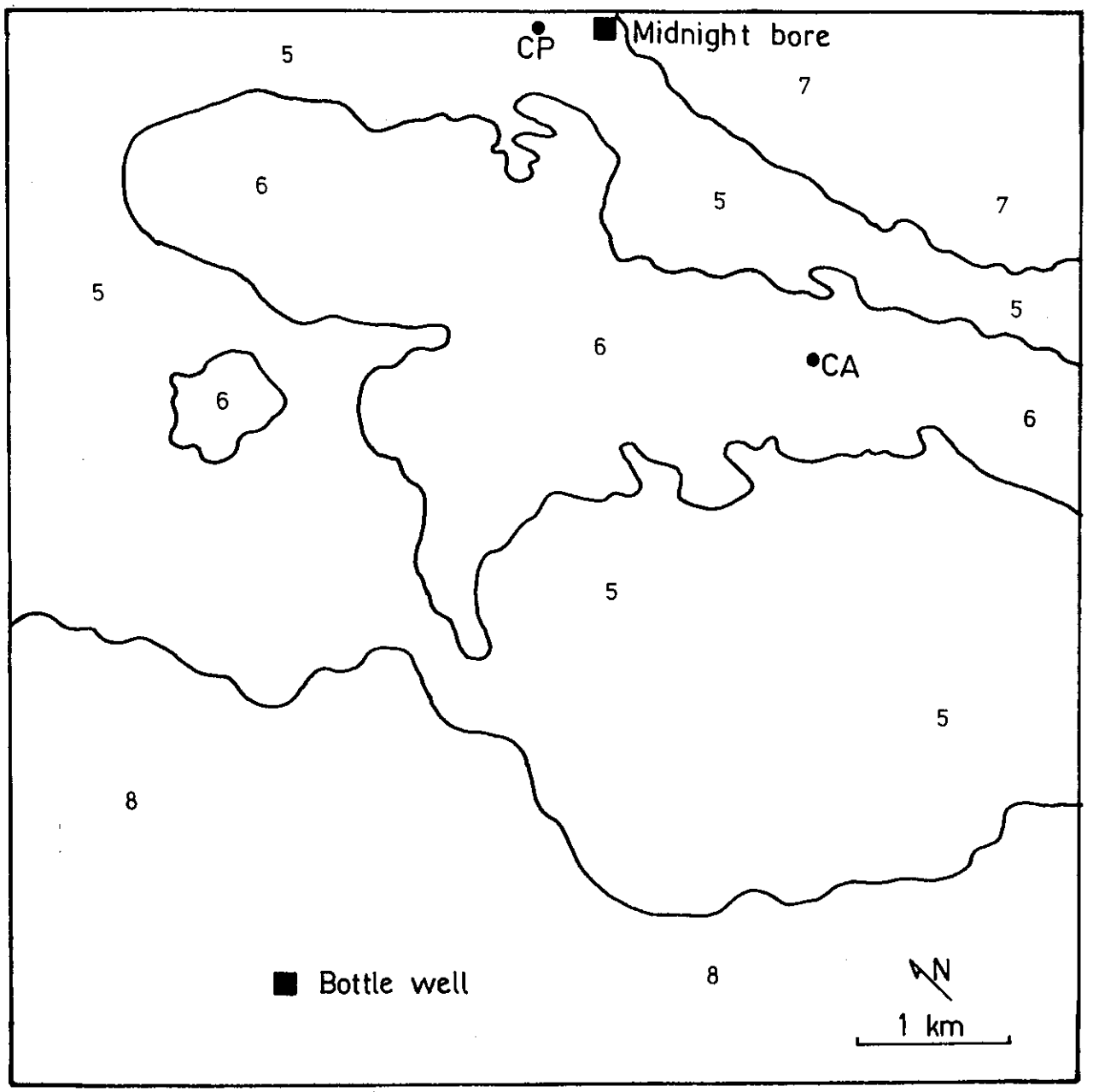

FIGURE 3. ECOLOGICAL MAP OF CALCRETE ZONE ABOVE OREBODY (AIR PHOTO KN 489/5921), WITH SAMPLE SITES AND LAND UNIT NUMBERS

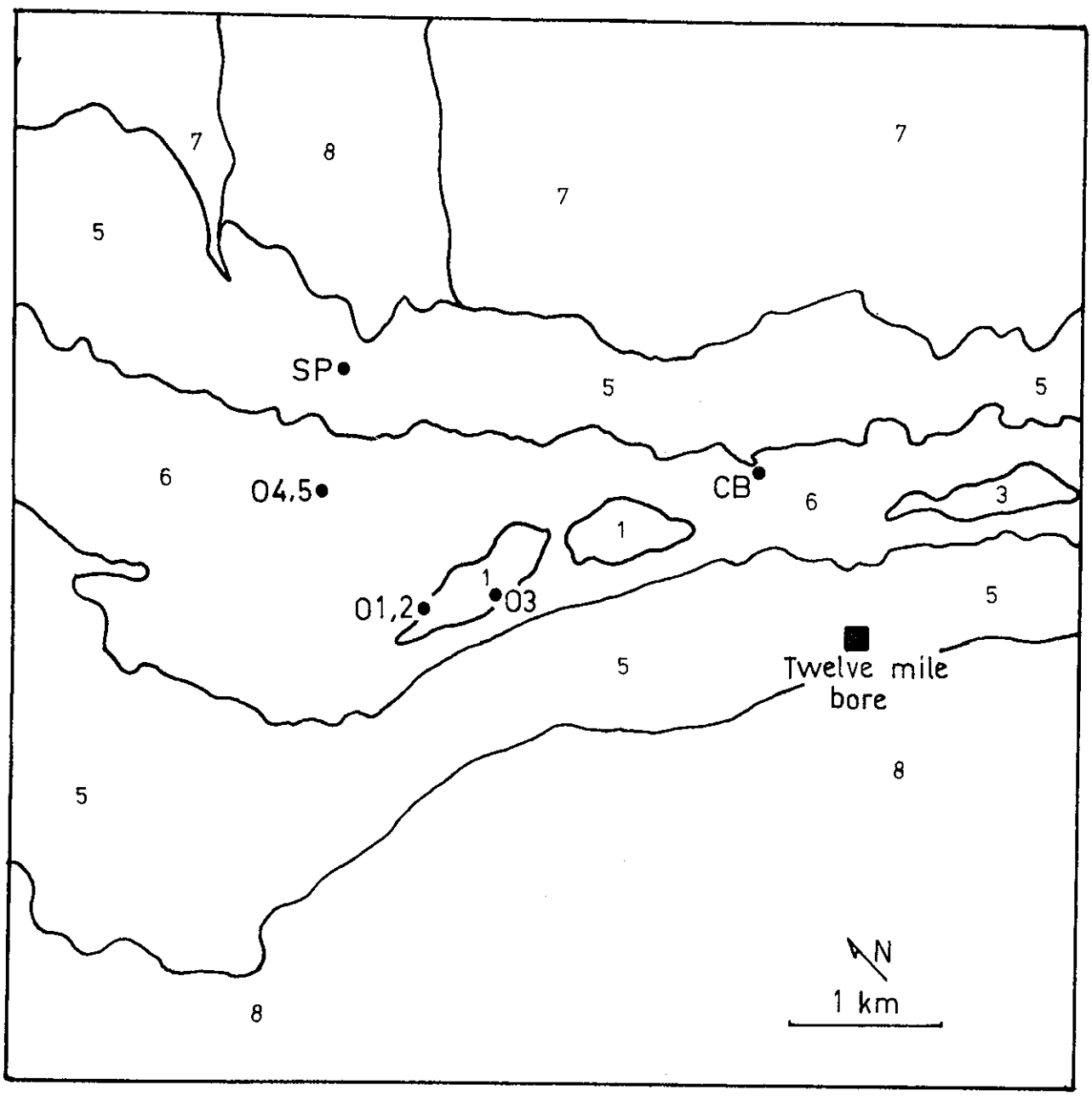

FIGURE 4. ECOLOGICAL MAP OF THE CENTRAL OREBODY ZONE (AIR PHOTO KN 489/5924), WITH SAMPLE SITES AND LAND UNIT NUMBERS

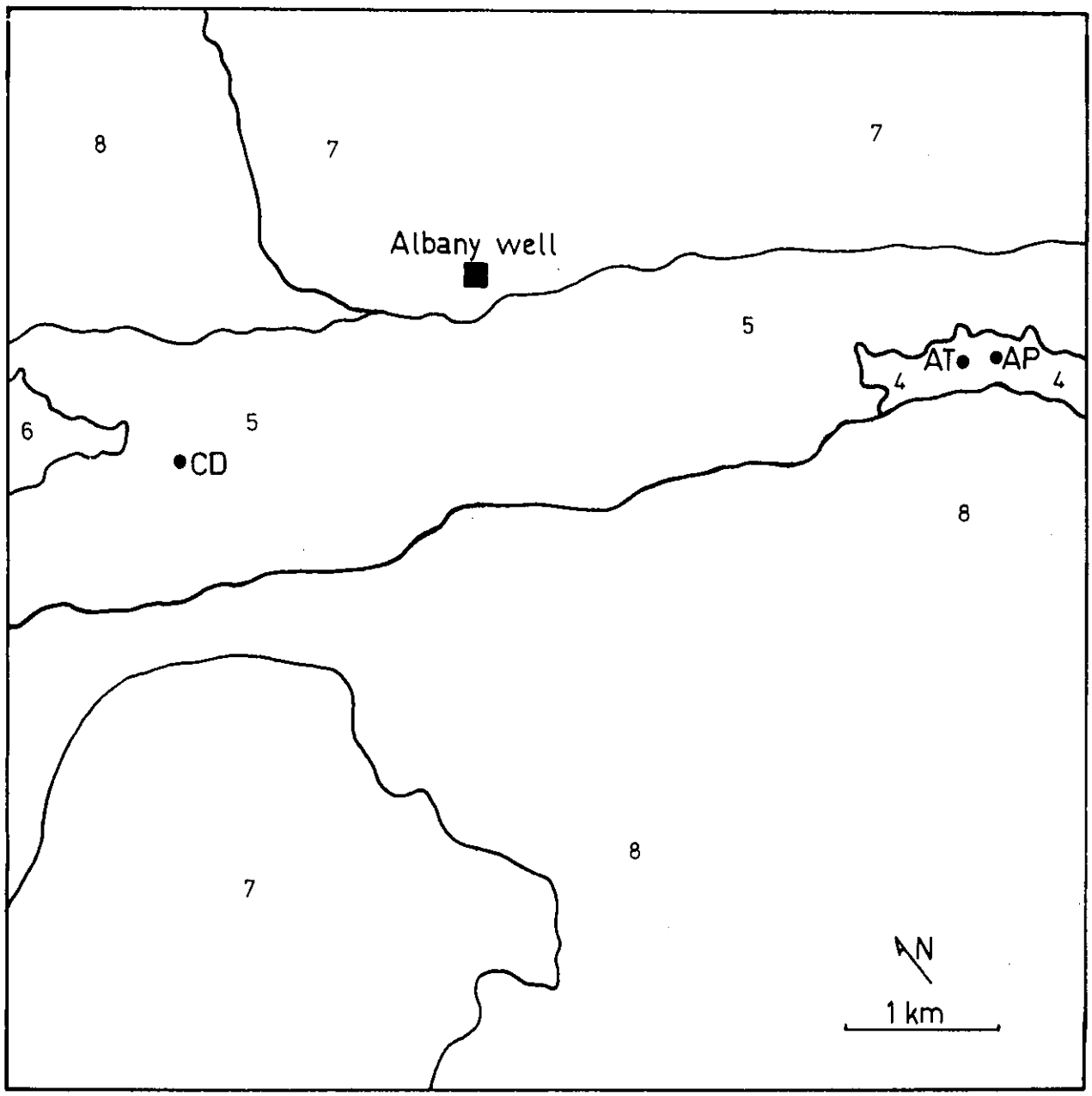

FIGURE 5. ECOLOGICAL MAP OF WATERWAY BELOW THE OREBODY (AIR PHOTO KN 489/5927), WITH SAMPLE SITES AND LAND UNIT NUMBERS

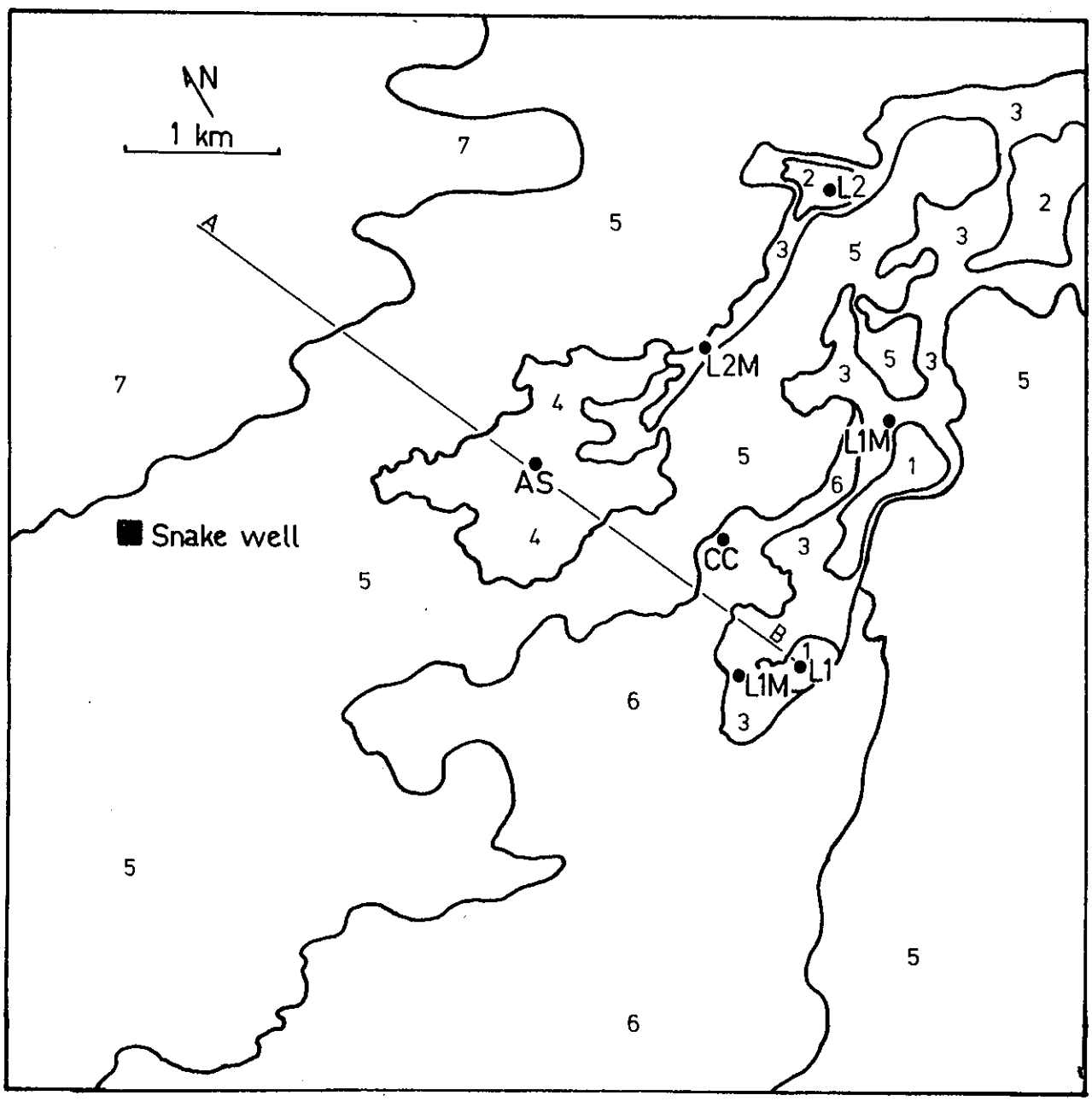

FIGURE 6. ECOLOGICAL MAP OF LAKE ZONE BELOW THE OREBODY (AIR PHOTO KN 489/5935), WITH SAMPLE SITES AND LAND UNIT NUMBERS

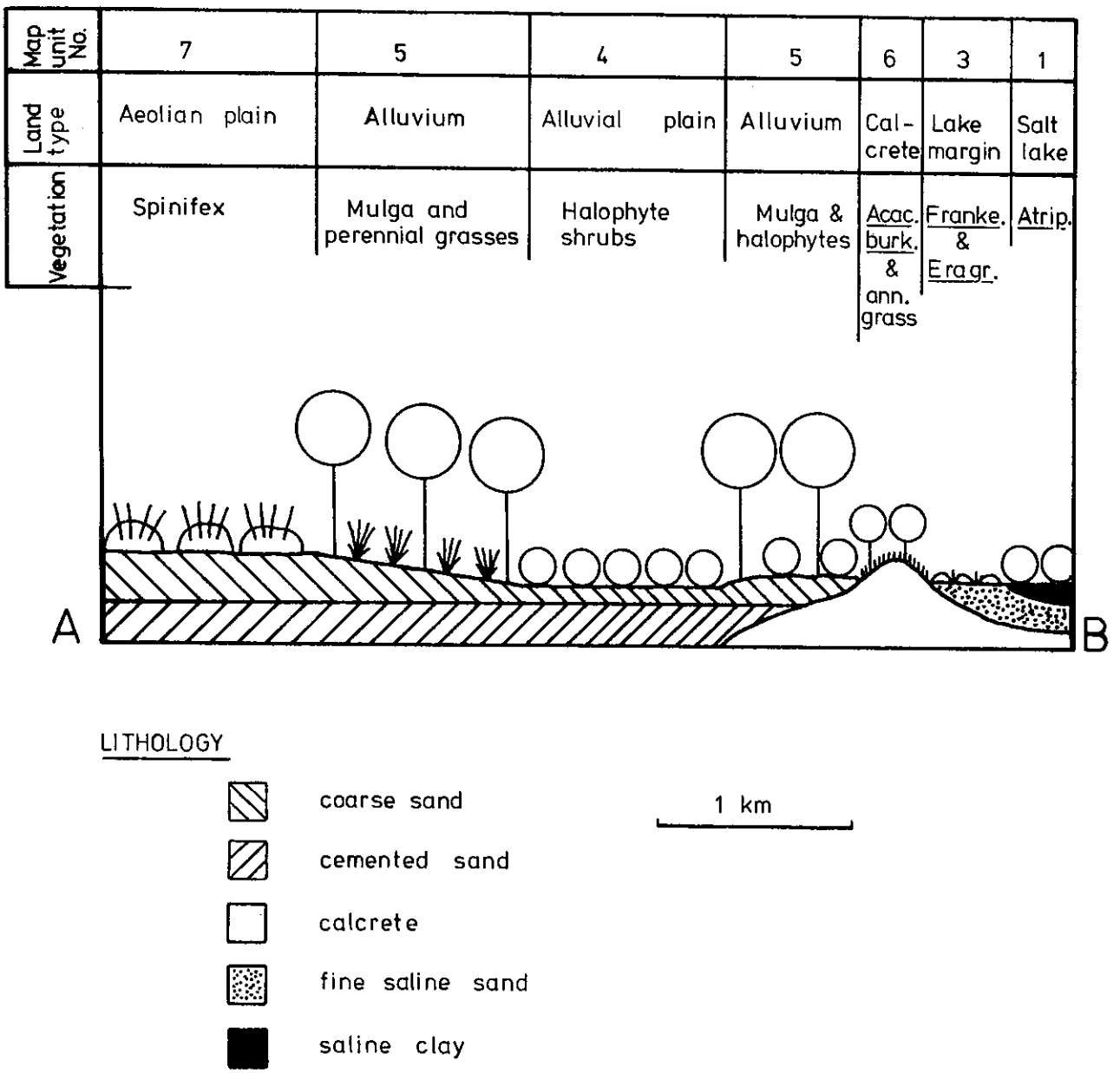

FIGURE 7. SCHEMATIC CROSS-SECTION (A–B) FROM FIGURE 6, SHOWING VEGETATION, SOIL AND TOPOGRAPHY

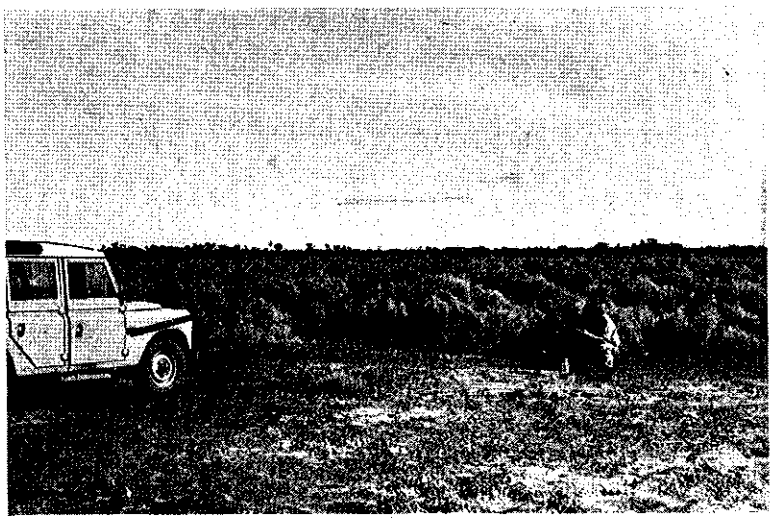

PLATE 1 Salt lake (site L1, land unit 1) formed on calcrete, dominated by salt bush (*Atriplex*)

PLATE 2 Salt lake (site L2, land unit 2) developed on alluvium, dominated by samphire (*Arthrocnemum*)

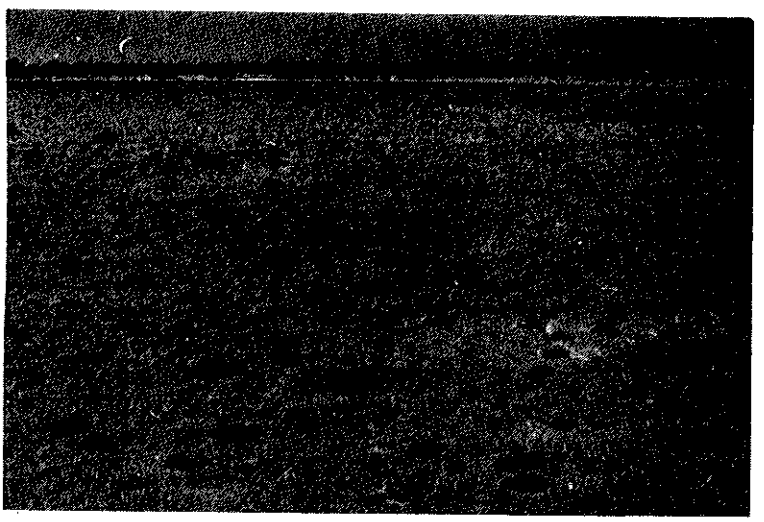

PLATE 3 Lake margin (site L1M, 1-3; land unit 3) dominated by *Frankenia* and *Eragrostis*

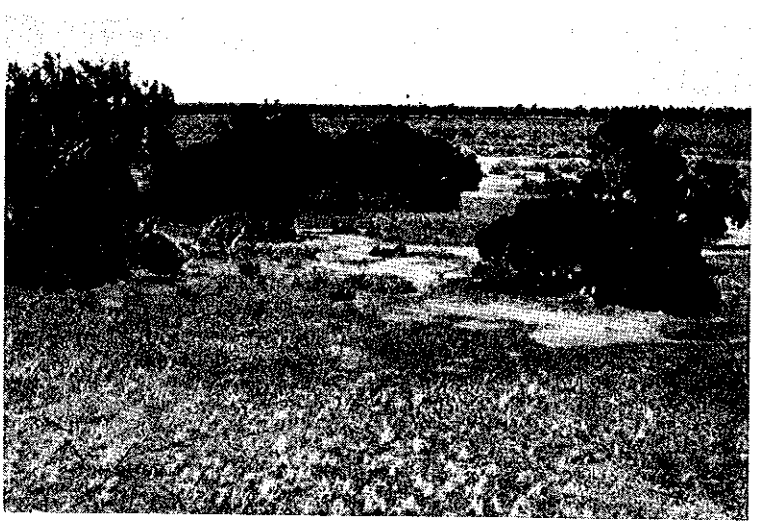

PLATE 4 Lake margin (site L1M, 4-6; land unit 3) with tea-tree (*Melaleuca*), and shallow soil over calcrete in the foreground, carrying remnant annual grasses

PLATE 5 Lake margin (site L2M; land unit 3) carrying *Atriplex*, *Frankenia* and *Cratystylis* shrubs

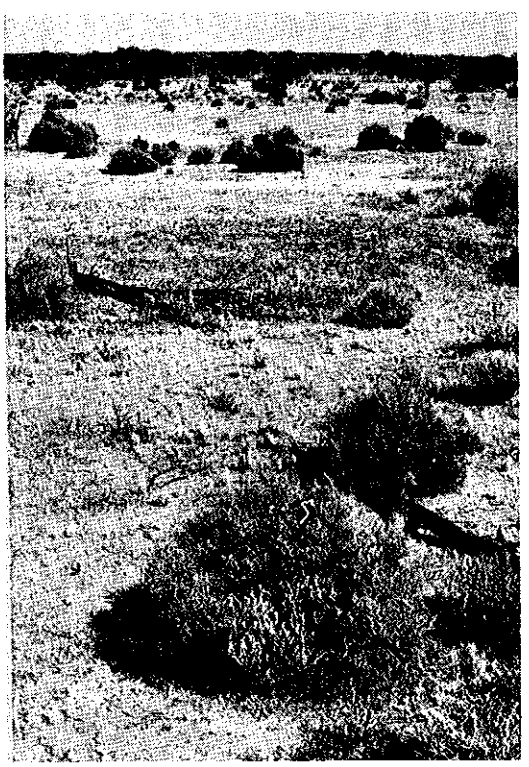

PLATE 6 Halophyte plain (site AT; land unit 4) with scattered *Maireana* and *Cratystylis* shrubs and remnants of annual ground cover

PLATE 7 Alluvial valley fill zone (land unit 5) carrying broad-leaf mulga (*Acacia aneura*) low woodland and Wanderrie (*Danthonia bipartita*) perennial grass layer

PLATE 8 Calcrete complex (land unit 6) with annual grass ground cover, *Acacia burkitti* shrub layer and *Eucalyptus* tree layer

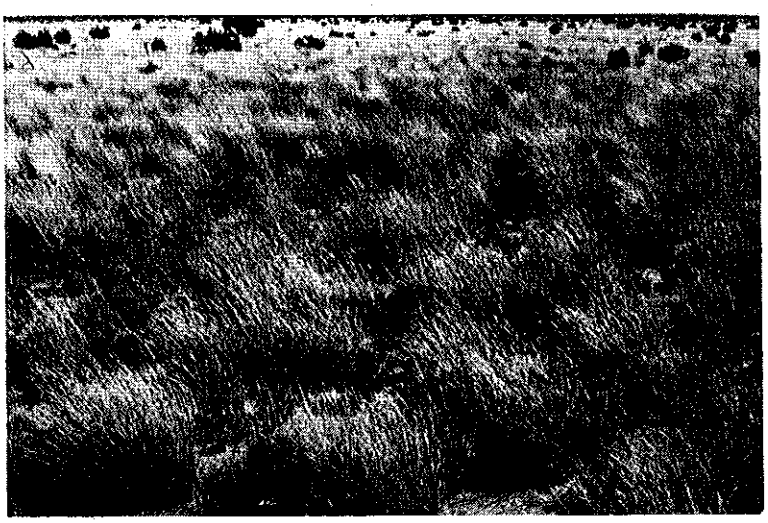

PLATE 9 Sandplain (land unit 7), carrying spinifex (*Triodia basedowii*) with scattered low shrubs of various types

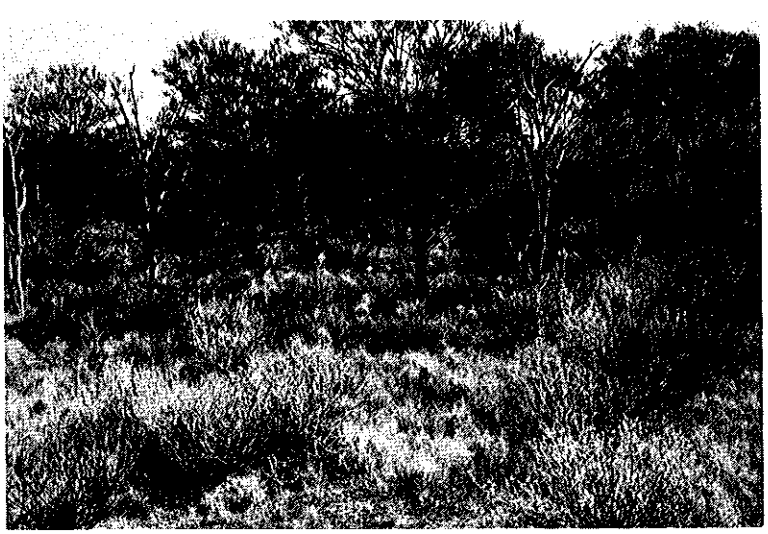

PLATE 10 Alluvial run-off zone (land unit 8), carrying narrow-leaf mulga (*Acacia aneura*) low woodland, shrub layer of *Ptilotus obovatus* and *Eremophila spp.* and remnants of annual ground cover

PLATE 11 Pan depression (site AP; land unit 4) carrying a dense shrub cover of many different species, and a sparsely covered, or scalded surface

APPENDIX A

SAMPLE DATA, SHOWING THE SPECIES COLLECTED, SAMPLE NUMBERS, SOIL TYPES AND PURPOSE OF SAMPLE

Site No/Date	Species Collected	Replicate Sample Numbers		Soil Type	Land Unit	Purpose of Site
		Plant	Soil			
April 1976						
AT	*Maireana pyramidata*	2179,2180,2181	2209	Loamy coarse sand	Halophyte plain	Downstream of orebody
	Bassia sp.	2175,2176,2177	2210			
	Ptilotus obovatus	2187,2188,2189	2211			
	Cratystylis subspinescens	2158,2159,2160				
AP	*Ptilotus obovatus*	2190,2191,2192		Clay loam	Pan	"
	Grevillea sp.	2172,2173,2174	2212			
	Eremophila longifolia	2162,2163,2164	2213			
	Acacia tetragonophylla	2141,2142,2143	2214			
	Acacia stowardii	2137,2138,2139				
L2M	*Atriplex bunburyana*	2149,2150,2151	2206	Sandy clay loam	Lake margin	Groundwater expression
	Cratystylis	2155,2156,2157	2207			
	Frankenia sp.2.	2169,2170,2171	2208			
L2	*Arthrocnemum leiostachyum*	2152,2153,2154	2203,2204,2205	Clay loam	Lake	Surface drainage accumulation
L1	*Atriplex sp.*	2145,2146,2147	2194,2195,2196	Friable clay	Lake	Surface drainage accumulation
L1M,1,2,3	*Frankenia sp.1*	2166,2167,2168	2197,2198,2199	Fine sand with clay crust	Lake margin	Groundwater expression
L1M,4,5,6	*Melaleuca sp.*	2183,2184,2185	2200,2201,2202	Friable clay	"	"
O1	*Atriplex sp.*	2148	2215	Friable clay	Lake	Lake overlying orebody
O2	*Cratystylis subspinescens*	2161	2216			
O3	*Melaleuca sp.*	2186	2217			
O4	*Acacia stowardii*	2140		Loam	Pan within calcrete complex	AT and AP species occurrence on orebody
	A. tetragonophylla	2144 (4)	2218			
	Eremophila longifolia	2165				
O5	*Maireana pyramidata*	2182				
	Ptilotus obovatus	2193 (5)	2219			

APPENDIX A (continued)

Site No/Date	Species Collected	Replicate Sample Numbers		Soil Type	Land Unit	Purpose of Site
		Plant	Soil			
06	*Maireana sp.* (annual)	2178	2220	Ore dump	-	Uptake of metals from ore
October 1976						
07	*Ptilotus obovatus*	4129	4086	Ore dump	-	"
08	*Maireana pyramidata*	4127	4087	"	-	"
AC	*Frankenia sp.1*	4124,4125,4126	4101,4102,4103	Fine sand with clay crust	Lake Margin	A control for site LlM:1-3
CP	*Acacia stowardii*	4130	4084,4085	Clay loam	Pan	Control for site AP
SD:1,2	Soil flooded with slot water		4076,4077,4078 4079	Loam	Calcrete complex over ore deposit	To measure infiltration of metals from discharged slot water
SD:3,4	Adjacent uncontaminated soil		4080,4081,4082 4083	Gravelly loam		
SP	*Maireana pyramidata*	4128	4088	Clay loam	Pan	Three plants marginally influenced by discharge of slot water
CA	*Acacia burkittii*	4112,4113,4114	4089,4090,4091	Loam with carbonate gravel	Calcrete ridge	Control for CD and CC
CB	"	4115,4116,4117	4092,4093,4094	"	"	Outcrop of ore at surface
CC	"	4118,4119,4120	4095,4096,4097	"	"	Edge of lake zone
CD	"	4121,4122,4123	4098,4099,4100	"	"	Downstream extremity of mineralised calcrete

APPENDIX A (continued)

Site No/Date	Species Collected	Replicate Sample Numbers		Soil Type	Land Unit	Purpose of Site
		Plant	Soil			
CB,CC, CD Composite	*Stipa scabra* (remnants with some green shoots)	4373				
Slot	*Ruppia maritima*	4131		Exposed ore	Orebody	The only vascular plant growing in the slot water
AS:1	Algal crust		4104,4105	Loamy sand	Halophyte plain	To examine influence of algal crust on metal distribution
AS:2	Adjacent bare soil		4106,4107	"	"	
AS:3	Algal crust		4108,4109	"	"	
AS:4	Adjacent bare soil		4110,4111	"	"	

APPENDIX B

SOIL CHEMICAL DATA ARRANGED IN GROUPS ACCORDING TO POLYTHETIC SIMILARITY

Sample No.	Sample Site	Depth (cm)	Na	K	Ca	Mg	Cu	Pb	Mo	V	Sb	As	Se	U	^{226}Ra	^{210}Pb	pH	Ash/ dry
			(%) ash				(ppm) ash								(pCi/g) ash		(wt%)	
Lake bed soils																		
2194	L1:1	0-10	0.40	1.0	0.8	11.6	24	12	6	140	1.5	15	0.5	3.5	16.0	9.1	8.5	96.2
2195	L1:2	"	0.13	0.9	0.8	11.3	22	8	4	130	1.5	35	0.4	2.6	17.0	9.1	8.2	96.0
2196	L1:3	"	0.45	1.0	1.1	11.1	26	6	6	120	1.5	15	0.5	4.4	16.0	9.1	8.0	95.3
2200	LIM:4	"	0.49	0.9	2.4	4.6	14	4	<4	50	1.0	35	0.6	13.2	2.3	4.6	8.2	95.3
2201	LIM:5	"	0.10	0.7	3.6	3.8	22	<4	12	50	0.5	35	0.3	17.9	3.2	5.8	8.1	97.1
2202	LIM:6	"	0.32	0.8	1.1	3.8	18	10	<4	10	1.5	30	0.5	6.9	4.0	9.2	8.2	95.8
2203	L2:1	"	0.56	1.3	1.9	5.0	30	6	14	60	1.0	90	0.3	14.0	3.0	3.6	8.2	95.9
2204	L2:2	"	1.27	1.3	3.6	4.7	26	10	12	60	1.0	25	0.4	9.4	4.2	3.8	8.1	94.9
2205	L2:3	"	1.17	1.5	0.8	6.0	34	16	10	100	2.5	35	0.7	9.4	3.6	3.7	8.1	94.6
2215	01	"	0.10	1.0	2.0	7.3	22	10	<4	130	<0.5	35	0.6	53.6	22.0	27.2	8.2	95.5
2216	02	"	0.09	0.9	1.3	5.3	20	10	<4	110	<0.5	20	0.5	37.0	22.0	26.0	8.7	96.0
2217	03	"	0.28	0.9	2.3	6.7	24	10	6	120	<0.5	60	0.3	51.7	21.0	40.0	8.3	94.9
		Mean	0.45	1.0	1.8	6.8	24	9	7	89	1.3	35	0.5	18.6	11.2	12.6	8.2	95.6
		s.d.	0.40	0.2	1.0	3.0	5	3	4	41	0.6	20	0.1	18.3	8.4	11.8	0.2	0.7
Lake margin soils																		
2197	LIM:1	0-10	0.26	0.6	8.4	4.4	10	4	8	40	2.0	10	0.6	64.0	4.8	3.6	8.2	97.1
2198	LIM:2	"	0.32	0.3	17.8	2.4	8	6	<4	10	0.5	5	0.3	43.9	2.8	2.4	8.0	97.9
2199	LIM:3	"	0.72	0.6	10.8	3.3	10	4	<4	30	2.5	5	0.4	65.0	2.5	3.2	8.1	97.1
4101	AC:1	"	1.39	0.3	22.1	0.5	7	4	3	20	<.5	5	0.4	3.8	0.61	1.5	8.5	84.2
4102	AC:2	"	0.84	0.2	23.3	0.5	3	2	6	10	<.5	<5	0.4	3.5	0.24	2.4	9.0	82.1
4103	AC:3	"	0.98	0.2	61.0	0.5	7	3	4	20	<.5	<5	0.4	3.1	0.10	1.1	8.7	82.0
		Mean	0.75	0.4	23.9	1.9	8	4	5	22	0.5	6	0.4	30.4	1.84	2.4	8.4	90.1
		s.d.	0.42	0.2	19.1	1.7	3	1	2	12		2	0.1	30.5	1.86	1.0	0.4	8.0

APPENDIX B (continued)

Sample No.	Sample Site	Depth (cm)	Na	K	Ca	Mg	Cu	Pb	Mo	V	Sb	As	Se	U	^{226}Ra	^{210}Pb	pH	Ash/dry
			(%) ash				(ppm) ash								(pCi/g) ash		(wt%)	
Water influenced soils																		
2206	L2M:1	0-10	0.49	1.4	0.3	1.4	26	12	<4	50	0.5	25	0.3	24.1	1.4	3.5	8.1	97.6
2207	L2M:2	"	0.36	1.5	0.2	1.6	30	20	8	80	<0.5	35	0.3	26.2	1.8	3.3	8.2	97.0
2208	L2M:3	"	0.36	1.3	1.8	2.2	24	12	4	40	<0.5	25	0.2	13.6	0.9	2.6	8.0	96.7
4076	SD1	0-1	0.58	1.2	2.1	3.1	23	16	8	80	<0.5	10	0.4	8.0	88.4	46	10.2	82.3
4077	SD1	1-20	0.52	1.2	2.8	3.1	23	15	8	80	<0.5	15	0.3	8.1	54.2	39	9.6	94.9
4078	SD2	0-1	0.38	1.1	2.2	3.0	21	16	10	60	<0.5	10	0.3	6.2	73.0	35	9.7	93.8
4079	SD2	1-20	0.70	1.1	3.2	3.1	22	15	8	75	<0.5	10	0.3	6.1	24.9	13	9.3	93.6
4080	SD3	0-1	0.08	0.9	3.9	2.6	17	12	7	60	<0.5	5	0.3	6.2	115	121	9.1	95.8
4081	SD3	1-20	0.07	0.8	7.6	2.9	18	10	6	60	<0.5	5	0.4	8.4	114	25	9.2	94.4
4082	SD4	0-1	0.08	0.9	3.8	2.8	21	15	12	80	<0.5	5	0.2	15.1	144	84	8.9	94.9
4083	SD4	1-20	0.09	0.9	6.6	3.1	20	14	7	80	<0.5	5	0.3	22.6	145	76	9.3	94.5
		Mean	0.34	1.1	3.1	2.6	22	14	7	68	<0.5	14	0.3	13.1	69.3	41	9.1	94.1
		s.d.	0.23	0.2	2.3	0.6	4	3	2	14		10	0.1	7.8	56.4	39	0.7	4.1

APPENDIX B (continued)

Sample No.	Sample Site	Depth (cm)	Na (%) ash	K (%) ash	Ca (%) ash	Mg (%) ash	Cu (ppm) ash	Pb (ppm) ash	Mo (ppm) ash	V (ppm) ash	Sb (ppm) ash	As (ppm) ash	Se (ppm) ash	U (ppm) ash	^{226}Ra (pCi/g) ash	^{210}Pb (pCi/g) ash	pH (wt%)	Ash/dry (wt%)
Dry valley fill soils																		
2209	AT:1	0-10	0.12	1.3	0.1	0.2	18	12	<4	40	<0.5	15	0.2	2.6	0.66	3.1	7.6	98.4
2210	AT:2	"	0.13	1.3	0.1	0.1	18	10	<4	10	0.5	15	0.3	3.3	1.60	3.0	7.2	98.4
2211	AT:3	"	0.11	1.3	0.1	0.1	18	8	<4	40	1.0	15	0.4	3.5	0.74	2.6	7.3	98.2
2212	AP:1	"	0.08	1.3	0.1	0.2	26	20	10	100	1.0	20	0.3	9.2	2.50	5.4	6.6	96.5
2213	AP:2	"	0.08	1.3	0.1	0.2	26	12	6	40	0.5	20	0.4	11.0	1.70	5.8	6.6	97.2
2214	AP:3	"	0.10	1.4	0.1	0.3	30	18	<4	90	1.5	20	0.3	14.0	0.94	4.3	6.6	98.0
2218	O4	"	0.07	1.1	0.1	0.3	22	8	<4	50	1.5	10	0.3	3.7	2.00	7.6	7.5	97.2
2219	O5	"	0.07	0.9	0.1	0.2	18	6	6	30	0.5	5	0.3	2.9	1.30	1.7	7.3	98.7
4084	CP	0-1	0.07	1.1	0.1	0.1	19	14	8	55	<0.5	8	0.2	2.6	0.37	3.2	7.8	96.9
4085	CP	1-10	0.06	1.1	0.1	0.1	21	14	12	70	<0.5	5	0.3	3.2	0.44	2.1	7.1	97.4
4088	SP	0-10	0.15	1.1	0.3	0.3	19	19	10	70	<0.5	8	0.2	9.1	6.7	2.7	8.5	96.2
4104	AS:1	0-0.5	0.09	1.0	0.1	0.1	15	10	16	60	<0.5	5	0.2	3.5	1.2	1.5	6.2	98.1
4105	AS:1	0.5-3	0.09	1.0	0.1	0.1	10	9	8	45	<0.5	<5	0.2	2.7	1.6	1.2	6.7	99.3
4106	AS:2	0-0.5	0.04	0.7	0.1	0.1	9	7	5	25	<0.5	5	0.1	1.0	0.7	1.5	6.6	99.0
4107	AS:2	0.5-3	0.06	0.9	0.1	0.1	9	9	4	30	<0.5	5	0.2	1.6	0.23	1.2	6.3	99.3
4108	AS:3	0-0.5	0.10	1.0	0.1	0.1	13	10	5	50	<0.5	<5	0.3	2.6	0.35	1.9	6.5	97.6
4109	AS:3	0.5-3	0.07	0.8	0.1	0.1	8	8	2	35	<0.5	<5	0.2	2.0	0.43	0.9	6.5	99.2
4110	AS:4	0-0.5	0.07	0.9	0.1	0.1	7	8	6	20	<0.5	<5	0.2	1.5	0.36	1.0	6.9	99.1
4111	AS:4	0.5-3	0.05	0.8	0.1	0.1	5	9	5	10	<0.5	5	0.2	1.5	0.35	1.1	7.2	99.7
		Mean	0.08	1.1	0.1	0.2	16	11	6	46	<0.5*	10	0.3	4.1	1.27	2.7	7.0	98.1
		s.d.	0.03	0.2	0.05	0.1	7	4	3	24		6	0.1	3.8	1.47	1.9	0.6	1.0

* = median

APPENDIX B (continued)

Sample No.	Sample Site	Depth (cm)	Na (%) ash	K (%) ash	Ca (%) ash	Mg (%) ash	Cu (ppm) ash	Pb (ppm) ash	Mo (ppm) ash	V (ppm) ash	Sb (ppm) ash	As (ppm) ash	Se (ppm) ash	U (ppm) ash	^{226}Ra (pCi/g) ash	^{210}Pb (pCi/g) ash	pH (wt%)	Ash/dry (wt%)
Calcreted valley fill soils																		
4089	CA:1	0-10	0.08	1.1	2.1	0.7	20	13	4	70	<.5	5	0.3	3.1	1.28	2.3	8.6	96.1
4090	CA:2	"	0.07	0.9	4.3	0.6	14	12	4	45	<.5	5	0.1	1.8	0.83	2.3	8.9	97.5
4091	CA:3	"	0.08	1.1	3.4	0.3	16	14	8	50	<.5	5	0.3	1.7	0.98	8.9	8.8	97.8
4092	CB:1	"	0.09	1.1	0.7	0.6	13	15	3	50	<.5	5	0.2	36.0	15.4	58.4	8.8	97.6
4093	CB:2	"	0.10	1.2	0.4	0.5	14	13	2	55	<.5	5	0.1	5.7	32.7	42.4	8.7	96.8
4094	CB:3	"	0.10	1.1	1.3	0.7	12	17	2	60	<.5	5	0.2	5.6	80.1	66.8	8.6	97.3
4095	CC:1	"	0.08	1.0	0.9	0.5	10	11	6	45	<.5	<5	0.3	1.2	1.0	1.2	8.6	98.4
4096	CC:2	"	0.10	1.1	2.0	0.6	12	10	3	35	<.5	5	0.2	1.1	2.7	2.7	8.5	97.6
4097	CC:3	"	0.07	0.9	0.2	0.3	10	11	4	45	<.5	<5	0.1	1.3	0.85	3.1	8.3	98.5
4098	CD:1	"	0.09	1.1	1.2	0.4	10	13	4	25	<.5	5	0.2	5.9	6.67	6.7	8.9	98.3
4099	CD:2	"	0.08	1.1	0.8	0.5	13		4	45	<.5	<5	0.2	7.5	13.30	12.3	8.6	97.6
4100	CD:3	"	0.08	1.1	0.2	0.3	13	12	5	45	<.5	<5	0.2	3.9	9.40	3.9	8.5	98.8
		Mean	0.09	1.1	1.5	0.5	13	13	4	48	<.5	5	0.2	3.5*	4.7*	5.3*	8.7	97.7
		s.d.	0.01	0.1	1.3	0.1	3	2	2	11	0	0	0.1				0.2	0.8
Mineralized calcrete																		
2220	06	0-10	0.22	0.9	7.3	8.9	20	4	<4	900	<0.5	20	0.1	2920	970	1196	9.2	96.5
4086	07	"	0.30	1.1	7.2	8.1	19	11	27	1050	<0.5	10	0.2	3375	966	1069	9.4	91.7
4087	08	"	0.41	0.7	11.8	10.9	14	5	32	1050	<0.5	12	0.2	4602	1070	580	10.9	96.5
		Mean	0.31	0.9	8.8	9.3	18	7	27*	1000	<0.5	14	0.2	3632	1002	948	9.8	94.9
		s.d.	0.10	0.2	2.6	1.4	3	4		87		5	0.1	870	59	325	0.9	2.8

APPENDIX C

VEGETATION CHEMICAL DATA ARRANGED BY SPECIES, WITHIN GROUPS OF POLYTHETIC SIMILARITY

Sample No.	Sample Site	Na (%) ash	K (%) ash	Ca (%) ash	Mg (%) ash	Cu (ppm) ash	Pb (ppm) ash	Mo (ppm) ash	V (ppm) ash	Sb (ppm) ash	As (ppm) ash	Se (ppm) ash	U (ppm) ash	^{226}Ra (pCi/g) ash	^{210}Pb (pCi/g) ash	Ash/Dry (wt%)	Ash/Fresh (wt%)
XEROPHYTE SHRUBS - with phyllodes																	
Acacia stowardii																	
2137	AP:1	0.1	6.6	33.0	1.9	46	<2	40	2	<4	13	1.6	0.6	0.17	14	9.6	6.6
2138	AP:2	0.1	8.7	30.6	2.1	58	<2	65	<1	<4	13	1.1	0.6	0.13	16	9.0	6.1
2139	AP:3	0.2	14.8	25.6	2.0	94	<2	15	1	<4	14	1.4	0.8	0.10	34	5.6	4.1
2140	O4	0.2	15.6	24.2	2.2	80	2	260	6	<4	9	2.9	0.8	0.47	40	6.8	4.0
4130	CP	0.1	9.1	30.5	1.3	59	<2	2	<1		24	0.8	0.3	0.09	22	6.7	5.4
	Mean	0.1	11.0	28.8	1.9	67	<2	40*	2	<4	15	1.6	0.6	0.19	25	7.5	5.2
	s.d.	0.05	4.0	3.7	0.4	19			2		6	0.8	0.2	0.16	11	1.7	1.2
Acacia burkitti																	
4112	CA:1	1.3	11.5	24.4	2.9	58	<2	24	<1	<4	220	1.0	0.1	0.19	35	5.0	3.1
4113	CA:1	2.2	14.1	21.3	2.4	39	2	38	<1	<4	67	1.0	0.3	0.25	30	5.1	3.3
4114	CA:3	1.6	14.9	21.6	2.5	79	3	49	<1	<4	226	1.9	0.2	0.23	32	5.3	3.1
4115	CB:1	2.0	14.0	22.0	3.9	37	<2	16	<1	<4	47	2.1	3.3	3.38	152	4.7	3.1
4116	CB:2	1.4	13.9	21.6	4.2	37	<2	9	2	<4	35	1.0	3.2	2.43	78	5.1	3.0
4117	CB:3	2.8	16.9	19.5	3.1	73	<2	9	2	<4	87	1.4	2.1	8.74	118	3.7	2.2
4118	CC:1	2.5	20.9	15.0	2.6	35	<2	30	1	<4	45	1.3	0.4	0.32	36	4.0	2.5
4119	CC:2	1.9	11.7	25.2	2.0	29	<2	38	1	<4	74	< 0.9	0.2	0.20	35	5.4	3.7
4120	CC:3	1.9	14.9	21.6	2.7	32	<2	42	1	<4	55	2.3	1.1	0.33	30	4.4	2.7
4121	CD:1	1.0	12.0	26.3	2.2	37	<2	123	2	<4	33	0.9	1.1	1.94	32	5.4	3.1
4122	CD:2	1.3	11.2	25.5	3.1	44	<2	67	1	<4	36	1.8	2.6	1.79	67	5.5	3.3
4123	CD:3	1.3	13.7	21.8	2.4	78	<2	99	2	<4	32	2.3	2.0	0.44	100	4.4	2.6
	Mean	1.8	14.1	22.2	2.8	48	<2	45	1	<4	80	1.5	1.4	0.38*	62	4.8	3.0
	s.d.	0.5	2.7	3.1	0.7	19		35	0.5		69	0.6	1.2		41	0.6	0.4
Acacia tetragonophylla																	
2141	AP:1	0.2	14.8	23.4	3.2	95	5	80	2	<4	< 4	1.9	1.4	0.94	51	5.4	4.7
2142	AP:2	0.3	15.3	22.4	3.9	100	2	155	2	<4	20	3.7	1.1	1.10	39	4.1	3.1
2143	AP:3	0.3	14.6	24.6	2.8	93	<2	105	1	<4	16	3.1	0.9	1.20	25	4.9	4.0
2144	O4	0.3	12.4	26.0	3.5	66	4	190	2	<4	15	5.5	0.8	1.30	50	5.5	4.8
	Mean	0.3	14.3	24.1	3.4	89	3	133	2	<4	14	3.6	1.1	1.14	41	5.0	4.2
	s.d.	0.05	1.3	1.6	0.5	15	1.5	49	0.5		7	1.5	0.3	0.15	12	0.6	0.8
GROUP MEAN		1.1	13.4	24.1	2.7	60	<2	58	1	<4	52	1.9	1.2	0.48	49	5.5	3.8

APPENDIX C (continued)

Sample No.	Sample Site	Na	K	Ca	Mg	Cu	Pb	Mo	V	Sb	As	Se	U	^{226}Ra	^{210}Pb	Ash/ Dry	Ash/ Fresh
		(%) ash				(ppm) ash								(pCi/g) ash		(wt%)	
XEROPHYTE SHRUBS - with leaves																	
Eremophila longifolia																	
2162	AP:1	0.1	30.1	12.2	2.3	141	3	25	<1	<4	10	1.3	0.3	0.61	6	7.7	3.3
2163	AP:2	0.1	30.2	10.4	2.7	105	2	65	<1	<4	16	< 0.7	1.0	0.76	8	7.2	3.1
2164	AP:3	0.1	29.6	12.4	2.2	138	<2	25	<1	<4	< 3	< 0.6	1.1	0.74	5	7.9	3.5
2165	04	0.2	29.5	13.4	2.4	134	<2	75	<1	<4	15	1.9	0.4	2.8	31	7.9	3.5
	Mean	0.1	29.9	12.1	2.4	130	2	48	<1	<4	11	1.0*	0.7	0.75*	7*	7.8	3.4
	s.d.	0.04	0.4	1.2	0.2	17	0.5	26			6		0.4			0.3	0.2
Grevillea sp.																	
2172	AP:1	0.3	10.6	21.5	3.4	45	2	15	2	<4	52	2.2	3.9	0.10	42	4.6	2.6
2173	AP:2	0.5	13.0	19.0	4.2	62	5	35	2	<4	20	5.1	2.5	0.51	39	5.9	3.6
2174	AP:3	0.9	11.2	19.7	4.0	78	4	36	1	<4	71	4.5	3.7	0.37	75	5.6	3.2
	Mean	0.6	11.6	20.1	3.9	62	4	29	2	<4	48	3.9	3.4	0.33	52	5.4	3.1
	s.d.	0.3	1.2	1.3	0.4	17	1.5	12	0.6		26	1.5	0.8	0.21	20	0.7	0.5
Ptilotus obovatus																	
2187	AT:1	1.3	22.4	8.5	4.3	38	5	21	1	6	53	1.3	3.3	1.80	48	7.5	5.4
2188	AT:2	1.1	16.0	15.1	5.7	32	5	14	<1	<4	33	2.9	1.7	3.67	10	8.5	7.2
2189	AT:3	0.3	14.9	15.0	4.5	33	4	28	<1	<4	24	1.0	5.2	1.15	10	10.0	8.2
2190	AP:1	0.1	15.8	17.4	3.1	28	<2	17	<1	<4	7	2.2	1.1	5.12	8	11.3	7.5
2191	AP:2	0.1	17.5	13.2	5.3	28	2	16	1	<4	20	2.2	2.5	3.92	14	6.9	6.0
2192	AP:3	0.2	18.3	14.0	3.3	44	4	34	1	<4	25	4.4	1.7	2.70	19	5.7	4.8
2193	05	0.2	19.2	12.0	5.2	42	4	36	<1	6	14	6.5	0.9	1.90	16	8.5	6.3
4129	07	0.3	19.3	12.4	6.0	88	<2	5	95	<4	27	<0.4	1100	380	583	12.0	4.8
	Mean	0.5	17.9	13.5	4.7	36*	4	21	1*	<4*	25	2.6	2.1*	3.19*	15*	8.8	6.3
	s.d.	0.5	2.4	2.6	1.1	20	1	11			14	2.0				2.2	1.3
GROUP MEAN		0.4	19.8	14.4	3.9	66	3	30	1	<4	13	2.4	2.0	1.97	20	7.9	4.9

APPENDIX C (continued)

Sample No.	Sample Site	Na	K	Ca	Mg	Cu	Pb	Mo	V	Sb	As	Se	U	^{226}Ra	^{210}Pb	Ash/ Dry	Ash/ Fresh
		(%) ash				(ppm) ash								(pCi/g) ash		(wt%)	
HALOPHYTE SHRUBS - sodic																	
Arthrocnemum leiostachyum																	
2152	L2:1	24.8	5.4	5.2	2.4	24	<2	5	2	<4	3	0.3	6.7	0.64	5.0	27.4	13.2
2153	L2:2	28.6	4.2	3.0	2.0	20	<2	5	5	<4	1	0.5	7.1	1.50	2.5	27.9	14.2
2154	L2:3	28.6	3.5	2.7	1.9	29	3	10	20	<4	3	0.3	9.3	0.36	2.8	30.1	14.0
	Mean	27.3	4.4	3.6	2.1	24	<2	7	9	<4	2	0.4	7.7	0.83	3.4	28.5	13.8
	s.d.	2.2	1.0	1.4	0.3	5		3	10		1	0.1	1.4	0.58	1.4	1.4	0.5
Atriplex sp.																	
2145	L1:1	12.6	15.8	9.4	4.9	25	<2	10	<1	<4	10	0.4	2.2	4.49	3.8	12.5	8.5
2146	L1:2	14.8	16.6	6.2	3.9	34	<2	10	2	<4	3	1.4	2.7	1.29	3.8	14.6	10.2
2147	L1:3	17.3	15.3	5.8	4.2	27	<2	15	2	<4	4	1.2	1.4	2.80	3.8	17.1	9.6
2148	O1	16.1	14.4	7.2	3.9	36	<2	10	5	<4	4	2.9	3.4	15.00	13.1	12.0	9.9
	Mean	15.2	15.5	7.2	4.2	31	<2	11	3	<4	5	1.5	2.4	3.64*	3.8*	14.1	9.6
	s.d.	2.0	0.9	1.6	0.5	5		3	2		3	1.0	0.8			2.3	0.7
Atriplex bunburyana																	
2149	L2M:1	23.5	11.8	4.6	1.9	10	<2	10	<1	<4	1	0.4	1.3	0.61	5.2	23.0	14.5
2150	L2M:2	24.1	12.2	3.2	2.1	14	<2	10	<1	<4	<1	0.4	0.8	0.91	2.7	25.2	14.2
2151	L2M:3	24.0	11.1	3.7	2.2	9	<2	10	2	<4	1	0.3	0.7	0.45	2.9	28.9	16.8
	Mean	23.9	11.7	3.8	2.1	11	<2	10	<1	<4	1	0.4	0.9	0.66	3.6	25.7	15.2
	s.d.	0.3	0.6	0.7	0.2	3		0				0.1	0.3	0.23	1.4	3.0	1.4
Cratystylis subspinescens																	
2155	L2M:1	13.7	13.2	10.4	2.3	47	<2	40	3	4	16	1.7	0.8	0.65	6.4	8.8	4.7
2156	L2M:2	14.2	12.4	9.8	2.5	72	<2	55	6	<4	8	1.9	0.8	0.72	9.5	7.9	4.4
2157	L2M:3	13.5	14.3	9.0	2.7	37	<2	40	<1	<4	11	1.1	1.1	0.93	9.2	9.1	5.0
2158	AT:1	14.8	12.8	9.2	1.9	76	6	20	<1	4	17	5.8	0.1	4.30	10.2	6.9	5.8
2159	AT:2	13.1	13.0	10.0	2.1	144		25	2	<4	8	8.5	0.4	2.30	15.3	5.3	4.9
2160	AT:3	11.9	13.8	9.4	2.5	129	3	40	<1	4	14	9.8	0.7	0.64	32.7	5.6	5.1
2161	O2	11.9	14.8	10.2	2.6	129	<2	65	4	<4	< 3	3.6	2.2	23.40	145	7.0	4.0
	Mean	13.3	13.5	9.7	2.4	91	<2	41	3	<4	11	4.6	0.9	0.93*	10.2*	7.2	4.8
	s.d.	1.1	0.9	0.5	0.3	43		16	2		5	3.5	0.7			1.5	0.6

APPENDIX C (continued)

Sample No.	Sample Site	Na (%) ash	K (%) ash	Ca (%) ash	Mg (%) ash	Cu (ppm) ash	Pb (ppm) ash	Mo (ppm) ash	V (ppm) ash	Sb (ppm) ash	As (ppm) ash	Se (ppm) ash	U (ppm) ash	^{226}Ra (pCi/g) ash	^{210}Pb (pCi/g) ash	Ash/Dry (wt%)	Ash/Fresh (wt%)
HALOPHYTE SHRUBS - sodic (cont.)																	
Maireana pyramidata																	
2179	AT:1	24.2	7.0	2.5	2.7	35	2	9	1	<4	17	1.1	0.3	0.45	9.9	13.8	7.4
2180	AT:2	22.0	9.4	3.6	3.3	45	<2	8	<1	<4	9	1.3	0.2	0.90	13.4	15.6	9.7
2181	AT:3	17.1	10.1	4.0	4.4	42	2	9	2	<4	6	1.8	1.0	0.66	12.0	14.2	8.3
2182	O5	24.6	8.2	3.2	4.3	32	2	14	2	<4	4	3.8	0.3	0.85	7.3	15.6	7.7
4127	O8	23.7	10.5	3.4	2.2	72	<2	8	5	<4	21	<0.3	84.0	39.0	30.2	17.9	5.3
4128	SP	25.6	6.8	4.1	3.5	41	<2	2	2	<4	16	<0.2	1.1	1.80	4.9	21.6	6.9
	Mean	22.9	8.7	3.5	3.4	45	2	8	2	<4	12	1.4	0.7*	0.88*	13.0	16.5	7.6
	s.d.	3.0	1.6	0.6	0.9	14		4	1.5		7	1.3			9.0	2.9	1.5
Maireana sp.																	
2178	O6	16.6	4.7	4.1	1.0	14	<2	15	<1	<4	10	0.3	4.1	22.0	29.9	29.1	6.7
Bassia sp.																	
2175	AT:1	21.1	4.9	3.0	3.5	15	3	16	1	<4	2	1.2	1.2	0.86	4.5	34.4	11.9
2176	AT:2	16.1	3.7	3.1	3.2	14	4	12	1	<4	3	0.8	1.8	0.48	5.9	46.3	14.7
2177	AT:3	12.2	4.5	3.7	3.6	17	7	14	<1	<4	9	0.5	4.7	1.90	5.3	37.6	16.4
	Mean	16.5	4.4	3.3	3.4	15	5	14	1	<4	5	0.8	2.6	1.08	5.2	39.4	14.3
	s.d.	4.5	0.6	0.4	0.2	2	2	2			4	0.4	1.9	0.74	0.7	6.2	2.3
Melaleuca sp.																	
2183	LIM:4	12.5	9.1	10.4	4.1	22	4	18	2	<4	16	0.5	4.7	1.7	88.5	10.3	5.2
2184	LIM:5	10.2	9.5	12.0	4.0	32	4	19	<1	<4	13	0.9	1.7	3.7	12.6	10.8	5.4
2185	LIM:6	10.8	7.9	10.9	4.6	14	2	22	1	4	9	0.6	2.5	3.5	130	8.9	5.6
2186	O3	9.3	8.3	12.4	3.5	40	2	40	1	4	55	1.1	4.2	22.0	92.6	9.1	5.4
	Mean	10.7	8.7	11.4	4.1	27	3	25	1	4	15*	0.8	3.3	3.6*	90.5*	9.8	5.4
	s.d.	1.3	0.7	0.9	0.5	11	1	10	0.5			0.3	1.4			0.9	0.2
GROUP MEAN		17.9	10.0	6.4	3.0	42	2*	19	3	<4	8	1.8	2.3	2.16	19.1	20.4	8.3

APPENDIX C (continued)

Sample No.	Sample Site	Na	K	Ca	Mg	Cu	Pb	Mo	V	Sb	As	Se	U	^{226}Ra	^{210}Pb	Ash/ Dry	Ash/ Fresh
		(%) ash				(ppm) ash								(pCi/g) ash		(wt%)	
HALOPHYTE SHRUBS - calcic																	
Frankenia sp.1.																	
2166	LIM:1	3.7	0.7	19.8	4.0	10	5	9	<1	<4	2	1.0	48.6	2.4	6.4	41.9	31.2
2167	LIM:2	3.2	0.7	20.5	4.6	9	4	10	<1	<4	3	2.5	57.6	3.6	5.1	40.7	31.2
2168	LIM:3	3.1	0.6	20.5	4.1	8	3	8	2	<4	7	0.5	56.7	3.6	7.0	43.7	35.7
4124	AC:1	4.3	0.9	27.0	2.8	6	<2	2	5	<4	5	0.3	3.8	1.4	4.1	33.8	26.9
4125	AC:2	4.0	0.7	26.0	2.6	6	3	2	4	<4	7	0.4	3.2	1.2	4.4	39.9	32.1
4126	AC:3	4.8	0.8	23.5	3.2	7	3	1	4	<4	15	0.4	4.7	1.1	4.4	39.0	29.6
	Mean	3.9	0.7	22.9	3.6	8	3	5	3	<4	7	0.9	26.7*	2.2	5.2	39.8	30.7
	s.d.	0.7	0.1	3.1	0.8	2	1	4	2		5	0.8		1.2	1.2	3.4	3.4
Frankenia sp.2.																	
2169	L2M:1	12.0	2.5	18.6	3.8	15	4	20	1	<4	24	2.4	5.4	1.9	4.2	16.7	13.2
2170	L2M:2	13.3	2.3	16.6	3.5	14	3	12	1	<4	9	1.2	5.0	1.1	3.4	16.2	11.6
2171	L2M:3	13.4	2.4	15.6	3.3	16	2	15	2	<4	16	0.7	3.9	1.7	4.6	14.7	11.3
	Mean	12.9	2.4	16.9	3.5	15	3	16	1	<4	16	1.4	4.8	1.6	4.1	15.9	12.0
	s.d.	0.8	0.1	1.5	0.3	1	1	4	0.6		8	0.9	0.8	0.4	0.6	1.0	1.0
GROUP MEAN		5.6	1.3	20.9	3.6	10	3	9	2	<4	10	1.1	5.0*	2.0	4.8	21.4	14.6
GRASSES																	
Stipa scabra																	
4373	CA-D Composite	0.1	4.6	2.6	0.9	19	10	10	17	<4	19	0.9	2.5	14.0	19.4	16.5	15.6
HYDROPHYTES																	
Ruppia maritima																	
4131	Slot water	11.4	8.6	4.0	5.4	13	<2	16	100	<4	18	0.9	200	160	105	21.3	4.4

APPENDIX D

METAL LEVELS IN ANIMAL TISSUE CLASSIFIED INTO POLYTHETIC GROUPS

Sample No.	Sample Site	Cu	Pb	Mo	Ni	Cr	V	Sb	As	Se	U	^{226}Ra	^{210}Pb	Ash/ Dry	Ash/ Fresh
		(ppm) ash										(pCi/g) ash		(wt%)	
HIGH LEVEL SHEEP VISCERA															
Liver															
2099	SW1	4800	15	85	5	20	<2	0.70	16	49	0.33	0.4	4.0	6.1	2.5
2103	SW2	4100	4	60	2	20	<2	0.15	27	27	0.50	0.3	3.0	7.4	2.7
2107	AD1	12400	4	20	1	10	<2	0.15	28	89	<.13	0.02	12.0	9.0	3.4
2111	AD2	11400	8	30	3	10	<2	0.15	20	163	<.13	< 0.3	16.9	4.9	1.6
	Mean	8175	8	49	3	15	<2	0.29	23	82	0.27	0.3*	9.0	6.9	2.6
	s.d.	4330	5	30	2	6		0.27	6	60	0.18		6.6	1.8	0.7
Kidney															
2100	SW1	310	15	25	3	35	<2	0.10	< 10	12	0.31	1.0	20.5	4.3	2.0
2104	SW2	65	15	20	2	30	<2	0.15	53	132	0.22	<0.2	17.0	3.8	2.0
2108	AD1	280	15	25	5	15	<2	0.20	192	78	<.13	1.6	18.9	1.3	0.9
2112	AD2	225	20	30	10	30	<2	0.35	200	133	<.13	3.0	25.0	1.5	1.0
	Mean	220	16	25	5	28	<2	0.20	114	89	0.20	1.5	20.4	2.7	1.5
	s.d.	109	3	4	4	9		0.11	97	57	0.09	1.2	3.4	1.5	0.6
LOW LEVEL SHEEP VISCERA															
Liver															
2131	Y1	6000	<2	55	2	1	<2	0.20	< 10	< 10	<.13	0.09	3.3	4.9	1.8
2135	Y2	2600	<2	45	1	<.5	<2	0.50	< 10	< 10	<.13	0.14	4.1	4.5	1.7
	Mean	4300	<2	50	2	0.5	<2	0.35	< 10	< 10	<.13	0.11	3.7	4.7	1.8
Kidney															
2132	Y1	350	10	70	10	1	<2	<.05	< 10	19	<.13	1.4	15.4	5.4	1.1
2136	Y2	20	<2	20	5	<.5	<2	0.30	< 10	< 10	<.13	1.1	14.4	7.7	1.6
	Mean	185	5	45	8	0.5	<2	0.15	< 10	< 10	<.13	1.3	14.9	6.6	1.4

APPENDIX D (continued)

Sample No.	Sample Site	Cu	Pb	Mo	Ni	Cr	V	Sb	As	Se	U	^{226}Ra	^{210}Pb	Ash/ Dry	Ash/ Fresh
		(ppm) ash										(pCi/g) ash		(wt%)	
KANGAROO VISCERA															
Liver															
2115	SL1	40	<2	40	4	1	<2	0.25	< 10	< 10	<.13	< 0.2	41	5.7	1.7
2119	SL2	50	380	65	8	2	<2	140	< 10	78	<.13	3.3	492	5.2	1.2
2123	ND1	110	15	75	4	1	<2	2.0	< 10	< 10	<.13	7.8	41	5.1	1.8
2127	ND2	10	<2	55	10	20	<2	0.25	< 10	< 10	<.13	< 0.4	27	5.5	1.6
Kidney															
2116	SL1	150	<2	2	8	2	<2	0.30	< 10	57	0.54	3.8	63	4.4	1.3
2120	SL2	150	70	45	4	<.5	<2	5.0	< 10	16	2.35	< 0.2	241	9.1	2.1
2128	ND2	140	<2	10	8	2	<2	0.30	< 10	< 10	0.58	< 0.8	48	4.7	1.3
	Mean	93	<2*	42	7	2*	<2	0.30*	< 10	< 10*	<.13*	< 0.8*	48*	5.7	1.6
	s.d.	59		27	3									1.6	0.3
SHEEP FLESH															
2097	SW1	100	15	<2	3	5	<2	0.20	42	42	0.34	< 0.3	4	3.6	1.6
2101	SW2	40	8	<2	1	45	<2	1.00	45	34	0.26	< 0.3	< 2	4.4	1.6
2105	AD1	45	4	<2	1	15	<2	0.15	13	26	0.24	0.5	< 2	3.9	1.7
2109	AD2	35	4	<2	2	15	<2	0.10	83	14	<.13	0.09	2	3.6	0.5
2129	Y1	80	5	5	4	2	<2	0.10	<10	<10	<.13	0.08	< 2	4.0	1.1
2133	Y2	110	10	<2	4	3	<2	0.50	<10	<10	<.13	0.08	< 2	3.8	1.1
	Mean	68	8	<2	3	14	<2	0.34	34	23	0.21	0.09*	< 2	3.9	1.3
	s.d.	33	4		1	16		0.36	29	13	0.09			0.3	0.5
KANGAROO FLESH															
2113	SL1	120	5	<2	4	1	<2	0.10	< 10	10	0.56	0.02	2	4.5	1.2
2117	SL2	140	5	<2	5	1	<2	0.10	< 10	< 10	<.13	0.88	12	4.6	1.1
2121	ND1	140	5	<2	5	3	<2	0.25	< 10	< 10	<.13	0.05	3	4.5	1.1
2125	ND2	140	10	<2	4	2	<2	0.15	< 10	< 10	<.13	0.05	1	4.6	1.1
	Mean	135	6	<2	5	2	<2	0.15	< 10	< 10	*<.13	0.05*	3*	4.6	1.1
	s.d.	10	3		1	1		0.07						0.1	0.1

APPENDIX D (continued)

Sample No.	Sample Site	Cu	Pb	Mo	Ni	Cr	V	Sb	As	Se	U	^{226}Ra	^{210}Pb	Ash/ Dry	Ash/ Fresh
		(ppm) ash										(pCi/g) ash		(wt%)	
SHEEP BONE															
2098	SW1	3	2	<2	2	2	<2	0.05	6	1.3	0.48	4.1	1.3	39.6	29.4
2102	SW2	4	<2	<2	2	5	<2	0.10	4	1.2	2.98	6.8	5.8	40.8	29.4
2106	AD1	3	2	<2	3	5	<2	0.05	7	1.4	<.13	2.8	4.0	35.6	26.4
2110	AD2	2	2	<2	1	5	<2	0.05	5	2.7	<.13	2.8	0.8	37.3	28.1
2130	Y1	10	<2	5	<1	<.5	<2	<.05	<1	< 1.0	<.13	1.6	2.2	35.5	26.6
2134	Y2	5	<2	5	<1	1	<2	0.30	< 1	< 1.0	<.13	2.0	2.0	32.9	23.3
	Mean	5	2	<2	2	3	<2	0.10	4	1.4	<.13*	3.4	2.7	37.0	27.2
	s.d.	3			1	2		0.10	3	0.6		1.9	1.9	2.9	2.3
KANGAROO BONE															
2114	SL1	8	5	<2	<1	0.5	<2	0.20	< 1	< 1.0	<.13	3.8	1.3	45.0	31.8
2118	SL2	10	<2	<2	<1	0.5	<2	0.15	< 1	2.2	<.13	38.0	5.5	44.5	32.9
2122	ND1	10	<2	5	<1	0.5	<2	0.25	< 1	< 1.0	<.13	2.0	2.3	43.2	30.7
2126	ND2	8	<2	<2	<1	<.5	<2	0.05	< 1	< 1.0	<.13	2.0	0.6	47.5	33.4
	Mean	9	<2	<2	<1	0.5	<2	0.16	< 1	< 1.0*	<.13	2.9*	2.4	45.1	32.2
	s.d.	1						0.09					2.2	1.8	1.2

THREE BASELINE STUDIES IN THE ENVIRONMENT OF THE URANIUM DEPOSIT AT YEELIRRIE, WESTERN AUSTRALIA

PAPER II

GROUNDWATER QUALITY IN THE GENERAL AREA OF THE YEELIRRIE URANIUM DEPOSIT

by

M. S. GILES

ABSTRACT

Water samples from 26 windmill-pumped stockwatering points, 25 geological exploration boreholes and 2 deep water bores drilled for higher quality water were collected in and around the Yeelirrie uranium deposit, and analysed for cations, anions, pH, total dissolved solids, total suspended solids, hardness, alkalinity, ^{226}Ra, ^{210}Pb and U.

The results were examined with respect to the quality of the water against criteria recommended by the Australian Water Resources Council, the Australian Commonwealth Department of Health, the International Commission on Radiological Protection and the World Health Organization.

Some samples were measured for their tritium content and the 'average' age of the water examined was calculated to be greater than 25 years.

The data collected were subjected to a hierarchical sorting technique which grouped most of the sampling points together when values were expressed as ratios of their relevant chloride concentrations. Five stock water bores to the north-east of Yeelirrie station homestead were grouped as being separate from the majority of sampling points.

NOTES

CONTENTS

(continued)

CONTENTS (continued)

1. INTRODUCTION

The purpose of this work was to examine the chemical characteristics of the groundwater in the general area surrounding the Yeelirrie uranium deposit to establish base-line levels of water quality and to gain some insight into the age and functioning of the aquifers present.

The sampling program was arranged in conjunction with Australian Groundwater Consultants (AGC) so that mutual use could be made of the published results. Further interpretation of the geohydrology of the area by groundwater specialists is planned.

Because the region is arid, permanent surface water is restricted to one or two small 'rockholes' in the granite 'breakaway' country. The closest of these holes is 13 km from the orebody, lying at a height of 70 m above it, so no effects from mining on these rockholes are expected.

Rainfall quickly infiltrates the sandy soil thus there are no aquatic fauna in the region other than occasional ephemeral creatures such as the shield shrimp *(Triops australiensis)* which may proliferate for short periods in puddles formed after heavy storms. For this reason, the effect of any mining operation on aquatic organisms could be ignored, allowing attention to be centred on evaluating water quality from the point of view of its use as a resource by man. This strategy has led to techniques which would give samples representative of water as it is normally used. Samples were taken as delivered from windmill pumps, or commonly used centrifugal pumps and decanted after a settling period rather than filtered. The inclusion in the samples of some solids, which are subsequently acidified for preservation, is somewhat conservative; at the same time, it is considered to be nearer the actual process involved since sheep do not drink filtered water and their stomach juices normally have a low pH.

2. DESCRIPTION OF THE AREA

2.1 General

The region investigated is shown in Figure 1 and described in Paper I of this report. Additional details are as follows:

- Topographical gradients are low, varying from 0 to 1:1500 along the length of the valley; the average gradient from the valley floor to the nearby plateau above the breakaway region is 1:250.
- Those piezometric gradients which were measured are also low; 1:1000 between hole L and hole O; 1:1500 between hole K and hole H and 1:2000 along the line of the valley between hole H and hole D.

- Annual rainfall averages around 240 mm and annual evaporation is about an order of magnitude larger.

2.2 Present and Proposed Uses of Groundwater

The area surrounding the orebody, which comprises the Yeelirrie pastoral lease, has been developed for sheep grazing. Fences and tracks have been constructed around the paddock boundaries, each of which is roughly 8-10 km square. Windmill-pumped bores have been installed as near to the corners of the fences as possible so that a number of paddocks can be served by one pump.

Stock has been removed from Yeelirrie, but windmills are kept operational in compliance with requirements of the pastoral lease agreement under which Western Mining Corporation operates.

The main activity at adjacent properties such as Albion Downs and Yakabindi is sheep grazing. At the time of this study, Albion Downs was running 20 to 30 cattle with some horses and was maintaining approximately 20 acres of lucerne by irrigation.

Station homesteads, including Yeelirrie, also use borewater for domestic purposes and to irrigate fruit and vegetable gardens. Rainwater, collected from the roofs of buildings, is used for drinking by preference.

Future requirements for groundwater in the area include domestic water for the proposed townsite and industrial water for mining operations.

3. GROUNDWATER SAMPLING PROGRAM

3.1 Types of Samples Collected

Three categories of samples can be distinguished among those collected; these are based on differing sampling techniques and the original reason for drilling into the groundwater. These differences should be borne in mind when interpreting the data.

The first category contains those samples taken from bores and wells which were put down to serve as stock watering points. The windmills, which tap these sources, pump at rates of about 100 dm^3 per hour and only draw from the upper 1 m of the aquifer. Bores are normally cased and some contamination by metals in the pumps and casings can be expected. Wells, on the other hand, are usually more exposed to the atmosphere and some evaporative concentration of dissolved solids may occur.

These sampling points have been given their specific names, *e.g.* Snake Well, Deep Bore, *etc.* throughout this paper.

Samples in the second category were collected from boreholes which were drilled for mineral exploration. Most of these holes were uncased and the depth and positioning of the holes were related to geological considerations

rather than being specifically designed to supply usable water. Before sampling, the holes were cleared of contaminants by pumping for twenty minutes at rates of about 1500 dm^3 per hour. Wherever possible, samples of the upper 1 m ('top' sample) and 1 m from the bottom ('bottom' sample) were taken at the faster pumping rates. Included in this group are six holes which were drilled and cased to act as monitoring points during the progress of the Yeelirrie mining operation. Boreholes will be referred to alphabetically as hole A, hole B, *etc.* in the text.

The third category consists of samples from holes K and L. These holes were drilled away from the calcrete areas, to at least 40 m depth, to locate and test a supply of higher quality water. The two holes were bailed rather than pumped because of the depth to the water table.

The positions of all sampling points are shown on Figure 1. Holes E, F, G, H, I and J are within the orebody.

3.2 Sampling Schedule

On an initial excursion in April 1976, six windmill bores (North Bore, Big Mill Bore, Mica Well, Snake Well, 12 Mile Bore and Easter Mile Bore), ten boreholes in transects across the valley fill (holes A, B, C, D, E, F, G, H, I and J), and two deep water bores (holes K and L) were sampled. Sampling was extended, on a second excursion in September 1976, to include a further twenty windmill samples (Boundary Bore, Black Tank Well, Yakabindi Well, Garden Bore, Howard's Bore, Deep Bore, Southern Cross Bore, Gidgee Well, Never Despair Bore, Corkscrew Bore, Centipede Bore, Tony Bore, Rubber Bore, 30½ Mile Well, Old Government Well, Independence Bore, Midnight Bore, Bottle Well, Mallee Hen Bore and Albany Well) plus six monitoring boreholes (holes M, N, O, P, Q and R).

4. METHODS

4.1 Sampling

All windmill pumps were allowed to function for at least three days before sampling. Samples were taken directly from the windmill outlets into chemically clean 1 dm^3 polythene bottles. pH was measured immediately using a Townson Model 1853/X portable pH meter. pH measurements were also done in the laboratory by Amdel.

Boreholes were cleared of mud and decaying organic material before sampling. This was done by pumping at about 1500 dm^3 per hour for twenty minutes or until the hole was dry. Note was then taken of the water level and the particular pumping rate.

After a delay of at least two days to allow for salinity profiles to be re-established, the variation of 'salinity' and temperature with depth was

measured using an Autolab Model 602 salinometer. This instrument measures the conductivity of the water and from this computes salinity. Normally these instruments are calibrated assuming that the ions present are in the same ratio as those in seawater and that no suspended solids are present. The groundwater examined did have some suspended solids and the ionic balance may not have been the same as in seawater. Because of this, these results may only be considered as semi-quantitative, but they still have value in measuring profile variations.

Water samples were collected after a two-day settling period, by pumping with a standard centrifugal pump having a metal impeller and casing and delivering through Nylex tubing. Two representative bores were bailed with a polyvinyl chloride (PVC) bailer to check on metal contamination from the pump (see Table 1). Differences in results are negligible except for copper and iron but, since the water is being examined as a resource normally collected by pumping, these differences may be ignored.

Holes K and L had to be bailed since the water level was too deep to permit pumping.

4.2 Transport and Storage of Samples

Samples were allowed to stand for 24 hours to allow sediments to settle before water was decanted into 1 dm^3 polythene bottles. Three bottles were prepared for each sampling point: one for ^{226}Ra, ^{210}Pb and U analyses to which 20 mℓ AR HNO_3 was added; one for cation analysis to which 5 mℓ AR HNO_3 was added; and a third for anion and total dissolved solids (TDS) analysis which was not acidified. Table 2 gives a list of the analyses, the laboratories involved and the general methods.

5. RESULTS AND DISCUSSION

5.1 General

Points of interest which relate to a particular result will be discussed as that result is presented, for ease of reference to the tables. A discussion of a more general nature will be given at the end of this section.

5.2 Tritium Ageing Technique

Sixteen samples collected during the first visit were analysed for tritium content; the results are given in Table 3.

The tritium ageing technique depends on the presence of radioactive tritium in rainfall which can be used as a tracer of recent precipitation. Tritium is present in rainfall as a result of natural production in the upper atmosphere and from weapons testing. The latter source has injected very little tritium into the atmosphere since the early 1960s.

In the AAEC laboratory, tritium measurements have an estimated standard deviation of 0.4 tritium units (TU) or 8.5 per cent whichever is the larger (see Table 3 for definition of TU). This means that values of less than 1 TU can be considered as 'dead' to tritium at the 2 σ level.

The tritium content of rainfall in any one year is dependent on time of the year (maximum in late spring/early summer) and on geographical location. Yearly means for tritium, weighted by total amount of precipitation, are set out below:

Station	1970	1971	1972	1973	1974	1975
Alice Springs	31.9	23.0	14.0	16.4	13.2	10.4
Darwin	14.2	11.1	11.4	7.4	8.3	6.2
Perth	20.6	15.9	12.6	11.2	8.4	9.3

With a knowledge of the levels of tritium in rain before and since the period of weapons testing, the age of water can be calculated within the restrictions imposed by the half-life of physical decay of 12.3 years. This means that the age to about fifty years can be determined. When interpreting the tritium values, it should be borne in mind that one can only calculate the 'average' age of the water. This average age could be the actual age or it could derive from the mixture of older water with some percolation of recent rain.

The average age of 12 Mile Bore was calculated to be about 25 years whereas the other bores are probably fifty years or older. Since most of the bores sampled showed little evidence of tritium, it is likely that 12 Mile Bore has old water mixed with some more recent percolation.

Concentrations of tritium, approaching the limits of the method (2σ = 0.8 TU), were found at Easter Mile Bore, Snake Well, and hole B (top and bottom) but age estimations using these figures would not be reliable. The data for hole B suggest some collection of recent water, since they are supported by low salinity readings.

No firm statement can be made about the recharge mechanisms in the aquifer, based on the tritium data collected, without more detailed supportive information on the geohydrology of the area.

5.3 Salinity and Total Dissolved Solids

A list of salinity and temperature profiles, bore depths, water heights, pumping details and pH measurements are given in Tables 4 - 6. As stated in Section 4, salinity readings are helpful in understanding profiles within boreholes but the values for TDS provide a more quantitative measure.

A feature of the results is the large variation in TDS values, sometimes

between sampling points which are relatively close together. For example, holes A, B and C are only 400 metres apart but their TDS values vary over an order of magnitude. This suggests that the calcrete aquifers may be dissected into small areas in which localised recharge and dilution can occur. In general, salinities near the orebody are higher, suggesting that evaporation is occurring in that area.

It is interesting to note that TDS and chloride values at hole P are higher than those in the orebody and also that these same values, as measured in holes E, F, G, H, I and J, decrease in a northerly direction.

On the second excursion, since no rain had fallen in the intervening five months, boreholes which had been logged on the first visit were relogged to see if any increase in salinity could be detected. It was also hoped to gain information on the repeatability of the sampling methods. A comparison of the salinity readings and TDS values for water from the upper 1 m of the aquifer collected on the two excursions is given in Tables 7 and 8.

The comparisons were restricted to the upper layer because:

(i) variations in suspended solids levels in the deeper water of the uncased boreholes affected the salinometer readings;

(ii) the bottom of the borehole was difficult to judge since mud tended to collect there; and

(iii) any loss of water by evapo-transpiration would affect the upper layers of the aquifer first.

No statistically significant increase in salinity was observed. In fact, the TDS results show a slight though statistically significant drop between the two dates. This drop may be real or it could be due to a systematic difference between the two sets of results owing to analytical procedures. As previously stated, the latter results are more reliable.

Because of high TDS values, much of the water examined was unsuitable for stockwater and irrigation. Boundary Bore, Black Tank Bore, Centipede Bore, Yakabindi Bore, Albany Well, Rubber Bore, Bottle Well, Snake Well, Mica Well and 12 Mile Bore exceeded the maximum *desirable* levels set by the Australian Water Resources Council (AWRC) for cattle supplies. Black Tank Bore, Albany Well, Snake Well, and Mica Well had TDS levels which were above the maximum *desirable* for sheep as defined by AWRC. All bores examined, however, were within the maximum *permissible* levels of TDS for sheep drinking water (13 000 mg dm^{-3}).

5.4 Cations

A range of cations were selected for analysis from a knowledge of the

minerals in the area and from the results of spark gap spectrometry of samples collected there. Several more toxic elements such as antimony and arsenic were included since they were known to occur in nearby areas and could present a problem.

The results of cation analysis are given in Table 9. Values for antimony, which were all found to be less than the minimum detectable level (10 µg dm^{-3}), are omitted from the table. All results which lie outside the permissible levels for domestic use recommended by the Australian Water Resources Council (AWRC 1974) have been underlined in the table (see also Table 10). Where the value is also considered to be unfit for stockwater by AWRC standards (see Table 11), it has a vertical line beside it and where it lies outside the AWRC recommendations for irrigation use (see Table 12), it is marked with a black spot.

Lead

All samples were acceptable for domestic use.

Arsenic

Howard's Bore, Bottle Well and Never Despair Bore were at or above the maximum recommended for domestic use but were acceptable as stockwater.

Iron

More than 60 per cent of the samples analysed would be considered unfit for domestic use by AWRC standards and Gidgee Well (12 800 µg dm^{-3}) would be unsuitable for stockwater. There may be some effect from the bore casing in these samples.

Chromium

Chromium levels were low in all samples. Only 30½ Mile Well reached the AWRC limit for domestic use (10 µg dm^{-3}).

To check against possible contamination, the analytical grade nitric acid which was added to each sample was analysed for metals. In the case of chromium, it was found to contain 45 µg dm^{-3} which would be equivalent to an additional 0.2 µg dm^{-3} in the samples after dilution. This is a systematic positive variation in each of the results quoted but it does not substantially alter them.

Copper

All samples were acceptable for domestic use by AWRC standards.

Molybdenum

No upper limits have been set for molybdenum. In general, samples taken nearer to the orebody had higher values.

Selenium

Many of the exploration boreholes sampled would not be considered suitable for domestic or stockwater. Black Tank Bore and Albany Well are above recommended levels for stock. Concentrations of selenium in many of the samples were close to the minimum detectable level of the method used (5 μg dm^{-3}) and this figure is near to the maximum permissible drinking water level (10 μg dm^{-3}). For this reason, eight samples which could have been considered for domestic use were re-analysed to a new lower detection limit of 1 μg dm^{-3} and are reported at that level in the tables.

Selenium levels were higher in calcrete areas in general and the orebody region in particular.

Vanadium

No specific recommendations on vanadium could be found. Concentrations of vanadium varied in a similar way to those of molybdenum and selenium.

Uranium

Uranium levels were highest near the orebody and ranged between 310 and 1200 μg dm^{-3}. Most windmill bores were less than 80 μg dm^{-3}, the exceptions being Big Mill Well (140 μg dm^{-3}), Mica Well (150 μg dm^{-3}), Easter Mile Bore (180 μg dm^{-3}), Centipede Bore (190 μg dm^{-3}) and Albany Well (260 μg dm^{-3}). Some difficulty arises in setting a standard for uranium in water for human consumption since its chemical toxicity overrides its radiobiological effect. The Australian standard set by the Commonwealth Department of Health [CDOH 1975] recommends a level of 60 mg dm^{-3} for occupational categories during their forty hours of employment per week and 2 mg dm^{-3} for 168 hours per week (*i.e.* all the time) for all members of the general public. None of the samples from the Yeelirrie area reached the lower of these figures.

Radium-226

Levels of ^{226}Ra varied over a wide range (0.5 to 902 pCi dm^{-3}; 0.019 to 33.4 Bq dm^{-3}), being generally higher in the region of the orebody. Some stockwater points, *e.g.* Mica Well (167 pCi dm^{-3}; 6.18 Bq dm^{-3}), Mallee Hen Bore (75 pCi dm^{-3}; 2.78 Bq dm^{-3}), and Old Government Well (32 pCi dm^{-3}; 1.18 Bq dm^{-3}) were also high. Differing criteria are set for the levels of ^{226}Ra in drinking water by international authorities.

The World Health Organization recommendations for ^{226}Ra in drinking water [WHO 1971] state that, "If ^{226}Ra activity is below 3 pCi ℓ^{-1} [0.11 Bq dm^{-3}], no further examination is necessary, but if it exceeds 3 pCi ℓ^{-1} [0.11 Bq dm^{-3}] the results should be referred to the appropriate health authorities for further investigations".

The International Commission on Radiological Protection [ICRP 1959] recommends a level of 10 pCi dm^{-3} (0.37 Bq dm^{-3}) and this figure is used in the Australian Commonwealth Department of Health code of practice [CDOH 1975] which also recommends that the "maximum permissible concentration in water ingested by a member of the public in the neighbourhood of a mine or mill exposed continuously for 168 hours per week" be 10^{-8} Ci m^{-3} (10 pCi dm^{-3}; 0.37 Bq dm^{-3}).

AWRC recommendations use the lower WHO criterion, without qualification, for domestic and livestock supplies and, if this were applied to the present results, it would exclude eleven of the existing stockwatering points from use.

It may be unnecessarily restrictive to equate consumption of ^{226}Ra by stock to that of humans because human intake criteria are related to low risk situations in which there is a possibility of small increases in the occurrence of bone cancer resulting from 70 years' exposure. Such increased risks of cancer would be undetectable with respect to natural incidence of the disease.

This means that risk to the animals need not be taken into consideration in setting levels of ^{226}Ra in stockwater but some control over the exposure of humans to ^{226}Ra is necessary where animal products, *e.g.* sheep and cattle flesh and dairy products, are consumed by man.

Samples collected from the deep bores at holes K and L have ^{226}Ra levels of 19 pCi dm^{-3} (0.7 Bq dm^{-3}) and 44 pCi dm^{-3} (1.63 Bq dm^{-3}) respectively. Except for a slightly high value for sodium at hole L, the ^{226}Ra concentrations are the only measurements which prevent them being used as a source of domestic water. Since these bores were cleared by bailing rather than pumping during the initial survey, resampling after yield test pumping is advisable to confirm these results.

Lead-210

All ^{210}Pb results were below the maximum permissible levels set by the ICRP (100 pCi dm^{-3}; 3.7 Bq dm^{-3}).

Chromium

Only one sample (30½ Mile Well) approached the AWRC recommended limit for domestic use.

Sodium and Magnesium

Many of the samples collected were above the domestic water limits for these elements. Albany Well exceeded the livestock water criterion for Mg.

Calcium

Many of the bores sampled were unsuitable for domestic use but all were clear for livestock watering.

5.5 Anions

Chloride, sulphate and nitrate values were higher than domestic water criteria in many of the samples. Of the stockwater points, Black Tank Bore, Albany Well, Mallee Hen Bore and Snake Well were above recommended limits.

5.6 pH

Most sampling points yielded water with a pH between 7.5 and 8. The exceptions were North Bore (7.4), holes A, B, C and D (7.3), Big Mill Bore (7.2) and Mica Well (7.1). Mallee Hen Bore gave a pH reading of 6.5 when measured in the field.

6. SUMMARY OF GENERAL WATER QUALITY

6.1 Domestic Water Use

Very few of the sampling points proved acceptable for domestic use. 30½ Mile Well and Howard's Bore were the only ones which reached AWRC standards, but Garden Bore, Deep Bore and hole B are acceptable if assessed by WHO standards for iron.

The deep bores at holes K and L would be acceptable for domestic use if ^{226}Ra levels were lower.

6.2 Livestock Water Use

Four existing stock watering points are unacceptable by AWRC standards for chemical constituents. These are:

- Black Tank (high selenium and sulphate)
- Albany Well (high selenium, magnesium, sulphate and nitrate)
- Gidgee Bore (high iron)
- Snake Well (high sulphate).

A further eleven windmill-pumped supplies do not meet AWRC standards for ^{226}Ra.

None of the geological boreholes examined reached AWRC standards but holes B, K, L and O could be used for stockwatering if their ^{226}Ra levels were neglected.

7. POLYTHETIC SORTING OF DATA

On examination of the data, it appeared that some groupings of sampling points could be made on the basis of the geochemistry of the water. This was particularly true of the water taken from the orebody region and, to increase the understanding of the groundwater of the region, it was decided to sort the data and put them into groups with areas of similarity.

Since the large amount of data was difficult to interpret by simple techniques, it was subjected to a special sorting method available in the CSIRO Cyber 76 computer system. Details of the programs used are given in Appendix A.

A general text book on the subject has been presented by W.T. Williams [1976].

The sorting, which is polythetic, is based on a measure of similarity applied to all parameters so that a sampling point is grouped with those sampling points it most closely resembles, on the average, over the full range of measured attributes. By another strategy, dissimilarity may be used to group sampling points.

These methods of grouping data have become popular in sorting agricultural data matrices and have been used for such things as soil chemistry correlations. The method is complex and is based on a multi-dimensional grouping of points in an artificial space according to their Euclidean distance from each other. It does not provide any test of the significance of the groupings; these groupings must be viewed against other available information to support their validity and by repeated sortings to gain mutual support.

As an example, the result of the first grouping of the raw data is presented as a dendrogram in Figure 2. A division into eight groupings was arbitrarily chosen and each group is represented by a coloured symbol. One or more sampling points may occur in each group and the sampling points in a particular group are shown next to the appropriate symbol in Figure 6 under the column labelled 'First Sort'. The vertical height of the fusion points on the branches of the diagram (Figure 2) indicates the measure of similarity of the fused groups.

The major division of the sampling points into two parts has been represented by different colours. Samples which are grouped as being similar to water collected in the orebody are coloured red and dissimilar groups are coloured blue.

Four sortings were carried out with the main aim of increasing the understanding of the underground water system. In particular, the relationship between water from the various sampling points to that collected in the orebody was examined.

In the first sorting (Figure 2) all data were sorted. This biased the result towards a separation according to the salinity or age of the water since the majority of the parameters measured were related to this. Thus Na, TDS, Cl, SO_4, K, Mg, hardness and Ca were the parameters which separated the major groupings (*i.e.* red from blue). The geographical positioning of the groups is shown on Figure 7.

The second fusion (see Figures 3 and 6) was confined to sorting the data on Mo, Se, V, ^{226}Ra, ^{210}Pb and U as these attributes were known to be associated with the ore. This strategy grouped those sampling points directly in

the orebody (holes E, F, G, H and I) tightly together. Hole J was grouped with Mica Well and hole L.

For the third fusion, nineteen parameters were divided by their respective chloride concentrations to remove the predominance of salinity found in the first sorting. The chloride ratios examined were Pb:Cl, As:Cl, Fe:Cl, Cr:Cl, Cu:Cl, Mo:Cl, Se:Cl, V:Cl, Ca:Cl, Mg:Cl, Na:Cl, K:Cl, HCO_3:Cl, SO_4:Cl, NO_3:Cl, hardness:Cl, U:Cl, ^{226}Ra:Cl and ^{210}Pb:Cl and their values are shown in Table 13. The results of the third sorting are shown in Figures 4 and 6. This sorting suggests that most of the sampling points yielded water which was similar to orebody water when salinity is taken into account. The attributes which separated the two main groups were HCO_3, Ca, hardness, NO_3, Pb, Cr, As and V in this sorting.

Since Mo, Se, V, ^{226}Ra, ^{210}Pb and U had proved to be good indicators of orebody water in the second sorting, the chloride ratios of these six elements were examined separately during the fourth sorting. The results (Figures 5 and 6) do not change the major division revealed in the third sorting but tighten the intragroup structures. The geographical positioning of the groups is shown on Figure 8.

The results of these sortings are supported by the following considerations:

(i) The first sorting can be tied geographically to known calcrete areas (Figure 7).

(ii) The second sorting, which was based on elements known to be associated with the ore, distinctly separated water in that area from all other sampling points.

(iii) The third sorting, based on the knowledge that chloride ion does not precipitate from groundwater to any great degree, suggests that much of the groundwater could be expected to progress toward the condition of water in the calcrete areas as it evaporated. This proposition is supported by the fact that the calcrete areas exist, at least partially, due to an evaporative effect on groundwater.

(iv) The fourth sorting suggests that those sampling points which remained discrete from the others can be expected to have derived their mineral loads from different sources, or under different conditions to those waters associated with the orebody. This is supported by the tightness of the second sorting and the fact that these sampling points remained together through all groupings.

In summary, most of the water samples examined could be related to water taken from the orebody when allowance was made for increasing salinity. Never Despair Bore, Howard's Bore, Garden Bore, Southern Cross Bore and Deep Bore, however, remained discrete from other sampling points throughout all the grouping strategies and were related most closely to 30½ Mile Well, Tony Bore and holes K and L.

A more detailed description of the sortings is given in Appendix A which includes a list of the parameters responsible for the separation of the minor groups.

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9. REFERENCES

AWRC [1974] - A Compilation of Australian Water Quality Criteria. Technical Paper No. 7, Australian Government Publishing Service, Canberra.

CDOH [1975] - Code of Practice on Radiation Protection in the Mining and Milling of Radioactive Ores. Australian Commonwealth Department of Health, Canberra.

ICRP [1959] - Report of Committee II on Permissible Dose for Internal Radiation. ICRP Publication No. 2, Pergamon Press, London.

WHO [1971] - International Standards for Drinking Water. World Health Organization, Geneva, (3rd Edition).

Williams, W.T. [1976] - Pattern Analysis in Agricultural Science. Elsevier Scientific Publishing Company, Oxford.

NOTES

TABLE 1

COMPARISON OF PUMPED AND BAILED SAMPLES

Element	Hole B Top		Hole G Top	
	Pumped	Bailed	Pumped	Bailed
Sb ($\mu g\ dm^{-3}$)	< 10	< 10	< 10	< 10
Pb "	5	10	10	15
As "	< 1	< 1	2	2
Fe "	760	970	260	230
Cr "	5	5	5	6
Cu "	5	9	6	19
Mo "	4	6	210	170
Se "	5	5	20	25
V "	< 10	10	130	130
Si ($mg\ dm^{-3}$)	32	31	46	43
Ca "	44	47	151	157
Mg "	29	27	241	249
Na "	274	250	2050	2010
K "	20	20	233	233
HCO_3 "	117	123	369	346
SO_4 "	122	121	1189	1230
Cl "	408	393	3055	3119
NO_3 "	35	40	185	45
TDS "	1068	1065	7546	7790
Hardness ($mg\ dm^{-3}$ as $CaCO_3$)	229	228	1369	1417
Alkalinity "	96	101	302	284
pH (units)	7.3	7.3	7.7	7.7
U ($\mu g\ dm^{-3}$)	4.3	7.7	310	320
^{210}Pb ($pCi\ dm^{-3}$) *	0.46	0.64	8.9	7.9
^{226}Ra "			244	212

* $1 pCi\ dm^{-3} = 3.7 \times 10^{-2}\ Bq\ dm^{-3}$

TABLE 2

DETAILS OF ANALYTICAL PROCEDURES

Analysis	Minimum Detectable Level or Precision	Laboratory	General Method Employed
U	2 µg dm^{-3}	AAEC	Spectrophotometry
^{226}Ra	± 12% lower values	"	Emanation of radon
^{210}Pb	0.1 pCi dm^{-3} *	"	From deposition of ^{210}Pb on silver
^{3}H	± 0.4 TU	"	Liquid scintillation after concentration
As	5 µg dm^{-3}	Amdel	Atomic Absorption spectrophotometry
Se	5 "	"	"
Fe	50 "	"	"
Cr	1.5 "	"	"
Cu	1 "	"	"
V	10 "	"	"
Pb	3 "	"	"
Mo	10 "	"	"
Sb	10 "	"	"
Ca	± 5%	"	"
Mg	± 5%	"	"
Na	± 5%	"	"
K	± 5%	"	"
HCO_3		"	Titrimetry
Hardness		"	"
Alkalinity		"	"
Cl		"	"
SO_4		"	Turbidimetry
NO_3		"	Spectrophotometry
Si		"	"

* 1pCi dm^{-3} = 3.7 x 10^{-2} Bq dm^{-3}

TABLE 3

RESULTS OF TRITIUM ANALYSES

Sample	^{3}H (Tritium Units*)
Snake Well	1.1
North Bore	0
Big Mill Bore	0
Mica Well	0
12 Mile Bore	2.3
Easter Mile Bore	1.4
Hole A Top	0
Hole A Bottom	0
Hole B Top	1.3
Hole B Bottom	1.0
Hole C Top	0.8
Hole C Bottom	0.2
Hole F Bottom	0.4
Hole H	0.2
Hole K	0.1
Hole L	0.3

* 1 Tritium unit (TU) = 1 atom of ^{3}H per 10^{18} atoms ^{1}H

TABLE 4

SALINITY, TEMPERATURE, pH MEASUREMENTS OF WINDMILL PUMPS AND HOLES K AND L

Site	Salinity ‰		Temp. °C		pH (Field)		pH (Lab)	
	April	Sept.	April	Sept.	April	Sept.	April	Sept.
Hole K	0.7*	0.7*	25.3	25.3	7.65		7.6	
Hole L	1.0*	1.3*	25.1	25.1	7.4		7.5	
12 Mile Bore	5.0	4.5	24.0	22.0	7.95	8.02	7.4	
Easter Mile Bore	1.5	1.5	26.0	25	7.65	7.6	7.6	
North Bore	1.4	1.3		25.3	7.6	7.45	7.4	
Big Mill Well	2.0	1.9	24.4	25.0	7.05	6.96	7.2	
Mica Well	6.0	5.0		23.7	7.5	7.25	7.1	
Snake Well	8.9	7.5	23.5	21.5	7.9	7.56	7.6	
Never Despair Bore		0.7		25.1		7.45		7.8
Tony Bore		0.6		27.0		7.5		7.7
Gidgee Well		1.5		24.0		7.65		8.0
Howard's Bore		0.5		25.2		7.85		8.0
Garden Bore		1.0		25.0		7.6		7.8
Boundary Bore		3.7		22.3		7.75		7.5
Black Tank Bore		7.3		21.0		8.0		8.0
Centipede Bore		4.7		26.3		7.2		7.6
Southern Cross Bore		0.6		25.7		7.7		7.9
Yakabindi Well		4.7		20.0		8.0		7.9
Deep Bore		0.7		26.1		7.8		7.9
Corkscrew Bore		1.2		26.0		7.7		7.9
Albany Well		10.05		20.05		7.66		7.9
Rubber Bore		3.4		26.0		7.16		7.7
Bottle Well		3.45		23.7		7.8		8.0
Midnight Bore		2.75		26.4		7.25		7.9
Independence Bore		0.5				7.45		7.8
Mallee Hen Bore		2.0				6.45		7.5

* Same throughout profile

TABLE 5

HOLE DEPTHS, WATER LEVELS AND PUMPING RATES OF BOREHOLES

Hole	Depth (m)	Depth to Water (m) Apr.	Sept.	Depth to Water after 20 min Pumping (m) Apr.	Sept.	Pumping Rate (dm^3 min^{-1}) Apr.	Sept.
A	15.7	4.8	4.8		5.0		27
B	17.3	5.5	5.6	6.8	6.2	20	25
C	18.3	3.2	3.3	4.5	3.5	34	36
D	9.7	3.3	3.4	7.9	7.1	14	16
E	10.5	4.1	4.0	4.1	4.1	30	36
F	11.5	4.3	4.2	4.8	4.2	32	32
G	10.6	4.1	4.2	4.2	4.2	38	34
H	6.5	4.3	4.3	4.3	4.4	36	36
I	7.5	4.5	4.5	Pumped down immediately			
J	7.4	4.0	4.0				
K	69	21.4	21.4	Too deep to pump			
L	>40	12.7	12.3				
M	13.6		6.0		6.0		22
N	10.9		3.7		3.7		27
O	10.0		4.2		4.2		22
P	18.0		10.0				
Q	60		9.0				
R	35		17.0				

TABLE 6

SALINITY AND TEMPERATURE

PROFILES OF BOREHOLES

HOLE A

Depth (m)	26.4.1976		17.9.1976		21.9.1976	
	S ‰	T°C	S ‰	T°C	S ‰	T°C
4.8	2.5	25.6	3.2	25.1	3.2	25.4
5.3	2.5	25.6				
5.8	3.2	25.4	3.3	25.4	3.2	25.4
6.3	3.3	25.3				
6.8	2.7	26.1	3.5	25.5	3.5	25.5
7.3	2.7	26.1				
7.8	2.7	26.1	4.1	25.5	4.4	25.5
8.3	2.7	26.1				
8.8	4.3	26.2	4.9	25.5	5.1	25.5
9.3	4.6	26.2				
9.8	5.6	26.4	5.6	25.5	5.6	25.5
10.3	6.0	26.4				
10.8	6.2	25.4	6.0	25.5	6.2	25.5
11.3	6.4	26.4				
11.8	6.5	26.4	6.4	25.5	6.8	25.5
12.3	7.7	26.4				
12.8	7.8	25.5	7.9	25.5	7.9	25.5
13.3	7.9	25.5				
13.8	7.9	25.5	7.9	25.5	7.9	25.5
14.3	7.9	25.5				
14.8			8.0	25.5	7.9	25.5
15.3	7.9	25.5	8.0	25.5	8.0	25.5

(continued)

TABLE 6 (continued)

HOLE B

Depth (m)	26.4.1976		17.9.1976		21.9.1976	
	S ‰	T°C	S ‰	T°C	S ‰	T°C
5.5	0.8	24.6	1.0	24.6	1.0	24.6
6.0	0.8	24.5				
6.5	0.9	24.5	1.0	24.6	1.0	24.6
7.0	0.9	24.5				
8.0	0.9	24.5	1.0	24.6	1.0	24.6
9.0	0.9	24.5	1.0	24.6	1.1	24.6
10.0	0.9	24.5	1.0	24.6	1.1	24.6
11.0	0.9	24.6	1.0	24.6	1.1	24.6
12.0	0.9	24.7	1.1	24.6	1.1	24.6
13.0	0.9	24.7	1.1	24.6	1.1	24.6
14.0	1.0	24.8	1.1	24.7	1.2	24.6
15.0	1.3	24.9	1.1	24.7	1.3	24.8
16.0	1.5	25.0	1.8	24.8	1.7	24.8
17.0	0.8	25.0	2.4	24.8	2.1	24.8

(continued)

TABLE 6 (continued)

HOLE C

Depth (m)	26.4.1976		17.9.1976		21.9.1976	
	S ‰	T°C	S ‰	T°C	S ‰	T°C
3.2	8.3	26.5	11.8	24.9	12.0	25.2
3.7	9.1	26.3				
4.2	9.9	25.6	12.1	25.3	12.1	25.3
4.7	10.1	25.4				
5.2	11.3	25.3	12.2	25.4	12.2	25.3
5.7	11.6	25.2				
6.2	12.0	25.1	12.3	25.4	12.3	25.5
6.7	12.0	25.1				
7.2	12.2	25.1	12.4	25.4	12.4	25.5
8.2	12.8	25.3	12.5	25.4	12.5	25.5
9.2	13.4	25.3	12.6	25.4	12.8	25.5
10.2	13.9	25.4	14.2	25.4	14.5	25.5
11.2	14.1	25.4	15.0	25.4	14.8	25.5
12.2	14.3	25.4	15.0	25.4	14.9	25.5
13.2	14.5	25.4	15.0	25.4	15.0	25.6
14.2	14.6	25.5	15.0	25.5	15.0	25.6
15.2	14.9	25.5	15.4	25.5	15.3	25.6
16.2	15.0	25.6	15.8	25.5	15.6	25.6
17.2	15.0	25.6	16.0	25.5	15.7	25.7
17.9	15.0	25.6				

(continued)

TABLE 6 (continued)

HOLE D

Depth (m)	26.4.1976		17.9.1976		21.9.1976	
	S ‰	T°C	S ‰	T°C	S ‰	T°C
3.3	7.5	26.9	10.8	24.2	10.9	24.2
3.8	8.1	26.5				
4.3	9.3	25.8	10.8	24.3	10.9	24.5
4.8	9.6	25.2				
5.3	9.6	24.9	10.9	24.8	10.9	24.6
5.8	9.9	24.6				
6.3	10.0	24.6	11.0	25.0	11.0	24.9
6.8	10.0	24.6				
7.3			11.2	25.0	11.1	25.0
7.8	10.0	24.6				
8.3						
8.8	10.3	24.6	11.2	25.0	12.2	25.0
9.3						
9.8	10.3	24.6	11.2	25.0	12.2	25.0

HOLE E

Depth (m)	25.4.1976		17.9.1976		22.9.1976	
	S ‰	T°C	S ‰	T°C	S ‰	T°C
4.1	19.4	24.1	20.4	23.7	19.7	23.5
4.6	20.1	24.0				
5.1	20.6	24.0	22.5	23.8	22.2	23.9
5.6	21.6	23.9				
6.1	23.6	23.4	23.4	23.8	23.4	23.9
6.6	23.6	24.1				
7.1	24.4	23.6	24.0	23.8	24.1	23.9
7.6	24.9	23.6				
8.1	25.2	23.5	27.0	23.8	25.3	23.8
8.6	25.5	23.5				
9.1	26.0	23.5	28.4	23.8	27.2	23.8
9.6	26.2	23.5				
10.1	26.2	23.5				

(continued)

TABLE 6 (continued)

HOLE F

Depth (m)	25.4.1976		17.9.1976		22.9.1976	
	S ‰	T°C	S ‰	T°C	S ‰	T°C
4.3	9.3	23.8	8.2	23.2	8.4	23.3
4.8	9.5	23.6				
5.3	10.1	23.4	9.3	23.5	10.8	23.6
5.8	11.1	23.4				
6.3	12.9	23.3	13.5	23.6	14.6	23.6
6.8	14.9	23.3				
7.3	16.6	23.3	15.4	23.6	16.9	23.6
7.8	18.4	23.3				
8.3	20.6	23.3	18.8	23.6	21.0	23.6
8.8	22.0	23.3				
9.3	23.4	23.3	25.1	23.6	21.1	23.6
9.8	24.2	23.3				
10.3	25.0	23.4	27.2	23.5	25.8	23.6
10.8	25.4	23.4				
11.3	25.6	23.4	27.2	23.5	27.3	23.6

(continued)

TABLE 6 (continued)

HOLE G

Depth (m)	25.4.1976		17.9.1976		22.9.1976	
	S ‰	T°C	S ‰	T°C	S ‰	T°C
4.1	6.1	24.0				
4.6	6.1	23.7	5.9	22.8	5.8	22.8
5.1	6.5	23.6				
5.6	8.9	23.5	10.0	23.2	9.9	23.2
6.1	12.4	23.4				
6.6	13.0	23.3	12.0	23.4	13.6	23.5
7.1	13.6	23.3				
7.6	14.6	23.3	13.4	23.5	14.2	23.5
8.1	15.4	23.3				
8.6	19.4	23.3	14.0	23.5	14.5	23.5
9.1	20.3	23.3				
9.6	20.6	23.3	14.2	23.5	20.8	23.5
10.1	20.7	23.3				
10.6	20.7	23.3	22.0	23.5	20.8	23.5

HOLE H

Depth (m)	25.4.1976		17.9.1976		22.9.1976	
	S ‰	T°C	S ‰	T°C	S ‰	T°C
4.3	10.8	26.1	11.0	25.4	10.9	25.4
4.8	10.8	26.1				
5.3	11.0	26.0	11.0	25.3	11.0	25.7
5.8	11.2	25.7				
6.3	11.3	25.6	11.2	25.6	11.0	25.7

(continued)

TABLE 6 (continued)

HOLE I

Depth (m)	25.4.1976		17.9.1976		22.9.1976	
	S ‰	T°C	S ‰	T°C	S ‰	T°C
4.5	11.7	25.6	11.4	25.3	11.2	25.3
5.0	11.9	25.6				
5.5	11.9	25.4	11.4	25.3	11.3	25.4
6.0	12.0	25.3				
6.5	12.0	25.2	11.6	25.3	11.7	25.5
7.0	12.1	25.2				
7.3	12.3	25.2	12.8	25.4	11.7	25.5

HOLE J

Depth (m)	24.4.1976		17.9.1976		22.9.1976	
	S ‰	T°C	S ‰	T°C	S ‰	T°C
4.0	11.7	26.7	11.6	24.5	10.8	24.3
4.5	11.7	26.4				
5.0	11.7	26.2	12.6	24.9	12.6	25.0
5.5	14.3	25.6				
6.0	14.7	25.5	14.5	25.1	15.1	25.2
6.5	15.1	25.3				
7.0	15.6	25.3	16.9	25.3	17.5	25.3

(continued)

TABLE 6 (continued)

Hole M			Hole N			Hole O		
Depth (m)	27.9.1976		Depth (m)	27.9.1976		Depth (m)	27.9.1976	
	S ‰	T°C		S ‰	T°C		S ‰	T°C
6.0	7.2	24.3	3.5	8.2	24.8	3.5	3.6	23.9
7.0	7.2	24.3	4.5	8.3	25.1	4.5	4.1	24.2
8.0	8.2	24.5	5.5	8.6	25.5	5.5	5.8	24.7
9.0	9.1	24.5	6.5	9.5	25.8	6.5	6.5	24.9
10.0	9.2	24.5	7.5	10.2	25.8	7.5	7.0	25.0
11.0	9.3	24.5	8.5	10.6	25.9	8.5	8.7	25.0
12.0	9.3	24.5	9.5	11.2	25.9	9.5	10.0	25.0
13.0	9.3	24.5	10.5	11.5	25.9			
13.5	9.4	24.5						

(continued)

TABLE 6 (continued)

Hole P 4.10.76			Hole Q 4.10.76			Hole R 4.10.76		
Depth (m)	Salinity ‰	Temp °C	Depth (m)	Salinity ‰	Temp °C	Depth (m)	Salinity ‰	Temp °C
			9	2.8	24.4			
10	26.5	25.7	10	2.8	24.5			
11	26.7	25.8	11	3.0	24.5			
12	26.7	25.8	12	3.5	24.6			
13	26.6	25.8	13	4.7	24.6			
14	26.7	25.8	14	5.6	24.6			
15	26.7	25.8	15	5.9	24.6			
16	26.7	25.7	16	6.3	24.6			
17	26.8	25.7	17	7.2	24.6	17	2.3	24.4
18	26.8	25.7	18	8.6	24.6	18	2.3	24.5
			19	9.4	24.6	19	2.4	24.5
			20	9.7	24.6	20	2.4	24.6
			21	9.9	24.7	21	2.4	24.6
			22	10.4	24.7	22	2.4	24.6
			23	11.2	24.7	23	2.4	24.6
			24	11.8	24.7	24	2.4	24.6
			25	12.5	24.8	25	2.4	24.7
			26	13.0	24.8	26	2.4	24.7
			27	13.4	24.8	27	2.4	24.7
			28	14.0	24.9	28	2.4	24.8
			29	15.0	24.9	29	2.4	24.8
			30	15.6	24.9	30	2.4	24.8
			31	15.8	24.9	31	2.4	24.8
			32	16.1	25.0	32	2.4	24.9
			33	16.1	25.0	33	2.4	24.9
			34	16.1	25.0	34	2.4	24.9
			35	16.1	25.0	35	2.4	24.9
			36	16.3	25.0			
			37	17.0	25.0			
			38	17.7	25.0			
			39	18.3	25.0			

TABLE 7

SALINITIES MEASURED BY AUTOLAB

SALINOMETER ON EACH EXCURSION (TOP SAMPLES ONLY)

(parts per thousand)

Sampling Point	April	September	% Difference
Snake Well	8.9	7.5	- 15.7
North Bore	1.4	1.3	- 1.3
Big Mill Well	2.0	1.9	- 5.0
Mica Well	6.0	5.0	- 16.7
12 Mile Bore	5.0	4.5	- 10
Easter Mile Bore	1.5	1.5	0
Hole K	0.7	0.7	0
" L	1.0	1.3	+ 33.3
" A (Top)	2.5	3.2	+ 28
" B (Top)	0.8	1.0	+ 25
" C (Top)	8.3	11.8	+ 42.2
" D	7.5	10.8	+ 44
" E (Top)	19.4	20.4	+ 5
" F (Top)	9.3	8.2	- 11.8
" G (Top)	6.1	5.9	- 3.3
" H	10.8	11.0	+ 1.9
" I	11.7	11.4	- 2.6
" J	11.7	11.6	- 0.9

Mean % difference + 6.23

t = 1.37, 17 d.f.

P = 0.2 to 0.1

TABLE 8

TOTAL DISSOLVED SOLIDS LEVELS FOR EACH EXCURSION

(TOP SAMPLES ONLY)

($mg\ dm^{-3}$)

Sampling Point	April	September	% Difference
Snake Well	9142	8288	- 9.34
North Bore	1484	1499	+ 1.0
Big Mill Well	2126	2023	- 4.84
Mica Well	6215	5762	- 7.29
12 Mile Well	5132	5017	- 2.24
Easter Mile Bore	1542	1526	- 1.04
Hole A (Top)	4529	4070	-10.13
" B (Top)	1068	1121	+ 4.96
" C (Top)	13 522	13 787	+ 1.96
" D	12 396	12 262	- 1.08
" E (Top)	23 719	23 029	- 2.91
" F (Top)	13 672	14 171	+ 3.65
" G (Top)	7546	7036	- 6.76
" H	12 283	12 225	- 0.47
" I	12 828	12 865	+ 0.29
" J	15 862	15 233	- 3.97
" K	942	940	- 0.21
" L	1227	1219	- 0.65

Mean % difference - 2.17

t = 2.17, 17 d.f.

P = 0.05 to 0.02

TABLE 9

RESULTS OF THE ANALYSIS OF GROUNDWATER SAMPLES TAKEN AT YEELIRRIE IN 1976

	LEAD	ARSENIC	IRON	CHROMIUM	COPPER	MOLYBDENUM	SELENIUM	VANADIUM	.UM
	(MICROGRAMS PER CUBIC DECIMETRE)								
NEVER DESPAIR	5	60	800	2	2	● 15	5	10	
HOWARDS	5	40	200	2	25	6	1	20	
GARDEN	10	30	320	2	6	6	1	10	
SOUTHERN CROSS	5	5	● 2150	2	4	6	5	10	
DEEP	5	1	900	2	30	2	1	20	
30.5 MILE	25	35	230	10	12	● 185	1	10	
TONY	35	1	● 6100	2	● 440	● 15	1	10	
K	25	1	260	6	45	● 45	1	10	
L	35	1	200	6	60	● 25	1	10	
OLD GOVT	5	1	160	6	2	● 35	5	10	
GIDGEE	5	1	● 12800	2	40	2	10	10	
BOUNDARY	35	1	460	4	8	2	1	10	
BLACK TANK	5	1	440	8	20	3	● 20	20	
CENTIPEDE	5	20	● 2300	2	65	● 15	10	10	
YAKABINDI	5	35	410	4	8	2	5	40	
CORKSCREW	5	10	● 5400	2	25	2	1	10	
ALBANY	5	30	130	4	15	2	● 30	10	
RUBBER	5	15	● 1900	2	40	2	5	10	
BOTTLE	45	45	● 1890	4	● 950	2	5	10	
MIDNIGHT	5	1	900	2	155	2	10	20	
MALLEE HEN	10	5	● 4850	6	● 240	2	10	10	
SNAKE	5	1	140	2	45	● 10	5	10	
NORTH	25	1	● 5300	3	● 240	2	5	40	
BIG MILL	5	1	710	5	95	4	5	30	
INDEPENDENCE	40	20	● 4900	2	145	2	5	10	
MICA	5	1	135	2	25	● 18	5	10	
12 MILE	5	1	590	3	145	● 14	10	10	
EASTER MILE	5	1	990	3	70	8	5	10	
A TOP	5	1	90	3	5	8	5	10	
A BOTTOM	25	1	120	2	10	● 10	10	20	
B TOP	5	1	760	5	5	4	1	10	
B BOTTOM	5	1	850	5	4	4	1	10	
C TOP	5	1	220	5	9	● 55	● 40	20	
C BOTTOM	5	1	210	5	10	● 60	● 25	40	
D	10	1	350	4	11	● 45	● 35	20	
E TOP	10	1	210	4	10	● 370	● 70	60	
E BOTTOM	10	1	190	4	14	● 430	● 55	80	
F TOP	10	2	260	3	5	● 190	● 25	130	
F BOTTUM	10	1	110	2	20	● 530	10	60	
G TOP	10	2	260	5	6	● 210	● 20	130	
G BOTTOM	5	1	90	3	8	● 390	● 20	110	
H	5	1	190	3	11	● 340	● 30	70	
I	5	1	510	5	10	● 330	● 20	20	
J	10	1	● 2200	5	60	● 165	5	10	
M TOP	5	30	90	2	12	● 175	● 25	40	
M BOTTOM	5	15	90	6	20	● 140	● 40	30	
N TOP	5	5	100	6	14	● 75	15	10	
N BOTTOM	5	1	90	6	16	● 200	15	30	
O TOP	35	5	130	2	8	● 65	10	40	
O BOTTOM	5	20	70	4	10	● 120	10	20	
P	15	2	350	2	25	● 46	● 50	10	
Q	15	2	70	4	24	● 37	● 40	39	
R	5	2	160	5	10	2	● 20	10	

TABLE 9 (continued)

	SILICON	CALCIUM	MAGNESIUM	SODIUM	POTASSIUMS	BICARBONATE	SULPHATE	CHLORIDE	NITRATE	T.D.S.
	(MILLIGRAMS PER CUBIC DECIMETRE)									
NEVER DESPAIR	25	41	29	236	5	196	109	298	50	954
HOWARDS	36	56	34	141	12	193	83	240	50	783
GARDEN	33	80	37	250	13	240	151	380	50	1179
SOUTHERN CROSS	20	50	32	224	11	279	118	249	65	911
DEEP	35	53	36	224	21	224	126	318	65	1062
30.5 MILE	21	30	21	132	16	154	63	189	3	575
TONY	25	41	35	188	24	126	125	306	35	845
K	25	50	32	215	15	265	123	276	10	942
L	25	60	45	286	19	196	161	442	45	1227
OLD GOVT	23	88	71	253	29	366	186	456	9	1385
GIDGEE	22	97	87	386	15	243	252	692	60	1869
BOUNDARY	38	130	130	1100	53	207	435	● 1938	85	● 4107
BLACK TANK	38	270	265	2187	105	282	1386	● 3607	130	● 8463
CENTIPEDE	23	267	290	1165	99	293	759	● 2395	80	● 5344
YAKABINDI	34	148	175	1387	20	254	782	● 2274	65	● 5239
CORKSCREW	22	54	62	297	46	151	131	538	70	1302
ALBANY	33	445	600	2468	209	221	1432	● 5313	320	● 11148
RUBBER	32	205	165	787	86	254	632	● 1491	50	● 3736
BOTTLE	33	325	213	935	75	263	668	● 2129	30	● 4584
MIDNIGHT	43	143	125	663	57	263	377	● 1261	110	3018
MALLEE HEN	24	244	153	178	33	39	209	● 957	195	1934
SNAKE	49	213	314	2400	204	302	1221	● 4113	175	● 9142
NORTH	47	62	45	356	25	162	150	563	60	1484
BIG MILL	30	84	70	531	32	73	302	● 909	70	● 2126
INDEPENDENCE	30	43	31	116	12	218	41	174	40	504
MICA	29	122	219	1720	108	78	768	● 2957	45	● 6215
12 MILE	41	156	185	1300	124	201	668	● 2303	110	● 5132
EASTER MILE	34	82	61	344	31	173	184	624	45	1542
A TOP	45	128	134	1245	89	190	673	● 1968	45	● 4529
A BOTTOM	50	201	278	2160	128	190	1423	● 3498	75	● 8163
B TOP	32	44	29	274	20	117	122	408	35	1068
B BOTTOM	32	45	32	322	24	131	113	493	35	1223
C TOP	45	325	539	3488	296	282	2113	● 6002	90	● 13522
C BOTTOM	34	394	645	4000	339	360	2523	● 6986	85	● 15834
D	40	309	499	3075	260	274	1828	● 5368	80	● 12396
E TOP	38	386	780	6250	725	414	3782	● 10115	410	● 23719
E BOTTOM	31	514	970	7525	848	391	4708	● 12162	425	● 28790
F TOP	39	276	492	3450	413	475	2264	● 5638	215	● 13672
F BOTTOM	29	510	947	6475	709	500	4338	● 10745	320	● 25605
G TOP	46	151	241	2050	233	369	1189	● 3055	185	● 7546
G BOTTOM	39	284	505	3440	400	447	2271	● 5688	185	● 13654
H	48	222	386	3220	372	391	1938	● 5225	210	● 12283
I	37	235	420	3450	369	1023	1596	● 5668	75	● 12828
J	38	280	556	4313	425	1693	1621	● 7183	30	● 15862
M TOP	40	154	248	2188	259	405	1271	● 3393	160	● 8150
M BOTTOM	33	208	338	2688	285	374	1592	● 4368	160	● 10228
N TOP	42	242	340	2388	211	165	1293	● 4343	80	● 9368
N BOTTOM	33	235	398	3025	292	198	1586	● 5338	110	● 11468
O TOP	38	86	133	1295	123	257	551	● 2054	110	● 4600
O BOTTOM	35	158	275	2280	210	226	1263	● 3731	95	● 8416
P	22	734	1212	7850	673	486	3856	● 14368	47	● 29640
Q	33	100	119	785	88	246	507	● 1274	85	3151
R	27	117	119	563	64	168	335	● 1085	59	2431

TABLE 9 (continued)

	TOTAL HARDNESS (MILLIGRAMS/DM**3	TOTAL ALKALINITY AS CACO3)	TOTAL SUSPENDED SOLIDS (MILLIGRAMS/DM**3)	PH	URANIUM (MICROGRAMS/DM**3)	LEAD 210 (PICOCURIES/DM**3)	RADIUM 226
NEVER DESPAIR	222	61	0.7	7.8	27.0	0.83	2.0
HOWARDS	280	158	0.7	8.0	12.0	0.25	0.5
GARDEN	352	197	0.6	7.8	13.0	0.22	0.5
SOUTHERN CROSS	257	229	2.5	7.9	18.0	0.55	2.2
DEEP	280	183	2.3	7.9	11.0	0.11	0.5
30.5 MILE	161	126	3.2	8.0	2.0	0.18	1.3
TONY	246	103	13.8	7.7	40.0	2.20	● 10.0
K	257	218	25.2	7.6	120.0	1.70	● 19.0
L	335	160	5.2	7.5	220.0	7.20	● 44.0
OLD GOVT	512	300	8.8	8.0	64.0	0.27	● 32.0
GIDGEE	600	199	25.4	8.0	3.7	0.55	2.0
BOUNDARY	860	169	4.5	7.5	34.0	0.24	● 4.1
BLACK TANK	1765	231	4.3	8.0	19.0	0.26	0.5
CENTIPEDE	1860	240	7.7	7.6	190.0	1.80	● 11.3
YAKABINDI	1090	208	1.2	7.9	22.0	0.97	2.5
CORKSCREW	390	124	12.2	7.9	34.0	1.10	● 10.7
ALBANY	3580	181	1.0	7.9	260.0	0.33	1.5
RUBBER	1191	208	3.7	7.7	67.0	0.27	● 6.8
BOTTLE	1688	215	8.8	8.0	85.0	0.23	1.0
MIDNIGHT	871	215	2.8	7.9	61.0	0.45	1.7
MALLEE HEN	1239	32	14.1	7.5	2.0	1.20	● 75.0
SNAKE	1824	247	1.1	7.6	56.0	0.18	2.1
NORTH	340	133	0.1	7.4	19.0	0.41	● 4.8
BIG MILL	498	60	0.1	7.2	140.0	1.10	● 14.6
INDEPENDENCE	235	179	11.6	7.8	11.0	0.37	2.4
MICA	1200	64	0.1	7.1	150.0	5.20	● 167.0
12 MILE	1151	165	2.3	7.4	37.0	0.31	2.0
EASTER MILE	456	142	1.4	7.6	180.0	1.10	● 8.2
A TOP	871	150	0.1	7.5	16.0	0.39	● 12.9
A BOTTOM	1646	156	27.0	7.3	48.0	0.38	● 8.8
B TOP	229	96	44.0	7.3	4.3	0.46	1.4
B BOTTOM	244	108	40.0	7.4	2.5	0.34	0.6
C TOP	3030	231	1.1	7.3	220.0	0.65	● 12.5
C BOTTOM	3638	295	14.7	7.3	310.0	0.61	● 6.5
D	2825	224	20.5	7.3	160.0	0.21	● 7.2
E TOP	4174	339	10.4	7.5	910.0	17.00	● 902.0
E BOTTOM	5275	321	16.7	7.4	740.0	6.30	● 530.0
F TOP	2714	389	7.9	7.5	690.0	8.40	● 291.0
F BOTTOM	5170	410	19.8	7.4	950.0	2.20	● 154.0
G TOP	1369	302	7.4	7.7	310.0	8.90	● 244.0
G BOTTOM	2787	366	9.7	7.6	640.0	5.20	● 162.0
H	2143	321	7.1	7.5	440.0	6.50	● 170.0
I	2315	838	16.0	7.6	1200.0	9.90	● 120.0
J	2987	1388	26.1	7.7	710.0	5.00	● 38.0
M TOP	1405	332	3.2	8.0	420.0	0.43	● 20.0
M BOTTOM	1910	307	3.9	7.8	320.0	0.29	● 7.3
N TOP	2003	135	5.3	7.6	54.0	0.30	● 3.6
N BOTTOM	2225	163	110.0	7.6	85.0	0.68	2.4
O TOP	762	211	9.4	7.9	64.0	0.61	● 4.2
O BOTTOM	1526	186	3.9	7.7	94.0	0.57	● 12.0
P	6820	398	14.4	7.5	370.0	0.52	● 46.0
Q	739	202	6.1	7.7	120.0	4.20	● 68.0
R	782	137	3.5	7.5	120.0	0.31	● 31.0

TABLE 10

DOMESTIC WATER CRITERIA

Substance	Maximum Desirable	Maximum Permissible	Agency
Arsenic		50 μg dm^{-3}	WHO AWRC
Calcium		200 mg dm^{-3}	AWRC
Chloride	200 mg dm^{-3}	600 mg dm^{-3}	WHO AWRC
Chromium		10 μg dm^{-3}	AWRC
Copper	50 μg dm^{-3}	1500 μg dm^{-3}	WHO
		1000 μg dm^{-3}	AWRC
Iron	100 μg dm^{-3}	1000 μg dm^{-3}	WHO
		300 μg dm^{-3}	AWRC
Lead		100 μg dm^{-3}	WHO
		50 μg dm^{-3}	AWRC
Lead-210		100 pCi dm^{-3} *	ICRP
Magnesium		150 mg dm^{-3}	AWRC
		(If SO_4<250 mg dm^{-3})	WHO AWRC
Nitrate		45 mg dm^{-3} (as NO_3)	AWRC
pH		6.5 - 9	AWRC
Radium-226		3 pCi dm^{-3} *	WHO
		10 pCi dm^{-3} *	ICRP CDOH
Selenium		10 μg dm^{-3}	WHO AWRC
Sulphate	200 mg dm^{-3}	400 mg dm^{-3}	WHO
		250 mg dm^{-3}	AWRC
Sodium		270 mg dm^{-3}	AWRC
Total alkalinity		30-500 mg dm^{-3} (as $CaCO_3$)	AWRC
Total hardness	100 mg dm^{-3} (as $CaCO_3$)	500 mg dm^{-3} (as $CaCO_3$)	WHO AWRC
Total suspended Solids		1000 mg dm^{-3}	AWRC
Uranium		2 mg dm^{-3}	CDOH

Acronyms WHO World Health Organisation
AWRC Australian Water Resources Council
CDOH Commonwealth Department of Health
ICRP International Commission on Radiological Protection

* 1 pCi dm^{-3} = 3.7 x 10^{-2} Bq dm^{-3}

TABLE 11

CRITERIA FOR LIVESTOCK WATER SUPPLIES

(FROM AWRC 1974)

Substance	Stock	Maximum Desirable	Maximum Permissible	Derived Working Level
Arsenic				1.0 mg dm^{-3}
Calcium				1000 "
Chromium				1-5.0 "
Copper				0.5-2 "
Iron				10 "
Lead				0.5 "
Magnesium	Sheep			500 "
	Cattle			400 "
Molybdenum				0.01 "
Nitrate				90-200 "
Radium-226				3 pCi dm^{-3} *
Selenium				0.02 "
Sulphate				1000 "
TDS	Sheep	6000 mg dm^{-3}	13000 mg dm^{-3}	
	Beef cattle	4000 "	5000 "	

* 1 pCi dm^{-3} = 3.7 x 10^{-2} Bq dm^{-3}

TABLE 12

CRITERIA FOR IRRIGATION WATER

(FROM AWRC)

Element	Derived working level for continuous use on all soils
Arsenic	0.1 mg dm^{-3}
Chloride	* 35-710 mg dm^{-3}
Chromium	1.0 "
Copper	0.2 "
Iron	1.0 "
Lead	5.0 "
Molybdenum	0.01 "
^{226}Ra	3 pCi dm^{-3} **
Selenium	0.02 mg dm^{-3}
TDS (Class 4)	1500-3500 mg dm^{-3}

* Varies with crop and soil e.g. upper levels for stone fruit (175 mg dm^{-3}), citrus (265 mg dm^{-3}), vines (350 mg dm^{-3}).

** 1 pCi dm^{-3} = 3.7 x 10^{-2} Bq dm^{-3}

TABLE 13

CHLORIDE RATIOS OF LEAD, ARSENIC, IRON, CHROMIUM, COPPER, MOLYBDENUM, SELENIUM, VANADIUM, CALCIUM, MAGNESIUM, SODIUM, POTASSIUM, BICARBONATE, SULPHATE, NITRATE, HARDNESS. URANIUM. RADIUM-226, LEAD-210

	PB:CL	AS:CL	FE:CL	CR:CL	CU:CL	MO:CL	SE:CL	V:CL	CA:CL	MG:CL
NEVER DESPAIR	0.017000	0.200000	2.700000	0.007000	0.007000	0.050000	0.017000	0.030000	0.140000	0.100000
HOWARDS	0.020000	0.170000	0.830000	0.008000	0.100000	0.025000	0.004000	0.080000	0.230000	0.140000
GARDEN	0.026000	0.078000	0.840000	0.005000	0.016000	0.016000	0.003000	0.026000	0.210000	0.100000
SOUTHERN CROSS	0.020000	0.020000	8.600000	0.008000	0.016000	0.024000	0.020000	0.040000	0.200000	0.130000
DEEP	0.016000	0.003000	2.800000	0.006000	0.094000	0.006000	0.003000	0.060000	0.170000	0.110000
30.5 MILE	0.130000	0.190000	1.200000	0.050000	0.060000	0.980000	0.005000	0.050000	0.160000	0.110000
TINY	0.110000	0.003000	0.750000	0.030000	0.039000	0.600000	0.003000	0.030000	0.100000	0.070000
K	0.091000	0.003600	0.940000	0.020000	0.160000	0.160000	0.003600	0.036000	0.180000	0.115000
L	0.079000	0.002300	0.450000	0.014000	0.135000	0.057000	0.002300	0.022000	0.136000	0.102000
OLD GOVT	0.010000	0.002000	0.350000	0.013000	0.004000	0.076000	0.010000	0.020000	0.190000	0.160000
GIDGEE	0.307000	0.001000	18.490000	0.002900	0.058000	0.002900	0.014000	0.014000	0.140000	0.130000
BOUNDARY	0.018000	0.000500	0.240000	0.002000	0.004000	0.001000	0.000500	0.005000	0.067000	0.067000
BLACK TANK	0.001400	0.000400	0.140000	0.002000	0.006000	0.002000	0.006000	0.006000	0.075000	0.073000
CENTIPEDE	0.002000	0.008000	0.960000	0.000800	0.027000	0.006000	0.004000	0.004000	0.110000	0.120000
YACKABINDI	0.002000	0.015000	0.180000	0.001800	0.004000	0.000900	0.002000	0.018000	0.065000	0.077000
CORKSCREW	0.009000	0.013000	10.000000	0.004000	0.046000	0.004000	0.002000	0.018000	0.100000	0.120000
ALBANY	0.000900	0.005600	0.024000	0.000800	0.003000	0.000400	0.005600	0.002000	0.083000	0.110000
RUBBER	0.003000	0.010000	1.270000	0.001000	0.027000	0.001000	0.003400	0.007000	0.130000	0.110000
BOTTLE	0.020000	0.020000	0.890000	0.002000	0.450000	0.000900	0.002000	0.005000	0.150000	0.100000
MIDNIGHT	0.004000	0.000800	0.710000	0.002000	0.120000	0.002000	0.008000	0.016000	0.110000	0.100000
MALLEE HEN	0.010000	0.005000	5.070000	0.006000	0.250000	0.002000	0.010000	0.010000	0.250000	0.160000
SNAKE	0.001000	0.000200	0.030000	0.000500	0.010000	0.002000	0.001000	0.005000	0.050000	0.080000
NORTH	0.044000	0.007000	9.400000	0.005000	0.430000	0.004000	0.009000	0.070000	0.110000	0.080000
BIG MILL	0.006000	0.001000	0.780000	0.006000	0.100000	0.004000	0.006000	0.033000	0.092000	0.080000
INDEPENDENCE	0.230000	0.110000	28.199990	0.011000	0.830000	0.010000	0.023000	0.057000	0.300000	0.180000
MICA	0.001700	0.003000	0.046000	0.000700	0.008000	0.006000	0.001700	0.003000	0.040000	0.074000
12 MILE	0.002000	0.000400	0.260000	0.001000	0.060000	0.006000	0.004000	0.004000	0.068000	0.080000
EASTER MILE	0.008000	0.001600	1.590000	0.005000	0.110000	0.013000	0.008000	0.016000	0.130000	0.098000
A TOP	0.002500	0.000500	0.046000	0.001500	0.002500	0.004000	0.002500	0.005000	0.065000	0.068000
A BOTTOM	0.007100	0.000300	0.034000	0.000600	0.002900	0.002900	0.002900	0.005700	0.057000	0.079000
B TOP	0.012000	0.002500	1.860000	0.012000	0.012000	0.009800	0.002500	0.025000	0.110000	0.070000
B BOTTOM	0.010000	0.002000	1.720000	0.010000	0.008000	0.008000	0.002000	0.020000	0.091000	0.065000
C TOP	0.000800	0.000200	0.037000	0.000800	0.001500	0.009000	0.006700	0.003000	0.054000	0.090000
C BOTTOM	0.000700	0.000100	0.030000	0.000700	0.001400	0.008600	0.003600	0.005700	0.056000	0.092000
D	0.001900	0.000190	0.065000	0.000700	0.002000	0.008000	0.006500	0.003700	0.058000	0.093000
E TOP	0.000990	0.000099	0.020000	0.000400	0.000990	0.037000	0.006900	0.005900	0.038000	0.077000
E BOTTOM	0.000820	0.000080	0.016000	0.000300	0.001200	0.035000	0.004500	0.006600	0.042000	0.080000
F TOP	0.001800	0.000350	0.046000	0.000500	0.000890	0.033000	0.004400	0.023000	0.049000	0.087000
F BOTTOM	0.000900	0.000090	0.010000	0.000190	0.001900	0.049000	0.000900	0.005600	0.047000	0.088000
G TOP	0.003300	0.000650	0.085000	0.001600	0.002000	0.069000	0.006500	0.043000	0.049000	0.079000
G BOTTOM	0.000880	0.000180	0.015000	0.000530	0.001400	0.068000	0.003500	0.019000	0.050000	0.089000
H	0.000960	0.000190	0.036000	0.000570	0.002100	0.065000	0.005700	0.013000	0.042000	0.074000
I	0.000880	0.000180	0.090000	0.000880	0.001800	0.058000	0.003500	0.003500	0.041000	0.074000
J	0.001400	0.000140	0.306000	0.000700	0.008400	0.023000	0.000700	0.001400	0.039000	0.077000
M TOP	0.001500	0.008800	0.027000	0.000590	0.003500	0.052000	0.007400	0.012000	0.061000	0.100000
M BOTTOM	0.001100	0.003400	0.021000	0.001400	0.004600	0.032000	0.009200	0.006900	0.048000	0.077000
N TOP	0.001200	0.001200	0.023000	0.001400	0.003200	0.017000	0.003500	0.002300	0.056000	0.078000
N BOTTOM	0.000940	0.000190	0.017000	0.001100	0.003000	0.037000	0.002800	0.005600	0.044000	0.075000
O TOP	0.002400	0.002400	0.063000	0.000970	0.003900	0.032000	0.004900	0.019000	0.042000	0.065000
O BOTTOM	0.001300	0.005400	0.019000	0.001000	0.002700	0.032000	0.002700	0.005400	0.042000	0.074000
P	0.001000	0.000140	0.024000	0.000140	0.001700	0.003200	0.003500	0.000700	0.051000	0.084000
Q	0.012000	0.001600	0.055000	0.003000	0.019000	0.029000	0.031000	0.031000	0.078000	0.093000
R	0.004600	0.001800	0.147000	0.004600	0.009200	0.001800	0.018000	0.009200	0.108000	0.110000

TABLE 13 (continued)

	NA:CL	K:CL	HCO3:CL	SO4:CL	NO3:CL	HARD:CL	U:CL	RA:CL	PB210:CL
NEVER DESPAIR	0.792000	0.017000	0.660000	0.370000	0.170000	0.744000	0.091000	0.006700	0.002800
HOWARDS	0.588000	0.050000	0.800000	0.350000	0.208000	1.170000	0.050000	0.002100	0.001040
GARDEN	0.658000	0.034000	0.632000	0.397000	0.132000	0.926000	0.034000	0.001300	0.000580
SOUTHERN CROSS	0.900000	0.044000	1.120000	0.474000	0.261000	1.030000	0.070000	0.008800	0.007200
DEEP	0.704000	0.066000	0.704000	0.396000	0.204000	0.880000	0.035000	0.001500	0.000350
30.5 MILE	0.698000	0.085000	0.820000	0.330000	0.016000	0.850000	0.010000	0.006900	0.000950
TONY	0.614000	0.078000	0.412000	0.408000	0.114000	0.800000	0.130000	0.033000	0.007200
K	0.779000	0.054000	0.960000	0.446000	0.036000	0.930000	0.435000	0.069000	0.006200
L	0.647000	0.043000	0.443000	0.364000	0.102000	0.758000	0.498000	0.100000	0.016300
OLD GOVT	0.555000	0.064000	0.800000	0.410000	0.020000	1.100000	0.140000	0.070000	0.000590
GIDGEE	0.558000	0.022000	0.350000	0.364000	0.087000	0.870000	0.005000	0.002900	0.000790
BOUNDARY	0.568000	0.027000	0.107000	0.224000	0.044000	0.444000	0.018000	0.002100	0.000120
BLACK TANK	0.606000	0.029000	0.078000	0.384000	0.036000	0.489000	0.005300	0.000140	0.000072
CENTIPEDE	0.486000	0.041000	0.122000	0.317000	0.033000	0.777000	0.079000	0.004700	0.000750
YACKABINDI	0.610000	0.009000	0.112000	0.344000	0.029000	0.479000	0.009600	0.001000	0.000430
CORKSCREW	0.552000	0.086000	0.281000	0.243000	0.130000	0.725000	0.063000	0.019900	0.002000
ALBANY	0.465000	0.039000	0.042000	0.270000	0.060000	0.674000	0.049000	0.000280	0.000062
RUBBER	0.528000	0.058000	0.170000	0.424000	0.034000	0.799000	0.045000	0.004600	0.000180
BOTTLE	0.439000	0.035000	0.124000	0.314000	0.014000	0.793000	0.040000	0.000460	0.000110
MIDNIGHT	0.525000	0.045000	0.208000	0.299000	0.087000	0.690000	0.048000	0.001300	0.000360
MALLEE HEN	0.186000	0.035000	0.041000	0.218000	0.204000	1.295000	0.002000	0.078000	0.001300
SNAKE	0.584000	0.050000	0.073000	0.297000	0.043000	0.443000	0.014000	0.000500	0.000044
NORTH	0.632000	0.044000	0.288000	0.266000	0.107000	0.604000	0.034000	0.008500	0.000730
BIG MILL	0.584000	0.035000	0.080000	0.332000	0.077000	0.548000	0.154000	0.016000	0.001200
INDEPENDENCE	0.667000	0.069000	1.250000	0.236000	0.230000	1.350000	0.063000	0.014000	0.001200
MICA	0.582000	0.037000	0.026000	0.260000	0.015000	0.408000	0.051000	0.056000	0.001800
12 MILE	0.564000	0.054000	0.087000	0.290000	0.048000	0.500000	0.016000	0.000900	0.000130
EASTER MILE	0.551000	0.050000	0.277000	0.295000	0.072000	0.730000	0.288000	0.013000	0.001800
A TOP	0.633000	0.045000	0.097000	0.342000	0.023000	0.443000	0.008000	0.006600	0.000200
A BOTTOM	0.617000	0.037000	0.054000	0.407000	0.021000	0.471000	0.014000	0.002500	0.000110
B TOP	0.672000	0.049000	0.287000	0.299000	0.086000	0.561000	0.011000	0.003400	0.001100
B BOTTOM	0.653000	0.049000	0.266000	0.229000	0.071000	0.495000	0.005000	0.001200	0.006900
C TOP	0.581000	0.049000	0.047000	0.352000	0.015000	0.504000	0.037000	0.002100	0.000110
C BOTTOM	0.573000	0.049000	0.052000	0.361000	0.012000	0.520000	0.044000	0.000930	0.000087
D	0.573000	0.048000	0.051000	0.341000	0.015000	0.526000	0.030000	0.001300	0.000069
E TOP	0.618000	0.072000	0.041000	0.374000	0.041000	0.413000	0.090000	0.089000	0.001700
E BOTTOM	0.619000	0.070000	0.032000	0.387000	0.035000	0.434000	0.061000	0.044000	0.000520
F TOP	0.612000	0.073000	0.084000	0.402000	0.038000	0.481000	0.122000	0.052000	0.001500
F BOTTOM	0.603000	0.066000	0.047000	0.404000	0.030000	0.481000	0.088000	0.014000	0.000200
G TOP	0.671000	0.076000	0.121000	0.389000	0.061000	0.448000	0.101000	0.080000	0.002900
G BOTTOM	0.605000	0.070000	0.079000	0.399000	0.033000	0.490000	0.113000	0.028000	0.009100
H	0.616000	0.071000	0.075000	0.371000	0.040000	0.410000	0.084000	0.033000	0.001200
I	0.609000	0.065000	0.180000	0.282000	0.013000	0.408000	0.212000	0.021000	0.001700
J	0.600000	0.059000	0.236000	0.226000	0.004000	0.416000	0.099000	0.005300	0.000700
M TOP	0.645000	0.076000	0.119000	0.375000	0.047000	0.414000	0.124000	0.006000	0.000130
M BOTTOM	0.615000	0.065000	0.086000	0.364000	0.037000	0.437000	0.073000	0.001700	0.000000
N TOP	0.550000	0.049000	0.038000	0.298000	0.018000	0.461000	0.012400	0.000830	0.000069
N BOTTOM	0.567000	0.055000	0.037000	0.297000	0.020600	0.417000	0.016000	0.000450	0.000130
O TOP	0.630000	0.060000	0.125000	0.268000	0.054000	0.371000	0.031000	0.002040	0.000300
O BOTTOM	0.611000	0.056000	0.060600	0.339000	0.025500	0.409000	0.025200	0.003200	0.000040
P	0.546000	0.047000	0.033800	0.268000	0.003300	0.475000	0.025800	0.003200	0.000040
Q	0.616000	0.069000	0.193000	0.398000	0.067000	0.580000	0.094000	0.053000	0.003300
R	0.519000	0.059000	0.155000	0.309000	0.054000	0.721000	0.111000	0.029000	0.000290

FIGURE 1 MAP OF YEELIRRIE AREA SHOWING SAMPLING POINTS

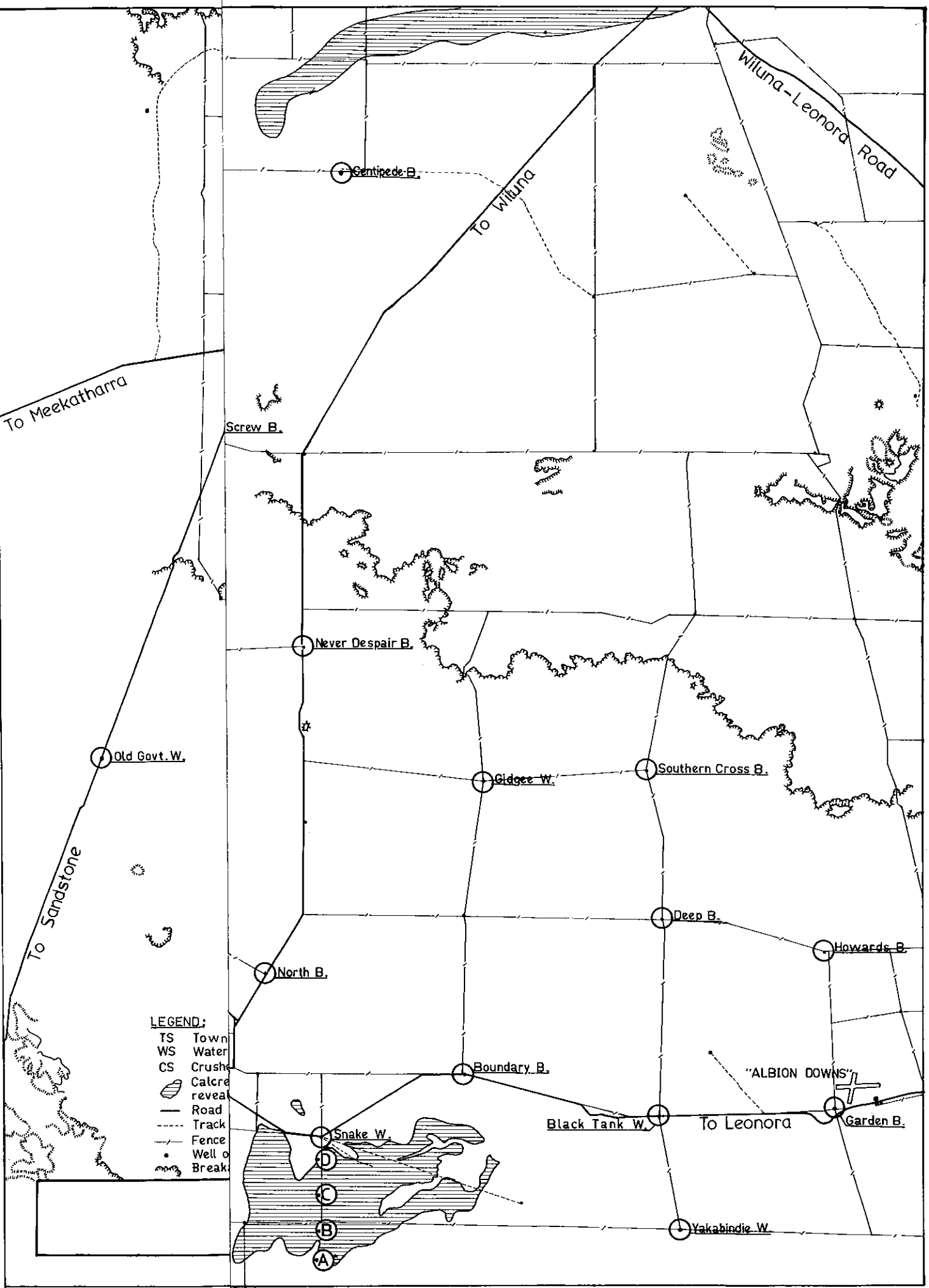


FIGURE 1. MAP OF YEELIRRIE AREA SHOWING SAMPLING POINTS

COLOUR CODING FOR FIGURES 2 TO 8

Red colouring indicates that a sampling point was grouped as being similar to sampling points in the ore body. Dissimilar groups are coloured blue.

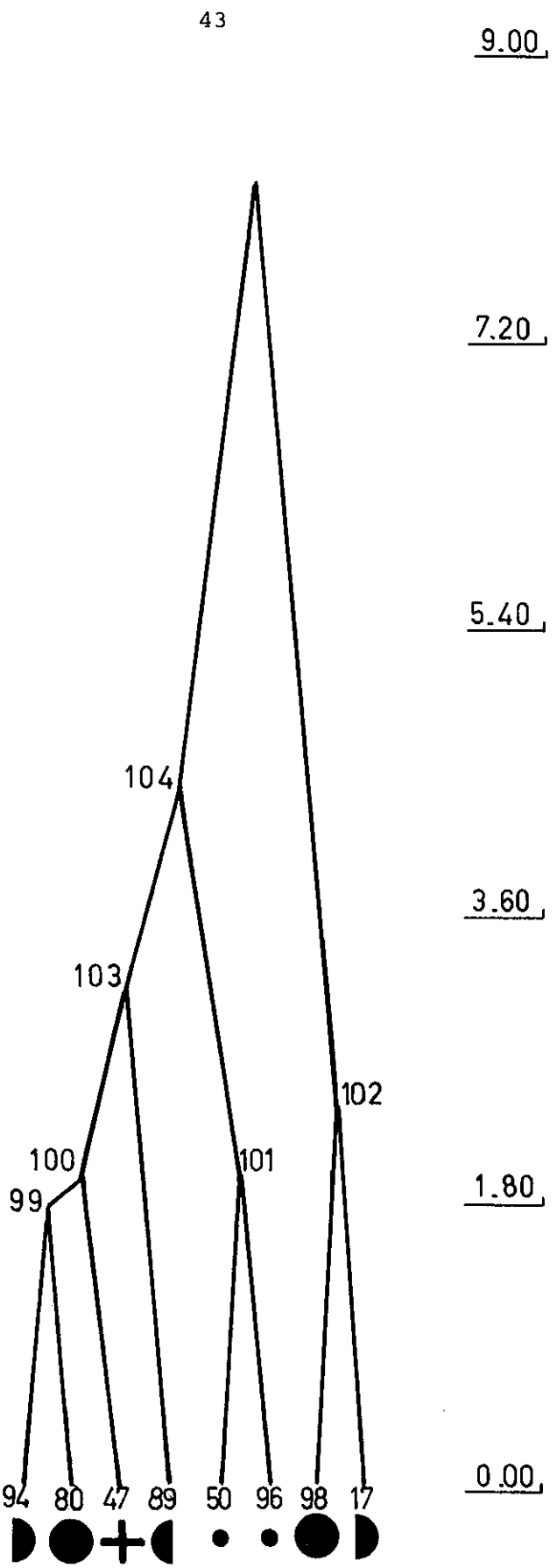


FIGURE 2 Dendrogram showing the sorting of complete data.

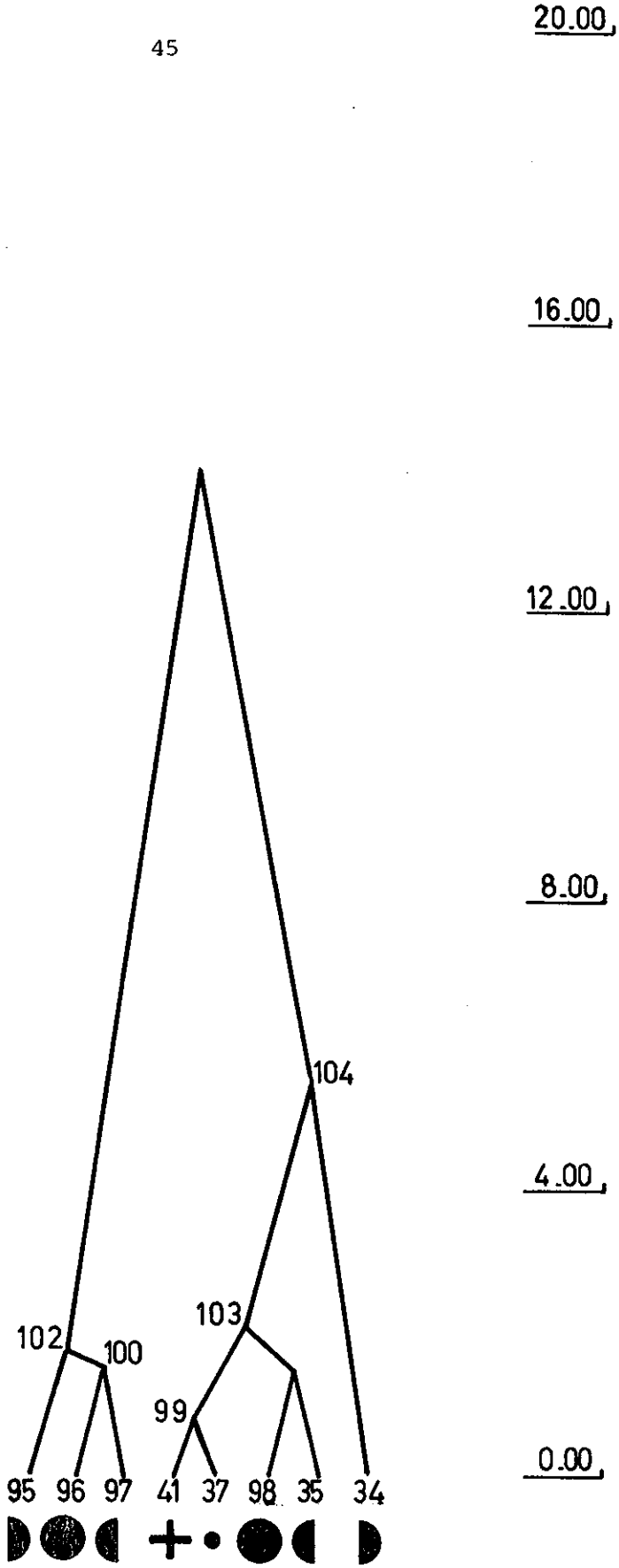


FIGURE 3 Dendrogram showing Mo, Se, V, U, ^{210}Pb and ^{226}Ra sorted separately

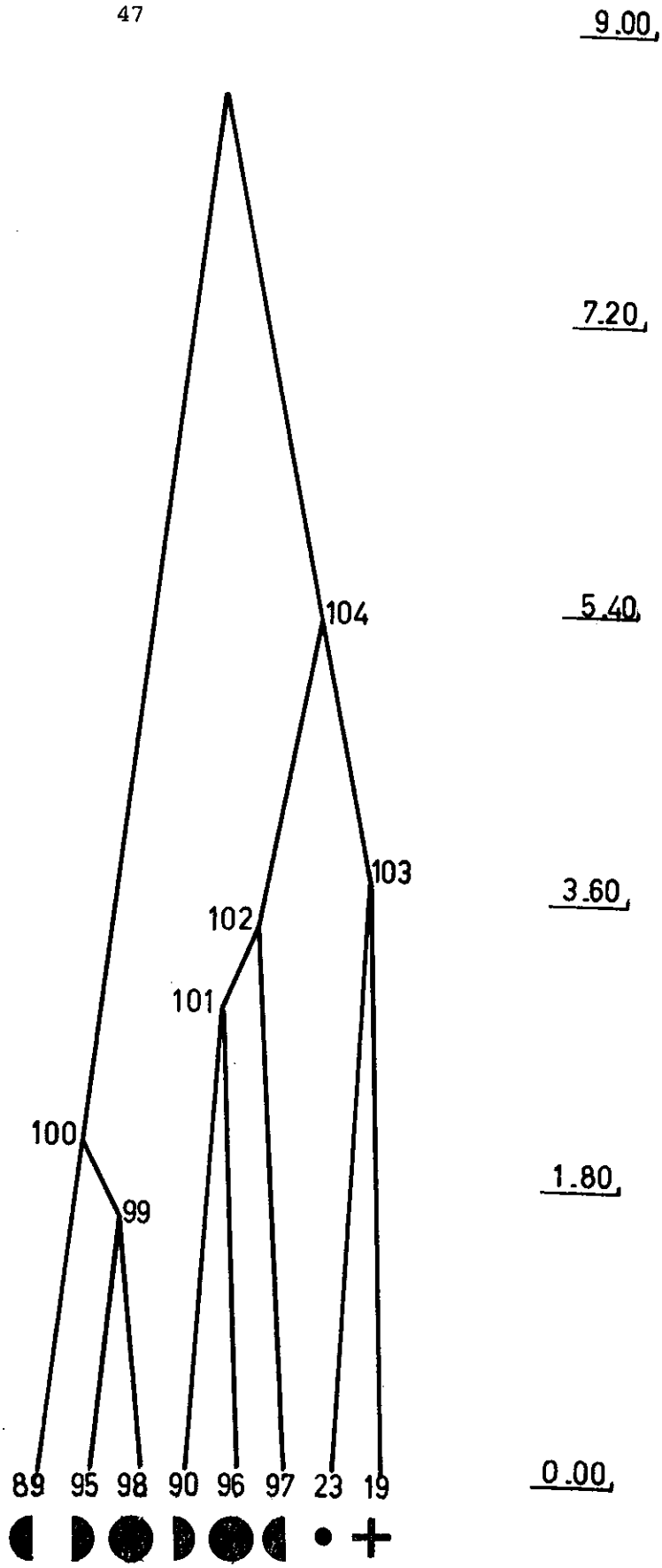


FIGURE 4 Dendrogram showing the ratios of Pb:Cl, As:Cl, Fe:Cl, Cr:Cl, Cu:Cl, Mo:Cl, Se:Cl, V:Cl, Ca:Cl, Mg:Cl, Na:Cl, K:Cl, HCO_3:Cl, SO_4:Cl, NO_3:Cl, Hardness:Cl, U:Cl, ^{226}Ra:Cl, ^{210}Pb:Cl sorted

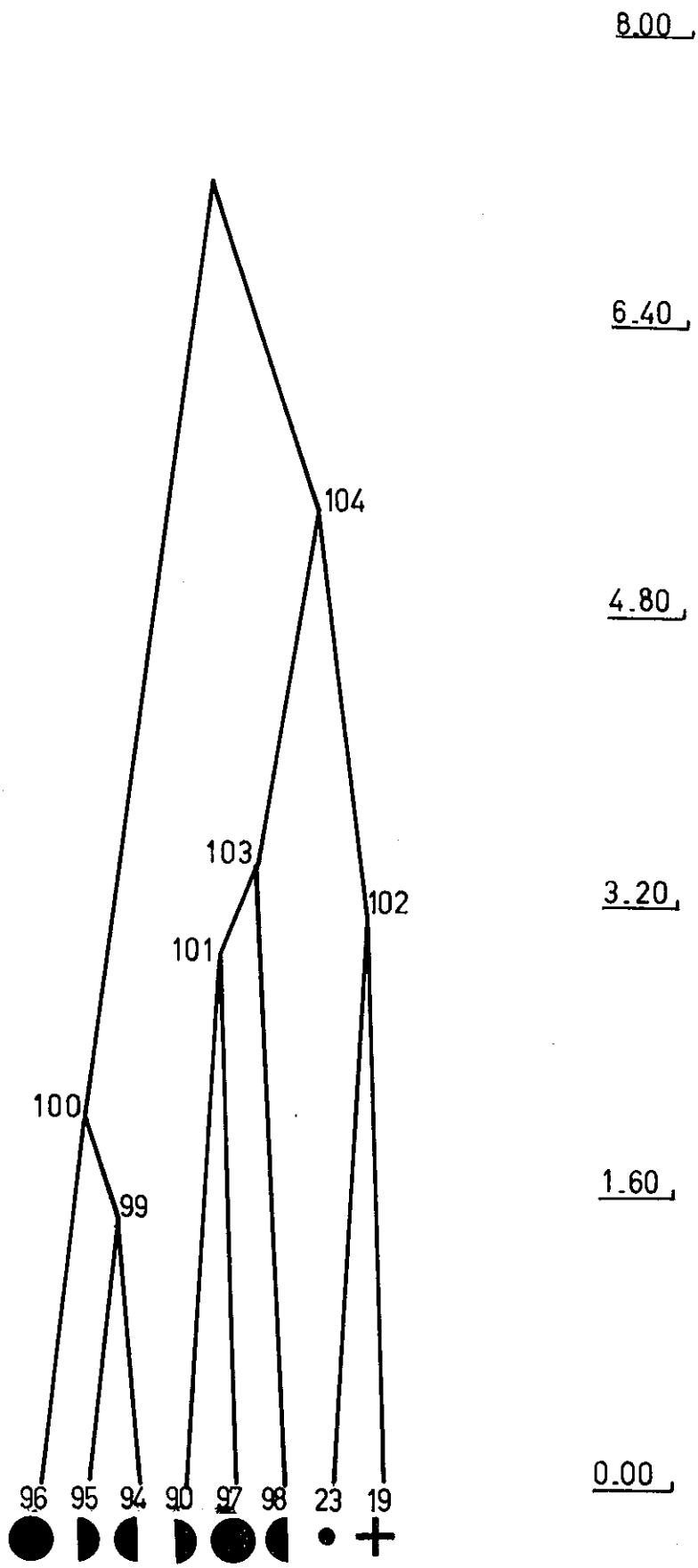
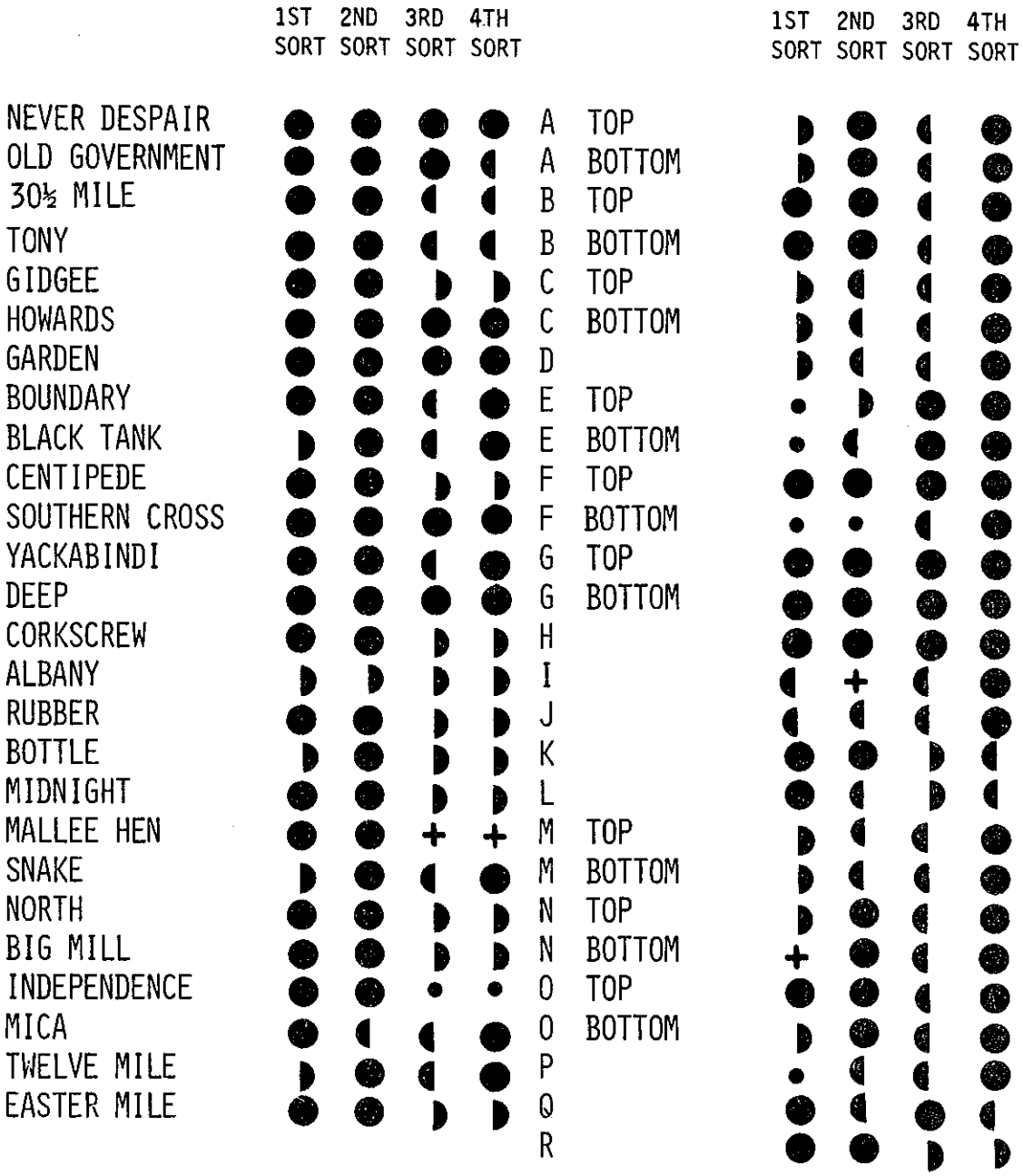


FIGURE 5 Dendrogram showing the ratios Mo:Cl, Se:Cl, V:Cl, U:Cl, ^{210}Pb:Cl, ^{226}Ra:Cl sorted separately.



KEY

1st Sort:- All data.

2nd Sort:- Mo, Se, V, ^{226}Ra, ^{210}Pb, U data only.

3rd Sort:- Chloride ratios Pb:Cl, As:Cl, Fe:Cl, Cr:Cl, Cu:Cl, Mo:Cl, Se:Cl, V:Cl, Ca:Cl, Mg:Cl, Na:Cl, K:Cl, HCO_3:Cl, SO_4:Cl, NO_3:Cl Hardness:Cl, U:Cl, ^{226}Ra:Cl, and ^{210}Pb:Cl.

4th Sort:- Chloride ratios Mo:Cl, Se:Cl, V:Cl, ^{226}Ra:Cl, ^{210}Pb:Cl and U:Cl.

FIGURE 6 Outline of Data Sorting

FIGURE 7 RESULT OF FIRST SORTING

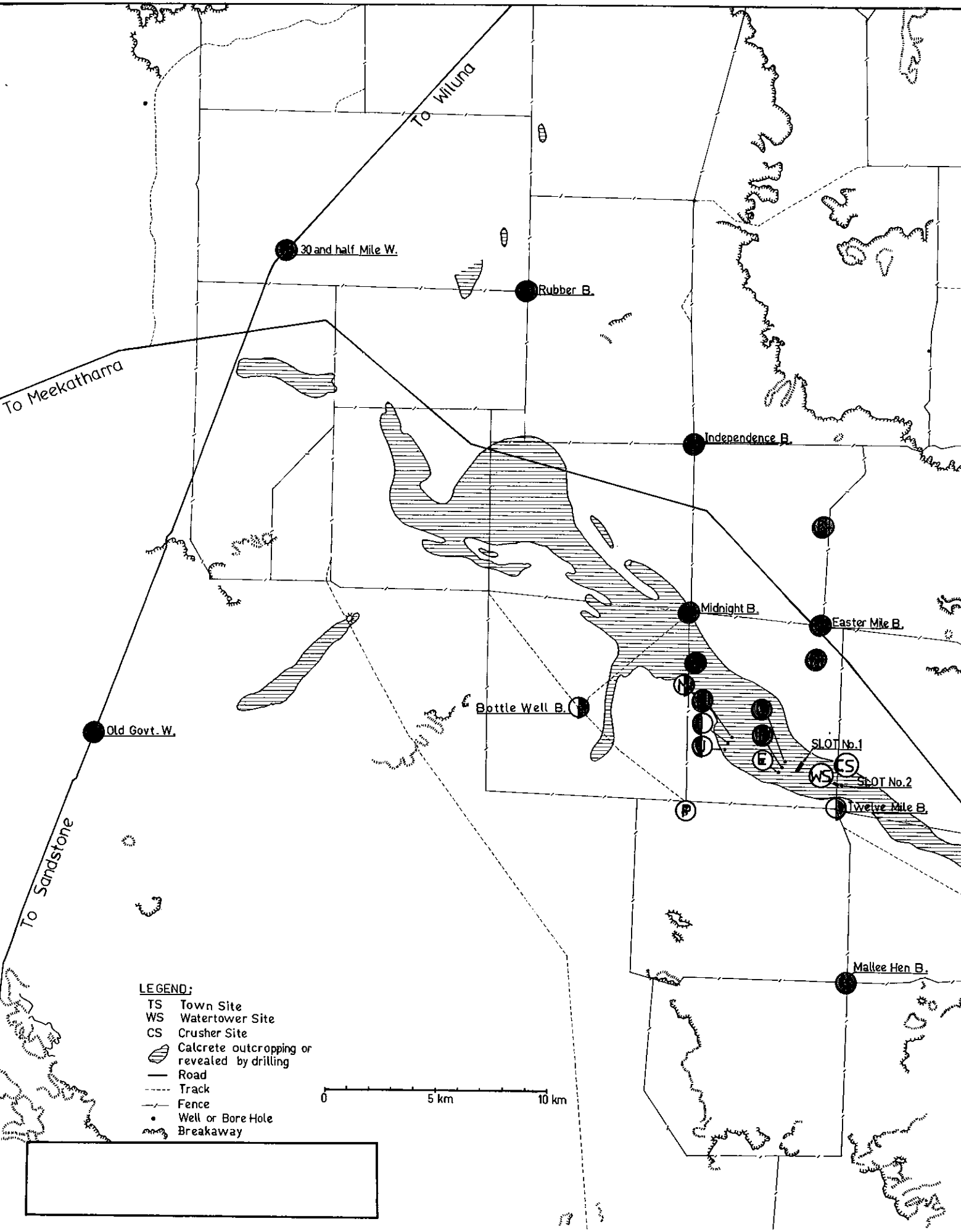
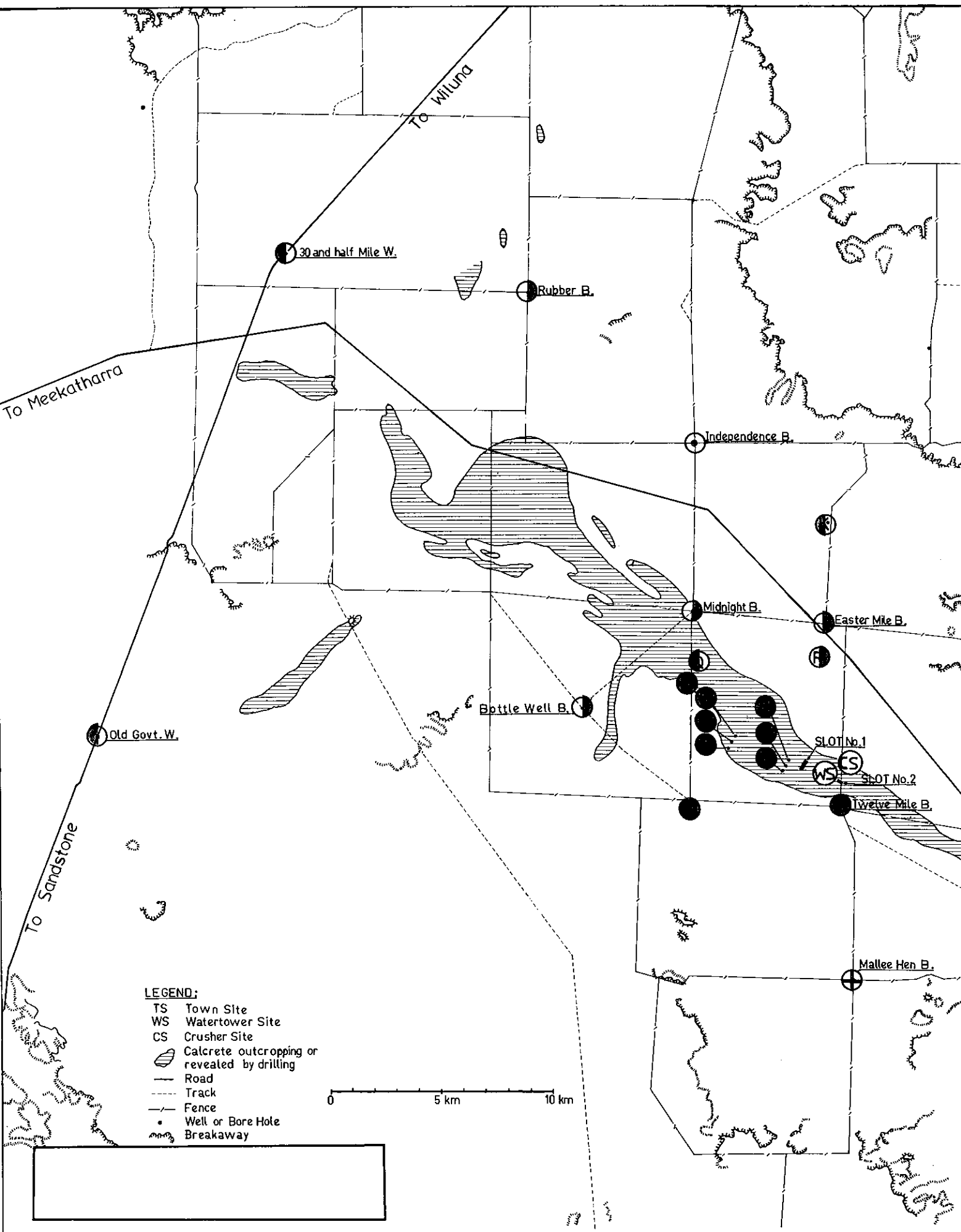

To Wiluna
To Meekatharra
To Sandstone
30 and half Mile W.
Rubber B.
Independence B.
Midnight B.
Easter Mile B.
Bottle Well B.
Old Govt. W.
SLOT No.1
SLOT No.2
Twelve Mile B.
Mallee Hen B.
LEGEND:
TS Town Site
WS Watertower Site
CS Crusher Site
Calcrete outcropping or revealed by drilling
Road
Track
Fence
Well or Bore Hole
Breakaway
0
5 km
10 km

FIGURE 8 RESULT OF FOURTH SORTING


To Wiluna
30 and half Mile W.
Rubber B.
To Meekatharra
Independence B.
Midnight B.
Easter Mile B.
Bottle Well B.
Old Govt. W.
SLOT No.1
SLOT No.2
Twelve Mile B.
To Sandstone
Mallee Hen B.
LEGEND;
TS Town Site
WS Watertower Site
CS Crusher Site
Calcrete outcropping or revealed by drilling
Road
Track
Fence
Well or Bore Hole
Breakaway
0
5 km
10 km

APPENDIX A

POLYTHETIC SORTING

The hierarchical sorting strategy chosen was agglomerative and based on a combinatorial model of Lance & Williams [1967]. A flexible strategy was used giving β the arbitrary value of -0.25 which led to $\alpha_i = \alpha_j = 0.625$.

The programs used on the Cyber 76 computer were MULCLAS and GROUPER. The similarity measure was Euclidean metric, standardised according to Burr [1968].

A more detailed outline of the results of the GROUPER analysis than shown in the text is given in Table A1. This should be read in conjunction with the dendrograms in Figures 2 - 5. Table A1 shows

- the sampling points combined in the various groups,
- the parameters mainly involved in the separations, and
- the values of the parameters averaged over the group.

Discussion of Tables A1, A2, A3 and A4

In general, it can be seen that as the groups compared gather more attributes, the parameters which separated them become more diffuse and the percentage contribution of each parameter becomes less. Some separations point to particular differences and these will be discussed separately for each sorting.

The first sorting shows that

- hole N (bottom) need not be separated from groups 94 and 80 since it was sorted out on the basis of a high total suspended solids value only;
- the preponderance of parameters such as TDS, chlorinity, Mg, Na, *etc.* which are related to the salinity of the water, have outweighed other values and grouped otherwise unlike sampling points together, *e.g.* hole P has been associated with holes E (top), E (bottom) and F (bottom), whereas these holes would more logically be associated with holes F (top), G (top) and G (bottom);
- Bottle Well showed a very high copper value; and
- the separation of the two main groups was based on parameters associated with the salinity of the water.

In the second sorting only six parameters were examined. Separations within the orebody water samples are of minor importance but hole J was grouped with Mica Well and hole L on the basis of low Se and V levels and similar ^{210}Pb values. It is interesting to note that hole J is positioned close to the edge of the orebody zone.

(continued)

APPENDIX A (continued)

In the third sorting, 19 parameters were examined, as ratios of their relevant chloride levels, to reduce the importance of salinity (see Table 12). This system does not take into account the variable rates of precipitation of HCO_3, SO_4, Mg and Ca as salinity increases. Hole J is again associated with Mica Well but the two are included as similar to orebody samples in the major sorting.

Since it was restricted to the chloride ratios of six parameters associated with the mineralisation of the orebody, the fourth sorting caused a tightening of the relationship between holes E, F, G, H, I and J. Mica Well was again associated with hole J. It is interesting to note that the Never Despair Bore, Howard's Bore, Garden Bore, Southern Cross Bore, Deep Bore, 30½ Mile Well, Tony Bore and holes K and L, which were separately grouped from other samples in all sortings, showed higher V:Cl ratios particularly when contrasted to holes E, F, G, H, I and J. They were also higher for average levels of Se:Cl, Mo:Cl, and ^{210}Pb:Cl than holes E, F, G, H, I and J but these values were more variable within groups.

Mallee Hen Bore and Independence Bore were associated through all sortings. In the last two sortings, they were grouped as a pair separated on the basis of high Cu:Cl and Fe:Cl values and a lower Na:Cl value in the third sorting. In the fourth sorting, they were distinguished by a high Se:Cl value and low Mo:Cl and U:Cl levels.

The large difference between the chloride ratios for Independence Bore and Mallee Hen Bore would suggest that they are not similar to each other and this makes these two sampling points stand out as somewhat unique from the rest.

In the fourth sorting, water from Mica Well was again grouped as similar to samples taken in the orebody region.

REFERENCES

Burr, E.J. [1968] - Cluster sorting with mixed character types. 1. Standardisation of character values. *Aust. Comput. J.* 1, 97-99.

Lance, G.N. & Williams, W.T. [1967] - A general theory of classificatory sorting strategies. 1. Hierarchical systems. *Comput. J.* 9, 373-80.

TABLE A1

DETAIL OF FIRST SORTING (Refer to Figure 2 in text)

			Mean (A)	Mean (B)	
Group 94 (A)	Black Tank Bore, Albany Well, Snake Well, 12 Mile Bore, A (Top), A (Bottom), C (Top), C (Bottom), M (Top), M (Bottom), N (Top), O (Bottom)				
was separated by	V *	40% contribution ...	20	110	$\mu g\ dm^{-3}$
	^{210}Pb	18% contribution ...	0.38	7.25	$pCi\ dm^{-3}$
from Group 80(B)	F (Top), G (Top), G (Bottom), H.				

			Mean (A)	Mean (B)	
Groups 94+80(A)					
were separated by	Total suspended solids 89% contribution	...	7.1	110	$mg\ dm^{-3}$
from Group 47(B)	N (Bottom)				

			Mean (A)	Mean (B)	
Groups 94+80+47(A)					
were separated by	HCO_3^-	35% contribution ...	297	1358	$mg\ dm^{-3}$
	Alkalinity	35% contribution ...	244	1113	$mg\ (CaCO_3)\ dm^{-3}$
	U	13% contribution ...	232	955	$\mu g\ dm^{-3}$
from Group 89(B)	I, J				

			Mean (A)	Mean (B)	
Group 50 (A)	P				
was separated by	NO_3	64% contribution ...	47	385	$mg\ dm^{-3}$
	^{226}Ra	15% contribution ...	46	529	$pCi\ dm^{-3}$
	Mo	11% contribution ...	46	443	$\mu g\ dm^{-3}$
from Group 96(B)	E (Top), E (Bottom), F (Bottom)				

			Mean (A)	Mean (B)	
Groups 94+80+47+89(A)					
were separated by	^{226}Ra	9% contribution ...	56	408	$pCi\ dm^{-3}$
	K	9% contribution ...	261	739	$mg\ dm^{-3}$
	SO_4	8% contribution ...	1558	4171	$mg\ dm^{-3}$
	TDS	8% contribution ...	10590	26939	$mg\ dm^{-3}$
	Na	8% contribution ...	2741	7025	$mg\ dm^{-3}$
	Cl	7% contribution ...	4639	11848	$mg\ dm^{-3}$
from Groups 50 + 96 (B)					

TABLE A1 (continued)

Group 98 (A)	Never Despair Bore, Old Govt. Well, Tony Bore, Gidgee Bore, Howard's Bore, Garden Bore, Boundary Bore, Centipede Bore, Southern Cross Bore, Yakabindi Bore, Deep Bore, Corkscrew Bore, Rubber Bore, Midnight Bore, Mallee Hen Bore, North Bore, Big Mill Bore, Independence Bore, Mica Well, Easter Mill Bore, B (Top), B (Bottom), H, L, O (Top), Q, R.					
				Mean (A)	Mean (B)	
was separated by	Cu	64% contribution	...	65	950	$\mu g\ dm^{-3}$
from Group 17 (B)	Bottle Well					

Groups 94+50+89 +47+80+96(A)						
				Mean (A)	Mean (B)	
were separated by	Na	8% contribution	...	3455	529	$mg\ dm^{-3}$
	TDS	8% contribution	...	13315	2255	$mg\ dm^{-3}$
	Cl	8% contribution	...	5841	944	$mg\ dm^{-3}$
	SO_4	8% contribution	...	1993	295	$mg\ dm^{-3}$
	K	8% contribution	...	341	41	$mg\ dm^{-3}$
	Mg	7% contribution	...	482	91	$mg\ dm^{-3}$
	Hardness	7% contribution	...	2715	627	$mg\ (CaCO_3)\ dm^{-3}$
	Ca	6% contribution	...	293	101	$mg\ dm^{-3}$
from Groups 98 + 17 (B)						

* % contribution gives a measure of the degree to which a parameter contributed to the separation. The total contribution of all the 25 parameters sorted is 100%.

TABLE A2

DETAIL OF SECOND SORTING (Refer to Figure 3 in text)

				Mean (A)	Mean (B)	
Group 41 (A)	I					
was separated by	^{210}Pb	*50% contribution	...	9.9	2.2	pCi dm^{-3}
	Mo	21% contribution	...	330	530	µg dm^{-3}
from Group 37 (B)	F (bottom)					

				Mean (A)	Mean (B)	
Group 98 (A)	F (top), G (top), G (bottom), H					
was separated by	^{226}Ra	38% contribution	...	217	530	pCi dm^{-3}
	Se	35% contribution	...	24	55	µg dm^{-3}
	Mo	11% contribution	...	283	430	µg dm^{-3}
from Group 35 (B)	E (bottom)					

				Mean (A)	Mean (B)	
Groups 41 + 37 (A)						
were separated by	V	44% contribution	...	40	104	µg dm^{-3}
	U	31% contribution	...	1075	564	µg dm^{-3}
from Groups 98 + 35 (B)						

				Mean (A)	Mean (B)	
Group 34 (A)	E (top)					
was separated by	^{226} Ra	51% contribution	...	902	239	pCi dm^{-3}
	^{210} Pb	25% contribution	...	17	6.8	pCi dm^{-3}
from Groups 41+98+37+35 (B)						

				Mean (A)	Mean (B)	
Group 96 (A)	Never Despair Bore, Old Govt. Well, 30½ Mile Well, Tony Bore, Gidgee Bore, Howard's Bore, Garden Bore, Boundary Bore, Black Tank Bore, Centipede Bore, Southern Cross Bore, Yakabindi Bore, Deep Bore, Corkscrew Bore, Rubber Bore, Bottle Well, Midnight Well, Mallee Hen Bore, Snake Well, North Bore, Big Mill Bore, Independence Bore, 12 Mile Bore, Easter Mile Bore, A (top), A (bottom), B (top), B (bottom), K, N (top), N (bottom), O (top), O (bottom), R.						
was separated by	^{210}Pb	60% contribution	...	0.61	5.8	pCi dm^{-3}
	U	30% contribution	...	52	360	µg dm^{-3}
from Group 97 (B)	Mica Well, J, L.					

TABLE A2 (continued)

				Mean (A)	Mean (B)	
Group 95 (A) Albany Well, C (top), C (bottom), D, M (top), M (bottom), P, Q.						
was separated by	Se	83% contribution	...	36	6.2	$\mu g\ dm^{-3}$
from Groups 96 + 97 (B).						
Groups 95+96+97(A)						
were separated by	Mo	22% contribution	...	37	349	$\mu g\ dm^{-3}$
	V	19% contribution	...	17	83	$\mu g\ dm^{-3}$
	U	19% contribution	...	111	735	$\mu g\ dm^{-3}$
	^{210}Pb	17% contribution	...	1.0	8.1	$pCi\ dm^{-3}$
from Groups 41+34+98+37 +35 (B)						

* % contribution gives a measure of the degree to which a parameter contributed to the separation. The total contribution of all the 6 parameters sorted is 100%.

TABLE A3

DETAIL OF THIRD SORTING (Refer to Figure 4 in text)

				Mean (A)	Mean (B)	
Group 95 (A)	Gidgee Bore, Centipede Bore, Corkscrew Bore, Albany Well, Rubber Bore, Bottle Well, Midnight Bore, North Bore, Big Mill Bore, Easter Mile Bore, R.					
was separated by	^{226}Ra:Cl	*28% contribution	...	0.009	0.056	pCi dm^{-3}
	K:Cl	18% contribution	...	0.047	0.071	mg dm^{-3}
	SO_4:Cl	15% contribution	...	0.312	0.391	mg dm^{-3}
from Group 98 (B)	Old Govt. Well, E (top), E (bottom), F (top), G (top), G (bottom), H, Q.					
Group 89 (A)	Boundary Bore, Black Tank Bore, Yakabindi Bore, Snake Well, Mica Well, 12 Mile Bore, A (top), A (bottom), B (top), B (bottom), C (top), C (bottom), D, F (bottom), I, J, M (top), M (bottom), N (top), N (bottom), O (top), O (bottom), P.					
was separated by	^{226}Ra:Cl	15% contribution	...	0.006	0.029	pCi dm^{-3}
	Mg:Cl	15% contribution	...	0.078	0.1	mg dm^{-3}
	Hardness:Cl	12% contribution	...	0.46	0.647	mg ($CaCO_3$) dm^{-3}
	Mo:Cl	11% contribution	...	0.004	0.008	µg dm^{-3}
from Groups 95+98 (B)						
Group 90 (A)	K, L					
was separated by	U:Cl	35% contribution	...	0.467	0.056	µg dm^{-3}
	^{210}Pb:Cl	17% contribution	...	0.011	0.002	pCi dm^{-3}
	^{226}Ra:Cl	17% contribution	...	0.085	0.004	pCi dm^{-3}
from Group 96 (B)	Never Despair Bore, Howard's Bore, Garden Bore, Southern Cross Bore, Deep Bore.					

TABLE A3 (continued)

				Mean (A)	Mean (B)	
Group 97 (A)	30½ Mile Well, Tony Bore					
was separated by	Mo:Cl	44% contribution	...	0.79	0.048	$\mu g\ dm^{-3}$
	Cr:Cl	25% contribution	...	0.04	0.01	$\mu g\ dm^{-3}$
from Groups 90+96(B)						
Group 23 (A)	Independence Bore					
was separated by	Pb:Cl	21% contribution	...	0.23	0.01	$\mu g\ dm^{-3}$
	Na:Cl	20% contribution	...	0.67	0.19	$mg\ dm^{-3}$
	Fe:Cl	20% contribution	...	28.2	5.1	$\mu g\ dm^{-3}$
	Cu:Cl	12% contribution	...	0.83	0.25	$\mu g\ dm^{-3}$
from Group 19 (B)	Mallee Hen Bore					
Groups 90 + 97 + 96 (A) were separated by	Cu:Cl	18% contribution	...	0.07	0.54	$\mu g\ dm^{-3}$
	Na:Cl	14% contribution	...	0.71	0.43	$mg\ dm^{-3}$
	Fe:Cl	14% contribution	...	2.1	16.6	$\mu g\ dm^{-3}$
	SO_4:Cl	11% contribution	...	0.39	0.23	$mg\ dm^{-3}$
from Groups 23+19(B)						
Groups 89+95+98(A) were separated by	HCO_3:Cl	12% contribution	...	0.14	0.71	$mg\ dm^{-3}$
	Ca:Cl	12% contribution	...	0.074	0.19	$mg\ dm^{-3}$
	Hardness:Cl	11% contribution	...	0.54	0.98	$mg(CaCO_3)\ dm^{-3}$
	NO_3:Cl	11% contribution	...	0.043	0.15	$mg\ dm^{-3}$
	Pb:Cl	8% contribution	...	0.005	0.068	$\mu g\ dm^{-3}$
from Groups 90+23+97+96+19(B)						

* % contribution gives a measure of the degree to which a parameter contributes to the separation. The total contribution of all the 19 parameters sorted is 100%.

TABLE A4

DETAIL OF FOURTH SORTING (Refer to Figure 5 in text)

				Mean (A)	Mean (B)	
Group 95 (A)	Gidgee Bore, Centipede Bore, Corkscrew Bore, Albany Well, Rubber Bore, Bottle Well, Midnight Bore, North Bore, Big Mill Bore, Easter Mile Bore, R.					
was separated by	Se:Cl	*50% contribution	...	0.007	0.021	$\mu g\ dm^{-3}$
	^{226}Ra	43% contribution	...	0.009	0.062	$pCi\ dm^{-3}$
from Group 94 (B)	Old Govt. Well, Q.					
Group 96 (A)	Boundary Bore, Black Tank Bore, Yakabindi Bore, Snake Well, Mica Well, 12 Mile Bore, A (top), A (bottom), B (top), B (bottom), C (top), C (bottom), D, E (top), E (bottom), F (top), F (bottom), G (top), G (bottom), H, I, J, M (top), M (bottom), N (top), N (bottom), O (top), O (bottom), P					
was separated by	Se:Cl	66% contribution	...	0.004	0.009	$\mu g\ dm^{-3}$
	V:Cl	21% contribution	...	0.01	0.019	$\mu g\ dm^{-3}$
from Groups 94+95(B)						
Group 97 (A)	Never Despair Bore, Howard's Bore, Garden Bore, Southern Cross Bore, Deep Bore					
was separated by	U:Cl	47% contribution	...	0.056	0.467	$\mu g\ dm^{-3}$
	^{210}Pb:Cl	23% contribution	...	0.002	0.011	$pCi\ dm^{-3}$
	^{226}Ra:Cl	23% contribution	...	0.004	0.085	$pCi\ dm^{-3}$
from Group 90 (B)	K, L					
Group 98 (A)	30½ Mile Well, Tony Bore					
was separated by	Mo:Cl	93% contribution	...	0.79	0.048	$\mu g\ dm^{-3}$
from Groups 90+97(B)						

TABLE A4 (continued)

				Mean (A)	Mean (B)	
Group 23 (A)	Independence Bore					
was separated by	Se:Cl	40% contribution	...	0.028	0.01	µg dm^{-3}
	V:Cl	31% contribution	...	0.057	0.01	µg dm^{-3}
	^{226}Ra:Cl	27% contribution	...	0.014	0.078	pCi dm^{-3}
from Group 19 (B)	Mallee Hen Bore					
Groups 23 + 19 (A)						
were separated by	Se:Cl	41% contribution	...	0.019	0.007	µg dm^{-3}
	Mo:Cl	19% contribution	...	0.006	0.213	µg dm^{-3}
	U:Cl	16% contribution	...	0.033	0.15	µg dm^{-3}
from Groups 90+98+97(B)						
Groups 96+95+94(A)						
were separated by	V:Cl	42% contribution	...	0.013	0.04	µg dm^{-3}
	^{210}Pb:Cl	21% contribution	...	0.001	0.004	pCi dm^{-3}
	Mo:Cl	19% contribution	...	0.02	0.18	µg dm^{-3}
from Groups 90+23+98+ 97+19(B)						

* % contribution gives a measure of the degree to which a parameter contributed to the separation. The total contribution of all the 6 parameters sorted is 100%.

THREE BASELINE STUDIES IN THE ENVIRONMENT OF THE URANIUM DEPOSIT AT YEELIRRIE, WESTERN AUSTRALIA

PAPER III

ENVIRONMENTAL LEVELS OF RADON-222 AND ITS DAUGHTERS

by

A. J. BROWNSCOMBE

D. R. DAVY

ABSTRACT

Results on the concentration of radon daughters (in working level units (WL)) in the atmosphere near the uranium deposit at Yeelirrie, West Australia, during late spring are reported.

Measurements were concentrated downwind of the ore body and taken at times (before and after sunset and sunrise) when concentrations were likely to be highest. Prevailing levels were low with 80 of the 190 determinations being < 0.001 WL. Highest values were associated with atmospheric inversion conditions and occurred at first light.

Measurements of the concentration of radon in groundwater were made. The use of drums sealed to the ground as monitors for changes in surface emanation of radon is also reported.

NOTES

CONTENTS

1. INTRODUCTION

The radon level in an atmosphere, expressed in terms of the activity of ^{222}Rn per unit volume, is not well correlated with the radiological consequences of its inhalation. The radiation dose to the respiratory tract due to radon is negligibly small compared with that delivered by its associated short-lived daughter products. If radon were always in radioactive equilibrium with its decay products in the atmosphere and these were always in the same physical state, radon concentration would be a good index of its radiological hazard. This, however, is not the case.

The concept of the 'Working Level' (WL) was introduced to provide a better physical measure of the hazard of radon exposure. The most important contributors of dose to the lung are the two α-emitting radon daughters, RaA and RaC'. The dose contribution from the β particles and γ rays emitted by RaB and RaC is negligible, but the long-lived daughters, RaD, RaE and RaF are eliminated from the bronchi before any significant number of disintegrations of these isotopes has occurred.

The basis of the definition of the working level is the potential alpha energy associated with 100 pCi (3.7 Bq) of ^{222}Rn in radioactive (secular) equilibrium with its short-lived decay products. This value (1.3×10^5 MeV) is derived by summing the alpha particle energy ultimately delivered by the decay through RaC' of each of the short-lived decay products. Table 1 lists the data used to arrive at this sum.

The assumption is then made that any combination of RaA, RaB, RaC and RaC' which will result in this ultimate emission has the same potential hazard as the equilibrium combination, if distributed in the same volume of air. It is assumed that the potential hazard is independent of the details of how disequilibrium may be achieved, and independent also of the distribution of the decay products among the various aerosols in the atmosphere. One WL is defined as 'any combination of the short-lived decay products of radon (RaA, RaB, RaC and RaC') in one litre of air which will result in the ultimate emission by them of 1.3×10^5 MeV of α particle energy'.

One WL is equivalent to 100 pCi ℓ^{-1} (3.7 Bq ℓ^{-1}) of radon only in the one special case when the radon is in equilibrium with its short-lived decay products. To express a radon concentration of pCi ℓ^{-1} (or Bq ℓ^{-1}) in WLs, it is necessary to know the state of disequilibrium between the radon and its short-lived daughters under the conditions obtaining at the time. In general, concentration in WLs = F x $\left(\frac{\text{concentration in pCi } \ell^{-1}}{100}\right)$, where F is a factor,

variously called the 'disequilibrium factor' or 'working level ratio', which is a measure of the lack of equilibrium between the radon and its short-lived daughters.

In practice, F is very variable and rarely has the value of one. Because of the half-lives of RaB and RaC, it would take about three hours for initially fresh radon to come to equilibrium with its short-lived daughters. Any process which removes the daughter products, particularly movement and dilution of the air, will prevent equilibrium being attained and ensure that F remains less than one.

A WL is a measure of a concentration. To obtain an accumulated or integrated exposure, it must be multiplied by the time of exposure. Integrated exposures are usually measured in terms of the 'Working Level Month' (WLM). Inhalation of air with a concentration of 1 WL of radon daughters for the working hours in a month (taken as 170 h) results in a cumulative exposure of 1 WLM.

The WL, though a considerable improvement upon the measurement of radon concentration, is still deficient as a physical correlative of biological hazard. As defined, the WL is independent of the distribution of the potential α emission amongst the attached and unattached fraction, and also of the manner in which disequilibrium is achieved.

It has been noted [Jacobi 1964, Morken 1969] that the bronchial dose can vary by an order of magnitude for a given inhaled potential α energy. Much of this difference results from the contribution of RaA (^{218}Po) to the calculated dose to the basal cells being considerably greater than its contribution to the WL [Harley & Harley 1974].

An enhanced incidence of lung cancer has been observed in underground miners from a number of regions and attempts have been made to relate excess cancers to cumulative radon exposure. The most thorough study of this kind was carried out by the US National Institute for Occupational Safety and Health [Lundin et al. 1971] and deals with the incidence of lung cancer in underground uranium miners from the Colorado Plateau.

2. EXPERIMENTAL METHODS

2.1 Integrated WLM

2.1.1 Head unit design

The principal features of the head unit are shown in Figure 1. This unit is designed to measure and discriminate between the α particles emitted from RaA and RaC' decay.

Air entering the head through the holes in the head unit is filtered through a membrane filter [1] which retains the radon daughters on the surface.

The emitted α particles pass through a collimator [2] and then through the moderating films [3] which reduce the energy of the α particles to about 3.5 MeV. The collimator is divided into two sections with different size holes for high and low sensitivity measurements. Different thicknesses of moderating films are used to distinguish between α particles from RaA and RaC' decay. The resulting α particles then pass through the detector film [4] producing a damaged track in the film. This film is later removed, etched and the number of tracks counted.

Originally, the detector film was made from thin cellulose nitrate manufactured at the AAEC Research Establishment, Lucas Heights, and the counting was done electronically. More recently, particularly for the work at Yeelirrie, a commercially available cellulose nitrate was used and optically counted. Sunlight can affect the ability to etch this type of film and so, when in use, the head is shielded completely in the region from the air inlet vents upwards. The head design was originally covered by a provisional patent which was allowed to lapse because of a predating application from CEA-STEPPA (France) for an almost identical development.

When operating, a battery operated pump drew air through the sampling head at 0.1 ℓ min^{-1}. This flowrate was checked daily with a rotameter. Some significant losses and complete breakdowns of flowrate occurred at times at all sites. Details of these failures and the correction factors used to reduce their significance are given in Section 3.

2.1.2 Sampling sites

The samplers were mounted in the Stevenson screens used for the site meteorological studies and located at the breakaway ('town site'), homestead and crusher sites. A fourth unit, also mounted in a Stevenson screen, was placed immediately to the south-west of slot No. 2. The nominal hours of integration (*i.e.* including breakdown) were respectively 307, 494, 353 and 189 h.

2.1.3 Calibration of detector foil

The efficiency of the sampling head, membrane filter, etching and counting procedures was assessed at the Australian Radiation Laboratory by running the units in enclosures containing high levels of radon daughters (radon strong room and radon daughter generator facility) and at Lucas Heights [Svenson 1976]. In all cases, the calibration related back to a determination of WL by the Rolle [1972] method (see Section 2.2.2). While these calibration procedures did not include dust loadings that might exist during mining/blasting operations, they were adequate for the studies reported here.

The geometric efficiency, defined as the ratio of the number of tracks observed to the number of disintegrations produced on the surface of the filter, is 4.4×10^{-4}. The value for the CEA/STEPPA unit is reported to be 7×10^{-4}; the difference is, no doubt, due to the greater degree of collimation provided by the AAEC head.

2.2 Spot WL Measurements

2.2.1 Sampling procedures

For these measurements air was sampled through Millipore 37 mm 0.8 μm filters, held in a standard Millipore holder, at a rate of 2 ℓ min^{-1} as measured on a calibrated rotameter. Sampling was for 10 minutes. The α activity of the particulate retained by the filter paper was measured by an AERE zinc sulphide/photomultiplier 'α drawer assembly' feeding an AAEC prototype field ratemeter/scaler with a built-in EHT supply.

The EHT was set at the mid point of the voltage/countrate plateau determined with a standard ^{241}Am thin source. The geometrical counting efficiency was measured with the standard source and the value agreed with that estimated with a Monte Carlo code. The self-absorption of α particles resulting from particulate being retained within the body of the filter rather than as surface deposition was estimated from the front-to-back activity ratio and the attenuation resulting from a series of frontally placed blank filters of the same type. The self absorption factor was 0.98 and the overall counting efficiency was 0.217.

The counting equipment had some temperature dependence that made the unit less sensitive for those times of day (1500 - 1700 h) when ambient temperatures were relatively high (∿35°C). A correction for this change of sensitivity could be applied by referencing each counting measurement back to a count from the standard source taken at the time of measurement. This was done for measurements related to ground emissivity (Section 3.6), but not for spot WL measurements since the statistical error associated with them swamps the error due to changing sensitivity.

2.2.2 Data reduction

The influence of sample collection time, delay time and counting time on the estimation of WL for a range of possible radon daughter disequilibria was discussed by Rolle [1972]. The times used by us (10, 4.35 and 5 minutes respectively) were consistent with his recommendations for minimising the effect of disequilibria on WL determinations.

2.2.3 Sampling sites

With one exception (the homestead on 4/11/76) all spot measurements of WL

were taken downwind of the ore body. Wind direction and subjective estimation of speed and nature are presented in Section 3. Almost all measurements were taken in the hours before and after dawn and sunset (0400 - 0700 h; 1630 - 1930 h). In all, twelve sites were evaluated, four of which were on the ore body, two were near stockpiles and the remainder were at varying distances from the ore body or stockpiles.

To provide a further area of comparison with prevailing radon levels in the Northern Territory's Uranium Province, a costean (8 m x 1 m x 3.2 m depth) with a north-south orientation was dug with a backhoe south-west of slot No. 2. In fact, although little ore was intersected, the results indicate the importance of local turbulence (generated by 'waste' piles) and solar heating for reducing radon levels in excavations even as small as costeans. These attributes are recorded elsewhere [Davy 1973, 1974].

2.2.4 Prevailing climatological conditions

Strong inversion conditions did not prevail at any time during the study; however, there were mild to moderate inversions observed from temperature differences recorded at the three meteorological stations (Section 3).

2.3 Concentration of Radon in Air

2.3.1 The two-filter method

In this approach, the air to be assayed is drawn through two filters in series, these filters are separated by a delay volume to permit radon decay. The radon concentration is then calculated from the α activity of the decay products caught on the downstream filter.

The method is fully discussed by Thomas & Le Clare [1969]. The overall counting efficiency was determined as described in Section 2.2.1.

The parameters of the system used were:

Sampling rate:	11.5 ℓ min^{-1}	Sampling time:	10 min
Tube - length:	0.846 m	Delay time:	1 min
- diameter:	38.1 mm	Counting time:	5 min
		Counting efficiency:	0.385

In practice, prevailing radon levels were never sufficiently high for statistically meaningful results to be obtained (*i.e.* Rn concentration $<<$ 20 pCi ℓ^{-1}).

2.3.2 Activated charcoal trap method

On five occasions (three mornings, two evenings) at three sites (near slot 2 on the orebody, crusher site near the stockpiles and site N on a calcrete outcrop downstream from the ore body), the radon concentration was measured by drawing 20 ℓ of air (2 ℓ min^{-1} for 10 minutes) first through a molecular sieve

trap (to remove water vapour) and thence through an activated (400°C for 4 h) charcoal trap (stored under vacuum) held at about -80°C with a dry ice/alcohol slurry. After collection, the charcoal trap was sealed and returned to Lucas Heights for measurement on a radium/radon emanation rig of standard design [Davy & Conway 1973].

2.4 Concentration of Radon in Groundwater

The groundwater at Yeelirrie could be supersaturated in CO_2 and N_2. If samples for radon determinations were not sealed at the point of collection, any escaping CO_2/N_2 would carry off some radon. The sampler used is shown in Figure 2. The stainless steel bomb was evacuated before sample collection. The two solenoids (electrically operated from ground surface) were placed back-to-back to give positive operation even at high external pressures. After the solenoids were opened, water flowed from the nozzle through stainless steel capillary tubes to the sample bomb. The amount of water collected (∿500 mℓ) was determined by weighing the bomb before and after collection.

Eight samples were collected in this way (bores Q, M, P, R, H, N, B and C). The relationship of these sites to the ore body and the local geology are discussed in Section 3. Each bore was bailed out (∿8 ℓ) 48 hours before sampling. After lowering the sampler, about ten minutes or so was allowed for settling. Filling time was about five minutes.

The sealed, collected sample was returned to Lucas Heights for determination on the Ra/Rn rig. After this determination (which flushes away all contained radon), the radon was allowed to re-equilibrate with any radium contained in the sample and then redetermined. The results are expressed in terms of supported ^{222}Rn (*i.e.* arising from dissolved ^{226}Ra and unsupported ^{222}Rn (*i.e.* transported by diffusion through groundwater from ^{226}Ra contained in the soil matrix).

2.5 Ground Surface Radon Emanation Rates

The rate at which radon gas emanates from the soil surface is influenced by many factors; these include barometric pressure, height and rate of change of groundwater table, soil-air temperatures and temperature differentials, the matrix of the soil strata and their moisture contents.

Western Mining Corporation (WMC) has several options for the disposal of mine water, each of which would influence radon emanation rates from different parts of the aquifers in varying ways. The purpose of this part of the survey was to provide an evaluation of a measure of surface emanation rate so that:

- An array of such devices would allow some correlation with surface geology and underlying mineralisation and thus provide

an estimate of the amount of radon given off by the undisturbed ore body.

- An array of such devices over piles of waste rock, below ore grade material and ore of different grades, would provide an estimate of the amount of radon gas given off as a result of mining both during and after the operation.
- The change in emanation rate as a result of mine water extraction/ disposal could be monitored.

Much work has been done in the USA on the emanation rates for radon from tailings dumps and a method described by Bernhardt *et al.* [1973] is now more or less accepted as standard. Duplication of this approach was rejected on the following grounds.

Tailings are by their very nature homogeneous. The surface geology at Yeelirrie is not; for example, at site H, a calcrete outcrop is only some 30 m from an extensive area of sink holes. Thus, the collecting device must be permanently located. In practice they were located with a concrete collar.

The method of Bernhardt *et al.* relies on the collecting device being essentially free of radon at the start of the measurement. The measurements are then done on the first part of the exponential build-up curve which can be assumed to be linear. Although this could be done with a permanently located drum it is inconvenient in the sense that about 50 drum volumes of air would be needed to sweep out the radon in the drum.

The US interest is in the present amount of radon being given off by the tailings (for decisions to be made on remedial measures). They are less interested in how this value will change in future years. Western Mining Corporation's interest is the reverse of this; the greater the extent to which variables (with periodicity of days or less) can be smoothed out, the better.

The approach adopted was to leave the collector (an open-ended 44 gallon drum) sealed from the atmosphere. If the collector was infinite in extent (*i.e.* if it did not prevent the establishment of a uniform concentration gradient of radon in the soil profile), and if it underwent the same diurnal temperature cycle as the concentration weighted soil profile, then the rate of change of radon concentration in the collector would be controlled by radioactive decay and the changing ground emissivity would vary with the changing concentration gradient.

The effect of the finite collector cannot be found analytically but a solution from transport computer codes is possible.

For the experimental arrangement, the factor that has a major influence on the build-up of radon in the collector is the ground-collector temperature differential. Groundwater in the Yeelirrie area is at a temperature of ∿25°C. Thus, for a collector completely shielded from sunlight, the temperature difference would range from about +10°C to -20°C. For a collector exposed to sunlight, these values would be closer to ±20°C. For a constant pressure and volume collector, this corresponds to a diurnal temperature pump equivalent to an injection of air from the ground of 14 per cent of the collector volume per day. For other reasons all measurements during the build-up phase were taken around sunrise. In such a case, the injection of ground air can be regarded as occurring linearly with time. The effect of solar heating on the collector was assessed by following the diurnal variation in two drums (one unshielded, one shielded) after the radon concentration in each had reached an equilibrium value.

Several practical factors related to the mockup collectors influenced the measurements:

(i) No stop cocks were fitted, therefore the drum had to be unsealed for inserting the two filter sampling heads (as described in Section 2.3.1). By working during the hours around sunrise, the atmospheric temperature changes were minimal and the collector-atmosphere temperature differential was near zero. Thus, convectively induced changes to the concentration of radon in the collector were minimised.

(ii) The drums were not fitted with a circulating fan. This was overcome by returning the sampled air to the drum and having large sampling volume (115 ℓ).

(iii) To overcome convectively induced changes, the sampling tube was left *in situ* for measurements on diurnal variation. This reduced the problem but did not eliminate it.

The measurement of real value is the equilibrium concentration in the drum. This value is directly related to the concentration of radon in the soil interstices, the 'constant' of proportionality being determined by all those hydrogeological and soil characteristics that influence surface emissivity. It is asserted that this is an adequate quantity for monitoring purposes.

2.5.1 Sampling sites

Six drums were installed - two over the ore body, one on outcropping calcrete (near site H) and one on soil overlaying calcrete (near site I), one on stockpile 18 (the dimensions of this stockpile are much smaller than what would be infinite from the point of view of radon diffusion), one at site N on the

calcrete aquifer but well downstream of the ore body, and two on the Snake Well aquifer at sites B and C.

3. RESULTS

3.1 Integrated WLM

Sampling time lost through equipment malfunction was estimated according to the following ground rules:

- If the unit had stopped completely, the time lost was taken to be the time elapsed since the previous inspection if the trouble was mechanical; if the trouble was electrical, the time lost was estimated from the capacity of the Ni-Cd batteries and their voltage/charge characteristic.
- If flows were significantly different from the calibration, the drop was assumed to have occurred linearly.

Listed below are the derivations of the sampling hours used in the estimation of average WL.

Site	Nominal hours	Max. hours 'lost'	Derived hours
Breakaway	307	24	300
Homestead	494	-	494
Crusher	353	77	312
Watertower	189	50	169

This method of deriving an average working level has an accuracy of ± 1 WLH. For the breakaway, homestead, crusher and watertower sites this would correspond respectively to ± 0.0033, 0.002, 0.0032 and 0.006 WL as the uncertainty in the average WL value. For the Yeelirrie exposures, the background 'noise' was higher than normal and corresponded respectively to ± 0.005, 0.006, 0.008 and 0.015 WL.

The dosimeter head has two sets of collimators which, for both RaA and RaC^- determinations, give a relative sensitivity of 6.4 for neighbouring quadrants. For all measurements reported the measured ratio was $\leqslant 1 \pm \delta$. Thus, it is highly probable that the tracks detected were not due to RaA and RaC' and that average WL at each of the four sites is substantially less than the respective uncertainties given above.

3.2 Spot WL Measurements

Table 2 lists the results and estimated errors for approximately 190 separate measurements of WL made 30 cm from the ground surface. Note that all

measurements were taken at those times of day when concentrations are highest and, with few exceptions, downwind of the ore body. Yet about 80 of the measurements were below the limit of detection (<0.001 WL).

The results show that the maximum values are clearly associated with inversion conditions and that, under inversion conditions, the maximum will generally occur between 0500 and 0530 h at that time of the year (late spring).

Secondary maxima occur in the late afternoon and their timing is related more to the changes in the nature of the winds than to direct effects of solar heating. There is a suggestion of secondary maxima at 1730 h.

The highest recorded value (0.051 WL) occurred at 0540 h on 22 November 1976 at the sampling site near slot No. 2 on the orebody.

3.3 Spot Radon Concentration Measurements

The values of spot radon concentrations determined by adsorption on activated charcoal are dispersed throughout Table 2. If it was assumed that the WL value determined immediately before the radon determination held, then the values of working level ratio ('F' in Section 1) were:

Site	Date	Time (h)	WL	Rn (pCi ℓ^{-1})*	F
No. 2 slot	11.11.76	1820	0.0013	3.3	0.039
	12.11.76	0515	0.0025	7.0	0.036
	12.11.76	1820	<0.001	0.68	<0.15
Crusher	13.11.76	0510	0.0086	3.0	0.29
N	10.11.76	0520	<0.001	0.50	<0.2

These values indicate significant disequilibrium, even when atmospheric conditions are what is generally called 'still'.

3.4 Vertical Distribution of Radon Daughters

The vertical distribution of radon daughter concentrations was measured at site M during the afternoon-evening of 16 November 1976 and the watertower site during the afternoon of 17 November 1976 and the mornings of 17 and 18 November 1976. Table 3 contains the results and indicates that the variations with time dominate over the height variations that occur from 1 - 7 m above ground. Recorded levels of <0.001 WL are not included in the table.

3.5 Radon Concentration in Groundwater

Table 4 contains the results. Some bores are cased and capped, some cased only and others are uncased, but it is not known what variability is

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* 1 pCi ℓ^{-1} ≡ 37 m Bq ℓ^{-1}

introduced by these factors. It is believed that the effect would be small. (Diffusion coefficients for radon-in-air and radon-in-water are, respectively, 0.12 (15°C) and 1.13 x 10^{-5} (18°C) $cm^2\ s^{-1}$.)

A reasonable generalisation for the Yeelirrie deposit is that ore occurs from the height of the groundwater downwards. Thus a first order approximation is that the radon emanating from the soil surface originates from the groundwater. Using the boundary conditions Z=0 and $(dc/dz)_{z=o}=0$, the effective diffusion coefficient can be calculated for those sites where groundwater and sealed collector (see Section 3.6) radon concentrations were measured:

$$A_Z = A_o\ [\exp(u) + \exp(-u)]\ /\ [\exp(v) + \exp(-v)]$$

where $u^2 = \lambda Z/D$, $v^2 = \lambda Z_o/D$

Z = depth to point of interest,

Z_o = depth to water table, and

D = effective diffusion coefficient.

The measurements for sites H, C, B and N were as follows:

Site	Depth to groundwater (m)	Groundwater radon concentration (pCi ℓ^{-1})*	Equilibrium radon concentration (pCi ℓ^{-1})	Effective diffusion coefficient ($cm^2\ s^{-1}$)
H	4.3	32 700	550	0.017
C	3.2	890	267	0.060
B	5.5	1250	72	0.050
N	3.7	2990	493	0.046

Errors in the effective diffusion coefficient have not been estimated; the largest uncertainty probably relates to depth to groundwater. No correction was made to the height measured in an open bore nor for the topography between bore and collector.

These limited results indicate that surface geology (outcropping calcrete, presence of sink holes) is not an important variable in determining the radon emissivity but leaves unresolved the question of whether the permeability of the orebody to radon is significantly different to the values for neighbouring aquifers.

3.6 Ground Surface Emanation Rates

Table 5 lists the results obtained in the manner indicated in Section 2.5; Table 6 reports the results aimed at revealing the effects of diurnal

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* 1 pCi ≡ 3.7 m Bq

temperature variations. In Table 7 the results of chi-squared tests on the data of Tables 5 and 6 are presented. Barometric pressure effects are most noticeable with respect to measurements taken on stockpile 18. This is to be expected from the limited size of this heap. It is also clear from this table that thermal insulation of the drums is a necessary part of the experimental protocol and that shielding from direct sunlight only is not always adequate.

4. CONCLUDING REMARKS

Radon in air concentrations in the Yeelirrie area are low by comparison with values recorded for the Ranger I orebody in the Northern Territory. This difference cannot be explained by differing ore grades, differing radon concentrations in groundwater nor by differing diffusion rates through the overburden. While no estimate of diffusion coefficients or surface emanation rates has been made for the Ranger I area*, the value for Yeelirrie (~ 0.05 cm^2 s^{-1}) implied in Section 3.5 is consistent with a value in the literature for alluvial-detrital deposits of granodiorite (0.045 cm^2 s^{-1}) and alluvial detrital deposits of granite (0.015 cm^2 s^{-1}. It is anticipated that only the sand pipes in the ferrocrete of the Ranger I overburden would have diffusion coefficients > 0.05 cm^2 s^{-1}. Of course in places the Ranger I orebody is much closer to the surface than is the case for Yeelirrie. This in turn lends support to the assumption about the nature of the Yeelirrie overburden in deriving a value for the diffusion coefficient (Section 3.5).

It appears that an extensive array of either radon concentrations in groundwater or surface emanation collectors could be used for estimating the total radon release from the undisturbed orebody; the former approach would need less development for easy field operation. Further work on the day to day variation in the radon concentration in collector drums is warranted but, the drum used should be thermally insulated, have installed fans and include soil/air differential thermometers.

5. REFERENCES

Bernhardt, D.E., Johns, F.B. & Kaufmann, R.F. [1973] - Radon exhalation from uranium mill tailings piles, ORP/LV-75-7(A).

Davy, D.R. [1973] - Prospects for control of radiological hazards in uranium mining - Paper XII. Proc. AAEC Symp. on Environmental and Radiological Safety Aspects of the Mining and Processing of Uranium. Lucas Heights, 9 - 10 December 1971. AAEC/E272.

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* These were measured in March 1978

Davy, D.R. [1974] - Environmental levels of radon-222 - Paper IV in *The Alligator Rivers Area Fact Finding Study* - Four AAEC Reports (Conway, N.F., Davy, D.R., Giles, M.S., Newton, P.J.F. (ed.) & Pollard, D.A.). AAEC/E305.

Davy, D.R. & Conway, N.F. [1973] - Practical dosimetry in uranium mining - Paper XI. Proc. AAEC Symp. on Environmental and Radiological Safety Aspects of the Mining and Processing of Uranium. Lucas Heights, 9 - 10 December 1971. AAEC/E272.

Harley, N.H. & Harley, J.H. [1974] - *Health Phys.* 27 : 593.

Jacobi, W. [1964] - *Health Phys.* 10 : 1163.

Lundin, F.E., Wagoner, J.K. & Archer, V.E. [1971] - Radon daughter exposure and respiratory cancer, quantitative and temporal aspects. Nat. Inst. Occupational Safety and Health, Joint Monograph No. 1, US Department of Health, Education and Welfare.

Morken, D.A. [1969] - *Health Phys.* 16 : 796.

Rolle, R. [1972] - *Health Phys.* 22 : 223.

Svenson, A.C. [1976] - private communication.

Thomas, J.W. & LeClare, P.C. [1969] - *Health Phys.* 18 : 113.

NOTES

TABLE 1

THE RELEVANT DATA USED TO DERIVE THE WL

Nuclide	α Energy (MeV)	Half-life (min)	No. atoms in 100 pCi*	Ultimate α energy/atom	Total ultimate α energy (MeV/100 pCi)*
^{218}Po (RaA)	6.00	3.05	977	6.00 + 7.68	0.134×10^5
^{214}Pb (RaB)	0	26.8	8580	7.68	0.659×10^5
^{214}Bi (RaC)	0	19.7	6310	7.68	0.485×10^5
^{214}Po (RaC')	7.68	10^{-6}	0.0008	7.68	0.000×10^5
				Total	1.278×10^5
				Round up to	1.3×10^5

* 1 pCi ≡ 37 m Bq

TABLE 2

'INSTANTANEOUS' (10 MINUTE SAMPLE) WORKING LEVELS

(a) Site: H

Date	Time (h)	WL	σ	Meteorological Conditions		
				Remarks	ΔT (°C) (TS-CS)	ΔT (°C) (TS-HS)
3-11-76	0430	0.0044	0.008	Still	3	2
	0450	0.0086	0.0013	"		
	0515	0.015	0.0018	"	3	1
	0535	0.011	0.0015	"		
	0555	0.0063	0.0011	"	1.5	-0.5
	0615	0.0045	0.001	Cont. E Breeze		
	0640	0.003	0.0006	" " "		
13-11-76	1630	<0.001	-	Gentle SSE Breeze		
	1650	0.0018	0.0005	" " "		
	1710	<0.001	-	+ gusts		
	1730	<0.001	-	"		
	1750	<0.001	-	"		
	1810	<0.001	-	vg S breeze + gusts		
	1830	<0.001	-	"		
14-11-76	0410	<0.001	-	mod SE breeze	1	3.5
	0430	<0.001	-	"		
	0450	0.0013	0.0004	light-mod SE breeze		
	0510	0.0026	0.001	"	1	2
	0530	0.0019	0.0006	"		
	0550	0.001	0.0003	mod SE breeze		
	0610	<0.001	-	mod-strong SE breeze	-1	2
	0630	0.0013	0.0004	"		
18-11-76	1635	0.0016	0.0005	light S-SW breeze		
	1655	0.003	0.0008	"		
	1715	<0.001	-	Light + mod gusts		
	1735	<0.001	-	Light + strong gusts		
	1755	0.0016	0.0005	Light + mod gusts		
	1815	0.0016	0.0005	"		
	1835	0.0027	0.0007	"		

TS = Town Site CS = Crusher Site HS = Homestead

vg = very gentle mod = moderate

vs = very strong cont = continuous

s = strong occ = occasional

(continued)

TABLE 2 (continued)

(b) Site I

Date	Time (h)	WL	σ	Meteorological Conditions		
				Remarks	ΔT (°C) (TS-CS)	ΔT (°C) (TS-HS)
19-11-76	0420	0.005	0.001	vg E breeze		
	0440	0.0088	0.0013	"		
	0500	0.01	0.003	calm		
	0520	0.034	0.003	"		
	0540	0.033	0.003	"		
	0600	0.010	0.003	vg E breeze		
	0620	0.003	0.0007	light-mod E breeze		
	0640	0.0017	0.0005	"		
	1630	0.0013	0.0004	gentle SE breeze		
	1650	0.0012	0.0004	"		
	1710	<0.001	-	vg SE breeze		
	1730	0.0025	0.0007	"		
	1750	<0.001	-	gentle SE breeze		
	1810	<0.001	-	"		
	1830	0.0016	0.0005	"		

TS = Town Site CS = Crusher Site HS = Homestead

(continued)

TABLE 2 (continued)

(c) Site: Slot No. 2

Date	Time (h)	WL	σ	Meteorological Conditions: Remarks	ΔT (°C) (TS-CS)	ΔT (°C) (TS-HS)
5-11-76	0420	0.04	0.003	Still	5	5.5
*	0440	0.043	0.002	"		
	0500	0.041	0.003	"	4.5	5.5
	0520	0.037	0.003	Odd gusts		
*	0540	0.012	0.001	" "		
	0555	0.0087	0.001	vg breeze	5	0.5
	0620	0.007	0.001	" "		
*	0635	0.005	0.0008	" "		
	0655	<0.001	-	strong E breeze	5	1
*	0715	0.003	0.0007	" " "		
11-11-76	1650	<0.001	-	Strong W gusts		
	1710	<0.001	-	vs W gusts		
	1730	0.0048	0.001	" " "		
	1750	0.003	0.0008	Fairly s W gusts		
	1810	0.0013	0.0004			
	1820	Air radon		concentration: 3.3 pCi ℓ^{-1}		
	1830	0.0025	0.0005	Fairly s W gusts		
12-11-76	0425	0.0048	0.001	mod. W gusts	1	0.5
	0445	0.0073	0.0012	" " "		
	0505	0.0025	0.0007	gentle W breeze	1	1
	0515	Radon		concentration: 7.0 pCi ℓ^{-1}		
	0525	0.004	0.001	mod-strong W gusts		
	0550	0.003	0.0008	mod W breeze	-1.5	1
	0610	<0.001	-	mod-strong W breeze		
	0630	0.0014	0.0004	strong W gusts		
	0650	0.0019	0.0005	vs W gusts	-3	0.5
	1630	0.0019	0.0006	strong W-SW gusts		
	1650	0.0013	0.0004	" " "		
	1710	0.0015	0.0004	" " "		
	1730	<0.001	-	" " "		
	1750	<0.001	-	" " "		
	1810	<0.001	-	" " "		
	1820	Air radon		concentration: 0.68 pCi ℓ^{-1}		
	1830	<0.001	-	mod. W-SW breeze		
21-11-76	1640	0.0026	0.0007	mod N breeze		
	1700	<0.001	-	strong N-NW gusts		
	1720	<0.001	-	light N-NE breeze		
	1740	<0.001	-	" " "		
	1800	<0.001	-	vg N-NE breeze		
	1820	0.002	0.0006	" " "		
22-11-76	0420	0.017	0.0019	vg NW breeze		
	0440	0.02	0.002	" " "		
	0500	0.03	0.0025	" " "		
	0520	0.048	0.003	" " "		
	0540	0.051	0.0033	" " "		
	0600	0.015	0.002	" " "		
	0620	0.0015	0.0005	light NW-SW breeze		
	0640	0.0034	0.0009	mod S-SW breeze		

* Costean measurements (see text) 1 pCi ≡ 37 m Bq (continued)

TABLE 2 (continued)

(d) Site: Crusher

Date	Time (h)	WL	S	Meteorological Conditions		
				Remarks	ΔT (°C) (TS-CS)	ΔT (°C) (TS-HS)
4-11-76	0420	0.0054	0.001	vg SE breeze	5.5	3
	0440	0.0095	0.002	" " "	5.0	
	0500	0.012	0.0015	" " "	4.6	2
	0535	0.0038	0.001	" " "	4.0	2.5
0555	0555	0.0042	0.0009	" " "	2.5	0
	0615	0.002	0.0006	" " "		
	0635	0.0018	0.0006	" " "		
13-11-76	0420	0.007	0.0017	vg S breeze	2.5	2.5
	0440	0.015	0.0009	" " "		
	0500	0.0086	0.0013	" " "	2.5	3.0
	0510	Air radon concentration: 3.0 pCi ℓ^{-1}				
	0525	0.0045	0.009	vg S breeze		
	0545	0.0025	0.0007	light S breeze		
	0605	0.0028	0.0007		-1	3.0
	0625	0.0014	0.0006	" + gusts		
	0645	<0.001	-	"	-1.5	1.5

(e) Site: 70 m SE of stockpile

4-11-76	1725	0.001	0.0004	gentle SE breeze		
	1745	0.001	0.004	still		
	1810	0.0018	0.0006	"		
	1830	0.001	0.0004	gentle SE breeze		
	1850	0.0025	0.0006	still		
	1910	0.0045	0.0009	"		

(f) Site: Clay pan (ex slot water)

8-11-76	1700	<0.001	-	mod SW breeze		
	1720	0.002	0.0006	mod SW breeze		
	1740	0.001	0.0005	" + gusts		
	1800	0.002	0.0006	still		
	1820	<0.001	-	W puffs		
	1840	<0.001	-	still		

(g) Site: P

6-11-76	0425	0.0045	0.00095	still	-0.5	1.5
	0445	0.002	0.0006	NE puffs		
	0505	0.0025	0.007	" "	-1.0	0
	0535	0.001	0.0005	" "		
	0600	0.001	-	" "	-1.0	0

TS = Town Site CS = Crusher Site HS = Homestead

1 pCi ≡ 37 m Bq

(continued)

TABLE 2 (continued)

(h) Site: N

Date	Time (h)	WL	σ	Meteorological Conditions: Remarks	ΔT (°C) (TS-CS)	ΔT (°C) (TS-HS)
3-11-76	1710	0.0013	0.0003	SW gusts		
	1730	0.0014	0.0003	" "		
	1800	<0.001	-	" "		
	1830	<0.001	-	" "		
	1900	<0.001	-	gentle SW breeze		
	1925	<0.001	-	" " "		
9-11-76	1630	<0.0001	-	strong E breeze		
	1700	0.0013	0.0004	" " "		
	1720	0.001	0.0003	" " "		
	1740	<0.001	-	" " "		
	1800	<0.001	-	" " "		
	1820	<0.001	-	" " "		
10-11-76	0420	<0.001	-	mod SSW gusts	0	2
	0440	<0.001	-	" " "		
	0500	<0.001	-	" " "	0.5	2.5
	0520	Air radon concentration: 0.5 pCi ℓ^{-1}				
	0535	<0.001	-	gentle SSW breeze		
	0555	<0.001	-	" " "		

(i) Site: M

15-11-76	1630	0.0016	0.0005	mod SE breeze		
	1650	<0.001	-	" + gusts		
	1710	<0.001	-	light SE breeze		
	1730	0.0018	0.0006	"		
	1750	<0.001	-	" + gusts		
	1810	0.001	0.0005	mod SE breeze		
	1830	<0.001	-	"		
16-11-76	0410	<0.001	-	light SE breeze		1
	0430	<0.001	-	"		
	0450	<0.001	-	" + gusts		
	0510	<0.001	-	"		1.5
	0530	<0.001	-	"		
	0550	<0.001	-	"	2.0	
	0610	<0.001	-	light E breeze		

(j) Site: Homestead

4-11-76	1030	<0.001	-	occ SE gusts		
	1130	<0.001	-	"		
	1240	<0.001	-	"		
	1340	<0.001	-	"		
	1435	<0.001	-	occ S gusts		
	1620	<0.001	-	"		

TS = Town Site CS = Crusher Site HS = Homestead

1 pCi ≡ 37 m Bq

(continued)

TABLE 2 (continued)

(j) Site: Homestead (continued)

Date	Time (h)	WL	σ	Meteorological Conditions		
				Remarks	ΔT (°C) (TS-CS)	ΔT (°C) (TS-HS)
22-11-76	1620	<0.001	-	strong S gusts		
	1640	<0.001	-	mod S-SW breeze		
	1700	<0.001	-	" + gusts		
	1720	<0.001	-	" "		
	1740	<0.001	-	" "		
	1800	<0.001	-	" "		
	1820	<0.001	-	" "		
	1840	<0.001	-	light SW breeze		
23-11-76	0430	0.003	0.0007	light SW breeze		
	0450	0.002	0.0006	"		
	0510	0.0016	0.0006	"		
	0530	0.0025	0.0007	"		
	0550	<0.001	-	"		
	0610	<0.001	-	light SE breeze		

(k) Site: C

6-11-76	1725	<0.001	-	light WNW breeze		
	1745	<0.001	-	still		
	1805	<0.001	-	"		
	1825	0.002	0.0007	"		
	1845	0.002	0.0007	"		
8-11-76	0445	0.006	0.001	still	2	
	0505	0.002	0.0007	W-SW puffs		
	0525	0.002	0.0006	"	2	
20-11-76	0430	<0.001	-	gentle-light E breeze		
	0450	<0.001	-	vg E breeze		
	0510	<0.001	-	"		
	0530	<0.001	-	"		
	0550	<0.001	-	"		
	0610	0.0015	0.0005	light E breeze		
	0630	0.001	0.0005	light-mod E breeze		

TS = Town Site CS = Crusher Site HS = Homestead

vg = very gentle mod = moderate

vs = very strong cont = continuous

s = strong occ = occasional

TABLE 3

VARIATION OF WL WITH HEIGHT ABOVE GROUND

CRUSHER SITE

Date	Time (h)	Height (m)	WL	S	Remarks
17.11.76	0430	1.0	0.009	0.0013	Gentle SE breeze
	0500	3.0	0.033	0.0027	" E "
	0530	7.0	0.005	0.001	vg E "
	0545	3.0	0.006	0.001	"
	0600	1.0	0.007	0.001	Gentle SE breeze
	0615	3.0	0.010	0.002	" + gusts
	0630	7.0	0.006	0.001	"
	0645	3.0	0.003	0.0007	"
	1400	1.0	<0.001	-	Moderate NW breeze
	1415	3.0	0.001	0.005	"
	1430	7.0	<0.001	-	"
	1600	1.0	<0.001	-	Light NW breeze
	1615	3.0	0.001	0.005	"
	1630	7.0	0.001	0.004	"
	1645	3.0	<0.001	-	Gentle NW breeze
	1700	1.0	0.001	0.005	"
18.11.76	0430	1.0	0.0015	0.0005	Light S breeze
	0445	3.0	<0.001	-	"
	0500	7.0	<0.001	-	"
	0515	3.0	<0.001	-	"
	0530	1.0	<0.001	-	"

vg = very gentle

TABLE 4

RADON CONCENTRATION IN GROUNDWATER

Date	Site	Depth below water table (m)	Supported Rn (pCi ℓ^{-1})*	Unsupported Rn (pCi ℓ^{-1})
5.11.76	Q	1.5	5.1	18 040
"	M	1.5	2.0	2020
"	R	1.5	19.2	1270
"	P	1.5	26	760
6.11.76	H	1.5	132	32 700
5.11.76	N	1.5	1.9	2990
6.11.76	B	1.5	6.7	1250
"	C	1.5	13.3	880
"	C	14.2	8.2	1840

Bores Q, M, R and N were cased (slotted) and capped.

Bore P was cased (slotted) but not capped.

Bores H, B and C were uncased.

* 1 pCi ≡ 37 m Bq

TABLE 5

GROUND EMANATION RATES

(RADON CONCENTRATION IN COLLECTOR)

Site	Date	Time (h)	Radon Conc. (pCi ℓ^{-1})*	δ (pCi ℓ^{-1})
Ore pile No.18	6.11.76	0830	- installed -	
	7.11.76	0635	2370	50
	9.11.76	0625	2890	53
	11.11.76	0640	2540	49
	15.11.76	0600	2495	48
	21.11.76	0620	2350	47
H	6.11.76	0930	- installed -	
	7.11.76	0525	390	24
	9.11.76	0535	575	24
	11.11.76	0535	540	24
	15.11.76	0505	545	23
	21.11.76	0520	540	24
I	6.11.76	1000	- installed -	
	7.11.76	0555	740	35
	9.11.76	0555	1020	32
	11.11.76	0600	1090	32
	15.11.76	0530	1000	31
	21.11.76	0545	972	31
C	7.11.76	1100	- installed -	
	8.11.76	0545	176	4
	9.11.76	0715	270	4
	11.11.76	0735	255	4
	15.11.76	0730	264	4
	21.11.76	0715	280	5
B	7.11.76	1000	- installed -	
	8.11.76	0620	38	3
	9.11.76	0730	70	4
	11.11.76	0755	70	4
	15.11.76	0755	68	4
	21.11.76	0740	78	4
N	8.11.76	1000	- installed -	
	9.11.76	0430	216	15
	11.11.76	0450	524	23
	15.11.76	0635	497	23
	21.11.76	0440	457	22

* 1 pCi $\equiv$ 37 m Bq

TABLE 6

DIURNAL VARIATION FOR RADON CONCENTRATION IN COLLECTOR

Site	Date	Time (h)	Radon Conc. (pCi ℓ^{-1})†	δ (pCi ℓ^{-1})
I	19.11.76	0400	1140	35
		0700	1000	33
		1000	970	30
		1300	1040	30
		1600	950	28
		1900	1050	31
C	20.11.76	0400	252	15
		0700	261	17
		1000	259	16
		1300	256	15
		1600*	220	16
		1900	250	16

Collector I : unshielded

Collector C : shielded

* some direct sunlight.

† 1 pCi ≡ 37 m Bq

TABLE 7

CHI-SQUARED TEST ON DATA OF TABLES 5 AND 6

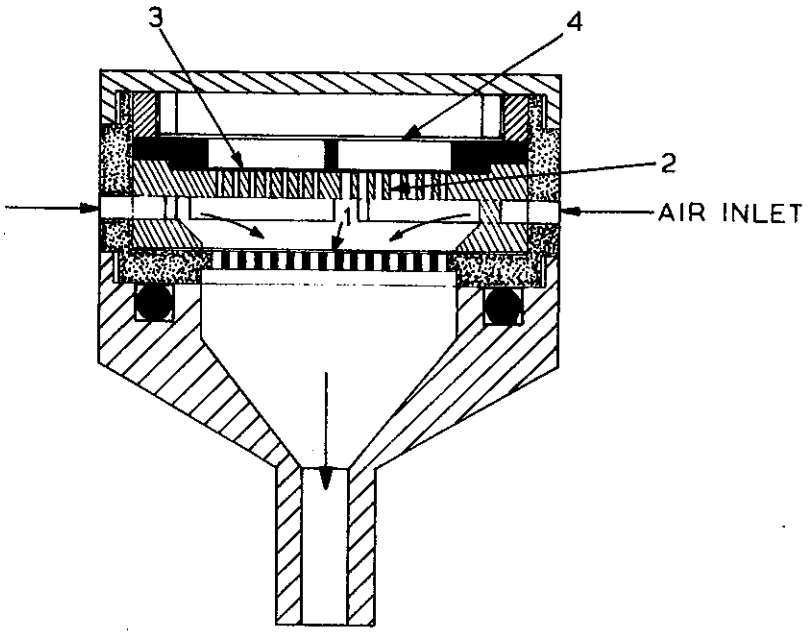
(a) Variable barometric pressure; sampling at approximate same time of day.

Site	χ^2	p range
Ore pile	61.2	< 0.001
H	1.55	0.8 - 0.9
I	7.45	0.1 - 0.2
C	1.24	0.8 - 0.9
B	0.83	0.9 - 0.95
N	4.61	0.2 - 0.3

(b) Approximately steady barometric pressure; sampling at variable time.

Site	χ^2	p range
I	22.8	< 0.001
C	4.6	0.5 - 0.7
C*	0.33	> 0.99

* Excluding reading at 1600 h



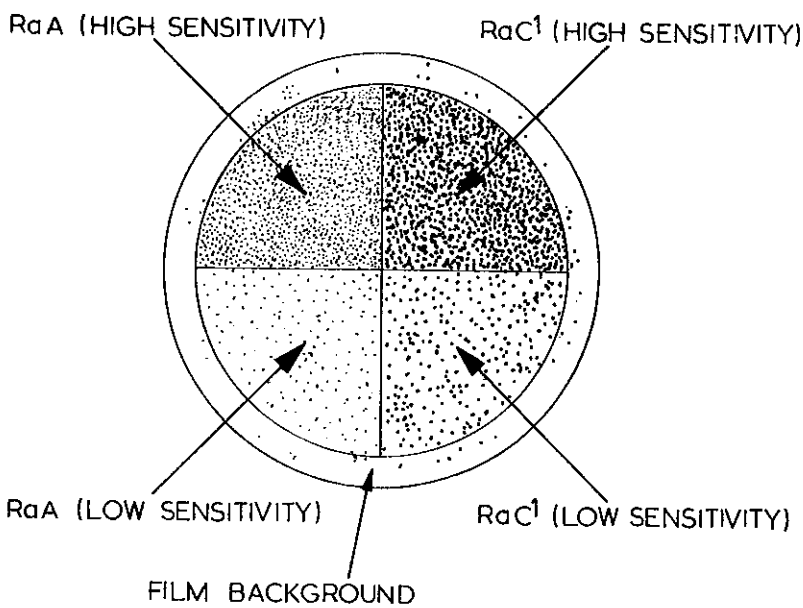


FIGURE 1. HEAD UNIT FOR WL INTEGRATOR

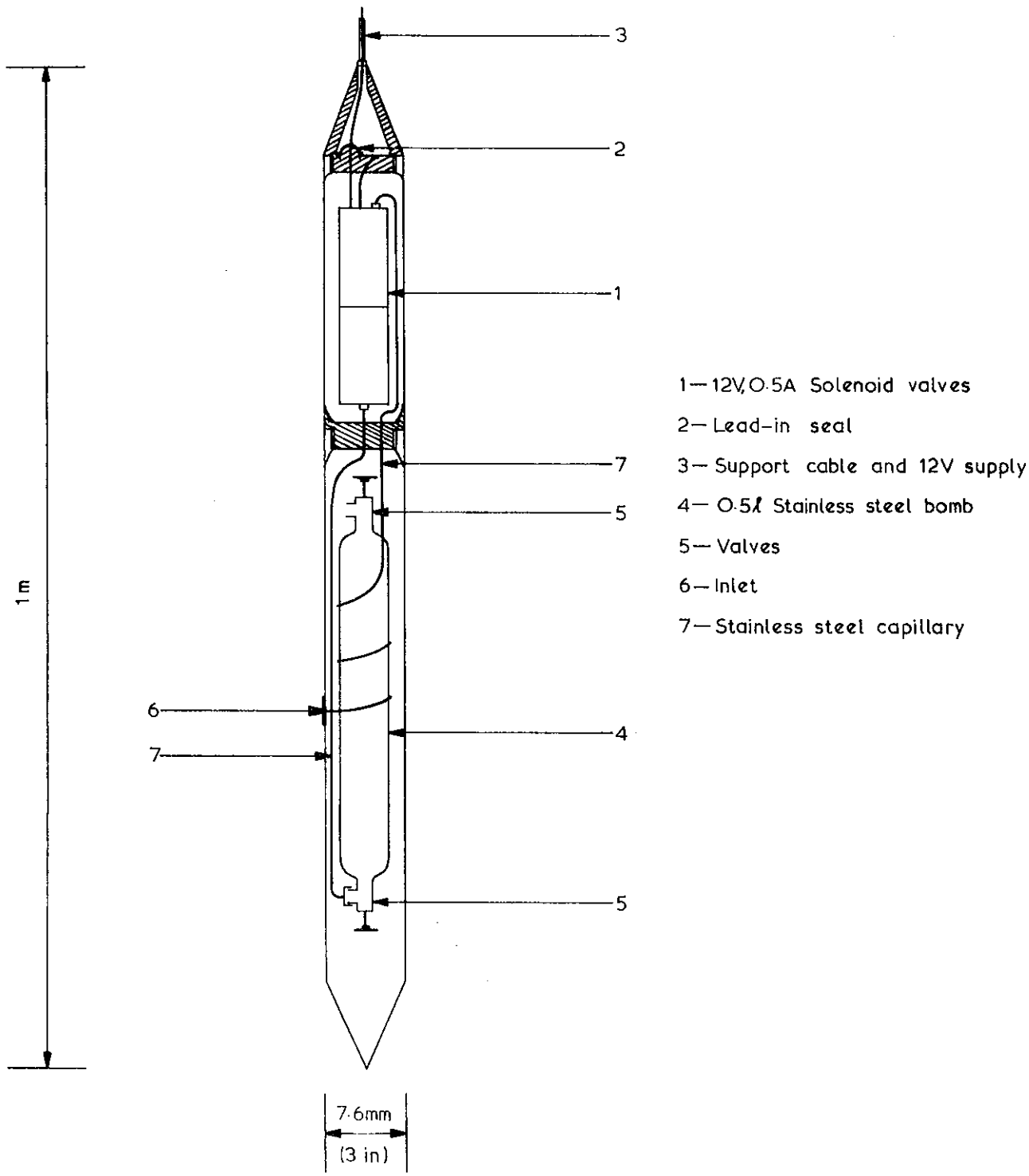


FIGURE 2. GROUND WATER SAMPLER