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BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

BMR Record 1979/84

OBSERVATIONS ON GEOLOGY, SOILS, AND GROUNDWATER RELEVANT TO PAVEMENT FAILURE IN CANBERRA, 1979

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ABSTRACT

The Bureau of Mineral Resources was requested to provide information concerning geology, soils and groundwater relevant to the investigation of road pavement failures in Canberra.

The gently sloping plain on which Canberra is built lies below the change of slope at the foot of the surrounding hills and ridges. The plain consists of a veneer of colluvium and alluvium, ranging in thickness to 30 m, that partly conceals the weathered profile of the underlying volcanics and sediments.

The low permeability of the superficial sediments and of the extremely weathered parts of rock formations has tended to confine groundwater in the underlying fractured rock. The potentiometric surface of this aquifer is at or near the surface in some areas. Saturated dark grey clay is associated with a high potentiometric surface in the underlying fractured-rock aquifer where the potentiometric surface ranges from above ground to less than 1 m below ground. Through much of the Canberra area the potentiometric surface is less than 6 m from the surface; it fluctuates during the year, generally being highest in October and lowest in April, and fluctuations range from less than 1 m in the lower central part of the valley to about 5 m near the change of slope.

Failure of the pavement subgrade is likely to occur if the moisture content of the subgrade is high enough to reduce its bearing capacity by the point that traffic causes deformation of the subgrade. The moisture content will be high wherever the potentiometric surface is at a level that will allow the rise of water by capillary movement to the subgrade. This condition is common because low-permeability clays are widespread and the potentiometric surface is at depths of less than 6 m over much of the area. A high moisture content may also be attained by inflow of water through shrinkage cracks, and this state is expected to persist for a number of days until the moisture is lost by evapotranspiration. As evapotranspiration is low in winter, a high moisture condition is maintained longer in winter than at other times of the year.

Reduction of the moisture content of low-permeability clays cannot be achieved readily by installing sand and rubble drains; in areas where the moisture content is maintained by a high potentiometric surface, such drains are useless.

Subgrades of clay commonly have a high moisture content in the Canberra area, particularly in the winter months. Pavements in Canberra should be designed in expectation of a low bearing strength for the subgrade; other measures should also be taken to exclude water from the subgrade throughout the life of the pavement.

INTRODUCTION

In conjunction with the Australian Road Research Board (ARRB), the Department of Housing and Construction (DHC) is undertaking an investigation into the durability of pavements of existing roads in Canberra. DHC asked BMR to provide them with information concerning the depth to the water-table at a number of pavement test siges and to nominate those parts of Canberra where the potentiometric surface was considered to be within 6 m of the surface.

The pavement test sites nominated by DHC (Plate 1) were visited and a table was prepared setting out information concerning geology, soils, groundwater conditions, and possible contributory factors to road subgrade failure at each site (Appendix 1).

It was found that failures were not all associated with a potentiometric surface at a depth of less than 1 m, nor in some cases with a potentiometric surface within 6 m of the surface. Low-permeability clay soils with large shrinkage cracks are common to many sites and the cracks appear to have been enlarged by the infiltration of rainwater; this enlargement may be due to the removal of dispersive clay minerals in a manner similar to that which causes piping in earth dams.

This report discusses the geomorphology and geology of Canberra, the distribution of superficial sediments, and the soils that are associated with them. It also provides a guide to the depth of the potentiometric surface in Canberra and its seasonal fluctuations, and examines the various situations that could produce a high moisture content in road subgrades in Canberra.

GEOMORPHOLOGY AND SUPERFICIAL SEDIMENTS

Canberra is built on a mature land surface of gentle dissection with a number of residual hills such as Mount Ainslie and Black Mountain. It lies within a broad north-trending valley bounded by a range of hills to the east of Queanbeyan and another to the west of the Murrumbidgee River. The valley has been described as a rift valley with the hills to the east and west formed of uplifted fault blocks.

Superficial sediments are widely distributed below the change of slope, which is at an elevation of about 670 m around the major hills, and the built-up area of Canberra is below the change of slope (Plate 1).

The land surface within the valley has been modified over a long period of time, probably as long as 20 million years; colluvial deposits were formed at the foot of the hills and soil profiles were developed on the colluvium. Dissection of the earlier colluvium was accompanied by deposition of other colluvial deposits farther downslope, and soil profiles were also developed on these later colluvial deposits. Kellett (in prep.) has mapped three colluvial units and their associated soils in the Lanyon area; the ages of the colluvium are considered to range from Late Tertiary to Recent times. Each colluvial deposit is associated with either a change in local base level of erosion brought about by faulting, or a change in the intensity of erosion resulting from a change in climate. Minor ground surface modifications of the older geomorphic surfaces followed, probably during the Quaternary (1.8 million years); gullying took place in the colluvium and a number of narrow alluvial terraces and their associated soils were formed farther downstream.

Although Canberra lies below the change in slope, it is not built solely on superficial sediments. The dissection of superficial sediments that took place at various times in the past has in some areas, such as Campbell, stripped away most of the superficial sediments to expose weathered rock of the underlying rock formations; at Campbell the rocks are volcanic.

SUPERFICIAL SEDIMENTS IN THE LANYON AREA

Table 1, taken from Kellett (in prep.), shows the association between geomorphic surfaces and soils at Lanyon, 22 km from the centre of Canberra, and gives the elevations of these surfaces.

Murrumbidgee Fanglomerate consists of a basal facies of lithic cobbles and gravels grading upward into massive indurated sand-silt size material. The basal facies is widespread, but the overlying finer-grained material generally thins rapidly downslope. A very old red and grey clay is associated with this fine-grained material, and is probably the B horizon of a once extensive soil profile.

TABLE 1

GEOMORPHIC SURFACE AND SOIL ASSOCIATION, LANYON
(Kellett, in prep.)

Geomorphic surface	Elevation (m) North basin	South basin	Soil association	Pedogenesis and diagenesis
Younger Basin Surface	570-610	580-600	Lanyon Clay Open gravel	Pedogenesis under hydromorphic conditions; or humid with high degree of leaching. No secondary pore filling in gravel
Older Basin Surface	610-625	600-610	Tuggeranong Clay	Pedogenesis under arid to semi-arid conditions. Major aeolian deposition
			Tuggeranong Fanglomerate	High degree of secondary pore filling in fanglomerate
Pediment	565-625	575-610	Murrumbidgee Fanglomerate	Alluvial fan deposits under semi-arid conditions. Minor aeolian deposition. High degree of secondary pore filling
Bajada	625-670	610-660		

Older basin sediments consist of scour and fill deposits of gravel overlain by a widespread blanket of up to 3 m of dense, highly plastic, uniform clay, referred to as Tuggeranong Clay, which was formed by prolonged pedogenesis under arid conditions of an aeolian parent material.

Tuggeranong Clay is a red-yellow clay with grey argillans and shiny ped fabric; calcareous concretions are in places present in the lower part of the profile.

Younger basin sediments consist of a basal facies of coarse gravel with a shoestring distribution grading upwards into sheets of sand-silt size material, the latter having undergone pedogenesis to form Lanyon Clay, about 1 m thick.

Lanyon Clay on well-drained slopes is generally a red earth with a thin leached silty A horizon: the red earth grades down to a strongly pisolitic horizon of sesquioxide nodules (ferruginous gravel) overlying yellow and grey clay of the lower B horizon. In depressions, the hydromorphic variant of the soil shows grey blocky peds with organic argillans grading into a yellow and grey coarse prismatic sandy fabric over yellow and grey clay. Illite and some montmorillonite are present in the hydromorphic variant of the clay.

CORRELATION OF SUPERFICIAL SEDIMENTS IN CANBERRA WITH THOSE OF LANYON

Sediments and soils in the urban area of Canberra may be correlated with those described by Kellett at Lanyon; however, a positive correlation should only be made on the basis of pedological and sedimentary characteristics, and should not be inferred solely by comparison of levels of the land surfaces.

Fanglomerates that may be correlated with the Murrumbidgee Fanglomerate are widespread below the change of slope around the hills of Canberra: a fanglomerate surrounds Mount Taylor; another is up to 10 m thick on the western slope of Mount Jerrabomberra; and other fanglomerates are present below the Red Hill-Mount Mugga Mugga ridge, and below the eastern slopes of Black Mountain and Mount Ainslie. At most of these locations there are also remnants of a highly organised heavy clay soil that formed within the original material; remnants of this clay remain in Pearce, Torrens, and Garran.

Fanglomerates that could be correlated with the Tuggeranong Fanglomerate are not extensive, and formed as infills of erosion gullies in the Murrumbidgee Fanglomerate. A dense highly plastic uniform clay is associated with a dissected pediment at about 580-600 m; this clay is probably the remnants of a soil profile developed on a blanket of aeolian sediments, and is considered to be the equivalent of the Tuggeranong Clay.

Clay that occupies a lower pediment throughout the Canberra valley, generally below 580 m, is regarded as being an equivalent of the Lanyon Clay; however the soil formation processes that produced the Lanyon Clay on the fine sediments also affected pre-existing soil profiles on the adjacent slopes, such as the Tuggeranong Clay, and a superimposed profile of soil with characteristics of the Lanyon Clay overlies that porion of the older Tuggeranong Clay that still remains.

A number of alluvial soils and their terraces are present in the lower parts of the stream valleys, but they are not widespread. They are silty and sandy clays, some of them grey, and are confined to the immediate alluvial deposit. They may have some problems of localised zones of saturation.

GEOLOGY

The rocks underlying the valley include mudstone, siltstone, and sandstone, in part calcareous and tuffaceous, and some limestone. Volcanic rocks are also present higher in the stratigraphic sequence; they comprise fine to coarse-grained tuffaceous rocks, often referred to as porphyries, and are associated with some flows. The composition of the volcanic rocks ranges from andesite to rhyolite, the most common types being dacite and rhyodacite.

The rocks have been folded and faulted to give a structure that is complex; three to four sets of joints are present and they are closely spaced in the vicinity of faults. Rocks in the hills display numerous open joints, and form blocky outcrops among skeletal, rubbly soils. The land surface has been deeply weathered particularly along fault zones; for example, the depth of weathering in the City East Fault Zone is 79 m. Extremely weathered sedimentary rock is classed as silty to sandy clay, and extremely weathered volcanic rock ranges from silty and sandy clay to clayey silt, sand, or gravel. The thick mantle of weathered rock is the source material for colluvial deposits in the valley, and the superficial deposits and the weathered rock have been modified by the development of soil profiles.

CLIMATE

Rainfall in Canberra totals about 600 mm per annum and is spread throughout the year, but most rain falls generally in the summer months (Fig. 1). Evaporation averages 1300 mm per annum and is seasonal, being high in summer and low in winter. Figure 2 shows plots of evaporation and precipitation, and combines the two in a plot of nett moisture that shows the strong seasonal contrast.

The climate is well summarised by Burton (1977):

> "The most significant feature of the climate is the annual range of evaporation. Whereas the rainfall is evenly distributed, evaporation rises sharply in November and declines equally sharply at the end of April. The beginning of the winter season in May, with the onset of frosts and the end of the growing season for grasses, coincides with a sharp drop in transpiration and evaporation, and soil moisture rapidly increases; transpiration of trees, however, continues and a different soil moisture regime prevails in forest catchments. Consequently, the year can be divided into two main hydrological seasons of six months each according to soil moisture, the "winter" or wet season beginning in May, and the "summer" or dry beginning in November."

HYDROGEOLOGY

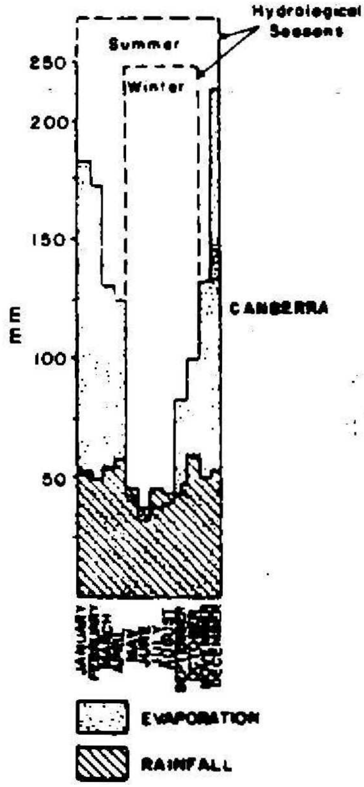
INFILTRATION

Infiltration on the hills takes place through open joints in rock, and contributes to groundwater in fractures in the rock underlying the valley (Fig. 3). Infiltration on the lower slopes and valley floor takes place through the thin silty A horizon to voids in the surficial sediments and shrinkage cracks in the clay soils. Infiltration into shrinkage cracks in the soil is high for the first 24 hours of rainfall, but is greatly reduced as expansion of the clays closes the cracks. The widening of shrinkage cracks where they are exposed at the surface by removal of the A horizon seems to have taken place following rainfall; this may be caused by the dispersion of clays such as illite and montmorillonite in water during infiltration, as is recognised as piping in the failure of small earth dams. It follows that soil that attains a high moisture

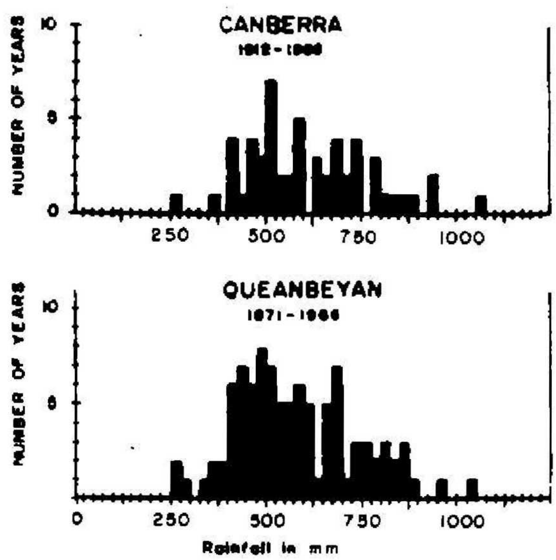
Fig. I

Climatological Data
Canberra - Queanbeyan Area

MEAN RAINFALL AND EVAPORATION



ANNUAL RAINFALL HISTOGRAMS



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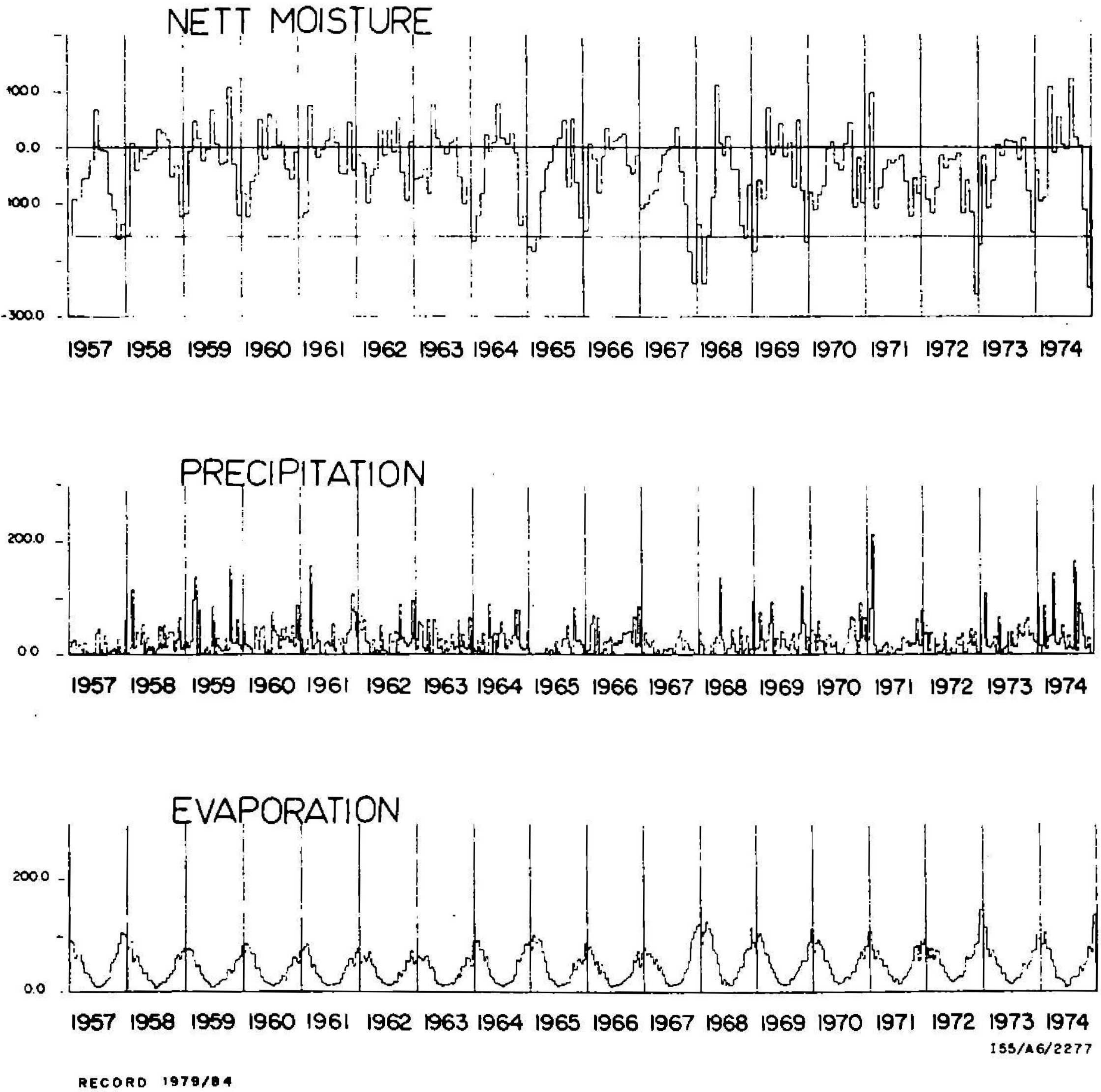
Precipitation and Evaporation Data, Yarralumla, 1957-74 FIG. 2



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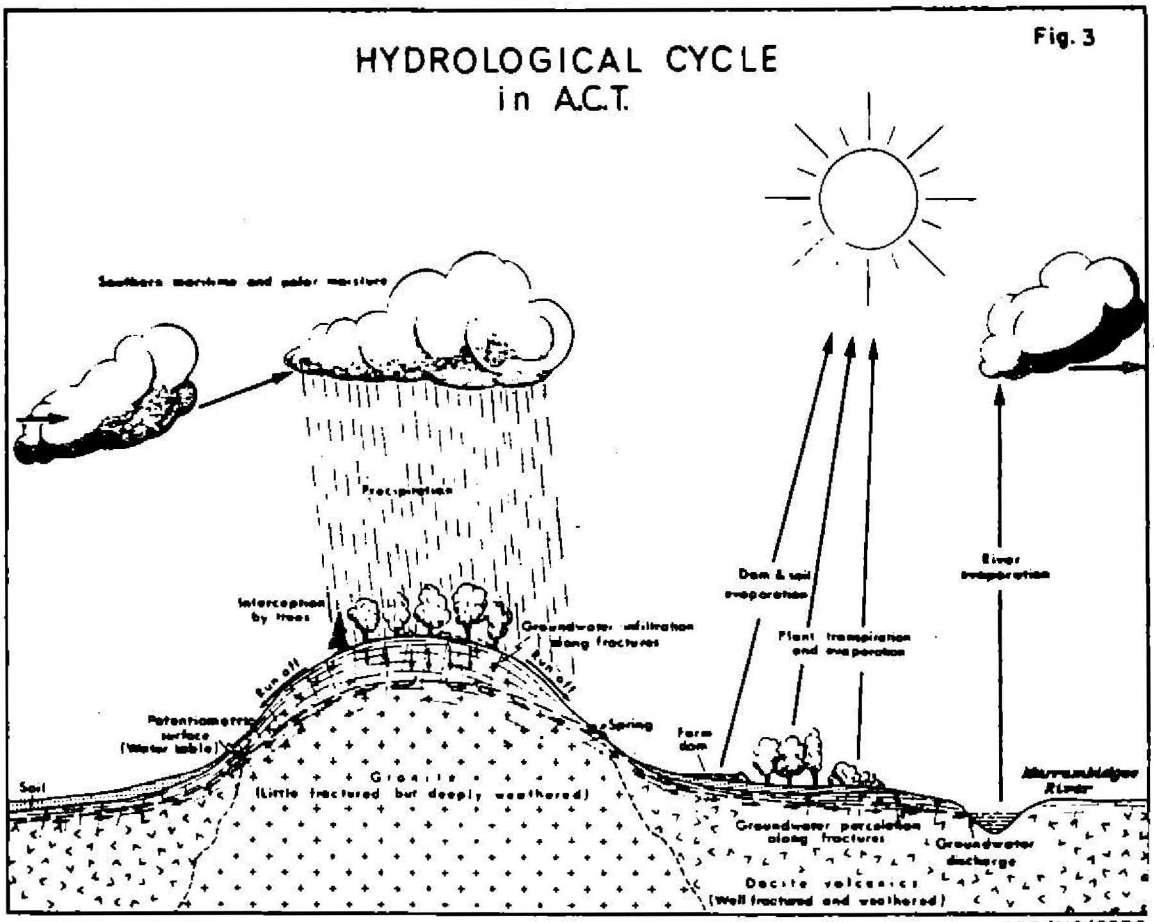

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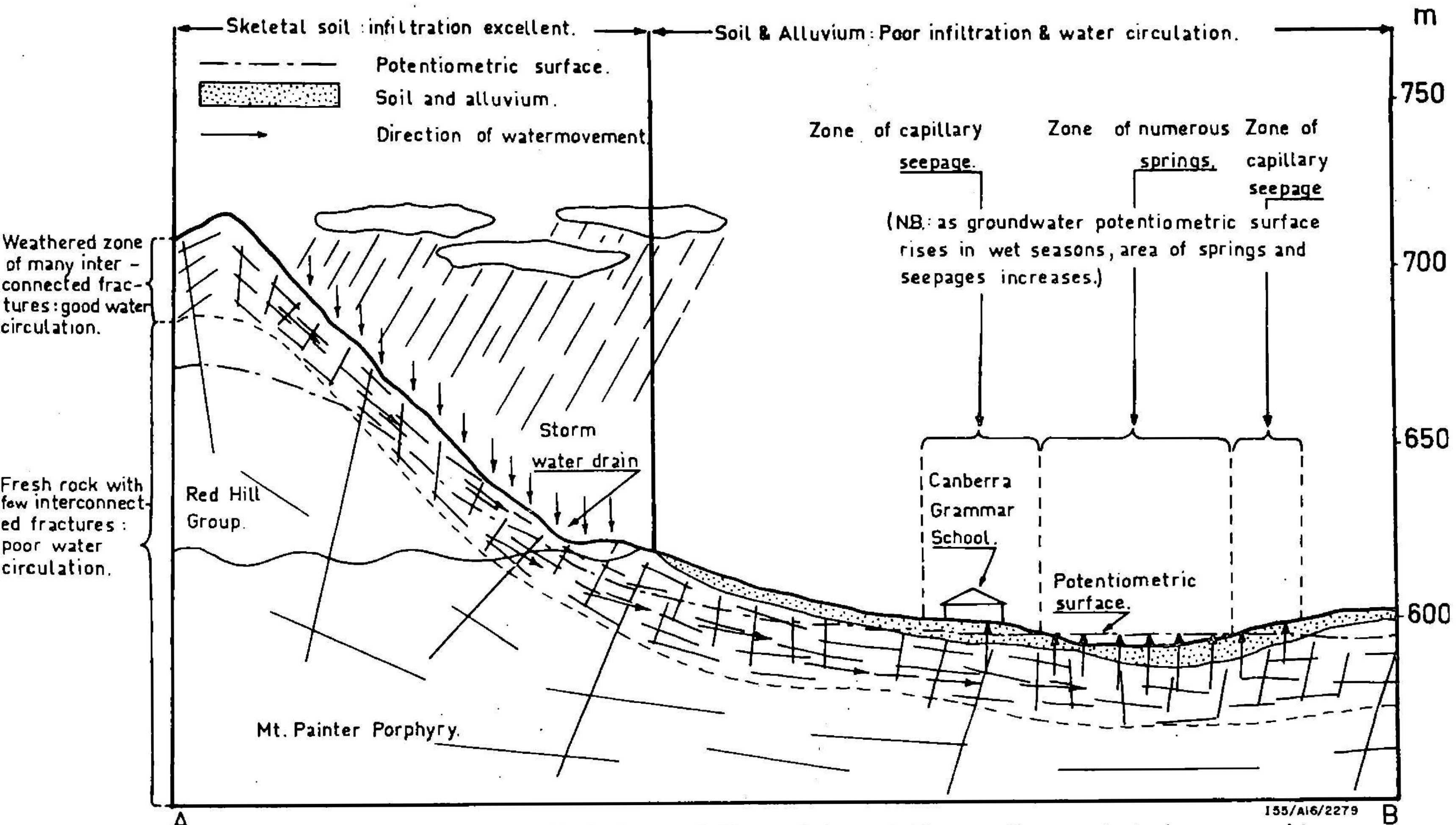
FIG: 4



Horizontal scale: 1:10,000 **Hydrology of the catchment, Monaro Crescent drainage problem**

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content in winter is likely to maintain that condition for a considerable time, possibly throughout the winter months, because of the consistently low level of evapotranspiration in winter.

As infiltration takes place, water is readily transmitted through the silty A horizon to the clay soils below. Shrinkage cracks in the clay readily accept water, but at depth the number of cracks is reduced and their width restricted; as infiltration to the clays is reduced, the silty A horizon becomes saturated. In this condition the A horizon has a very low bearing strength and is the main cause of vehicles becoming bogged after rain in the area.

In a saturated condition the A horizon acts as a perched unconfined aquifer; it transmits water laterally towards depressions, and will cause water inflows into excavations and may be a contributory cause of slumping of slopes.

POTENTIOMETRIC SURFACE

The potentiometric surface is that level to which water in a hole will rise when a formation containing free water is encountered, and the level of water will depend on the pressure in the water-bearing formation. Pressure in the fractured-rock aquifer builds up if the aquifer has a cover of low-permeability colluvium and/or clay soils that confine water within the aquifer. The confining beds then have a high moisture content, and water seeps through them at a rate depending on their permeability.

The potentiometric surface of a number of such underlying aquifers has been found to be near or above ground level (Fig. 4). At Monaro Crescent, Red Hill, the potentiometric surface of the fractured volcanic rock aquifer measured in bore 424 is generally 3 m above the ground (Saltet & Hohnen, 1965). At Yarralumla Sportsground (bore 82) the potentiometric surface is rarely more than 1 m below the surface (Jacobson & Schuett, 1975). Other observation bores at which the potentiometric surface is generally within 1 m of the surface are bore 87 near the BMR building, and bores 36 and 356 near Coranderrk Street, Reid, (near pavement test site 19). In all these locations the high moisture content will be maintained until the potentiometric surface is lowered.

A high potentiometric surface would not be recognised in an area of clay soil with a high moisture content unless a drillhole penetrated permeable material; water would then rise to the level of the potentiometric surface. It is common for holes in confining beds of low permeability to be logged as dry holes because water did not enter the hole; however, it does not exclude the possibility of a high potentiometric surface being present, and it is important to recognise that where low-permeability materials are concerned, a dry hole has little significance as far as ground-water is concerned. The 6-m potentiometric surface contour shown in Plate 1 purports to show the potentiometric surface of the underlying fractured-rock aquifer. However, many holes may be drilled in low-permeability materials to depths well below the potentiometric surface without encountering water; therefore, if the level of the potentiometric surface is significant to an engineering investigation, one or more deeper holes should be drilled to intercept permeable materials. Generally, a more permeable zone is found at the base of the superficial sediments, immediately overlying the weathered bedrock, and for most purposes inflows from this zone will provide the information required.

MOISTURE CONTENT IN CLAY SOILS

Water that is held within the structure of the clay minerals in a soil is not free draining. Water that occupies voids between the clay mineral aggregates is partly free draining, but some water will be retained in the voids by surface tension. A soil may have a high moisture content derived from water held within the structure of the clays and within the voids by surface tension; this condition is generally found in what is referred to as the unsaturated zone that lies immediately above the potentiometric surface.

The moisture content of soils is reduced in summer by evapotranspiration. However, if a high potentiometric surface is present, water from the underlying aquifer will replace water removed by evapotranspiration, and the soil moisture content will be unchanged.

In winter, rainfall generally exceeds evaporation, and transpiration from plants is at a minimum, so that the moisture content in soils will probably increase; the potentiometric surface will rise, and the level to which water rises in response to surface tension will also rise, bringing the high moisture content closer to the surface.

SOIL DRAINAGE PROBLEMS IN CANBERRA

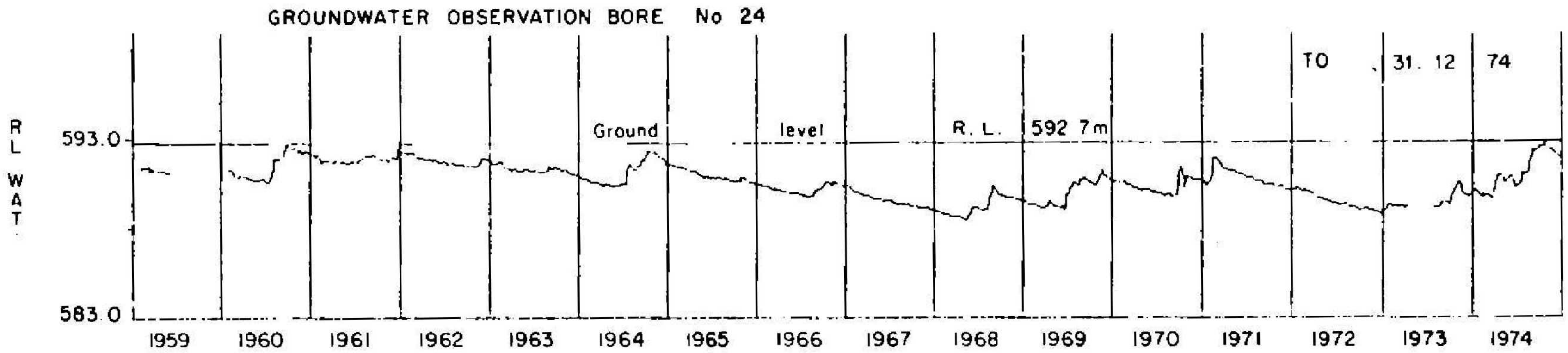
The Bureau has investigated poor soil drainage conditions at the following locations during the last 20 years, and at all of them the problem was associated with a high potentiometric surface causing the overlying soils to become saturated (see Plate 1).

Monaro Crescent, Red Hill (Saltet & Hohnen, 1975)
Torres Street, Red Hill (Hohnen, 1977)
Yarralumla Sportsground
Forrest Primary School
Coranderrk Street, Reid
Duffy Street, Ainslie (Wilson, 1959)
Cowper Street, Ainslie (Hohnen, 1974)
Duffy Primary School
Phillip Avenue, near Dickson College
Cook Primary School
Macquarie Primary School

The 6-m contour of the potentiometric surface is shown on Plate 1 has been estimated from hydrogeological records held by BMR, and is an approximation that makes no allowance for seasonal fluctuations; however, it indicates that more than half of the built-up area of Canberra is within the 6-m potentiometric surface contour. The annual rise and fall of the potentiometric surface ranges from less than 1 m in the lower parts of the valley to about 5 m near the change of slope, and the potentiometric surface is highest in October and lowest in April. The annual rise and fall of the potentiometric surface is shown in Figure 5 by hydrographs of observation bores 24 and 25 (located in Evatt, but now destroyed), in which the seasonal variation ranges to about 2.5 m. The ground level at these bores, 592 m approximately, is well below the general change of slope at about 670 m, where a seasonal variation may range to about 5 m.

There are other locations where a high potentiometric surface was observed before development in Woden Valley, Weston Creek, Tuggeranong, Belconnen, and Gungahlin. The installation of services during development has inproved drainage in the top 1-2 m of most areas because services are usually set in sand in the base of trenches, and the sand acts as a drain. However, if low permeability clays have a high moisture content and the potentiometric surface is high, the installation of services will not make any improvement unless the inverts of the services are set in a permeable unit beneath the clays; the more permeable material is generally at a depth of 2-3 m.

As the invert levels of main drains are generally too high to intercept permeable material, pumping has been found to be the only means of improving drainage. Pumping has been successful in lowering the potentiometric surface at Torres Street, Red Hill since 1959, and the effect is monitored by observing water-levels in nearby observation bores (Hohnen, 1977).



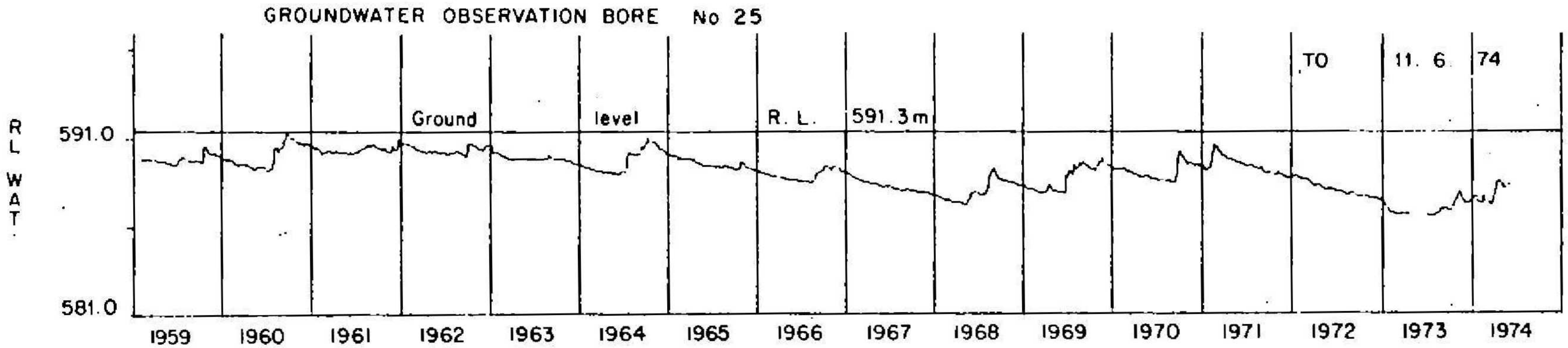


Fig. 5 Groundwater levels, Observation Bores 24 and 25

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ROAD SUBGRADES

The subgrade materials for roads in Canberra range from clayey sand to sandy and silty clay in extremely weathered volcanic rock; typical exposures can be seen in the Tuggeranong Freeway cut, south of the Cotter Road, and in the roadcut on Karinga Drive to the north of Spence. In extremely weathered sediments the subgrade will range from clayey sand and silt to silty clay; the roadcuts along the northern approach to Commonwealth Avenue Bridge, and those in State Circle and Capital Circle are typical.

Subgrades in the superficial sediments range from clayey sand and gravel to silty and sandy clay in sediments not affected by soil formation. Parkes Way, near the BMR Building (test site 16), traverses aeolian sand that is classified as clayey sand; the new section of the Monaro Highway beyond Isabella Drive traverses colluvium that is probably the equivalent of the Murrumbidgee Fanglomerate; and Barry Drive near David Street (test site 29) has a colluvium subgrade. Where the subgrade is the equivalent of Tuggeranong Clay, it consists of a yellow-red to yellow and grey heavy clay, possibly with calcareous concretions. If the Tuggeranong Clay has subsequently been affected by a later period of soil formations equated with the formation of the Lanyon Clay, then pea-sized ferruginous gravel is found beneath an A horizon of pale grey silt, and the gravel will persist in the upper part of the underlying yellow and grey Tuggeranong Clay. The association of Lanyon Clay overlying Tuggeranong Clay is found in many places along Canberra Avenue between Ipswich Street and Harman, and along Sturt Avenue and Jerrabomberra Avenue to beyond Narrabundah Lane (test sites 12, 13, and 14). Subgrade on the Lanyon Clay equivalent consists of yellow and grey clay with ferruginous gravel beneath an A horizon of pale grey silt; if the soil has been maintained in a saturated state due to a high potentiometric surface, the upper part consists of dark grey organic clay (test sites 3 and 19, and Monaro Crescent). Other subgrades on Lanyon Clay are at Cowper Street, Ainslie, Yarra Glen near Hughes, Yamba Drive opposite the Woden cemetery; Morshead Drive near Duntroon Gold Course; Dairy Flat; and Canberra Airport.

Remnants of clays associated with the earliest colluvial sediments, Murrumbidgee Fanglomerate, contain well-jointed clays in the higher parts of the colluvium. They are less frequently found with a high moisture content as they are generally well above the potentiometric surface in locations at Torrens, Pearce, and Garran; however, test site 26 at Haydon Drive is on a remnant of this older clay, and it had a high moisture content when inspected after rain during the preceding 24 hours.

CAUSES OF SUBGRADE FAILURE

The cause of subgrade failure is considered to be the establishment of a high moisture content for a period of time sufficient for the passage of traffic to induce failure.

Inflows of water from a saturated A horizon are to be expected wherever the A horizon is cut by a road excavation. Inflows only persist until the surrounding A horizon is drained of water, but it provides ready access for free water to come in contact with the subgrade, and this is a constantly recurring event. Any material with a higher permeability within the sediments would also transmit water in the same manner, but the A horizon is important to road construction in Canberra because it becomes an extensive perched aquifer after rain.

In the clayey subgrades that are common in Canberra, a high moisture content will be maintained in the unsaturated zone above the potentiometric surface by the upward movement of water in capillary-size openings caused by surface tension. Depending on the clay content of the material, a high moisture content in the unsaturated zone may exist more than 2 m above the potentiometric surface.

The infiltration of water into open cracks in clay raises the moisture content after rainfall. This condition is a recurring one, and may be found at levels well above the influence of the potentiometric surface.

Areas with a potentiometric surface at or near ground level are maintained in a saturated state permanently; Monaro Crescent near the Canberra Boys Grammar School is such an area.

The Canberra soils have very low permeability, high plasticity, and high shrinkage, and contain the dispersive clay minerals illite and montmorillonite; in a wet condition their bearing capacity is low, and they are readily transported in suspension in water.

CONCLUSIONS

1. The road subgrades in Canberra consist of clayey materials that contain the dispersive minerals, illite and montmorillonite; these clay minerals commonly exhibit the properties of low permeability, high plasticity and high shrinkage, and in a wet condition their bearing capacity is low; their presence in a subgrade causes some loss of strength, depending on the proportion present.

2. Water may be introduced into the subgrade by lateral drainage from the silty A horizon after rain.

3. The potentiometric surface lies within 6 m of road subgrades through more than half of the urban area of Canberra, and if a significant proportion of clay is also present in the subgrade, a high moisture content for some months of each year is to be expected.

4. A high moisture content will persist in clays below the potentiometric surface, and will be established and maintained within the unsaturated zone above the potentiometric surface, wherever interstitial water is held in the soil by surface tension. In locations removed from the effect of the potentiometric surface, a high moisture content derived from infiltration of rainfall may not persist.

5. High evapotranspiration will reduce the moisture content of soils in summer; soils remote from the potentiometric surface may attain a low moisture content, but soils that are affected by the potentiometric surface will have their water losses to evapotranspiration made up by water drawn from the underlying permeable materials by surface tension.

6. Evapotranspiration is at a minimum in winter, when water losses to evapotranspiration are more than offset by rainfall. Soils with a high moisture content are likely to acquire even more moisture in winter, and soils that attain a high moisture content in winter are likely to retain such a condition until the following summer.

<u>RECOMMENDATIONS</u>

1. Pavements in Canberra should be designed in the expectation of a low bearing strength in a subgrade of clay with a high moisture content consistent with winter conditions.

2. All measures possible should be taken during construction to exclude water from the subgrade throughout the life of the pavement and special measures should be considered to divert any water likely to flow through the A horizon to the subgrade.

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APPENDIX 1

A.C.T. ROAD PAVEMENT TEST SITE OBSERVATIONS

ON GEOLOGY, SOILS AND GROUNDWATER

TEST SITE LOCATION AND LEVEL (m)	GEOLOGY AND SOILS (LANYON EQUIVALENTS)	GROUNDWATER: ESTIMATED POTENTIOMETRIC SURFACE (PS)	POSSIBLE CAUSES OF FAILURE
1. Yamba Drive opposite cemetery 590 m	Colluvium ranging to 3 m; soils not visible; grey hydromorphic clay may be present in the profile. (Lanyon Clay)	PS 2-3 m; erosion gully with depth of 4 m (before urban development) about 50 m away).	Probably low-permeability podzolic soils with high PS.
2. Yamba Drive opposite Isaacs 640 m	Leached A hor. over heavy clay soil 1.5 m with numerous pisolites on EW volcs (exposed in cut); calcareous nodules; evidence of dispersive clays. (Lanyon over Tuggeranong Clay).	PS 1-2 m; base level of erosion gully 50 m away, now a stormwater channel, depth about 3 m.	High PS, low-permeability podzolic soil with pisolites; dispersive clay probably illite and some montmorillonite.
3. Beasley St (centre of Woden Valley) Athlone Drive 630 m	Colluvium ranging to 4 m thick; podzolic soils. (Lanyon Clay)	PS at surface before development; now about 1 m throughout year; base level erosion gully 4 m deep, now contains stormwater main.	Thick podzolic soils with low permeability and high PS.
4. Melrose Dr. near Ainsworth St 640 m	Strongly leached A hor. over strong pisolitic zone with remnants of heavy yellow clay soil with pisolites; some calc. nodules; enlarged shrinkage cracks by removal of dispersive clay with infiltration. (Lanyon over Tuggeranong Clay)	PS probably below 5 m on rise; perched water-table in clay soils after rain; an intermittent condition.	Remnant of low-permeability podzolic soil; well-developed pisolitic zone over dispersive clays; illite and some montmorillonite, some calc. nodules.
5. Melrose Dr. Parramatta Court to Botany St 600 m	Leached A hor. over strongly developed pisolites over heavy yellow clay with shrinkage cracks enlarged by removal of dispersive clays during infiltration. (Lanyon, probably over Tuggeranong Clay)	PS probably 2-3 m; perched water-table in clay soil to be expected after rain.	Low-permeability; podzolic soil with dispersive clays (illite and some montmorillonite).
6. Melrose Dr. Launceston to Theodore St 580 m	Leached A hor.; numerous pisolites; heavy clay soils expected but not exposed.	PS probably 2-3 m; this location is below perched basin; intermittent perched water-table in heavy clay soils is to be expected.	Probably low-permeability podzolic soil with dispersive clays.
7. Kent St near Deakin Inn 580 m	Leached A hor. over strongly developed pisolitic horizon over yellow heavy clay with shrinkage cracks opened by removal of dispersive clays during infiltration. (Lanyon Clay)	PS probably 3-4 m, but garden watering opposite and rainfall likely to establish perched water table in clay soils.	Intermittent saturation of low-permeability podzolic soils with dispersive clays.

TEST SITE LOCATION AND LEVEL (m)	GEOLOGY AND SOILS (LANYON EQUIVALENTS)	GROUNDWATER: ESTIMATED POTENTIOMETRIC SURFACE (PS)	POSSIBLE CAUSES OF FAILURE
8. Cotter Road below McCulloch Street 570 m	Red earth at surface over mottled strong pisolitic zone grading down to yellow clay; shrinkage cracks opened by removal of dispersive clays with infiltration.	PS probably 4-5 m; high infiltration through shrinkage cracks probably creates intermittent perched water-table.	Intermittent saturation of low permeability podzolic soils with dispersive clay.
9. Cotter Road opposite sewerage treatment plant 560 m	Roadcut in MW-EW volcanics with some boulders.	PS probably 5-6 m; perched water-table in the EW rock due to seepages from upslope.	Possibly differential settlement in the variably weathered volcanics, assisted by intermittent perched water-table.
10. Streeton Dr. Heyson to Hilder Sts 560 m	1.5 m colluvium with 0.5 m leached A hor. over well-developed pisolitic zone, over heavy yellow-grey clay. Manganese stain on ped surfaces. (Lanyon Clay)	PS probably 2-3 m; perched water-table may result from adjacent garden watering. PS likely to be within 1 m of surface in Oct.	Probably due to saturation of heavy clays as a semi-permanent condition with a contribution from garden watering.
11. Hindmarsh Drive, between Melrose Dr. Eggleston Cres. 600 m	AS FOR MELROSE DRIVE (5) (Location not visited but it occupies a similar position on same landform as 5.) (Lanyon, probably over Tuggeranong Clay)		
12. Jerrabomberra Avenue near Motel 7. 580 m	Red earth over well developed pisolitic zone over heavy yellow clay with calc. nodules, shrinkage cracks opened by removal of dispersive clay with infiltration. (Lanyon over Tuggeranong Clay)	PS probably about 1 m throughout year. Road crosses natural depression.	Low-permeability podzolic clay with dispersive clays and high PS.
13 & 14. Canberra Ave. from the Stockroute to Yallourn St 570 m	Red earth with leached A hor. over strong pisolitic zone over yellow-grey heavy clay with calc. nodules; shrinkage cracks opened by removal of dispersive clay with infiltration; overlies EW-MW calc. mudstones and interbedded volcanics. (Lanyon over Tuggeranong Clay)	PS variable from 1-5 m; however, perched water-table in clay soils considered a common event.	Low-permeability podzolic soil with dispersive clays; variable PS and intermittent perched water-table.
15. Morshead Drive Duntroon 560 m	Red earth with leached A hor. over strong pisolitic zone. No exposure but heavy clay expected below; adjacent area contains organic clays. (Lanyon Clay)	PS generally within 1 m of surface; higher levels common and maintained by golf course watering.	Probably low-permeability podzolic soil with dispersive clays, and a consistently high PS.

TEST SITE LOCATION AND LEVEL (m)	GEOLOGY AND SOILS (LANYON EQUIVALENTS)	GROUNDWATER: ESTIMATED POTENTIOMETRIC SURFACE (PS)	POSSIBLE CAUSES OF FAILURE
16. Parkes Way - East of BMR Building 565 m	Windblown sand-rises with sand up to 1 m with some pisolites and pisolitic development at about 0.7 m and clay accumulation beneath pisolites; overlies EW-MW calcareous mudstones, tuff, and volcanics. (Lanyon Clay)	PS generally 2-3 m; however, perched saturated zone expected in the clayey zone at base of sand after rain.	Probably due to intermittent saturation of clayey sand immediately above weathered rock; low cohesion in wet clayey sand.
17. Parkes Way Anzac Pde to Coranderrk St 550-560 m	Ranges from windblown sands in east near Anzac Pde to dark organic clays at Coranderrk St. (Lanyon Clay)	PS ranges from 2-3 m at Anzac Pde to less than 1 m at Coranderrk St.	Variable condition ranging from (16) above to dark organic clay with high PS at Coranderrk St.
18. Commonwealth Ave between London Cct and Molonglo Parkway 570 m	EW-SW mudstone, sandstone, and possibly calc. mudstone make up an emplaced embankment.	PS probably at least 5 m for most of the year; possibly infiltration of rain from road drainage.	Probably differential compaction by differences between physical character of calc. mudstone (hard & blocky) and EW mudstone & sandstone (readily compacted). Possibly assisted by local infiltration to produce saturated clay zones in EW rock.
19. Ballumbir Street 565 m	Dark grey organic clay; in places red earth over strong pisolitic zone, over mottled yellow-grey heavy clay. (Lanyon Clay)	PS generally within 1 m; known zone of saturated soils caused by high potentiometric surface over a long period.	Low-permeability organic clay and podzolic soils with a high moisture content maintained by the high PS.
20. Northbourne Ave. near Dunsmore Street 575 m	Thickness of yellow and grey podzolic soils derived from colluvium ranges in thickness to 7 m. (Lanyon Clay possibly Tuggeranong Clay at depth)	PS probably about 3 m but seasonally variable.	Possibly due to variation in seasonal expansion and contraction of thick clay sequence with variation in soil moisture; some expansive clays may be present.
21. Federal Hwy Flemington Road to Stirling Ave 585-590 m	Red earth with leached A hor. over strong pisolite zone; mottled clay grading down to yellow and grey clay; some calc. concretions, shrinkage cracks opened by removal of dispersive clay by infiltration; overlies EW mudstone, sandstone, and tuff. (Lanyon Clay)	PS probably 3-4 m but seasonably variable; perched water-table in clay soils expected after rain.	Low-permeability podzolic soils with dispersive clays; intermittent perched water-table in clay soils.

TEST SITE LOCATION AND LEVEL (m)	GEOLOGY AND SOILS (LANYON EQUIVALENTS)	GROUNDWATER: ESTIMATED POTENTIOMETRIC SURFACE (PS)	POSSIBLE CAUSES OF FAILURE
22. Federal Hwy. Antill Drive to ACT/NSW border 625-675 m	Volcanic rock ranging from EW to fresh rock, moderately to closely jointed. Weathered zone boundaries are irregular in horizontal and vertical distribution.	PS probably 6-8 m; hill slope seepages from perched water-tables common along route.	Probably variation in type of weathered rock and intermittent saturation caused by hillside seepage are responsible for differential settlement in the subgrade.
23. Barton Hwy near 2CY and 2CA transmitters 595 m	Varies from 1 m of fill, over mainly yellow to grey clay, to strongly structured in situ yellow-grey heavy clay; 0.3 m leached A hor. (Lanyon Clay)	PS at or near surface throughout the year; sedge grass indicates persistent waterlogged condition of soil.	Low-permeability podzolic soil with a consistently high potentiometric surface.
24. Barton Hwy Glebe Road to Gladstone Street 630-650 m	Varies from thin to 4-m thick clay soil; red earth with leached A hor. over well-developed pisolitic zone over mottled red-yellow clay grading to yellow and grey clay at depth. Overlies volcanics, EW to fresh. (Lanyon Clay possibly over Tuggeranong Clay)	PS generally about 4 m or more near Glebe Rd to 2-3 m at Gladstone St; perched water-table in clays after rain to be expected.	Near Glebe Rd Differential settlement associated with variably weathered rock. Towards Hall As podzolic soils bedcome thicker towards Hall, perched water-tables probably form in the clays from infiltration after rain.
25. Barton Hwy. beyond Hall 630-650 m	Not visited (Probably similar to (24)).		
26. Haydon Dr. College St. to Battye St 620 m	Red-brown heavy-structured clay, 1.5 m thick overlies pale grey to reddish mottled highly structured heavy clay, 1-2 m thick; overlies EW siltstone and sandstone of Pittman Fm. (Lanyon Clay over Murrumbidgee Clay)	PS probably about 5-6 m; however, perched saturated zones form in the clay soils after infiltration from rain along shrinkage cracks.	Low-permeability podzolic soils with dispersive clay; infiltration causes saturation; wide shrinkage cracks.
27. Belconnen Way Bindubi St to Benjamin Way 600 m	Red brown pisolitic heavy clay with 0.2 m leached A hor.; enlarged shrinkage cracks caused by infiltration of water; erosion of cuts suggests dispersive clay; heavy yellow and grey structured clay below. (Lanyon Clay over Tuggeranong Clay)	PS probably 2-3 m but higher at times; infiltration after rain causes local saturated zones.	Main road break-up seems to be where top 0.5 m has been removed and road formed on red-brown clay. fluctuating PS and local saturated zones from infiltration.
28. Belconnen Way near Hawker Oval 610 m	NOT VISITED (Landform similar to 27 and conditions expected to be same as at 27.)		

TEST SITE LOCATION AND LEVEL (m)	GEOLOGY AND SOILS (LANYON EQUIVALENTS)	GROUNDWATER: ESTIMATED POTENTIOMETRIC SURFACE (PS)	POSSIBLE CAUSES OF FAILURE
29. Barry Dr. near David St 600–620 m	Thick colluvial fan probably 20 m thick; exposed section 0.5 m red earth becoming mottled pale grey clay at 1 m, below which colluvium is earthy and friable.	PS variable but generally $><5$ m. Perched water-tables within colluvium are to be expected.	Not known; however, great thickness of colluvium and likelihood of heavy clay with expansive minerals should be considered.
30. State Circle between Commonwealth Ave and Kings Ave 570 m (in cut)	State Circle Shale and Camp Hill Sandstone; EW siltstones and sandstone in 5-7 m roadcut contain up to 30 percent clay minerals.	PS probably at or near surface in the cuts; local saturation of weathered rock to be expected.	Probably due to differential compaction of saturated weathered rock; more clayey sections failing.
31. Caswell Dr. near Belconnen Way 640 m	Acton Shale, ranging from EW clayey silt to hard siliceous slate is variably distributed throughout the road cuts; many shear zones present.	PS probably > 6 m; local zones of saturated silty clay caused by seepages after rain. Perched water tables intermittent.	Probably differential subsidence by failure of saturated zones of silty clay.

EW = extremely weatherd
MW = moderately weathered
SW = slightly weathered

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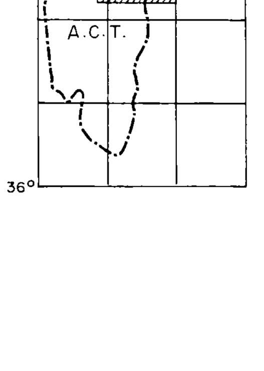

RECORD 1979/84

Hydrogeological data relevant to pavement failure in Canberra

0 1 2 3 km

× 21 Pavement test site and number

o 79 Water bore and number

Potentiometric surface, generally within 1m of surface

Potentiometric surface estimated within 6m of surface

Change of slope