COMMONWEALTH OF AUSTRALIA

DEPARTMENT OF NATIONAL DEVELOPMENT

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS.

RECORDS

1959 NO.93

GEOPHYSICAL SURVEY AT THE BARRON FALLS HYDRO-ELECTRIC SCHEME, KURANDA, NEAR CAIRNS, QUEENSLAND.

by

E.J. POLAK and P.E. MANN

RECORDS 1959 NO. 93

GEOPHYSICAL SURVEY AT THE BARRON FALLS HYDRO-ELECTRIC SCHEME, KURANDA, NEAR CAIRNS, QUEENSLAND.

by

E.J. POLAK and P.E. MANN

C O N T E N T S

P L A T E S

A B S T R A C T

This report covers the results of seismic refraction and resistivity investigations on two alternative tunnel projects for the Barron Falls Hydro-Electric scheme, Kuranda, Queensland, carried out at the request of the Co-ordinator General's Department.

The nature of the subsurface rocks along the tunnel was approximately determined by combining the available geological information with the apparent resistivities and seismic velocities, as measured along the tunnel traverses. It is indicated that 1000 ft. of the projected tunnel of the scheme III may pass through, or go close underneath the weathered zone, whereas the projected tunnel of scheme X will be situated along its whole length in unweathered rock.

Seven determinations of both longitudinal and transverse seismic wave velocities were made from which Poisson's Ratio and Young's Modulus have been calculated. These showed that Poisson's Ratio in the weathered rocks (0.30 to 0.34) is higher than in the unweathered rocks (0.21 to 0.22).

A very good correlation exists between Young's Moduli and longitudinal seismic velocities, which may be used to determine Young's Moduli along the tunnel traverses. The empirical relation between the two is given by $\log E = 2.18 \log V - 2.95$.

1. INTRODUCTION

The existing Hydro-Electric Power Stations on the Barron and Tully Rivers are unable to meet the power requirements of Northern Queensland and the supply is augmented by a thermal station at Townsville.

The Barron Falls power station is located about 10 miles upstream from Cairns and about 1 mile downstream from Kuranda (Plate:1). Here the Barron River descends from the Atherton Tableland in a series of falls to a deep gorge. The existing power station utilises 415 feet of the available 900 ft. through which the river falls.

The Co-ordinator-General's Office (C.O.G.) has investigated the possibility of constructing a new power station, and ten possible schemes have been considered, of which two, Schemes III and X, have been selected for more detailed investigation. Finally scheme X has been adopted.

In response to an application from the C.O.G. the Bureau of Mineral Resources, Geology and Geophysics, carried out a geophysical survey to determine the depth to and nature of the fresh rock along two tunnel lines. Seismic refraction and resistivity (constant spacing) methods were used. The survey was carried out between 1/8/58 and 10/9/58 by a geophysical party comprising E.J. Polak, party leader, and P.E. Mann, geophysicist. Field assistants were provided by the C.O.G., who also carried out a topographical survey of the traverse lines.

It is desired to acknowledge help given by officers of the C.O.G. at Kuranda and Koombooloomba and by the staff of the Cairns Regional Electricity Board.

2. GEOLOGY

A general geological survey of the area was made by J.K. Brooks of the Geological Survey of Queensland (Brooks, 1957). The results of this work are shown on Plate 2. A further detailed examination of the outcrops of rocks along the two tunnel lines was carried out by F.J. Carter (Carter, 1958). The result of this work forms the basis for correlating seismic velocities with rock type as shown on Plates 5, 6, 7, 8, 11, 12 and 13. Six diamond drill-holes were put down, the sections of which are shown on Plates 4 and 10.

The terrain is covered by rain-forest and except for the Barron River and a few creeks, the exposure of rocks is limited to road and railway cuttings (Plate:2).

The rock throughout the area is of Lower Palaeozoic age and is mostly metamorphosed. The principal rock-types are meta-greywacke, quartzite, slate and phyllite. The following summary is based on analyses of thin sections of rocks carried out by R.M. Tucker of the Geological Survey of Queensland (Brooks, 1957).

<u>Meta-greywacke</u> : The rock is slightly metamorphosed, clearly showing sedimentary characteristics. It is generally fine-grained, the grains being subangular. The rock is well-cemented, hard and massive. There are

two types of meta-greywacke recognised in the area - the lithic greywacke, containing quartzite, slate and chert, and the felsphatic greywacke, containing plagioclase, microcline and orthoclase, indicating that it is partially derived from granitic rock.

Quartzite : Quartzite forms only a small part of the sedimentary succession, apart from a thick layer near the Hydro sidings. This bed which is intensely folded and interbedded with slate shows an apparent thickness of 1000 ft. The quartzite is white to brown in colour and the grain size is very fine. Certain horizons of quartzite contain manganese.

Slate and phyllite : These rocks weather easily, except when thinly interbedded with other rocks. They are very poorly cleaved and are often silicified. Below the weathering zone the rock is strong and solid.

Epidote-Chlorite Rock : This rock occurs only on the Cairns-Kuranda railway near Robbs'Monument. In addition to epidote and chlorite, a high proportion of magnetite is often present. The rock is hard and massive.

Meta-conglomerate : This consists of pebbles of quartzite in a chlorite or phyllitic matrix. It occurs in the Barron Gorge, where it is interbedded with greywacke.

All the above mentioned rocks are very hard, tough and massive when located below the zone of weathering. The jointing is well-developed with three main directions - two vertical and one horizontal.

The regional strike is north-north-west and the regional dip is approximately 70 degrees west-south-west to vertical. Evidence of folding is confined to the quartzite horizons.

3. METHODS AND INSTRUMENTS

(A) Seismic refraction.

The seismic method of exploration depends on the contrast in the velocity of elastic waves through different rock formations. As regards the physical laws involved, seismic phenomena are comparable with optical phenomena, in that they deal with a type of energy propagated in waves.

The seismic recording equipment used in the survey was a 12-channel reflection-refraction seismograph manufactured by the Mid-Western Geophysical Laboratory, Tulsa, Oklahoma. "Mid-western" geophones having a natural frequency 8 c.p.s. were used to detect longitudinal waves and "S.I.E." geophones having a natural frequency 6 c.p.s. were used to detect transverse waves.

The seismic refraction method was used in this survey. When an explosive charge is fired in a shallow hole the seismic waves radiate in all directions. Geophones placed on the ground detect these waves and send a corresponding electric impulse along a cable, to be amplified and photographically recorded by an oscillograph.

The waves are identified by their different characteristics, longitudinal and transverse waves alone being considered in this report. The fastest wave arriving at the geophone is the longitudinal or compressional wave which consists of a forward and backward movement of particles along the direction of propagation. The transverse or shear wave is the second to arrive at the geophones and consists of a movement of particles normal to the direction of propagation. Both waves undergo refraction, reflection or may change from one type to another at the discontinuity. Transverse waves may be polarised.

Fig. 1 shows a sample record obtained during the survey. The vertical lines are timing lines at two millisecond intervals. The shot instant "SI" is shown on trace No. 6. Following the shot instant the deflections on the traces indicate the arrival times of the longitudinal waves, which may be measured relative to the shot instant. The arrival time of the longitudinal wave at each geophone is plotted against the distance of the geophone from the shot-point thus giving a Time-Distance curve. Fig. 2a shows the time-distance curve derived from Fig. 1. The slope of the curve is the reciprocal of the seismic wave velocity.

Fig. 2b represents a typical four layer instance with parallel, horizontal layers in which the seismic velocities are laterally constant. In this instance, the velocities indicated by the time-distance curve equal the true velocities through the layers. However, where the thickness of the layers increases away from the shot point, the down dip velocity on the time-distance curve is lower than the formation velocity and vice versa.

An analysis of the paths of various seismic rays of the longitudinal wave indicates the following pattern for the first impulse recorded by the successive geophones (see fig:2a & b).

(i) Geophones G1 and G2 indicate the velocity V_1 = 1600 ft/sec. The seismic wave travels from the shot-point A to point B with velocity V_o and thence along the refractor with velocity V_1. The position of point B is determined by the critical angle of incidence i01 where $\sin i01 = \frac{V_o}{V_1}$. As this refracted wave travels along the refractor, part of its energy is continually refracted back at the critical angle i01. This wave reaches geophone G_1 through point C.

(ii) Geophones G_3 to G_6 indicate a velocity of V_2 = 3200 ft/sec. The wave travels from point A to point B_1, with velocity V_o then to point D with velocity V_1. At point D it is critically refracted and travels with velocity V_2 to point E, A refracted wave from point E travels to point C_1, with velocity V_1, and thence to geophone G_3 with velocity V_o.

(iii) Geophones G_7 to G_{12} indicate a velocity of 15000 ft/sec. It is a wave which penetrates still deeper and it is refracted from the fourth horizon.

Where the bedrock is formed by rocks of different seismic velocity, the geometry of the paths of the seismic waves is more complicated than is shown on Fig. 2b. Fig. 3 shows an instance where a bed of uniform thickness and uniform velocity V_o overlies strata of varying velocities with vertical boundaries at which $V_o < V_1 < V_2 < V_3$. When a time-distance curve for the seismic waves is plotted the points do not fall on one line. The refractor velocity indicated by the time-distance curve is usually corrected where the upper layer is not of uniform thickness. If, as indicated in Fig. 3, the vertical layers (e.g. V_1 & V_2) are too thin in relation to the geophone spacing, no accurate velocity measurements can be made. For instance in Fig. 3, the velocities V_2 & V_1 cannot be deduced from the data recorded by geophones G_2, G_3, G_4 and G_5. However, V_3 can be deduced from data recorded by geophones G_5, G_6 and G_7. It follows that for any velocity measurements applicable to one medium at least three points on the corrected time-distance curve must be located on a straight line, as for instance x, y and z (Fig. 3).

The field arrangement and corresponding calculation method known as the "Method of Differences" was used. (Heiland, 1946 p. 548). The technique is illustrated in Fig. 4. A shot is fired at point A and the travel times are recorded at points B and C. A shot is then fired at point C and the travel times recorded at points A and B. The depth d measured to the refracting interface normally below point B is calculated from the formula:

$$d = \frac{1}{2} (T_{AB} + T_{CB} - T_{AC}) V_a$$

where

T_{AB} = time of travel of refracted wave from A to B.

T_{CB} = " " " " " " " C to B.

T_{AC} = " " " " " " " A to C.

V_a = the apparent velocity of the seismic wave within the overlying rocks.

The following types of spreads were shot :

(a) Weathering spreads: These were used to obtain the thickness and seismic velocity of the soil and surface layer. Geophones were spaced 10 ft. apart and shots were fired 5 and 100 ft. from each end of the spread and in line with it.

(b) Normal spreads : Geophones were spaced 25 or 50 ft. apart. Shots were fired 25 ft. and 250 ft. or more from each end of the spread and in line with it.

In engineering seismic investigations the velocities of longitudinal and transverse waves can frequently be correlated with and used to identify or indicate different rock-types, degree of weathering jointing or shearing near the surface.

Theoretically, the velocity of longitudinal and transverse waves in elastic media is given by the following formulae (Leet, 1950 pp. 45/46.

$$V_L = \frac{1}{12} \sqrt{\frac{E}{\delta} \frac{1 - \sigma}{(1 + \sigma)(1 - 2\sigma)}}$$

$$V_t = \frac{1}{12} \sqrt{\frac{E}{\delta} \frac{1}{2(1 + \sigma)}}$$

where

V_L = longitudinal velocity is ft/sec.

V_t = transverse velocity in ft/sec.

E = Young's Modulus in lb/sq.in

σ = Poisson's Ratio.

δ = density $\frac{\text{lb sec}^2 \text{ in}^{-1}}{\text{in}^3}$

It is therefore possible to calculate from the longitudinal and transverse velocities all the dynamical properties of the rock.

G = Modulus of rigidity (shear modulus) in lb/sq.in.
B = Bulk modulus (incompressibility) in lb/sq.in.

$$\left(\frac{V_L}{V_t}\right)^2 = \frac{\sigma - 1}{\sigma - \frac{1}{2}}$$

$$E = (12V_L)^2 . \delta . \frac{(1 + \sigma)(1 - 2\sigma)}{1 - \sigma}$$

$$G = \frac{E}{2(1 + \sigma)}$$

$$B = \frac{E}{3(1 - 2\sigma)}$$

B <u>Drill-hole velocity logs</u>

Seismic velocities were recorded in two drill-holes on Traverse X. A small explosive charge was detonated at several depths in the drill hole and the resulting waves were detected by geophones at the ground surface adjacent to the drill-hole. Longitudinal and transverse waves were recorded and from the travel times and the depth of the shot vertical velocities were calculated. These velocities are measured in a direction approximately normal to the direction in which velocities are measured in seismic refraction work. Where the vertical velocity differs, in some cases, from the velocities obtained from weathering and normal spreads, the differences may be accounted for by anisotropy of the rock, associated with depositional planes, folding, faulting and jointing.

(C) Resistivity.

Differences in the structure and composition of rocks produce variations in their electrical resistivity. Hard non-porous and unweathered rocks as a rule have a high resistivity. Shearing and fracturing result in localised weathered zones which in turn usually give rise to a relatively high salinity in the contained water and thus produce a corresponding relatively low resistivity. In general, it may be said that the resistivity of a rock is inversely proportional to the product of its porosity and the salt content of the solution in the pores.

The equipment used was the Megger Earth Resistivity Tester manufactured by Evershed and Vignoles Ltd., London.

The Wenner arrangement of electrodes was used for measuring resistivity. This is illustrated in Fig. 5. Four electrodes are equally spaced along a straight line. An alternating current is introduced into the ground through the current electrodes, C_1 and C_2, and the difference in potential is measured across the potential electrodes, P_1 and P_2. The depth of penetration of the current is controlled by the distance "a" between the electrodes. The technique used in this survey is known as resistivity traversing (Heiland 1946 page 644 et seq.). The four electrodes are moved as a unit along a traverse, centred on consecutive stations where readings are taken. In the interpretation, absolute values of resistivity are not so important as sudden changes, which usually indicate a change in rock type, such as a change from unweathered rock to sheared or fractured and weathered rock or a change from sandstone to shale.

In this survey two constant electrode spacings namely 50' and 100' were used.

(D) Magnetic method.

In the Barron Falls area short magnetic tests were carried out on proposed schemes III and X.

The measured magnetic intensity at any point on the earth's surface may be expressed as a vector. As such, it is mainly the resultant of two vectors, an induced magnetic intensity vector in the direction of the earth's magnetic field and a remanent magnetic intensity vector inherent to the rock, which may lie in any direction. Magnetic measurements may indicate, in certain areas, such features as faults and boundaries between near-surface formations and it is sometimes also possible to obtain rough depth estimates from these measurements.

The test in the Barron Falls area indicated that no useful information could be obtained by the use of this method, since apparently the difference in the magnetic susceptibility of the various rocks in the area is not sufficient to differentiate between them.

A Watts vertical force variometer, manufactured by Hilgar and Watts Ltd., London, was used.

Table 1 shows the total length of traverses covered with each geophysical method -

TABLE 1.

Method	Scheme III	Scheme X	Total
Seismic refraction	7000 ft.	7450 ft.	14450 ft.
Seismic hole logging	-	197 ft. 2 holes	197 ft. 2 holes
Resistivity	9300 ft.	5350 ft.	14650 ft.
Magnetic	1500 ft.	1200 ft.	2700 ft.

4. SCHEME III

(A) Lay-out. (Plate:3).

It is proposed in this scheme to divert water from the Barron River at a point near Fairyland through 9500 ft. of tunnel driven under the Macalister Range and thence through penstock pipes down to a power-station located on Deep Creek. The gross-head would vary with the height of the proposed weir, but would be at least 918 feet.

(B) Geology.

The geological information along the tunnel lines is very scarce. A few outcrops have been examined by F.J. Carter and the results of this examination are shown on Plates 5 to 8. A general prediction of rock types along the tunnel line (Brooks, 1957) is as follows :

Stations 0 to 40	-	Meta-greywacke, fine to medium grained with slate bands.
Stations 40 to 120	-	Slate, phyllite and interbedded greywacke. Three drill-holes have been drilled along this section and indicate that the tunnel would be driven in fresh rock, below the weathered zone (see Plate:4).
Stations 120 to 140	-	Quartzite containing beds of slate and phyllite.
Stations 140 to 195	-	Meta-greywacke with bands of quartzite and slate.

The beds dip steeply between 70 and 90 degrees, and the strike is nearly at right angles to the direction of the traverse.

(C) Results.

Seismic refraction method was used on Scheme III between stations 0 to 140. Further north the proposed tunnel of Scheme III goes deep into the rocks, so that there is no danger of the tunnel being in weathered rocks. The results of the seismic work are shown on Plates 5 to 7. The results of the constant electrode spacing resistivity survey are shown on Plates 5 to 8. The whole length of the proposed tunnel of Scheme III was surveyed using resistivity method.

(i) Depth determination.

The results of the seismic survey were interpreted as a four-layer structure as illustrated by Figure 2b.

Top layer. This is interpreted as soil with a velocity of around 1000 ft/sec. The layer seems to be thin on sections where it was measured. The maximum thickness of 10 ft. was found near station 14, but close to stations 85 and 132 the top layer appears either to be absent altogether or to be too thin to be recorded.

2nd layer. This is interpreted as completely decomposed to highly weathered rock with seismic velocities of from 1400 ft/sec. to 2800 ft/sec. This layer reaches (where measured) a maximum depth of 50 ft. on the section between stations Nos. 40 and 50.

3rd layer. This is interpreted as a weathered rock, with seismic velocities from 3200 ft/sec. to 5800 ft/sec. The maximum estimate of depth to its base is 98 ft. at stations Nos. 54 and 56.

4th layer. This is interpreted as fresh rock with a seismic velocity of from 10000 ft/sec. to 20000 ft/sec.

The error in depth determination is considered to be less than ±20 per centum of the true depth. This estimate is based on experience of results in other areas where comparable geological conditions exist. Although the error in absolute depth may be fairly large the error in relative depth of fresh rock from station to station along the traverse is likely to be much smaller and the profile shown for the surface of the fresh rock is expected to be quite accurate.

(ii) The character of the fresh rock.

The detailed interpretation of the rock types below the weathered zone is shown on Plates 5 to 7.

Table 2 shows the interpretation rules used to deduce the nature of the fresh rock from the apparent resistivity and the seismic velocity in the lowest refractor.

The rules were obtained by reviewing the geophysical data with the known geological data.

TABLE 2.

Rock type	Resistivity in ohm/cm.	Seismic velocity in ft/sec.
Slate	below 20000	below 14000
Meta-greywacke	20000 to 60000	over 14000
Quartzite	over 60000	over 14000

The interpretation rules shown on Table 2 must be used cautiously for the following reasons:-

(a) In the low lying parts of the traverse, meta-greywacke may have been mis-named as slate because the increased moisture content of the near surface layers may have lowered the apparent resistivity to below the 20000 ohm/cm limit.

(b) Narrow, low resistivity sections, which are interpreted as slates, may represent a shear zone, through which water penetrates deeper into the strata.

(c) The position of the boundary between rock types is approximate, as can be understood from the sections on seismic and resistivity methods.

Plate 8 shows a geophysical interpretation based on resistivity traversing and reconnaissance geological mapping only.

As an important result, the survey indicates that, between stations 20 and 30, and between stations 67 to 79 (plates 5 and 6) the proposed tunnel may pass through weathered rock, or may pass close to it.

5. SCHEME X

(A) Lay-out. (Plate:9).

In scheme X it is proposed to direct water from the Barron River at the existing pondage weir through 5350 ft. of tunnel, thence through a pressure tunnel down to an underground power station at the bottom of the gorge near Surprise Creek. The gross-head would be at least 933 ft.

(B) Geology.

A few rock outcrops have been examined by F.J. Carter and the results of this examination are shown on

Plates 11 to 13.

A general prediction of rock types along the tunnel-line is as follows (Brooks, 1957) :-

Stations 0 to 24	-	Slate and phyllite with inter-bedded greywacke and quartzite.
Stations 24 to 66	-	White and brown quartzite with some slate and phyllite bands.
Stations 66 to 107	-	Fine grained meta-greywacke with interbedded slate and quartzite. Massive epidote-chlorite rock to be encountered near the outlet of the tunnel in the Robb's Monument area.

The beds dip between 70 to 90 degrees and the strike is nearly north-south, thus cutting the proposed tunnel-line at a slight angle (see Plate 2).

(C) Results.

The results of the seismic work are shown on Plates 11 to 13. The results of constant electrode spacing resistivity survey are shown on Plates 11 and 12.

(i) Depth determinations.

The following layers with different velocities were recognised along the traverse (see Fig. 2b).

Top layer. Soil with a seismic velocity of about 1000 ft/sec. This layer seems to be thin (where measured) and on some sections completely missing. Vertical sections of this layer exposed in the railway cutting show non-uniform thickness merging gradually with the next layer.

2nd layer. Highly weathered rock containing some pieces of the original rock. This latter has a seismic velocity of from 1400 to 3100 ft/sec.

3rd layer. Partly weathered rock with a seismic velocity of up to 8000 ft/sec.

4th layer. Fresh rock with a seismic velocity of from 15000 to 20000 ft/sec.

The velocities listed above were determined on weathering and normal spreads along a direction corresponding roughly with the direction of the strike of the rocks. The velocity of the longitudinal wave was measured in two drill-holes, the results of these measurements are shown on Table 3.

TABLE 3.

Drill Hole No.	Depth	Time millisecond	Average velocity ft/sec	Depth interval ft	Time interval millisecond	Interval velocity ft/sec
9	147	35	4200			
				50	4½	11200
	97	30½	3200			
				17	2	8500
	80	28½	2800			
				30	3½	8500
	50	25	2000			
				16	6	2800
	34	19	1800			
				9	5	1800
	25	14	1800			
6	50	18	2770			

The seismic velocity is different when measured vertically and horizontally in sedimentary rocks. The vertical velocity in fresh rock determined on normal spreads exceeds that in borehole No. 9. This may be because the horizontal velocity was measured along the strike of the strata, while the vertical velocity was measured across the stratification planes. In sedimentary rocks the seismic velocity generally has the highest value parallel to the bedding planes of the rock.

To calculate the depth to fresh rock an apparent velocity obtained from weathering and normal spreads was used. The locations where an apparent velocity was obtained are indicated on the cross-section (Plates 11 and 12) as sub-divisions of the overburden. The apparent velocity compares well with the velocity obtained in drill-holes.

The error of the determination of the depth to fresh rock is expected to be within ± 15 per centum. This estimate is based on the results of other surveys where similar geological conditions exist. However, the accuracy may be substantially lower on the section from station 85 to station 101. Over this section shots were fired only on one side of the spread so as to avoid firing too close to Kuranda-Cairns railway line. When shots are fired from one direction only it is necessary to assume the seismic velocity of the rock to calculate the thickness of overburden. A small error in the assumed value of the velocity can produce large errors in final results.

The survey shows that over its whole length the tunnel in Scheme X will be well below the weathered zone.

Table 4 compares drilling data and seismic data in three drill-holes along the traverse line of scheme X.

TABLE 4.

Drill-Hole No.	Depth in feet to discontinuity seismic	drilling	Character of the rock below discontinuity (after F.J. Carter)
6	37	40	Solid fresh rock, some iron-stained joints (Pelitic Phyllite, Green-schists)
9	62	64	Moderately to slightly weathered slates and phyllites with meta-greywacke at 69-70'. Manganese stained joints and quartz stringers.
7	110	114	Phyllite (fresh) and slate with joints.

(ii) The character of the unweathered rock.

The interpretation of the probable rock types below the weathered zone is shown on Plates 11 to 13. The method of interpretation of geophysical data as described for scheme No. III was used here and the values of seismic velocity and resistivity, as listed on Plate 2, served as the basis for this interpretation. Since the strike of the rocks is more parallel with the traverse, the limiting velocity of 15000 ft/sec. for meta-greywacke and quartzite was accepted. All the other limitations apply here as well.

The interpretation of rock types on the pressure tunnel line (Plate:13) is based on seismic velocities and the projection of geological boundaries noted in the railway cutting and Barron River Gorge.

(iii) The dynamic properties of the rocks.

Table 5 shows the values of the dynamic properties of the rocks, calculated from the longitudinal and transverse wave velocities obtained in drill-holes and on normal spreads. The formulae used were given earlier in the report (part 3A).

Many rocks show velocity anisotropy. The velocity measured for a rock will depend on the direction in which the velocity is measured relative to the bedding or stratification planes. Hence it may be expected that the dynamic elastic constants of the rock vary in the same way. This means that the dynamic constants given in Table 5 for D.D.H.No.6 and D.D.H.No.9 are only valid for a direction parallel to the axis of the borehole.

TABLE 5.

Location	Depth	Longitudinal: Time in Millisecs.	Longitudinal: Velocity ft/sec	Transverse: Time in Millisecs.	Transverse: Velocity ft/sec	Interval Velocities: Long. in ft/sec	Interval Velocities: Trans. in ft/sec	σ	E: 10^6 lbs/in²	E: 10^{11} dyne/cm²	B: 10^6 lbs/in²	B: 10^{11} dyne/cm²	G: 10^6 lbs/in²	G: 10^{11} dyne/cm²
Drill-Hole No.9	147	35	4200	65	2250									
						11000	6700	.21	3.5	2.4	2.05	1.4	1.46	1.0
	80	29	2750	55	1560									
						9300	5600	.22	2.5	1.72	1.6	1.1	1.02	0.7
	52	26	2000	50	1080									
						2650	1240	.34	0.15	0.1	0.14	0.09	0.05	0.04
	36	20	1800	37	970									
Drill-Hole No.6	50	17	2950	35	1415			.325	0.18	0.12	0.17	0.11	0.07	0.05
Intake Tunnel X			7700		3600			.325	1.34	0.92	1.28	0.88	0.51	0.35
Near Collin's Bridge			6500		3500			.30	1.02	0.7	0.85	0.58	0.39	0.27
			8300		4300			.31	1.67	1.14	1.46	1.00	0.63	0.43

Table 5 shows that Poisson's Ratio in weathered rocks tends to be higher than in unweathered rocks (0.21 and 0.22 in unweathered, 0.30 to 0.33 in weathered rocks). In Fig. 6 Young's Modulus E is plotted against Poisson's Ratio for E between 0.15×10^6 and 3.5×10^6 lb/sq.inch. The figure clearly indicates the higher Poisson's Ratio corresponds with the lower Young's Modulus and vice versa. The relation may be represented by the empirical formula, in the range of E between 0.15 & 3.5×10^6 lb/sq.inch by :-

$$\sigma = -0.05E + 0.36 \pm 0.02$$

On Fig. 7 the values of Young's Modulus are plotted against the longitudinal velocity. Curve A was derived from data scattered in the literature in 1956. Curve B, which is compiled from the data of this survey, is similar to curve A.

Curve B can be used to evaluate Young's Modulus of the rock from the seismic velocities of longitudinal waves recorded on the traverse and shown on Plates 5, 6, 7, 11, 12 and 13.

The empirical formula representing curve B is :-

$$E = 0.00113V^{2.18}$$

or $$\log E = 2.18 \log V - 2.95$$

in which E is in lb/sq. inch and V in ft/sec.

6. CONCLUSIONS

The geophysical survey provided information on the depth to the bedrock along the tunnel lines of the alternative schemes. The overburden consists of soil, decomposed and highly-weathered, to less-weathered rock. The bedrock is of fresh but jointed rock.

Sections of the proposed tunnel line of scheme III will be situated within the weathered zone while the proposed tunnel line of scheme X is situated well below the weathered zone.

An attempt was made to deduce the character of fresh rock from seismic velocities and apparent resistivity values.

The dynamic elastic properties of the rocks have been calculated from longitudinal and transverse velocities. It was shown that Poisson's Ratio for the unweathered rocks in the area is about 0.21 to 0.22, and for weathered rocks between 0.30 and 0.33.

Fig. 7 shows a relation between Young's Modulus and seismic longitudinal wave velocity, which can be used to derive the value of Young's Modulus for the rock along both tunnel lines.

7. REFERENCES

Brooks, J.K., 1957 — Geological Survey Lower Barron River and Flaggy Creek Areas. Geological Survey of Queensland.

Carter, F.J., 1958 — Geology of the Barron Falls Area. Dept. of the Co-ordinator General of Public Works, Queensland.

Heiland, C.A. 1946 — Geophysical Exploration. Prentice Hall, New York.

Leet, L.D., 1950 — Earth Waves, Harvard University Press, Cambridge, Mass.

Shepherd, E.M., 1958 — Second Report on the Proposed Further Development of the Barron River Hydro-Electric Power Generation. Dept. of the Co-ordinator General of Public Works, Queensland.

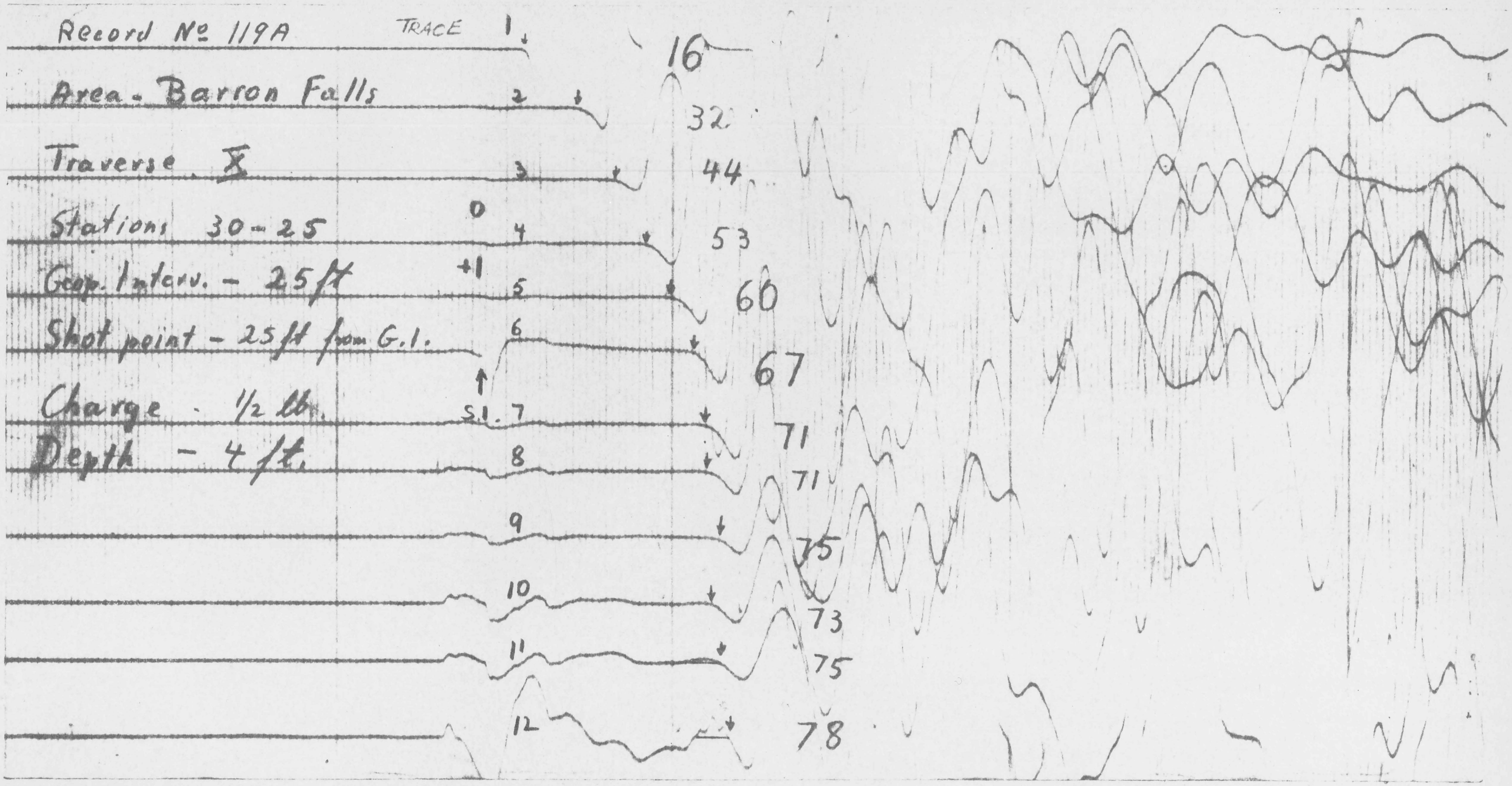


FIG. I : SAMPLE RECORD

Geophysical Section, Bureau of Mineral Resources, Geology and Geophysics.

To accompany Records 1959, No. 93

G327-14

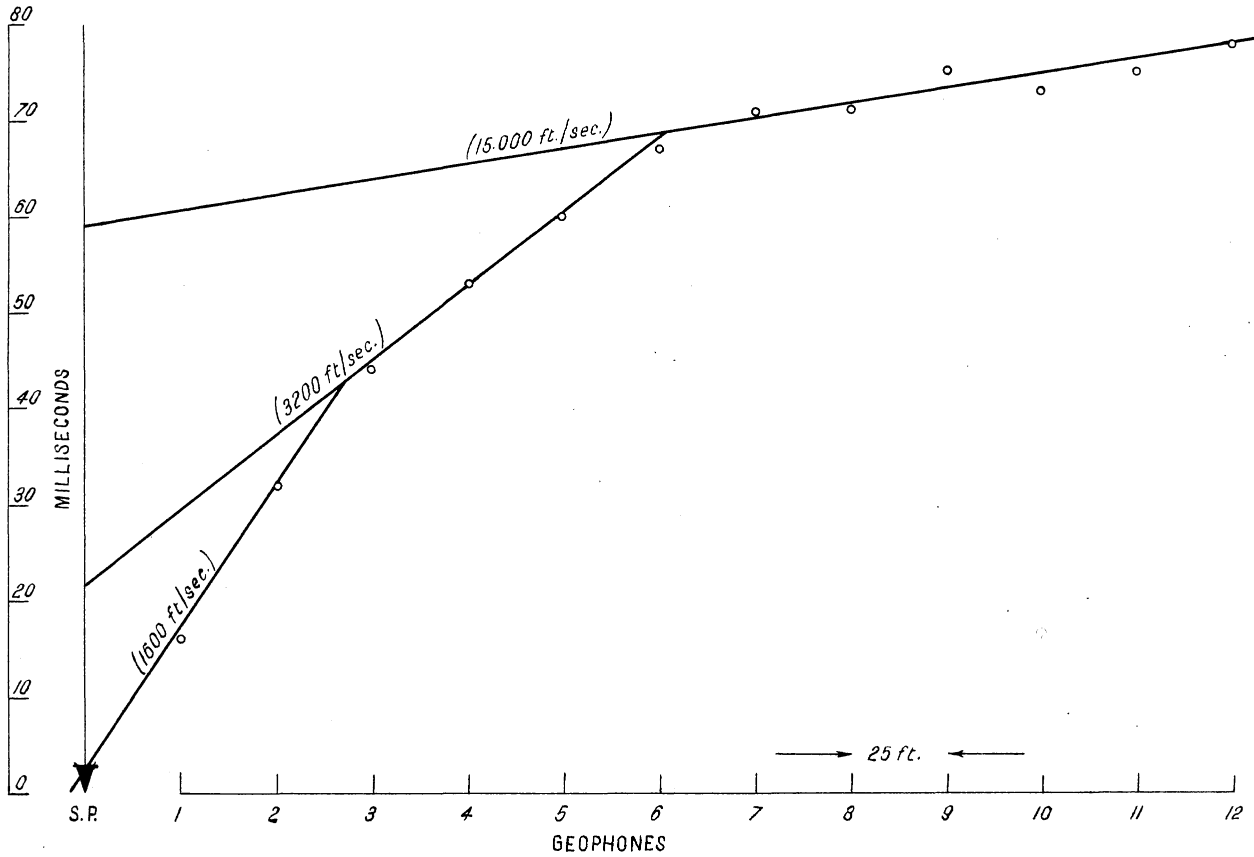


FIGURE 2a.

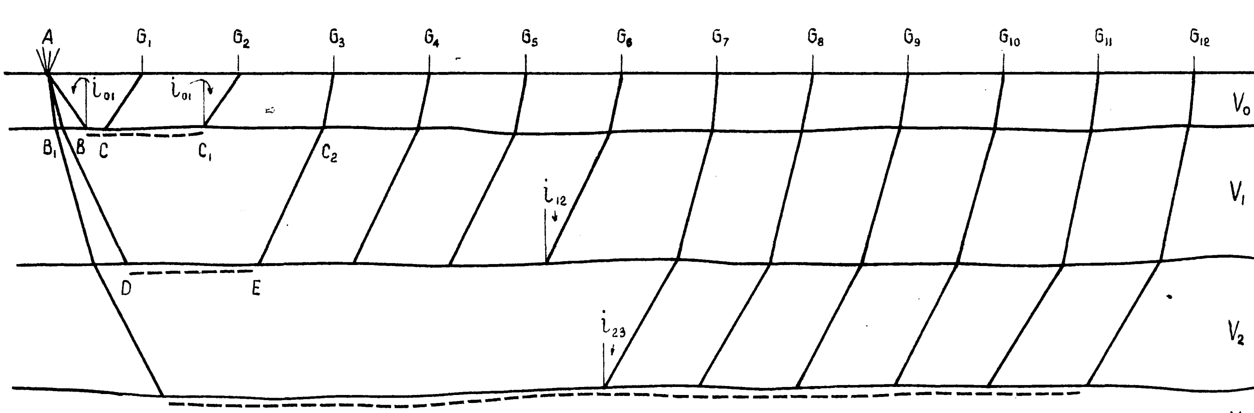


FIGURE 2b.

Geophysical Section, Bureau of Mineral Resources. Geology and Geophysics. G327-15

To accompany Records 1959, No. 93

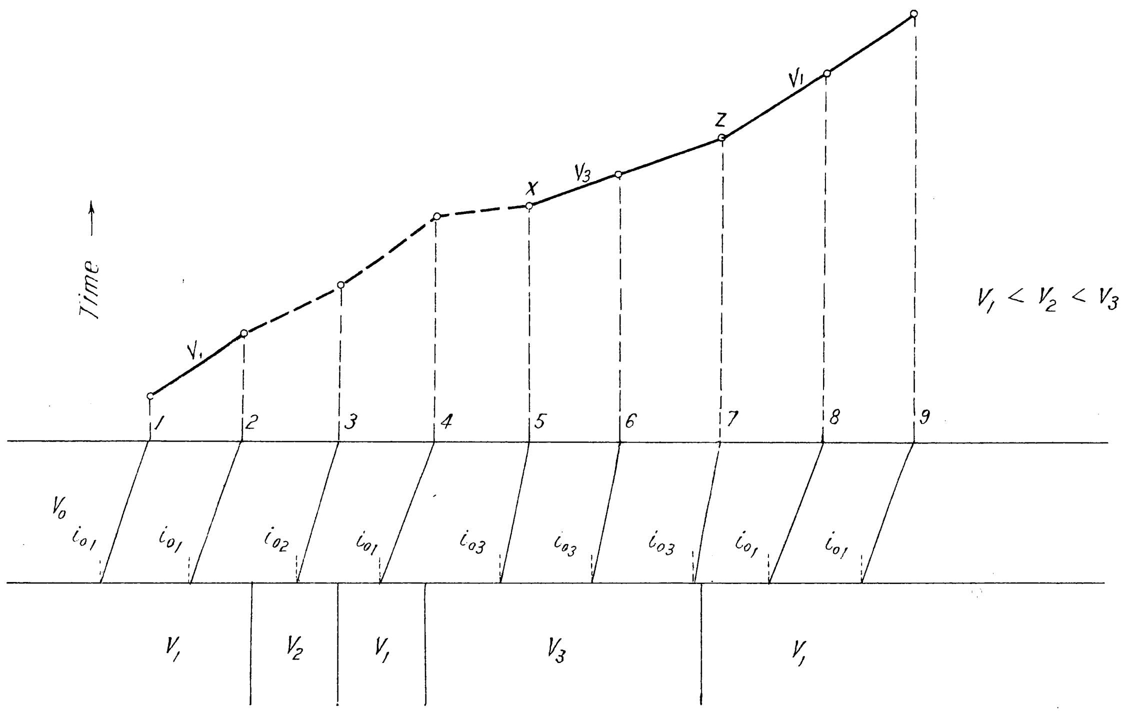


FIGURE 3. REFRACTOR WITH DIFFERING VELOCITIES

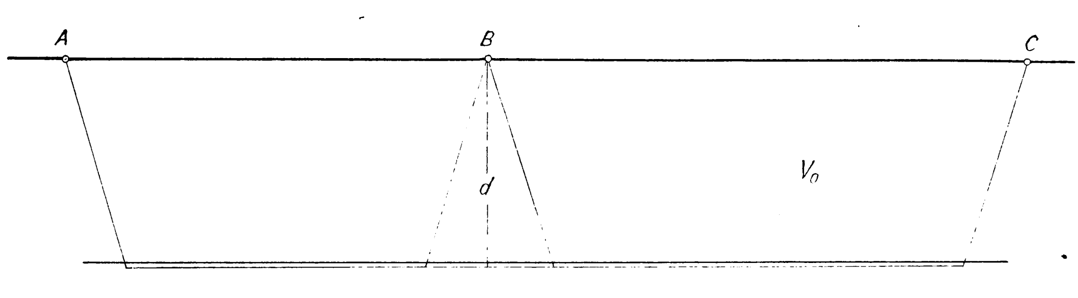


FIGURE 4. METHOD OF DIFFERENCES

To accompany Records 1959, No. 93

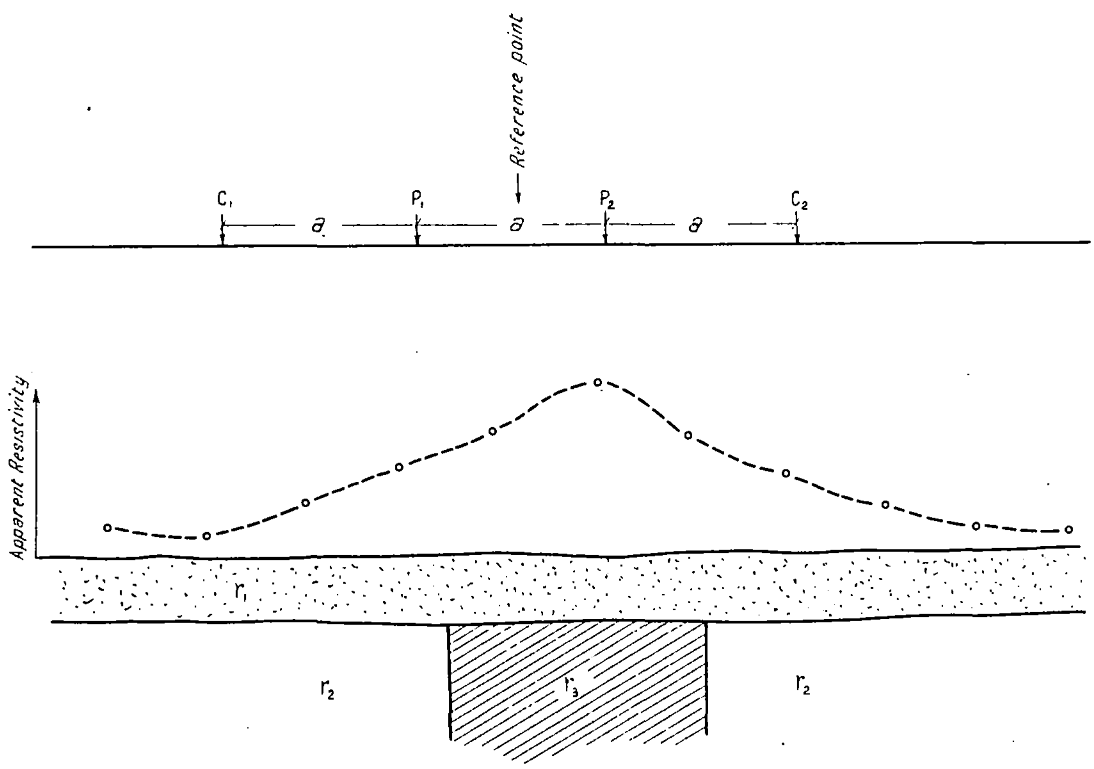


FIGURE 5. Wenner arrangement of electrodes and apparent resistivity curve over a high resistivity bed.

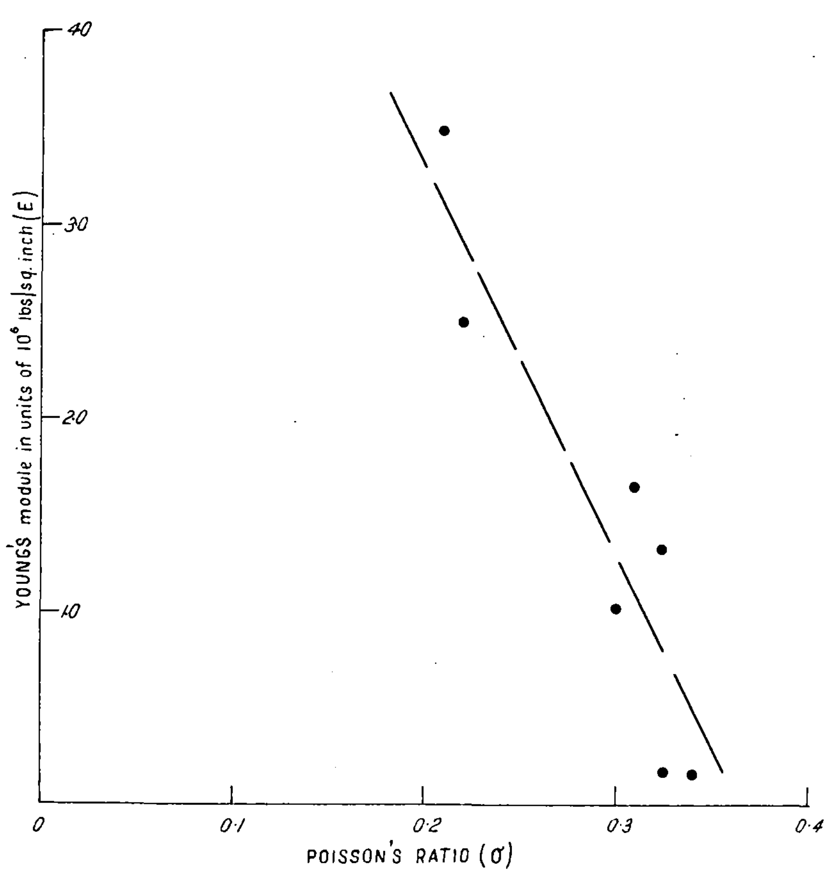
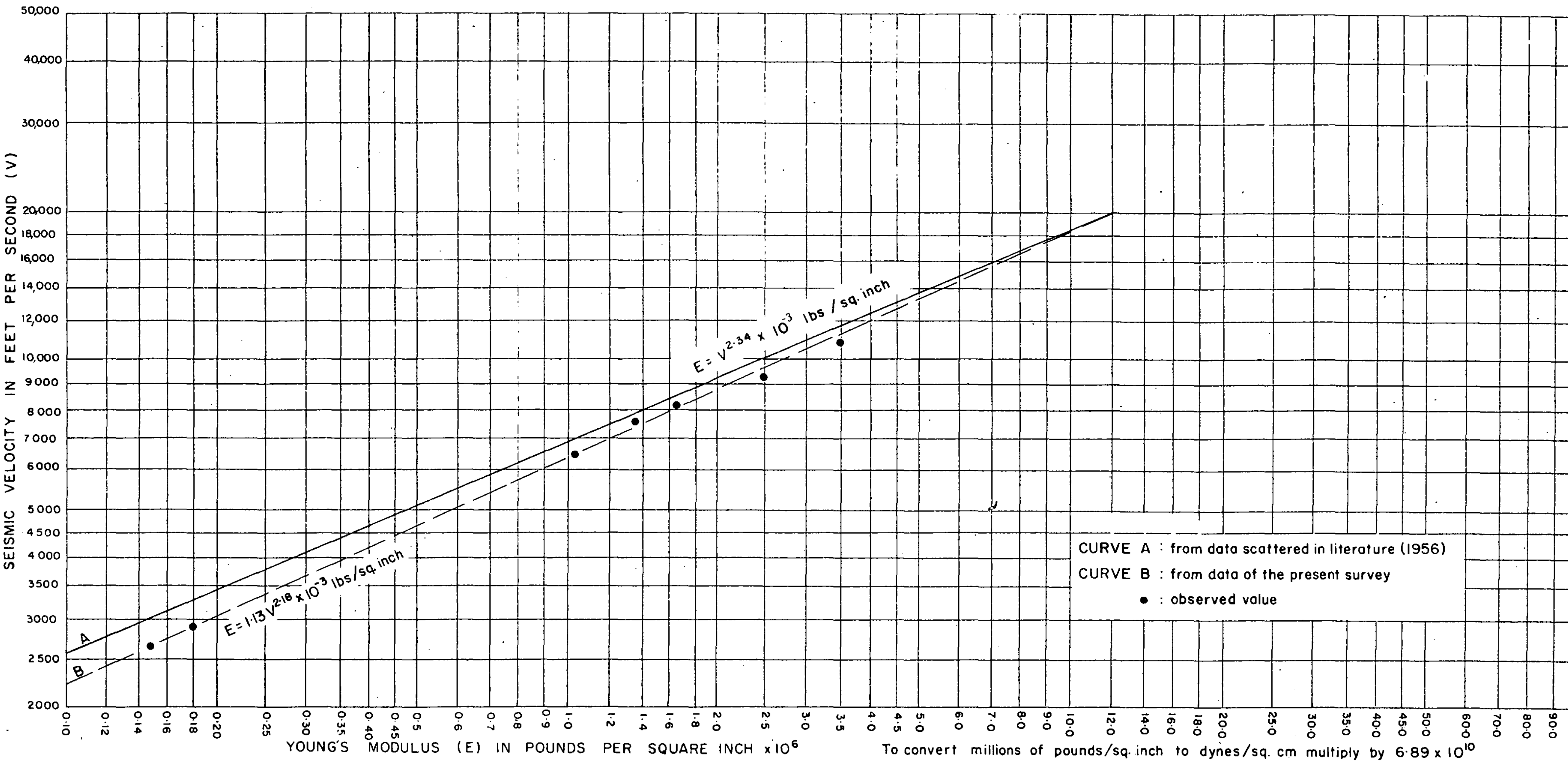


FIGURE 6.

To accompany Records 1959, No. 93

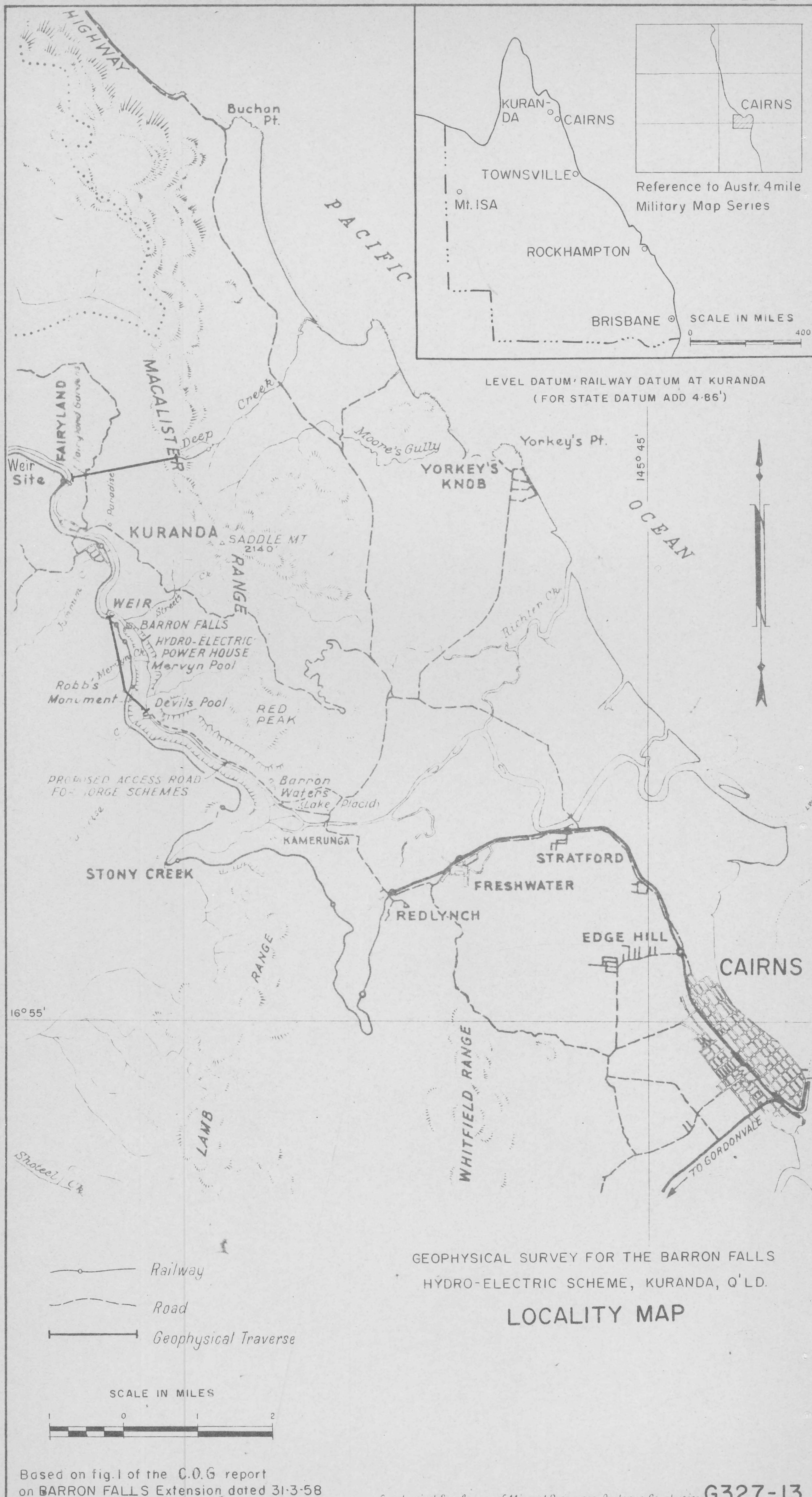


The values of Young's Modulus may be considered to have a maximum error of ± 30 %
The above relationship is approximately correct for most rock types, other than salts, silts and possibly limestones (Applies to curve A only)

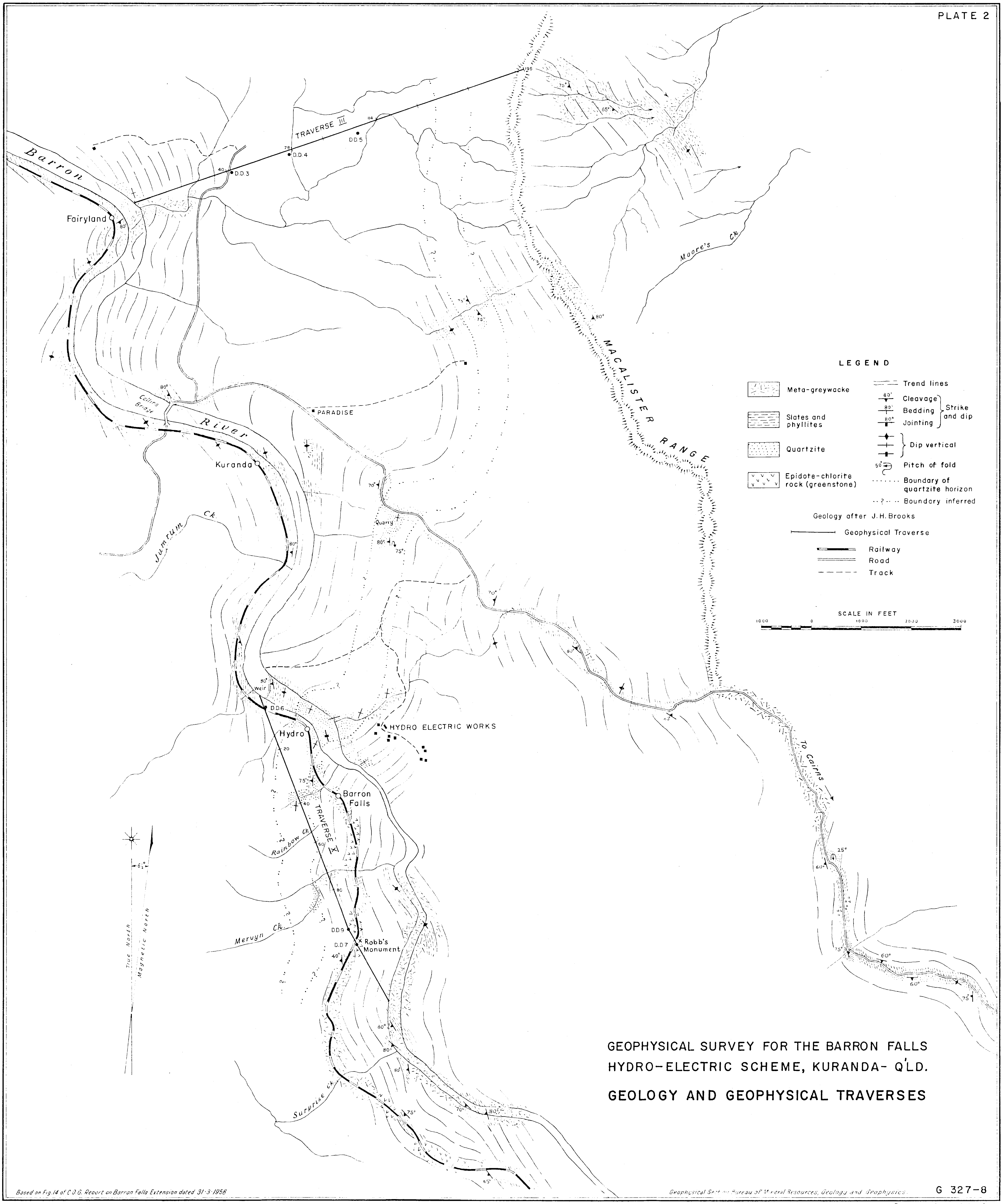
FIGURE 7. EMPIRICAL RELATION BETWEEN YOUNG'S MODULUS AND THE COMPRESSIONAL WAVE VELOCITY IN ROCKS

To accompany Records 1959, No 93

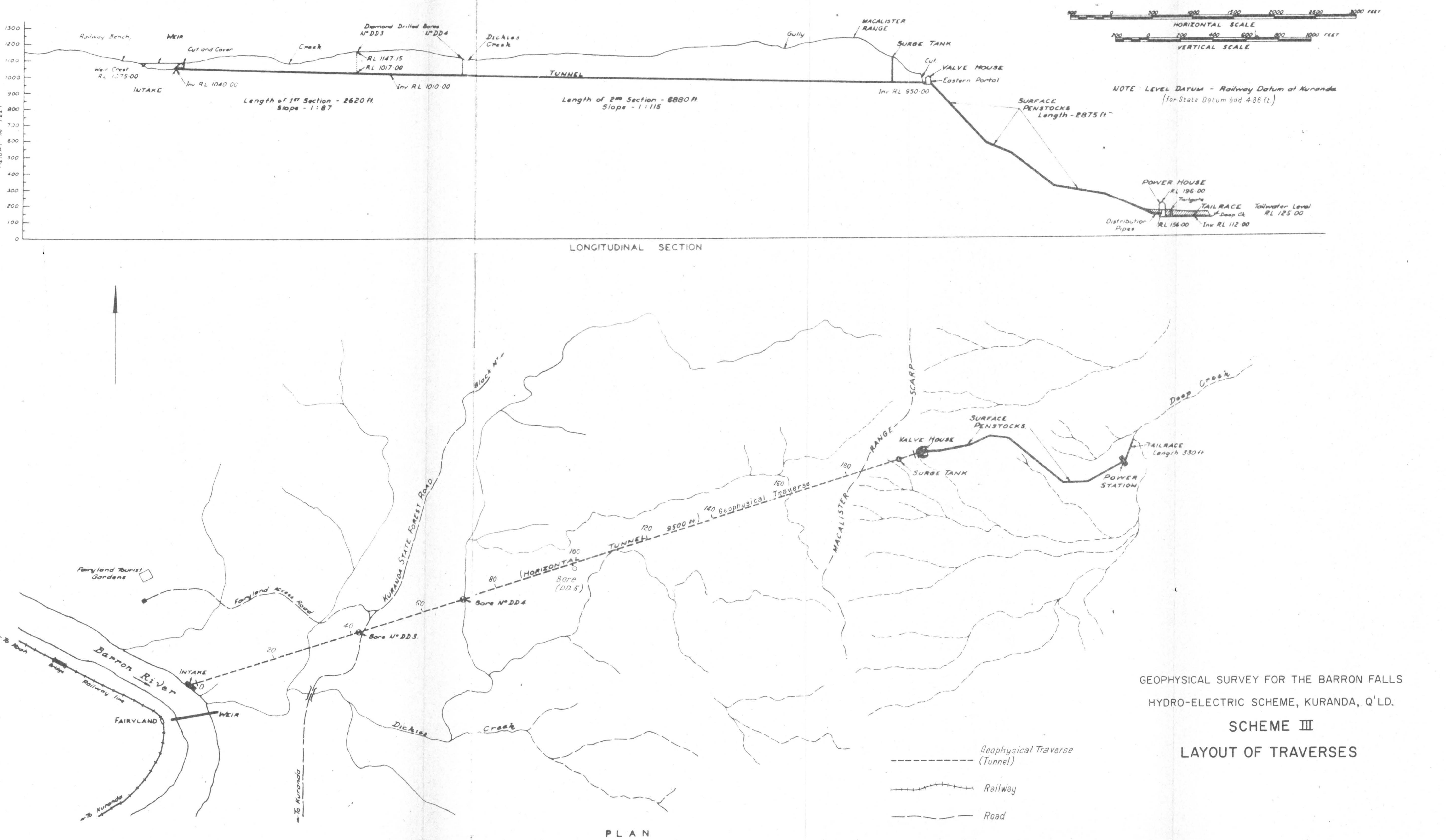
Geophysical Section, Bureau of Mineral Resources, Geology and Geophysics. G 327-18



TO ACCOMPANY RECORDS 1959, No. 93



To accompany Records 1958, No. 9?



GEOPHYSICAL SURVEY FOR THE BARRON FALLS

HYDRO-ELECTRIC SCHEME, KURANDA, Q'LD.

SCHEME III

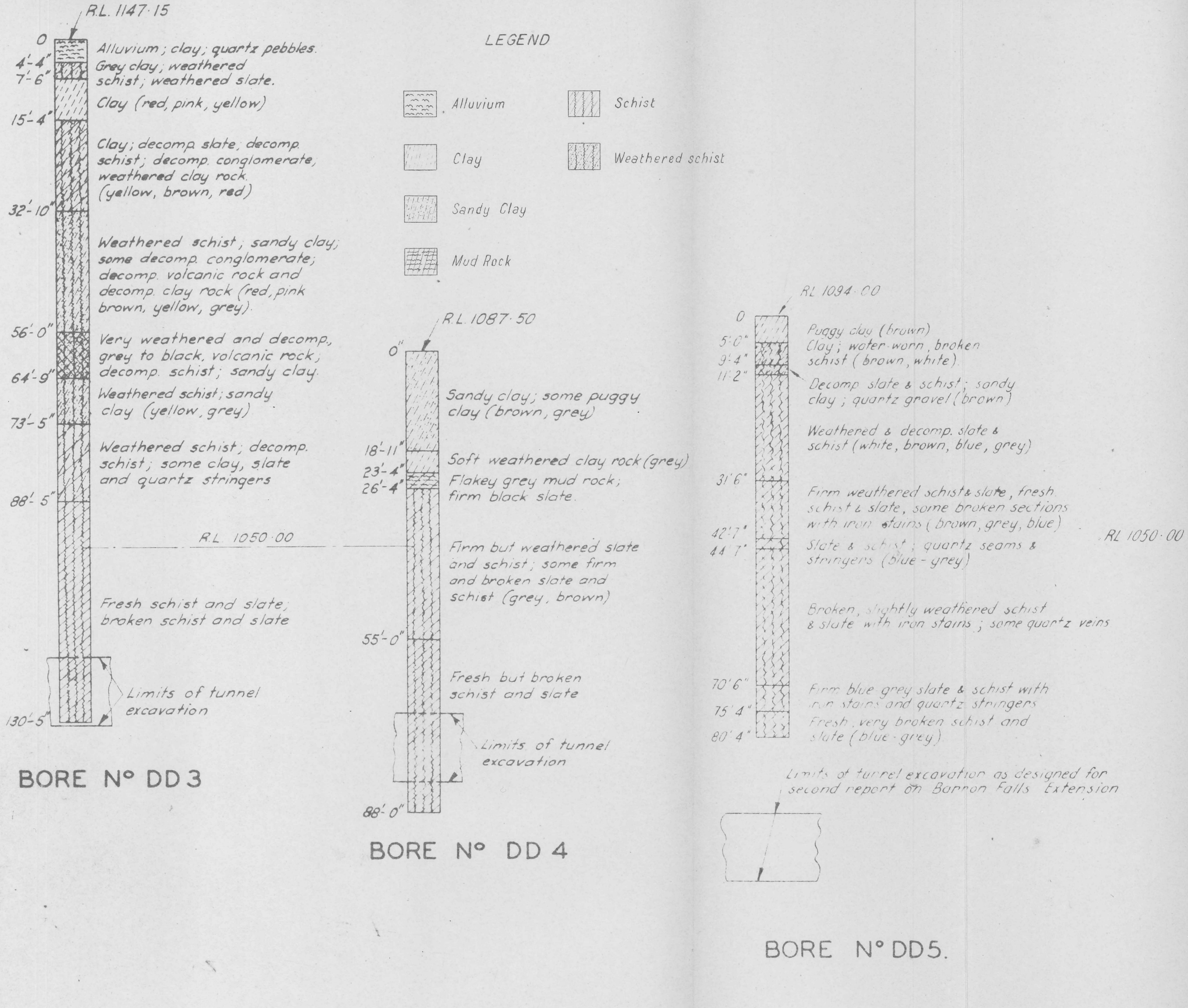
LAYOUT OF TRAVERSES

Based on fig. 4 of the C.O.G. report of BARRON FALLS Extension dated 31-3-58.

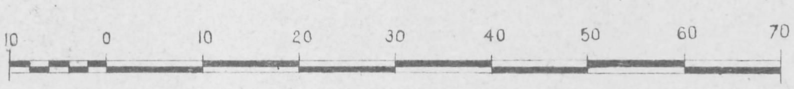
Geophysical Section, Bureau of Mineral Resources, Geology and Geophysics.

G327-12

To accompany Records 1959, No. 93



VERTICAL SCALE IN FEET



GEOPHYSICAL SURVEY FOR THE BARRON FALLS

HYDRO-ELECTRIC SCHEME, KURANDA, Q'LD.

TUNNEL III

DRILL HOLE LOGS

Based on figs. 6 & 6A of the C.O.G. report on BARRON FALLS Extension dated 31·3·58

Geophysical Section, Bureau of Mineral Resources, Geology and Geophysics. **G 327-10**

To accompany Records 1959, No. 93

Geology after F.J. Carter

Legend

- Proposed Tunnel Course
- 15000 Seismic velocity in ft/sec.
- H Higher } velocity than
- L Lower } neighbouring velocity
- Apparent resistivity ohm/cm.
- x------x 100' spacing
- Slates
- Meta-greywacke
- Quartzite

(8000) SEISMIC VELOCITY IN FT/SEC.
-5'- DEPTH TO LAYER WITH DIFFERENT SEISMIC VELOCITY

HORIZONTAL AND VERTICAL SCALE (IN FEET)
100 0 50 100 150 200

GEOPHYSICAL SURVEY FOR THE BARRON FALLS HYDRO-ELECTRIC SCHEME KURANDA, QUEENSLAND

TUNNEL III.

CROSS-SECTION ON GEOPHYSICAL TRAVERSE

STATION No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
SURFACE LEVEL	1097	1104	1108	1115	1129	1132	1137	1131	1132	1133	1132	1132	1130	1128	1124	1120	1115
DEPTH TO FRESH ROCK	64	64	59	62	69	74	78	70	74	70	74	77	77	-	73	65	60

STATION No.	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34
SURFACE LEVEL	1110	1104	1096	1076	1084	1090	1092	1091	1079	1067	1065	1072	1080	1082	1084	1090	1094
DEPTH TO FRESH ROCK	60	55	-	63	50	62	66	66	56	56	44	50	44	41	39	39	44

STATION No.	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
SURFACE LEVEL	1088	1101	1105	1112	1119	1126	1134	1141	1148	1150	1152	1153	1153	1153	1153	1154
DEPTH TO FRESH ROCK	41	55	46	61	61	63	58	75	73	75	75	88	81	84	80	87

To accompany Record 1959 No 93

Geophysical Section, Bureau of Mineral Resources, Geology & Geophysics.

G327-1

STATION No.	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75
SURFACE LEVEL	1154	1155	1155	1153	1150	1146	1142	1135	1134	1129	1127	1124	1121	1124	1120	1116	1106	1083	1081	1089	1093	1094	1100	1101	1100	1093
DEPTH TO FRESH ROCK	87	87	93	95	98	93	98	76	81	78	81	93	84	91	83	76	60	45	54	66	62	74	74	77	80	63

STATION No.	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100
SURFACE LEVEL	1091	1086	1085	1099	1092	1086	1096	1101	1099	1103	1106	1107	1109	1110	1110	1104	1094	1093	1101	1094	1089	1109	1110	1110	1111
DEPTH TO FRESH ROCK	60	57	80	64	64	64	55	65	70	67	58	61	62	56	57	46	33	31	27	35	50	59	58	60	61

GEOPHYSICAL SURVEY FOR THE BARRON FALLS HYDRO-ELECTRIC SCHEME KURANDA, QUEENSLAND

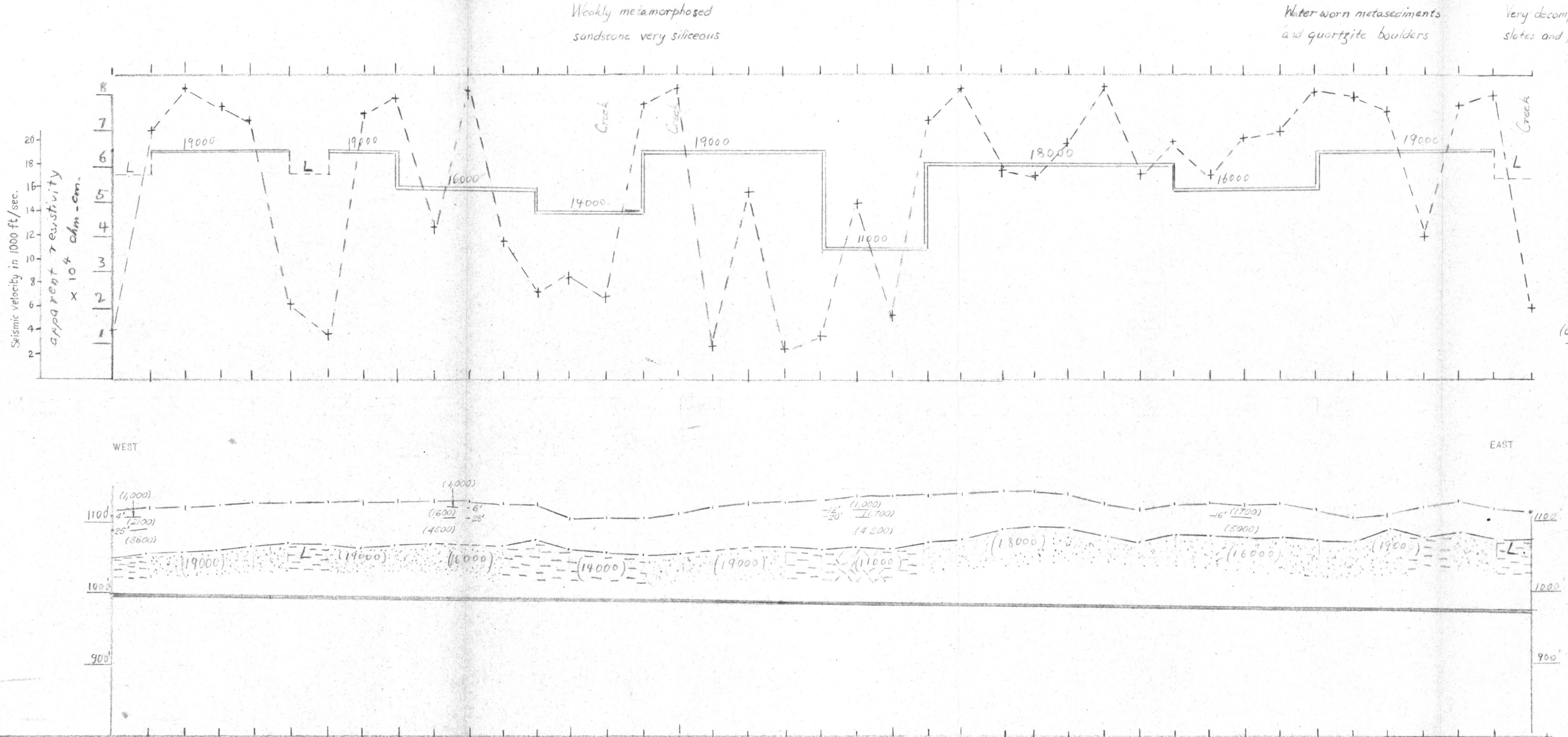
TUNNEL III

CROSS-SECTION ON GEOPHYSICAL TRAVERSE

Geophysical Section, Bureau of Mineral Resources, Geology & Geophysics.

G327-2

To accompany Record 1959 No 93



71°
N355°E

Geology after F.J. Carter

Legend

Proposed Tunnel Course
19000 Seismic velocity in ft/sec.
L Indicates lower velocity than neighbouring velocity
x - - - x Apparing resistivity ohm/cm. 100 ft spacing
Slates
Meta-greywacke
Quartzite

(8000) SEISMIC VELOCITY IN FT./SEC.
-51'- DEPTH TO LAYER WITH DIFFERENT SEISMIC VELOCITY

HORIZONTAL AND VERTICAL SCALE (IN FEET)
100 0 50 100 150 200

GEOPHYSICAL SURVEY FOR THE BARRON FALLS HYDRO-ELECTRIC SCHEME KURANDA, QUEENSLAND

TUNNEL III.

CROSS-SECTION ON GEOPHYSICAL TRAVERSE

STATION Nº	100	101	102	103	104	105	106	107	108	109	110	111	112	113
SURFACE LEVEL	1111	1116	1119	1121	1122	1122	1123	1125	1127	1128	1127	1122	1120	1100
DEPTH TO FRESH ROCK	61	61	64	61	60	57	60	64	58	58		58	47	41

STATION Nº	114	115	116	117	118	119	120	121	122	123	124	125	126	127
SURFACE LEVEL	1102	1100	1109	1119	1122	1121	1129	1132	1135	1137	1139	1141	1140	1137
DEPTH TO FRESH ROCK	47	50	53		60	60	70	70	73	64	63	54	48	49

STATION Nº	128	129	130	131	132	133	134	135	136	137	138	139	140
SURFACE LEVEL	1124	1116	1123	1126	1120	1123	1115	1107	1108	1120	1124	1119	1113
DEPTH TO FRESH ROCK	45	45	41	46	46	46	39	33	15	42	44	41	36

Geophysical Section, Bureau of Mineral Resources, Geology & Geophysics.

G327-3

To accompany Records 1959 No. 33

GEOLOGY AFTER F.J. CARTER

Legend

Apparent Resistivity in ohm/cm. electrode spacing: 100 ft

Slate

Meta-greywacke

Quartzite

Proposed Tunnel Course

STATION No	141	142	143	144	145	146	147	148	149	150	151	152	153	154	155	156	157	158	159
SURFACE LEVEL	1130	1125	1120	1137	1145	1142	1118	1140	1124	1134	1128	1150	1157	1159	1161	1164	1166	1148	1146

STATION No	160	161	162	163	164	165	166	167	168	169	170	171	172	173	174	175	176	177	178
SURFACE LEVEL	1148	1166	1163	1174	1171	1168	1178	1185	1193	1197	1202	1206	1211	1213	1214	1216	1220	1226	1231

STATION No	179	180	181	182	183	184	185	186	187	188	189	190	191	192	193	194	195
SURFACE LEVEL	1233	1230	1223	1214	1198	1188	1185	1164	1143	1118	1091	1068	1046	1028	1010	988	964

GEOPHYSICAL SURVEY FOR THE BARRON FALLS HYDRO-ELECTRIC SCHEME, KURANDA, Q'LD.

TUNNEL III

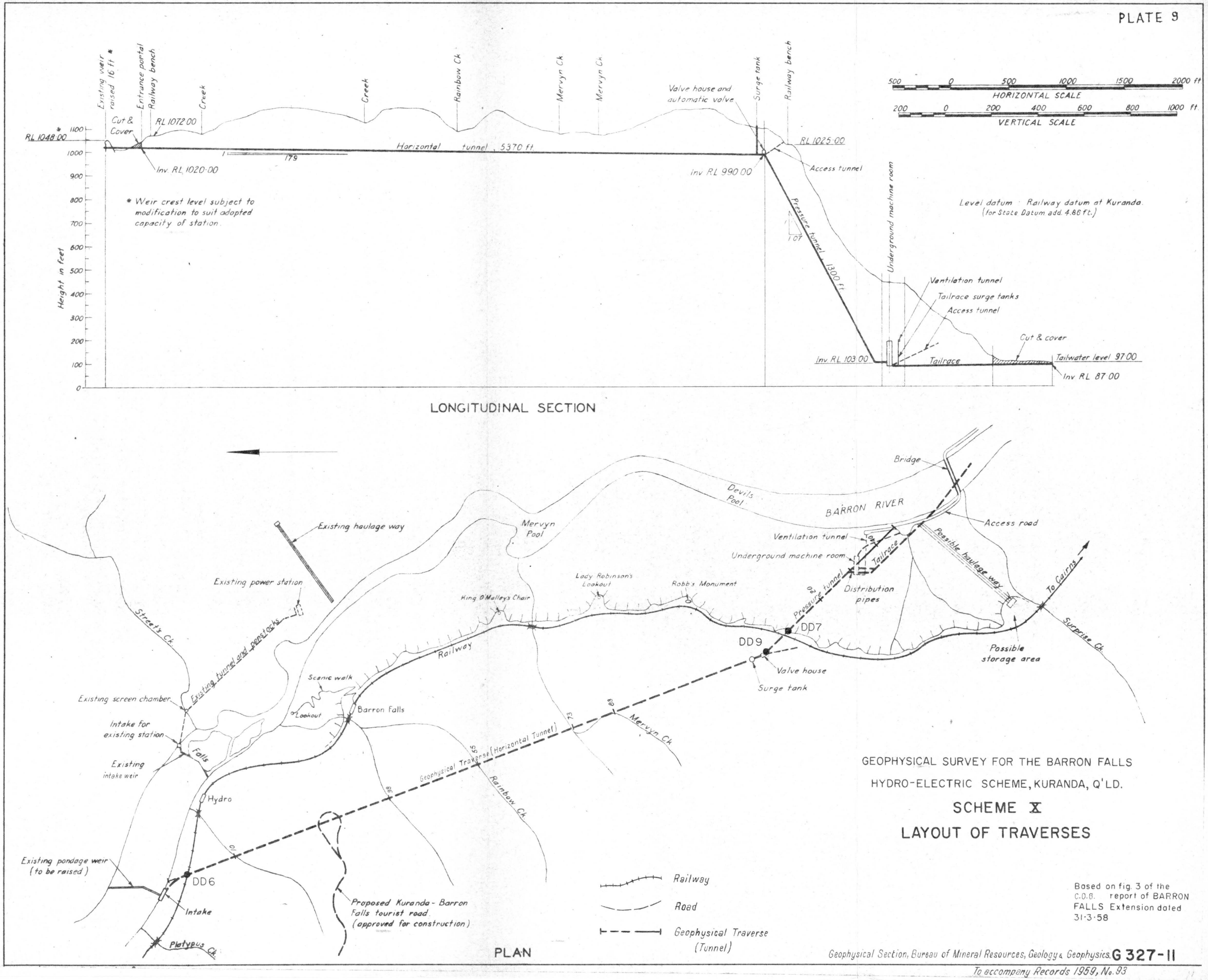
CROSS-SECTION ON GEOPHYSICAL TRAVERSE

Horizontal and Vertical Scales

100 0 100 200 300 Feet

Geophysical Section, Bureau of Mineral Resources, Geology and Geophysics. G 327-7

To accompany Records 1959, No. 93



GEOPHYSICAL SURVEY FOR THE BARRON FALLS HYDRO-ELECTRIC SCHEME, KURANDA, Q'LD.

SCHEME X

LAYOUT OF TRAVERSES

Based on fig. 3 of the C.O.G. report of BARRON FALLS Extension dated 31·3·58

Geophysical Section, Bureau of Mineral Resources, Geology & Geophysics. G 327-11

To accompany Records 1959, No. 93

To accompany Records 1959, No. 93

N 345 E
70°/80

Geology after F.J. Carter

Legend

Proposed Tunnel Course

19000 Seismic velocity in ft/sec.

Indicates

H Higher } velocity than
L Lower } neighbouring velocity

Apparent resistivity ohm/cm.

o———o 50' Spacing

x- - - -x 100 Spacing

Slates and Phyllites

Meta-greywacke

Quartzite

(8000) SEISMIC VELOCITY IN FT/SEC.
-51- DEPTH TO LAYER WITH DIFFERENT SEISMIC VELOCITY

HORIZONTAL AND VERTICAL SCALE (IN FEET)
100 0 50 100 150 200

GEOPHYSICAL SURVEY FOR THE BARRON FALLS HYDRO-ELECTRIC SCHEME KURANDA, QUEENSLAND TUNNEL X.

CROSS-SECTION ON GEOPHYSICAL TRAVERSE

STATION No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
SURFACE LEVEL	1073	1103	1128	1139	1133	1123	1109	1092	1092	1082	1071	1085	1104	1113	1122	1135	1146	1155	1162
DEPTH TO FRESH ROCK	36	37	65	65	70	66	60	42	42	28	21	34	61	92	82	101	109	108	95

STATION No.	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37
SURFACE LEVEL	1167	1170	1171	1173	1172	1173	1174	1176	1177	1178	1178	1177	1176	1165	1155	1144	1131	1117
DEPTH TO FRESH ROCK	88	93	104	90	92	70	72	80	76	81	78	—	84	83	84	74	67	49

STATION No.	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55
SURFACE LEVEL	1104	1115	1130	1144	1163	1173	1174	1173	1178	1181	1182	1178	1172	1168	1160	1146	1132	1111
DEPTH TO FRESH ROCK	40	39	70	73	84	85	82	79	75	76	75	69	55	58	60	55	—	23

G327-4

Geology after F.J. Carter

Legend

- Proposed Tunnel Course
- 18000 Seismic velocity in ft/sec
- H Higher / L Lower } velocity than neighbouring velocity
- Apparent resistivity ohm/cm.
  - o———o 50' Spacing
  - x– – –x 100' Spacing
- Slates and Phyllites
- Meta-greywacke
- Quartzite

(8000) SEISMIC VELOCITY IN FT/SEC.
-51- DEPTH TO LAYER WITH DIFFERENT SEISMIC VELOCITY

HORIZONTAL AND VERTICAL SCALE (IN FEET)
100 0 50 100 150 200

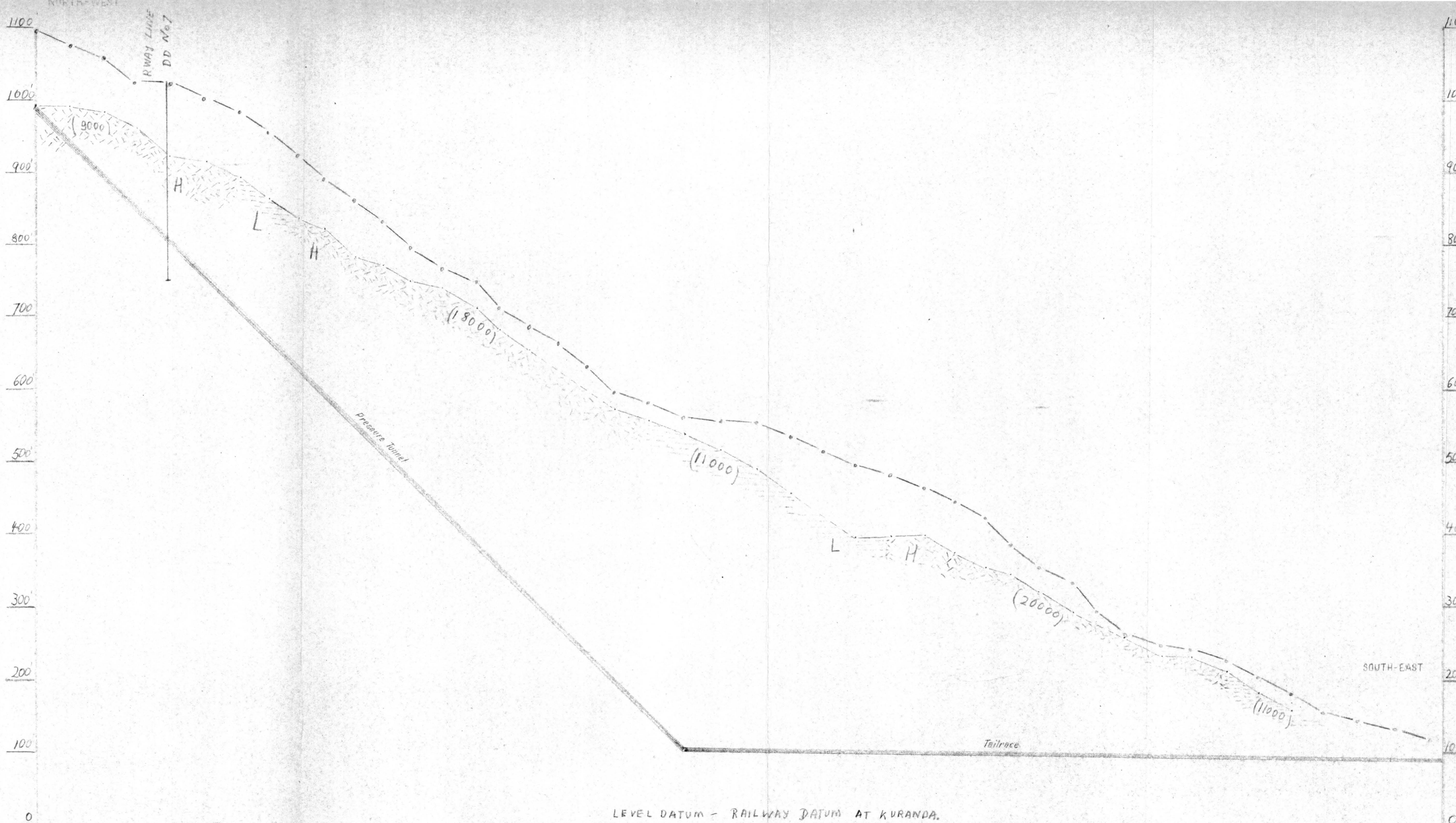
GEOPHYSICAL SURVEY FOR THE BARRON FALLS HYDRO-ELECTRIC SCHEME KURANDA, QUEENSLAND TUNNEL X

CROSS-SECTION ON GEOPHYSICAL TRAVERSE

STATION No	SURFACE LEVEL	DEPTH TO FRESH ROCK
55	1111	23
56	1131	47
57	1143	60
58	1156	79
59	1167	70
60	1171	81
61	1170	105
62	1165	83
63	1153	75
64	1147	86
65	1149	95
66	1143	98
67	1134	92
68	1124	60
69	1115	55
70	1113	47
71	1088	23
72	1072	20
73	1064	8
74	1063	14
75	1082	31
76	1088	42
77	1071	20
78	1072	24
79	1072	18
80	1076	16
81	1086	32
82	1086	40
83	1079	28
84	1081	30
85	1099	30
86	1104	31
87	1116	42
88	1127	–
89	1130	57
90	1127	52
91	1123	48
92	1118	43
93	1138	61
94	1153	60
95	1169	70
96	1184	83
97	1195	140
98	1203	140
99	1205	101
100	1201	109
101	1191	109
102	1179	–
103	1175	88
104	1159	58
105	1135	–
106	1123	69
107	1115	62
108	1113	72
109	1117	102

G327-5

To accompany Records 1959 No 93



LEVEL DATUM - RAILWAY DATUM AT KURANDA.

STATION No	SURFACE LEVEL	DEPTH TO FRESH ROCK
1	1091	98
2	1075	94
3	1057	85
4	1022	72
5	1022	110
6	1002	98
7	982	98
8	957	102
9	922	94
10	890	78
11	860	86
12	830	68
13	798	56
14	768	36
15	740	36
16	711	35
17	689	42
18	665	—
19	632	
20	599	31
21	581	30
22	562	30
23	557	47
24	553	70
25	534	86
26	519	—
27	495	104
28	481	86
29	467	75
30	448	77
31	422	71
32	387	47
33	356	38
34	336	46
35	296	—
36	262	3
37	247	16
38	242	15
39	228	19
40	205	25
41	180	25
42	158	—
43	141	—
44	132	—
45	120	—

Legend

Slates and Phyllites

Meta-greywacke

Quartzite

(8000) SEISMIC VELOCITY IN FT/SEC.
-5/- DEPTH TO LAYER WITH DIFFERENT SEISMIC VELOCITY

HORIZONTAL AND VERTICAL SCALE (IN FEET)
100 0 50 100 150 200

GEOPHYSICAL SURVEY FOR THE BARRON FALLS HYDRO-ELECTRIC SCHEME KURANDA, QUEENSLAND
PRESSURE TUNNEL

CROSS-SECTION ON SEISMIC TRAVERSE

Geoph. Sec. Bureau of Min. Res., Geology & Geoph. G.327-6

To accompany Records 1959, No 93