COMMONWEALTH OF AUSTRALIA

DEPARTMENT OF NATIONAL DEVELOPMENT

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

RECORD No. 1962-5

CALLIDE CREEK 49.8M DAM SITE SEISMIC REFRACTION SURVEY,

QUEENSLAND 1959

by

W.A. Wiebenga

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ABSTRACT

This Record describes a seismic refraction survey at Callide Creek 49.8-mile dam site, near Biloela, Queensland. The survey was made at the request of the Queensland Irrigation and Water Supply Commission.

Depths to unweathered bedrock and other rocks were determined by their seismic velocities and are shown on cross-sections. From general geological information and the results of drilling in the area, the seismic velocities can be translated into geological terms.

Comparison with drilling results suggests that seismic depth estimates are about 18 per cent too low. After correcting this systematic error, the depth determinations are accurate to within 10 ft.

Young's modulus for the unweathered bedrock, determined by the seismic method, is estimated at about 7 to 9 x 10^6 lb/in.^{2}

1. INTRODUCTION

The Irrigation and Water Supply Commission of Queensland has been requested to design a dam on the Callide Creek, about 7 miles north-east of Biloela. The dam is to provide pondage for water which will be used mainly as cooling water for the proposed Callide power station. The Commission refers to the site as the Callide Creek 49.8-mile dam site. The co-ordinates of the centre of the site are 357967 on the Monto 4-mile map.

The Commission requested the Bureau of Mineral Resources, Geology and Geophysics to make a geophysical survey to determine the depth to and, if possible, the type of foundation rock at the site. Geological information was prepared by Dunlop (1958).

The seismic refraction method was used in the survey, which was made by a Bureau field party consisting of W.A. Wiebenga (geophysicist and party leader), B.J. Bamber and E.E. Jesson (geophysicists), and J.P. Pigott (geophysical assistant). The Commission provided topographical survey data and supplied four field assistants to help with the geophysical field work, which lasted from 24th September to 6th October 1959.

2. GEOLOGY

The right* bank of the dam site is flat and is capped with Tertiary sediments consisting of sand, clay, and boulders. These sediments are considered to be a remnant of the Duaringa Formation, and are probably between 5 and 15 ft thick. They overlie Upper Palaeozoic weathered and unweathered andesite and tuff.

The creek channel is filled with poorly sorted alluvial material which carries sub-surface ground water during dry periods. River terraces are present on both banks. On the slopes of the right bank the alluvial material gradually changes to hill-wash material. The bedrock of the creek consists of Upper Palaeozoic weathered and unweathered tuff intruded by Tertiary gabbro dykes. The dykes are thought to be nearly vertical, with a strike approximately parallel to the creek bed. They range in width from a few feet to one hundred feet.

On the left bank of the site is a ridge formed by a mineralised gabbro dyke about one hundred feet wide and parallel to the creek. Basalt boulders cover the slope from the ridge to the creek bed. The bedrock consists of weathered and unweathered tuff. A broad saddle about 400 ft south-west of the ridge is believed to be a contact zone between the gabbro dyke and the volcanic rocks. South-west of the ridge the surface consists of red-brown sand and clay with boulders. The bedrock in this area is Upper Palaeozoic weathered and unweathered tuff.

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* looking down-stream

3. METHODS AND EQUIPMENT

A description of the seismic refraction technique used in this survey is given by Polak and Mann (1959).

The equipment used was a 12-channel portable seismograph designed for shallow reflection or refraction surveys and manufactured by the Midwestern Geophysical Laboratory, Tulsa, Oklahoma. Midwestern geophones with a natural frequency of about 8 c/s were used to record vertical movement of the ground, and a three-component T.I.C. geophone with a natural frequency of 19 c/s was used to record the arrival times of transverse waves.

To calculate the elastic properties of a refractor the ratio between transverse and longitudinal wave velocities must be measured, together with the longitudinal wave velocity. Young's modulus is then given by the formulae (Leet, 1950 44-46):-

$$V_P^2 / V_S^2 = (\sigma - 1)/(\sigma - \tfrac{1}{2})$$

and

$$E = V_P^2 \, d \, (1 + \sigma)(1 - 2\sigma) / (1 - \sigma)$$

in which

E = Young's modulus

V_P = longitudinal wave velocity

V_S = transverse wave velocity

σ = Poisson's ratio

d = density

If V_P, V_S, and d are in the c.g.s. system, then E is in dyn/cm^2.

When the thickness of "overburden" is small compared with the ground-roll wavelength, the transverse wave velocity can be obtained directly from the ground-roll wave velocity, and is 1.09 times the ground-roll wave velocity when Poisson's ratio = 0.25 (Leet, 1950,48). The ground-roll waves are a complex movement of the ground particles caused by the passage of near-surface waves (Leet, 1950,46-50), and are predominantly Rayleigh waves. A method for estimating the elastic constants of the bedrock from Rayleigh waves is described by Jesson, Wiebenga, and Dooley (1961).

4. RESULTS

Plate 2 shows the surface contours and layout of traverses. On the traverse plan and in the text, a geophone station where a bedrock depth determination was made, is indicated by a capital letter and a number; for example, X80 refers to station number 80 on Traverse X. Diamond-drill-holes are indicated by DDH.

Plates 3 and 4 show in cross-section the depth to bedrock along Traverses X, A, B, C, E and F.

Upper left bank; Traverse X from X96 to X155, and Traverse F

The top formation consists of soil and very weathered tuff, and has seismic velocities between 1100 and 2000 ft/sec.

Seismic velocities observed for weathered bedrock range from 3300 to 8000 ft/sec; the lower velocities correspond to very weathered tuff, and the higher velocities to slightly weathered tuff. A layer with 9000-ft/sec velocity near X134 (Plate 3) probably represents slightly weathered tuff.

The unweathered bedrock has seismic velocities between 14,000 and 18,600 ft/sec and is for the most part between 40 and 70 ft deep.

Creek area; Traverse X from X65 to X96, and Traverses C and E

The top formation has seismic velocities between 1050 and 1200 ft/sec; it consists of soil, sand, clay, and very weathered tuff, and its thickness ranges between 6 and 20 ft.

Two layers of rocks with seismic velocities of 3300 and 6500 ft/sec lie between the unconsolidated top formation and bedrock; the first of these is probably alluvial material and the other is probably weathered tuff.

Traverse C was surveyed along the creek. The observed 9000-ft/sec velocity, presumably of slightly weathered andesite or tuff, is about 3000 ft/sec higher than for the corresponding formation along Traverse X and indicates that the strike of the cleavage or fracture planes is approximately parallel to the creek.

On the lower left bank the formations between the top layer and the unweathered bedrock have seismic velocities between 3000 and 13,000 ft/sec. The geology in this locality has been shown by drilling to be complicated, and these formations may represent either gabbro or tuff and andesite in various stages of weathering and fracturing. However, the 13,000-ft/sec layer at X89 and the 8000-ft/sec layer at the intersection of Traverses E and X may be strong enough to serve as dam foundation rocks. The deepest refractor has seismic velocities between 16,500 and 20,000 ft/sec and its depth along Traverse X ranges between 32 ft near X86 and 59 ft near X94.

On the lower right bank the formation with a seismic velocity of about 5000 ft/sec is probably weathered tuff and andesite. The depth to unweathered bedrock ranges between 40 and 50 ft. The transition from weathered hill-slope material to creek deposits cannot be recognised seismically.

The seismic velocities of the deepest refractor in the creek area are between 15,500 and 20,000 ft/sec. The formation with 20,000-ft/sec velocity is probably gabbro, and the formation with 15,500-ft/sec velocity is probably tuff and andesite; the formationswith intermediate velocities are probably andesite or gabbro.

Upper right bank: Traverse X from X1 to X65, and Traverses A and B

The unconsolidated top formation consists of soil and very weathered tuff and has seismic velocities between 1000 and 2000 ft/sec; it is between 2 and 20 ft thick.

Between X34 and X65, there are two intermediate layers, with seismic velocities ranging from 4000 to 5800 ft/sec and from 8500 to 11,000 ft/sec respectively. The lower range of velocities is interpreted as weathered tuff, and the higher range as moderately to slightly weathered tuff and andesite. The depth to the slightly weathered tuff is between 22 and 39 ft; the depth to unweathered bedrock (probably andesite or tuff with velocities of 15,000 to 19,000 ft/sec) varies between 42 and 93 ft, the average being between 60 and 70 ft.

Between X2 and X32 the intermediate layer has seismic velocities of 7000 to 10,000 ft/sec and is interpreted as weathered and slightly weathered andesite. The unweathered bedrock has seismic velocities of 16,000 to 16,500 ft/sec, with depths between 40 and 76 ft.

Comparison of seismic depth determinations with diamond-drill-hole information

Table 1 shows the seismic results and the drilling information. If the seismic estimates of depth (S) are plotted against the depths to formation determined from drill-hole information (D), the following empirical formula may be derived from the graph :-

$$D = 1.18\, S \pm 10 \text{ ft}$$

This indicates that the depths found by the seismic method are, on the average, 18 per cent too low. After applying the 18 per cent correction, the accuracy of depth determination is within 10 ft.

Velocities

Although the principal objective of the seismic method was the determination of the depth to elastic discontinuities, the seismic velocities are an indication of weathering, jointing, and fracturing of the rock. In general, the higher the seismic velocities the more consolidated and unweathered are the sediments. Table 2 lists the interpretation in geological terms of the seismic velocities shown on the cross-sections of Plates 2 and 3.

On Plate 5 the bedrock velocities are indicated on a small-scale plan of the traverses. The area has been divided into two zones, A and B, having velocities greater and less than 17,000 ft/sec, respectively. Zone A includes the south-western part of the area and part of Traverse A. Drill-holes in this area show unweathered tuff or andesite as the bedrock. In Zone B, bedrock is generally slightly weathered or a mixture of rock types (e.g. gabbro and tuff) suggesting that fracturing has occurred.

Elastic properties

Between DDH 1 and DDH 2 the bedrock is unweathered andesite or gabbro; data from a three-component geophone show that the ratio of transverse to longitudinal wave velocities is in the range 0.50 to 0.45 for bedrock with a longitudinal wave velocity of 18,000 ft/sec and density of about 2.6 g/cm^3.

For this bedrock the corresponding elastic constants, calculated from the formulae in chapter3(Methods and Equipment) are:-

Poisson's ratio = 0.35 ± 0.01;

Young's modulus = 4.9×10^{11} dyn/cm^2

or 7.1×10^6 lb/in.^{2}

Another estimate of the elastic constants of the bedrock can be made by an analysis of the ground-roll waves (Jesson et al, 1961); which are predominantly Rayleigh waves.

Table 3 lists the location, ground-roll wavelength L, and phase velocity V_R as measured from the records, and the thickness of overburden H and the longitudinal seismic velocity of bedrock V_{P2} as determined by seismic refraction and shown on Plates 3 and 4. Average values have been taken for H and V_P for each spread. These have been listed separately for Zones A and B (see Plate 5).

The shape of the dispersion curve connecting wavelength with phase-velocity depends largely on the ratio of the seismic velocity in the overburden (V_{P1}) to that in the bedrock. Jesson et al. (1961) have given examples of curves for various values of this ratio $q = V_{P1}/V_{P2}$ for the two-layer case of homogeneous overburden. In the Callide Creek area, the overburden generally comprises two or three layers. In Table 3, an approximate value of q has been estimated for each spread, based on an average overburden velocity.

For each measurement in Table 3, the dimensionless quantities $x = H/L$ and $r = V_R/V_{P2}$ have been calculated and are tabulated. In Plate 6, r has been plotted as a function of x in Cartesian co-ordinates. Separate graphs have been used for Zones A and B, as the points for Zone A appear to lie somewhat lower than those for Zone B. Points representing data from the same spread are connected by lines. The value of q is shown for each point or group of points.

The average value of q for the observations in Zone A is about 0.45, and for those in Zone B about 0.50. The theoretical dispersion curves for these values of q and for Poisson's ratio = 0.25 have been plotted on Plates 6A and 6B as broken lines. On Plate 6A the theoretical curve appears to be too high for most of the points, and on Plate 6B it is too low. Curves parallel to these have been drawn to give a visual fit to the data, and it will be seen that they fit most of the points reasonably well. By using these curves to extrapolate to $x = \infty$, we obtain values of $r_o = 0.52$ for Zone A, and $r_o = 0.55$ for Zone B. Now r_o is a function of Poisson's ratio for the bedrock, and corresponding values of Possion's ratio are shown on the r scale. For Zone A, Poisson's ratio is estimated as 0.27, and for Zone B, 0.22.

There are a few points lying well above the graph for Zone B, which have not been given much weight in fitting the curve. These may be due to inaccuracies in measurement or to heterogeneous conditions, but extrapolation from them would lead to a value of Poisson's ratio approaching zero, which does not seem possible for bedrock. It is possible that they may represent Rayleigh waves of the M_2 or anti-symmetric mode described by Ewing, Jardetzky, and Press (1957, Fig.4-35, p.195).

The average velocity for Zone A is 18,100 ft/sec, and for Zone B 16,000 ft/sec. Substituting these values in the formula for Young's modulus given in Chapter 3, and assuming $d = 2.6\ g/cm^3$, we get, for Zone A

$$\begin{aligned} E &= 9.2 \times 10^6\ \text{lb/in.}^2 \\ &= 6.3 \times 10^{11}\ \text{dyn/cm}^2 \end{aligned}$$

and for Zone B

$$\begin{aligned} E &= 7.9 \times 10^6\ \text{lb/in.}^2 \\ &= 5.4 \times 10^{11}\ \text{dyn/cm.}^2 \end{aligned}$$

These estimates are somewhat higher than obtained from the three-component geophone. The latter should give a more precise determination, but the ground-roll data are representative of a larger area. The accuracy of the ground-roll determinations of Young's modulus has been estimated as about ± 20 to 25% (Jesson et al., 1961).

5. CONCLUSIONS

The geophysical survey provided information on the depth to bedrock and on the rock types. It is possible that some rocks shallower than those designated as bedrock may have sufficient strength to support a dam wall.

A comparison between seismic depth determinations and drilling information suggests that the depths indicated on the cross-sections and in the text of this Record are 18 per cent too low. After correcting this systematic error, depth determinations are accurate within 10 ft.

Young's modulus for the bedrock is estimated as about 7 to 9 x 10^6 lb/in.^{2}

6. REFERENCES

DUNLOP, R.A. 1958 Geological Inspection of Callide Creek 49.8M dam site. Memo to Senior Planning Engineer, Irrigation and Water Supply Commission, Queensland.

EWING, W.M., JARDETZKY, W.S. and PRESS, F. 1957 ELASTIC WAVES IN LAYERED MEDIA. McGRAW-HILL Book Co., Inc., New York.

JESSON, E.E., WIEBENGA, W.A. and DOOLEY, J.C. 1961 Bell Creek 17.3M dam site seismic refraction survey, Queensland, 1959. Bur. Min. Resour. Aust. Records 1961-162.

LEET, L.D.	1950	EARTH WAVES. Harvard University Press, Cambridge, Mass.
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TABLE 1

Drill hole	Dip of hole	Depth to discontinuity by seismic methods (S) ft	Refractor velocity ft/sec	Depth to discontinuity from drilling (D) ft	Geology of formation below discontinuity
DDH1	Vertical	33	18,000	32	Slightly weathered tuff
				39	Unweathered tuff
DDH2	Vertical	37	18,000	35	Slightly weathered tuff
				42	Unweathered tuff
DDH3	SW 35°	between 25 and 44	15,500	approx. 38	Unweathered gabbro and tuff
DDH4	SW 40°	49	15,500	approx. 56	Slightly weathered gabbro and tuff
DDH5	SW 40°	60	15,500	61	Slightly weathered gabbro
DDH6	NE 30°	7 to 13	6000 to 13,000	16	Mixture of weathered and unweathered gabbro
		32 approx.	19,000 to 20,000	48	Slightly weathered tuff
DDH7	NE 40°	13	13,000	10	Slightly weathered tuff overlying unweathered tuff
		38	20,000	51	Unweathered tuff
DDH8	Vertical	25	9000	20	Slightly weathered tuff
		65	18,000	35	Unweathered tuff (see footnote)
DDH15	Vertical	21	10,000	22	Unweathered andesite
DDH17	Vertical	41	18,000 to 19,000	49	Unweathered tuff

Footnote: The drilling log of DDH8 describes the rock below 35 ft as light green fresh tuff with numerous tightly bounded calcite and zeolite veinlets. Seismically this rock cannot be distinguished from the slightly weathered tuff between 20 and 35 ft, hence the discrepancy in depth determination.

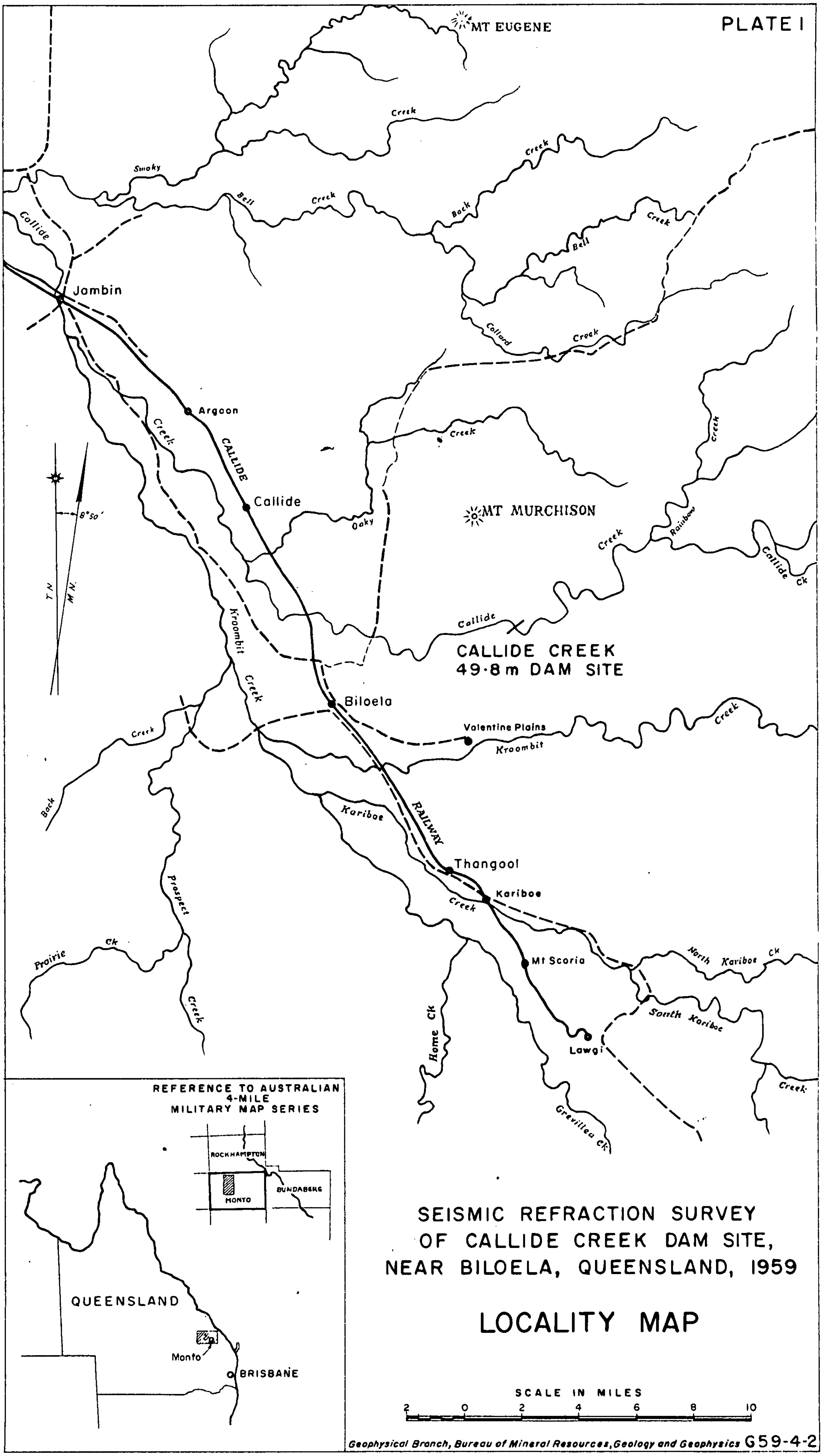
TABLE 2

Seismic velocity in ft/sec.	Rock type
1000 to 2000	Unconsolidated rocks: soil, sand, clay, and very weathered tuff.
3000 to 6000	Alluvial material, very weathered tuff.
6000 to 8000	Weathered tuff and andesite.
8000 to 13,000	Slightly weathered and fractured tuff and andesite, the fractures being partly or completely cemented with zeolite and calcite.
13,000 to 17,000	Slightly fractured to unfractured bedrock, or slightly weathered bedrock. Fractures may be partly or completely cemented with zeolite and calcite.
17,000 to 20,000	Unweathered gabbro, andesite, or tuff.

TABLE 3

GROUND-ROLL DATA

Spread	V_{P2} ft/sec	q	H ft	L ft	V_R ft/sec	x	r
ZONE A							
C12-C22	18,000	0.50	34	254	7700	0.13	0.43
				222	7650	0.15	0.43
				296	7800	0.12	0.43
X79-X89	19,000	0.34	40	259	7200	0.15	0.38
F12-F22	18,600	0.43	64	277	7100	0.23	0.38
				221	6150	0.29	0.33
F2-F12	17,000	0.41	63	213	6650	0.30	0.39
				226	6650	0.28	0.39
X110-X120	17,000	0.47	50	263	7300	0.19	0.43
X124-X134	18,000	0.36	69	190	5000	0.39	0.28
A2-A12	19,000	0.21	52	213	7800	0.19	0.41
				194	8100	0.17	0.43
ZONE B							
X69-X79	15,500	0.35	45	238	6800	0.19	0.44
X39-X49	16,500	0.48	72	190	5750	0.38	0.35
				210	6000	0.34	0.36
				194	5700	0.37	0.35
				235	6100	0.31	0.37
X22-X32	16,500	0.480	53	251	7600	0.21	0.46
				275	7650	0.19	0.46
X12-X22	16,200	0.43	64	370	8750	0.17	0.54
X2-X12	16,000	0.47	67	229	6950	0.22	0.40
				251	6600	0.27	0.41
X59-X69	15,500	0.32	59	233	6300	0.25	0.41
				280	7000	0.21	0.45
				260	7800	0.23	0.50
X49-X59	15,500	0.39	73	180	4850	0.40	0.31
				173	4800	0.42	0.31
C2-C12	16,000	0.56	48	296	7600	0.16	0.47
				256	6400	0.19	0.40
E2-E12	16,500	0.56	61	219	6850	0.28	0.42
B2-B12	16,000	0.4?	73	360	7900	0.20	0.49



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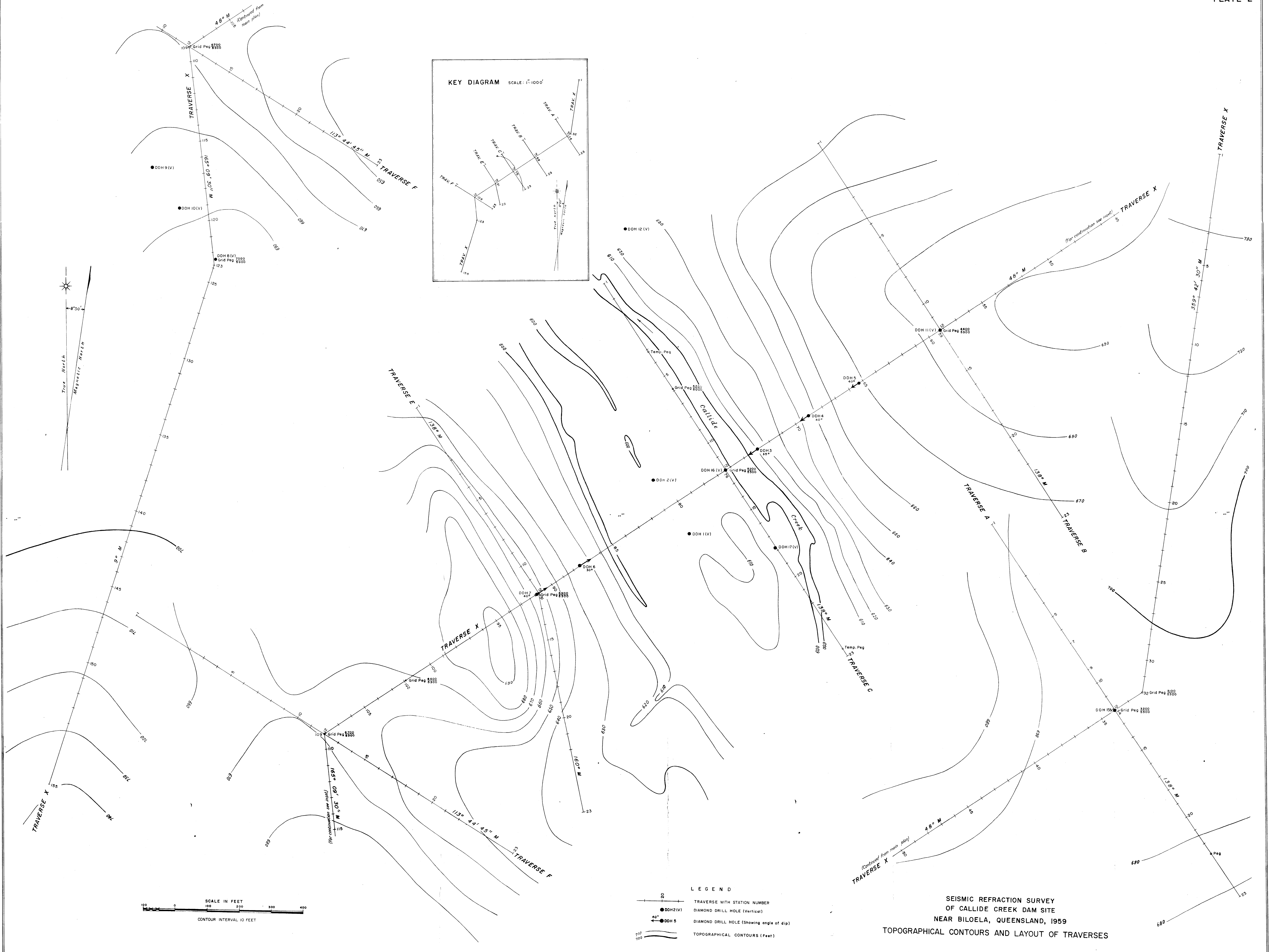
CALLIDE CREEK DAM SITE, QLD.

PLATE 2



SEISMIC REFRACTION SURVEY
OF CALLIDE CREEK DAM SITE
NEAR BILOELA, QUEENSLAND, 1959
TOPOGRAPHICAL CONTOURS AND LAYOUT OF TRAVERSES

Geophysical Branch, Bureau of Mineral Resources, Geology and Geophysics. G 59-4-3

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PLATE 3

ABREVIATIONS USED IN DRILL LOGS:

- W. Weathered
- S.W. Slightly weathered
- V.W. Very ,,
- F. Fresh

LEVELS DATUM : STATE

HORIZONTAL AND VERTICAL SCALES IN FEET

100 0 100 200 300 400 500

(14,000) SEISMIC VELOCITY IN FT/SEC

SEISMIC REFRACTION SURVEY OF CALLIDE CREEK DAM SITE NEAR BILOELA, QUEENSLAND, 1959

TRAVERSE X CROSS-SECTION

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G 59-4-4

To Accompany Record No 1962-5


PLATE 4
TRAVERSE A
TRAVERSE B
TRAVERSE C
TRAVERSE E
TRAVERSE F
NORTH-WEST
SOUTH-EAST
ELEVATION IN FEET
STATION No.
DEPTH TO UNWEATHERED BEDROCK IN FEET.
ELEVATION IN FEET
ABBREVIATIONS USED IN DRILL LOGS:
W. Weathered
S.W. Slightly weathered
V.W. Very "
F. Fresh
LEVELS DATUM: STATE
HORIZONTAL AND VERTICAL SCALES IN FEET
(14,000) SEISMIC VELOCITY IN FT/SEC
SEISMIC REFRACTION SURVEY
OF CALLIDE CREEK DAM SITE
NEAR BILOELA, QUEENSLAND, 1959
TRAVERSES A, B, C, E & F CROSS-SECTIONS
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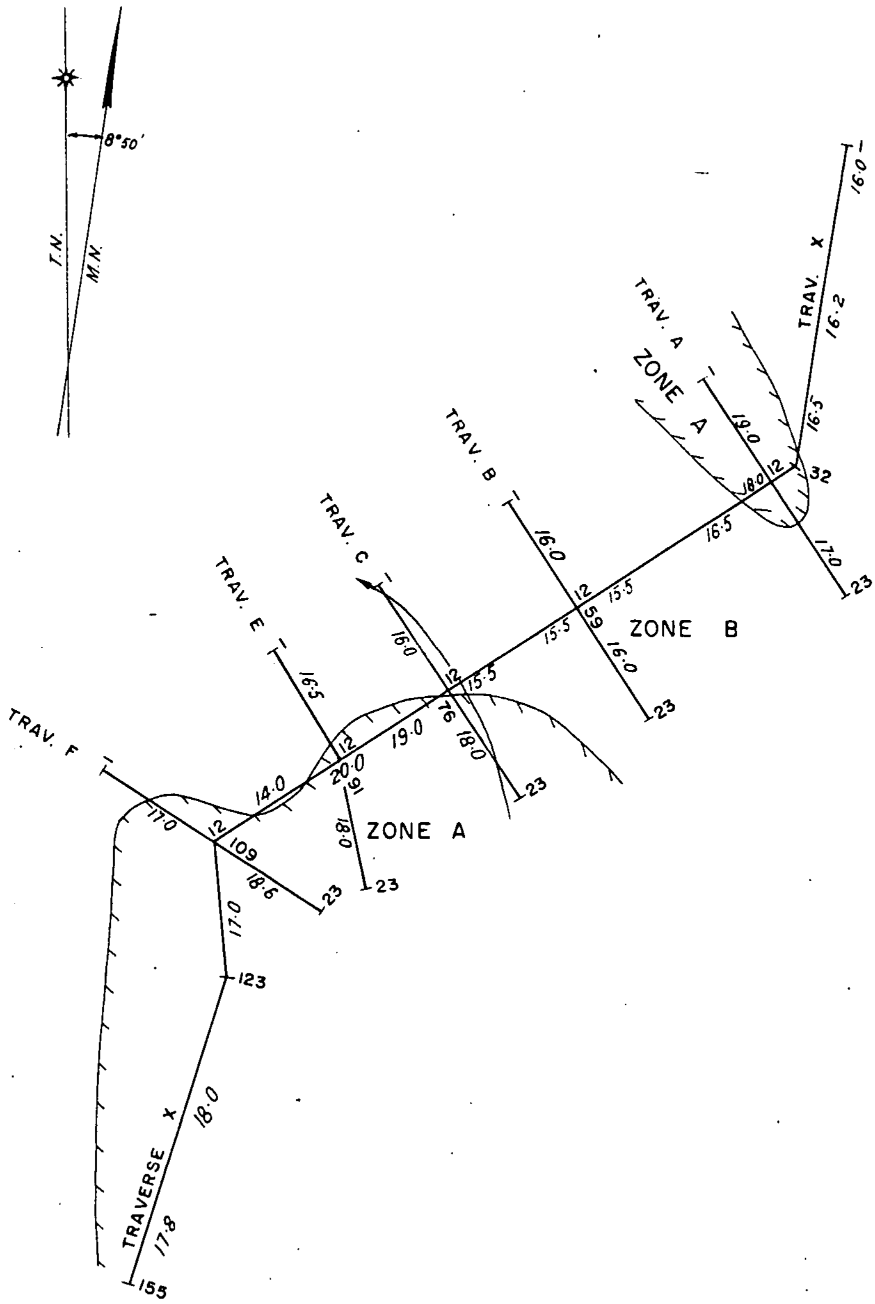
To Accompany Record No 1962-5
CALLIDE CREEK DAMSITE, QLD

PLATE 5



VARIATION OF SEISMIC VELOCITY OF BEDROCK

SCALE IN FEET

1000 0 1000 2000 3000

ZONE A: Velocity greater than 17,000 ft/sec
ZONE B: ,, less ,, ,, ,,

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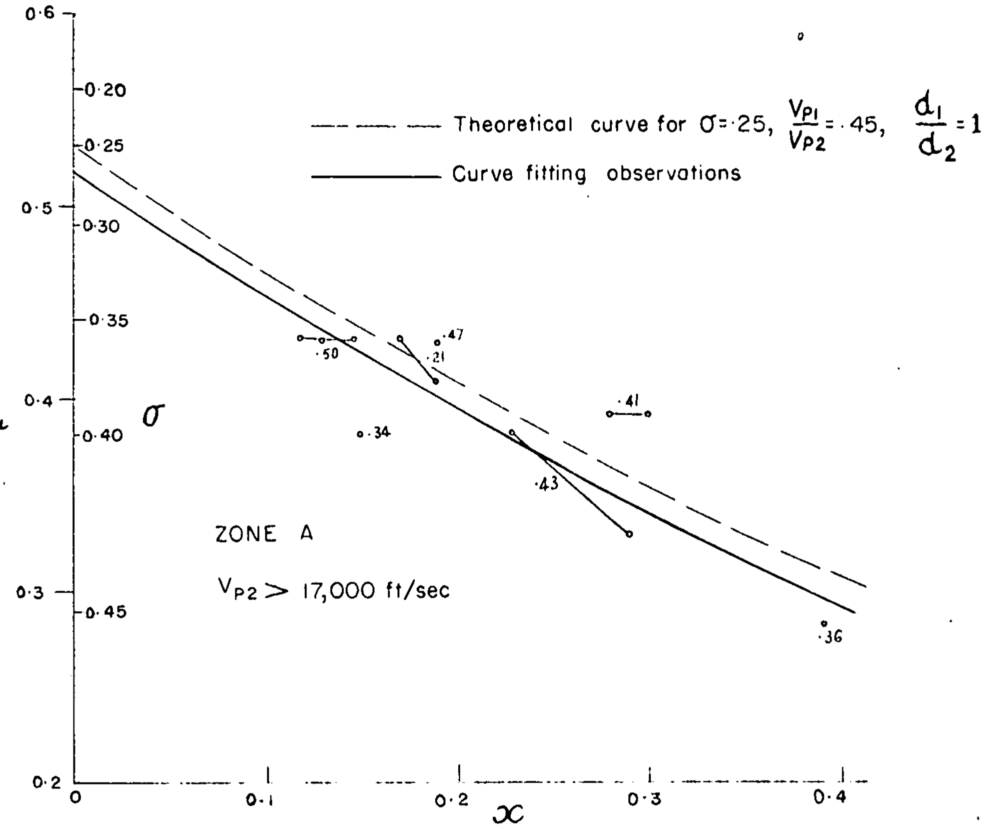
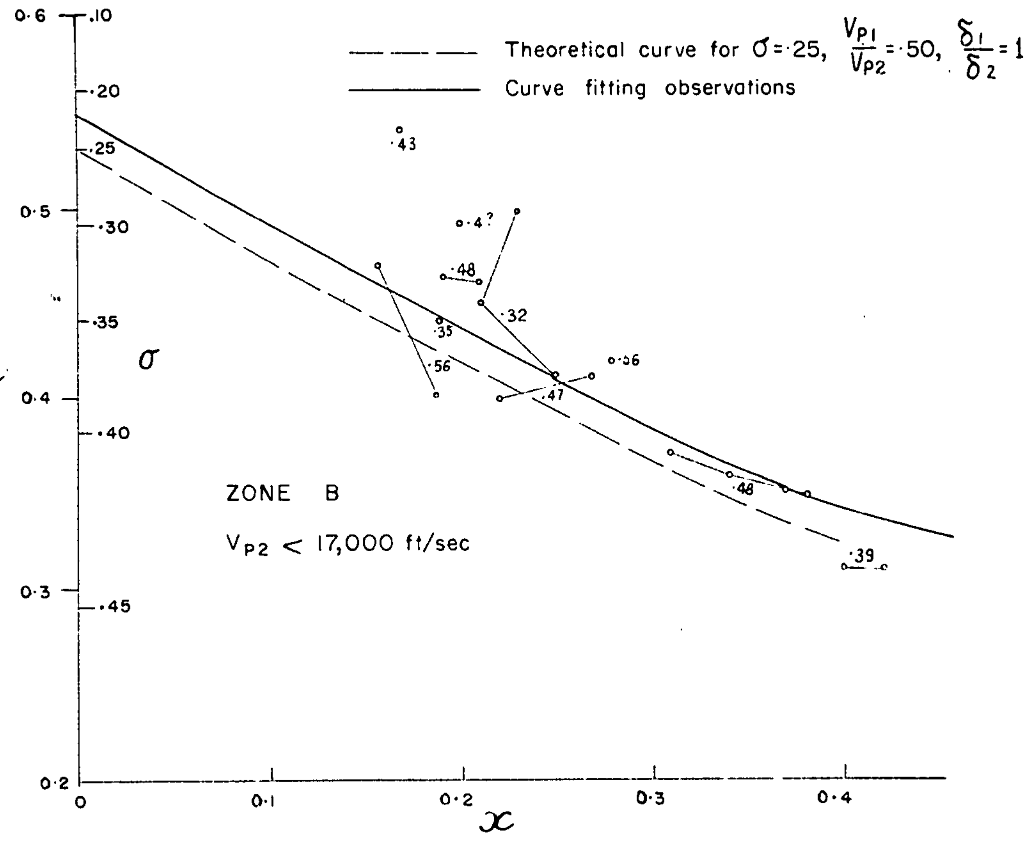
CALLIDE CREEK DAM SITE, QLD.





ESTIMATION OF POISSON'S RATIO FOR BEDROCK FROM GROUND-ROLL DATA

Note: Groups of points plotted from the same spread are joined by lines.
The numbers ·45 etc represent the value of q ($= V_{P1}/V_{P2}$) for each spread
σ = Poisson's ratio.

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