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DEPARTMENT OF ~~NATIONAL RESOURCES~~ NATIONAL DEVELOPMENT

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

Record 1979/63

DETAILED GEOPHYSICAL INVESTIGATIONS, TENNENT DAM SITES 2 AND 3, ACT

by

P.J. Hill

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ABSTRACT

Geophysical methods - seismic refraction; resistivity depth probes, profiling, and mapping; total field and vertical gradient magnetic profiling; and gamma-ray spectrometry profiling - were applied to investigate the geology of Tennent dam sites 2 and 3 on the Gudgenby River, ACT.

Bedrock at the sites consists of foliated adamellite. On the eastern side of the river, this rock has been extensively sheared in a north-south direction, concordant with the regional structural trends.

Much of the steep, unstable slope on the dam site 2 right abutment will have to be stripped to a depth of about 15 m to remove loose, open-jointed, and weathered bedrock. On the alluvial flat at the bottom of the gorge relatively fresh bedrock is less than 6 m down. Two major shear zones were delineated on the dam site 2 spillway area. Because of structural deformation here, foundation conditions are variable; however, the average depth to moderately weathered adamellite is about 7 m.

A zone of intense shearing was mapped on the upper part of the dam site 3 right abutment, and another at the western end of the proposed spillway. At the centre of the spillway, hard rock lies close to the surface and will have to be blasted out for the required excavation.

The position of the lithological boundary corresponding to the Murrumbidgee Fault was identified from the magnetic profile; a change in radiometric response was also noted. North-south-trending magnetic anomalies to the east of the sites correlate with highs in the K-gamma-ray count; the presence of dykes or hydrothermal mineralisation along shear

zones is inferred. A petrographic change in bedrock between this area and the Murrumbidgee Fault is indicated by a greater Th/U count ratio and higher magnetisation.

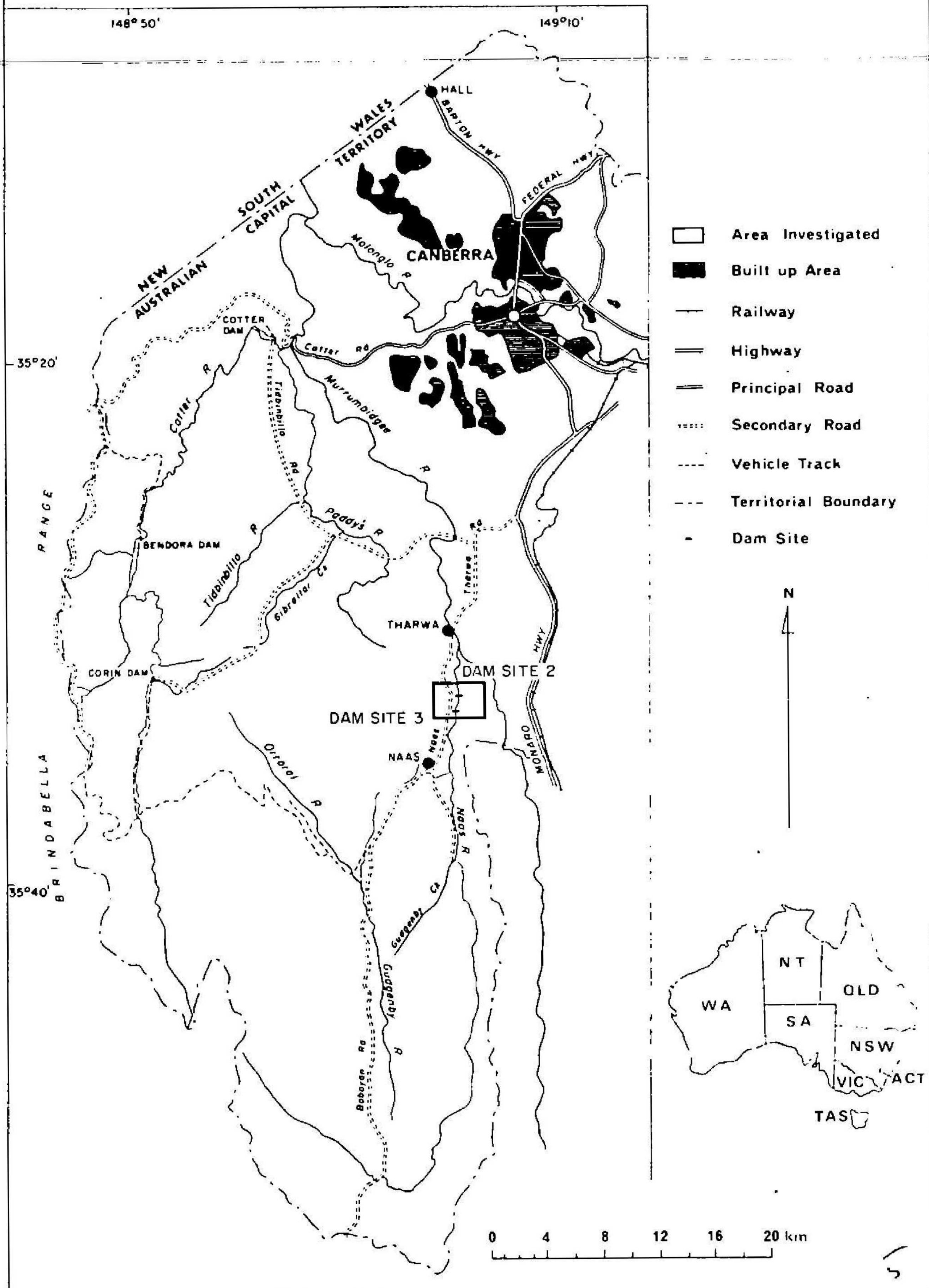

Fig.1 Location map

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1. INTRODUCTION

In 1975 the Bureau of Mineral Resources, Geology and Geophysics (BMR) was asked by the Department of Construction to conduct geological investigations of two alternative dam sites on the Gudgenby River, ACT. The two sites - dam sites 2 and 3, are located near Tharwa in a gorge incised by the Gudgenby River several kilometres upstream from its confluence with the Murrumbidgee River (Fig. 1). Construction of a dam 100 m high at the lower site (2) or a dam 85 m high at the upstream site (3) was envisaged. An earth-cored rock fill structure appeared to be the most suitable design.

Preliminary geological and seismic refraction surveys of the sites (Goldsmith & Briscoe, 1977; Horsfall, 1976, respectively) were carried out by BMR. This early work was followed up by further investigation of the subsurface geology (by geophysical techniques), concentrating on expected problem areas and those parts of the sites where insufficient information was available. The geophysical methods applied were seismic refraction, resistivity mapping and depth probing, total field magnetic and radiometric profiling. The results of this work, which was done by the BMR Engineering Geophysics Group, are presented in this Record.

2. GEOLOGY

The two dam sites and reservoir area are underlain by granitic rocks of the Murrumbidgee Batholith. A north-south-trending regional structural feature, the Murrumbidgee Fault lies about 1 km east of the sites and forms the boundary between the granitic rocks and Silurian sediments and volcanics which extend eastwards. Bedrock at both dam sites consists of Tharwa Adamellite, which exhibits a northerly striking, steeply dipping primary and secondary foliation. Extensive shearing (trending north) has altered and weakened the adamellite at the right dam abutments.

A detailed account of the geology is provided by Goldsmith & Briscoe (1977). Also relevant are the geotechnical reports of Buchhorn (1968), Dolan (1972), and Henderson (1973), which are related to the investigation of dam site 1 located between dam sites 2 and 3.

3. FIELDWORK AND EQUIPMENT

Figure 2 shows the dam site area in more detail, and the magnetic and radiometric coverage and resistivity depth probe locations. The resistivity profiling coverage is not marked on either Figure 2 or 3, but is given below.

Summary of geophysical coverage:

(a) Dam site 2

Seismic refraction	:	traverse 2A, ch. 284-403 m
		traverse 2B, ch. 00-265 m
		traverse 2C, ch. 00-220 m
Resistivity mapping	:	the area extending 30 m to either side of traverse 2A between ch. 540 m and ch. 780 m.
Resistivity depth probes	:	at ch. 590, 625, 650, and 671 m of traverse 2A
Magnetics	:	traverse 2A, ch. 00-540 m
		traverse 2B, ch. 00-265 m
		traverse 2C, ch. 00-950 m
Radiometric	:	traverse 2A, ch. 00-850 m

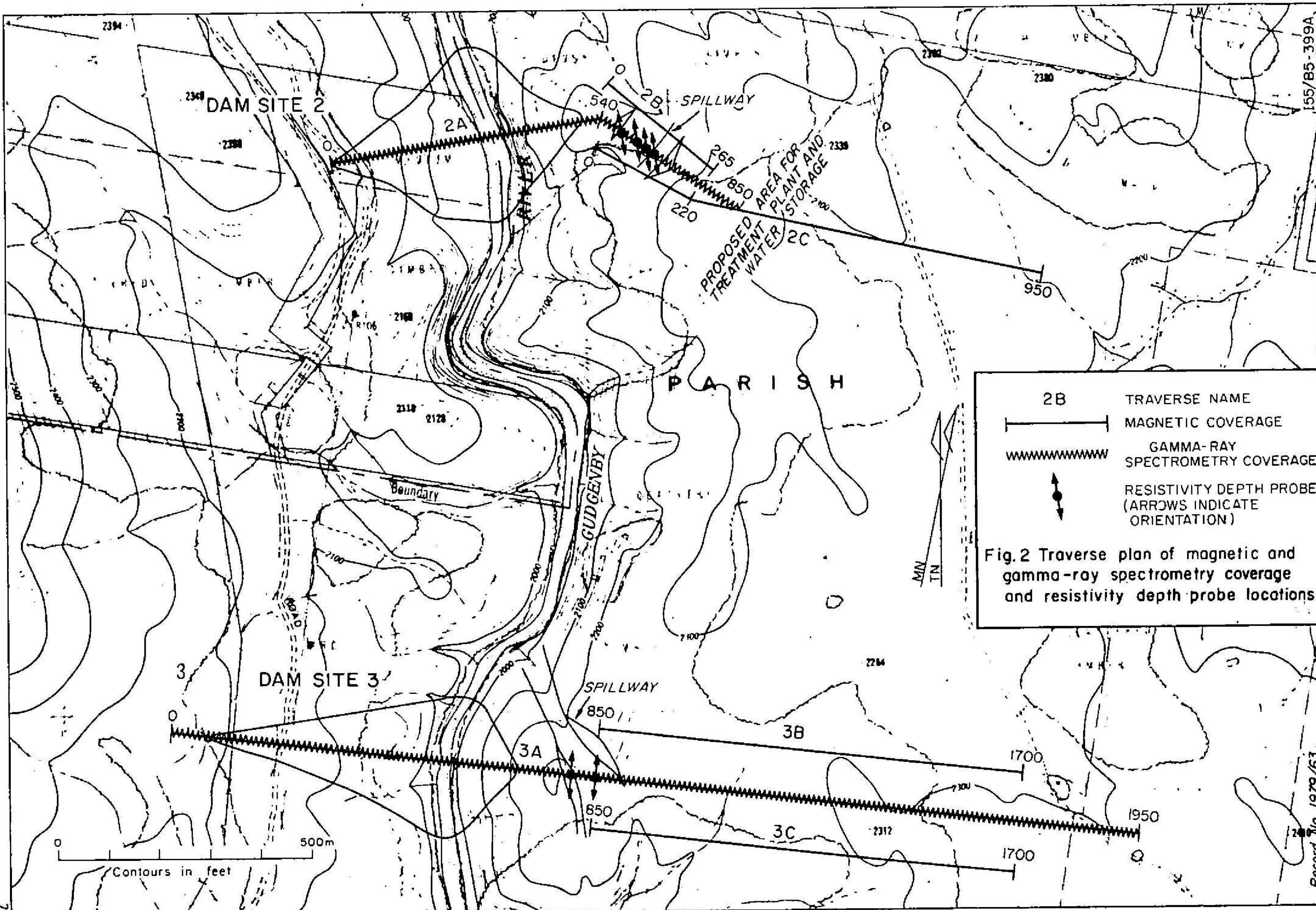

Fig. 2 Traverse plan of magnetic and gamma-ray spectrometry coverage and resistivity depth probe locations

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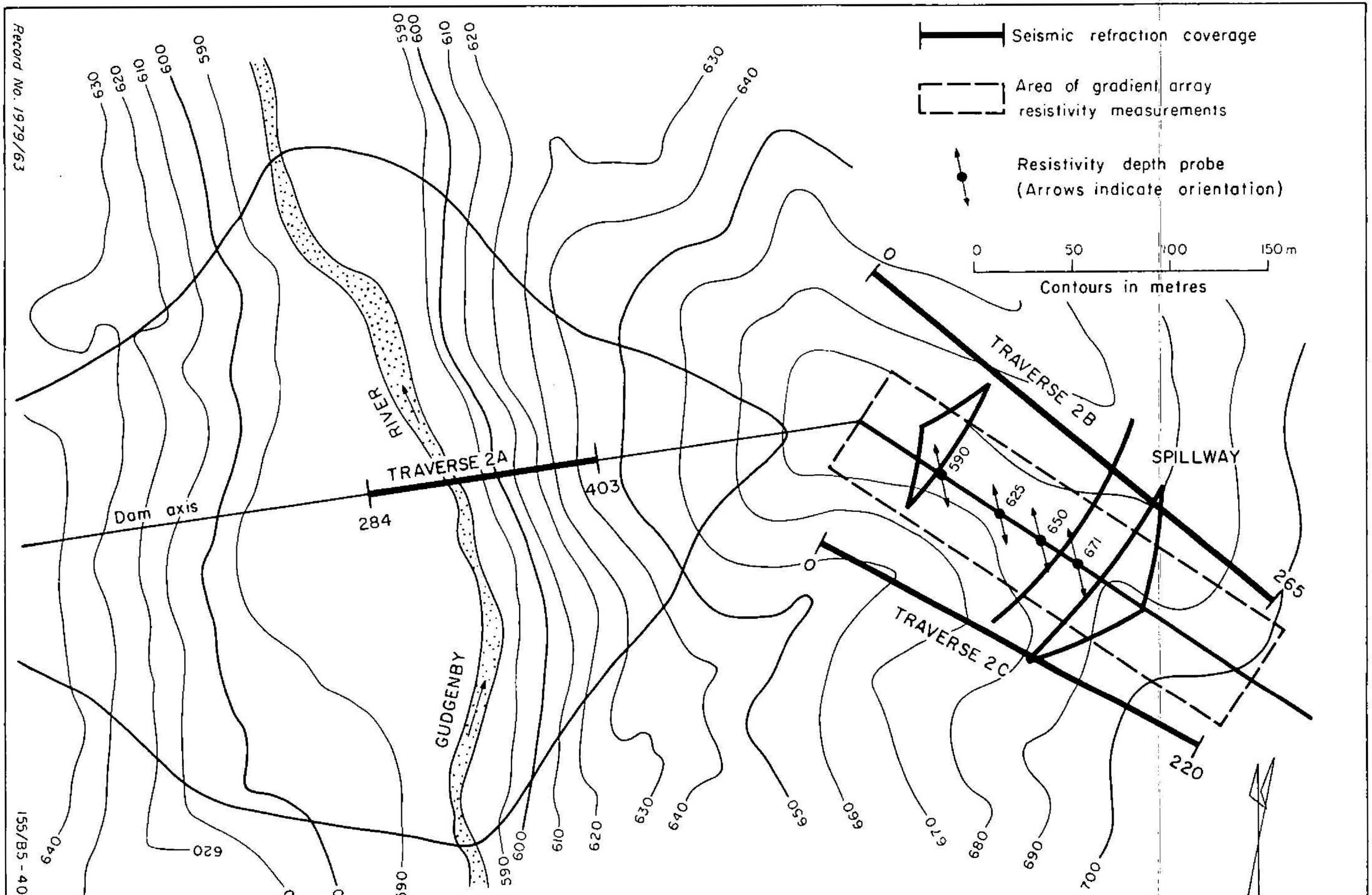

Fig. 3 Plan of Dam Site 2. Seismic and resistivity coverage.

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(b) Dam site 3

Resistivity profiling	:	traverse 3A, ch. 535-1025 m
Resistivity depth probes	:	at ch. 807 and 853 m on traverse 3A
Magnetics	:	traverse 3A, ch. 00-1950 m
		traverse 3B, ch. 850-1700 m
		traverse 3C, ch. 850-1700 m
Magnetics (vertical gradient)	:	traverse 3A, ch. 1000-1450 m
Radiometric	:	traverse 3A, ch. 00-1950 m

It is proposed to build various ancillary works such as treatment plants and water storages in the plateau area above and to the east of the river. For this reason, and because it was desirable to have more information on the geological setting of the dam site area, some of the traverses were extended eastwards out to the edge of the batholith.

The geophysical equipment used during the survey is listed in the Appendix.

The seismic refraction work was carried out by the routine 'reciprocal method' (Hawkins, 1961). A geophone spacing of 2 m was used, and five shots were fired for each spread, a long and a short shot off each end plus a centre shot. The number of spreads recorded at dam site 2 totalled thirteen - one at the bottom of the gorge, two on the steep right abutment, and ten in the spillway area.

Variations in the apparent resistivity of the dam site 2 spillway were mapped by the rectangle gradient array configuration (Kunetz, 1966, p. 31). The IP equipment was used with a current electrode separation of 180 m and a potential electrode separation of 10 m. The complete coverage was achieved by three current electrode placings, adjacent sets of potential readings being overlapped by one transverse line of readings. Wenner depth probes (dam sites 2 and 3) were expanded in the direction of the structural trend (roughly N-S) to maximum electrode separations (a) ranging from 30 to 90 m. The 'Megger' was used for this work. The probes were located so as to provide additional information on anomalous subsurface zones shown up by the earlier seismic work (Horsfall, 1976). The resistivity profiling along traverse 3A was done using the EM31 instrument held at waist height oriented normal to the traverse direction. This instrument operates on the principal of electromagnetic induction, and is stated by the manufacturers to have an effective depth of investigation of about 6 m under most geologic conditions. Readings were taken at 2.5 m intervals.

Apart from those sections of the traverses affected by artificial magnetic noise due to steel survey pegs, fences, etc., measurements of the total magnetic field were generally made every 2.5 m. Along traverses 3B and 3C, and for the vertical gradient measurements along traverse 3A, readings were taken every 5 m. The normal total field readings were taken with the sensor held 2.5 m above ground, while two sensor heights, 0.9 and 3.0 m, were used to obtain the vertical magnetic gradient. Before the magnetic survey was begun, outcrop samples were collected from both dam sites and submitted to the BMR Rock Measurements Laboratory for determination of magnetic susceptibility. Core samples of fresh adamellite from the original dam site 1 investigation were also tested. Table 1 shows the results. As expected for the granitic terrain, the susceptibilities are relatively low. No definite relation appears to exist between degree of weathering and susceptibility.

The Exploranium gamma-ray differential spectrometer used for the radiometric work has an NaI (Tl) crystal scintillation detector, and through the instrument analysers provides four channels of visual readout:

1. An integral channel for total count (energy above 0.4 MeV)
2. 1.46 MeV channel corresponding to the K^{40} peak
3. 1.76 MeV channel corresponding to the Bi^{214} peak
4. 2.62 MeV channel corresponding to the Tl^{208} peak

The window width of channels 2, 3 and 4 is 200 keV.

Bi^{214} and Tl^{208} are the daughter products of the radioactive decay of U^{238} and Th^{238} respectively; thus the outputs from channels 3 and 4 are related to the concentration of uranium (U) and thorium (Th). In the field the instrument console was mounted on the chest of the operator and the detector slung behind from his waist in a near-vertical position, the height of the detector above ground being about 65 cm. A 10-second set of readings was taken at 5-m intervals along the traverses (except for ch. 00-200 m and ch. 1450-1950 m of traverse 3A where the measurement interval was increased to 10 m).

4. GEOPHYSICAL RESULTS AND THEIR INTERPRETATION

Seismic refraction

The results of the seismic work done at dam site 2 are shown as seismic cross-sections in Figures 4 and 5. Figure 4 depicts the bottom of the gorge and east slope (right abutment); Figure 5 relates to the spillway area.

The following interpretation is given to the various seismic velocity layers. Basically, the higher the velocity the more unaltered and competent the rock is.

In situ seismic velocity (m/s)	Rock mass description
350-870	Soil, alluvium, or extremely weathered bedrock - possibly containing large blocks of relatively fresh rock. Generally unconsolidated and soft. This material can be handled by most earth-moving machinery.
870-1250	Highly weathered bedrock which may be intensely sheared or contain wide, open, or clay-filled joints. Ripping should be possible, though the occurrence of large loose blocks of rock may retard excavation operations.
1250-1900	Highly or moderately weathered bedrock that is closely jointed or sheared. Excavation by ripping using large tractors such as the D9 may be possible to some extent, but blasting will probably be required.
1900-2700	Moderately weathered bedrock. Seismic velocities within this range extending down into the deepest recorded refractor are a likely indication of major shear zones.
2700-5100	Moderately weathered to fresh adamellite. Joints are moderately to widely spaced and tight, or parted only slightly. Good foundation rock.

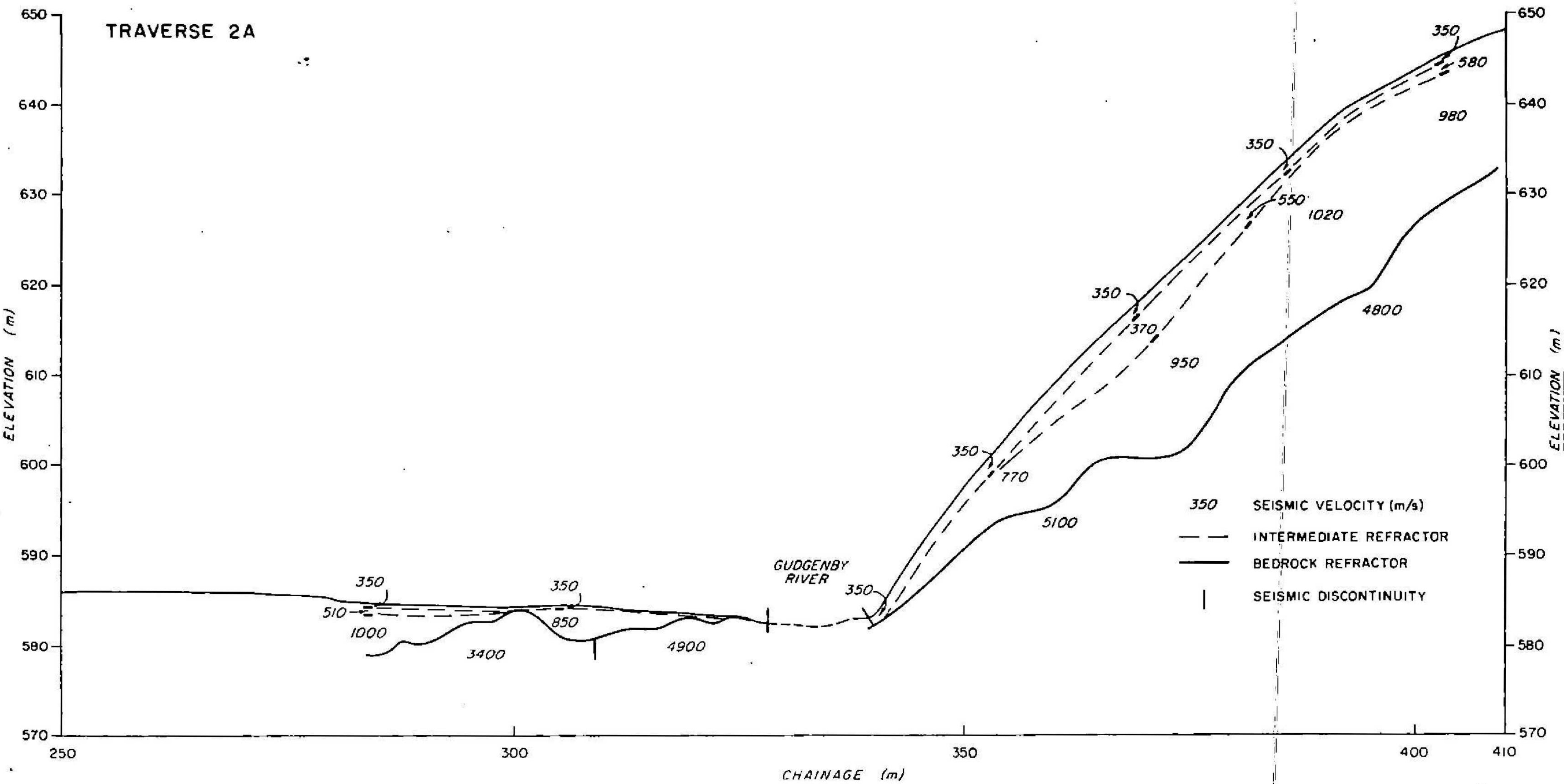

Fig.4 Tennent Dam Site 2. Seismic cross-section, Traverse 2 A

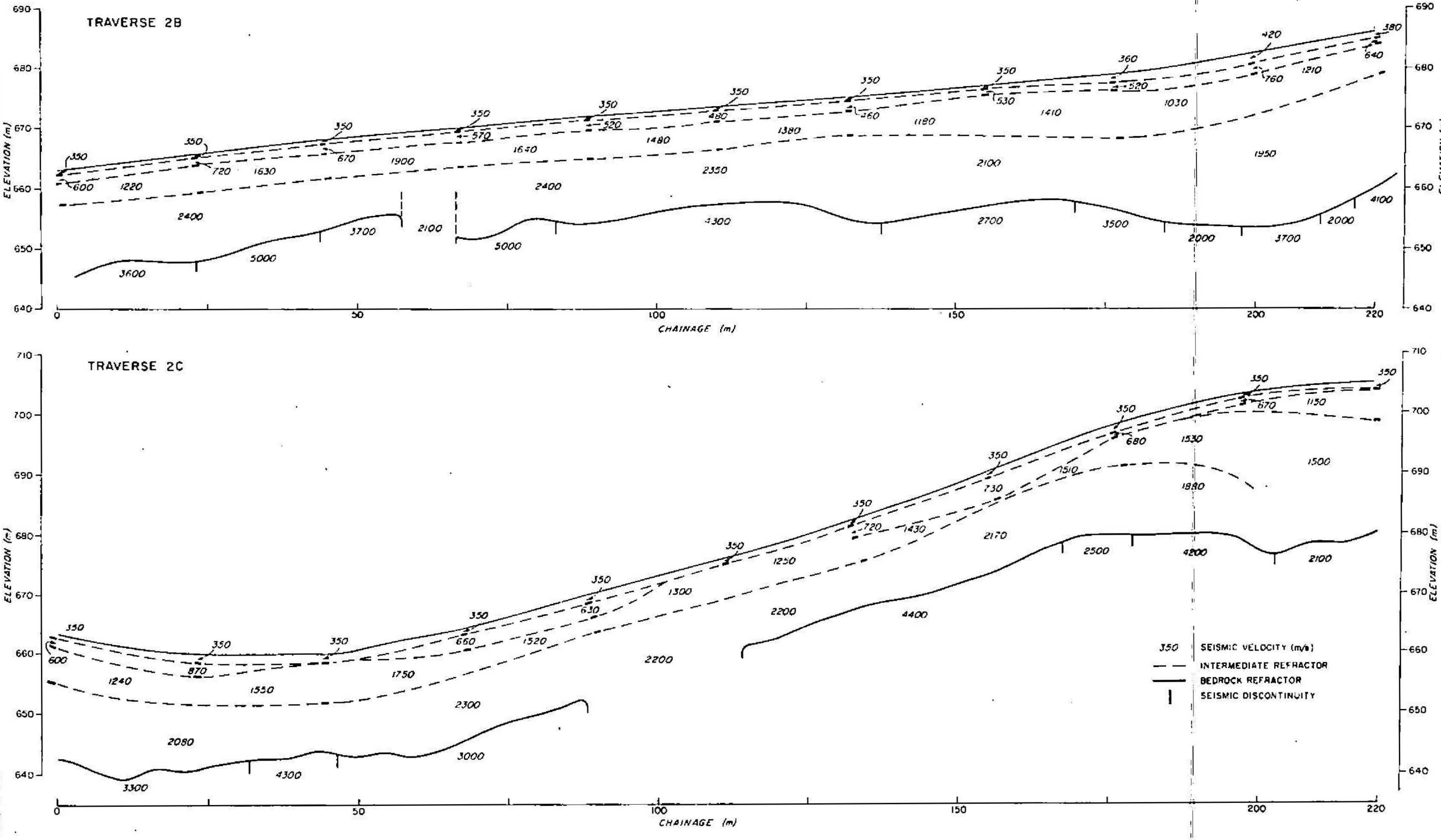

Fig 5 Tennent Dam Site 2. Seismic cross-sections, Traverses 2B and 2C

Sound, moderately to slightly weathered bedrock on the alluvial flat at the bottom of the gorge lies at a relatively shallow depth (Fig. 4); the overlying highly weathered rock and alluvium are no more than 6 m thick. The profile of the deepest refractor indicates that the relatively fresh bedrock comes right to the surface. Hence it appears that at least some of the massive 'boulders' seen on the flat are in fact in-situ bedrock exposures.

The middle and upper parts of the steep, unstable section of the right abutment slope show severe weathering and/or structural alteration to a depth of about 15 m (Fig. 4). Stripping of this material will be necessary to ensure secure foundations. Fortunately, the underlying rock has a high seismic velocity, indicating slightly weathered to fresh adamellite.

The spillway cross-sections (Fig. 5) show a gradual decrease in weathering with depth, from the surface to the deepest recorded refractor lying at a depth of about 18 m. Velocities of this refractor are not uniform, however, suggesting that the area is intersected by a number of shear zones. This is supported by evidence from surface geological mapping and the seismic results of Horsfall (1976). At least two major shear zones, each about 20 m wide and compatible with the structural trends in the area, are postulated. These zones of weakness cross the traverses at the following points.

	Traverse 2C	Traverse 2A (see Horsfall, 1976)	Traverse 2B
Shear zone 1	ch. 100 m	ch. 580 m	immediately to the west of ch. 00 m
Shear zone 2	ch. 210 m	ch. 725 m	ch. 155 m

Average depth to moderately weathered adamellite is about 7 m.

Resistivity

The resistivity of a rock formation is primarily a function of the amount and conductivity of the water contained in its pores. Weathering or structural deformation tends to increase the pore volume (and thus the water bearing capacity) and is often accompanied by a rise in pore-water ion content (salinity). Consequently altered rock is generally characterised by lower resistivities.

On the dam site 2 spillway area, resistivity mapping was done with a sufficiently large current electrode separation to allow significant current penetration deep into bedrock. The map of apparent resistivity (Fig. 6) thus reflects the combined effect of resistivity variations in the overburden and bedrock. The pronounced north-south pattern of the resistivity contours is consistent with the structural trends of the area. The resistivity high at the northeast corner signifies near-surface fresh bedrock. The elongated (N-S) resistivity lows crossing traverse 2A at ch. 580 m and ch. 725 m correspond exactly with the shear zones delineated by the seismic refraction method.

Interpretation of the depth probes centred on traverses 2A and 3A (Table 2) yields a resistivity of 500-700 ohm-m for the deepest layer, which represents moderately to slightly weathered adamellite. The maximum apparent resistivity recorded during the mapping of the dam site 2 spillway area was 880 ohm-m, suggesting that fresh adamellite bedrock probably has a resistivity of about 900-1000 ohm-m. The low resistivity of some of the layers can be attributed to higher clay content. The results correlate well with those of the earlier seismic work - the depth to the resistive substratum being much greater where recorded low velocities indicated the presence of shear zones. Deep bedrock alteration is present at depth probe locations ch. 590 m, ch. 650 m (dam site 2) and ch. 807 m (dam site 3).

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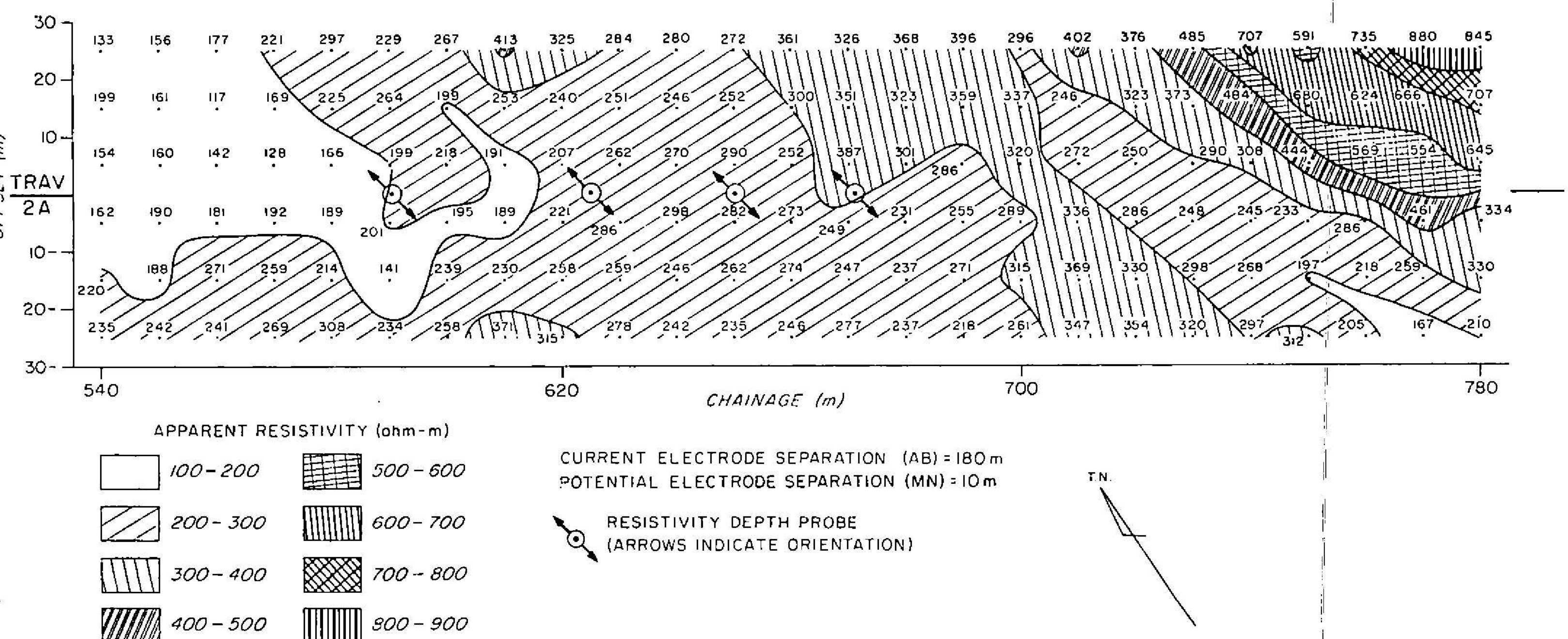

Fig. 6 Map of apparent resistivity, Dam Site 2, spillway area.

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The resistivity profile at dam site 3 (Fig. 7) provides a very revealing subsurface picture. The jagged, erratic nature of the profile between ch. 560 m and ch. 800 m in particular, suggests that the subsurface is very unevenly weathered. This is probably due to preferential weathering of local patches of highly sheared rock. In contrast, the profile east of ch. 900 m is very much smoother, and because of the lower average resistivity, deep uniform weathering is implied. The resistivity highs around ch. 740 m and ch. 860 m indicate shallow weathering. However, sound bedrock may be at greater depth near ch. 740 m because the resistivity high may have been accentuated to some extent owing to the rock being drier, since the area is located high on the ridge above the right abutment. Blasting will be required to excavate the rock near ch. 860 m for the spillway cut. The resistivity low at ch. 810 m corresponds to the shear zone detected by the seismic work (Horsfall, 1976) and depth probe (ch. 807 m). Another low from ch. 635 m to ch. 675 m is also interpreted as being due to extensive shearing of the rock. This area appears on the seismic cross-sections as a thickening of the intermediate-velocity refractors. Goldsmith & Briscoe (1977) deduced the presence of a fault zone here from the occurrence of phyllite and blastomylonite. The resistivity low at ch. 550 m is due to the relatively high conductivity of the river water and water-saturated sandy alluvium.

Magnetics

The magnetic traverses were run to detect any changes in geological structure or lithology. Granitic rocks have low susceptibilities in this area, as indicated by laboratory measurements on rock samples (Table 1), so that no large magnetic variations were expected - assuming uniform geology.

The total magnetic intensity profiles are presented in Plate 1 (together with the radiometric profiles). Some of the profiles, particularly those west of the river, are segmented because readings were omitted near artificial sources such as steel survey pegs and fences.

West of the river and at the dam sites proper, the profiles are relatively flat and show no significant anomalous behaviour. The situation is different, however, on the plateau area east of the Gudgenby gorge.

At the far eastern ends of traverses 2C and 3A there is a decrease in total magnetic intensity with the change in lithology across the Murrumbidgee Fault. The profiles indicate that the fault intersects the respective traverses at roughly ch. 900 m and ch. 1750 m. On traverse 2B, the magnetic high at ch. 240 m occurs where very high apparent resistivities were recorded during the resistivity mapping, and hence is associated with fresh near-surface bedrock.

The most striking feature of the profiles is the series of north-south-trending subparallel anomalies which appear on traverse 3A (between ch. 1000 m and ch. 1400 m), traverses 3C and 3B, and also on traverse 2C as a single broad anomaly. This feature is obviously controlled by the regional structure. The individual anomalies have forms consistent with vertically dipping dyke-shaped causative bodies.

From the shape of the vertical gradient profile, as well as computer interpretation (Hsu & Tilbury, 1977), the main sources of the anomalies seem to lie about 7-20 m below the surface (for traverses 3A, 3B, and 3C). The seismic work on traverse 3A (Horsfall, 1976) indicates a similar depth range for the deepest recorded refractor in the areas of the magnetic anomalies; very high-velocity (up to 5800 m/s) bedrock is present in the area, but is interspersed with low velocity zones which

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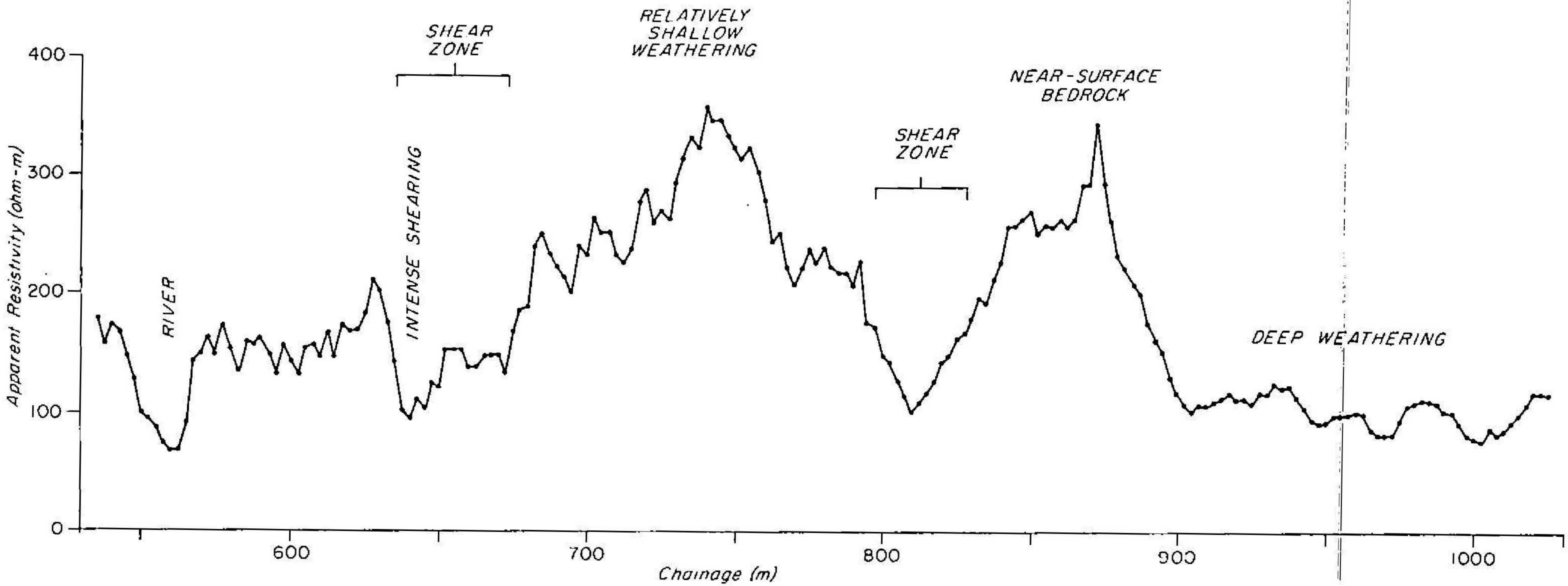

Fig.7 Dam Site 3. Resistivity profile

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are presumably shear zones. Two possible explanations for the anomalies are, (a) the high-velocity (therefore fresh) bedrock is magnetic, or (b) hydrothermal activity up through the shear zones has brought magnetic mineralisation with it. Near the surface, weathering has apparently destroyed much of the original magnetisation.

Gamma-ray spectrometry

Theoretical and practical aspects of gamma-ray spectrometry as applied to geological investigations are discussed by Adams & Gasparini (1970). This technique can be used to delineate rock formations that possess different gamma spectrometric 'signatures'. Granites possess a high gamma radioactivity because of the high potassium (K) content of their mineralogy - particularly the contribution from K-feldspar ($KAlSi_3O_8$) and muscovite ($H_2KAl(SiO_4)_3$). In addition, granites are generally relatively rich in thorium (Th) and uranium (U). Gamma radiation is appreciably attenuated by absorption in soil and rock, thus the main gamma response of the subsurface originates from the top 0.5 m.

Massive outcrops of slightly weathered to fresh adamellite (west of the Gudgenby River) gave the following typical count rates (counts/10 seconds).

Total	K	U	Th
1650	120	32	25

Measurements made on the river bed at dam site 3 over about 40 cm of water indicate a corresponding background count of

480	19	8	9

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The largest radiometric anomaly was recorded on the west bank of the Gudgenby at dam site 3 (see Plate 1). Concentration of radioactive elements, particularly uranium and thorium, in the dark silty alluvium present here is probably responsible. The high count rates on the left abutments between the river and the Naas road indicate relatively fresh adamellite lying at, or close to, the surface. The low at ch. 100 m of traverse 3A is probably due to deeper soil development. At the other (eastern) end of this traverse there is an overall drop in radioactivity, from about ch. 1780 m, associated with the change in lithology across the Murrumbidgee Fault.

The uranium count was consistently lower than the thorium count between ch. 1500 m and ch. 1780 m of traverse 3A, implying that bedrock here is petrologically different from the adamellite farther west - probably a magmatic differentiate or a separate intrusive body.

There is a marked correlation between potassium count highs and the magnetic anomaly peaks between ch. 1000 m and ch. 1400 m of Traverse 3A; no significant deviations in the uranium and thorium counts are evident. Thus there appears to have been a potassium and magnetite enrichment of the rocks in this area, brought about perhaps by dyke emplacement or hydrothermal deposition along zones of weakness within the bedrock.

5. CONCLUSIONS

The findings of this geophysical investigation, together with the results of previous surveys, particularly that of Goldsmith & Briscoe (1977) and Horsfall (1976), are considered to provide sufficient information on the geology of the dam sites and surrounding area to enable a confident decision to be made on the provisional choice of site and dam design. Some diamond drilling (especially in the eastern side of the river) should be done on the chosen site to confirm suitability before the final decision to commence construction is made.

Both of sites 2 and 3 have the common problem of weak rock at the right abutments and variable foundation conditions for the proposed spillways. Although up to 20 m of overburden may have to be stripped from both right abutments, there are no strong geological reasons why either site should not be developed successfully.

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APPENDIX: GEOPHYSICAL EQUIPMENT

Seismic refraction :	24-channel SIE PSU-19 amplifiers 25-channel SIE PRO-11 oscillograph 8-Hz GSC-20D geophones Electro-Tech HV blaster (BC-8A) Pye Cambridge (FM 10DV) two-way radios Energy source - AN60 gelignite and instantaneous detonators
Resistivity :	Scintrex IPR-8 time domain IP receiver Geotronics FT-10 IP transmitter Onan engine-generator set (model NH-MS) 'Megger' earth tester (null balance) Geonics EM31 terrain conductivity meter
Magnetics :	Geometrics (G816) portable proton magnetometer aluminium staff, 2.5 m long for the magnetometer head.
Gamma-ray spectrometry :	Exploranium (Geometrics) portable gamma-ray differential spectrometer model DISA-400A

TABLE 1

MAGNETIC SUSCEPTIBILITIES OF ROCK SAMPLES*

Dam site	Drillhole and depth	Geological description	Magnetic susceptibility (S.I. units x 10^6)
1	DG2, 32 m	Adamellite, fresh	28
1	DG3, 15 m	" "	26
1	DG5A, 59 m	" "	62
2	Surface	Adamellite, slightly weathered	35
2	"	Adamellite, moderately weathered	0
2	"	Aplite, slightly to moderately weathered.	0
2	"	Adamellite, extremely weathered	160
3	"	Adamellite, moderately weathered	160

* measured by Rock Measurements Laboratory, BMR

TABLE 2

RESISTIVITY DEPTH PROBE INTERPRETATIONS

		Layer no.	Resistivity (ohm-m)	Thickness (m)
Traverse 2A	ch. 590 m	1	100	0.2
		2	180	4.8
		3	120	35
		4	700 (approx.)	Infinite
	ch. 625 m	1	140	0.15
		2	75	1.3
		3	220	2.1
		4	80	3.5
		5	600	Infinite
	ch. 650 m	1	85	0.15
		2	150	9.9
		3	130	32
		4	700	Infinite
	ch. 671 m	1	130	0.2
		2	90	1.0
		3	230	4.3
		4	95	6.5
		5	500	Infinite
Traverse 3A	ch. 807 m	1	85	0.7
		2	27	0.7
		3	100	5.2
		4	700	Infinite
	ch. 853 m	1	240	0.4
		2	45	0.1
		3	320	2.7
		4	670	Infinite

MAGNETIC AND RADIOMETRIC PROFILES

(I) TRAVERSE CHAINAGES ARE IN METRES (m)
(II) TOTAL MAGNETIC INTENSITY MEASUREMENTS WERE MADE AT A HEIGHT OF 2·5 m; VERTICAL MAGNETIC GRADIENT VALUES WERE OBTAINED FROM MEASUREMENTS MADE AT 0·9 AND 3·0 m.

SPECTROMETER CHANNELS
TOTAL COUNT: ENERGY ABOVE 0·4 MeV
K: K-40 PEAK 1·46 MeV (WIDTH 0·2 MeV)
U: Bi-214 PEAK 1·76 MeV (WIDTH 0·2 MeV)
Th: Tl-208 PEAK 2·62 MeV (WIDTH 0·4 MeV)

DETECTOR HEIGHT 0·65 m

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