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BUREAU OF MINERAL
RESOURCES, GEOLOGY
AND GEOPHYSICS

Record 1972/42

TUGGERANONG SEWER TUNNEL SEISMIC REFRACTION AND MAGNETIC SURVEY, ACT, 1971

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by

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SUMMARY

A geophysical survey using seismic refraction and magnetic techniques was made by the Bureau of Mineral Resources, Geology and Geophysics along sections of the proposed Tuggeranong sewer tunnel route to determine rock conditions at tunnel level.

At the inlet (south) portal it was found that fresh bedrock of seismic velocity 15 000 ft/s would be encountered at about chainage 300 feet. In the Village Creek area near the middle of the tunnel line at chainage 10 430 feet, the tunnel will be about 80 feet below the top of high-velocity (18 600 ft/s), fresh bedrock. Towards the Western Creek (north) end of the tunnel line from chainage 20 900 to 22 625 feet the tunnel will lie well within fresh bedrock of velocity 15 200 to 16 000 ft/s; from chainage 23 200 to 25 500 feet, lower velocities ranging from 10 600 to 14 000 ft/s were recorded for the tunnel material corresponding to moderately to slightly weathered bedrock. The magnetic profile is also remarkably flat in this zone and may correlate with a change in rock type from dacite to rhyodacite which has a lower susceptibility and is encountered in bores T.S. 6 and T.S. 7. Along the section close to Weston Creek from chainage 26 570 to 28 870 feet very variable weathering of the bedrock is indicated at tunnel level; much of the proposed tunnel passes through completely to highly weathered rock of about 6 000 ft/s seismic velocity. The area adjacent to the tunnel line in this section was investigated by seismic and magnetic cross-traverses to locate a possible alternative route of more suitable tunnelling rock, but no appreciable improvement in rock conditions was found.

1. INTRODUCTION

The construction of a sewerage outfall tunnel is planned by the National Capital Development Commission, to link the new satellite town of Tuggeranong with existing and future Canberra trunk mains at the Weston Creek treatment works. The tunnel, of about seven-foot diameter, will have its inlet portal located close to Tuggeranong Creek about half a mile upstream from the Murrumbidgee River. The direct route (as shown in Plate 1) is much preferred and has tentatively been chosen, giving the tunnel a length of almost six miles.

The Commonwealth Department of Works, which is the supervising construction authority on the project, asked the Bureau of Mineral Resources, Geology and Geophysics (BMR) to make geophysical investigations of subsurface conditions along the tunnel line - e.g. depth to solid bedrock - and to locate any anomalous regions which could significantly affect tunnelling operations.

Using seismic refraction and magnetic methods, the survey was made during November-December 1970, and March and November 1971 by the Engineering Geophysics Group of BMR by a party consisting of P.J. Hill (geophysicist and party leader), B.H. Dolan (geophysicist), S. Hall (field assistant), and two field hands provided by the Commonwealth Department of Works.

Compressive strength and drillability tests were made on a number of cores from drill holes along the tunnel line. The results of these tests are given in a separate Record (Idnurm, 1971).

2. GEOLOGY

A BMR report on the geology of the proposed tunnel route including geological logs of drill holes is being prepared (Purcell).

The bedrock along the tunnel line is Upper Silurian volcanics consisting of welded dacite tuff and rhyodacite; near ch. 8 000 (abbreviation used in this Record meaning 'chainage 8 000 feet') the route crosses a formation of dacite porphyry which may be intrusive in origin (Rossiter, 1971). In the areas of Weston and Village Creeks, where the topography is relatively flat, the thickness of overburden (soils, alluvium, slopewash, and weathered bedrock) is fairly large - roughly 40 feet.

3. METHOD AND EQUIPMENT

The seismic refraction method (Dobrin, 1952) was initially used to determine the nature of the overburden and depth to bedrock along the tunnel line in the portal sections since here the tunnel will be close to the surface and so possibly within weathered or fractured rock (drilling carried out in the middle section encountered fresh bedrock well above tunnel level). At the inlet portal, where the tunnel is to be driven into a steep hillside, seismic work was done from ch. 00-460, while at the Weston Creek end, where there is only a gradual change in surface elevation, a longer section from ch.20 900-28 870 was investigated. In the sections ch.00-460 and ch.26 570-28 870 a 10-foot geophone spacing was used since in these areas the tunnel will be shallow and greater detail is required, while in the section ch.20 900-25 500, where the tunnel will be at some depth, a 25-foot geophone spacing was used with a weathering spread placed about every 1 000 feet. In addition, two 690-foot cross-traverses at ch.26 850 and ch.28 454 were completed with seismic refraction using 10-foot geophone spacing in an attempt to locate an alternative route of more competent rock for tunnelling, as the seismic work and drilling along the tunnel line indicated unsuitable weathered rock at tunnel level.

For the seismic work the equipment used consisted of a 24-channel SIE seismograph with 20-Hz TIC geophones. Shots were fired at the centre and 5 feet beyond the ends of each spread; long shots were also fired beyond the ends of each spread, the shot distance for spreads of 10-foot spacing being 200 feet and for those of 25-foot spacing, 275 feet.

Bedrock seismic velocity anisotropy tests were carried out at ch. 10 430 and ch.22 150 to determine the principal strike direction of dipping joints. At both locations a geophone spacing of 9.8 feet was employed and velocities were measured in direction (true bearings) 0°, 180°, 45°, 225°, 90°, 270°, 135°, and 315°; a shot distance of 510 feet was used at ch.10 430 and 360 feet at ch.22 150.

Calculation of depth to the refracting layers was done using intercept times from the time-distance plots and a modification of the 'reciprocal method' (Hawkins, 1961).

At the northern (Weston Creek) end of the tunnel line, readings of the earth's total magnetic field were taken at 50-foot intervals with an Elsec proton magnetometer along the main seismic traverses and on cross-traverses. It was hoped that these measurements might provide qualitative information on the location and extent of any anomalous features in the volcanic bedrock which may not have been revealed by the seismic work.

4. SEISMIC RESULTS

The seismic cross-sections of ch.00-460, ch.20 900-22 625, ch.23 200-25 500 and ch.26 570-28 870 are shown in Plates 2, 3, 4, and 5 respectively.

The nature of the seismic layers recorded is interpreted as indicated below; variations can occur, however, particularly in places the rock has been fractured or sheared, as those processes appreciably lower the seismic velocity.

1 000 - 3 000 ft/s	:	soil, clay, alluvium
2 500 - 5 000 ft/s	:	completely weathered bedrock
5 000 ft/s	:	water-saturated alluvium
5 000 - 9 000 ft/s	:	highly weathered bedrock (water-saturated or dry)
9 000 - 12 000 ft/s	:	moderately weathered bedrock
12 000 - 15 000 ft/s	:	slightly weathered bedrock
15 000 - 19 000 ft/s	:	fresh bedrock.

Inlet (South) Portal Ch.00-460, (Plate 2). The proposed tunnel enters fresh (15 000 ft/s) dacite at about ch.300. From about ch.50 to ch.300 the tunnel will pass through 8 500 ft/s velocity material which from the geological log of drill hole T.S. 1 consists of slightly weathered to fresh dacite which is closely jointed. This accounts for the lower velocity recorded.

Section Ch.20 000-23 000, (Plate 3). Along this section the proposed tunnel will lie well within fresh bedrock of seismic velocity 15 200 to 16 000 ft/s.

Section Ch.23 000 to 26 000 (Plate 4). Moderately to slightly weathered bedrock with a seismic velocity in the range 10 600 to 14 000 ft/s exists at the proposed tunnel level. A region of deeper weathering occuring near ch.24 350 could be acting as a reservoir for groundwater, and since the tunnel will be only about 15 feet below the 11 000-ft/s layer there is the possibility of this trapped water draining into the tunnel through joints and weathered zones during tunnel excavation.

Section Ch.26 000-29 000, Weston Creek, (Plate 5). The proposed tunnel along this section lies close to the top of the deepest refractor recorded, which ranges in seismic velocity from 11 600 to 16 800 ft/s corresponding to moderately weathered and fresh rock, respectively. Between ch.26 570 and ch.27 100, the high velocity layer is overlain by a layer of highly weathered rock with velocity 8 000 to 9 000 ft/s, while between ch.27 100 and ch.28 870 the overlying layer has a lower seismic velocity from 5 100 to 6 500 ft/s being that of highly weathered or water-saturated and completely weathered bedrock.

Anisotropy Measurements

The velocities measured in the different directions were corrected for variation in thickness of overburden and for uneveness of the ground surface. The corrected values are shown in the following table:

	Direction (true bearing)	Velocity (ft/s)
ch. 10 430	0° (180°)	18 610 ± 460
	45° (225°)	18 000 ± 390
	90° (270°)	19 310 ± 510
	135° (315°)	18 310 ± 560
ch. 22 150	0° (180°)	15 420 ± 490
	45° (225°)	14 320 ± 420
	90° (270°)	14 320 ± 270
	135° (315°)	13 710 ± 290

Variations in the calculated seismic velocities occur but no definite conclusion as to joint directions can be deduced. The velocity asymmetry is due to velocity changes along each spread, and this is probably caused by non-uniform and directionally random or inconsistent jointing and shear zones within the bedrock over the test areas. The large thickness of overburden, which is likely to possess some lateral inhomogeneity, would also reduce the accuracy of the measurements.

The seismic work at ch.10 430 gives the following depth information:

	Velocity (ft/s)	Geological Interpretation
0-6 feet	1 100	Soil
6-58 feet	3 000	Colluvium and completely weathered dacite
58-119 feet	9 500	Moderately weathered dacite
Below 119 feet	18 600	Fresh dacite.

5. MAGNETIC RESULTS

Readings of the earth's total magnetic intensity were taken along seismic traverses and are shown (corrected for diurnal variation) above the seismic cross-section in Plates 3, 4, and 5. Where the magnetic profiles showed anomalous features, magnetic readings were made on additional cross-traverses (Plate 6).

A number of magnetic high anomalies were found along the tunnel line (near ch.22 000, ch.27 100 and ch.28 300) which by comparison with the seismic cross-sections appear to be associated with regions of high seismic velocity within the deepest recorded refractor, where velocities greater than about 16 000 ft/s occur.

Susceptibility and longitudinal seismic velocity measurements on drill-hole cores were made in the BMR rock testing laboratory and are presented below.

Drill hole	Depth ft	Geological Description	Susceptibility $\times 10^{-6}$, c.g.s.	Longitudinal velocity, ft/s
T.S.6	76	Rhyodacite (slightly weathered)	17	12 300
T.S.7	59	Rhyodacite (fresh)	18	7 100
T.S.8	9	Soil and alluvium	37	*
T.S.8	15	Dacite (highly weathered)	28	*
T.S.8	31	Dacite (slightly weathered)	35	13 700
T.S.8	49	Dacite (fresh)	1 340	19 000
T.S.9	5	Soil and alluvium	34	*
T.S.9	28	Dacite (completely weathered)	380	*
T.S.9	60	Dacite (slightly to moderately weathered)	150	13 000

T.S.10	15	Soil and alluvium	185	*
T.S.10	30	Dacite (completely weathered)	170	*
T.S.10	57	Dacite (moderately weathered)	420	7 600
T.S.12	62	Dacite (moderately weathered)	277	17 300
T.S.12	187	Dacite (fresh, stained)	1 082	18300

* Specimen in powder form; no velocity measurement.

It can be seen that no definite correlation exists between the susceptibility and the degree of weathering; this may in part be due to magnetic inhomogeneity of the bedrock in the area. However, for the fresh dacite (T.S.8, T.S.12) the values of susceptibility are relatively high and exceed 1 000 x 10^{-6} c.g.s. units, whereas weathered dacite (even if only slightly weathered), rhyodacite, soil, and alluvium have relatively low values of tens to several hundred (x10^{-6}) c.g.s. units. Thus in areas where dacite occurs, anomalous high magnetic regions indicate fresh bedrock approcaching the surface.

There may be some correlation between susceptibility and rock types. Rhyodacite has a low susceptibility (according to the specimens measured) and would be expected to show a flat magnetic profile; fresh dacite on the other hand, has high susceptibility, and even weathered dacite was found to be appreciably magnetic, so that a more irregular profile would be expected over this rock type. On this basis, bedrock between about ch.23 300 and ch.26 000 may be rhyodacite.

In the case of the anomaly at ch.22 000, the seismic results show a rise in the deepest recorded refractor (16 000 ft/s) centred at ch.21 650 and not at the peak of the magnetic anomaly. However, the broad nature of this anomaly suggests that it may result from a deep source below the top of the high-velocity refractor; this is borne out by the susceptibility measurements on rock cores from drill hole T.S.12 where, at a depth of 187 feet, a high value of 1 082 x10^{-6} c.g.s. units was obtained.

6. ALTERNATIVE ROUTE IN WESTON CREEK AREA

The seismic cross-traverse at ch.26 850 shows no appreciable improvement in rock quality at tunnel level within 300 feet of the tunnel line. To the west of the tunnel line along the cross-traverse at ch.28 454 the bedrock is appreciably shallower and has a high seismic velocity of 18 500 ft/s, but at this chainage the top of this fresh rock coincides only approximately with the proposed level of the tunnel. The effect on the magnetic field of this high-velocity bedrock can be seen in the magnetic profiles along cross-traverses at ch.28 150, ch.28 454, and along the

tunnel line; the profile trend is such as to confirm that fresh bedrock approaches the surface to the west of approximately ch.28 400.

From ch.26 500 to ch.28 870 on the tunnel line and along the seismic cross-traverses the high-velocity (greater than 11 600 ft/s) rock predominantly lies below the proposed tunnel level; in addition both the drilling and the seismic results disclose the variable nature of the subsurface weathering. Furthermore the possibility of fresh bedrock aprroaching nearer the surface close to the tunnel line from ch.27 300 to ch.28 000 tends to be ruled out by the absence of magnetic highs or major irregularities in the magnetic profile. Conditions for tunnelling in the Weston Creek area would therefore be difficult, and here trenching may be of a more economical alternative to tunnelling.

Trenching is most warranted in the section ch.27 200-28 870, and the greater part of excavation should readily be accomplished by earthmoving equipment. The surface unconsolidated material of seismic velocity 1 000 to 3 000 ft/s, consisting of soil, alluvium, clay, and completely weathered rock, can be handled by blade, scraper, or shovel equipment; the 5 000 to 6 500 ft/s completely or highly weathered rock would be rippable by large tractor equipment such as the Caterpillar D9G (Caterpillar, 1966). Near tunnel level, blasting will be required to remove the high-velocity material. Relatively low-velocity material may well be below water-table in the area near Weston Creek, and the possibility of appreciable water inflow should be considered.

7. CONCLUSIONS

A summary of rock conditions to be expected during excavation of the proposed tunnel, as derived from interpretation of the geophysical survey results, is given below.

ch 00 - 50 : soil, scree material, closely jointed weathered rock

ch. 50 - 300 : slightly weathered to fresh bedrock, closely jointed

ch. 300 - 460 : fresh bedrock

ch. 10 430 : fresh bedrock

ch. 20 900-22 625 : fresh bedrock

ch. 23 200-25 500 : slightly to moderately weathered bedrock of lower magnetic susceptibility, possibly corresponding to the rhyodacite.

ch. 26 570-27 200 : slightly weathered to fresh bedrock, with some moderately weathered rock around ch.26 700.

ch. 27 200-28 870 : mostly completely to highly weathered rock, some slightly weathered to fresh bedrock near ch.27 500 and ch.27 900-28 250.

Tunnelling from ch.27 200 to 28 870 may be difficult and open cutting may therefore be adopted, in which case excavation should be possible with large bulldozers fitted with hydraulic rippers, supplemented by some blasting near tunnel level.

8. REFERENCES

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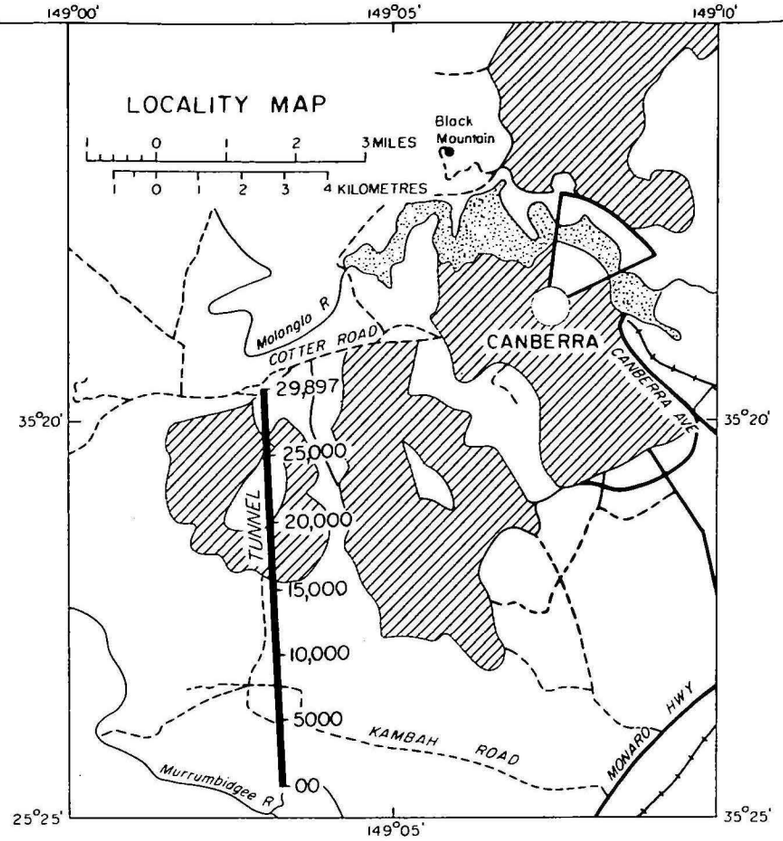
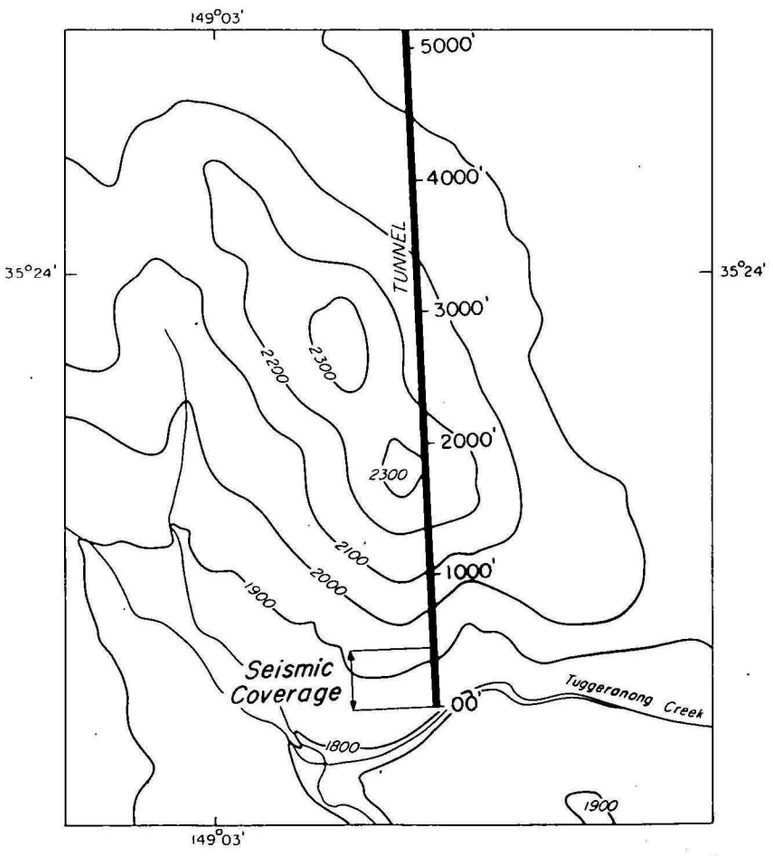
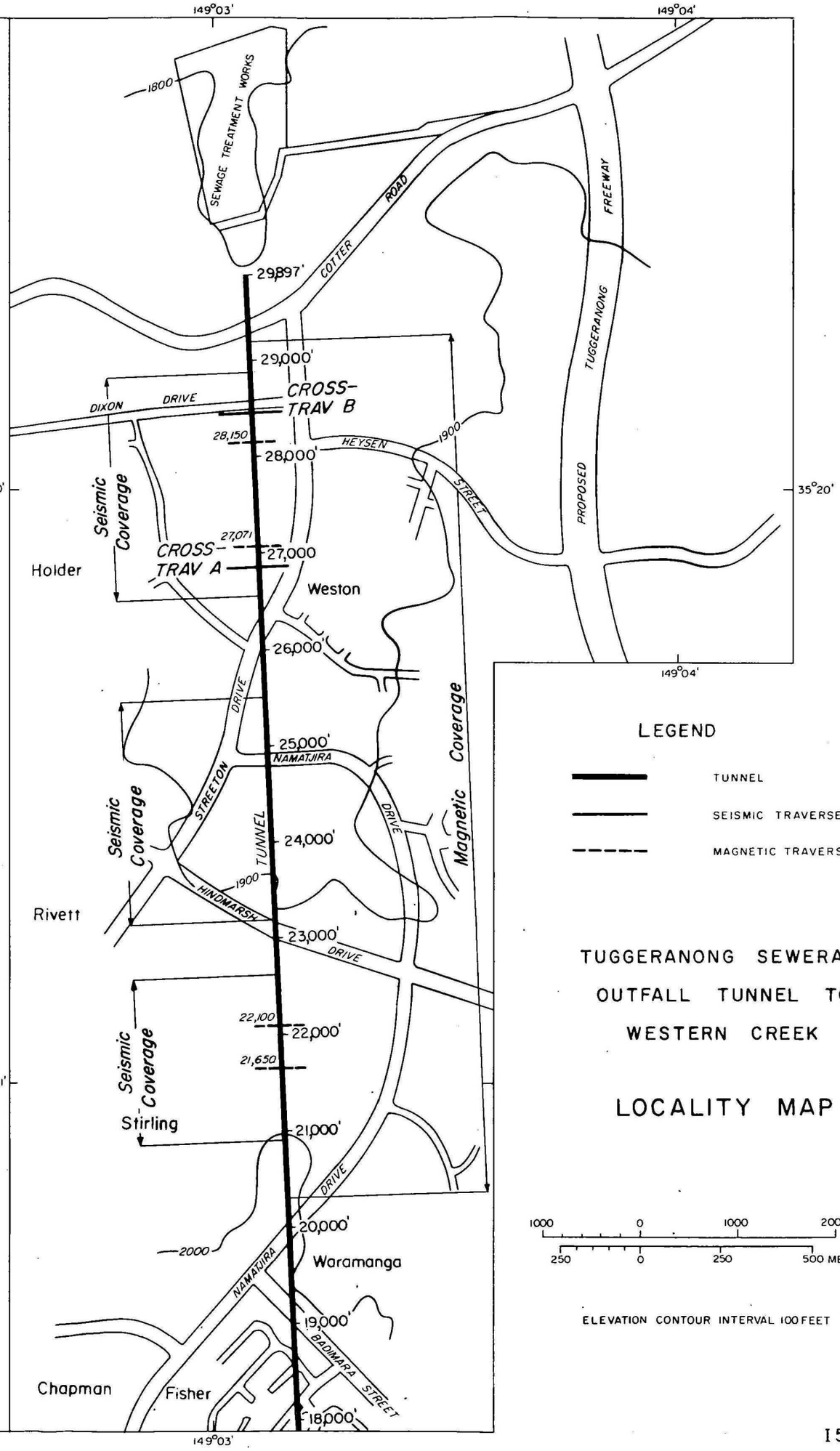
PLATE 1





1000 0 1000 2000 FEET
250 0 250 500 METRES

To accompany Record No. 1972/42



LEGEND

- TUNNEL
- SEISMIC TRAVERSE
- MAGNETIC TRAVERSE

TUGGERANONG SEWERAGE OUTFALL TUNNEL TO WESTERN CREEK

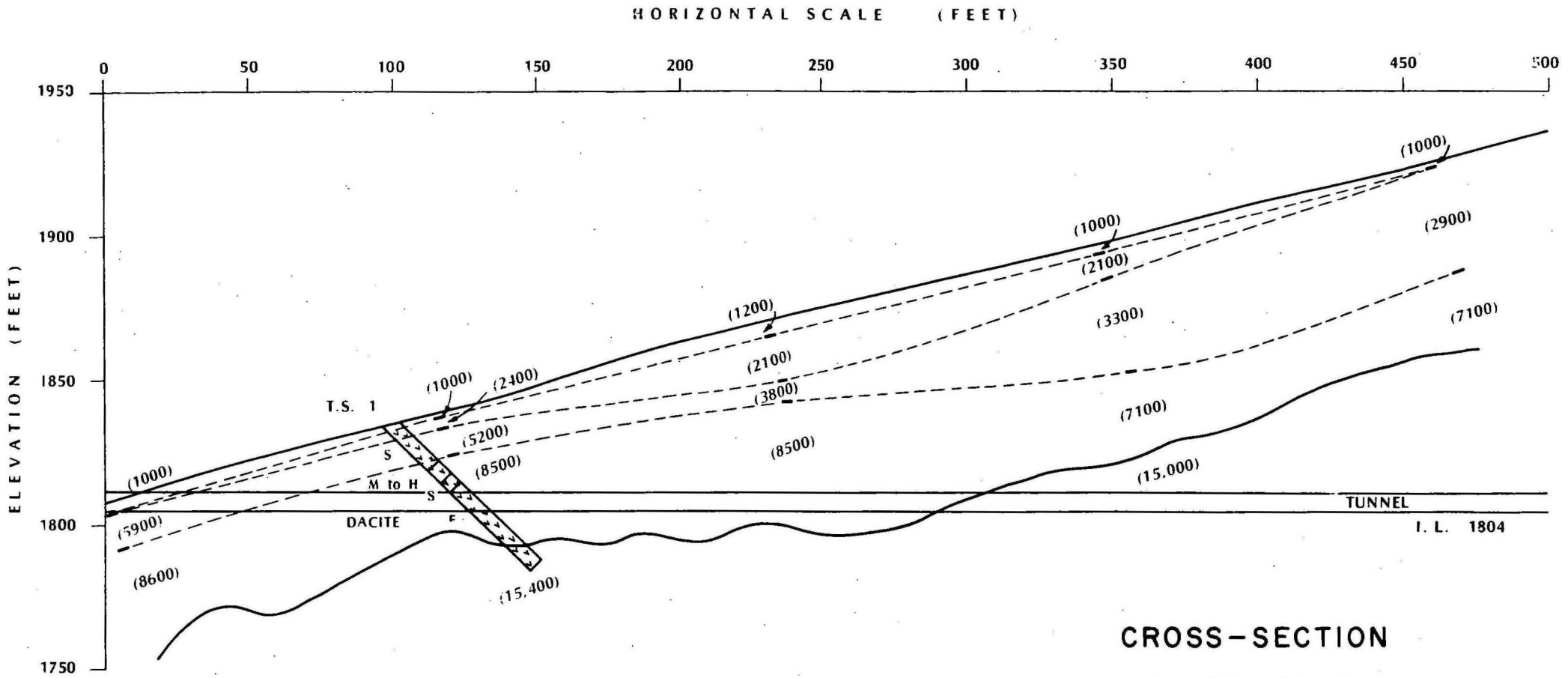
LOCALITY MAP

1000 0 1000 2000 FEET
250 0 250 500 METRES

ELEVATION CONTOUR INTERVAL 100 FEET

I55/B5-

To accompany Record No. 1972/42



CROSS-SECTION
TUNNEL INLET PORTAL
TUGGERANONG

LEGEND

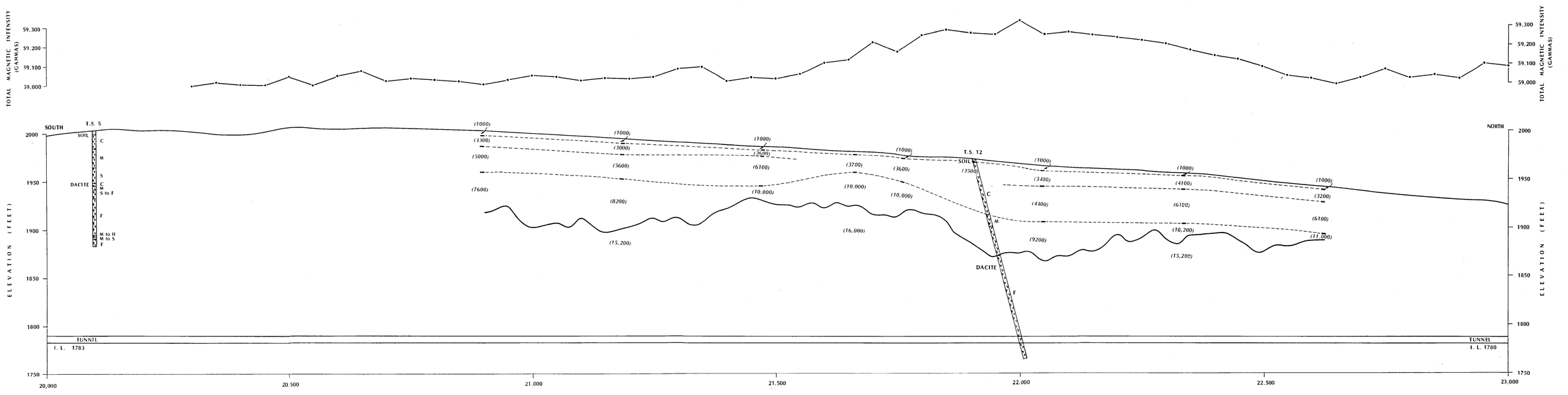
(5600)	Seismic velocity (ft/s)
- - - -	Boundary of formation with different seismic velocity
———	Bedrock boundary
T.S. 1	Drill hole number
I. L.	Invert level

Rock weathering

C	Completely weathered
H	Highly weathered
M	Moderately weathered
S	Slightly weathered
F	Fresh

PLATE 2

I 55/B5 – 106A



LEGEND

(5600) Seismic velocity (ft/s)

Boundary of formation with different seismic velocity

Bedrock boundary

T.S. 8 Drill hole number

I. L. Invert level

Rock weathering:

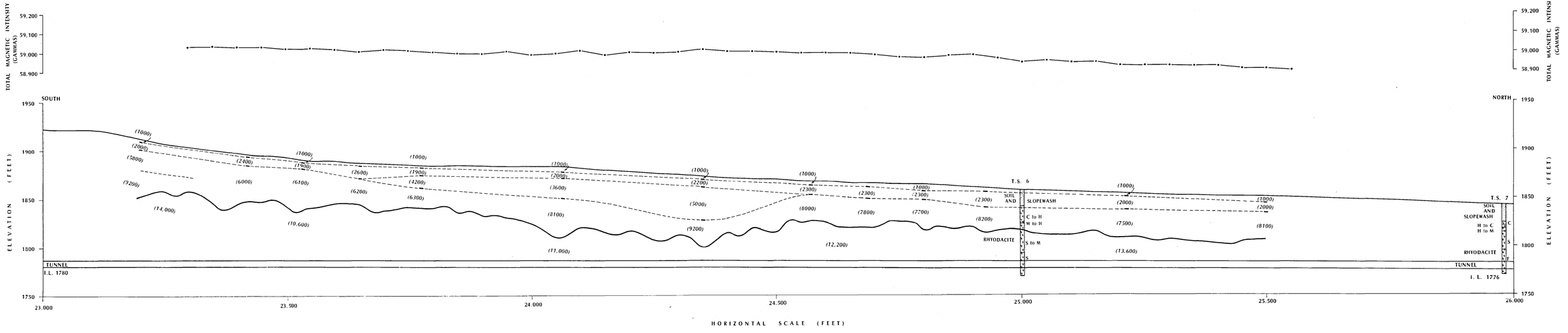
- C Completely weathered
- H Highly weathered
- M Moderately weathered
- S Slightly weathered
- F Fresh

HORIZONTAL SCALE (FEET)

SEISMIC CROSS-SECTIONS AND MAGNETIC PROFILE (20,000 – 23,000 FT)

To accompany Record No. 1972/42

I 55/85 – 107



LEGEND

(5600)	Seismic velocity (ft/s)
-----	Boundary of formation with different seismic velocity
———	Bedrock boundary
T.S. 8	Drill hole number
I.L.	Invert level

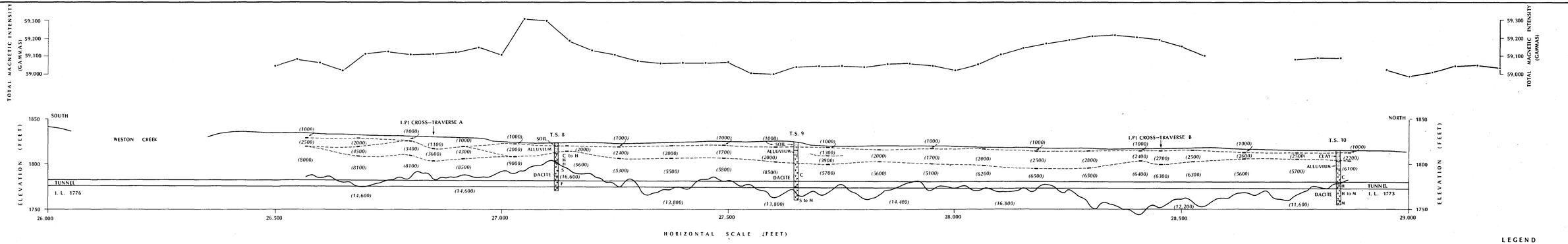
Rock weathering:

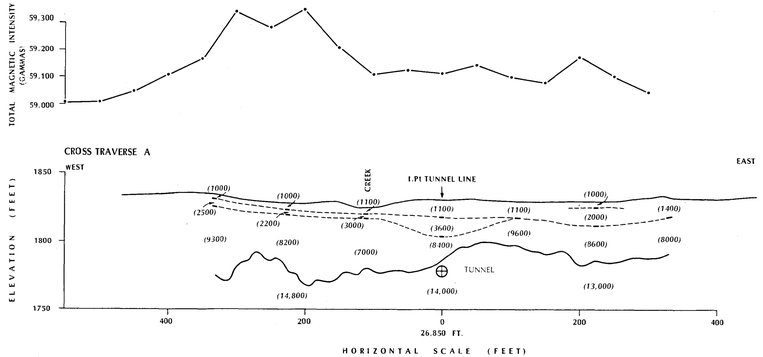
C	Completely weathered
H	Highly weathered
M	Moderately weathered
S	Slightly weathered
F	Fresh

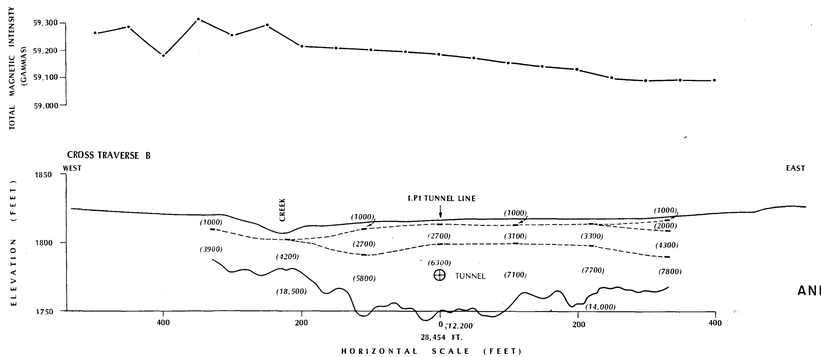
SEISMIC CROSS-SECTIONS AND MAGNETIC PROFILE (23,000–26,000 FT)

To accompany Record No. 1972/42

PLATE 5







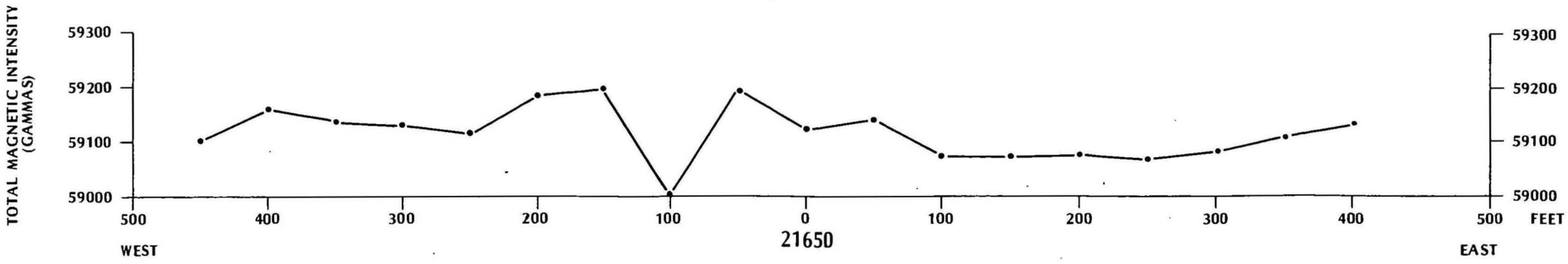
LEGEND

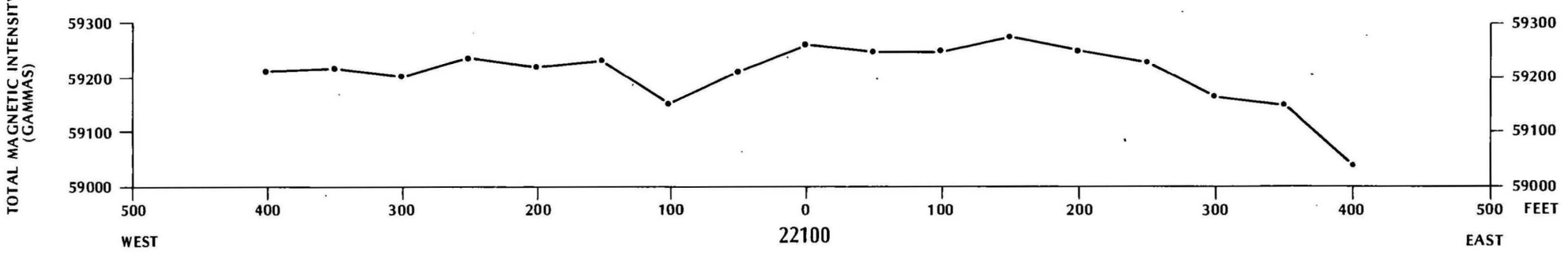
(5600)	Seismic velocity (ft/s)
– – – –	Boundary of formation with different seismic velocity
———	Bedrock boundary
T.S. 8	Drill hole number
I.Pt	Intersection point
I. L.	Invert level
Rock weathering: C	Completely weathered
H	Highly weathered
M	Moderately weathered
S	Slightly weathered
F	Fresh

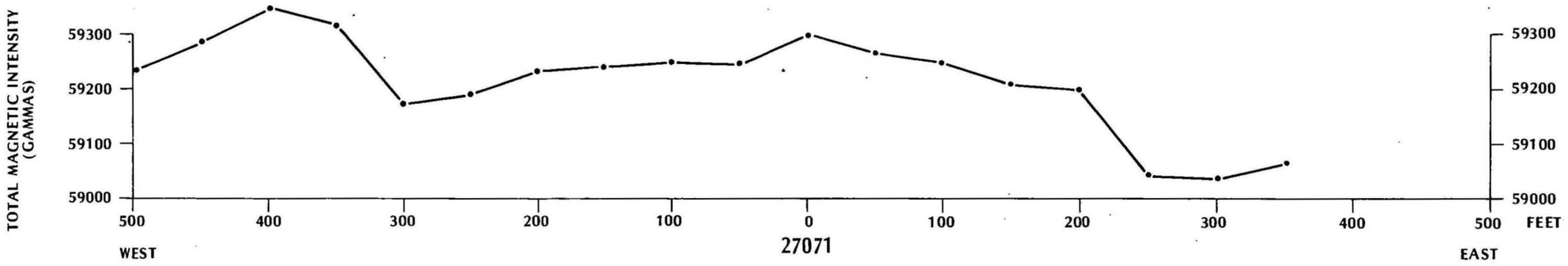
SEISMIC CROSS-SECTIONS AND MAGNETIC PROFILE AND CROSS-TRAVERSES A AND B (26,000–29,000 FT)

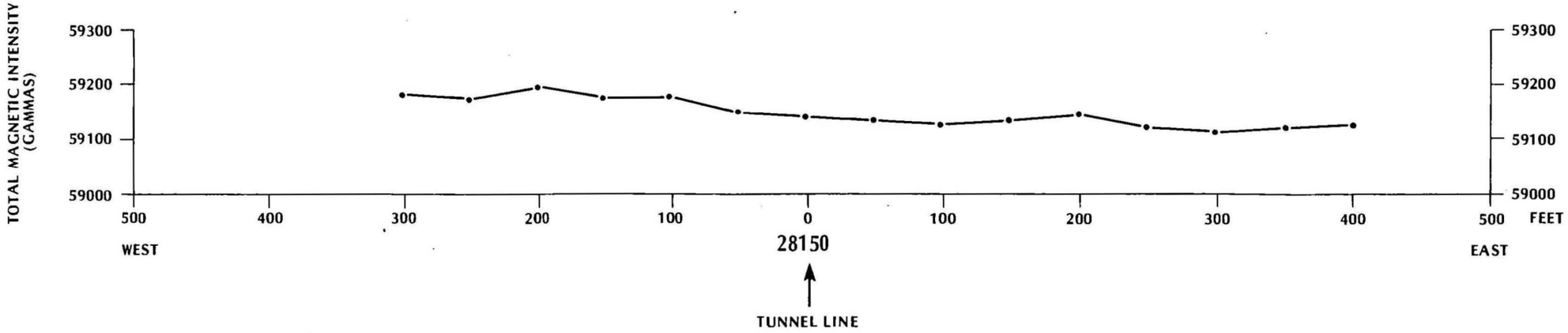
To accompany Record No. 1972/42

PLATE 6









ADDITIONAL MAGNETIC CROSS-TRAVERSES

To accompany Record No. 1972/42

155/B5-110