DEPARTMENT OF
MINERALS AND ENERGY

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

Record 1974/186

ENGINEERING GEOLOGY OF GUNGAHLIN URBAN DEVELOPMENT AREA, A.C.T.

by

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SUMMARY

This report presents the results of a geological study of the feasibility of development of Gungahlin, a proposed satellite town of Canberra.

The distribution of rock types, soils, groundwater, and natural resources have been mapped and their bearing on urban development discussed.

The area is underlain predominantly by shale and slate of Silurian age and by lesser amounts of acid volcanic rocks of probable Silurian age. These rocks have weathered to form residual soils up to 3 m thick that have been eroded locally and redeposited downslope in shallow depressions. The residual soils are predominantly lean to heavy clays (CL to CH of Unified Soils Classification); the thicker transported soils are silt, sand, or gravel where the deposits are very young, or gravel, sand, silt, and heavy clay where older soils are present.

Most shale and soil within 2 m of the surface will be rippable, but volcanic rocks and shale in the north of Gungahlin will probably require some blasting for excavations of up to 2 m in depth.

Bearing strengths of most soils are adequate for single-storied residential structures (Table 1), but buildings with high bearing pressures may have to be founded, either directly or by use of piles, on moderately weathered rock. Deep foundations will probably be necessary for multi-storied buildings sited on weathered limestone where hard boulders of limestone occur in heavy clay; careful site investigation of these areas is essential.

Groundwater is found throughout the area. Yields of bores 50 to 60 m deep are low, (about 0.5 m^3/h) except where they intersect major fractures, from which flows from 15 cm-diameter bores of up to 20 m^3/h have been pumped. Groundwater in some areas is confined under pressure beneath a mantle of soil and weathered rock. In some other areas groundwater springs and seepages are common, e.g. near Hall and over a large area of north Gungahlin. Conventional drainage is expected to be adequate, except in areas with saturated soils, which are not extensive.

Resources of brick shale occur through the area, and possible pit sites have been delineated. The area contains other resources that are scarce in the Canberra region, including porphyry (for aggregate), sandstone, 'plastic' gravel, kaolin, limestone, and topsoil. Topsoil resources in Gungahlin are considered inadequate for development of the area.

INTRODUCTION

The Bureau of Mineral Resources (BMR) was requested by the National Capital Development Commission (NCDC) to carry out a geotechnical investigation to determine the feasibility of urban development of the Gungahlin area, which includes parts of both Hall and Gungahlin Districts, A.C.T.

After the general feasibility study which was reported on in map form in March 1973, NCDC called specifically for comments on the following problem areas, which are shown on the design constraints map, Plate 5.

1. The source of springs in the most northern part of the study area, and suitability of the area for development of light industry (Area 1).

2. Slope stability in the hills, and the possible effect of springs, particularly along the parkway alignment (Area 2).

3. The extent and bearing strength of the saturated, organic soils along Ginninderra Creek near Mulligan's Flat (Area 3).

4. The boundaries and depths of the area of clay with boulders overlying limestone and limonitic gossan at 212500E, 614000N (Area 4).

5. The most suitable and economic quarry sites for rock aggregate and sandstone.

At the time of writing (December 1973), the town plan for the development of Gungahlin was NCDC Structure Plan A1. Comments on geological factors influencing planning were therefore made bearing this plan in mind.

The location of the area is shown in Figure 1. The geology of the Halls Creek area, which lies within the area of the Gungahlin study, has been reported on separately (Hohnen, 1973), and is not dealt with specifically in this text.

METHOD OF INVESTIGATION

Airphoto-interpretation of soils and geology was carried out and 60 auger holes were drilled to determine soil thickness and variation in physical properties with depth. Creek banks and gullies were also examined and soil* thicknesses measured. Geological mapping of most of the area was carried out at 1:25 000, and areas of complex geology were mapped in detail at 1:2400 or 1:9600 scale. The results of the investigation are presented as a superficial deposits map (Plate 2) and a geological map (Plate 1); the latter is an interpretative geological map, that also shows the lithologies that are expected to be found beneath the superficial deposits of alluvium and soil.

Seven bores were drilled by a rotary drill rig to depths ranging from 45.7 to 61 m to determine groundwater conditions. Flow rates were determined by airlifting at the completion of drilling and ranged from 0.18 m^3/hr to 18.0 m^3/hr (40 - 4000 gph) (Table 2). Logs of water-bores are shown in Plate 6. Springs, seeps, and marshy areas were mapped and information of standing water levels was obtained from the seven BMR bores (Table 2), and from seven privately-owned bores in order to prepare a contoured potentiometric-surface map. This map shows generalized flow lines indicating the direction of groundwater movement (Pl 3).

SOILS

Soils include completely weathered rock** and unconsolidated sedimentary deposits; they may be residual soils formed in situ by extensive weathering of solid rock, or transported soils that have been formed on parent material that has been transported to its present location. Both types of soils may or may not contain organic matter. Properties of soils in the mapped area that influence their performance as foundation material are broadly evaluated in Table 1.

The residual soils are generally less than 3 m thick and have been derived by the weathering of the underlying rock except on steep slopes where soil creep has moved the soil material downslope for several metres. In the Gungahlin area, residual soil which is also called 'completely weathered rock', may be classified as (i) lithosols, which are stony, silty, or clayey soils; (ii) red and yellow earths, which are generally sandy or silty lean clays; and (iii) podzolic soils, which are mainly heavy clays.

The transported soils are unconsolidated to partly consolidated sedimentary deposits which have been deposited by streams and by hillwash in shallow depressions where they have accumulated to thicknesses of up to 9 m. Transported soils are also present on hillwash material that has accumulated at the foot of hillslopes.

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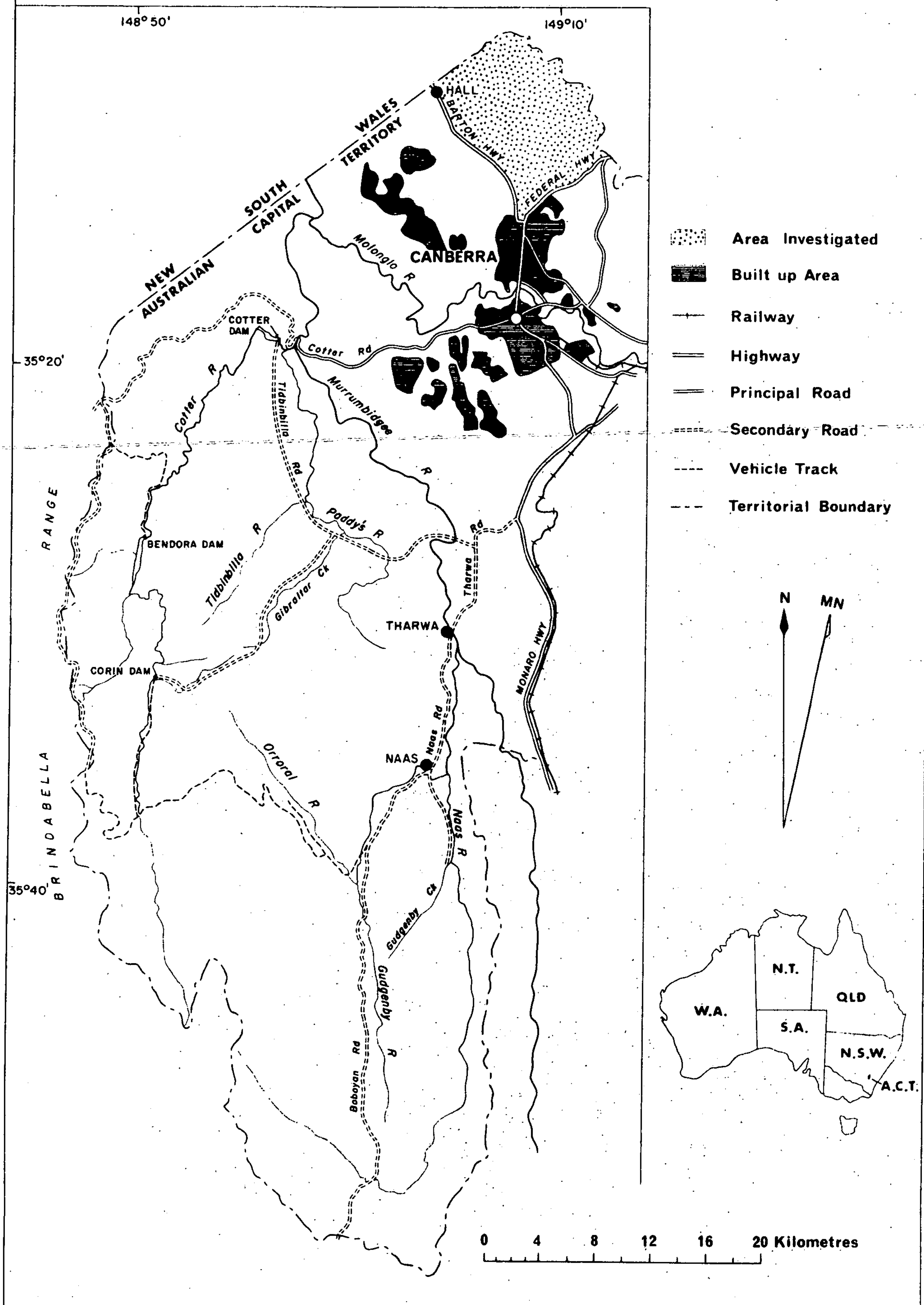
* Definition Soil is used here in the engineering sense i.e., a natural aggregate of mineral grains and/or organic matter that can be separated by such gentle mechanical means as agitation in water.

** For definition of terms see Appendix 2.

LOCALITY MAP — Figure 1

GUNGAHLIN URBAN DEVELOPMENT AREA



Record 1974/186

155/A16/1154

M(Pf)171

TABLE 1: SOIL PROPERTIES

Soil type - map unit (geological and pedological names)	Shallow soils (lithosols, colluvium, truncated podzolics)	Thicker residual and colluvial soils (podzolics, red earths, colluvium)	Stratified alluvium and gumbotils (alluvium, podzolics, gleyed podzolics and humic gleys).	Clays containing limestone and limonite boulders (terra rossa soils, red earths)	Solodic soils containing quartz veins, boulders, shale bands, colluvial stringers, grey billy, and lateritic soil remnants
Range of thickness of map unit (m)	1	1 - 3	1 - 10	highly variable	1.5
Range of categories according to Unified Soil Classification Scheme, commonly spanned by the pedological type in the area	GM, GH	GM, CL-CH	GP, GM-SM, SC, (CL, SP), CH-OH	GC, CL	CL, GP, GC
Colour	brown, red-brown, red, mottled yellow, and grey	brown, red-brown, red, mottled yellow, and grey	pale brownish red to yellow, dark greyish brown, medium grey	red-brown	predominantly red; grey billy, pale grey to white
Performance as foundation material for dwellings (two stories or less) under worst natural moisture conditions	good to fair	fair to poor	fair to very poor	poor	fair to good
Estimated tendency to shrink and swell with moisture fluctuations	weak to moderate	moderate to strong	nil to very strong	strong	Weak
Natural drainage of soil type	good	fair to good	good to very poor	poor	fair

Deposits of alluvium ranging in thickness from 3 to 10 m in valleys and basin-shaped depressions have been delineated on the 'superficial deposits map' (Pl. 2). These deposits generally include stratified gravel, sand, silt, and clay which are unconsolidated but, in places, they have been cemented to strengths approaching that of moderately weathered shale. Foundations for multi-storey buildings sited on transported soils need careful investigation to ascertain bearing strength because of the thickness and variability of the strata.

GEOLOGY

Lithology

Shale is the predominant rock type and this, with less common slate, siltstone, and mudstone, underlies about 70 percent of the area. It has been eroded to an undulating plain over much of the area except in the north, where the ground rises to form hills that mark the water-shed between the Molonglo and Yass rivers and the A.C.T./N S W border. Fossils within the shale indicate a Middle to Upper Silurian age.

Volcanic rocks are considered to overlie the shale to the east and west, where they occupy hills. Volcanic rocks are also present on a number of small ridges and hills on the plains. In the southwest of the area, sandstone, shale, and chert of Lower Silurian and Ordovician age form steep to rolling hills.

The shale and other sedimentary rocks have a total thickness of at least 150 m and are overlain with apparent conformity in the east and west by at least 100 m of welded ash-flow tuff, ash-fall tuff, and agglomerate. A small stock of quartz porphyry crops out in the area of Gold Creek. This stock probably represents an intrusive portion of the magma that formed the volcanic rocks in the Halls Creek area. The age of the volcanic rocks may range from Upper Silurian to Devonian.

Structure

The shales and the volcanics have been gently folded about north-northeast-trending axes. The style of folding appears to be concentric with dips of 5° to 30° commonly occuring on limbs of folds. Fold axes tend to be sub-horizontal, plunges are shallow and variable. An axial plane cleavage is well developed in the shale, and is also recognizable in weathered volcanics.

Reverse faults parallel or sub-parallel to the axial planes of folding have been mapped throughout the area. Some faults have been injected with hydrothermal fluids which have deposited quartz and magnetite and have altered wall rocks to kaolin. Weathering has oxidized magnetite limonite-hematite, which crops out as resistant gossans, particularly in the south of the area, where faulting and/or hydrothermal activity appear to have been most intense.

In the southwest, the Lower Silurian and Ordovician rocks have been exposed by the uplift and erosion of a large block of sedimentary rocks between the Gundaroo and Gungahlin Faults (Pl. 1).

Weathering and ease of excavation

The weathering profiles described in this report are restricted to completely and highly weathered rock; the moderately weathered rock is generally not rippable and provides stable foundation material. The profile generally thickens southwards from a few centimetres in the hills in the north to a maximum of about 50 m in shale at the southern extremity of the area. In the southwest, weathering of quartzose sandstone and silicified shale is only superficial (less than 1 m); other rocks interbedded with these are more deeply weathered.

Despite the general trend to greater depths of weathering to the south, the thickness of the weathered profile may change markedly within small areas. Borehole Gu 2 (Canberra 86), for example, was completed in soft, highly weathered shale at a depth of 50 m. About 100 m south, fairly hard moderately weathered shale crops out in the bed of Sullivans Creek, about 2 m below the surface of stratified slopewash and alluvium.

In general, shale north of 616000N is moderately weathered or non-rippable within about 1 to 2 m of the surface. South of this grid co-ordinate, the depth to moderately weathered shale increases rapidly to 20 to 25 m by 613000N.

The weathered profile is generally thinner on volcanic rocks and depths to non-rippable material range up to 2 to 3 m beneath residual soil and 4 to 6 m beneath alluvium and slopewash.

HYDROLOGY

The trend of the larger streams in the Gungahlin area, viz, Halls Creek, Ginninderra Creek, 'Gungaderra Creek', and Sullivans Creek, follows the strong northeast-southwest structural trend of the area. Erosion has tended to follow the directions of axial plane cleavage and faulting and drainage channels follow the same alignment.

Groundwater

Details of seven observation bores drilled by contractors for BMR in 1973 are summarized in Table 2 (Canberra 85 to 91); some details of privately-owned bores are also shown. Analyses of groundwater from 7 bores are shown in Table 3.

Groundwater is generally confined by low permeability clays formed by the weathering of shale, slate, and volcanic rocks.

Groundwater was intersected in bores at depths ranging from about 10 to 80 m and was derived from fractures in shale, slate, and volcanic rocks. Below about 80 to 100 m, the rock is expected to be fresh and without open fractures. From the ground surface to a depth of 10 to 20 m most fractures are filled with clay minerals and the rock lacks significant permeability. Such material tends to confine the groundwater, and pressure may build up in aquifers so that when they are tapped, groundwater may rise to within 0.3 m of the groundsurface (Table 2).

Groundwater may be held in joints, tension gashes, solution cavities in limestone, and in well-jointed rocks adjacent to fault planes. Faults, with

TABLE 2. BORE AND WELL DATA

Bore No. (See Plate 3)	Depth (m)	Length of casing (m)	Depth to first significant flow of groundwater (m)	Water yield (m^3/hr)	Standing water level (m below groundsurface)	Total interval cored (m)	Percentage core recovered	Lithology
CANBERRA 85 (Gu1)	45.7	6.1	11	3.4 (750 gph)	range over 4 months was 4.68 to 0.29	3.0	10	SHALE
" 86 (Gu2)	48.8	11.9	?	0 .18(40 gph)	25.7	Nil	-	SHALE
" 87 (Gu3)	45.7	18.0	38	3.3 (720 gph)	11.95	Nil	-	SHALE
" 88 (Gu4)	45.7	17.2	18	3.3 (720 gph)	6.95	3.0	20	SHALE
" 89 (Gu5)	60.0	23.3	25	0.5 (120 gph)	24.8	2.1	20	SHALE/ASHSTONE
" 90 (Gu6)	61.0	18.3	20	18.0 (4000 gph)	8.6	3.0	20	SHALE
" 91 (Gu7)	61.0	12.2	27	0.7 (150 gph)	5.67	1.5	5	SHALE/ASHSTONE
G2	39.0	N/A	9	1.67 (367? gph)	1.8	N/A	N/A	SHALE
G3	85.95	N/A	85.3	2.0 (450 gph)	N/A	N/A	N/A	SEDIMENTS
G6	22.25	N/A	21.3	1.3 (300 gph)	N/A	N/A	N/A	SEDIMENTS
G7	41.75	N/A	41.1	2.0 (450 gph)	N/A	N/A	N/A	SEDIMENTS
H 11	25.30	25.30	15.9	1.8? (400? gph)	11.00	N/A	N/A	QUARTZ/PORPHYRY
H 12	23.32	N/A	N/A	1.8 (400 gph)	3.66	N/A	N/A	QUARTZ/PORPHYRY
H 14 (Well)	3.96	N/A	N/A	N/A	2.13	N/A	N/A	N/A

TABLE 2 (Contd.)

Bore No. (See Plate 3)	Depth(m)	Length of casing (m)	Depth to first significant flow of groundwater (m)	Water yield (m^3/hr)	Standing water level (metres below ground surface)	Total interval cored (m)	Percentage core recovered	Lithology
H15	19.20	N/A	N/A	9.0 (2000 gph)	0.61	N/A	N/A	SHALE
H17	14.33	14.5	5.80	0.9 (200 gph)	1.22	N/A	N/A	SHALE
H18	21.03	N/A	N/A	3.3 (700+ gph)	7.92	N/A	N/A	PORPHYRY

NOTE: N/A = not available

TABLE 3. CHEMICAL ANALYSES OF BORE WATER

Bore No.	pH	Ca(ppm)	Mg(ppm)	Na(ppm)	K(ppm)	Sr(ppm)	HCO_3(ppm)	Cl(ppm)	SO_4(ppm)	NO_3(ppm)	total dissolved solids (ppm)
G2	7.0	147	52	69	-	-	486	161	86	-	878
G3	7.0	108	51	100 (approx.)	-	-	610	67	101	-	655
G6	7.2	101	52	157	1	2	500	183	110	-	856
G7	7.0	196	110	169	2	3	630	320	308	-	1560
H11	7.4	129	69	45	1	-	493	59	167	-	740
H12	7.0	128	71	124	-	-	750	90	124	-	900
H15	7.5	133	62	79	-	-	510	89	183	2	826

the increased fracturing in adjacent rocks, provide the highest yields of groundwater (Gu6 at 18 m^3/hr) and they probably exert a strong control on its direction and rate of circulation.

The almost continuous seepages during 1972/73 from shaly slopes to the north of Gungahlin (Pl. 3), suggests that the springs could be fed by vadose water from the dissected tableland immediately north of the A.C.T., rather than the saturated zone of groundwater that would lie at a much greater depth in that area. Such seepages will be encountered in road cuts and excavations, and will produce minor drainage problems in sub-grade material and possibly some instability in road cuts. The standing water level close to groundsurface in a well at 'Elmgrove' in November 1972 indicates that the potentiometric surface in depressions may lie very close to the ground surface after rainy periods. The absence of a thick mantle of completely and highly weathered rock on the shaly hill-slopes, owing to recent and continuing erosion, has facilitated the movement of vadose water to the surface as seepages.

For a more regional account of groundwater conditions, the reader is referred to Burton (1967, 1969).

Flooding

Infiltration of surface-water throughout the area is slow and so runoff is correspondingly high and flash-flooding of low areas is likely to take place. Aerial photographs taken in 1968 after heavy rain fell on the area show water lying on the surface of all areas of organic clays shown on the 'design constraints map' (Pl. 5).

Recharge of groundwater

Depressions filled with unconsolidated Holocene sediment to thicknesses of up to 10 m (Pl. 2) probably hold considerable amounts of water in soil voids and this water is probably lost slowly to deeper aquifers. Most recharge probably takes place in the north from jointed moderately weathered and slightly weathered shales on the hillslopes.

NATURAL RESOURCES

Brick Shale

Gardner (1960, 1974) carried out detailed investigations for brick shale in the Gungahlin area between 1959 and 1963. Areas selected by Gardner as possible sites for brickshale pits are shown on the 'Natural Resources' map (Pl. 4).

In the present survey several areas have been delineated which contain large reserves of shale, some of which would probably be suitable for brick making. The most favourable areas are indicated by numerals I to V on Plate 4. Factors considered in the selection of these sites were as follows: (a) natural drainage; (b) weathering; (c) quality of shale, which was determined by firing test-briquettes prepared from crushed shale; (d) proximity to an area reserved by NCDC for an industrial estate, and (e) screening from public view by topography and/or dense timber.

A brickworks in the Gungahlin area would require materials ranging from completely weathered shale (site V), through highly weathered shale (site IV), to moderately weathered, hard shale (sites I, II, & III). The most economic combination of sites in close proximity would be sites III, IV and V. Detailed site investigation would be needed to quantify reserves and determine the range of physical properties, and would involve power augering, diamond drilling with continuous core sampling, and test crushing and firing.

Aggregate

Quartz porphyry

An intrusion of quartz porphyry crops out over an area of about 3 km^2 to the west of Gold Creek (Pl. 4), and there are several possible locations for quarry sites. Site investigation for a quarry would be necessary to determine depths to fresh rock and to confirm mineralogical suitability of the rock, including absence of reactive minerals such as pyrite.

Rhyodacite porphyry

Another suitable source of aggregate may lie in the northwestern extremity of the area, where slightly weathered, greenish grey, porphyritic rhyodacite crops out on a prominent hill (Pls 4, 5). The rhyodacite has been examined in thin-section and contains quartz and feldspar phenocrysts up to 5 mm across set in a groundmass of fine-grained feldspar. Ferromagnesian minerals (relict orthopyroxenes), opaque oxides, and calcite constitute about 0.1% of the rock. The potash feldspar has undergone incipient to advanced alteration to sericite.

Topsoil*

In the north, soil is generally only a few centimetres thick and is underlain by highly to moderately weathered shale or heavy clay subsoil. In the central and southern areas there is generally less than 30 cm of soil on completely weathered shale; however, it generally contains a leached A horizon and is not well suited for gardens and lawns.

Introduction of topsoil will be necessary to allow the establishment of lawns and gardens owing to the absence or paucity of any type of soil in many areas, where moderately to highly weathered shale occurs at the ground surface. Only two small deposits of topsoil have been found in the area (Pl. 4). The northern deposit is at least 1.5 m thick, but greater thicknesses could be worked if cobble layers can be separated; the inferred reserves are 100 000 m^3. The southeastern deposit is up to 1 m thick and the inferred reserves are 25 000 m^3.

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* Refers to soil suitable for establishing lawns and gardens and in the Gungahlin area this is mainly a silt-sand mixture with organic matter.

Plastic gravel (material suitable for use in improving the subgrade and shoulders of sealed roads)

Plastic gravel is used for the construction and maintenance of surface course of rural roads and for the maintenance and construction of shoulders of sealed roads. Pits are generally required within 8 km of roadworks and should contain reserves of at least 10 000 m^3 of gravel to be economically justifiable and to warrant the ecological disturbance caused by excavation.

1. Residual deposits: Many of the volcanic rocks in the west and east are porphyritic and contain quartz phenocrysts 2 to 5 mm across. These rocks, provided that they do not contain more than about 5% of biotite, could provide sources of plastic or more rarely, non-plastic gravel where they are highly weathered.

2. Transported deposits: Slopewash deposits adjacent to Halls Creek in the west and to Sullivans Creek in the east could provide sources of plastic gravel. Slopewash may have excessive plasticity in the Sullivans Creek area because, as well as volcanic rock fragments, it contains shale which has partly weathered to clay.

Limestone

Limestone crops out over an area of about 60 000 m^2 at grid co-ordinates 614500N and 213900E. Known as the Wells Limestone, its thickness is not known, but is inferred to be at least 30 m. The limestone has been used as a source of aggregate, but indicated plus inferred reserves are only 1.1 million m^3, (Noakes & Perry, 1952). The limestone is jointed, but the joint spacing is wide enough to allow slabs to be cut for small facing stones.

Limestone lenses crop out in other areas both in volcanic and in shale country rock, but these occurrences are too small to warrant other than local use as large ornamental boulders for public gardens and parks.

Sandstone

A. Lower Silurian (?Black Mountain Sandstone)

Some of this formation is sandstone (Pl. 4) that is suitable for the construction of retaining walls where irregularly-shaped blocks of variable size are acceptable.

Bed thickness and joints control the maximum size of rock quarried from this area; the larger fragments are expected to be between 15 and 30 cm across and to consist of moderately weathered to fresh rock.

B. Ordovician (Pittman Formation)

Sandstone from this formation is suitable for use as permeable fill. Some beds might provide material suitable for retaining walls.

GEOLOGICAL AND HYDROLOGICAL DESIGN CONSTRAINTS: CONCLUSIONS AND RECOMMENDATIONS

Foundations

Foundations for buildings south of 613000N will be in highly to completely weathered, soft shale. Where high bearing pressures are involved, it might be necessary to found structures on moderately weathered shale which is at depths ranging to 50 m. From 613000N to 616000N, depths to moderately weathered shale are commonly 1 to 4 m but range to 20 m. North of 616000N, depths to moderately weathered rock range up to 11 m and are commonly less than 1 m on ridges and hills and 2 to 9 m on the flats and lower valley slopes.

Foundations on or near faults, particularly those that are not quartz-filled, will require careful site investigations because weathering is likely to be more variable in fault zones. Detailed site investigations will be needed to determine foundation conditions on clays derived from limestone, or on limonitic gossans, both of which have irregular weathering profiles and may lead to problems of differential settlement.

Excessive settlement due to consolidation could occur beneath most types of buildings with footings on saturated stratified alluvium and gumbotils (humic gleys, Pl. 5). Multi-storied buildings in these areas should be founded on moderately weathered rock, which in most cases will be no more than about 10 m below the ground surface.

The thickness of extensively weathered volcanic rock within the area of the NCDC Structure Plan A1 is more irregular than that of shale, and foundation conditions are less predictable. In general, depths of weathering of the volcanic rocks, and consequently foundation depths will be less than in the shale. Boulders of strong rock occur in soil near outcrops of volcanic rocks even where the latter are extensively weathered.

Residential development should generally avoid areas shown on the design constraints map (Pl. 5) as 'poor bearing strength; at times water-saturated', and as 'organic clays of very poor bearing strength that are frequently saturated'. The latter will not respond favourably to stabilization, but the former could be stabilized for residential construction by drainage followed by delay of construction to allow consolidation of alluvium to take place.

Seismic risk

Accurate seismic records are available for the last 12 years for the Canberra region and four earthquakes were recorded in the Gungahlin area during that period. Two of these had shallow foci (less than 2 km), and they could possibly be attributed to activities such as blasting. Foci of the other two earthquakes were intermediate (more than 9 km) and deep (more than 20 km); both were of low magnitude (about 2.5 on the Richter Scale), and could be associated with one of the faults in the area. Although many of the faults are partly filled with quartz, some may still be undergoing minor movements.

Small-scale tremors can be expected in the area, but most will be below human detection. The proximity of the area to the Gunning-Dalton area of relatively high seismic activity means that the possibility of a stronger earthquake cannot be excluded, but the chances of such an event occuring beneath the Gungahlin area are low. There are no large thicknesses of unconsolidated, uncemented deposits in Gungahlin that would be likely to exhibit excessive earthquake reaction.

Excavation difficulties

Medium strong to strong rocks occuring within 2 m of the surface include vein quartz, volcanic rocks, and chert, and these occur in small quantities over most of the area. The alignments of main roads shown on NCDC Structure Plan A1 avoid most large areas with potential excavation difficulties and only about 1 km of the parkway running north-south along the western limit of the area should intersect medium strong non-rippable rock near the surface. However, as this length of parkway is in a gentle depression, fill will probably be emplaced over the volcanics to achieve a gentle, uniform gradient, minimizing excavation.

The most common excavation problem will be associated with the moderately weathered shale that crops out extensively in the northern part of Gungahlin (Pl. 5). Much of this shale is close to the limit of rippability and blasting may be required for excavation for sewerage, water, and storm-water reticulation. Trial excavation in representative shale is recommended before development of the area is costed.

Slope stability

Natural slopes within the area are generally stable. Joints in all rocks may be unfavourably oriented to the direction of road alignment and should be closely investigated for all proposed cuts. The presence of shears that are unpredictable in both occurrence and orientation is also likely to cause some instability in cuts; however, stability problems will generally be similar to those encountered in Canberra.

If the depth of cut can be kept to a minimum, remedial work on slope stability problems will be cheaper and easier to carry out. Open trenches in water-saturated soil and highly weathered shale will be liable to collapse, and should be treated with caution.

Poorly drained areas

North Gungahlin (Area 1, Pl. 5): The continuous natural supply of surface water in this area during at least the past two years is partly due to the presence of a high potentiometric surface in the area and seepage from leaky aquifers and partly due to seepage of vadose water along depressions. Open drains along present watercourses are expected to adequately drain the area. Flows are expected to be low but heavy storms could result in flash-flooding of low-lying areas such as those underlain by peaty clays (Pl. 5). Soil cover is generally only a few centimetres thick and rarely more than 1 m. Excavations in this area should have little or no effect on the amount of groundwater that reaches the surface.

Eastern branch of Ginninderra Creek near Mulligans Flat: An arterial road is planned to pass through an area of poorly drained, dark grey organic clays near Mulligans Flat (Pl. 5). It is recommended that the organic clay be excavated and replaced along the alignment of the arterial road with a more suitable subgrade material with provision for adequate drainage.

Other poorly drained areas such as the catchment of 'Gungaderra Creek' and the northeastern part of the catchment of the eastern branch of Ginninderra Creek should improve with development provided that stormwater drains make provision for some inflow of groundwater, and that other service trenches are provided with a permeable path to the stormwater drainage trenches.

Natural resources

Brick Shale. The Gungahlin area contains the largest and most accessible brick shale reserves in the A.C.T.; the deposits are closer to planned urban development areas than are other shale deposits. The Gungahlin brick shale has been fired and found to produce satisfactory briquettes.

Topsoil. Two topsoil deposits have been delineated with total inferred reserves of 125 000 m^3. As topsoil is scarce in the Gungahlin area, it is recommended that this material be reserved for future general use.

Sandstone. Sandstone suitable for use as building stone is rare in the Canberra area. Because large quantities of stone are used for building retaining walls in Canberra, a quarry in the Black Mountain Sandstone near Ginninderra Creek might be considered. A tentative location of a quarry is shown on Plate 5; this site would require a detailed site investigation before quarrying of sandstone for a particular purpose is considered.

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UNIFIED SOIL CLASSIFICATION SYSTEM

CLASSIFICATION CHART

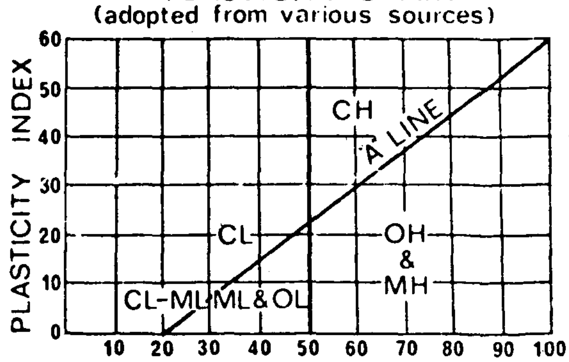
MAJOR DIVISIONS		SYMBOLS	TYPICAL NAMES
COARSE GRAINED SOILS (More than 1/2 of soil > No 200 sieve size)	GRAVELS (More than ½ of coarse fraction > no. 4 U.S. sieve size)	GW	Well graded gravels or gravel-sand mixtures, little or no fines*
		GP	Poorly graded gravels or gravel-sand mixtures, little or no fines
		GM	Silty gravels, gravel-sand-silt mixture
		GC	Clayey gravels, gravel-sand-clay mixture
	SANDS (More than ½ of coarse fraction > no.4 U.S. sieve size)	SW	Well graded sands or gravelly sands, little or no fines
		SP	Poorly graded sands or gravelly sands, little or no fines
		SM	Silty sands, sand silt-mixtures
		SC	Clayey sands, sand-clay mixtures
FINE GRAINED SOILS (More than 1/2 of soil < No. 200 sieve size)	SILTS AND CLAYS Liquid limit > 50	ML	Inorganic silt and very fine sands, rock flour, silty or clayey fine sands or clayey silts with low plasticity
		CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays
		OL	Organic silts and organic silty clays of low plasticty
	SILTS AND CLAYS Liquid limit > 50	MH	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts
		CH	Inorganic clays of high plasticity, fat clays
		OH	Organic clays of medium to high plasticity, organic silty clays, organic silts
HIGHLY ORGANIC SOILS		Pt	Peat and other highly organic soils

*fines – portion of a soil finer than a no. 200 sieve

GRAIN SIZE CHART

Classification	Range of grain size: U.S. Standard Sieve Size	Range of grain size: Grain Size in Millimetres
BOULDERS	Above 12"	Above 305
COBBLES	12" to 3"	305 to 76·2
GRAVEL	3" to No. 4	76·2 to 4·76
coarse	3" to 3/4"	76·2 to 19·1
fine	3/4" to No. 4	19·1 to 4·76
SAND	No. 4 to No. 200	4·76 to 0·074
coarse	No 4 to No 10	4·76 to 2·00
medium	No. 10 to No. 40	2·00 to 0·420
fine	No. 40 to No. 200	0·420 to 0·074
SILT & CLAY	Below No. 200	Below 0·074

PLASTICITY CHART
(adopted from various sources)



APPENDIX 2

Explanation of Terms

AGGLOMERATE: pyroclastic volcanic rock comprising clasts (blocks) coarser than 32 mm in diameter.

ALLUVIUM: sediment deposited by running water.

BIOTITE: dark green or black, platy and easily cleaved mineral that is a silicate of magnesium iron, aluminium, and potassium with hydroxyl and fluorine. Original constitutent of volcanic and plutonic, acid to basic rocks.

CEMENTED: naturally bonded by chemical precipitate or by clay.

GLEYED PODZOLIC SOILS: These are poorly drained acid soils with strongly differentiated profiles consisting of brownish grey sandy to loamy A horizons with a distinct paler A_2, overlying grey and yellow-grey clay B horizons with coarse ochreous and some reddish mottles. Varying gley features may occur in any part of the profile, but rusty and ochreous root tracings and spotting are usually concentrated in the A horizons. The poor drainage is due either to perching of water, and seepage on the clay subsoil, or deeper-seated seepage intermittently affecting most of the profile. The B horizon is dominantly some shade of grey sandy clay to clay, coarsely mottled with bright yellow-brown or brownish yellow and with a few reddish spots. Consistence is plastic to sticky when wet and hard when dry.

GREY BILLY: silicified quartz sand and conglomerate formed beneath pre-existing lava flows by siliceous thermal waters.

HILLWASH: a loose or cemented, porous, natural aggregate of rock fragments of silt to gravel grainsize that accumulates downslope of steep hillslopes by surficial mass movement.

HUMIC GLEY: acid to neutral, predominantly mineral soils with significant but widely varying amounts of organic matter incorporated in the dark A horizons. These grade into subsoils marked by rusty and ochreous streaks and mottles on a blue-grey matrix. Below this mottled horizon the soil is typically grey to bluish grey and permanently waterlogged. Occasionally the soils are flooded for short periods.

ILLUVIATION: Deposition of clay minerals generally in the B horizon from perculating soil water and groundwater.

INFERRED RESERVES: are those for which quantitative estimates are based largely on broad knowledge of the geologic character of the deposit and for which there are few, if any, samples or measurements. The estimates are based on an assumed continuity or repetition, of which there is geologic evidence.

JOINT: Naturally occurring planar or curviplanar facture in rock that is not parallel to a rock fabric.

LITHOSOL: lithosols are essentially stony or gravelly soils lacking profile development other than an A_1 (topsoil) owing to organic matter accumulations and structure development in the surface. Normally they are shallow sand, silt, and clayey silt and usually contain a large proportion of coarse-textured material in the form of fragmented rock, which may show some degree of weathering. Stoniness and lack of pedological differentiation are the essential features.

MEDIUM STRONG: rock strength term applying to rocks with an unconfined compressive strength in the range 200-700 kg/cm^2. The rock rings and breaks to a firm hammer blow.

MODERATELY WEATHERED ROCK: change in appearance but with significant loss in strength from fresh rock.

NON-PLASTIC GRAVEL: The word 'gravel' in this term is used in an engineering rather than a geological sense. It is defined as an unconsolidated, well graded mixture of gravel-sized rock fragments and/or mineral grains such as quartz and feldspars, together with sand and silt, in a feebly plastic soil binder. Gravel derives its strength from mechanical interlock owing to high internal friction of its subangular components and specifications have been designed by the Commonwealth Department of Works for quality control. These specifications are based on the assumption that the performance of 'gravel' is influenced by two characteristics, particle size and plasticity. Non-plastic gravel is used as a surface course underneath a seal and its plasticity index must not exceed 6 and its maximum particle size should not exceed 3.8 cm.

PEDOLOGICAL: the scientific description of soils.

PLASTIC GRAVEL: 'Plastic gravel' is 'gravel' (see under 'non-plastic gravel') that is used for surfacing unsealed roads and for shoulders on sealed roads. Its plasticity index should not exceed 8 and its maximum particle size should not exceed 3.8 cm in diameter. In general, the 'plastic' variety should have a higher percentage of fine-grained rock and soil material than the 'non-plastic' type because vehicle-traffic tends to remove a considerable portion of the finer-grained material.

PODZOLIC SOIL: one which has a strongly differentiated profile with contrasting A and B horizons; light grey-brown sandy silt changes abruptly to red-brown, yellow brown, or mottled, fine sandy clay to heavy clay.

POTENTIOMETRIC SURFACE: Surface passing through levels to which groundwater will rise in piezometers installed to below aquifer.

RED EARTH: soil that shows gradual vertical differentiation from greyish brown sandy silt to reddish brown fine sandy silt or light clay.

<u>SEMICONFINED AQUIFER</u>: is one that is confined by beds that do not form a perfect seal, thus permitting leakage into or out of the aquifer, depending on the head relative to the head in overlying and underlying beds.

<u>SHALE</u>: a compacted clay or mud; feels smooth to the touch; stratified and finely laminated; grainsize less than 0.002 mm. Used for tile and brick manufacture.

<u>SLATE</u>: shale metamorphosed slightly by stress and moderate temperature; tough and capable of being split into thin cohesive plates parallel to the clevage.

<u>STRONG</u>: a rock strength term applying to rocks with an unconfined compressive strength 1800 kg/cm^2. The rock is very difficult to break with a hammer and generally requires use of a sledge-hammer.

<u>TENSION GASH</u>: minor fractures developed in rocks abutting a fault plane and caused by differential tension in the strata.

<u>TUFF</u>: pyroclastic rock comprising clasts of grainsize less than 32 mm.

<u>VALLEY-PEDIPLAIN</u>: collective term referring to the sloping, rock-floored plains on either side of a river that are exposed by hillwash.

<u>YELLOW EARTH</u>: these soils are very similar to the red earths, but are predominantly yellow in colour and sometimes have a more pronounced increasing texture gradient down the profile. They are essentially massive, moderately to highly porous, earthy soils with weak profile definition, gradual horizon boundaries, acid reaction, and yellow to yellow-brown colour. Typically they are deep and increase in clay content with depth.

APPENDIX 3

LOGS OF BMR BORES DRILLED IN 1973

Gu1 (Canberra 85) - Cased from 75 cm above groundlevel to 6.0 m.

Depth in metres	Lithology of cuttings
0 - 43	moderately weathered, red and yellow shale;
43 - 46	30 cm of core of buff shale recovered.

Gu2 (Canberra 86) - Cased from 75 cm above groundlevel to 11.9 m.

Depth in metres		Lithology of cuttings
0 - 1.5	calcareous	brown-grey silt
1.5 - 3.0	calcareous	mottled yellow and grey clay
3.0 - 4.5	calcareous	grey and white clay
4.5 - 6.0	calcareous	sandy slopewash with shale and volcanic rock fragments
6.0 - 7.6	calcareous	buff shale
7.6 - 9.1	calcareous	manganiferous shale
9.1 - 12.2	calcareous	soft, buff shale
12.2 - 16.7	calcareous	soft, buff plastic shale
16.7 - 30.5	non-calcareous	soft, dark red-brown plastic clay and shale
30.5 - 36.6	non-calcareous	completely weathered acid volcanics with quartz crystals to 1.5 mm
36.6 - 39.6	non-calcareous	brown plastic clay
39.6 - 48.8	non-calcareous	buff shale with red liesegang rings

Gu3 (Canberra 87) - Cased from 33 cm above groundlevel to 17.9 m.

Depth in metres	Lithology of cuttings
0 - 1.5	mottled red and yellow clay
1.5 - 7.6	strong, buff shale
7.6 - 15.2	completely weathered fine-grained volcanics (red and grey clay with white flecks)
15.2 - 18.3	soft, grey, clayey shale
18.3 - 19.8	buff shale and some milky quartz
19.8 - 22.9	grey and buff shale
22.9 - 25.9	grey shale and yellow clay
25.9 - 39.6	strong, pale to medium grey shale
39.6 - 44.2	strong, blue-grey slate with some vein quartz
44.2 - 45.7	strong, blue-grey slate with finely disseminated pyrite.

Gu4 (Canberra 88) - Cased from 23 cm above groundlevel to 17.2 m.

Depth in metres	Lithology of cuttings
0 - 7.6	strong, grey-brown shale
7.6 - 9.1	soft, buff shale
9.1 - 13.7	moderately strong buff shale
13.7 - 16.7	softer buff shale
16.7 - 18.3	moderately strong buff shale
18.3 - 42.7	strong grey, slightly graphitic, phyllitic slate with finely disseminated pyrite
42.7 - 45.7	recovered 60 cm of core of strong grey phyllitic slate with pyrite

Gu5 (Canberra 89) - Cased from groundlevel to 23.3 m

Depth in metres	Lithology of cuttings
0 - 6.0	moderately weathered, altered, fine-grained acid volcanics
6.0 - 18.3	soft, highly weathered, buff shale or acid volcanics; some vein quartz at 18 m
18.3 - 23.2	soft buff shale
23.2 - 24.7	vein quartz
24.7 - 44.2	blue-grey, moderately weathered ? ashstone; breaks in many directions along curved fractures; no cleavage evident. Contains pyrite at 41 to 43 m.
44.2 - 57.9	greyish dark-green ? ashstone containing pyrite; some milky quartz
57.9 - 60.0	45 cm of core of greyish green, very hard flinty, finely jointed ashstone containing pyrite

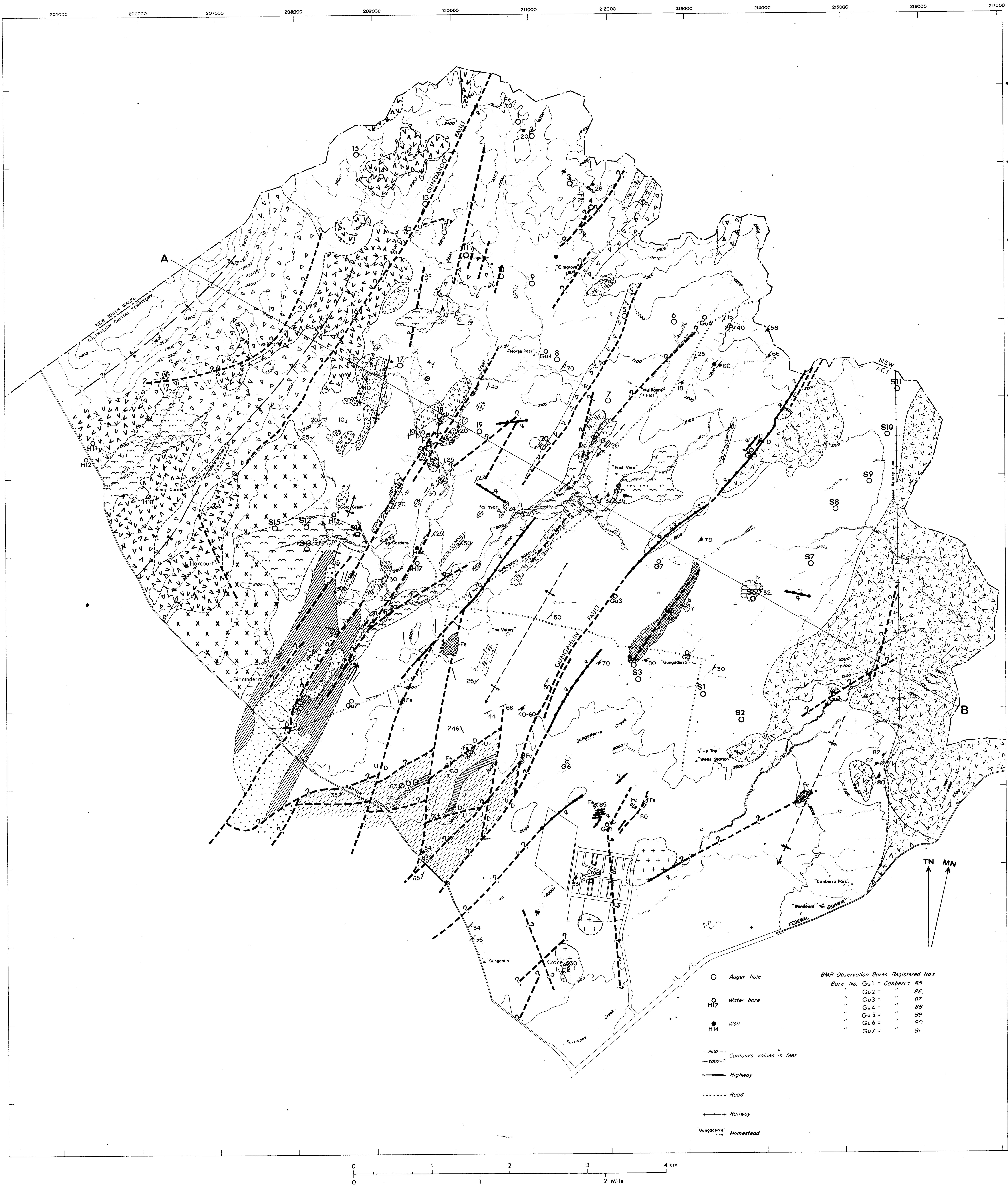
Gu6 (Canberra 90) - Cased from 71 cm above groundlevel to 18.3 m.

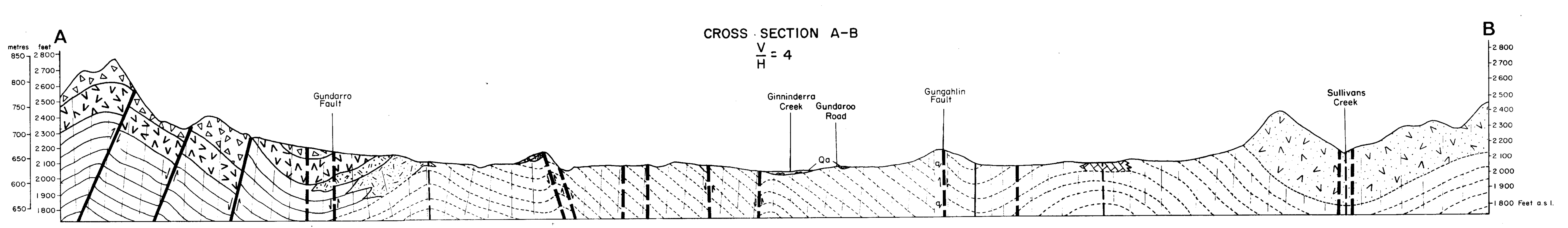
Depth in metres	Lithology of cuttings
0 - 4.6	mottled grey and yellow heavy clay (CH)
4.6 - 10.7	greyish buff soft shale
10.7 - 21.3	moderately strong greyish buff shale
21.3 - 27.4	strong brownish grey shale
27.4 - 59.4	medium grey, strong slate; some vein quartz
59.4 - 61.0	30 cm of strong, medium to dark grey slate.

Gu7 (Canberra 91) - Cased from 76 cm above groundlevel to 12.2 m.

Depth in metres	Lithology of cuttings
0 - 1.5	pinkish brown silty topsoil
1.5 - 4.6	highly to completely weathered pinkish red shaley tuff
4.6 - 10.7	highly weathered buff and red shaley tuff
10.7 - 21.3	predominantly pink to grey-brown; some red and yellow, highly to moderately weathered fine-grained shaley tuff
21.3 - 24.4	moderately highly weathered grey-green ? ashstone
24.4 - 25.9	slightly to moderately weathered, grey green ashstone
25.9 - 57.9	strong, pale green and grey-green, finely laminated, pyritic ashstone which is finely jointed
57.9 - 61.0	recovered 15 cm of core of above

GEOLOGICAL MAP OF GUNGAHLIN





QUATERNARY
- Alluvium

POST-SILURIAN
- Limonite gossan
- Vein quartz

MIDDLE TO UPPER SILURIAN
- Quartz porphyry
- Pyroclastics
- Purple and green dacitic welded breccia
- Greenish grey rhyodacitic flow
- Grey-green ash-flow tuff
- Welded rhyolitic tuff
- Chert or devitrified ashstone
- Predominantly shale with slate, siltstone, mudstone, and limestone lenses
- Dacitic tuff; lithic tuff, biotite, plagioclase, quartz porphyry; greenish grey tuff; grey-green quartz porphyry

LOWER SILURIAN
- Sandstone
- State Circle Shale: Shale, mudstone

MIDDLE TO UPPER ORDOVICIAN
- Acton Shale Member: Siliceous shale
- Pittman Formation: Sandstone, siltstone, shale, mudstone, chert

Palmer — Trigonometrical station

- Geological boundary, position approximate
- Geological boundary, position inferred or concealed
- Fault, (U, D indicate relative vertical displacements)
- Fault, position approximate
- Fault, position inferred or concealed

- 30 Strike and dip of bedding
- 80 Strike and dip of joint
- Anticline, showing direction of plunge
- Syncline, showing direction of plunge

PLATE 1

AMENDMENTS					
No.	DESCRIPTION	AUTHOR	DATE	CHECKED	DATE
A1					
A2					
A3					
A4					
A5					
A6					

SCALE 0 250 500 750 1000 1250 m

BASE MAP/SURVEY: T.P./197/72

GEOLOGY BY: P.D. HOHNEN AND J. CEPLECHA

COMPILED AND CHECKED: PROJECT GEOLOGIST — CHECKED AND APPROVED: SENIOR GEOLOGIST

SUPERVISING GEOLOGIST

COMMONWEALTH OF AUSTRALIA
BUREAU OF MINERAL RESOURCES
CANBERRA, A.C.T.

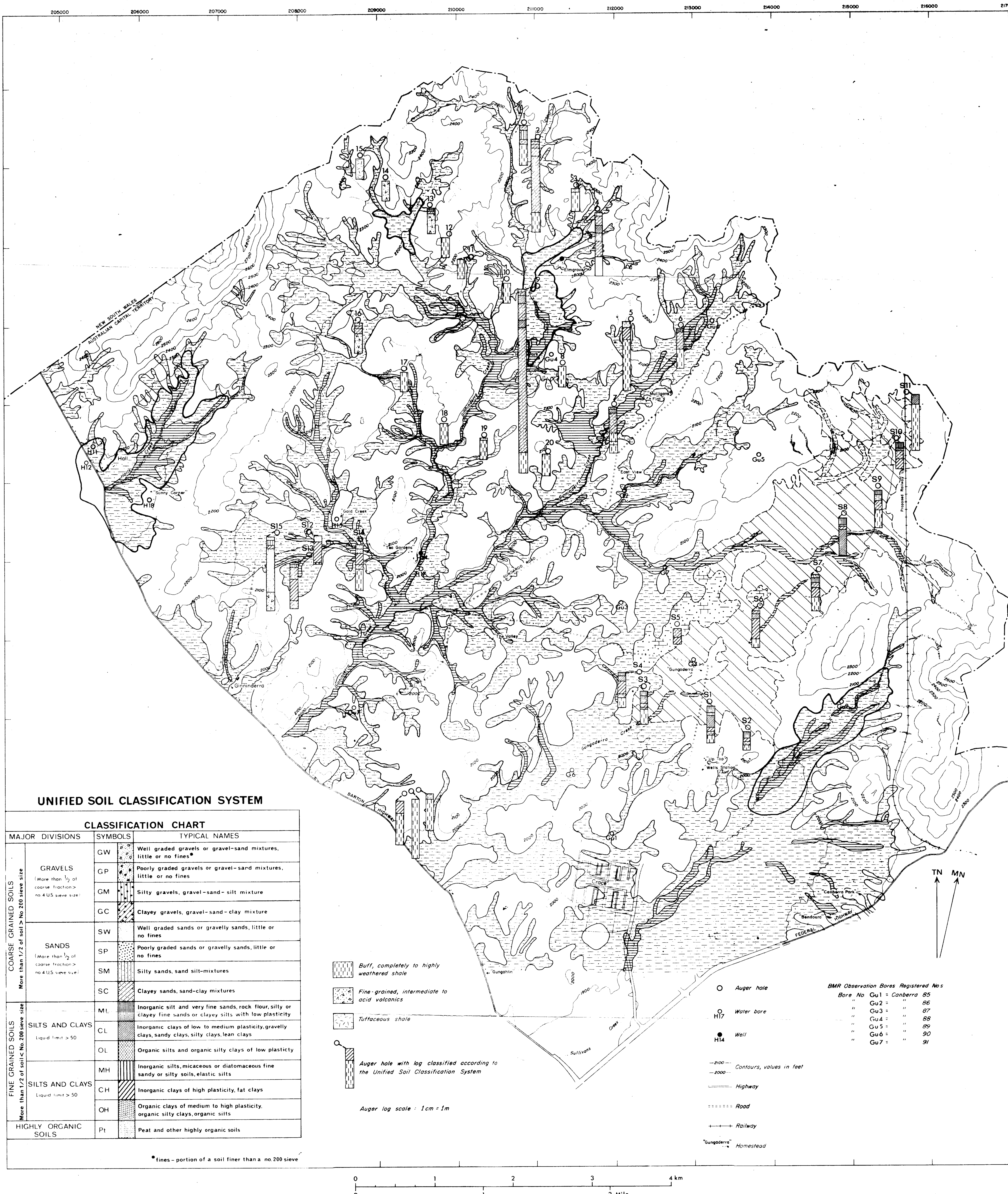
TITLE: GEOLOGICAL MAP OF GUNGAHLIN

PROJECT: GUNGAHLIN ADVANCED FEASIBILITY STUDY

TO ACCOMPANY RECORD: 1974/186 — DRAWN BY: G.A. YOUNG — DRAWING NUMBER: 155/A16/1247

SUPERFICIAL DEPOSITS MAP, GUNGAHLIN

(MAP COMPILED FROM AIR-PHOTO INTERPRETATION AND LIMITED FIELD WORK)



UNIFIED SOIL CLASSIFICATION SYSTEM

CLASSIFICATION CHART

MAJOR DIVISIONS		SYMBOLS	TYPICAL NAMES
COARSE GRAINED SOILS (More than 1/2 of soil > No 200 sieve size)	GRAVELS (More than 1/2 of coarse fraction > no. 4 U.S. sieve size)	GW	Well graded gravels or gravel-sand mixtures, little or no fines*
		GP	Poorly graded gravels or gravel-sand mixtures, little or no fines
		GM	Silty gravels, gravel-sand-silt mixture
		GC	Clayey gravels, gravel-sand-clay mixture
	SANDS (More than 1/2 of coarse fraction > no 4 U.S. sieve size)	SW	Well graded sands or gravelly sands, little or no fines
		SP	Poorly graded sands or gravelly sands, little or no fines
		SM	Silty sands, sand silt-mixtures
		SC	Clayey sands, sand-clay mixtures
FINE GRAINED SOILS (More than 1/2 of soil < No. 200 sieve size)	SILTS AND CLAYS Liquid limit > 50	ML	Inorganic silt and very fine sands, rock flour, silty or clayey fine sands or clayey silts with low plasticity
		CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays
		OL	Organic silts and organic silty clays of low plasticty
	SILTS AND CLAYS Liquid limit > 50	MH	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts
		CH	Inorganic clays of high plasticity, fat clays
		OH	Organic clays of medium to high plasticity, organic silty clays, organic silts
HIGHLY ORGANIC SOILS		Pt	Peat and other highly organic soils

*fines - portion of a soil finer than a no. 200 sieve

Shallow soils up to 1 metre thick
Lithosols
Truncated podzolics
Colluvium

Thicker residual and colluvial soils
Podzolics
Red earths 1 to 3 metres thick
Colluvium

Stratified alluvium and gumbotils 1 to 3 metres thick

Clays containing limestone (Terra Rossa) and limonite boulders

Solodic soils containing quartz veins, boulders, shale bands, colluvial stringers and greybilly lateritic soil remnants.

Deposit of alluvium and slopewash 3 to 10m thick

Soil boundary

Soil boundary, position approximate

PLATE 2

SCALE 0 250 500 750 1000 1250 m	COMMONWEALTH OF AUSTRALIA **BUREAU OF MINERAL RESOURCES** CANBERRA, A.C.T.
BASE MAP/SURVEY T.P. 197/72	TITLE SUPERFICIAL DEPOSITS MAP, GUNGAHLIN
SOILS BY J. R. KELLETT & G. W. BARNES	
COMPILED AND CHECKED: PROJECT GEOLOGIST / CHECKED AND APPROVED: SENIOR GEOLOGIST	PROJECT GUNGAHLIN ADVANCED FEASIBILITY STUDY
SUPERVISING GEOLOGIST	TO ACCOMPANY RECORD 1974/186 / DRAWN BY G. A. YOUNG / DRAWING NUMBER 155/A16/1250

GUNGAHLIN URBAN DEVELOPMENT AREA
HYDROLOGY AND DRAINAGE

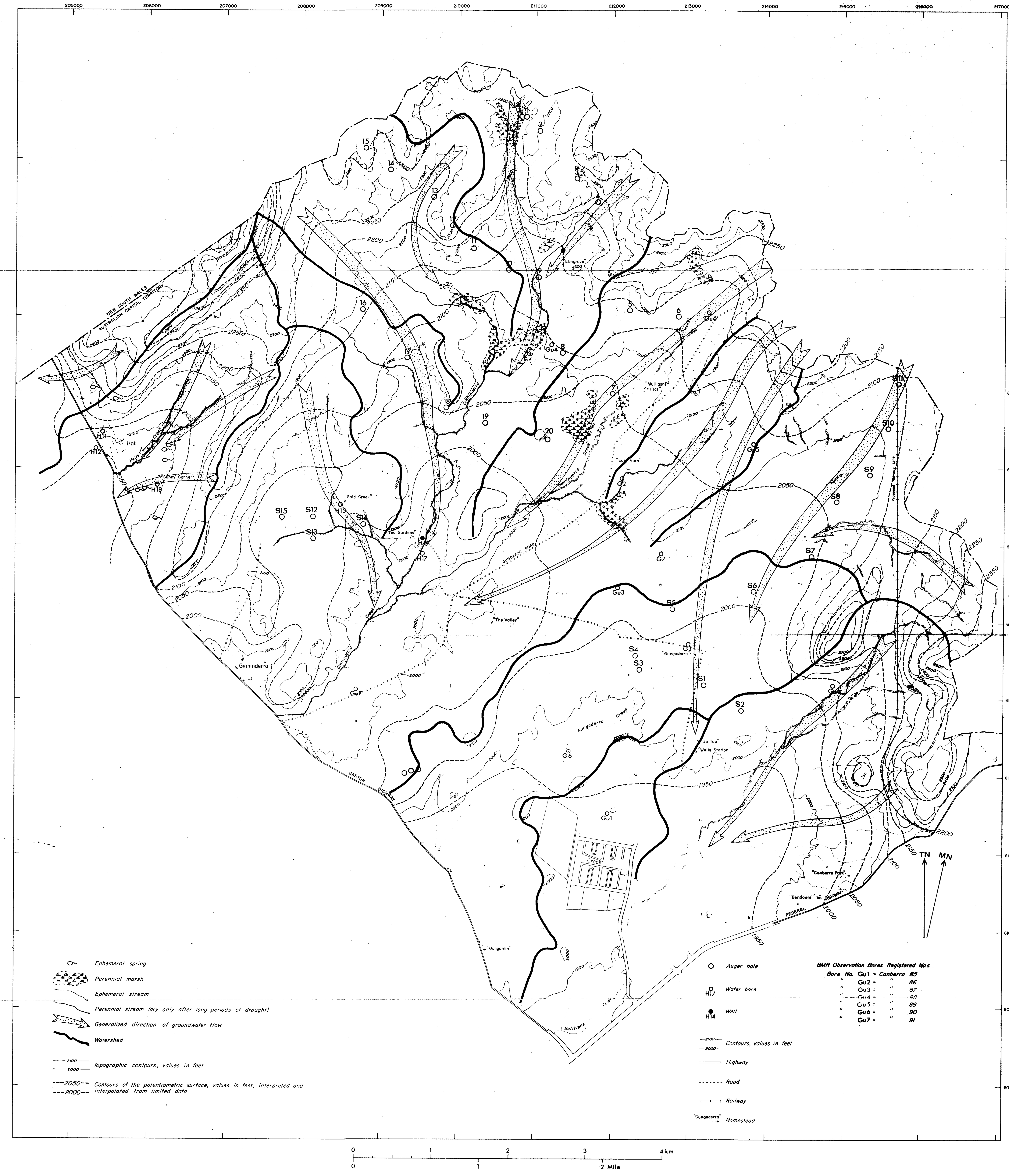
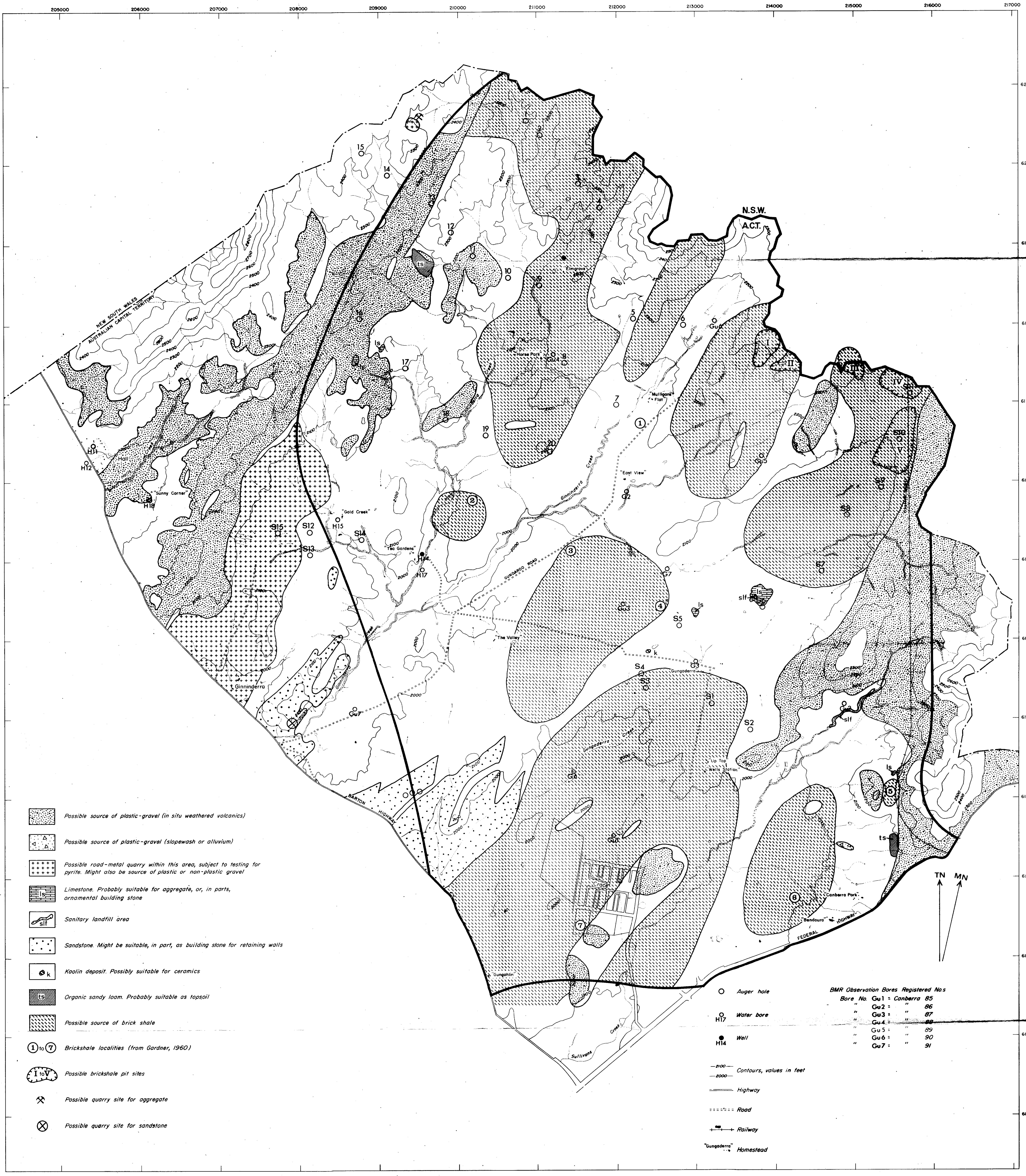


PLATE 3

AMENDMENTS						SCALE 0 250 500 750 1000 1250m	COMMONWEALTH OF AUSTRALIA **BUREAU OF MINERAL RESOURCES** CANBERRA, A.C.T.		
No.	DESCRIPTION	AUTHOR	DATE	CHECKED	DATE	BASE MAP/SURVEY: ACT Planning Series			
A1						GEOLOGY BY: P. D. HOHNEN	TITLE: HYDROLOGY AND DRAINAGE		
A2						COMPILED AND CHECKED: PROJECT GEOLOGIST	CHECKED AND APPROVED: SENIOR GEOLOGIST		
A3							PROJECT: GUNGAHLIN ADVANCED FEASIBILITY STUDY		
A4									
A5						SUPERVISING GEOLOGIST	TO ACCOMPANY RECORD: 1974/186	DRAWN BY: G.A.YOUNG	DRAWING NUMBER: I55/A16/1251
A6									

GUNGAHLIN URBAN DEVELOPMENT AREA

NATURAL RESOURCES MAP



0 1 2 3 4 km
0 1 2 Mile

LOCALITY MAP

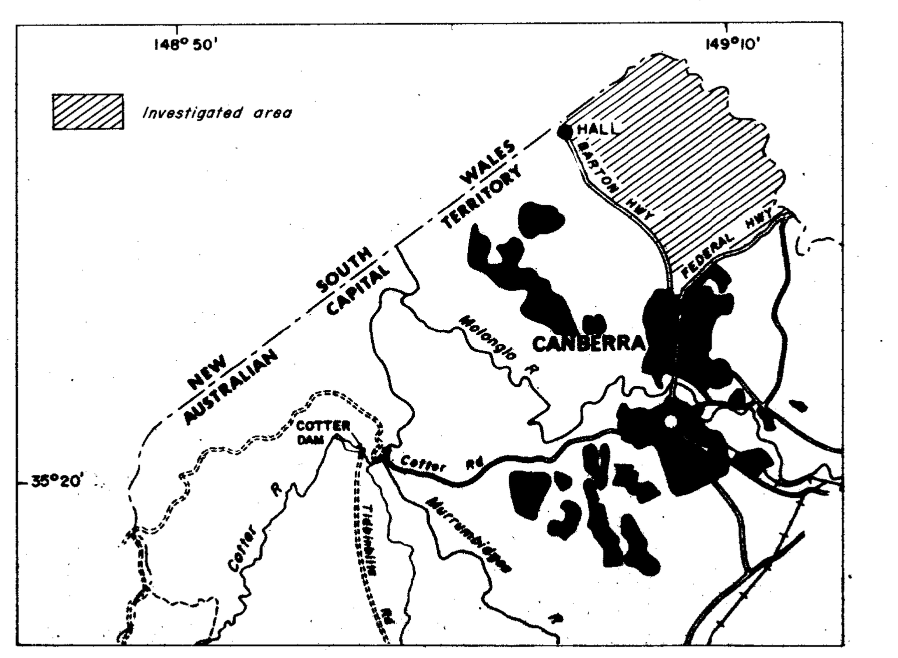


PLATE 4

AMENDMENTS					
No.	DESCRIPTION	AUTHOR	DATE	CHECKED	DATE
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A2					
A3					
A4					
A5					
A6					

SCALE 0 250 500 750 1000 1250m

BASE MAP/SURVEY: T.P./197/72

GEOLOGY BY: P. D. HOHNEN

COMPILED AND CHECKED: PROJECT GEOLOGIST

CHECKED AND APPROVED: SENIOR GEOLOGIST

SUPERVISING GEOLOGIST

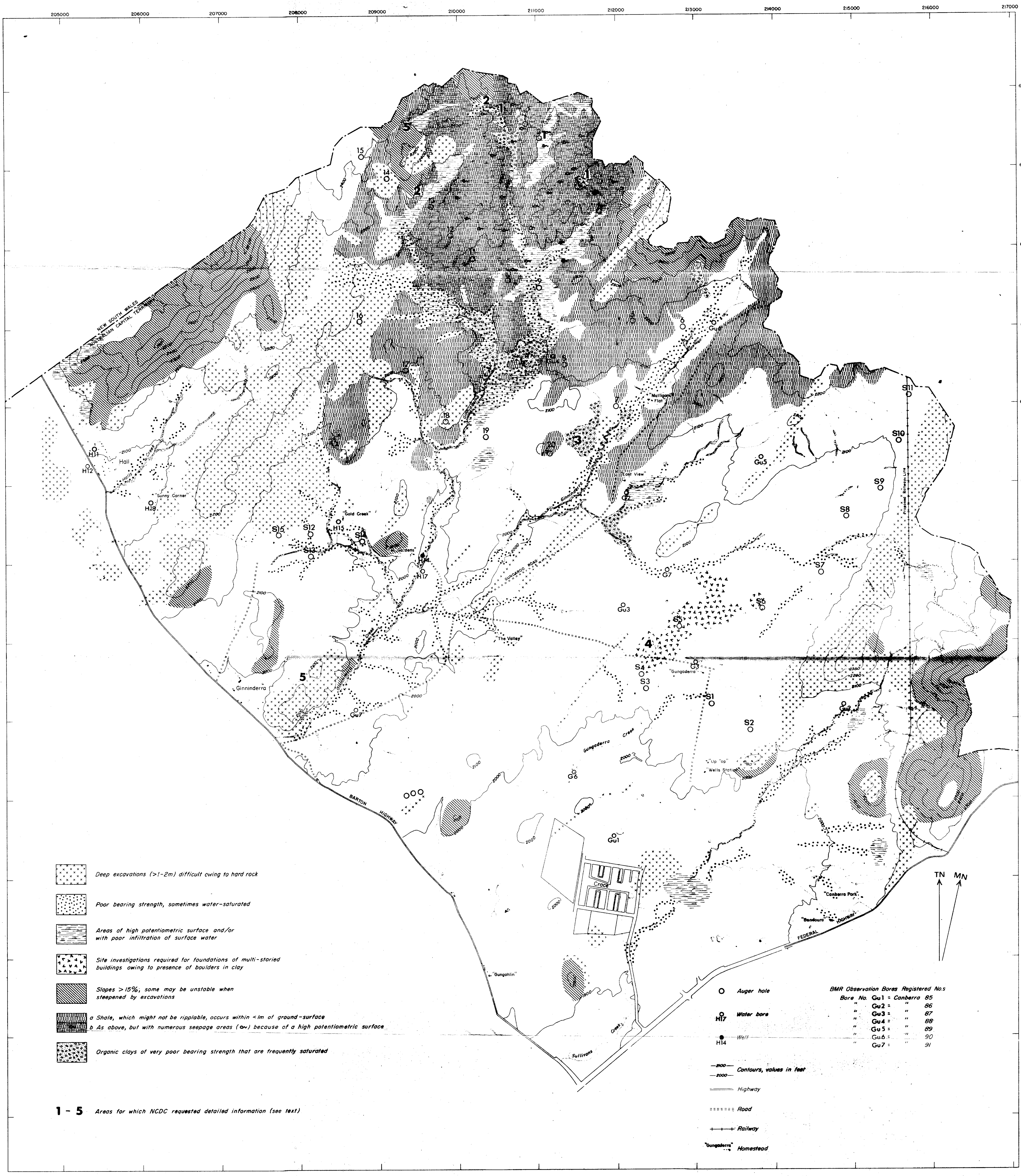
COMMONWEALTH OF AUSTRALIA
BUREAU OF MINERAL RESOURCES
CANBERRA, A.C.T.

TITLE: NATURAL RESOURCES MAP, GUNGAHLIN

PROJECT: GUNGAHLIN ADVANCED FEASIBILITY STUDY

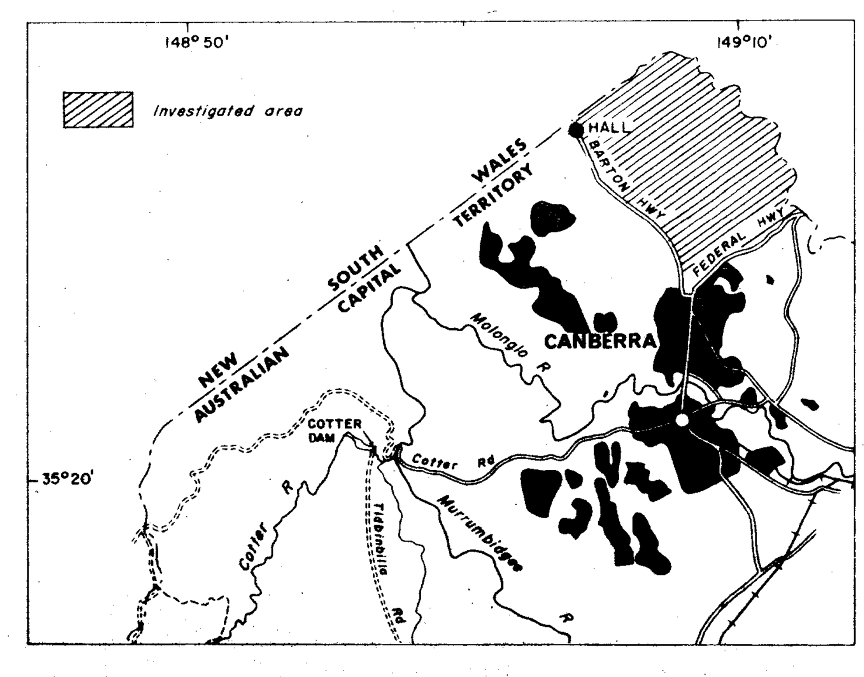
TO ACCOMPANY RECORD	DRAWN BY	DRAWING NUMBER
1974/186	G. A. YOUNG	155/A16/1248

GUNGAHLIN URBAN DEVELOPMENT AREA
DESIGN CONSTRAINTS MAP



0 1 2 3 4 km
0 1 2 Mile

LOCALITY MAP



AMENDMENTS					
No.	DESCRIPTION	AUTHOR	DATE	CHECKED	DATE
A1					
A2					
A3					
A4					
A5					
A6					

SCALE 0 250 500 750 1000 1250m

BASE MAP/SURVEY: T.P./197/72

GEOLOGY BY: P. D. HOHNEN

COMPILED AND CHECKED	CHECKED AND APPROVED
PROJECT GEOLOGIST	SENIOR GEOLOGIST

SUPERVISING GEOLOGIST

PLATE 5

COMMONWEALTH OF AUSTRALIA
BUREAU OF MINERAL RESOURCES
CANBERRA, A.C.T.

TITLE: DESIGN CONSTRAINTS MAP, GUNGAHLIN

PROJECT: GUNGAHLIN ADVANCED FEASIBILITY STUDY

TO ACCOMPANY RECORD	DRAWN BY	DRAWING NUMBER
1974/186	G. A. YOUNG	155/A16/1249