DEPARTMENT OF ~~NATIONAL RESOURCES~~ NATIONAL DEVELOPMENT

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

Record 1979/27

MOLONGLO VALLEY INTERCEPTOR SEWER, ACT:

ENGINEERING GEOLOGY COMPLETION REPORT, 1978

by

D.C. PURCELL

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PLATES

* These plates are not included under this cover but can be obtained from BMR by quoting the drawing numbers shown in brackets.

1. ABSTRACT

1. Construction of 3.5 km of tunnel, 10.3 km of buried pipeline, and five steel-pipe bridges commenced in June 1973 and was completed in March 1976.

2. Two tunnels - the Pine Ridge and Ryan Tunnels - were excavated by the drill-blast-muck method, and the intervening buried pipeline route was pre-blasted and then excavated by a Poclain HC 300 excavator.

3. Geological conditions were generally as predicted, although more sedimentary rocks were found in Pine Ridge Tunnel than expected. Excavation of the pipeline trench was a little more difficult than forecast in the pre-construction geological report.

4. Tunnelling conditions were generally good, and only 16 percent of Ryan tunnel and 17 percent of Pine Ridge tunnel had to be supported by steel sets.

5. Estimated overbreak during construction was moderate: 65 percent in Ryan Tunnel and 42 percent in Pine Ridge Tunnel.

6. The flow of water into the tunnels after they had been lined with concrete was insignificant: 1650 l/h in Ryan Tunnel and 2650 l/h in Pine Ridge Tunnel.

7. No major problems were encountered during construction of the pipeline section of the route, and the bridges.

8 Materials suitable for backfilling the pipeline trench was in short supply in a few sections, and some had to be imported.

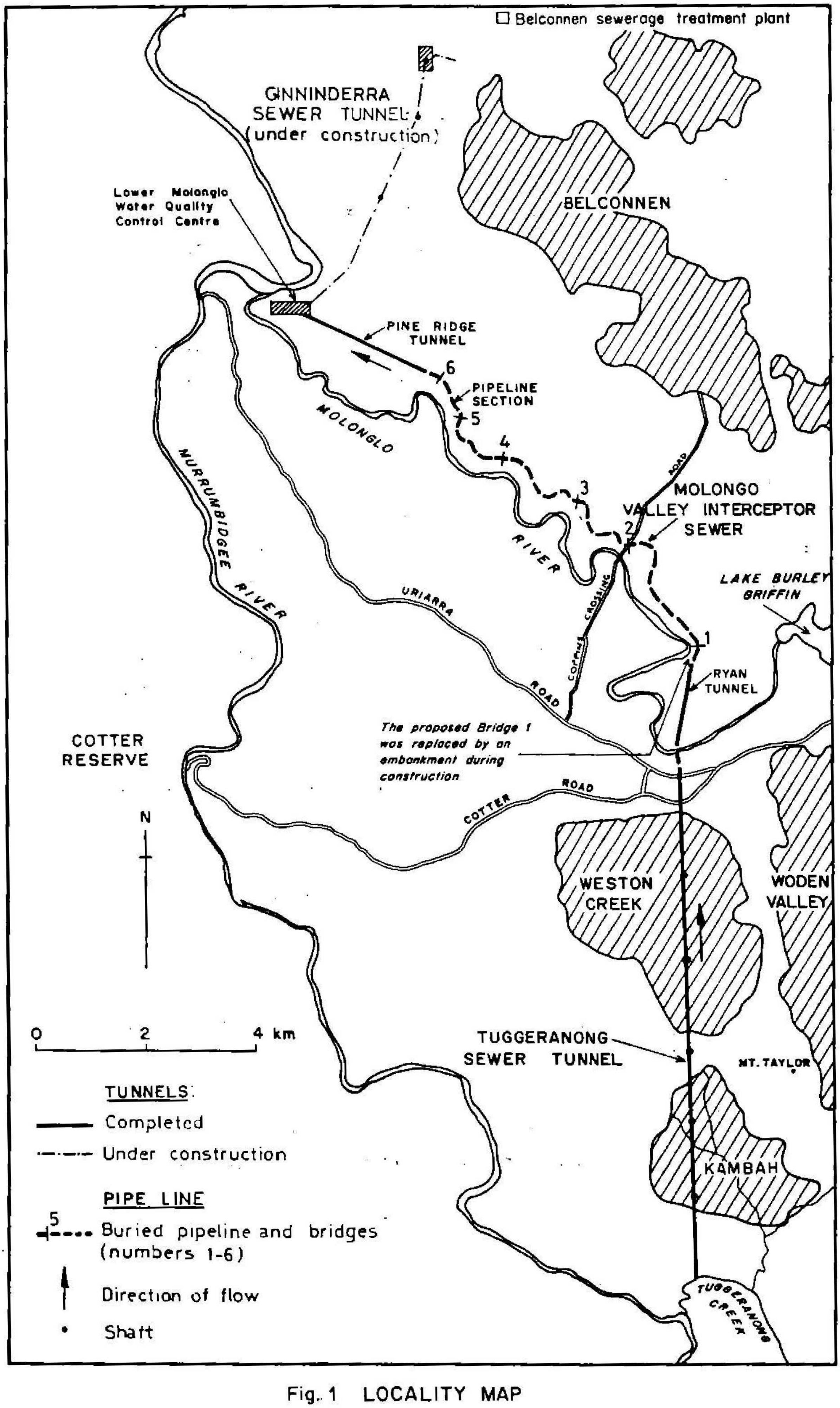


Fig. 1 LOCALITY MAP

2. INTRODUCTION

The Molonglo Valley Interceptor Sewer (MV15) conveys raw sewage from the north portal of the Tuggeranong Tunnel at Weston Creek to the Lower Molonglo Water Quality Control Centre (LMWQCC) at the junction of the Murrumbidgee and Molonglo Rivers (Fig. 1). It comprises 10.3 km of buried pipeline, 5 bridges (total length 718 m), two tunnels (total length 3.5 km), and appurtenant works.

The contract for the construction of the MV15 was awarded to John Holland Holdings Ltd for a price of $7.2 m. The contract period was from 8/6/73 to 16/1/76, although the completion date was subsequently extended to 18/3/76. The Department of Construction (DC) designed and supervised construction of the works for the National Capital Development Commission. A pre-construction geological report was prepared by BMR for DC and was subsequently incorporated into an 'Information for Tenderer' document. On request from DC, BMR provided a Project Geologist whose duty was to provide DC with a complete geological service during construction. Detailed geological logs of both tunnels and of the pipe trench are not included in this report, but are available from the (refer to CONTENTS for plan file nos.).

Pipeline section and bridges

The pipe that was laid was of two diameters: 885 m of 1980-mm diameter pipe between Tuggeranong Tunnel and Ryan tunnel; 9405 m of 2590-mm diameter pipe between Ryan and Pine Ridge Tunnels (Fig 1). The 2590-mm pipes were laid between 29 August 1973 (starting at Coppins Crossing) and 27 August 1975. The 1980 mm diameter pipes were laid between 24 February and 6 June 1975.

The pipe trench was pre-blasted in a single row of widely spaced (>1m) holes along its entire route; holes spaced more closely were required where hard rock was close to the surface. Most sections of harder rock were successfully predicted in the pre-tender information. Excavation was by a Poclain HC 300 excavator with a bucket capacity of 1.7 m^3.

Five of the 6 steel-pipe bridges originally planned were constructed across major creeks and gullies; bridge 1 was replaced by concrete pipes located in a fill embankment. The Molonglo River was cross by a 55-m long concrete weir which housed tthe 1980-mm diameter concrete pipes. The first bridge to be constructed was No. 2, and the last No. 6. TThe time taken to erect the 5 steel bridges was about 30 weeks.

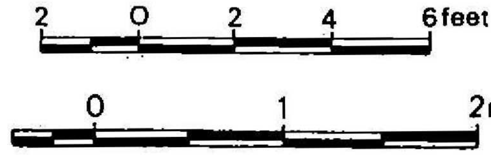
Tunnels

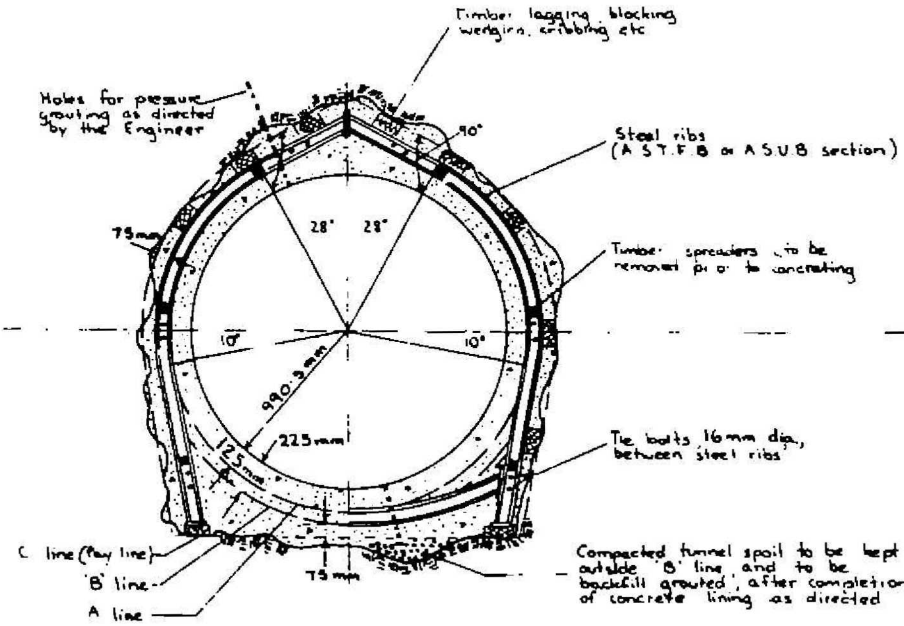
Ryan Tunnel. This tunnel is 1521 m long, with an internal diameter after concrete lining of 1981 mm (Fig. 2). Tunnelling commenced on 3 July 1974 from the downstream portal at stn 50 + 34 as a one-shift-per-day operation (Plate 1). Three shifts per day started on 17 October 1974 at stn 49 + 38. Excavation of the upstream heading (Fig. 13) started on 26 November 1974 but was carried on intermittently.

The tunnel face was drilled with Atlas Copco BBD90 drifters on BMK 91 air legs. The average hole depth was about 1.8 m, and between 30 and 35 holes were drilled per advance. The explosive was mainly AN60 but Dynamex was used in some rounds. A burn cut was used and 0-10 millisecond delays were used (i.e., ten delays of 1 millisecond per delay). Tunnel muck was removed in rubber-tyred Wagner ST 2B LHD (load, haul, dump) units with bucket capacities of between $1.2 m^3$ and $1.5 m^3$. Initially tunnel invert was unlined, but owing to invert roughness and vehicular erosion a concrete slab was poured below B line. The concrete invert was kept as close to the face as possible.

Pine Ridge Tunnel. This tunnel is 2004 m long, with an internal diameter of 2591 mm (Fig. 2). The upstream portal was established at stn 2 + 56 and tunnelling commenced on 10 September 1973 and ceased from this heading on 6 April 1974 at stn 37 + 60. The downstream portal was established at stn 68 + 12 and tunnelling commenced on 9 April 1974; breakthrough, at stn 37 + 60, was made on 10 October 1974.

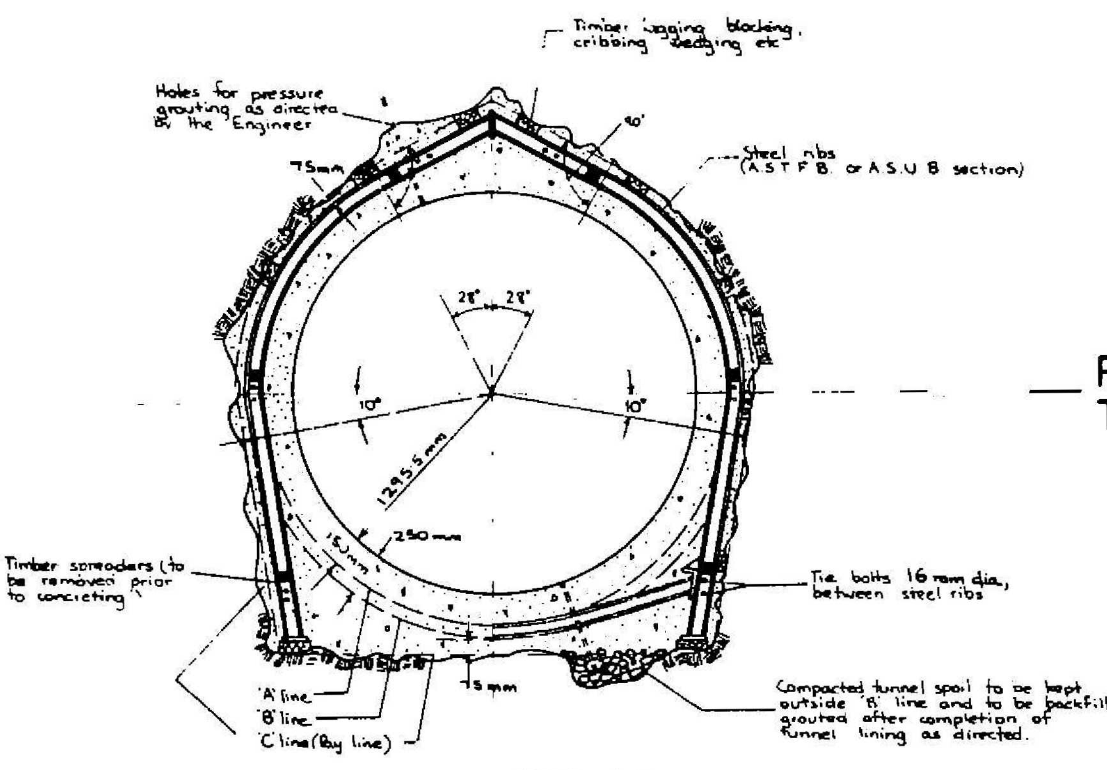
TYPICAL TUNNEL CROSS SECTIONS





RYAN TUNNEL

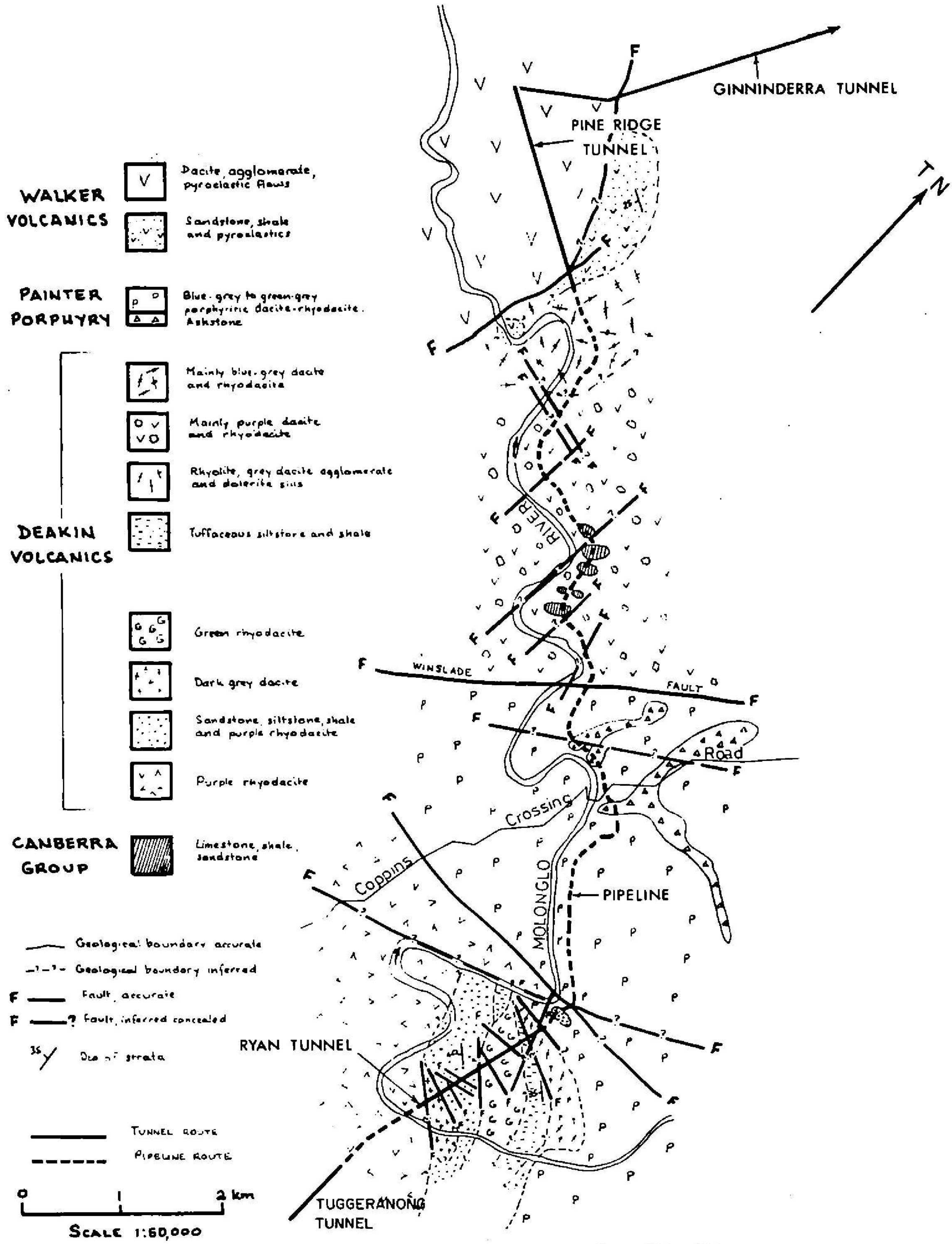
STEEL RIB SUPPORTED + STEEL RIB SUPPORTED WITH INVERT STRUT



PINE RIDGE TUNNEL

STEEL RIB SUPPORTED + STEEL RIB SUPPORTED WITH INVERT STRUT

FIGURE 2



MOLONGLO VALLEY INTERCEPTOR SEWER

GENERAL GEOLOGY

Fig. 3

Initially the tunnel face was drilled with a rubber-tyred Ingersoll-Rand boom Jumbo with two D300M and one D475A drifters. The Jumbo suffered mechanical problems and most of the drilling was done with Atlas Copco 13B D90 Drifters on BMK 91 air legs. The average number of holes drilled per round was 40 to 45. In poor ground (steel-supported sections) the average hole depth was 1.5 m, but increased to 2.4 m in good rock (fresh volcanic rock). Explosives used were AN60 and Exactex or sometimes AN60 and AN/FO. A burn cut was used 10 millisecond delays. Tunnel muck was removed in the same way as in the Ryan Tunnel excavation; invert was also lined below B line during excavation.

<u>Tunnel Survey</u>. Survey in the Ryan and Pine Ridge Tunnels employed Siemens Helium-Neon LG68 lasers, which had an effective range of 215 m in these tunnels.

<u>Tunnel concreting</u>. Concrete was placed by the full circle method in separate lengths with full height vertical joints formed by a bulkhead at the end of each length; concrete pouring was not continuous. Concreting of the Ryan Tunnel commenced on 29 August 1975 at stn 0 + 51 and was completed on 16 January 1976 at stn 50 + 31. Concreting of the Pine Ridge upstream heading (stn. 2 + 56 + 34 + 36) was done between 6 June 1974 and 21 January 1975, and the remainder of the tunnel between 7 April 1975 and 31 July 1975.

3. GENERAL GEOLOGY

The geology of the entire route is shown in Figure 3 at a scale of 1:50 000.

3.1 Ryan Tunnel

The tunnel is located almost entirely in the Upper Silurian Deakin Volcanics (Plate 1), except for 39 m of weathered Mount Painter Porphyry immediately south of the outlet portal. The inserted Deakin Volcanics consist mainly of acid volcanics with some interbedded sediments. Dolerite intrudes the volcanics near the outlet portal (Fig. 14). The volcanics dip from 30° to 50° in a direction ranging from west to south.

Faulting is common in the rock units intersected by the tunnel. Most rock unit boundaries are sheared or fractured and the less competent beds such as shale are commonly intensely fractured. The sedimentary rocks are generally more closely jointed than the volcanics, but jointing in the volcanics was the main feature in determining the response of the rock mass to tunnelling. Weathering of all rock types is greatest within about 15 m of the ground surface. Weathering along major defects to depths in excess of 15 m is common.

3.2 Pine Ridge Tunnel

Pine Ridge Tunnel was driven through the upper part of the Walker Volcanics (Fig. 3), which are of Wenlockian age. The volcanics intersected in the tunnel consist of densely welded pyroclastic flows and tuffs, mostly massive but with some thin-bedded welded tuff and some thin lenses of waterlaid shale and tuffaceous sandstone. The massive welded rocks grade up into well-bedded crystal tuffs near the west portal of the tunnel. The general dip is 20° to the southwest, although gentle folding was observed in the tunnel and in LMWQCC excavations.

The volcanics are generally blue-grey to purple, but green-grey rocks are also common. Chemical analyses of five samples collected from the tunnel are shown in Appendix 2; they have a similar chemistry, but the FeO/Fe_2O_3 ratios are high in the green varieties and low in the purple varieties. Total Fe as FeO ranges from 4 percent to 6 percent; FeO/FeO_2O_3 ranges from 4.3 to 0.45.

The purple appears to be due to secondary oxidation which has permeated into the rock along permeable defects in the rock mass. Oxidation is more advanced in the more permeable rock (close jointed and fractured) than in the very tight wide-jointed zones (see Appendix 1 - Joint spacing). Calcite veins are common in the blue-grey to purple rock but rare in the green-grey rock.

Many narrow faults and fractured zones (0.3-1 m wide), particularly in and near the interbedded shale and sandstone were intersected during tunnelling. Most faults are parallel to the main fault directions in the area - i.e., striking southeast or southwest.

The main joint sets in Pine Ridge Tunnel are $90^\circ/060^\circ$, $90^\circ/160^\circ$ and parallel to bedding. The first two sets are subparallel to the major fault directions (including the Deakin and Winslade Faults) and to the most common photo-lineament directions in the area.

3.3 Pipeline section

The geology of the pipeline route (Fig. 3) is in close agreement with that predicted by Purcell & Simpson (1973). Some modification of the geology of the various volcanic units between the Winslade Fault and the Pine Ridge outlet portal is presented in Figure 3.

Rock units. From the north portal of Ryan Tunnel to the Winslade Fault Zone the pipeline route lies within the Mount Painter Porphyry, which is composed of blue-grey and green-grey porphyritic dacite and minor ashstone. The remainder of the pipeline route from west of the Winslade Fault to the east portal of Pine Ridge Tunnel and the short section south of the Molonglo River lie within the Deakin Volcanics. The rocks of the Deakin Volcanics along the trench excavation range from blue-grey and green-grey dacites to purple-grey and purple dacites. The pipeline open cut intersected a number of lenses of Canberra Group sediments between stns 200 + 00 and 235 + 00. The sediments include tufffaceous sandstone, calcareous shale and mudstone, and massive and bedded limestone.

<u>Structure</u>. Both the Mount Painter Porphyry and the Deakin Volcanics contain many sheared and fractured zones; tthe main ones are shown in Figure 3. Most of these zones are clearly visible in new exposures even in highly and extensively weathered rocks. As well as the fractured and sheared rock, these small fault zones (<4 m) are marked by colour differences due to greater degree of weathering, clay infilling and seams, and the occurrence of secondary minerals (limonite, calcite, silica, epidote). The larger fault zones which were detected on the ground surface by shearing, quartz veins, and silification (Purcell & Simpson, 1973) were often disguised in the trench cut by the weathering of the rock mass.

As reported by Purcell & Simpson (1973) the volcanic rocks are generally thickly bedded, but the distinction between bedding and jointing is not always clear; many of the prominent joint sets are probably bedding joints. Where definite bedding occurrs it is gently dipping to the west or to the south (<40^{o}). The sjdiments of the Canberra Group generally have altitudes similar to those of the associated volcanics, but contacts between the volcanics and the sediments are usually sheared and fractured.

The lenses of sediment (Canberra Group) in the Deaking Volcanics are elongated lenticular masses of hard brittle pale grey and blue-grey massive limestone and interbedded black mudstone and grey to brown-orange calcareous shale. The massive limestone is irregularly jointed in large blocks and some joints contain heavy plastic grey and red clay seams up to 15 cm thick. The finely laminated and cleaved shales are interbedded with mudstone units up to 1.5 m thick. Thin clay seams (<1 cm) are present on most open bedding planes in the shale and mudstone.

The massive limestone and argillites occur largely as discrete units but there is a minor occurrence of bedded limestone. Thin beds of tuffaceous sandstone (thickness less than 15 cm) are interbedded with the limestones and the argillites in several places. Nodular limestone and shale in the sedimentary lenses contain nodules of calcium carbonate, up to 30 cm in diameter, formed by precipitation of limestone in a concretionary form.

4. ENGINEERING GEOLOGY OF THE TUNNELS

4.1. Ryan Tunnel

4.1.1. Tunnelling Conditions

Tunnelling conditions (summarised in Plate 1) were good, as shown below by the lower percentage associated with rock condition numbers (RCN) 4 and 5 (see Appendix 1):

RCN	PERCENTAGE OF TUNNEL
2 and 2-3	13
3	43
3-4	15
4	19
4-5	6
5	4

Most of the tunnel was driven through slightly weathered or fresh rock (see Appendix 1). A breakdown is given below:

Degree of weathering	Percentage of tunnel length
Fresh	72
Slightly weathered	13
Moderately weathered	11
Highly weathered	2
Extremely weathered	2

4.1.1.1 Rock types (Plate 1)

Tunnelling in the purple rhyodacite was generally good. Sheared and fractured zones generally stood up well. Between stations 20 + 50 and 22 + 50, subhorizontal jointing with heavy limonite staining resulted in poorer tunnelling conditions, and overbreak of up to 1 m beyond C-line in places.

Tunnelling conditions were very good in the dark-grey dacite, which is very hard and strong. Most of the overbreak appeared to be induced by poor mining techniques rather than poor rock condition. Only a few narrow seams or shears were intersected.

Tunnelling conditions in the sandstone-mudstone-siltstone unit were fair to good. Contacts with other units were faulted; many fractures and sheared zones occurred along and across bedding-plane surfaces. Where fresh to moderately weathered, this unit stood up well, but steel support was required in sheared and highly weathered sections.

Tunnelling conditions in the shale were poor. Where fractured and clayey, the shale was steel supported.

The Rhyolite unit was intersected in two places along tunnel line and was found to be fractured and seamy, resulting in poor tunnelling conditions.

Tunnelling conditions in the green rhyodacite were generally good, except in a few wide zones of blocky rock and occassional sheared and fractured zones. This is reflected in lower seismic veocities than for the purple rhyodacite and the dark grey dacite units. The tunnel profile was generally ragged with clay and heavy limonite staining commonly on joint surfaces; most other major joint surfaces are slickensided.

The tuffaceous siltstone and shale are very finely laminated and fissile, with closely spaced (but generally not continuous) joints, resulting in blocky rock. This rock unit stood well, and tunnelling conditions were generally good. Minor clay and narrow sheared zones along bedding planes resulted in instability in some zones above springline, and required steel-set support.

Tunnelling conditions were generally good in the grey dacite agglomerate (Fig. 5). Most joints were tight and not continuous, but in places were partly open, resulting in blocky conditions. Most of the overbreak appeared to be due to poor mining techniques. Shearing and the presence of a dolerite sill near crown level, resulted in poor tunnelling conditions between stations 48 + 00 and 49 + 00.

Tunnelling conditions in the Mount Painter Porphyry were only fair, mainly because the tunnel was located in the weathered zone. Shearing had weakened the rock mass even further in places.

A summary of rock condition versus rock type is given below:

ROCK CONDITION NUMBER (RCN)

Rock type	3 or less	3-4	4	More than 4	% steel support for rock type
Dark grey dacite	92	8	-	-	2
Tuffaceous siltstone and shale	68	-	10	22	12
Sandstone, siltstone	64	-	36	-	24
Grey dacite agglomerate	63	-	11	26	28
Purple rhyodacite	58	15	13	14	17*
Green rhyodacite	41	30	23	6	8*
Shale	25	-	17	58	65
Rhyolite	10	-	45	45	75
Mount Painter Porphyry	-	-	-	100	100

* lower due to high rock mass of RCN 3-4 in which need for support was only marginal.

4.1.1.2 Tunnel support

The statistics on tunnel support are as follows:

Type of steel sets used:	10 x 7.5 cm x 4.5 kg (4 x 3 inch x 10 lb) RSJ (inside radius of steel 2.5 cm, or 1 inch, greater than B-line radius)**
No. of sets installed:	214
Timber lagging:	15 x 10 cm (6 x 4 inch) and some 15 x 5 cm (6 x 2 inch) hardwood*; spreaders 7.5 x 7.5 cm (3 x 3 inch) hardwood
Length of tunnel supported with steel:	242 m
Average spacing of sets:	1.1 m
Percentage of tunnel steel-set supported:	16%
Type of rock bolts used:	2.5-cm (1-inch) diameter, ungrouted slot and wedge anchors of 183 cm (6 ft) or 244 cm (8 ft) length
No. of rock bolts installed:	31

* 17 800 super feet used in tunnel

** Weight, including connecting and foot plates 95 kg (215 lb)

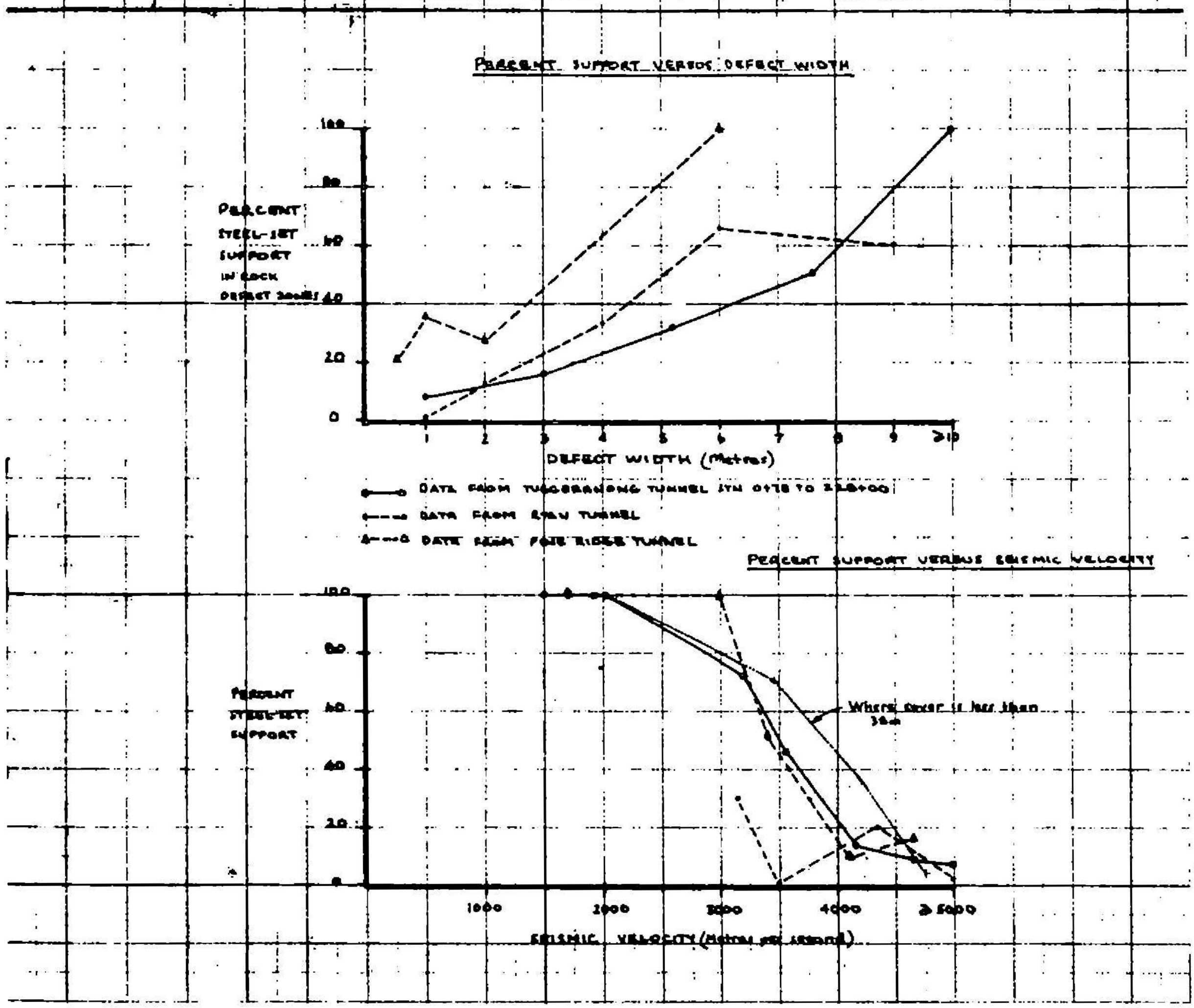
Rock unit	Length excavated	Percentage of total tunnel (m)	Percent of rock type supported
Mount Painter Porphyry	37	2	100
Green rhyodacite	591	39	8
Dolerite	< 3	<1	100
Grey dacite agglomerate	97	6	28
Rhyolite	30	2	75
Tuffaceous siltstone and shale	76	5	12
Purple rhyodacite	360	24	17
Shale	18	1	65
Sandstone and siltstone	128	8	24
Dark grey dacite	183	12	2
		100	100

Figure 4 shows the relationship between support and defect width, and support and seismic velocity, from data derived from Pine Ridge, Ryan and Tuggeranong Tunnels.

As with Tuggeranong Tunnel and to a slightly lesser extent Pine Ridge Tunnel, the dominance of steel-set support over rock-bolting for small diameter tunnels is evident. Where the rock condition is bad enough for support, the condition is generally bad enough for steel, although isolated slabs were more easily pinned with rock bolts.

PERCENT SUPPORT VERSUS SEISMIC VELOCITY AND DEFECT WIDTH

FIGURE 4



4.1.1.3 Excavation rates

Figure 5 compares the excavation rates for all three tunnels. The average excavation rate per day for Ryan Tunnel was about 7 m. This compares with 9.9 m for Tuggeranong Tunnel and 6 m for Pine Ridge Tunnel. The average tunnelling conditions for the three tunnels were about the same; the difference in excavation rates between the MVIS tunnels and Tuggeranong tunnel stems from the fact that 3 shifts per day were worked in the Tuggeranong tunnel, but not in the MVIS tunnels.

4.1.2 Tunnel overbreak

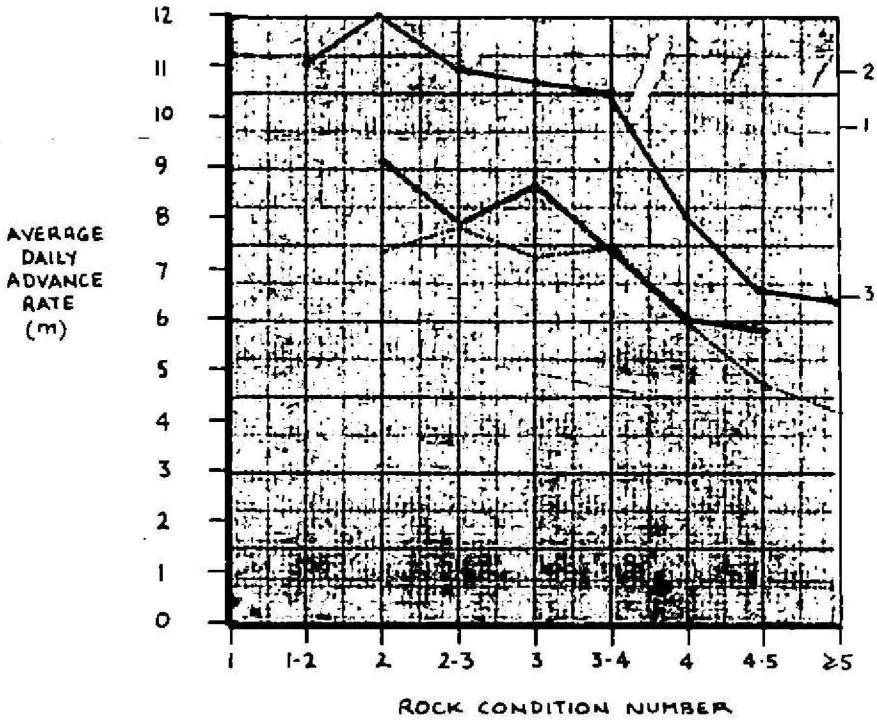
Calculations of percentage overbreak have been based on concrete placement quantities only (cf. Tuggeranong Tunnel). No survey data on overbreak was collected during construction. The percentages given are only considered approximate and are based on the following:

-C-line diameter	=	2.6 m at springline
-section area of tunnel	=	5.8 m^2 (C-line)
-internal tunnel diameter area	=	3.1 m
-area of pay concrete	=	2.7 m^2
-*volume of pay concrete per 29.2-m length of tunnel	=	79 m^3

* Most pours were over a length of 29.2 m.

Calculation of the average percent overbreak is as follows:

ROCK CONDITION AND TUNNEL EXCAVATION RATE FIGURE 5



NOTES:

———— Data from Tuggeranong tunnel

-------- Data from Ryan tunnel

.... Data from Pine Ridge tunnel

Tuggeranong tunnel:

1. Average tunnel advance rate
2. Average advance rate in unsupported rock
3. Average advance rate in supported rock

Sections of tunnel not included in these calculations are from:
- Stn. 0+78 to 6+00 (South portal)
- Stn. 294+00 to 296+30 (North portal)
- Sections of tunnel where switching stations excavated

Pine Ridge tunnel: Most of the data for Pine Ridge tunnel plots of RCN 4-5 and 5 were obtained from incompetent sediment beds within the dacite near the east portal. (stn. 6+80 to 12+20)

RELIABILITY OF PLOTS CAN BE ASSESSED BY COMPARING LENGTHS OF SECTIONS TALLIED FOR EACH ROCK CONDITION NUMBER (OBTAINED FROM TUNNEL LOGS)

ROCK CONDITION NUMBER	TOTAL LENGTH (m)			NUMBER OF DAYS TAKEN TO EXCAVATE		
	TUGGERANONG	RYAN	PINE RIDGE	TUGGERANONG	RYAN	PINE RIDGE
1-2	119			10.5		
2	250	17	73	20.5	2	10
2-3	774	143	125	70	18	16
3	3706	509	570	335	58.5	79.5
3-4	1327	79	396	123.5	7	54.5
4	1079	119	330	130	19	56
4-5	678	49	98	101	8.5	20.5
≥5	378		216	57		51.5

Concrete pours:		Volume concrete placed (m^3)
1-10		1275
11-20		1327
21-30		1269
31-40		1350
41-52		1661
	TOTAL	6882

The theoretical volume of pay concrete is the product of the cross-sectional area and the tunnel length:

$$2.74\ m^2 \times 1518\ m = 4159\ m^3$$

Average percentage overbreak is:

$$\frac{6882 - 4159}{4159} \times 100 = 65\%$$

The average overbreak for each rock unit is set out below: the percentages are regarded as approximate only.

Dark grey dacite	46
Green rhyodacite	66
Sandstone and siltstone	66
Tuffaceous siltstone and shale	66
Purple rhyodacite	70 (includes portal)
Rhyolite	74

Dacite agglomerate	81
Shale	82
Mount Painter Porphyry	114 (north portal)

Comparisons of overbreak with Pine Ridge and Tuggeranong Tunnels (set out below) are derived from concrete placement volumes, excluding grouting, and are related to C-line.

	Ryan	Pine Ridge	Tuggeranong
Unsupported tunnel	61	40	20 (30)*
Steel-supported tunnel	82	50	43 (56)*
Tunnel average overbreak	65	42	24 (35)*

* Percentages in brackets were obtained by averaging survey-derived and concrete placement figures obtained from Figure 5, Tuggeranong Tunnel completion report (Purcell, 1977).

The differences in the average tunnel overbreak in the three tunnels may be explained in three ways: (i) only 1% of Tuggeranong Tunnel was located in RCN more than 4, compared with 10% for Ryan and 15% for Pine Ridge Tunnels; (ii) errors in concrete placement measurements; survey derived overbreak data from Tuggeranong Tunnel (Purcell, 1977) gives an average of 44% overbreak which is closer to concrete figures for Ryan and Pine Ridge Tunnels; and (iii) more concrete was placed in Ryan and Pine Ridge Tunnels than shown in the batching figures.

4.1.3 Tunnel grouting, groundwater inflows, and repairs.

Groundwater inflows during excavation. The maximum outflow from the tunnel at any one time was about 11.4 m^3/h (11 400 l/h). Small and isolated water inflows or seepages were recorded from the south portal to about stn 36 + 00, particularly between stns 11 + 00 to 12 + 20. Most significant inflows were north of stn 36 + 00. The wettest section was between stns 36 + 00 and 42 + 00, where individual inflows were mostly between 200 and 500 l/hr. One inflow of 4500 l/hr was from an open joint at stn 39 + 40. North of stn 42 + 00, numerous moderate inflows (up to about 500 l/hr) leaked from open joints, fractured zones (including rock type contacts), and sheared zones. The first 30 m in the north portal was wetter immediately after periods of heavy rain. Most inflows dried up quite rapidly after excavation (generally within 1-3 days). The more significant inflows continued at a reduced rate, generally less than about 200 l/hr. During excavation, observation bores MV 4 and MV 12 were monitored; their results are shown in Figures 10 and 11.

Tunnel grouting and groundwater inflows. There was no apparent correlation between backfill-grout takes and steel-supported versus unsupported ground (see section 4.2.2.).

A pattern of circumferential cracks (other than construction joints) developed in the lining and allowed the entry of some groundwater. The volume of groundwater entering the tunnel after lining was measured by V-notch weirs situated at the downstream portals:

Ryan Tunnel:	1650 l/hr	(May 1976)
Pine Ridge Tunnel:	2650 l/hr	(February 1976)

No particular areas of lining made significant quantities of groundwater. Water accumulated as small dribbles and seepages, and it was concluded that pressure grouting was not necessary in either tunnel.

Concrete shrinkage cracks ranged in width from 0.04 mm to 1.33 mm. Most were less than 0.30 mm wide, and most were spaced about 7 m apart, but some were as little as 3 m apart.

Tunnel repairs. Repairs to the tunnel lining were of three types:

(i) Those required as a result of construction methods such as spud bore and grout holes. These were repaired by filling with a dry pack mixture of one part cement to three parts of sand and enough water to allow the mixture to be moulded and tamped by hand. Where water seepage hindered repairs the holes were plugged with a calcium chloride mix, followed by the dry mix.

(ii) Where the standard of finish was poor, such as honey combed concrete; (iii) other damage. Repairs to (ii) and (iii) were in the form of gunite (shallow wide areas up to 10 cm deep), concrete placement (large areas, especially in invert), epoxy mortar and epoxy concrete (mainly in invert where quick seting is required) or expoxy paste (chipped and spalled areas, especially precast pipes).

4.1.4 Predicted versus construction conditions

4.1.4.1 Rock types

The rock types intersected during tunnelling were predicted quite accurately, except for some shale, sandstone, and siltstone between stns 11 + 00 and 18 + 00 (470 feet). The sediments between stns 11 + 00 and 18 + 00 were not evident on the surface although a major airphoto-lineation marks their northern boundary. Several different flows with in particular units were recognisable in the tunnel but not in surface outcrop (e.g., the dark grey dacite and purple rhyodacite between stns 0 + 47 and 11 + 00).

4.1.4.2 Airphoto-lineations

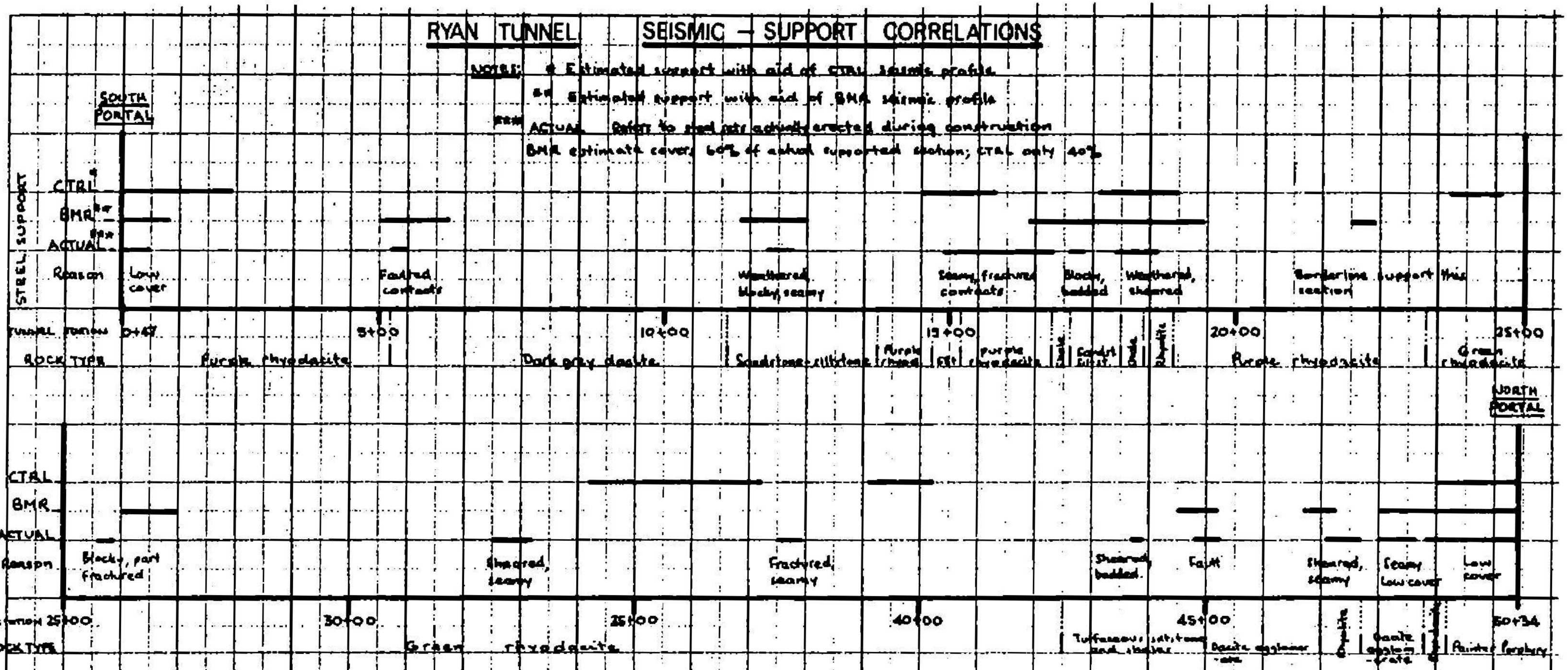
Airphoto-lineations were generally a good indication of major structures, but many minor features went undetected (Plate 1). Some difficulty was experienced in interpreting the geology in the pine forest over much of the route. Lineations also correlated well with seismic anomalies. The geological significance of each lineation is outlined below:

- lineations at 6 + 00 probably related to change in lithology (faulted contact)
- lineation at 12 + 50 represents sheared zone
- lineation at 19 + 00 represents change in lithology
- lineation at 36 + 50 represents sheared zone
- lineation at 38 + 60 has an uncertain significance
- lineation at 44 + 90 represents sheared zone

4.1.4.3 Seismic refraction survey

A poor correlation was found between the Department of Construction Central Testing and Research Laboratories (CTRCL) seismic results and actual tunnelling conditions in the first tunnel sections, and BMR re-shot the entire route. Correlation of the BMR seismic results with excavation conditions was excellent (Plate 1). Figure 6 shows seismic-support correlations for both BMR and CTRL results: BMR results are shown to be more accurate than CTRL. Anomalies in bedrock velocities indicated both structural and lithological changes. Certain velocities could also be correlated fairly well with different lithologies and also with rock producing poor tunnelling conditions (see Plate 1).

Correlations of seismic anomalies and velocities with defects and lithologies have been summarised below.



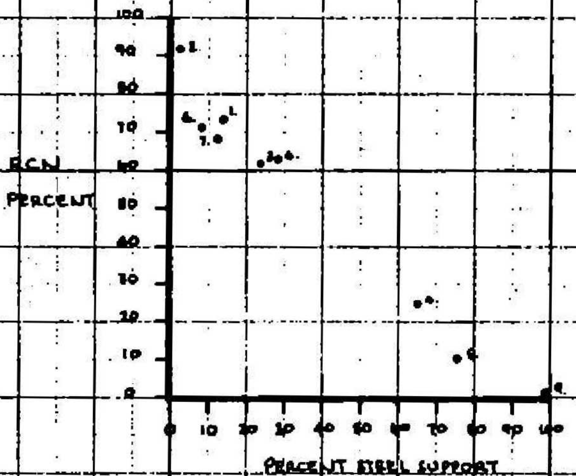
ROCK TYPE CONDITION VERSUS SUPPORT

RYAN TUNNEL

NOTE:

RCN PERCENT: Totalled length (feet) of RCN 2, 2-3, 3, and 3-4 expressed as a percentage of total length of each rock type tunnelled.

This graph shows tunnelling conditions in rock units 4, 5 and 7 to be significantly worse than in the other units.



KEY:
1. Purple rhyodacite
2. Dark grey dacite
3. Sandstone/siltstone
4. Shale
5. Rhyolite
6. Green rhyodacite
7. Tuffaceous siltstone/shale
8. Grey dacite agglomerate
9. Painter porphyry

FIGURE 6

Anomaly stn	Significance
6 + 20	Change in lithology. Faulted boundary
11 + 40 to 12 + 50	Low-velocity zone; rock blocky and seamy
16 + 40 to 19 + 30	Many lithological changes - faulting common
20 + 80	Possibly faulting
22 + 10 to 22 + 50	Low-velocity zone associated with several small faults
26 + 00	Decrease in velocity due to many narrow sheared zones
44 + 50 to 45 + 00	Low-velocity zone - major sheared zone and lithology change.

The sandstone-siltstone unit with a velocity of 3200 m/s (stn 11 + 00 to 18 + 00) and the green rhyodacite unit with a velocity of 3200 to 4100 m/s are the only two units whose velocities are noticeably lower than the others.

4.1.4.4 Groundwater inflows

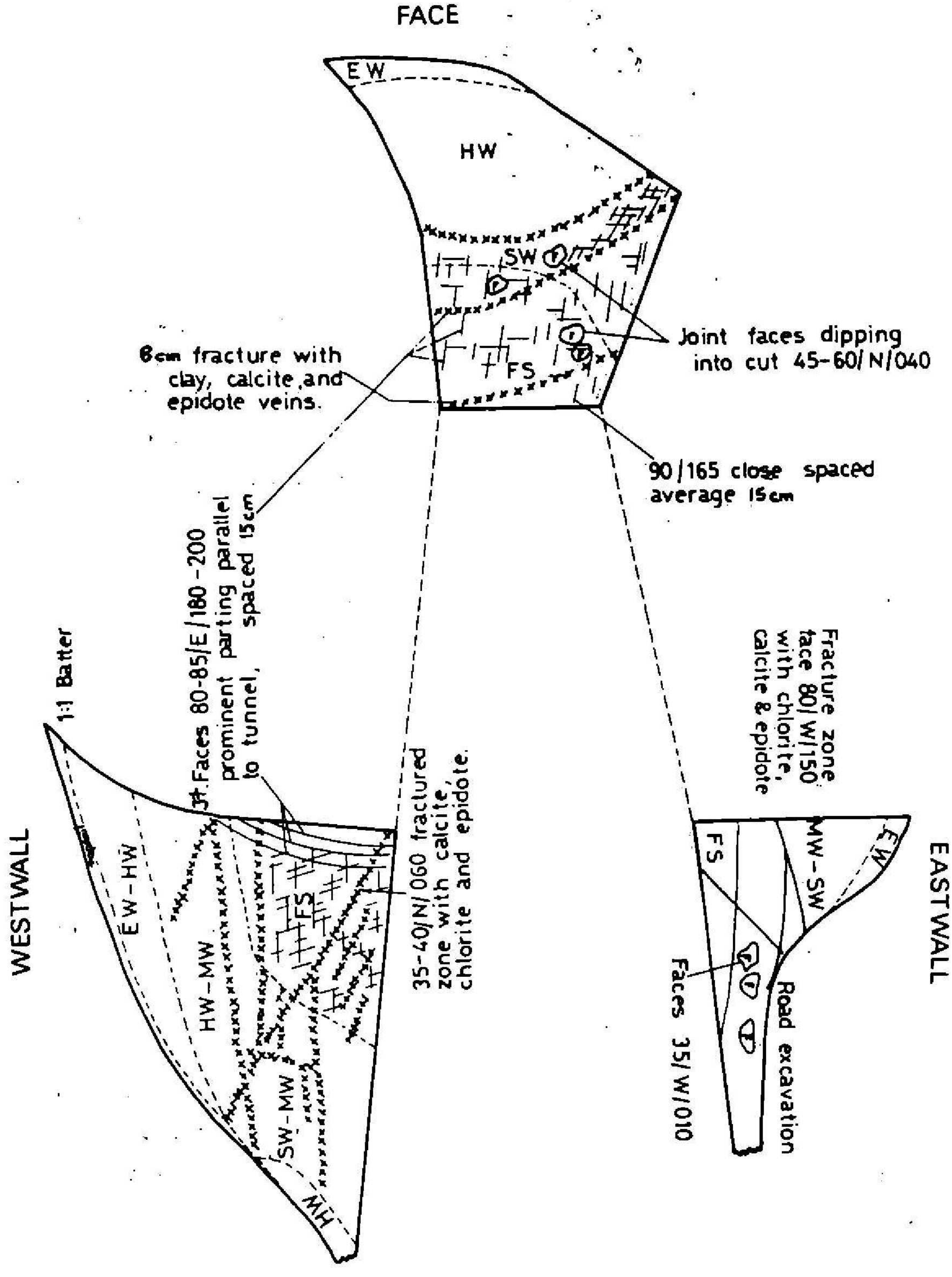
Groundwater inflows were generally as predicted from the south portal to about stn 36 + 00. Initially, the tunnel made more water north of stn 36 + 00 than expected, but flows decreased rapidly and did not hinder tunnelling progress.

4.1.4.5 Tunnel portals (Fig 7 and 8)

South portal (inlet)

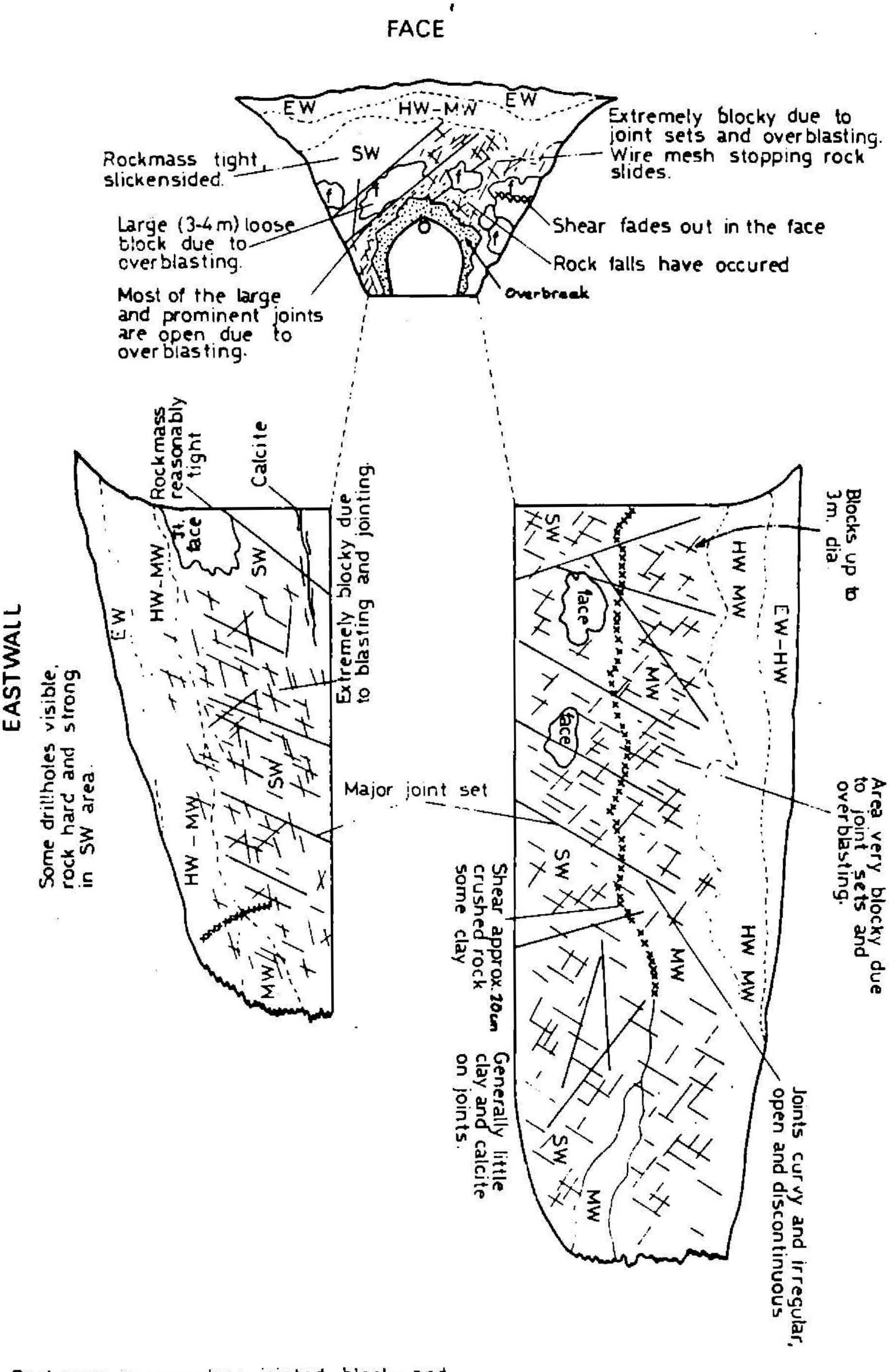
Less support was required than predicted (11 m instead of 58 m).

RYAN TUNNEL - SOUTH PORTAL



Rock mass is very close jointed, blocky and very loose. Narrow fracture zones (less than 15cm) with clay seams and calcite; clay and epidote veins are common. Rock is a very hard and strong blue-grey Dacite, with large quartz and felspar phenocrysts in an aphanitic dark grey groundmass.

RYAN TUNNEL - NORTH PORTAL



Rockmass is very close jointed, blocky and very loose. A few narrow shear zones (width less than 20cm) with occassonal clay seams and calcite veins. Rock is a hard and strong blue-grey Rhyodacite.

FIGURE 8

The original assessment was based primarily on the CTRL seismic profile. The BMR seismic profile was more accurate and correlated better with drillhole MV 1. The BMR-survey bedrock refractor, which had a velocity of 4800 m/s compared with 3000 m/s in the CTRL survey, was located 4-5 m above that of CTRL; the amount of support estimated from the BMR seismic results would have been about 18 m.

North Portal (outlet).

More support was required at this portal than for the south portal, but it was predicted fairly accurately. BMR seismic results gave a more pessimistic picture than did the CTRL profile, but proved to be a more accurate prediction of geological conditions.

4.2 Pine Ridge Tunnel

4.2.1 Tunnelling conditions

Tunnelling conditions (summarised in Plate 2) were generally good, with similar RCN percentages to the Ryan Tunnel.

RCN	PERCENT OF TUNNEL
1, 2, 2-3	15
3	30
3-4	20
4	20
4-5	4
5	11

Most of the tunnel was driven through fresh and slightly weathered rock as shown below:

Degree of weathering	Percentage of tunnel length
Fresh and slightly weathered	88
Moderately weathered	3
Highly and extremely weathered	9

4.2.1.1 Rock types

Dacite agglomerate. This rock type was generally highly weathered at tunnel level and was soft and friable. Several sheared zones caused some overbreak and instability.

Shale and sandstone. Between stns 7 + 00 and 12 + 00 the shale and sandstone gave poor tunnelling conditions owing to bedding-plane shears, other fractures, folds, and high to extreme weathering of certain beds. Many shears were badly oriented for the tunnel alignment and caused up to 2 m of overbreak, mostly in the tunnel crown. The sediments near stn 26 + 00 were generally quite competent with only minor shearing and mainly discontinuous (but close) jointing.

Green-grey and red stained dacite. Those rocks are generally hard, tight, and competent, and provided the best tunnelling conditions of all the rock types. Several sheared and fractured zones up to about 2 m wide occur; other sections are blocky, producing a ragged tunnel profile. Tunnelling conditions were very good (Fig. 16).

Blue-grey dacite. This rock type gave good tunnelling conditions. Some blocky seamy and sheared zones required supprot.

The lengths and percentages of each rock type excavated are as follows:

Rock type	Length	Percentage of tunnel
Dacite agglomerate:	125 m	6
Shales and sandstones:	186 m	9
Green and green-red dacite:	701 m	35
Blue-grey dacite:	987 m	50
TOTALS	1999 m	100

A summary of rock condition versus rock type is given below:

ROCK TYPE	ROCK CONDITION NUMBER 3 or less	3-4	4	More than 4	% steel support for rock type
Dacite agglomerate	-	-	-	100	100
Sediments	15	-	10	75	82
Blue-grey dacite	50	30	14	6	5
Green-grey dacite	70	7	22	1	1.4

4.2.1.2 Tunnel support

The statistics on tunnel support are as follows:

Type of steel sets used:	10 x 7.5 cm x 4.5 kg (4 x 3 inch x 10 lb) RSJ (inside radius of steel 2.5 cm, or 1 inch greater than B-line radius)**
No. of sets installed:	311
Timber lagging:	15 x 10 cm (6 x 4 inch) and some 15 x 5 cm (6 x 2 inch) hardwood*. Spreaders 7.5 x 7.5 cm (3 x 3 inch) hardwood.
Length of tunnel supported with steel:	340 m
Average spacing of steel sets:	1.1 m
Type of rock bolts installed:	2.5 cm (1 inch) diameter ungrouted slot and wedge anchors 244 cm (8 ft) long.
No. of rock bolts installed:	330

* 33,000 super feet used in this tunnel

** Weight, including connecting and foot plates 123 kg (272 lb).

Rock type	Length supported (m)		Percentage of rock type supported	
	Steel set	Random Rock bolts	Steel sets	Rock bolts
Dacite agglomerate	125	none	100	none
Sediments	151	17	82	9
Blue-grey dacite	54	88	5	9
Green-grey red dacite	10	155	1.4	22
TOTALS	340	260	17	13

Figure 4 shows the relation between support, defects, and seismic velocity.

More rock bolts were used in Pine Ridge Tunnel than in Tuggeranong or Ryan tunnels. Most bolts were inserted as required in blocky and seamy rock; spacing was random. The following is a breakdown of where the bolts were used:

- blocky and seamy rock : 83%
- sheared mudstone : 8%)) 12%
- individual poorly oriented sheared zones : 4%)
- Shallow dipping joints in tunnel crown : 5%

4.2.1.3 Excavation rates

Figure 5 shows the excavation rates for the different rock conditions encountered in the Pine Ridge, Ryan, and Tuggeranong Tunnels. The average excavation rate for the Pine Ridge Tunnel was 6 m per day. Excavation rate in the sediments of 4 m per day was slower than in the volcanics because most of the sediments were supported.

4.2.2 Tunnel overbreak

Calculations of percentage overbreak have been taken from concrete placement data. The percentages given are approximate only and are based on the following:

- C-line diameter of tunnel = 3.2 m (at springline)
- section area of tunnel = 9.05 m^2 (C-line)
- internal tunnel diameter area = 5.28 m^2
- area of pay concrete = 3.77 m^2
- *volume of pay concrete per 27.4 m length of tunnel = 103.3 m^3
- *volume of pay concrete per 18.3 m length of tunnel = 69.0 m^3

* Concrete pours were over 27.4 m or 18.3 m of tunnel length.

Calculation of the average percentage overbreak is as follows:

Concrete pours	Volume of concrete placed (m^3)
1-10	1306
11-20	1482
21-30	1395
31-40	1545
41-50	1265
51-60	1410
61-70	1429
71-75	734
TOTAL	$10566 m^3$

The theoretical volume of pay concrete is the product of the measured length of concrete poured and the area of pay concrete:

$$1977\ m \times 3.77\ m^2$$

$$= 7453\ m^3$$

Average percentage overbreak is:

$$\frac{10566 - 7453}{7453} \times \frac{100}{1} = 41.8\%$$

Values for overbreak in unsupported (40%) and steel supported rock (50%) have been given in section 4.1.2. Also of interest, is the fact that rock-bolted sections of tunnel were calculated to have an average overbreak of 47%, which is closer to the figure for steel-supported tunnel than for unsupported tunnel. Additional discusson, comparing results from Pine Ridge, Ryan, and Tuggeranong tunnels, also appear under section 4.1.2 of this report.

Overbreak and rock type

Overbreak percentages for the different rock types are as follows:

Dacite agglomerate	:	49%
Sediments	:	35%
Blue-grey dacite	:	46%
Green-grey-red dacite	:	45%

Overbreak and rock condition

Overbreak percentages (C-line) for rock with various RCNs are given below. Percentages are approximate and are compared with concrete placement overbreak from Tuggeranong Tunnel.

RCN	Pine Ridge	Ryan	Tuggeranong		
	Concrete placement			Survey	Mean
1 to 3	30%	60%	15%	(32%)*	(23)**
3-4 and 4	45	70%	30	(52)*	(41)**
4-5 and worse	48	86%	35	(60)*	(47)**

* Concrete overbreak calculated from tunnel survey

** Mean of both percentages

As discussed for the Tuggeranong Tunnel (Purcell, 1977), the percentage overbreak is probably somewhere between the figures obtained from concrete placement and survey-derived figures. In the percentages given above the percentage overbreak for the Tuggeranong Tunnel may be nearer the mean values 23%, 41%, and 47%. These mean percentages are closer to the figures for the Pine Ridge Tunnel than those for the Ryan Tunnel. The discrepancy between the Ryan Tunnel and Pine Ridge percentages cannot be determined on the existing data. Possible explanations could be: (i) unreliability of some of the concrete placement data (particularly of the Ryan Tunnel?); (ii) careless excavation of Ryan Tunnel; and (iii) the backfill grout figures for steel supported sections of the Ryan Tunnel are significantly greater than for the Pine Ridge Tunnel (as shown below), and suggest that more overbreak was associated with rock zones requiring steel support.

Average backfill grout takes (in bags per linear foot)

	Steel supported tunnel	Not supported	Tunnel averave
Pine Ridge	0.28	0.29	0.29
Ryan	0.79	0.19	0.27

4.2.3. Groundwater inflows

East heading. Groundwater outflows gradually increased with excavation from the east portal to about stn 30 + 00; outflows gradually decreased until tunnel breakthrough at stn 37 + 60. The maximum outflow was estimated at 7000 l/h and much of this water was intersected between stns 18 + 00 and 20 + 00 and to a lesser extent stns 26 + 00 to 30 + 00. Other significantly wetter sections were in the sediments (e.g., stns 7 + 50 and 19 + 00, where individual inflows in excess of 1000 l/h occurred), and at stns 30 + 00 and 36 + 00 to 37 + 00, where smooth open joints occur. Inflows decreased quite rapidly within a few days to a fraction of their initial flow rate.

West heading. Most significant inflows originated from fractured and sheared zones.

Measured outflows from this heading were larger than from the east heading. The maximum outflow recorded was about 20 000 l/h, mostly as a result of inflows between stns 49 + 00 and 53 + 00, where rock is fractured and open and most was supported by rock bolts and steel sets. Increased outflows due to this zone were only temporary, and within a few days had reverted back to about 8000 l/h. Water inflows occurred where fractured, loose, and open zones were intersected; these zones made up to 1500 l/h initially (e.g., stns 50 + 92 and 45 + 60).

Inflows after breakthrough. After tunnel breakthrough the tunnel was making a constant 4500 l/h. This figure would have been greater than 4500 l/h had concrete lining of the east heading not commenced before breakthrough, by which time the east heading had been concrete-lined to stn 25 + 96.

Water quality. During excavation two water-quality readings were taken by the authors:

- stn 51 + 00 (23/6/74):
  pH = 7.5, 967 Micro S/cm at 25°C

- stn 60 + 80 (17/5/74)

An additional five water-quality analyses were carried out by AMDEL during construction, and the results are given in Appendix 3.

Effect of inflows on construction. Inflows were generally considered of nuisance value and did not result in significant losses in construction time. Excessive water accumulated in the east heading only when pumping was discontinued (e.g., over some weekends).

4.2.4 Predicted versus construction conditions

4.2.4.1 Rock types

Surface mapping for the design investigation did not extend far enough away from the tunnel line to prove the existence of sedimentary rocks within the volcanics; however, the possible occurrence of sediments along the tunnel line was stated in the design report. More detailed mapping during construction of this tunnel, combined with the design investigation for the Ginninderra Sewer Tunnel, accurately located the extent of the sediments in Pine Ridge Tunnel, but only after they were first intersected. No strong airphoto-lineations cross the tunnel route; it was difficult to correlate the few weak lineations with any structure or lithology change.

4.2.4.2 Rock condition

The seismic profile from the inlet portal to stn. 35 + 00 (Plate 2) was done by CTRL before construction started. In an attempt to define structure more clearly, the downstream half of the tunnel route was re-shot by BMR during excavation of the east heading.

The CTRL seismic profiles were successful in locating a lower-velocity bedrock section, between stns 5 + 00 and 12 + 00; however, the character of the rocks in the 3000 to 3200 m/s velocity section was not known until excavation had started. Apart from this zone, the CTRL seismic profile was not detailed enough to locate narrower zones of poorer quality rock, and this was the reason why BMR duplicated the CTRL work on the west heading.

The BMR seismic profiles did define narrow low-velocity zones in otherwise high-velocity, high-quality rock. Matching the low-velocity zones with geology was not always possible, but the frequency and width of these zones did relate quite well to construction conditions.

4.2.4.3 Groundwater inflows

In the design report only small groundwater inflows were predicted. Predicted inflows based on water-pressure tests in drillholes MV 7 and 11 gave expected inflows of 1800 l/h, which proved to be consistent with flows intersected. Mention was also made of wet conditions likely to be encountered if sedimentary rocks were intersected, and one of the wettest sections of tunnel turned out to be the sedimentary section near the east portal.

4.2.4.4 Tunnel portals

East portal (inlet; Plate 3). The design report inferred that steel-set support would be required to about stn 7 + 50. Support was placed from the portal (stn 2 + 60) to stn 12 + 20. The large number of sets required was mainly due to the occurrence of the sediments. The portal cut was quite stable (Plate 3).

West portal (outlet; Fig. 9). Very little support was predicted at the outlet portal, but no gigures were given. CTRL seismic profiles suggested steel support would be required from the portal face to about stn 67 + 40: supprot was erected to 67 + 70 (i.e., 30 feet less than anticipated). No major instability of the portal cut existed.

4.3 Groundwater observation bores

4.3.1 Ryan tunnel

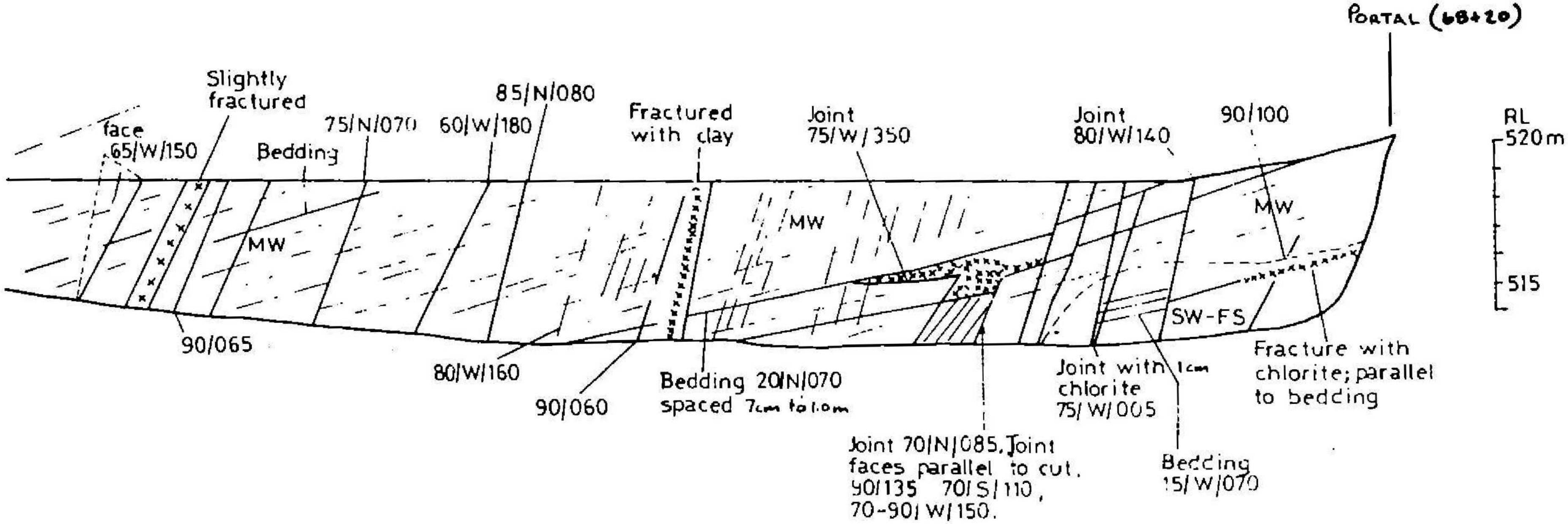
Two bores were monitored during tunnel construction:

(i) drillhole MV 4 (8 cm diamond-drill hole)
(ii) bore MV 12 (15 cm observation bore)

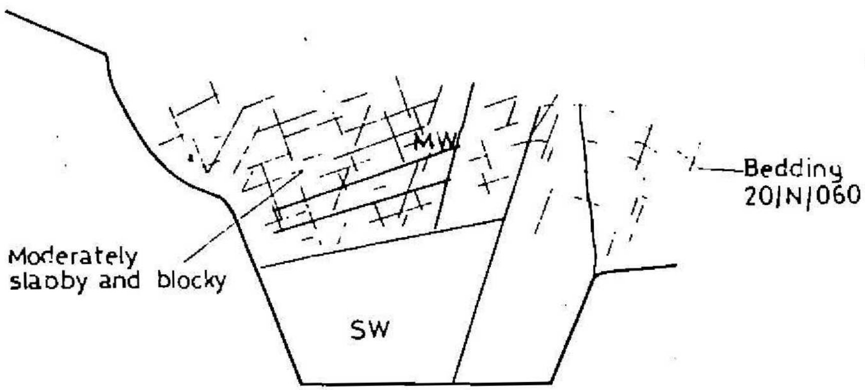
FIGURE 9

PINE RIDGE TUNNEL WEST PORTAL

NORTHWALL



ROCK TYPE: BLUE DACITE



SCALE 1:250 (approx.)

PORTAL FACE

The effect of tunnelling on water-levels in the two bores is shown in Figures 10 and 11. In both bores, groundwater-levels were lowered to near tunnel invert quite rapidly (78 days for MV 4 and 95 days for MV 12). The drop in water-level in hole MV 4 was more irregular than that in MV 12. In hole MV 4, water subsidence commenced when the tunnel face was at stn 40 + 60, (245 m away from the bore). An increase in the rate of subsidence occurred when the tunnel face was at about stn 34 + 50 (about 75 m away from the bore); the reason for this may be explained by the worsening in rock condition from RCN 3 and 3-4 (stns 40 + 60 to 34 + 50) to a RCN of 4 and 4-5 between stn 34 + 50 to the bore at stn 32 + 00. Between 34 + 50 and the bore the rock is blocky and seamy with many open joints and fractures allowing a rapid draining of groundwater from the zone between the tunnel and the bore.

Since concrete lining of the tunnel was completed in January 1976, groundwater-levels in the bores have risen less than 1 m from the bore-levels attained after excavation.

4.3.2 Pine Ridge Tunnel

Detailed observations of groundwater-levels in drillholes were not kept. However levels before and after excavation are known for holes MV 11 (investigation drillhole) and MV 13 (15 cm observation bore):

	Pre-construction levels	Post-construction levels
MV 11	7.3 m	50m
MV 13	16.5 m	66m

Record 1979/27

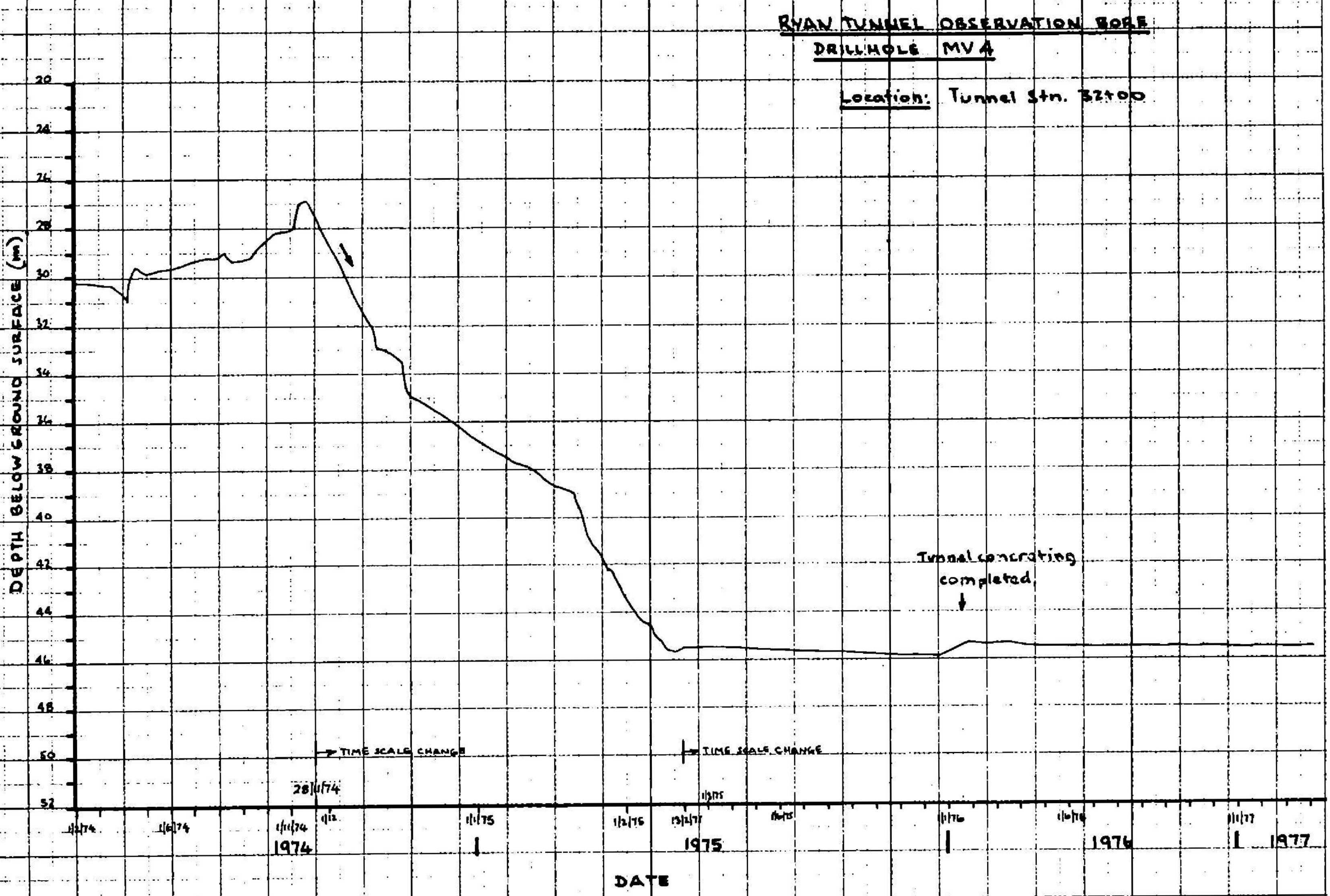


FIGURE 10

I55/A16/2002

Record 1979/27

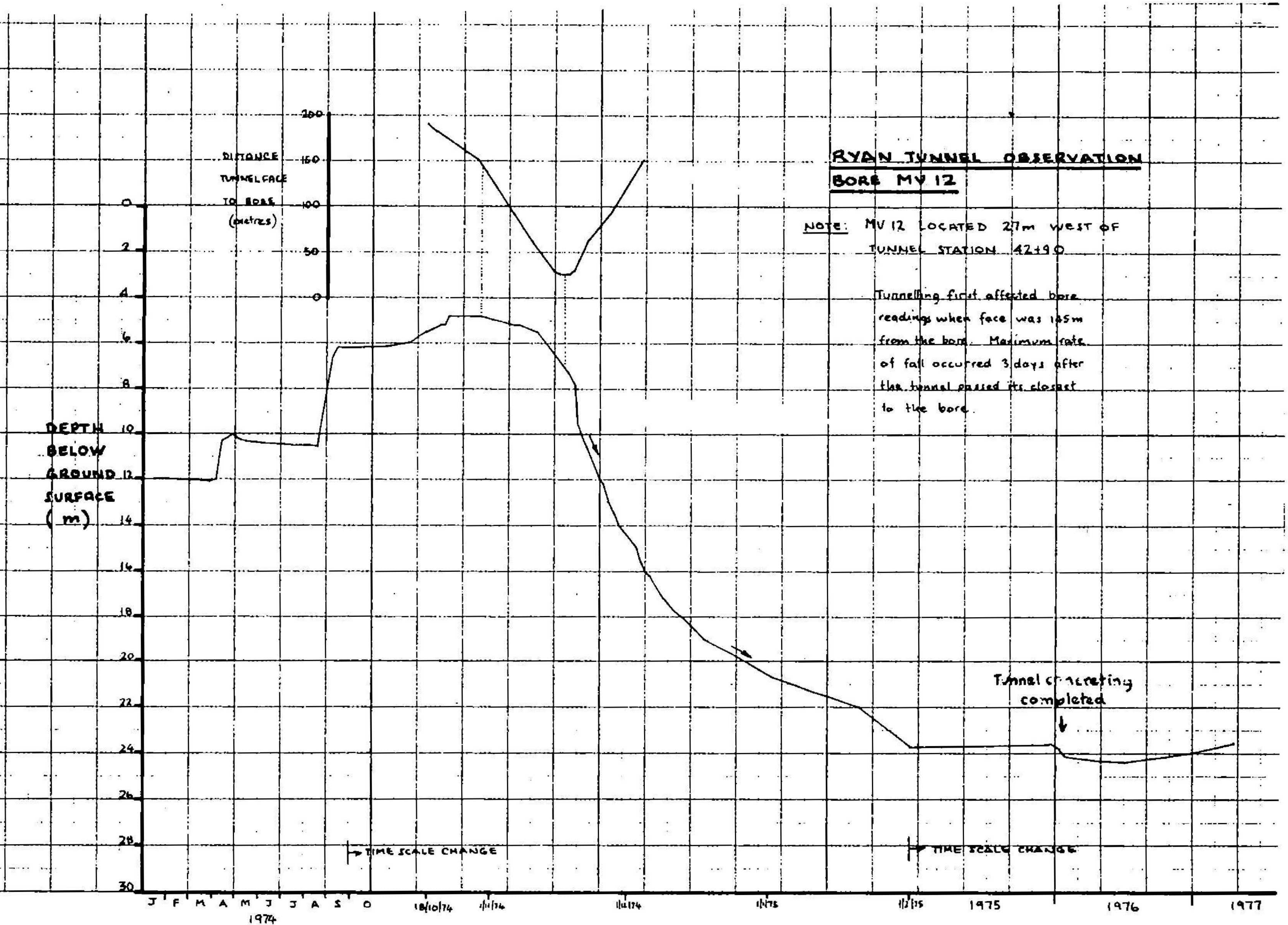


FIGURE 11

4.4 Conclusions

1. Excavation conditions for both tunnels were generally as predicted, although some beds of sediments encountered were not predicted. Both tunnels required about the same amount to support: Ryan 16%, Pine Ridge 17%.

2. Tunnelling in the welded volcanics was generally good to excellent, but ranged from poor to good in rhyolite and sedimentary beds.

3. All contacts between different rock units were fractured, faulted, or sheared to varying degrees. This is not unusual and has also been noted in other tunnels through Silurian strata in the ACT.

4. As expected, water inflows were relatively minor, and were only a nuisance whenever the pumps were shut down for several days, allowing water to accumulate in tunnel invert.

5. Overbreak percentages for both tunnels, calculated from concrete placement data, differ markedly. Poor tunnelling techniques or inaccurate concrete placement records are the likely reasons, as overall tunnelling conditions in both tunnels were similar.

6. Seismic profiles provided the best pre-construction data for the geologist in the prediction of tunnelling conditions. CTRL seismic profiles were not as reliable as BMR profiles, probably because BMR geophysicists are more experienced in Canberra's geological environment, and are able to work more closely with the project geologist during the interpretive stage.

5. ENGINEERING GEOLOGY OF THE PIPELINE SECTION

5.1 Excavation Conditions

5.1.1. General

The pipeline trench was excavated by pre-blasting a linear pattern of blast holes to loosen the rock. This was followed by excavation with a Poclain HC 300 excavator with a bucket capacity of 1.7 m^3. Tight spots in the trench were removed with a jackhammer or blasted if too large.

5.1.2 Mount Painter Porphyry and Deakin Volcanics

Excavation conditions and stability of open cut in the Mount Painter Porphyry and Deakin Volcanics depended on the degree of weathering and structure. The Deakin Volcanics were generally less weathered than the Mount Painter Porphyry at similar depths and required heavier primary blasting and more drilling of tight spots.

Excavation in the Mount Painter Porphyry was mainly in highly weathered and completely weathered rock, soil, and colluvium (Fig. 17). Although moderately weathered and slightly weathered rock does dominate some sections of the trench (e.g., stn 0 + 00 to 9 + 00) it is mainly confined to isolated elongated and dome-shaped occurrences. Fresh and fresh stained rock is relatively rare in the trench in the Mount Painter Porphyry. As the pipeline approaches the Ryan Tunnel (stn 0 + 00 to 9 + 00) it is located deeper within the Molonglo River Gorge where the rock is less weathered. An increasing amount of moderately weathered, and slightly weathered porphyry was excavated from the trench, and heavy blasting was required.

In the Deakin Volcanics, moderately to slightly weathered rock was excavated wherever the trench cut through spurs; presumably the less weathered material had been removed by erosion. (e.g., stns 310 + 80 to 313 + 00, 234 + 50 to 238 + 00 and 284 + 00 to 288 + 00).

Highly and completely weathered rock was easily excavated after primary blasting and provided a good trench profile. Where large zones of moderately weathered rock were encountered secondary blasting was sometimes required but generally it was rippable with a mechanical shovel after primary blasting. Most of the slightly weathered and fresh rock sections required secondary blasting of tights (under excavated sections) except where they were small and could be ripped.

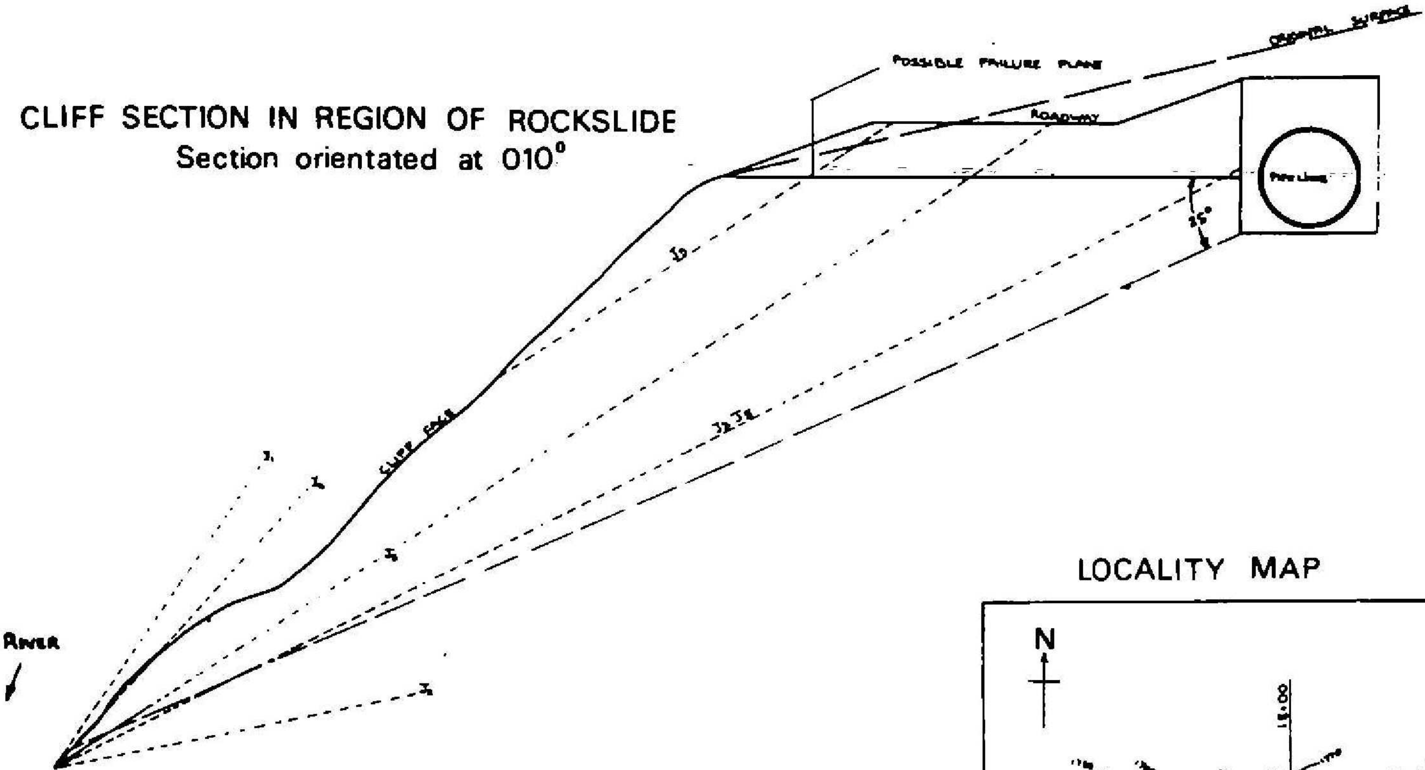
The structure of the dacite controlled excavation conditions and stability to a lesser degree than weathering. Jointing was the principal defect affecting instability in the trench. Overbreak was usually due to: (a) close-spaced joint sets dipping steeply into the trench, or (b) intersection of two or more prominent joint sets promoting planar and wedge failures. These conditions often resulted in partial failure of the trench walls resulting in a ragged trench profile. Joint planes which formed failure surfaces were usually coated with heavy, plastic grey clay up to several centimetres thick, and some of the larger wedge failures were bounded by clay seams and shears.

5.1.3 Canberra Group

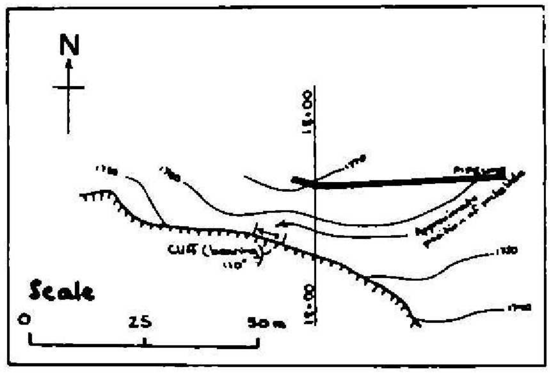
The Canberra Group sediments provided difficult excavation conditions because of the contrast in degree of weathering between the limestone (fresh and fresh-stained), shale (highly to completely weathered), and mudstone (slightly to moderately weathered). The massive limestone required extensive secondary blasting that shattered and fractured the shales, causingg large overbreak, particularly where the sequence dipped into the trench (e.g., stns 204 + 30 to 205 + 30). Overbreak in the mudstone-shale interbeds was assisted by thin clay coatings on the bedding planes and the presence of prominent steeply dipping joint sets.

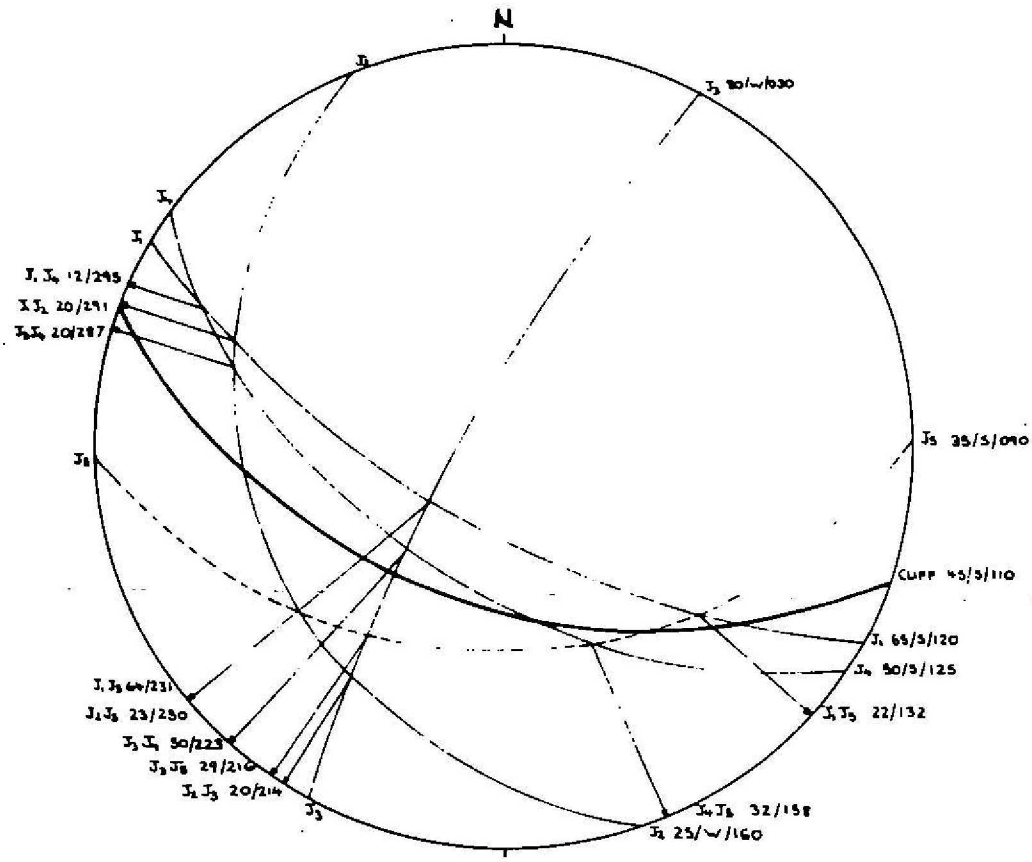
PIPELINE ROUTE
ROCKSLIDE AT STATION 18+30

CLIFF SECTION IN REGION OF ROCKSLIDE
Section orientated at 010°



LOCALITY MAP





LOWER HEMISPHERE STEREOGRAM
OF JOINT SETS

The massive limestone was hard and brittle and steeply and irregularly jointed in large blocks. Considerable overbreak occurred on blasting because the limestone had to be removed in large blocks (up to 2 m), resulting in a ragged trench profile.

5.1.4 Rockslide at stn 18 + 30

A small rockslide occurred in the cliff section adjacent to the road at about stn 18 + 30 along the pipeline route (Fig. 12). The rockslide occurred in moderately weathered to extensively weathered porphyry which failed along a zone of extreme weathered rock. The slide is 5 m wide at the top of the cliff and extendds about one third of the way down the cliff face. A number of trees t the base of the cliff partly support sections of the rockmass. Rubble from the slide piled up against these trees, which are being undercut by the river during flood times. These trees will eventually fall and bring about additional minor sliding.

The slip surface has an average slope of 45° but failure occurred on two principal joint sets, 60-80/S/110-145 (J1) and 20-30/SW/140-190 (J2). The secondary joint sets 50-60/S/115-140 (J4) and 35-40/S/085-090 (J5) also form some slip surfaces. The joint 75-90/W010-060 (J3) has further increased the blockiness of the rock in the vicinity of the slide, facilitating planar failure as well as wedge failure.

Wedge failure is most favoured on J3, J5 (29/216), and planar failure on J5 (35/S/090; see stereogram, Fig. 12). Failure along these joint surfaces would probably not endanger the pipeline (see cross section) but sections of the pipeline roadway may be affected. Some small slips will occur along the joint sets (J1, J2) adjacent to the present slide, and will assist in undermining the roadway beside the pipeline. J2 is the only joint set that extends back under the pipeline, but it is probably too shallow (less than the angle of friction) to form a failure plane and thus it is unlikely that the pipeline is endangered by slip along J2 joint surfaces.

Owing to the likelihood of future small slides along the steeper joint sets, and to the possibility of larger scale planar (J5) or wedge failure (J3, J5), this section of the pipeline route should be kept under observation.

5.2 Groundwater and surface water

Groundwater infiltration was minor in the Mount Painter Porphyry and was not a problem in excavation. However, groundwater infiltration into some sections of the open cut in the Deakin Volcanics was a problem. Abnormally high rainfall during 1974 caused problems of surface runoff into the trench and groundwater inflows through shears, open joints, and seepages from clay seams; as a result, sections of wall collapsed. Pumping was required in some sections of the trench and waterlogging of rolled pipe bedding material caused instability and resulted in concrete pipe supports cracking and subsiding.

The biggest problem with groundwater was at Drain Crossing 17 (stn 216 + 00), which was interpreted as a possible ancient landslip. Excavation through this zone (stn 215 + 70 to 217 + 30) revealed about 3 m thickness of saturated silt, silty loam overlying completely weathered dacite. At the head of the landslip is a spring with a rocky scarp behind and several thousand litres per hour was draining into the excavation from the slip material. On advice from BMR a gravel drain was constructed under the sewer pipe to prevent the water being dammed by the pipe. An agricultural pipe in a gravel bed was used as a catchment along the trench section facing the slide material and water collected was piped through the concrete support at the base of the sewer pipe.

Surface inflow at gully and creek crossings was piped over the top of the trench or allowed to flow into the trench and drained through the base of the opposite wall. Delays in pouring concrete bedding and box culvert sections (gully crossings) sometimes occurred when silt and clay was being continually washed in by groundwater and/or surface water inflow.

Fig 13 : Ryan Tunnel inlet portal - large overbreak with support and logging; mesh and rock bolts around the portal.

Fig 14 : Ryan Tunnel, stn 47 + 20 west wall, showing dark green olivine dolerite sill in rhyolite agglomerate. (RCN 4-5).

Fig 15 : Ryan Tunnel, stn 46 + 20. Overbreak in wall as a result of planar slickensided joints in grey dacitic agglomerate. (RCN 3-4).

Fig 16 : Pine Ridge Tunnel, stn 62 + 70. Joints (? bedding) in blue grey dacite. (RCN 3-4).

Fig 17 : Pipe-laying in Mount Painter Porphyry near Coppins Crossing Road. (M2256/4)

After completion of the pipeline section of the route there was no evidence of any groundwater inflows into the pipes. If there is some defect in the pipes themselves or their joints, groundwater seepage would be expected to be small. Most of the pipe is above the water-table and seepage of surface water down through the pipe backfill would be the only source of water able to seep into the pipeline.

5.3 Foundations of appurtenant structures

5.3.1 Molonglo River weir crossing

Excavation of piers for the crossing was in fresh to fresh-stained, blue-grey porphyritic dacite, which was close-jointed with smooth, planar, and tight joints. The frequency of joints increased from the south (pier 1) to the north (pier 5) abutment; the joints in pier 5 were slickensided, stained with limonite, and chlorite-coated.

All alluvium and weathered rock was removed before foundation treatmnt commenced. The final pier foundations were washed clean by air and water jets before concrete was poured. All excavation for piers was in hard, strong dacite, as expected from tthe drillhole and seismic information. (Purcell & Simpson 1973). Some minor vertical shears trending 040° and 060° were encountered, but these were not considered a problem because of their small size and because the foundation anchors extended each side of the shears.

5.3.2 Pipeline bridges 2-6

Bridge 2. The seismic traverse indicated two layers (up to 10 m thick) of fairly low-velocity material (350 m/s and 1000 m/s). When excavated this zone was found to be highly to slightly weathered cobbles and boulders (5-60 cm in diameter) and siliceous fragments embedded in slopewash. Excavation for the southern pylon reached a depth of about 7.6 m before rock of adequate bearing strength was found.

Bridge 3. The foundations for bridge 3 were excavated in the Winslade Fault Zone, which is indicated on the surface by shearing and quartz veins. The rock is altered but the original texture of quartz phenocrysts in hard clay matrix remains. This fault is inactive, and the seismic traverse across bridge site 3 indicated little deterioration in rock quality in the fault zone. Excavation conditions were fairly good; pier 1 was located in highly and completely weathered rock with an altered and sheared zone, 1.2 m wide, with many quartz veins; the project engineers considered it had the necessary bearing strength 50 tonnes/m^2 (4 1/2 tons/ft^2). Piers 2,3,4,5,7,8 were excavated in moderately to highly weathered porphyry which was sheared but firm, and pier 6 foundation was excavated through slopewash to highly weathered bedrock.

Bridge 4. Bridge pier foundations were in sound rock varying from slightly to highly weathered at the base of the excavations. A few clay seams (2 cm wide) were found in the excavation for pier 4.

Bridge 5. The footings were excavated to slightly to highly weathered blue-grey and purple-grey dacite with tight joints and no clay.

Bridge 6. Excavations continued down to moderately to highly weathered blue-grey and purple-grey dacite. White-grey leached zones with limonite stains on joint planes were common especially in footing 1, which lies in a small depression. Footing 3 is below water-table (creek bed) and water inflow was a problem when concrete was being poured.

5.4 Materials

Suitable material for selected* and ordinary** backfill was deficient in some sections of the trench where soil profiles were thin or unweathered rock was close to the surface. Trucking of fill from better supplies areas of the trench was required for these sections.

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* Less than 45% of material shall pass the 200 sieve; no stones larger than 8 cm allowed.

** Maximum 30 cm, graded from coarse to fine.

5.5 Conclusions

1. Excavation conditions were generally more difficult than suggested by the rippability limits proposed by Purcell & Simpson (1973) from the seismic velocities. Purcell & Simpson suggested that '85% of the length of the trench could probably be excavated by equipment with performance similar to a D9 bulldozer, with a small amount of blasting'. In the Deakin Volcanics heavy secondary blasting was required where slightly to moderately weathered rock occurred close to the surface, and blasting to loosen ground was necessary to enable excavation with the mechanical shovel to proceed at a suitable rate of advance.

2. Light blasting was required to loosen ground in most of the Mount Painter Porphyry and some excavation was possible with a backhoe. Heavier blasting and secondary drilling of tight spots was required in the Mount Painter Porphyry in the trench section close to the Ryan Tunnel north portal.

3. As predicted, excavation in the limestone required extensive blasting. The associated highly cleaved and fractured shale (velocity of 1200 m/s) were easily excavated with the backhoe.

4. The bridge foundations were all excavated to sound rock.

5. There was no evidence of movement along fault zones, and foundation conditions in known fault zones (e.g., Winslade Fault) were not markedly worse than in the adjacent rock. Sheared zones in the dacite in places resulted in overbreak, but will not affect operation of the pipeline.

5.6 Recommendations

1. The exploratory backhoe pits were excavated with small tractor-mounted machines* with low rippability limits. It is recommended that future pits for such a pipeline be excavated with a machine with similar performance to that required for the actual excavation.

2. Seismic data provided the most useful information, and was especially valuable in determining rock conditions for the bridge foundations. Auger results correlated fairly well with rock conditions, but, like the backhoe, they lacked penetration. However, a good auger-hole coverage as used in the MVIS pipeline is recommended for a major pipeline investigation as it provides a good estimation of rock boundaries and weathering, which can be compared with the seismic data.

3. Thorough photo-interpretation is recommended for open-cut pipelines such as the MVIS. Excavation hazards such as potential slip zones, old landslides, large springs, etc. can be identified early and advice given to the engineers.

4. Recognition and mapping of sediment lenses in the volcanics in the Canberra area is important for projects like the MVIS. As excavation conditions in sediments differed markedly from the volcanics, the contractor had some trouble in adapting to the changing cconditions after the much more uniform dacite; seismic work is recommended for delineating sediment lenses and other significant lithology changes.

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* Massey Ferguson tractor - 30 cm bucket (H1-83). Remainder were done with a Ford 4500 backhoe within 45 cm bucket.

5. Regular inspection of the pipeline route is recommended. It is important to monitor any significant erosion of pipelin overburden (gullies, etc.) and zones of failure, such as the slip zone at stn 18 + 30. It is recommended that this slip zone be inspected occasionally, as the roadway might eventually fail.

6. ACKNOWLEDGEMENTS

Most of the tunnel logging was carried out by P.A. Lang, and the trench, bridge foundations, and gully crossings were logged by G. Anderson. Some of the pipeline section of this report was written by G. Anderson.

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APPENDIX 1

GLOSSARY OF TERMS

ROCK CONDITION NUMBERS

1. Descriptions of the rock condition numbers (RCN) have been modified after Terzaghi (1946) and Deere, Merritt, & Coon (1969) to suite geological conditions encountered in tunnelling operations carried out in the ACT since 1971. To date these tunnels have passed mainly through acid volcanics and sedimentary rocks derived from them.

2. The predicted support requirements for each RCN should be used only as a guide, as very narrow but poorly oriented defects in an otherwise long section of competent rock (e.g., RCN 2) may require 2 or 3 steel sets or a few rockbolts for stabilisation. The predictions of support assume an excavated tunnel diameter of up to 4 m.

3. It should also be noted that RCN 7 and 8 have not been recorded to date in the ACT.

ROCK CONDITION NUMBER	DESCRIPTION OF THE ROCK MASS
1.	HARD INTACT ROCK: Rock massive, very hard and very strong, with no significant joints or other defects. Breaks across sound rock when blasted. No support necessary.

ROCK CONDITION NUMBER	DESCRIPTION OF THE ROCK MASS
1.	HARD INTACT ROCK: Rock massive, very hard and very strong, with no significant joints or other defects. Breaks across sound rock when blasted. No support necessary.
2.	HARD WIDELY JOINTED ROCK: As above, but may be foliated or bedded with a fairly high resistance to separation of surfaces. Prominent continuous joints spaced 1-3 m are tight; joints usually not continuous for more than a few metres. No support required.
3.	MASSIVE, MODERATELY JOINTED: Rock mostly hard and strong. Continuous joints generally spaced 0.5-1 m are usually fairly tight, but some water seepage along joints may occur. Rock may be partly blocky in places, and generally breaks along joint surfaces when blasted. Steel or rockbolt supports generally not required in 3 m diameter tunnel; in a 4 m tunnel, some rockbolts may be required where blocky or poorly oriented defects cross the tunnel.
4.	MASSIVE, MODERATELY JOINTED, SEAMY: As above but defect surfaces generally clay-coated and loose. Clay seams and sheared or fractured rock with clay common. Rock may be moderately weathered or altered and soft in parts. Steel-set support (1-1.3 m spacing) sometimes required in tunnels up to 3 m diameter; more often in 4 m tunnel. Rockbolts may be preferable in places.

ROCK CONDITION NUMBER	DESCRIPTION OF THE ROCK MASS
5.	CLOSELY JOINTED AND SEAMY: Closely jointed, seamy, and fractured rock; joints and fractures are loose and open (where no clay-filled), and may result in large water flows into the excavation; includes highly and extremely weathered (or altered) rock. May exert considerable weight on steel-set supports; steel supports spaced at 1 m (or less) with heavy timber lagging. Rockbolts not usually effective.
6.	SEAMY AND CRUSHED ROCK: Includes unconsolidated sand, slopewash, etc. Refers to fault zone material (gouge) or shattered rock where clay and gravel sized fragments makes up the greater percentage of the material mass. If water content is high, these materials may run or flow and exert significant side pressures. Stand-up time near zero. Rockbolts not effective. Steel sets $<$ 0.5 m centres, invert struts, and possibly linear plates. Shotcrete or gunite often effective in containing running ground.
7.	SQUEEZING GROUND: Slow movement of rock into the tunnel without perceptible volume increase (rock with clay minerals with low swelling characteristics).
8.	SWELLING GROUND: Material expands in volume upon exposure to water (e.g. montmorillonite clay, serpentinite, anhydrite, etc.).

DEGREES OF ROCK WEATHERING

FRESH	: No discolouration or loss in strength.
FRESH STAINED	: Limonitic staining along fractures; rock otherwise fresh and shows no loss of strength.
SLIGHTLY WEATHERED	: Rock is slightly discoloured, but not noticeably lower in strength than the fresh rock.
MODERATELY WEATHERED	: Rock is discoloured and noticeably weakened; N-size (54-mm) drill core generally cannot be broken by hand across the rock fabric.
HIGHLY WEATHERED	: Rock is discoloured and weakened; N-size (54 mm) drill can generally be broken by hand across the rock fabric.
EXTREMELY WEATHERED	: Rock is decomposed to soil, but the original rock fabric is mostly preserved.

ROCK SUBSTANCE

This is defined as intact, effectively (for engineering purposes) homogenous rock. Repeated mechanical tests on the material would give acceptable coefficients of variations (e.g., uniform results).

SHEARED ROCK

Consists of rock intersected by close (<1 cm), slightly curving intersecting fracture planes; the fracture surface may be smooth, polished, slickensided, or coated with clay.

CRUSHED ROCK

Consists of rock which is mechanically disintegrated, but not obviously chemically decomposed.

FRACTURED ROCK

Consists of rock which is intensively jointed in several directions. Fracture surfaces are often clay-coated.

FAULTED ROCK

Faults can be sheared, crushed, or fractured rock, and where relative displacement of rock can be seen. Unless evidence for faulting is quite definite the term should not be used.

JOINT SPACING

Very close	- joints spaced <5 cm
Close	- joints spaced 5 cm to 30 cm
Moderately close	- joints spaced 30 cm to 1 m
Wide	- joints spaced 1 m to 3 m
Very wide	- joints spaced >3 m

JOINT APERTURE

Describes the amount of separation of the joint surfaces. Joints may be open or tight.

BEDDING

Laminated	-	< 10 mm thick
Thinly bedded	-	10 mm to 100 mm thick
Thickly bedded	-	> 100 mm thick

GRAINSIZE

Coarse-grained	-	1 mm to 4 mm in diameter
Medium-grained	-	1/4 mm to 1 mm in diameter
Fine-grained	-	> 1/4 mm in diameter

ROCK QUALITY DESIGNATION (RQD)

RQD is the ratio expressed as a percentage of length of core recovered to the total length of the core run, counting only those pieces of hard and sound rock 10 cm in length or longer.

APPENDIX 2

CHEMICAL ANALYSES, PINE-RIDGE TUNNEL ROCK SAMPLES

CIPW NORM OF SAMPLE NO. 73840487

RED STAINED DACITE. STN 23+70 PINE RIDGE TUNNEL
(N 607086, W198220)

SILICATE ANALYSIS

OXIDE	PERCENT
SiO_2	67.78
TiO_2	.54
Al_2O_3	13.95
Fe_2O_3	2.12
FeO	2.08
MnO	0.00
MgO	1.70
CaO	1.75
Na_2O	2.33
K_2O	3.55
P_2O_5	.11
H_2O (+)	2.53
H_2O (-)	.33
CO_2	.90
TOTAL	96.93
F	0.0000
S	.0100
Cl	0.0000
V	.0130
Cr	.0065
Co	.0006
Ni	.0020
Cu	.0014
Zn	.0056
Rb	.0250
Sr	.0095
Zr	.0180
Ba	.0450
Pb	.0105

FEMIC CONSTITUENTS

MINERAL	PERCENT	COMPONENT	PERCENT
ACMITE	0.00		
WOLLASTONITE	0.00		
DIOPSIDE	0.00	WO	0.00
		EN	0.00
		FS	0.00
HYPERSTHENE	5.52	EN	4.37
		FS	1.15
OLIVINE	0.00	FO	0.00
		FA	0.00
MAGNETITE	3.23		
CHROMITE	.03		
HEMATITE	0.00		
ILMENITE	1.06		
RUTILE	0.00		
TITANITE	0.00		
PEROVSKITE	0.00		
APATITE	.27		
FLUORITE	0.00		
CALCITE	2.11		
PYRITE	.02		
SPHALERITE	0.00		

SALIC CONSTITUENTS

MINERAL	PERCENT
QUARTZ	37.59
CORUNDUM	5.58
ZIRCON	.03
ORTHOCLASE	22.00
ALBITE	20.33
ANORTHITE	2.27
NEPHELINE	0.00
LEUCITE	0.00
KALIOPHILITE	0.00
HALITE	0.00

TRIANGULAR DATA DIAGRAM

Q - Plag - Or		K_2O - Na_2O - CaO		Wo - Fs - En	
Q	45.73	K_2O	46.65	Wo	0.00
Plag	27.51	Na_2O	30.62	Fs	20.82
Or	26.76	CaO	22.73	En	79.18

Q - Ab - Or		Or - Ab - An		F - M - A		Ol - Ne - Q	
Q	47.03	Or	49.32	F	34.47	Ol	6.23
Ab	25.44	Ab	45.58	M	14.70	Ne	17.36
Or	27.52	An	5.10	A	50.83	Q	76.41

PLAGIOCLASE = An	10.00
COLOUR INDEX IS	.15
CALC. DENSITY	2.85
SOLIDIFICATION INDEX	14.43
THORNTON - TUTTLE DIFFERENTIATION INDEX	79.91
PERALKALITY INDEX	.55
K_2O/Na_2O	1.52
TOTAL Fe as FeO	3.99

CIPW NORM OF SAMPLE NO. 73840488 — BLUE-GREY TO PURPLE DACITE. STN. 50+00 PINE RIDGE TUNNEL (N 607430, W197500)

SILICATE ANALYSIS		FEMIC CONSTITUENTS				SALIC CONSTITUENTS	
OXIDE	PERCENT	MINERAL	PERCENT	COMPONENT	PERCENT	MINERAL	PERCENT
SiO_2	68.42	ACMITE	0.00				
TiO_2	.51					QUARTZ	39.52
Al_2O_3	12.86	WOLLASTONITE	0.00			CORUNDUM	5.46
Fe_2O_3	2.58					ZIRCON	.03
FeO	3.73	DIOPSIDE	0.00	WO	0.00		
MnO	.09			EN	0.00	ORTHOCLASE	33.99
MgO	1.63			FS	0.00	ALBITE	6.29
CaO	.41					ANORTHITE	1.05
Na_2O	.72	HYPERSTHENE	8.32	EN	4.20		
K_2O	5.46			FS	4.12	NEPHELINE	0.00
P_2O_5	.11					LEUCITE	0.00
H_2O (+)	2.22	OLIVINE	0.00	FO	0.00	KALIOPHILITE	0.00
H_2O (-)	.26			FA	0.00		
CO_2	.05					HALITE	0.00
		MAGNETITE	3.92				
		CHROMITE	.03				
TOTAL	96.77	HEMATITE	0.00				
		ILMENITE	1.00				
		RUTILE	0.00				
F	0.0000	TITANITE	0.00				
S	.0100	PEROVSKITE	0.00				
Cl	0.0000	APATITE	.27				
V	.0110	FLOURITE	0.00				
Cr	.0060	CALCITE	.12				
Co	.0008	PYRITE	.02				
Ni	.0015	SPHALERITE	0.00				
Cu	.0008						
Zn	.0055						
Rb	.0240						
Sr	.0040						
Zr	.0160						
Ba	.1180						
Pb	.0006						

TRIANGULAR DATA DIAGRAM

Q - Plag - Or		K_2O - Na_2O - CaO		Wo - Fs - En			
Q	48.88	K_2O	82.85	Wo	0.00		
Plag	9.08	Na_2O	10.93	Fs	49.54		
Or	42.04	CaO	6.22	En	50.46		
Q - Ab - Or		**Or - Ab - An**		**F - M - A**		**Ol - Ne - Q**	
Q	49.52	Or	82.24	F	43.66	Ol	11.31
Ab	7.88	Ab	15.23	M	11.76	Ne	6.30
Or	42.59	An	2.53	A	44.58	Q	82.39

PLAGIOCLASE - An	14.26
COLOUR INDEX IS	.16
CALC. DENSITY	2.86
SOLIDIFICATION INDEX	11.54
THORNTON - TUTTLE DIFFERENTIATION INDEX	79.81
PERALKALITY INDEX	.55
K_2O/Na_2O	7.58
TOTAL Fe AS FeO	6.05

CIPW NORM OF SAMPLE NO. 73840489 — GREEN-GREY DACITE. STN 26+50 PINE RIDGE TUNNEL
(N 607130, W198140)

SILICATE ANALYSIS		FEMIC CONSTITUENTS				SALIC CONSTITUENTS	
OXIDE	PERCENT	MINERAL	PERCENT	COMPONENT	PERCENT	MINERAL	PERCENT
SiO_2	67.84	ACMITE	0.00				
TiO_2	.55					QUARTZ	30.53
Al_2O_3	14.10	WOLLASTONITE	0.00			CORUNDUM	4.92
Fe_2O_3	87					ZIRCON	.03
FeO	4.06	DIOPSIDE	0.00	WO	0.00		
MnO	0.00			EN	0.00	ORTHOCLASE	39.44
MgO	1.92			FS	0.00	ALBITE	10.99
CaO	.32					ANORTHITE	.38
Na_2O	1.27	HYPERSTHENE	10.80	EN	4.89		
K_2O	6.43			FS	5.90	NEPHELINE	0.00
P_2O_5	.14					LEUCITE	0.00
H_2O (+)	2.17	OLIVINE	0.00	FO	0.00	KALIOPHILITE	0.00
H_2O (-)	.19			FA	0.00	HALITE	0.00
CO_2	.05						
		MAGNETITE	1.36				
		CHROMITE	.03				
TOTAL	97.74	HEMATITE	0.00				
		ILMENITE	1.07				
		RUTILE	0.00				
F	0.0000	TITANITE	0.00				
S	.0150	PEROVSKITE	0.00				
Cl	0.0000	APATITE	.34				
V	.0140	FLOURITE	0.00				
Cr	.0050	CALCITE	.12				
Co	.0008	PYRITE	.03				
Ni	.0020	SPHALERITE	0.00				
Cu	.0006						
Zn	.0053						
Rb	.0230						
Sr	.0045						
Zr	.0180						
Ba	.1020						
Pb	.0010						

TRIANGULAR DATA DIAGRAM

Q - Plag - Or		K_2O - Na_2O - CaO		Wo - Fs - En			
Q	37.53	K_2O	89.17	Wo	0.00	PLAGIOCLASE - An	3.35
Plag	13.98	Na_2O	15.84	Fs	54.67	COLOUR INDEX IS	.16
Or	48.49	CaO	3.99	En	45.33	CALC. DENSITY	2.83

Q - Ab - Or		Or - Ab - An		F - M - A		Ol - Ne - Q			
								SOLIDIFICATION INDEX	13.20
								THORNTON - TUTTLE DIFFERENTIATION INDEX	80.96
Q	37.71	Or	77.62	F	33.49	Ol	15.27	PERALKALITY INDEX	.64
Ab	13.57	Ab	21.63	M	13.28	Ne	11.38	K_2O/Na_2O	5.06
Or	48.72	An	.75	A	53.24	Q	73.35	TOTAL Fe AS FeO	4.84

CIPW NORM OF SAMPLE NO. 73840490

GREEN-GREY TO RED DACITE STN. 45+00 PINE RIDGE TUNNEL
(N 607360, W197150)

SILICATE ANALYSIS		FEMIC CONSTITUENTS				SALIC CONSTITUENTS	
OXIDE	PERCENT	MINERAL	PERCENT	COMPONENT	PERCENT	MINERAL	PERCENT
SiO_2	65.86	ACMITE	0.00				
TiO_2	.62					QUARTZ	30.45
Al_2O_3	14.37	WOLLASTONITE	0.00			CORUNDUM	4.29
Fe_2O_3	3.62					ZIRCON	.03
FeO	1.63	DIOPSIDE	0.00	WO	0.00		
MnO	.08			EN	0.00	ORTHOCLASE	39.74
MgO	1.70			FS	0.00	ALBITE	10.54
CaO	1.44					ANORTHITE	2.90
Na_2O	1.22	HYPERSTHENE	4.33	EN	4.33		
K_2O	6.46			FS	0.00	NEPHELINE	0.00
P_2O_5	.13					LEUCITE	0.00
H_2O (+)	2.02	OLIVINE	0.00	FO	0.00	KALIOPHILITE	0.00
H_2O (-)	.22			FA	0.00		
CO_2	.55					HALITE	0.00
		MAGNETITE	3.75				
		CHROMITE	.03				
TOTAL	97.91	HEMATITE	1.16				
		ILMENITE	1.20				
		RUTILE	0.00				
F	0.0000	TITANITE	0.00				
S	.0100	PEROVSKITE	0.00				
Cl	0.0000	APATITE	.31				
V	.0150	FLOURITE	0.00				
Cr	.0055	CALCITE	1.28				
Co	.0006	PYRITE	.02				
Ni	.0018	SPHALERITE	0.00				
Cu	.0006						
Zn	.0050						
Rb	.0310						
Sr	.0060						
Zr	.0170						
Ba	.1330						
Pb	.0014						

TRIANGULAR DATA DIAGRAM

Q - Plag - Or		K_2O - Na_2O - CaO		Wo - Fs - En			
Q	36.41	K_2O	70.83	Wo	0.00		
Plag	16.07	Na_2O	13.38	Fs	0.00		
Or	47.52	CaO	15.79	En	100.00		
Q - Ab - Or		Or - Ab - An		F - M - A		Ol - Ne - Q	
Q	37.72	Or	74.73	F	34.26	Ol	6.69
Ab	13.06	Ab	19.82	M	11.91	Ne	12.60
Or	49.23	An	5.45	A	53.83	Q	80.71

PLAGIOCLASE - An	21.56
COLOUR INDEX IS	.14
CALC. DENSITY	2.82
SOLIDIFICATION INDEX	11.62
THORNTON - TUTTLE DIFFERENTIATION INDEX	80.72
PERALKALITY INDEX	.63
K_2O/Na_2O	5.30
TOTAL Fe AS FeO	4.89

CIPW NORM OF SAMPLE NO. 73840491 GREEN-GREY TO RED DACITE STN. 45+00 PINE RIDGE TUNNEL (N 607360, W197650)

SILICATE ANALYSIS | FEMIC CONSTITUENTS | SALIC CONSTITUENTS

OXIDE	PERCENT	MINERAL	PERCENT	COMPONENT	PERCENT	MINERAL	PERCENT
SiO_2	66.80	ACMITE	0.00				
TiO_2	.55					QUARTZ	33.58
Al_2O_3	13.68	WOLLASTONITE	0.00			CORUNDUM	4.39
Fe_2O_3	3.32					ZIRCON	.03
FeO	1.63	DIOPSIDE	0.00	WO	0.00		
MnO	.09			EN	0.00	ORTHOCLASE	36.17
MgO	1.46			FS	0.00	ALBITE	11.91
CaO	1.83					ANORTHITE	1.71
Na_2O	1.38	HYPERSTHENE	3.71	EN	3.71		
K_2O	5.88			FS	0.00	NEPHELINE	0.00
P_2O_5	.12					LEUCITE	0.00
H_2O (+)	2.07	OLIVINE	0.00	FO	0.00	KALIOPHILITE	0.00
H_2O (-)	.15			FA	0.00	HALITE	0.00
CO_2	1.05						
		MAGNETITE	3.96				
		CHROMITE	.04				
TOTAL	98.01	HEMATITE	.70				
		ILMENITE	1.07				
		RUTILE	0.00				
F	0.0000	TITANITE	0.00				
S	.0050	PEROVSKITE	0.00				
Cl	0.0000	APATITE	.29				
V	.0150	FLOURITE	0.00				
Cr	.0085	CALCITE	2.44				
Co	.0006	PYRITE	.01				
Ni	.0018	SPHALERITE	0.00				
Cu	.0012						
Zn	.0058						
Rb	.0280						
Sr	.0050						
Zr	.0190						
Ba	.1310						
Pb	.1150						

TRIANGULAR DATA DIAGRAM

Q - Plag - Or		K_2O - Na_2O - CaO		Wo - Fs - En	
Q	40.28	K_2O	64.69	Wo	0.00
Plag	16.33	Na_2O	15.18	Fs	0.00
Or	43.39	CaO	20.13	En	100.00

Q - Ab - Or		Or - Ab - An		F - M - A		Ol - Ne - Q	
Q	41.12	Or	72.65	F	34.62	Ol	5.29
Ab	14.58	Ab	23.92	M	10.95	Ne	13.11
Or	44.29	An	3.43	A	54.43	Q	81.60

PLAGIOCLASE - An	12.54
COLOUR INDEX IS	.14
CALC. DENSITY	2.81
SOLIDIFICATION INDEX	10.68
THORNTON - TUTTLE DIFFERENTIATION INDEX	81.66
PERALKALITY INDEX	.63
K_2O/Na_2O	4.26
TOTAL Fe AS FeO	4.62

APPENDIX 3

WATER ANALYSES, PINE RIDGE TUNNEL

(from AMDEL Computer Services)

APPENDIX 3 WATER ANALYSIS REPORT

SAMPLE NO. 74270050 JOB NO. 632-75

CHEMICAL COMPOSITION		MILLIGRAMS PER LITRE mg/l	MILLIEQUIVS. PER LITRE mg/l	DERIVED AND OTHER DATA	MILLIGRAMS PER LITRE mg/l	REMARKS
				CONDUCTIVITY (E.C.) MICRO-S/CM AT 25 DEG. C 871.		
CATIONS				TOTAL DISSOLVED SOLIDS		Fe 0.08 mg/l
CALCIUM	(Ca)	124.	6.2	A. BASED ON E.C.		
MAGNESIUM	(Mg)	22.	1.8	B. CALCULATED (HCO_3=CO_3)	489.	
SODIUM	(Na)	25.	1.1	C. RESIDUE ON EVAP. AT 180 DEG. C	520	
POTASSIUM	(K)	3.	.1			
ANIONS						
				TOTAL HARDNESS AS $CaCO_3$	400.	
HYDROXIDE	(OH)	.	.0	CARBONATE HARDNESS AS $CaCO_3$	315.	
CARBONATE	(CO_3)	.	.0	NON-CARBONATE HARDNESS AS $CaCO_3$	85.	
BICARBONATE	(HCO_3)	384.	6.3	TOTAL ALKALINITY AS $CaCO_3$	315.	
SULPHATE	(SO_4)	115.	2.4	FREE CARBON DIOXIDE (CO_2)		
				SUSPENDED SOLIDS		
CHLORIDE	(Cl)	11.	.3	SILICA (SiO_2)		
				BORON (B)		
NITRATE	(NO_3)	<1	.0			

TOTALS AND BALANCE					UNITS
CATIONS (me/l)	9.2	DIFF =	.2	REACTION - Ph	7.5
ANIONS (me/l)	9.0	SUM =	18.2	TURBIDITY (JACKSON)	
				COLOUR (HAZEN)	
DIFF*100. / SUM =	.9%			SODIUM TO TOTAL CATION RATIO (me/l)	11.9%

NAME- BMR
ADDRESS-

HUNDRED-
SECTION-
HOLE NO - PINE RIDGE TUNNEL (394)
- 200200 0654700

WATER CUT-
WATER LEVEL-

DATE COLLECTED - 12.7.74
DATE RECEIVED - 9.8.74

SAMPLE COLLECTED BY - G. ANDERSON

DEPTH BENEATH SURFACE - 91.4 m

APPENDIX 3 WATER ANALYSIS REPORT

SAMPLE NO. 74270051 JOB NO. 632-75

CHEMICAL COMPOSITION		MILLIGRAMS PER LITRE mg/l	MILLIEQUIVS. PER LITRE mg/l	DERIVED AND OTHER DATA	MILLIGRAMS PER LITRE mg/l	REMARKS
				CONDUCTIVITY (E.C.) MICRO-S/CM AT 25 DEG. C 871.		
CATIONS				TOTAL DISSOLVED SOLIDS		Fe <0.01 mg/l
CALCIUM	(Ca)	85.	4.2	A. BASED ON E.C.		
MAGNESIUM	(Mg)	20.	1.6	B. CALCULATED (HCO_3=CO_3)	355.	
SODIUM	(Na)	20.	.9	C. RESIDUE ON EVAP. AT 180 DEG. C	405	
POTASSIUM	(K)	2.	.1			
ANIONS						
				TOTAL HARDNESS AS $CaCO_3$	295.	
HYDROXIDE	(OH)	.	.0	CARBONATE HARDNESS AS $CaCO_3$	252.	
CARBONATE	(CO_3)	.	.0	NON-CARBONATE HARDNESS AS $CaCO_3$	43.	
BICARBONATE	(HCO_3)	307.	5.0	TOTAL ALKALINITY AS $CaCO_3$	252.	
SULPHATE	(SO_4)	66.	1.4	FREE CARBON DIOXIDE (CO_2)		
				SUSPENDED SOLIDS		
CHLORIDE	(Cl)	11.	.3	SILICA (SiO_2)		
				BORON (B)		
NITRATE	(NO_3)	<1	.0			

TOTALS AND BALANCE					UNITS
CATIONS (me/l)	6.8	DIFF =	.1	REACTION - Ph	7.7
ANIONS (me/l)	6.7	SUM =	13.5	TURBIDITY (JACKSON)	
				COLOUR (HAZEN)	
DIFF*100. / SUM =	.7%			SODIUM TO TOTAL CATION RATIO (me/l)	12.8%

NAME- BMR
ADDRESS-

HUNDRED-
SECTION-
HOLE NO - PINE RIDGE TUNNEL (394)
200200 0654700

WATER CUT-
WATER LEVEL-
DEPTH HOLE - 300' (91.4 m)

DATE COLLECTED - 12.7.74
DATE RECEIVED - 9.8.74

SAMPLE COLLECTED BY - G. ANDERSON

DEPTH BENEATH SURFACE - 91.4 m

SAMPLE NO. 74270052 JOB NO. 632-75

CHEMICAL COMPOSITION		MILLIGRAMS PER LITRE mg/l	MILLIEQUIVS. PER LITRE mg/l	DERIVED AND OTHER DATA	MILLIGRAMS PER LITRE mg/l	REMARKS
				CONDUCTIVITY (E.C.) MICRO-S/CM AT 25 DEG. C 871.		
CATIONS				TOTAL DISSOLVED SOLIDS		Fe 0.04 mg/l
CALCIUM	(Ca)	73.	3.6	A. BASED ON E.C.		
MAGNESIUM	(Mg)	20.	1.6	B. CALCULATED (HCO_3=CO_3)	329.	
SODIUM	(Na)	19.	.1	C. RESIDUE ON EVAP. AT 180 DEG. C	410	
POTASSIUM	(K)	2.	.1			
ANIONS						
				TOTAL HARDNESS AS $CaCO_3$	265.	
HYDROXIDE	(OH)	.	.0	CARBONATE HARDNESS AS $CaCO_3$	208.	
CARBONATE	(CO_3)	.	.0	NON-CARBONATE HARDNESS AS $CaCO_3$	57.	
BICARBONATE	(HCO_3)	254.	4.2	TOTAL ALKALINITY AS $CaCO_3$	208.	
SULPHATE	(SO_4)	83.	1.7	FREE CARBON DIOXIDE (CO_2)		
				SUSPENDED SOLIDS		
CHLORIDE	(Cl)	8.	.2	SILICA (SiO_2)		
				BORON (B)		
NITRATE	(NO_3)	<1	.0			

TOTALS AND BALANCE

					UNITS
CATIONS (me/l)	6.2	DIFF =	.1	REACTION - Ph	7.7
ANIONS (me/l)	6.1	SUM =	12.3	TURBIDITY (JACKSON)	
				COLOUR (HAZEN)	

DIFF*100. / SUM = .5%

SODIUM TO TOTAL CATION RATIO (me/l) 13.4%

NAME- BMR
ADDRESS-

HUNDRED-
SECTION-
HOLE NO - PINE RIDGE TUNNEL (394)
200200 0654800

WATER CUT-
WATER LEVEL-
DEPTH HOLE - 400 (122.0 m)

DATE COLLECTED - 12.7.74
DATE RECEIVED - 9.8.74

SAMPLE COLLECTED BY - G. ANDERSON

DEPTH BENEATH SURFACE - 91.4 m

APPENDIX 3 WATER ANALYSIS REPORT

SAMPLE NO. 74270053 JOB NO. 632-75

CHEMICAL COMPOSITION		MILLIGRAMS PER LITRE mg/l	MILLIEQUIVS. PER LITRE mg/l	DERIVED AND OTHER DATA	MILLIGRAMS PER LITRE mg/l	REMARKS
				CONDUCTIVITY (E.C.) MICRO-S/CM AT 25 DEG. C 871.		
CATIONS				TOTAL DISSOLVED SOLIDS		Fe <0.01 mg/l
CALCIUM	(Ca)	139.	6.9	A. BASED ON E.C.		
MAGNESIUM	(Mg)	45.	3.7	B. CALCULATED (HCO_3=CO_3)	651.	
SODIUM	(Na)	28.	1.2	C. RESIDUE ON EVAP. AT 180 DEG. C	720	
POTASSIUM	(K)	2.	.1			
ANIONS						
				TOTAL HARDNESS AS $CaCO_3$	532.	
HYDROXIDE	(OH)	.	.0	CARBONATE HARDNESS AS $CaCO_3$	378.	
CARBONATE	(CO_3)	.	.0	NON-CARBONATE HARDNESS AS $CaCO_3$	155.	
BICARBONATE	(HCO_3)	461.	7.6	TOTAL ALKALINITY AS $CaCO_3$	378.	
SULPHATE	(SO_4)	201.	4.2	FREE CARBON DIOXIDE (CO_2)		
				SUSPENDED SOLIDS		
CHLORIDE	(Cl)	10.	.3	SILICA (SiO_2)		
				BORON (B)		
NITRATE	(NO_3)	<1	.0			

TOTALS AND BALANCE

						UNITS
CATIONS	(me/l)	11.9	DIFF = .1	REACTION - Ph		7.5
ANIONS	(me/l)	12.0	SUM = 23.9	TURBIDITY (JACKSON)		
				COLOUR (HAZEN)		

DIFF*100.
--------- = .5%
SUM

SODIUM TO TOTAL CATION RATIO (me/l) 10.2%

NAME- BMR
ADDRESS-

HUNDRED-
SECTION-
HOLE NO - PINE RIDGE TUNNEL (394)
199200 0646200

WATER CUT-
WATER LEVEL-
DEPTH HOLE - 255' (68.6 m)

DATE COLLECTED - 16.7.74
DATE RECEIVED - 9.8.74

SAMPLE COLLECTED BY - G. ANDERSON

DEPTH BENEATH SURFACE - 91.4 m

APPENDIX 3 WATER ANALYSIS REPORT

SAMPLE NO. 74270054 JOB NO. 632-75

CHEMICAL COMPOSITION

		MILLIGRAMS PER LITRE mg/l	MILLIEQUIVS. PER LITRE mg/l
CATIONS			
CALCIUM	(Ca)	139.	6.9
MAGNESIUM	(Mg)	54.	4.4
SODIUM	(Na)	25.	1.1
POTASSIUM	(K)	3.	.1
ANIONS			
HYDROXIDE	(OH)	.	.0
CARBONATE	(CO_3)	.	.0
BICARBONATE	(HCO_3)	367.	6.0
SULPHATE	(SO_4)	302.	6.3
CHLORIDE	(Cl)	10.	.3
NITRATE	(NO_3)	<1	.0

DERIVED AND OTHER DATA

CONDUCTIVITY (E.C.)
MICRO-S/CM AT 25 DEG. C 871.

TOTAL DISSOLVED SOLIDS	MILLIGRAMS PER LITRE mg/l
A. BASED ON E.C.	
B. CALCULATED (HCO_3=CO_3)	713.
C. RESIDUE ON EVAP. AT 180 DEG. C	774
TOTAL HARDNESS AS $CaCO_3$	569.
CARBONATE HARDNESS AS $CaCO_3$	301.
NON-CARBONATE HARDNESS AS $CaCO_3$	268.
TOTAL ALKALINITY AS $CaCO_3$	301.
FREE CARBON DIOXIDE (CO_2)	
SUSPENDED SOLIDS	
SILICA (SiO_2)	
BORON (B)	

REMARKS

Fe 0.03 mg/l

TOTALS AND BALANCE

						UNITS
CATIONS	(me/l)	12.5	DIFF =	.0	REACTION - Ph	7.8
ANIONS	(me/l)	12.6	SUM =	25.1	TURBIDITY (JACKSON)	
					COLOUR (HAZEN)	

DIFF*100. / SUM = .2%

SODIUM TO TOTAL CATION RATIO (me/l) 8.7%

NAME- BMR
ADDRESS-

HUNDRED-
SECTION-
HOLE NO - PINE RIDGE TUNNEL (394)
198900 0646300

WATER CUT-
WATER LEVEL-
DEPTH HOLE - 100' (30.5 m)

DATE COLLECTED - 17.7.74
DATE RECEIVED - 9.8.74

SAMPLE COLLECTED BY - G. ANDERSON

DEPTH BENEATH SURFACE - 91.4 m

Record 1979/27

I55/A16/2027

REFERENCE

SHEARED ZONES 30

FRACTURED ZONES (WIDE)

TRACE OF BEDDING

DIP OF BEDS 20

SEISMIC PROFILE — GROUND SURFACE; Intermediate velocity layer 1600; 3000; Highest recorded velocity refractor 4600; Abrupt velocity change (anomaly); BEDROCK VELOCITY

NOTE: Velocities given are in metres/second

NOTE: STN. 2+60 TO 35+00 .... SURVEY BY C.T.R.L
STN. 35+00 TO 68+20 .... SURVEY BY B.M.R.

WEATHERING:

FR	Fresh
FRS	Fresh-stained
SW	Slightly weathered
MW	Moderately "
HW	Highly "
EW	Extremely "

AMENDMENTS

No	DESCRIPTION	AUTHOR / CHECKED	DATE
1	(i) Seismic profiles added. (ii) Support histogram corrected. (iii) Reference added	D C Purcell / DCP	14/8/77 / 14/?/77
2	Drillhole locations + water inflow histogram added	DCP	24/7/78
3			
4			
5			
6			

GEOLOGY BY P. A. LANG

COMPILED AND CHECKED: P.A. LANG + D.C. PURCELL, PROJECT GEOLOGIST

CHECKED AND APPROVED: D.C. PURCELL, SENIOR GEOLOGIST

SUPERVISING GEOLOGIST

Scale 0 100 200 300 400 ft; $\frac{V}{H} = 1$

TITLE

SUMMARY GEOLOGICAL LOG CHAINAGE 00 TO 7071 FEET

PROJECT

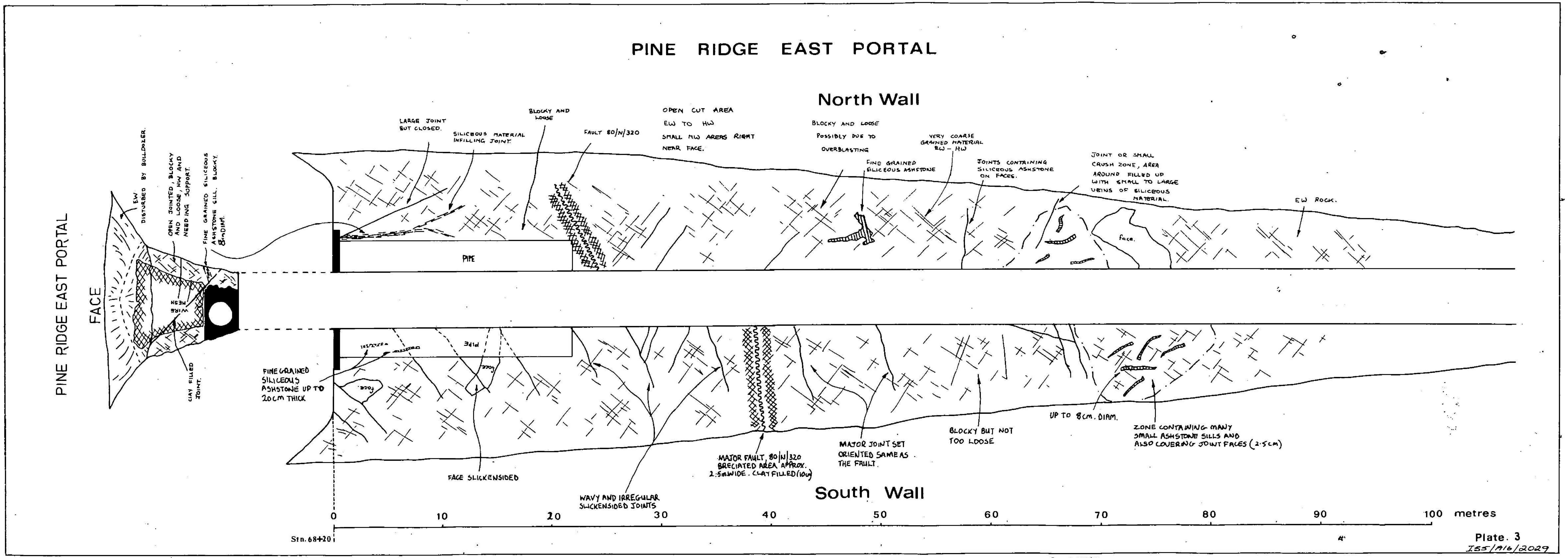
MOLONGLO VALLEY INTERCEPTOR SEWER
PINE RIDGE TUNNEL

TO ACCOMPANY RECORD 1979/27

SHEET 1 OF 1

DRAWING NUMBER I55/A16/2028

PLATE 2



Record 1979/27