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WILHELMINA FALLS PUMPED STORAGE HYDRO-ELECTRIC SCHEME, S.E.C., VICTORIA, 1971

by

B.H. Dolan, P.J. Hill and E J. Polak

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SUMMARY

A seismic refraction survey was carried out in February 1971 by the Bureau of Mineral Resources, Geology and Geophysics on the site of the proposed pumped storage hydro-electric scheme of the State Electricity Commission of Victoria (S.E.C.) at Wilhelmina Falls near Yea, Victoria. Two 24-channel seismic refraction sets were used with geophone spacing of 50 ft on normal spreads and 10 ft on weathering spreads.

The bedrock in the area consists of Devonian granodiorite and metamorphosed siltstone, sandstone, and mudstone and is characterized by a very high seismic velocity. The surface of the bedrock is very uneven.

The overburden consists of weathered rock, hillwash and alluvium. The weathered rock extends on some locations to depths of more than 150 ft.

The values of Poisson's ratio and modulus of elasticity measured in situ, and in the BMR laboratory on cores, are given. Correlation between field and laboratory measurements is high.

1. INTRODUCTION

The State Electricity Commission of Victoria proposes to construct two pumped storage hydro-electric schemes; one at Wilhelmina Falls near Yea, the second on the Ada and La Trobe Rivers near Powelltown. Investigations, consisting of geological mapping, drilling and seismic refraction surveying were carried out on both sites. The results of the seismic refraction survey on the Wilhelmina Falls site are dealt with in this record and the results of the survey on the other site are the subject of another record (Dolan et al., 1972).

The proposed Wilhelmina Falls pumped storage scheme is located in the Murrindindi area, approximately 60 miles northeast of Melbourne.

The scheme consists of an upper water storage located on Falls Creek immediately upstream from the Wilhelmina Falls, and a lower water storage located on the Murrindindi River. The water storages would be connected through a power-station by a water conduit two-thirds of a mile in length; the head available for power generation being of the order of 1000 ft. During the low power demand in Melbourne the turbines will be reversed and the water pumped up from the lower storage area into the upper reservoir. The details of the schemes are discussed by Howard (1970).

A seismic refraction survey was carried out by the BMR Engineering Geophysics Group to assist in the site investigations. The party consisted of E.J. Polak, P.J. Hill, B.H. Dolan (geophysicists) and M. Dickson, Technical Assistant. The work was carried out between 18 February 1971, and 26 February 1971. The State Electricity Commission provided the topographic survey and six field hands to assist in the geophysical work.

The interpretation of the results was carried out by the three geophysicists from the party and Mr F.J. Taylor, also of BMR Engineering Geophysics Group.

The field measurements were made in British units. The laboratory measurements and plots of modulus of elasticity, which resulted from the laboratory measurements, were made in metric units.

2. GEOLOGY

(Prepared by P. Learmonth, S.E.C. Vic.)

The Wilhelmina Falls area lies within the Black Range Granodiorite and its contact aureole.

The granodiorite is a grey, medium-grained variety of Upper Devonian age which has intruded a series of Lower Devonian siltstones, sandstones and mudstones. The sediments have been thermally metamorphosed to hornfels and quartzite within the contact aureole, which is about one mile wide.

The intrusive is regarded by Hills (1959) as forming part of a ring dyke structure associated with a cauldron subsidence.

The contract between granodiorite and hornfels is marked over part of its length by granodiorite boulders. However, the occurrence of granodiorite boulders either along this contact or elsewhere does not necessarily indicate, in situ, fresh rock at shallow depth. The large, sheet-like exposures in the vicinity of the Wilhelmina Falls are indicative of in situ rock, but elsewhere the granodiorite is generally extensively weathered.

Along the contact zone the hornfels is highly fractured.

The granodiorite is jointed and the stream pattern follows lineaments which may represent faulting or intense jointing.

Most of the proposed works will be located within the granodiorite. However, the right abutment of the upper dam and the lower portion of the outlet channel will cross the contact zone, and the lower dam will be located entirely within metamorphosed sediments.

At the lower dam site the meta-sediments strike northwest, parallel to the stream direction, and dip 60° to 70° southwest. Hornfels outcrops on the left abutment while 60 to 70 ft of colluvial material overlies hornfels on the right abutment.

3. METHODS AND EQUIPMENT

The seismic refraction method was used in the survey (Heiland, 1946). The depths of the different velocity layers at the shotpoints were calculated using the time intercept method (Heiland, 1946, 512) and the depth at each geophone along the traverse was obtained using a modified method of differences (Heiland, 1946, 548).

The equipment used during the survey consisted of two identical 24-channel S.I.E. seismic refraction sets and 20 Hz T.I.C. geophones. The spacing of geophones was 50 ft for normal spreads and 10 ft for weathering spreads. Shots were fired 5 ft and 200 - 400 ft from each end geophone and in line with the spread, with an additional shot in the centre of the spread.

The values of Poisson's ratio and modulus of elasticity for bedrock material at a number of localities were calculated from in situ measurements of longitudinal and transverse wave velocities (Polak, 1963). To determine the ratio of longitudinal to transverse velocities, three Hall Sears 7 Hz 3-component shallow-borehole geophones were used. These were buried at 25 ft spacings along the traverse line and the shot fired at sufficient distance from the geophones to ensure that bedrock velocities were recorded.

In the BMR Rock Testing Laboratory, Poisson's ratio, modulus of elasticity, and logarithmic decrement, were determined on borehole cores from the area. These values were calculated from measurements of ultrasonic velocities in the cores and the longitudinal resonant frequencies of cores of known dimensions and the shape of their frequency response curves near resonance (Polak, 1963).

4. RESULTS

The layout of seismic traverses is shown on plate 2, and the sections obtained from seismic interpretations are shown on plates 3 to 7.

4.1 Seismic velocities

On the seismic sections, two broad categories of materials can generally be resolved on the basis of seismic velocities (1) unconsolidated material and (2) weathered and unweathered bedrock.

4.1.1 Unconsolidated material

Unconsolidated material consist of soil, alluvium, hillwash and scree material. Their seismic velocities are generally below 5,000 ft/sec.

1) Soil - a thin layer maximum 2 to 3 feet shows a seismic velocity of 1,000 to 1,200 ft/sec.

2) Hillwash - found on the right abutment of the lower dam site, and on part of the portal, consists of clay, angular and partly rounded boulders and gravels. The velocities in hillwash are about 3,000 ft/sec.

3) Scree material - found mostly on steep slopes (tunnel line, left abutment of the lower dam) and on upper dam sites. The velocities recorded in this layer are between 3,000 to 4,200 ft/sec.

It is possible that on the tunnel line, where large blocks (6 ft and more) may be embedded in the scree material, the recorded seismic velocity may rise above the general value for scree material, and in this case it would be classified with the less weathered rock in this report.

4) Alluvium - a velocity of 5,000 ft/sec in alluvium indicates it is water saturated and presumably below the water table. This occurs on the lower dam site and portal.

4.1.2 Weathered and unweathered bedrock

Weathered and unweathered bedrock, both granodiorite and hornfels, have seismic velocities ranging from 3,500 ft/sec for very weathered, but in situ, rock to 23,000 ft/sec for unweathered rock.

Seismic velocities of 3,500 to 4,500 ft/sec indicate completely weathered granodiorite and hornfels in situ. Measurements in Koombooloomba, Queensland, indicated that weathered granite with velocity of 4,500 ft/sec may contain about 40 percent of "core stones", and therefore may not be suitable for the impermeable core of an earth dam. This could also apply to the granodiorite in this area.

Higher seismic velocities 4,500 ft/sec to approximately 8,000 ft/sec indicate rock less weathered than above, with seismic velocities increasing with the decrease in weathering. Above 8,000 ft/sec, the rock should be jointed, possibly with some weathering on joints, and the joints may be open for lower velocities in this range. With velocities above 12,000 ft/sec the rock should be fresh with joints closed. The maximum velocity recorded was 23,000 ft/sec.

It is clear that a division between unconsolidated material and weathered bedrock cannot be derived from seismic velocities alone.

It is generally possible to remove, without blasting, rock with a seismic velocity of 6,000 ft/sec using a D 9 bulldozer. This criteria should be applicable on this area. In general, rock with a seismic velocity of 8,000 ft/sec will support a medium height earth dam, and this would also be expected to apply as a general guide in this area.

4.2 Depth to bedrock

Seismic cross-sections calculated from the survey results are shown on plates 3 to 7. Points to be remembered when making use of these sections are listed below:

1) Using a spacing of 50 ft between geophones, some of the details of the bedrock surface can be missed, and thus narrow zones of deeper weathering may not be recorded at all; the depresssions in the buried surface may be shown to be shallower and the uplifts to be depressed.
   This fact is illustrated clearly on plate 6, on the upper dam where spacing of 25 ft was used. The surface of the bedrock shows much more detail.

2) The depth to the bedrock is calculated using a conversion factor obtained at the shotpoints. Between the shotpoints the conversion factor is interpolated assuming a gradual lateral change of properties of upper layers. This may introduce some inaccuracy in depth determinations.

3) The boundaries between upper layers are determined at shotpoints, but interpolated between them. For this reason they are shown as broken lines on the section.

4) The error of the absolute depth determination is estimated to be about 15 percent. This is based on experience from previous surveys, where the interpretations of the seismic survey results have been tested by drilling. The relative depth to the bedrock and the general shape of the interface will show greater accuracy.

4.3 Dynamic properties of bed rock in situ

Table 1 gives the dynamic properties of bedrock as calculated from longitudinal and transverse velocities measured in situ. The locations of the geophones for each test are indicated on the table.

In computing the dynamic properties of the rock in situ, it is necessary to know specific gravity. In order to obtain a value for specific gravity, use was made of a plot of longitudinal velocity against specific gravity of core samples from boreholes in the area. Hence from the known values of longitudinal velocity in situ, the specific gravity was chosen.

This procedure gives a value of modulus of elasticity for the rock in situ higher than the true value. This arises from an overestimation of density, since the average density of in situ rock is reduced by jointing, etc. This overestimation may be up to 10% for rock of lower velocity. For deeper rocks, where the joints are more closed, the overestimation is very small.

4.4 Laboratory measurements on cores

Table 2 gives values of the principal physical properties of rocks from Wilhelmina Site bores measured in the BMR Rock Testing Laboratory. Where there are gaps in the table for the values for Poisson's ratio and the modulus of elasticity, the cores were too short to carry out measurements of the resonant frequency of the specimens (See 3).

Plate 8 shows plots of modulus of elasticity versus the seismic velocity for the rocks listed on tables 1 and 2. The regression coefficients are very high (0.989 and 0.997). The regression equations are shown on the plate and indicate that for corresponding velocities, the values of modulus of elasticity in laboratory measurements are about 10% higher than for in situ measurements.

5. CONCLUSIONS

The following conclusions can be reached from the results of the seismic refraction survey:

5.1 The depth of weathering

The extent of weathering is considerable in all parts of the surveyed area, and weathering depth exceeds 150 feet on several locations. Deeper narrow zones of weathering can be partly missed, but the velocities in the bedrock, which are generally higher than experienced on other dam sites with the same rock type, indicate that there are no wide zones of deeply weathered bedrock.

5.2 The character of bedrock

High seismic velocities indicate good quality rock. This is supported by the high values of the modulus of elasticity, obtained in situ. Poisson's ratio is higher than generally found in previous surveys in granite, and may indicate more closely jointed character of the rock. Generally, the lower velocity in the bedrock along the axis of the upper dam may be an expression of more open jointing close to the slope.

5.3 The character of the overburden

The overburden in the area of the upper dam sites is characterized by a lower velocity than in other parts of the survey area. This fact can be explained by the slower erosion of an area protected by a hard band of rock on which Wilhelmina Falls was developed.

The overburden on parts of the portal and lower dam site is characterized by a seismic velocity of 5,000 ft/sec which indicates it is saturated with water.

The overburden on the right abutment of the lower dam is partly composed of relatively dry hillwash.

Overburden along the tunnel line may contain large blocks.

5.4

Moduli of elasticity of the bedrock, as measured in the field and in the laboratory, are high and the values of both measurements correlate closely. It is expected that the bedrock, if jointed, has the joints closed (Polak, 1963).

6. REFERENCES

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TABLE 1 - IN SITU MEASUREMENTS

Location	Longitudinal velocity m/sec	Longitudinal velocity ft/sec	Poisson's ratio	Modulus of Elasticity kg/cm^2 $x\ 10^5$	Modulus of Elasticity lbs/in^2 $x\ 10^6$	S.G. as measured from the plot of S.G. against velocity for core samples
Lower Dam Site						
axis 2/550	4,500	13,700	0.25	4.49	6.39	2.61
axis 00	3,350	10,200	0.28	2.26	3.21	2.52
axis 31	4,570	13,900	0.27	4.47	6.36	2.62
cross-trav.1/0	5,180	15,800	0.28	5.65	8.04	2.64
Tunnel line						
- 200	3,660	11,200	0.265	2.82	4.01	2.55
900	4,880	14,900	0.29	4.88	6.94	2.63
1000	4,800	14,600	0.275	4.87	6.93	2.62
2000	4,570	13,900	0.29	4.24	6.04	2.61
3300	5,490	16,700	0.27	6.57	9.34	2.67
Upper Dam Site						
2/580	4,820	14,700	0.305	4.57	6.49	2.63
3/300	5,270	16,100	0.28	5.87	8.35	2.65
1/250	4,870	14,800	0.30	4.73	6.72	2.63
2/200	4,800	14,600	0.285	4.76	6.77	2.62
Alternative Upper Dam Sites						
0	4,570	13,900	0.29	4.41	6.27	2.71
CT2/100	5,180	15,800	0.305	5.29	7.53	2.64

TABLE 2 - LABORATORY MEASUREMENTS

Borehole	Depth feet	Rock type	S.G.	Longitudinal velocity m/sec	Modulus of Elasticity kg/cm^2 x 10^5	Modulus of Elasticity lbs/in^2 x 10^6	Poisson's ratio	Logarithmic decrement
M 7	33.0- 33.5	Granodiorite slightly weathered	2.57	3818	3.02	4.29	0.28	0.054
M 7	36.0- 36.5	Fresh	2.62	4683	5.13	7.30	0.22	0.034
M 9	16.0- 16.5	Medium weathered	2.40	2300				
M 9	39.25- 39.75	Slightly weathered	2.61	2958	2.14	3.04	0.19	0.061
M 10	11.0- 11.5	Medium weathered	2.32	2400				
M 10	19.0- 19.5	Fresh	2.69	5198	6.21	8.83	0.25	0.028
M 13	141.1-141.5	Fresh	2.70	5488	6.83	9.70	0.26	0.021
M 24	42.0- 42.5	Medium weathered	2.49	3000				
M 29	110.2-110.7	Hornfels fresh	2.69	6235	9.15	13.01	0.23	0.018

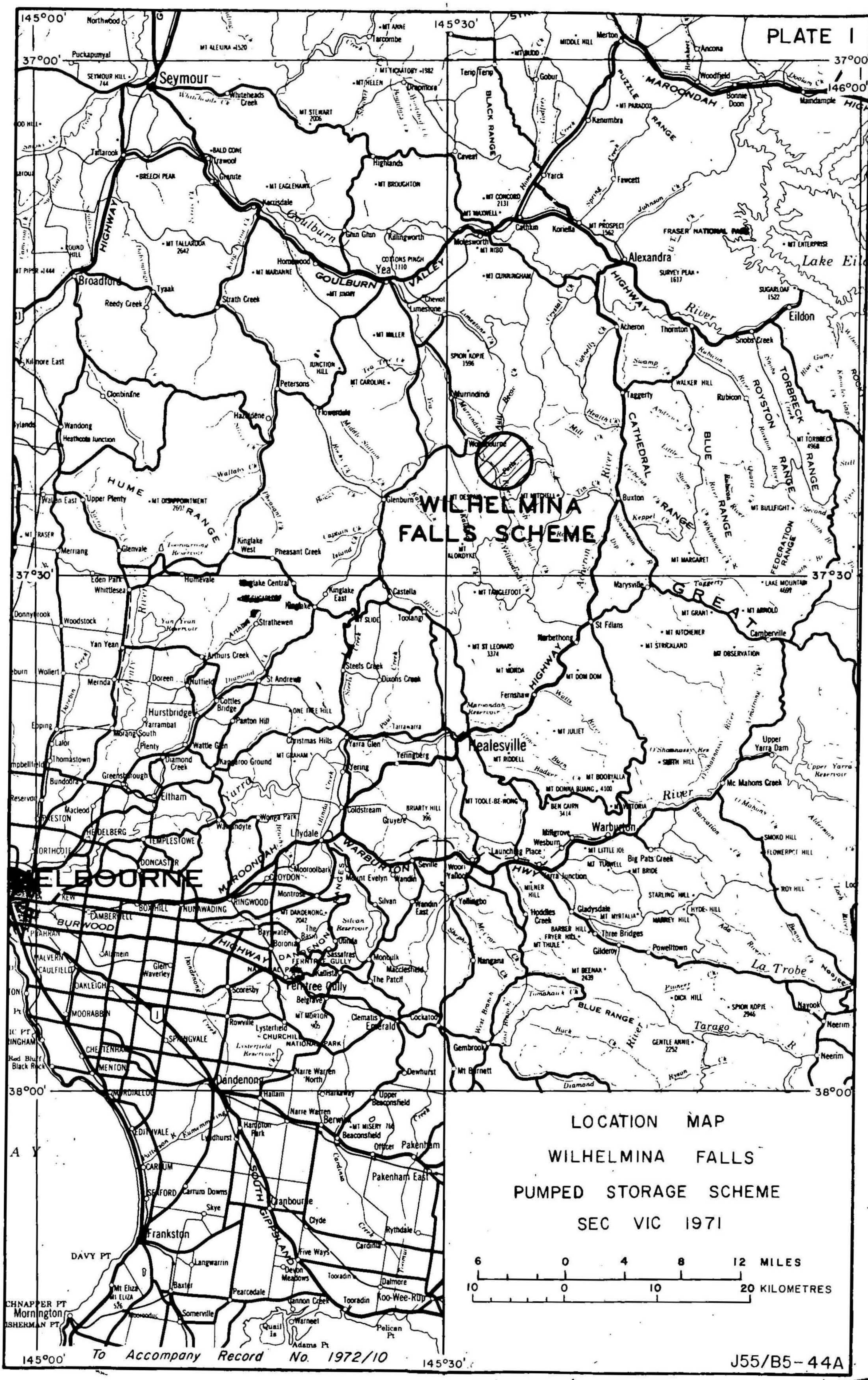

PLATE I
WILHELMINA FALLS SCHEME
LOCATION MAP
WILHELMINA FALLS
PUMPED STORAGE SCHEME
SEC VIC 1971
6 0 4 8 12 MILES
10 0 10 20 KILOMETRES
145°00'
145°30'
146°00'
37°00'
37°30'
38°00'
Seymour
Broadford
Yea
Alexandra
Eildon
Healesville
Warburton
Marysville
Lilydale
Dandenong
Frankston
Mornington
MELBOURNE
Lake Eildon
FRASER NATIONAL PARK
HUME RANGE
CATHEDRAL RANGE
BLUE RANGE
GOULBURN VALLEY
MAROONDAH
HIGHWAY
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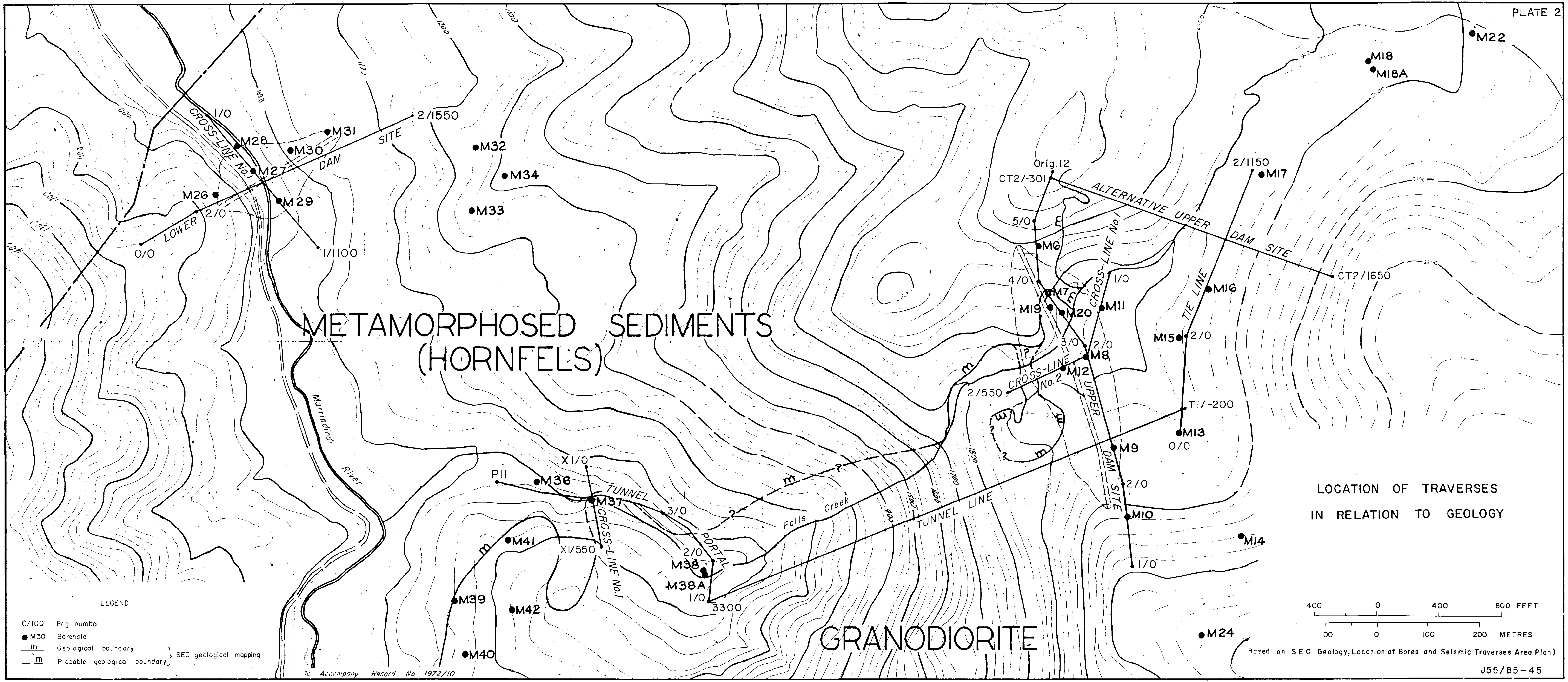
PLATE 2



LEGEND

0/100 Peg number

● M30 Borehole

m Geological boundary

m Probable geological boundary

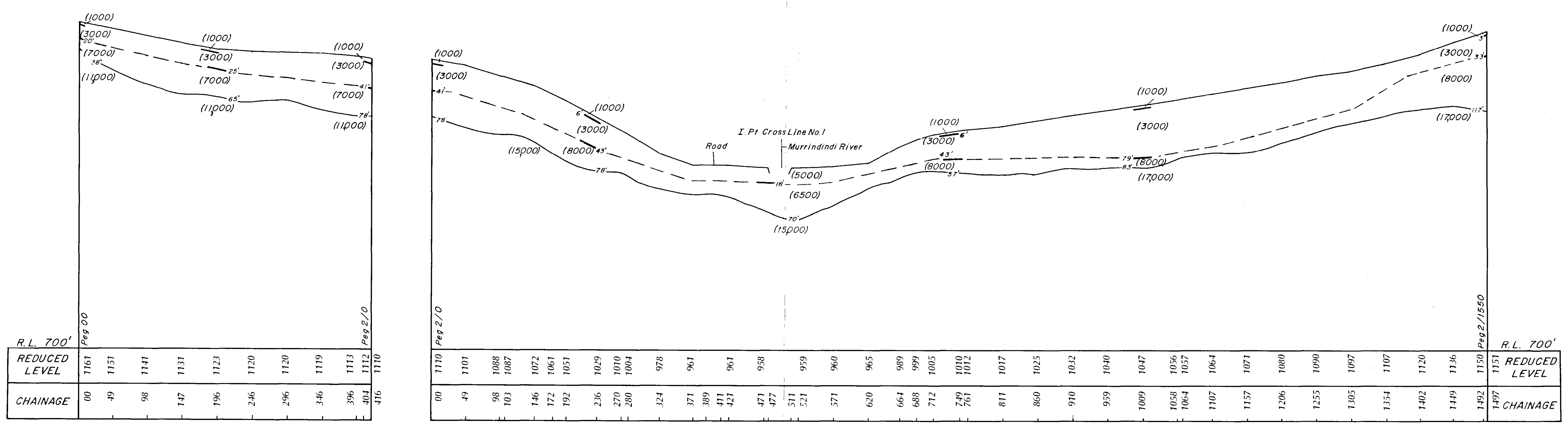
SEC geological mapping

To Accompany Record No 1972/10

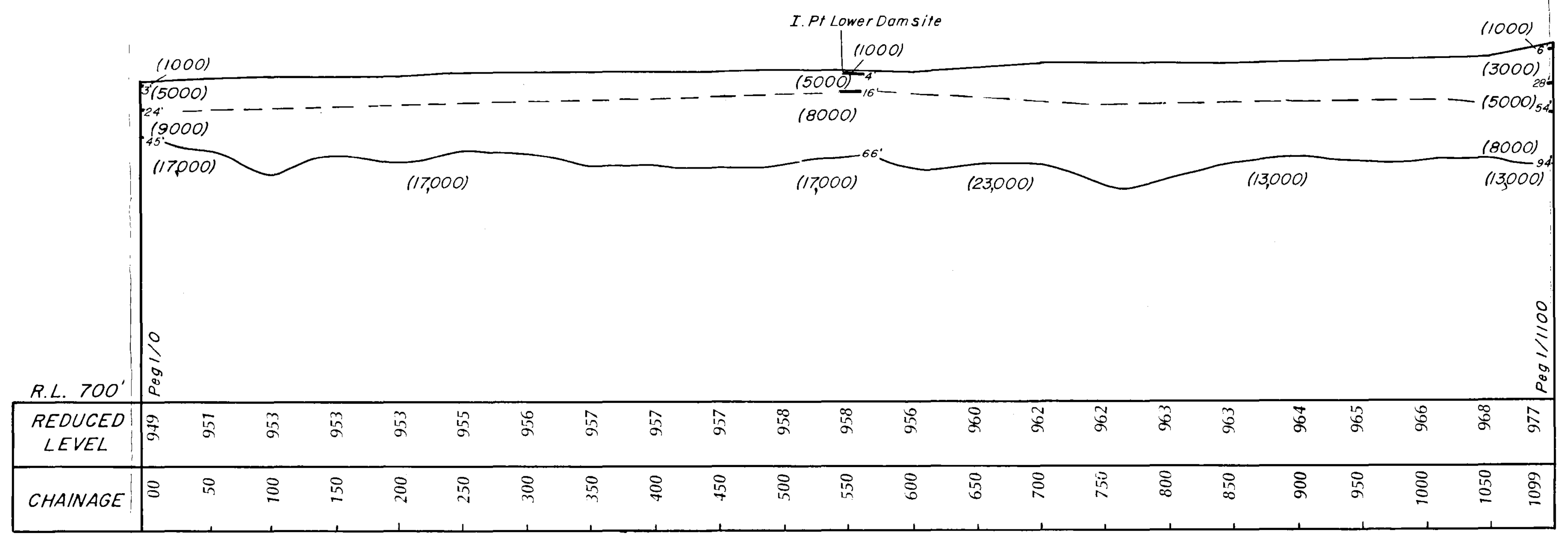
Based on SEC Geology, Location of Bores and Seismic Traverses Area Plan)

J55/B5-45

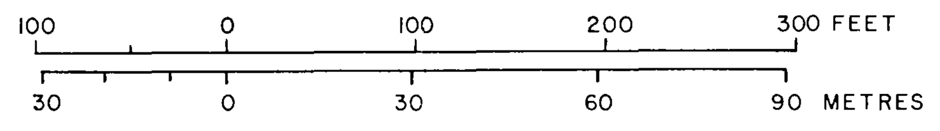
SEISMIC CROSS-SECTIONS AT THE LOWER DAMSITE



LOWER DAM SITE



CROSS LINE No. I
(LOWER DAM SITE)



SEISMIC CROSS-SECTIONS AT THE TUNNEL PORTAL

SEISMIC CROSS-SECTIONS ALONG THE TUNNEL LINE

R.L. 1100'

CHAINAGE	REDUCED LEVEL
−200	1921
−184	
−150	1923
−100	1923
−50	1926
00	1929
50	1930
100	1932
150	1931
192	1934
200	1935
250	1937
300	1931
310	1930
350	1927
399	1920
449	1913
499	1909
548	1905
598	1901
648	1898
698	1896
748	1894
798	1891
848	1886
897	1875
945	1861
993	1849
995	1849
1039	1831
1084	1808
1130	1787
1175	1767
1220	1746
1254	1730
1266	1724
1306	1702
1310	1703
1348	1673
1389	1646
1434	1614
1461	
1469	1590

R.L. 900'

CHAINAGE	REDUCED LEVEL
1461	
1469	1590
1508	1561
1547	1540
1592	1519
1627	1482
1672	1459
1708	1433
1750	1407
1794	1382
1840	1363
1849	1360
1887	1346
1933	1327
1979	1309
2024	1284
2071	1268
2120	1260
2170	1257
2219	1243
2266	1227
2315	1218
2340	1213
2362	1202
2405	1180
2450	1158
2498	1142
2544	1124
2593	1115
2640	1099
2688	1086
2738	1096
2761	1095
2788	1091
2836	1080
2885	1088
2935	1086
2985	1079
3031	1061
3038	1061
3078	1079

SEISMIC CROSS-SECTIONS AT THE UPPER DAMSITE

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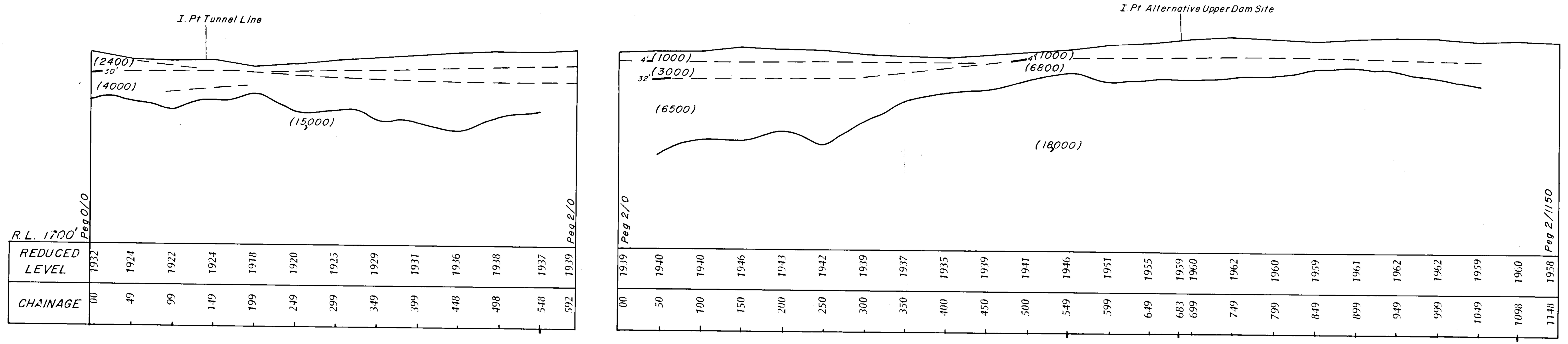
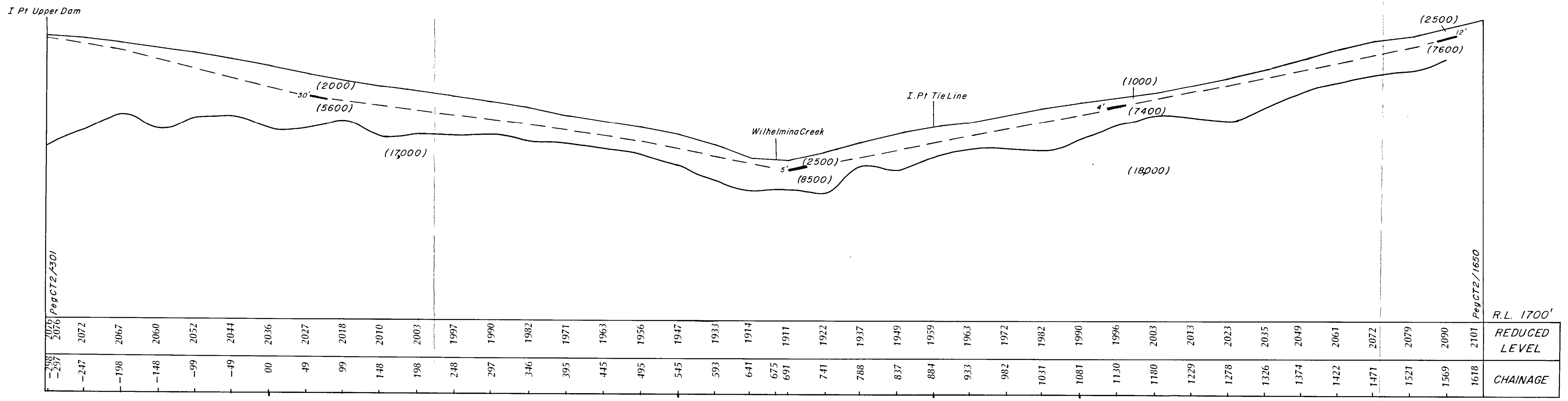
PLATE 7

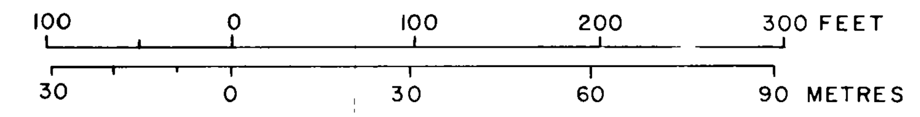
SEISMIC CROSS-SECTIONS AT THE ALTERNATIVE UPPER DAMSITE AND TIE-LINE



TIE LINE



ALTERNATIVE UPPER DAM SITE



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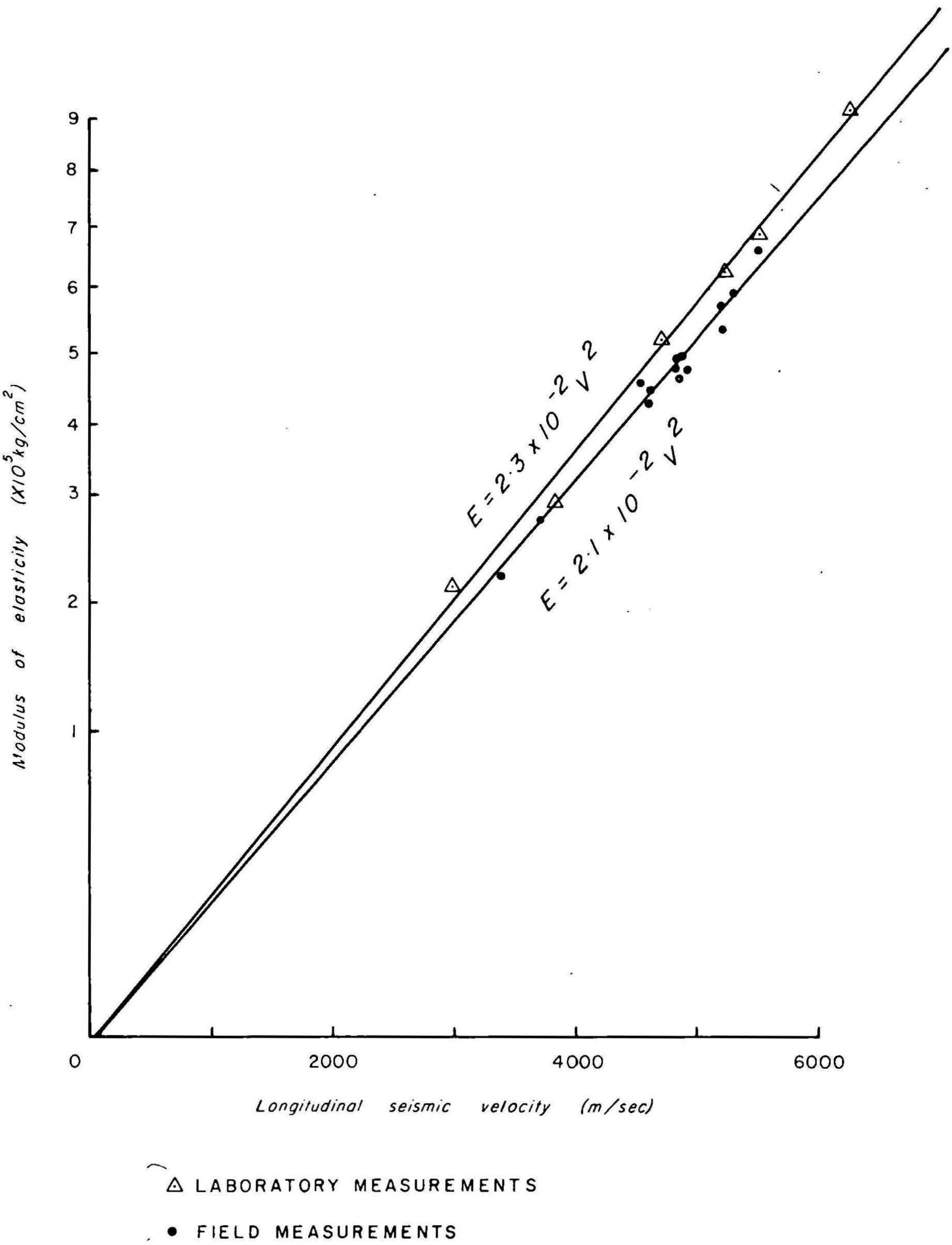

PLOTS OF MODULUS OF ELASTICITY AGAINST SEISMIC VELOCITY