Australia's National Radioactive Waste Repository - Phase 3 Site Assessment and Stage 2 Drilling

Stage 2 Assessment Report

Department of
AGRICULTURE
FISHERIES and
FORESTRY -
AUSTRALIA

Bureau of Rural Sciences
AUSTRALIA

Introduction

Stage 1 drilling at eleven sites was completed 1 September 1999. After scientific assessment of results, and taking into account the views expressed in public consultation, the intention was to select 5 sites for further investigation in Stage 2. Sites 14, 45, 12, 16, 33 and 40 performed best against the selection criteria, although all sites were considered potentially suitable to site the national repository.

After further consideration of the heritage significance of the sites by Aboriginal groups, and consultation with other stakeholders, none of the sites were cleared for further drilling.

Further site inspection and investigation occurred, and five new sites were cleared for further work; these were sites 10a, 14a, 40a, 45a and 52a. The ‘a’ suffix indicated that the site was close to a previously considered site but relocated nearby due to Aboriginal heritage considerations. Site 52a was located approximately 10km west of Site 33. Drilling at the five sites (**Figure 1**) was commenced 5 June 2000. Two reverse circulation percussion hammer drillholes were required in opposite corners at all but one site (Site 40N became Site 40aS) due to the relocation of the sites. In all, for the renewed Stage 1 and Stage 2 drilling, 846 metres was hammer drilled, sampled and geologically described. Stage 2 diamond core drilling commenced on 20 June and concluded on 19 July resulting in 522 m of PQ (96 mm) and HQ (63mm) core being obtained. The diamond core was photographed, described geologically, and sampled for pore fluid and bulk density measurements.

The Phase 3 field assessment program has therefore completed the Stage 1 initial reverse circulation hammer drilling, Stage 2 follow-up reverse circulation, and core drilling at the five sites according to the drilling pattern shown in **Figure 2**.

Stage 3 will involve reverse circulation drilling at an infill spacing around the 1.5km square perimeter of three sites and around a 500m square central area (Figure 2).

The Stage 1 report (BRS, 1999) described how the drilling information and other data were used to identify preferred sites for Stage 2 assessment, and similar techniques were applied to determine three preferred sites for Stage 3 assessment. The general site descriptions provided in the Stage 1 report apply for each of the five sites assessed in Stage 2.

When the target depth was reached at each of the percussion hammer drill sites the holes were purged, cased with 100 mm PVC and geophysically logged. Each of these holes is now equipped as an observation piezometer (groundwater monitoring well).

Each drillsite was cleaned up and photographed at the end of the drilling activities.

The drilling and samples provided the information necessary to indicate the relative suitability of each site against several of the site selection criteria (NHMRC 1992). The main use of the drilling information was for the geological and physical criteria (Criteria b, c, f, g and h). More specifically these criteria relate to the groundwater, geological, geochemical and geotechnical conditions, and to the potential for economic mineralisation.

Figure 1: Investigative Sites – Stage 2 Assessment

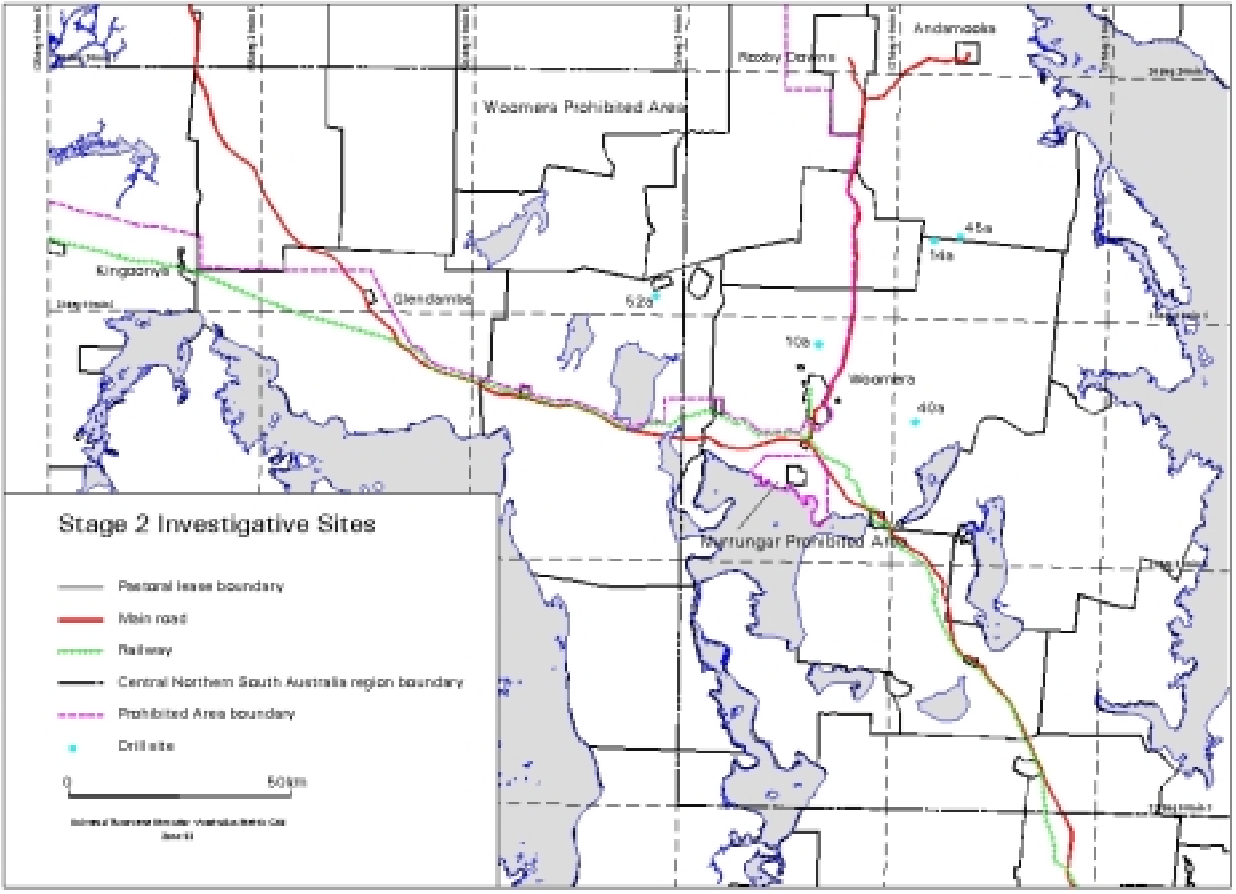
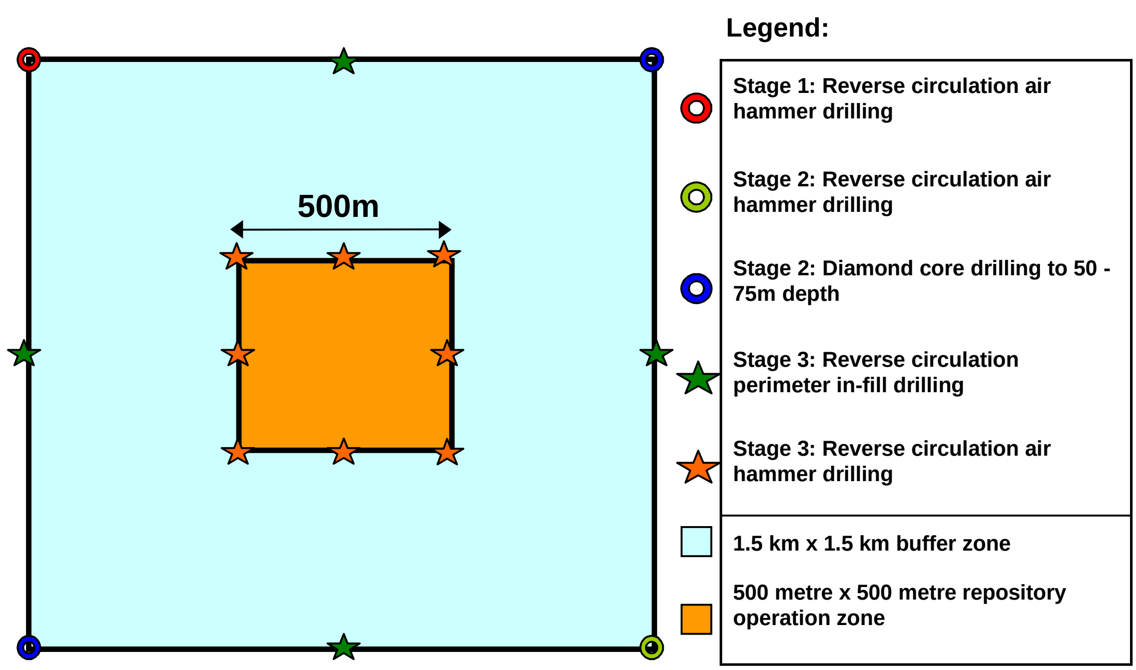


Figure 2: Drill hole lay-out for Phase 3 Assessment



Geological assessment

Method

The geological assessment of the five sites was based on field observations, reverse circulation hammer and diamond core drilling, groundwater yield, salinity and pressure, and data interpretation to give estimates of sediment size and formation hardness.

Regional geology

The land surface on the plains is covered by Quaternary-age orange-red clay which is powdery to a depth of a few centimetres and is then an earthy or loamy cracking clay of medium to high plasticity. In most areas the ground is also partly covered by an armour-plating of gibbers, ranging in size from less than one centimetre across to more than 50 centimetres, with most being in a range from 2 to 30 centimetres. The gibbers are composed mainly of silicified sandstone and silcrete. Gilgai microrelief is ubiquitous in the landscape.

The main rock exposures in the region covering the five sites occur in incised drainage courses and at the margins of the larger ephemeral lake depressions. These reveal stratigraphic sections ranging from a few metres in road cuts to more than 100 metres along the northern escarpment of Island Lagoon. The scattered drainage-line exposures indicate that the regional geology of the five sites is nearly flat-lying to gently dipping layered sediments, mainly comprising cross-bedded and interlayered sand to clay-sized units of the Simmens Quartzite and Corraberra Sandstone (Neo-Proterozoic age).

The steeper slopes and cliffs adjacent to the surrounding plains are often capped by hard silcrete (~1 – 5m thick) which overlies the Simmens Quartzite, and ranges from a few metres to a few tens of metres thickness. Elsewhere silcrete of varying hardness, and in some places, calcrete or gypcrete, underlie the Quaternary clay. In most places the Simmens Quartzite contains abundant claybands and is interpreted as a silicified variant of the underlying Corraberra Sandstone, formed by prolonged and intense chemical alteration and remobilisation of silica and platy silicate minerals of the substrate. The recrystallisation is thought to have occurred during the early Tertiary, but it may be much older because the undeformed nature of the rocks indicates the landscape has been stable since the Proterozoic. The surface silcrete is probably middle to late Tertiary. The stratigraphically older (and deeper) Woomera Shale outcrops in only few places and mostly has a gentle to flat dip.

Reverse circulation drilling

Stage 1 drilling confirmed that the stratigraphy and unit thicknesses shown in localised outcrops were representative of the geology beneath the surrounding plains. Despite the apparent predictability and expected evenness of the geology, Stage 2 drilling at the four corners of each site was needed to obtain a site specific three-dimensional characterisation, including depth to groundwater, subregional hydraulic gradient, variation in groundwater salinity, formation depth and thickness. The diamond core drilling was required to confirm, with certainty, sedimentary structures, local dip and brittle fracture characteristics of each site. Geological and hydrogeological descriptions based on drilling are summarised below and the geological logs for the reverse circulation drilling are in **Appendix 1**.

In Stage 2, nine reverse circulation holes were drilled by Underdale Drillers between 5/6/00 and 20/6/00; two each at sites 10a, 14a, 45a and 52a, and one at site 40a. All holes were drilled by air hammer and sampling from the cyclone separator was done every metre. When target depth was reached, the holes were purged and cased with 100 mm PVC and completed as observation piezometers. Geophysical logging was carried out at all sites after the holes were cased. All holes apart from 40aN were pumped for chemical and isotope analyses.

The reverse circulation method provided high-quality samples, but the hammer, and sometimes the inner tubes, tended to become blocked in saturated fracture zones and puggy clay sections. Samples were split on site into two large sub-samples – one composite for BRS, ANSTO/CSIRO, AMDEL, PIRSA and a reference sample which is currently stored in Woomera. From the residue, material was wet-sieved and placed into miniature sample trays. Each drillsite was cleaned up and photographed at the cessation of the drilling activities.

Table 1 contains a summary of the stratigraphy from the reverse circulation drilling at the nine drillsites.

Sites 10a, 14a, 40a and 45a comprised a thin veneer of Cainozoic sediments (clays, underlain by silcrete/porcelanite at seven locations) unconformably overlying Late Proterozoic rocks of the Tent Hill Formation (Wilpena Group). Site 52a encountered a thin clay veneer overlying Early Cretaceous Bulldog Shale and Cadna-owie Formation sandstones comprising an outlier of Eromanga Basin sediments. The Mesozoic sequence overlies a clayey and micaceous fractured sandstone, tentatively assigned to the Proterozoic Corraberra Sandstone.

Table 1: Summary stratigraphy (reverse circulation drilling)

Formation (metres) / Site #	10aN	10aS	14aNW	14aSE	40aN	40aS*	45aNE	45aSW	52aNW	52aSE
Clay	0-2.5	0-2.5	0-2.5	0-3	0-3	0-0.5	0-3	0-3	0-1	0-1.5
Silcrete	2.5-3	2.5-3.5	2.5-6	3-5	3-4	-	3-5.5	3-5	-	-
Simmens Quartzite	3-80	3.5-84	6-43	5-26	4-34	0.5-37	-	-	-	-
Bulldog Shale		-	-	-	-	-	-	-	1-19	1.5-18
Cadna-owie Formation		-	-	-	-	-	-	-	19-47	18-36.5
Corraberra Sandstone	80-88+	84-112+	43-94+	26-77+	34-80	37-85	5.5-31	5-21	-	-
Woomera Shale					80-84+	85-120+	31-77+	21-70+	47-61+	36.5-63+

* Drilled during Stage 1 investigations, previously known as '40N'.

The surface clays are generally reddish brown of medium plasticity, sometimes gypsiferous, becoming more plastic with depth, and with minor calcrete nodules at the base. The underlying silcrete at Site 14aSE, 45aNE and 45aSW is hard in bands, whereas massive hard to very hard silcrete occupies the top 0.5 to 1 metre of the Tertiary sequence at Site 10aN, 10aS and 40aN, and extends for 3.5 metres in Site 14aNW. The silcrete is generally ferruginised at the top and contains quartzite cobbles in many places. Without further drilling or geophysical surveys, it is not possible to determine the continuity and hardness of the silcrete layers across the sites.

The abundance of interbedded clays in the Simmens Quartzite (**P**ws) is highly variable, and again, hardness and clay content may change significantly across sites. Where the clay content of **P**ws is highest, the quartzite is replaced (in bands) by white kaolinitic clay and pale greenish grey clays of low to medium plasticity. The kaolin is probably derived from the Late Cretaceous regional (SE Australia) bleaching event, whereas the greenish grey clays (chlorite/illite?) were probably derived from weathering of micas from Proterozoic rocks underlying **P**ws. The most advanced weathering profiles in **P**ws are preserved beneath the silcretes, and on limited observations, weathering is deeper and more intense northward. **P**ws appears to be a diagenetic weathering surface of the Corraberra Sandstone.

The boundary between **P**ws and the Corraberra Sandstone (**P**wc) is somewhat arbitrary – it was designated primarily on lithology (a change to maroon, generally fissile, silicified micaceous sandstone with siltstone interbeds typical of the **P**wc red beds), but also on hardness. At all locations, unaltered **P**ws is consistently harder than **P**wc, but the latter member is harder in drilling than it appears in outcrop. **P**wc invariably contains micaceous siltstone interbeds and is generally flaggy (most rock chips fracture along bedding planes). Highly micaceous sandstone bands within the **P**wc sequence were intersected in Site 40aN and were probably sourced from (Mid Proterozoic) Pandurra Formation rocks which outcrop a few kilometres away to the north of Lake Windabout. Interbedded chocolate brown, very puggy, micaceous sandstones and siltstones underlying the Eromanga Basin sediments at Site 52a are tentatively correlated with **P**wc. The basal member of the Tent Hill Formation, the Woomera Shale (**P**wm), is a hard laminated and fissile pale bluish grey mudstone grading down to puggy brown shale.

The Bulldog Shale (Kmb) intersected in Site 52a is a monotonous sequence of white massive mudstone and siltstone, grading to pale yellowish brown or grey mudstone at depth. The top is kaolinised by prolonged and intense weathering (bleaching) – it is also gypsiferous and ferruginised here – and generally plasticity increases with depth. The lower part of Kmb contains well rounded cobbles and boulders of quartzite; these clasts are also exposed at the base of an earth tank adjacent to Site 52aNW. Kmb conformably overlies weakly indurated lithic and quartzose sandstones of the Cadna-owie Formation (Kco), a coarsening upward sequence from clayey fine sandstones at the base to medium sandstones, and in some places unconsolidated sands, at the top. Porosity increases upward in Kco sediments, as induration decreases.

Diamond core drilling

In Stage 2 ten diamond drillholes, two at each site, were drilled by Underdale Drillers between 20/6/00 and 19/7/00. All holes were drilled by a top drive Almet Masters rig using a hydraulic feed, drilling typically HQ push tube through the soil veneer, then PQ wireline to around 20 metres depth, then HQ wireline to the end-of-hole at around 50 metres. Holes were collar-cased to 1.5 metres using 150mm white polythene casing and then were cased using 100mm white polythene pipe through the PQ drilled interval prior to commencing the HQ coring (typically 20 metres). A 1.5 metre core barrel was used.

The core was sampled using a brick bolster for quartzite and sandstone lithologies, or a breadknife for softer claystones. Samples were taken for pore fluid analysis and bulk densities at 0.5m intervals from 0 – 20m, then every metre until end-of-hole. The samples were from intervals of solid core, which were trimmed to remove drilling fluid and mud, and chosen to avoid partings where fluids could have been introduced. Samples were bagged and heat-sealed in the field to maintain moisture content. The drill core was geologically and geotechnically described recording core recovery, lithology, fracture frequency and type, and lithological alteration. Geological logs for each diamond drill hole appear in **Appendix 2**.

The lithologies cored included silicified sandstone (quartzite), sandstone, siltstone, mudstone and claystone. The condition of the core recovered was generally good with the main losses and ground away core coinciding with lithology changes such as from silicified sandstone to claystone. Intervals of poorly consolidated sandstone or unconsolidated sand also caused low core recovery but this represented less than 5% of the total cored interval for the drill hole. Most partings in the core occurred on bedding planes where a change in texture and material strength caused the core to break.

Table 2 contains a summary of the stratigraphy from diamond core drilling at the ten drillsites.

The diamond drill core confirmed the accuracy, within practical limits, of the geological logging of rock type and thickness based on the percussion hammer method. The diamond core made it possible to accurately measure and describe thin interbeds of sandstone, siltstone and clays, the nature of lithological contacts and the number, distribution and type of partings.

The following observations were made based upon visual inspection of the drill core:

From ground surface to a few metres depth consists of a reddish-brown heavy textured clay. The clay is powdery and loose to a few centimetres and is then firm and stiff with sparse, sub-vertical, rough-surfaced partings indicative of moderate to weak pedological organisation. The clays become increasingly plastic with depth. The basal contact is typically abrupt with a thin contact zone of clay filling discontinuous, rough cracks in underlying silcrete. At Site 52a the contact is with weakly silicified and ferruginised equivalents of the underlying Bulldog Shale; the silcrete unit encountered at other sites is not as well developed here.

At all but Site 52a a hard silcrete unit occurs beneath the clay which varies in thickness, uniformity and hardness between drill holes. The silcrete can be massive and hard in bands to 30 cm thick but is mainly irregularly interspersed with partially silicified sandstone composed of recrystallised spherical quartz grains imparting an ‘oolitic’ texture to the rock. The basal contact is typically irregular and often changes rapidly from massive silcrete to weakly silicified sandstone over a few centimetres. At all sites except Site 52a the underlying unit is the Simmens Quartzite.

The Bulldog Shale and Cadna-owie Formation only occur in drill core at Site 52a. The Bulldog Shale is typically a pale yellowish-grey massive siltstone with interbeds of claystone, mudstone, silt and fine-grained clayey sandstone. Massive beds are commonly 30 – 50 centimetres thick with clear, sharp, sub-horizontal contacts. Iron-staining is mainly weak and diffuse, particularly on bedding planes. The contact with the underlying Cadna-owie Sandstone is marked by a facies change to medium to coarse-grained sandstones interbedded with proportionally less, and more thinly bedded, siltstone and mudstone. The sandstone is pinkish-white to pale pinkish-grey and consists of poorly consolidated quartzose to quartz-lithic sandstones. Core recovery was typically poor in the sandstone and this is attributed to the poor consolidation and the occurrence of cohensionless sand beds. The base of the Cadna-owie Sandstone is marked by a sharp erosional unconformity with the Corraberra Sandstone. The contact is clear both in texture and composition because the Corraberra Sandstone is harder and has thin interbeds of hard sandstone and softer claystones. There is also a marked colour change to maroon or chocolate brown.

The Simmens Quartzite consists of medium to coarse-grained pale cream, pale pink and pale grey-green sandstone and quartzite with interbedded fine-grained silt and claystone. The sand-sized beds are commonly 30 - 40 cm thick whereas the fine-grained interbeds are typically less than 20 cm thick and commonly less than 10 cm thickness. Most structures are parallel to bedding surfaces and appear as partings induced by contrasting mechanical properties of interbedded units. There are minor brittle fractures perpendicular to bedding in the thinner silicified sandy interbeds close to the top. Minor iron-staining and silicification of some fractures suggests that these are brittle fractures caused by near surface unloading with subsequent mineral precipitation by percolating groundwater. The contact with the underlying Corraberra Sandstone is a diffuse chemical weathering surface and is distinguished by progressively weaker silicification of the sandstones. The Simmens Quartzite does not occur at Site 52a.

The Corraberra Sandstone grades with depth to darker greys and then to a light brown to chocolate interbedded sandstone/claystone. The coarsest units are cross-bedded with sets occurring typically at up to 30 centimetre intervals, with foreset angles between 0-30 degrees. Ripples also occur occasionally in cross sets (eg 40aE, 45.7m). The finer-grained sandstones tend to be finely laminated and horizontally bedded in all drillholes. The claystones are finely laminated and increase in proportion to a gradational and conformable contact with the chocolate brown Woomera Shale.

At site 14aNE poor core recovery made it necessary to redrill the interval from 15.8 - 26.0 metres depth in a new drill hole 10 m distant from the first. This provided some intervals of overlapping recovered core and a comparison between the matching intervals demonstrated that many of the thin clayey interbeds were laterally discontinuous. Rapid lateral thinning is common in braided sedimentary facies. Lateral thinning and lens-shaped beds may also be produced by differential compaction of sediments, with a greatly reduced proportional thickness and lateral extent of clayey units compared to sandy units.

Table 2: Summary stratigraphy (diamond core drilling)

Formation (metres) / Site #	10aW	10aE	14aSW	14aNE	40aW	40aE	45aNW	45aSE	52aSW	52aNE
Clay	0-1.7	0-1.45	0-2.0	0-2.45	0-2.2	0-0.7	0-1.3	0-3.2	0-1.6	0-1.5
Silcrete	1.7-4.2		2.0-4.7	2.45-5.5	2.2-2.8	0.7-2.1	1.3-2.0	3.2-3.5	1.6-2.0	1.5-2.8
Bulldog Shale									2.0-19.2	2.8-7.85
Cadna-owie Formation									19.2-47.6	7.85-45.0
Simmens Quartzite	4.2-50.8+	1.45-51.05+	4.7-32.2	5.5-44.0	2.8-34.0	2.1-37.35	2.0-23.5	3.5-25.0		
Corraberra Sandstone			32.2-50.0+	44.0-53.8+	34.0-50.5+	37.35-49.1+	23.5-44.05+	25.0-48.0+	47.6-52.9+	45.0-51.6+

Geotechnical measurements

A variety of methods was used to obtain information about the geotechnical properties at each site. The observations made from the drilling included:

1. an assessment of formation hardness during reverse circulation drilling (**Table 3**);

2. an estimate of the proportion of sand to clay/silt from the rock chip samples using a binocular microscope (**Table 4**);

3. core recovery from diamond core drilling and a count of fractures and partings over 25 cm increments, accompanied by detailed geotechnical and geological descriptions.

1. Formation hardness

The hardness assessments are qualitative and are based on the drilling rate experienced in the top 20 metres using one compressor on the rig. For the VERY HARD category it was necessary to use both compressors and maximum engine revs. The rocks were very abrasive on the hammer. These results represent the hardness characteristics at two corners of the site only and there may be substantial variation in hardness across the whole site. However, the general trend observed was one of increasing hardness of both **P**ws and **P**wc southward.

The degrees of hardness may be approximately equated with rippability as follows:

DESCRIPTION	**ABBREVIATION**	**IMPLICATION FOR TRENCH EXCAVATION**
SOFT	SOFT	No ripping required
SOFT with minor HARD BANDS	SMHB	Some ripping may be required
ALTERNATING SOFT and HARD BANDS	ASHB	Limited ripping required
HARD BANDS	HB	Ripping required
ALTERNATING HARD and SOFT BANDS	AHSB	Extensive ripping required
HARD	HARD	Ripping and blasting required
VERY HARD	VH	Blasting required

Table 3 shows the interpreted hardness of the drilled intervals at two corners of each site.

Table 3: Formation hardness

10aN	**10aS**	**14aNW**	**14aSE**	**40aN**	**40aS**	**45aNE**	**45aSW**	**52aNW**	**52aSE**
0-2.5 SOFT	**0-2.5 SOFT**	**0-2.5 SOFT**	**0-3 SOFT**	**0-3 SOFT**	**0-0.5 SOFT**	**0-3 SOFT**	**0-3 SOFT**	**0-1 SOFT**	**0-20+ SOFT**
2.5-3 HARD	**2.5-3.5 HARD**	**2.5-6 HARD**	**3-9 HBANDS**	**3-19 HARD**	**0.5-7 HARD**	**3-17 AHSB**	**3-5 AHSB**	**1-3 SMHB**	
3-4.5 HBANDS	**3.5-20+ AHSB**	**6-7 HBANDS**	**9-20+ ASHB**	**19-20 AHSB**	**7-9 AHSB**	**17-18 HBANDS**	**5-7 HBANDS**	**3-20 SOFT**	
4.5-9 AHSB		**7-18 SMHB**			**9-10 HBANDS**	**18-19 ASHB**	**7-10 ASHB**		
9-10 SMHB		**18-20+ SOFT**			**10-12 AHSB**	**19-20+ HARD**	**10-12 SMHB**		
10-20+ AHSB					**12-13 SOFT**		**12-15 ASHB**		
					13-17 AHSB		**15-16 SMHB**		
					17-18 ASHB		**16-19 AHSB**		
					18-20 AHSB		**19-20+ SMHB**		

SMHB = soft with minor hard bands (soft >> hard)
ASHB = alternating soft and hard bands (soft > hard)
HBANDS = hard bands (soft ~ hard)
AHSB = alternating hard and soft bands (hard > soft)

2. Sediment proportions

Table 4: Estimated silt and clay-size percentages by visual inspection

Interval	10aN	10aS	14aNW	14aSE	40aN	(40aS)	45aNE	45aSW	52aNW	52aSE
0-1 (m)	90	90	90	90	90	50	90	90	90	90
1-2	90	90	90	90	90	0	90	90	80	80
2-3	40	40	40	90	90	0	90	90	80	80
3-4	30	0	0	0	0	0	0	0	80	80
4-5	20	0	0	0	0	0	0	0	80	80
5-6	0	0	0	0	10	0	0	0	80	80
6-7	0	0	10	0	20	0	10	10	80	80
7-8	10	0	70	10	0	10	30	30	80	80
8-9	20	0	80	20	20	10	30	40	80	80
9-10	60	0	80	30	30	30	30	50	80	80
10-11	20	0	70	40	20	10	20	80	80	80
11-12	20	10	70	40	30	10	20	80	80	80
12-13	0	20	70	40	30	90	30	40	80	80
13-14	20	20	60	30	30	10	40	50	80	80
14-15	20	10	70	30	0	10	30	50	80	80
15-16	20	0	80	40	0	10	40	80	80	80
16-17	0	10	80	40	10	10	30	50	80	80
17-18	0	20	80	40	20	60	80	50	80	80
18-19	10	0	80	40	40	20	70	50	80	20
19-20	20	0	80	40	50	20	30	80	10	10
20-21	20	0	80	30	10	0	40	80	10	30
21-22	0	0	60	40	0	0	30	10	10	0
22-23	0	0	80	40	10	0	80	20	10	30
23-24	10	0	70	30	20	20	50	20	10	10
24-25	0	0	30	60	20	30	80	10	10	0
25-26	0	0	70	30	30	0	40	30	30	0
26-27	0	0	70	30	20	30	60	20	10	0
27-28	0	0	70	30	30	40	30	20	40	10
28-29	10	0	70	40	30	50	30	20	0	10
29-30	0	0	60	40	30	70	20	20	40	20
30-31	10	0	40	10	10	30	10	20	0	20
31-32	0	0	40	10	20	0	10	10	0	20
32-33	0	0	40	10	10	0	0	10	50	10
33-34	0	10	70	10	10	0	0	20	50	10
34-35	0	20	30	10	30	20	0	20	0	10
35-36	0	0	20	10	20	0	10	20	70	10
36-37	0	0	20	10	30	0	10	10	70	10
37-38	0	0	20	10	40	10	10	10	0	10
38-39	0	0	40	10	10	0	10	20	10	10
39-40	0	0	50	10	0	0	0	10	0	10
Mean 0-20 (m)	25	16	60	36	29	18	38	51	77	74
Mean 20-40 (m)	3	2	52	24	19	15	26	20	21	12

3. Core recovery and fracture summary

Mixed hard and soft lithologies were anticipated from the results of the reverse circulation drilling program, and the choice of core sizes was made to maximise core recovery in soft or loose material. There was low core recovery over intervals in several holes for a range of reasons, mainly due to inter-banding of hard material with very soft of loose material (Appendix 3). The driller used options of bit matrix (hard, ranging to soft), drill penetration and rotation rate in order to maximise core recovery.

Fractures density was recorded over 0.25 metre intervals and plotted in the drill logs (Appendix 2). However, the fracture densities are overestimated because the claystones tend to part on bedding planes with the inter-layered sandstones. Based on observations made of the drilling conditions and the interlayered materials it is concluded that the ground was predominantly unfractured, with only minor zones of localised fracturing/jointing.

Hydrogeology

Pwc is the regional aquifer at all sites. Regional groundwater flows through distinct fracture zones, and rises in a drill hole standpipe to equilibrate with the regional watertable. **P**wc is unconfined at Site14aSE, 40aN, 45aNE, 45aSW and 52aSE. Elsewhere the water table lies in **P**ws at Site10aN, 10aS and 14aNW and in Kco at Site52aNW (samples at the base of Kco were moist at this site). Although the basal section of Kco is partially saturated at the Site52 site, it is not hydraulically connected to the extensive aquifers of the Eromanga Basin to the west, nor is there any groundwater flow northward to the GAB from this area.

Table 5 summarises the water cuts, estimates of yield, quality measurements and standing water levels.

Yields from all bores drilled during stage 2 were low (< 1L/sec) and salinities were high (>= 10,000 mg/L TDS). In common with the bores drilled in stage 1, yields are higher west of the Woomera – Roxby Downs Road than the east.

Table 5: Hydrogeology

	10aN	10aS	14aNW	14aSE	40aN	40aS*	45aNE	45aSW	52aNW	52aSE
Anticipated unsaturated zone (m)	30	30-40	30	30	55-60	55-60	30	35	40-45	40
Actual unsaturated zone (m)	32.0	39.7	42.6	41.5	67.1	67.9	54.7	54.6	40.0	37.4
Anticipated salinity (mg/L TDS)	15,000	15,000	12,000	14,000	15,000	15,000	10,000	12,000	10,000	12,000
Estimated salinity from field EC (ppm)	18,000	16,000	10,000	18,000	N/A	13,000	16,400	12,000	12,000	16,000
Airlift yield (L/sec)	0.5	0.8	0.05	0.05	0.05	0.05	0.4	0.3	0.6	0.6

* Drilled during Stage 1 investigations, previously known as ‘40N’.

Hydrology and nuclide sorption

In the Stage 1 report, studies by ANSTO and CSIRO were outlined which provided estimates of water balance, deep drainage below the surface clay and the nuclide retardation properties for characteristic materials appropriate to the sites. Their reports also recommended additional quantitative site studies which will are being done currently and will continue as a part of the Stage 3 assessment.

Performance assessment

The performance of each site was reviewed according to the majority of the NHMRC (1992) site selection criteria. Many of the criteria refer to geotechnical considerations and the field assessment program was designed to provide both the quantitative and qualitative data needed to assess site suitability. Other criteria relate to broad issues, such as tectonism, for which the suitability of each site was determined during the national and large scale regional assessments. Criteria dealing with social and cultural matters are considered through public consultation, and ecological significance will need to be reviewed as a part of a future environmental impact assessment.

Two approaches were used to assess the comparative suitability of each site. The first approach was semi-quantitative and was based on the geotechnical conditions, including the hardness and clay proportion of the ground in a potential trench zone, and the deeper conditions that could affect hydrogeological modelling and radionuclide sorption (**Table 6**). The second approach was a relative judgement of the site and whether performed better, the same, or worse than another site for each criterion (**Table 7**).

1. Comparative suitability – geological and hydrogeological criteria

The drilling results permit a semi-quantitative ranking to be made of their suitability for a repository, based on the geological and hydrogeological criteria. In order to rank them objectively, measures of hardness in the top 20 m, proportion of fine-grained sediment (above and below a 20-metre deep trench), thickness of the unsaturated zone below 20 m, and water quality/yield were used. The following ratings were used to rank the sites according to the geological and hydrogeological criteria:

Hardness	Rating	% silt + clay	Rating	Unsat. zone (below 20 m)	Rating	Groundwater quality (mg/L TDS)	Rating	Airlift yield (L/sec)	Rating
VHARD	0	<5	0	0 – 5	0	<3000	0	>5	0
HARD	1	5 – 10	1	5 – 6	1	3000 – 7000	1	1 – 5	1
AHSB	3	10 – 20	2	6 – 7	2	7000 – 12,000	2	0.5 – 1	2
HBANDS	4	20 – 30	3	7 – 8	3	12,000 – 20,000	3	0.2 – 0.5	3
ASHB	6	30 – 40	4	8 – 9	4	20,000 – 35,000	4	0.1 – 0.2	4
SMHB	8	40 – 50	5	9 – 10	5	>35,000	5	<0.1	5
SOFT	10	50 – 60	6	10 – 11	6				
		60 – 70	7	11 – 12	7				
		70 – 80	8	12 – 13	8				
		80 – 90	9	13 – 14	9				
		>90	10	>14	10				

Under this scheme, the maximum possible score is 50 if the percentage silt + clay is counted twice, ie. for 20 m above and below the base of the trench, and salinity/yield are combined. The suitability matrix is shown in **Table 6**. This table can be refined when clay mineralogy and other parameters become available.

Table 6: Ranking of sites based on geology and hydrogeology field parameters

Field Parameter	10aN	10aS	14aNW	14aSE	40aN	40aS	45aNE	45aSW	52aNW	52aSE
Hardness (0 –10)	4	4	7	6	3	3	4	6	10	10
% Silt + Clay 0 – 20 m (0 – 10)	3	2	6	4	3	2	4	6	8	8
% Silt + Clay 20 – 40 m (0- 10)	0	0	6	3	4*	4*	3	2	3	2
Unsat. zone below 20 m (0 – 10)	7	10	10	10	10	10	10	10	10	10
Water quality (0 – 5)	3	3	2	3	3	3	3	3	3	3
Airlift yield (0 – 5)	3	2	5	5	5	5	3	3	2	2
Score (max. 50)	20	21	36	31	28	27	27	30	36	35
Average score	21.5		33		27.5		28.5		35.5	
RANKING	5		2		4		3		1	

*Score doubled because of abundance of mica/illite below 20m at this site.

2. Comparative suitability – relative assessment

Table 7: Relative assessment using all criteria

Criterion/Site Number:	10a	14a	40a	45a	52a
a (surface drainage etc)	+	-	+	+	+
b (water table)	-	0	+	+	0
c (groundwater modelling)	-	0	0	0	+
d (seismicity, tectonism)					
e (development prospects)	-	+	-	+	-
f (groundwater quality)	+	+	+	+	+
g (sorption, trench operation)	-	0	0	0	+
h (minerals, agriculture)					
i (transport access)	+	-	-	-	+
j (ecological significance)					
k (culture, history signif.)					
l (regional services)					
m (long-term control)	+	-	-	-	+
Net result:	0	-1	2	0	5
Preference:	x	x	√	√	√

Conclusion

The performance assessment shows that Site 10a was the least favourable but still suitable site, mainly because it had the shallowest standing groundwater level (32m) and because of the hard and typically massive nature of the Simmens Quartzite. Also, Pws was up to 80 m thick at this site and exhibited the least favourable sorption characteristics. Sites 14a and 45a always ranked well and had similar characteristics but Site 45a was chosen because the surrounding landforms indicate superior surface drainage and the site is also marginally closer for transport access. It was considered that the similarity of the two sites made it desirable to select a different site to maintain options if Stage 3 assessments indicated any type of deficiency in the area of either site. Site 40a performed very well for most criteria, the least favourable aspects being transport access and its location well within a pastoral lease. Site 52a performed exceptionally well but further data is required to confirm that the sorption properties of the Bulldog Shale are satisfactory.

Based on the data obtained from drilling and the assessment of the selection criteria, all the sites performed well and are considered suitable for the repository. Sites 45a, 40a and 52a meet the selection criteria <u>better</u> and are preferred for Stage 3 assessment.

Appendix 1: Geological logs (reverse circulation drilling)

Appendix 2: Geological logs (diamond drill core)

Appendix 3: Core recovery and fracture summary

Drill site number	Interval / Core size	Poor recovery intervals	Fracture densities (0.25m basis), average
10aW re-collar of 0-6m, 8m to south	0-0.75 (push HQ) 0.75-20.6 (PQ) 20.6-50.8+ (HQ) new 0-6+ (PQ)	0-.75; 1.8-3.3; 3.3-4.2; 4.4-4.9; 4.9-6.0. new 2.9-4.4	broken 6-50.8 3/.25m
10aE	0-1.45 (PQ cored) 1.45-19.55 (PQ) 19.55-51.15E (HQ)	0-0.8	5.0 8/.25m 5.0-19.5 4/.25m 19.5-50.8 2/.25m
14aSW	0-2.3 (push HQ) PQ 17.4-50.0+ (HQ)	0-2; 14.9-16.3	6/.25m 2/.25m 16.25-50.0 3/.25m
14aNE recollar15.8-53.8m 10m to south	0-0.75 (push HQ) 0.75-21.1 (PQ) 21.1-28.0+ (HQ) 0-15.8 6" (hammer) 15.8-53.8+ (HQ)	2.0-3.5; 3.8-4.8; 4.8-5.5; 5.5-7.3; 18.3-19.6; 25.8-26.1; 26.1-27.7; 27.7-28.0+ 0-15.8 not recov'd	2.0-7.3 3/.25m 7.3-26.1 3/.25m 15.8-53.8+ 2/.25m
40aW	0-1.3 push H(Q) 1.3-17.6 P(Q) 17.6-50.5+ (HQ)	3.7-4.9; 7.9-9.3	3/.25m 8.0-50.5 2/.25m
40aE	push HQ PQ 20.55-49.1 (HQ)	4.75-6.1	2/.25m 3/.25m 16.0-49.12/.25m
45aNW	0-0.75 (push HQ) 0.75-17.65 (PQ) 17.65-44.05+ (HQ)	2.6-3.4; 6.4-7.9; 7.9-9.15	1.0-11.0 3/.25m 2/.25m 20.5-44.05 2/.25m
45aSE	0-0.75 (push HQ) 0.75-20.6 (PQ) 20.6-48.0+ (HQ)	1.25-2.0	1/.25m 4/.25m 1/.25m 3/.25m 15.0-48.0 2/.25m
52aSW	0-1.6 push HQ 1.6-24.1 PQ 24.1-52.9+ HQ	1.6-2.0; 3.5-5.0; 22.6-24.1; 24.1-25.3; 25.3-26.7; 29.7-31.2; 31.2-32.7; 32.7-33.7; 48.6-49.6	3/.25m 1/.25m 4/.25m 2/.25m 5/.25m 48.5-52.9 3/.25m
52aNE	0-1.5 push HQ PQ 24.6-51.6+ HQ	1.8-2.6; 2.6-4.1; 4.1-4.8; 23.2-24.6; 25.9-27.0; 31.5-32.7	3/.25m 4/.25m 38.0-51.6 2/.25m