COMMONWEALTH OF AUSTRALIA

DEPARTMENT OF NATIONAL DEVELOPMENT

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS.

RECORDS

1959 NO. 62.

A SEISMIC REFRACTION SURVEY AT THE MOOGERAH DAM SITE NEAR KALBAR, QUEENSLAND.

by

E.J. POLAK and P.E. MANN.

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CONTENTS

TABLES

PLATES

ABSTRACT

This report covers the results of a geophysical investigation which was carried out by the Bureau of Mineral Resources at the Moogerah Dam Site, Queensland. This dam is part of the Warrill Valley Irrigation Project being investigated by the Queensland Irrigation and Water Supply Commission.

The seismic refraction method was used to determine the depth to the bedrock at the proposed site. The maximum depth to bedrock was approximately 25 feet. The depths determined by the seismic method are compared with results of drilling.

Dynamic elastic properties of the bedrock, trachyte, are calculated from longitudinal, transverse and Rayleigh wave velocities which were measured during the survey.

1. INTRODUCTION

The Irrigation and Water Supply Commission (I.W.S.C.) of Queensland proposes building a dam on Reynolds Creek as part of the Warrill Valley Irrigation Project. The purpose of the dam is to provide water storage and to control the flow of water and ensure continuity of the water supply for the irrigation of existing farms along the Reynolds and Warrill Creeks.

The proposed site of the dam is in a narrow gorge, two miles east of Mt. Edwards Railway Station and eight miles south-west of Kalbar. (Plate 1). The approximate co-ordinates of the site are:- 566750E, 1522600N on the military 4-mile map of Warwick.

The geological investigation of the damsite was carried out by Tucker (undated report) of the Geological Survey of Queensland. Twenty-seven drillholes were drilled in this damsite area. (Dunlop, 1958).

The Commission requested the Bureau of Mineral Resources, Geology and Geophysics, to carry out a geophysical survey to determine the depth to and seismic velocities in the foundation rock at the site. A survey was carried out by a geophysical party from the Bureau, with E.J. Polak (party leader) and P.E. Mann, geophysicists. The Commission provided three field assistants. The field work was done on 10th, 11th and 12th November, 1958.

The method used was the seismic refraction method.

2. GEOLOGY

The area investigated is situated at the upstream end of a steep-sided gorge. Further upstream the gorge opens into a wide valley.

In this report the terms overburden and bedrock are used. By overburden is meant soil, mud, scree and decomposed and weathered rock; by bedrock is meant fresh, unweathered but jointed rock.

The bedrock in the area consists of trachyte. There are outcrops of rock in certain areas of the gorge, while on the sides of the gorge the rock is covered with scree and on the banks of the creek with soil and mud.

The rock is massive, fine-grained and is heavily jointed, with two vertical directions of jointing (with bearings of 70° and 340° respectively) and one horizontal. The joints are tight, although some are stained with iron. The depth of weathering, as shown by drillholes, ranges between 4 and 24 feet.

3. METHODS AND EQUIPMENT

The seismic refraction technique, which was used in this survey, is particularly suitable for shallow investigations such as the determination of the thickness of overburden. The method is based on the contrast in velocity of elastic waves in different rock formations.

An explosion sets up a wave train in the ground and times of travel of the wave from the shot point to geophones accurately located on the ground are measured. From the travel time data the seismic velocities and depths to successive formations can be calculated.

The seismic recording equipment used in the survey was a 12-channel portable shallow reflection-refraction seismograph manufactured by the Midwestern Geophysical Laboratory, Tulsa, Oklahoma, with Midwestern geophones having a natural frequency of about 8 cycles per second to record vertical movement of the ground, and a three-component geophone made by the Technical Instruments Company, Houston, Texas, to record movement in three mutually perpendicular directions.

Generally the geophones and shot points are set up in a straight line at intervals of 50 feet (the arrangement is known as a "normal geophone spread") and the first arrival times of the seismic waves (in milliseconds) are plotted against the distance (in feet) from the shot point to give "time-distance-curves". The slope of the time-distance-curve indicates the velocities in the successive formations, and from these data it is possible to compute the depth to these different formations. However, the arrangement of geophones, positions of shot points and the computations may be varied to suit any particular field conditions.

The Bureau commonly uses a technique known as the "method of differences" (Heiland, 1946, p.548). Referring to Plate 3A, a shot is fired at A and the travel times (T_{AB} and T_{AC}) are recorded at B and C. A shot is then fired at C and the travel times (T_{CB} and $T_{CA} = T_{AC}$) are recorded at A and B. The depth to the first discontinuity below B is calculated from the formula:-

$$d = \frac{V_2}{\sqrt{V_2^2 - V_1^2}} \left(\frac{T_{AB} + T_{CB} - T_{AC}}{2} \right) V_1$$

in which the meaning of T_{AB}, T_{CB} and T_{AC} was explained above. V_2 is the velocity below the first discontinuity, V_1 the velocity between the surface and the first discontinuity, and d the depth to the first discontinuity below point B. The term $\frac{T_{AB} + T_{CB} - T_{AC}}{2}$ represents an apparent vertical travel time, and the term $V_2 / \sqrt{V_2^2 - V_1^2}$ serves as a correction factor for V_1.

Apart from the "normal spreads", so called "broadside spreads" were convenient to obtain information across the gorge. With a broadside spread (see Plate 3B) the geophones are placed in a line along the traverse and the shot point is a few hundred feet away in the direction normal to the traverse (see Polak and Hawkins, 1956).

To obtain information concerning velocities close to the surface, so called "weathering spreads" were used. Weathering spreads are the same as normal spreads, except that the distance between the geophones is smaller, generally 10 ft.

Velocity logging was carried out in two drillholes and in one test-pit. Shots were fired at several levels in the drillholes the resulting vibrations being recorded by geophones placed on the surface. From the recorded travel-times, velocities of propagation in the vertical direction were calculated.

In Plate 4 are shown sample records obtained during the survey. The vertical lines are timing lines at intervals of two milliseconds. The shot-instant, S.I., is shown on trace No.6. Following the shot instant, the deflections on the traces show the arrival times at the geophones of the seismic waves.

The velocity with which any wave travels through earth material is controlled by the dynamic properties of the material. The following notations will be used in this report:-

V_p = Longitudinal velocity in ft./sec.
V_s = Transverse velocity in ft./sec.
E = Young's Modulus in lb/in^2
σ = Poisson's Ratio
G = Modulus of Rigidity (shear modulus) in lb/in^2
B = Bulk Modulus (Modulus of incompressibility) lb/in^2
δ = density in $\frac{lb.\ sec^2\ in^{-1}}{in^3}$

Note:- Dynamic properties are measured in the direction of propagation of seismic wave.

An examination of the character of different seismic waves follows (Leet, 1950, p.45).

1. Longitudinal Mode (compressional, primae). This wave is the fastest of all and arrives first at the geophones. It consists of a forward and backward movement of the rock particles in the direction of propagation. The velocity of this wave V_p is expressed by a formula:-

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

Plate 5 shows a plot (time-distance curves) of the arrival times of longitudinal waves from records shown on figures 3 and 4. The velocities computed from the time-distance-curves must be corrected for the dip of the formations concerned. Above the time-distance curves of Plate 5 the corrected time-distance-curve indicates the true velocity of the refractor, 15,500 ft./sec.

2. Transverse Mode (shear, secundae). This wave arrives later than the longitudinal wave. The movement of the particle is at right angles to the direction of propagation. These waves can be polarised into movement in two planes; parallel to, and normal to, the stratification planes. (Leet, 1950 p.45).

The velocity of this wave V_s is expressed by the formula:-

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

in which the constant 1/12 is the result of using an inch as the unit of length in E and δ, and the foot as the unit in V_s.

3. Ground Roll. This is a very complicated movement of the ground particles resulting from the passage of near surface waves, of which the Rayleigh (R) and the Love (Q) are the most important. (Leet, 1950 p.46).

For a medium with Poisson's Ratio σ = 0.25 the velocity of the Rayleigh wave is approximately 0.91 V_s. A time-distance-curve for ground roll is shown on Plate 5.

Plate 6 shows a field record obtained using vertical geophones on traces 1,2,3,4,7,8,9,10,11,12 and horizontal geophones on traces 5 and 6.

The actual ground movement is shown on Plate 7. The different waves are identified and indicated.

The dynamical properties of rocks are calculated from formulae (Leet, 1950):-

$$\left(\frac{V_p}{V_s}\right)^2 = \frac{\sigma - 1}{\sigma - \frac{1}{2}}$$

$$E = 144\, V_p^2 \cdot \delta . \frac{(1 + \sigma)(1 - 2\sigma)}{1 - \sigma}$$

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

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

4. RESULTS

(a) Survey Results.

Plate 2 shows the arrangement of seismic traverses at the Moogerah damsite. Traverses A-D were shot using normal geophone spreads, traverse E using broadside spread.

Plate 8 shows the results of the interpretation of the seismic refraction work. The results were calculated assuming a two-layer structure, overburden and bedrock.

Overburden. The overburden consists of soil, mud, gravel, boulder and weathered trachyte along creek bed and of scree and weathered trachyte higher up the slope. Seismic velocity in this bed, as obtained from weathering spreads, is 1200 $\pm$ 200 ft./sec. but may be up to 3000 $\pm$ 200 ft./sec. in some places, where weathering is not so far advanced.

Bedrock. The bedrock consists of rock with the very high seismic velocity of 15000 - 17000 $\pm$ 1000 ft./sec. This rock has been proved in all drillholes in the area as trachyte.

Seismic velocities mentioned above are velocities calculated from the time-distance curves plotted from results obtained on weathering and normal spreads. Thus these are velocities measured in horizontal directions.

Vertical velocities were measured in drillholes and are listed in Table 1.

TABLE 1.

Drillhole	Depth ft.	Time m/sec.	Average velocity	Interval feet	Interval time in m/seconds	Interval velocity in ft./sec.
1	21	8	2630	11	1.5	7300
	10	6.5	1540			
7	74	16	4600	34	4	8500
	40	12	3300	20	4	5000
	20	8	2500	10	3	3300
	10	5	2000			
Test pit	10	6	1660			

The thickness of the overburden indicated on Plate 3 was calculated using an average velocity obtained from the velocity tests carried out in the drillholes. The overburden in the area is thin. The maximum observed thickness of overburden is 25 ft. near drillhole 11, on the junction of traverses B and E.

It is very difficult to assess the percentage error in the bedrock depth determination for very small thickness of overburden, where the difference of a few feet gives considerable percentage error. Table 2 gives a comparison of the depth to the fresh rock as obtained from drilling and from seismic survey. In eight comparisons the error is five feet or less.

TABLE 2.

Drillhole	Depth in feet		Character of bedrock
	Seismic	Drilling	
1	3	2	Hard and fine trachyte
2	14	12	" " " "
7	14	14	Fine trachyte with Iron-stained joints
10	10	12	Hard trachyte with Iron-stained joints
11	25	22	" " " " " "
22	17	17	" " " " " "
23	14	10	" " " " " "
24	15	10	" " " " " "

(b) Anisotropy.

Differences between vertical and horizontal velocities are defined as velocity anisotropy. In this area of jointed trachyte the velocity anisotropy probably indicates that the horizontal joints are more open than the vertical ones. Further study may show that a quantitative estimate of the joint spacing in any direction may be derived from the study of the velocity in that direction. More open horizontal joints may be connected with the erosion of the trachyte by the creek. This erosion would reduce the vertical pressure on near surface rock. The inspection of the Commission's drilling record shows that the horizontal joints are more open than the vertical.

To obtain more information on the anisotropy, geophones were placed along the slope of the gorge and shots were fired in drillhole No.7 (Plate 9A). The probable paths of the seismic waves are shown on the drawing and the seismic velocities in several directions are calculated. The results are shown on Plate 9B and prove the existence of anisotropy in seismic velocity.

(c) Dynamical properties of bedrock.

Table 3 shows the dynamic values of the elastic properties of the rocks with the data from which they are calculated.

TABLE 3.

Traverse	Refr. velocity		App. velocity		Poisson's Ratio	$\times 10^6$ lb/in^2		
	Longitudinal	Transverse	Longitudinal	Transverse		E	B	G
A	15,000	8,500	-	-	.27	6.6	4.8	2.6
B	17,000	10,000	-	-	.24	9.0	5.8	3.65
B	17,000	-	10,000	6,450	.245	8.8	5.75	3.50
C	16,000	-	10,500	5,700	.28	7.3	5.55	2.85
C	16,000	-	9,800	5,900	.265	7.55	5.40	3.00
D	17,000	10,000	-	-	.24	9.0	5.8	3.65

The elastic properties of rocks have generally higher values when determined dynamically than those determined in static tests. (U.S.Dept. of Interior, 1953).

On some traverses the apparent velocity was used to calculate Poisson's Ratio. The apparent velocity is defined as a velocity obtained by dividing the distance between the shot point and geophone by the time taken for the wave to cover this distance.

Poisson's Ratio calculated from the apparent velocity may differ from the value calculated from true velocities. For instance with the following conditions at the Moogerah dam site the errors are:- for a theoretical velocity ratio $V_P / V_S = 1.73$, Poisson's Ratio is 0.25; for a depth of overburden of about 10 ft. and a shot distance of 400 ft. the velocity ratio, based on apparent velocities, is 1.8, and the Poisson's Ratio is 0.28, which means that it is 0.03 too high. For the same overburden depth of 10 ft., but a shot distance of 750 ft., the velocity ratio, based on apparent velocities, is 1.76, and the Poisson's Ratio is 0.265. In this case it is only 0.015 too high.

The above illustrates that under favourable conditions of shallow overburden, and relatively long shot distances, the errors in computing Poisson's Ratio from apparent velocities are small, and effectively negligible.

5. CONCLUSIONS

The geophysical survey of the Moogerah Dam Site provided information of the depth to the bedrock. The overburden near the creek consists mostly of soil, mud and weathered trachyte and attains a maximum thickness of 25 ft. on traverse B Station No.5. The overburden of scree on the slopes of the gorge is thin, measuring between 3 and 15 feet thick.

The bedrock exhibits seismic velocity anisotropy. The seismic velocity measured for horizontal paths varies between 15,000 and 17,000 ft.sec^{-1}, while the maximum vertical velocity measured in drillhole No.7 is 8,500 ft.sec^{-1}.

A comparison of the depths found by the seismic method and diamond drilling shows that most of the differences are less than 5 feet.

The result of six observations of Poisson's Ratio for the unweathered bedrock, computed from longitudinal, transverse and Rayleigh waves travelling in the horizontal direction, is 0.255 ± 0.015.

The corresponding average value of Young's Modulus calculated for the same observations is 8.4×10^6 lbs/in^2.

6. REFERENCES

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U.S. DEPT. OF INTERIOR., 1953 - Physical Properties of Some Typical Foundation Rocks. Concrete Laboratory Report No. SP-39. Bureau of Reclamation, Denver, Colorado.

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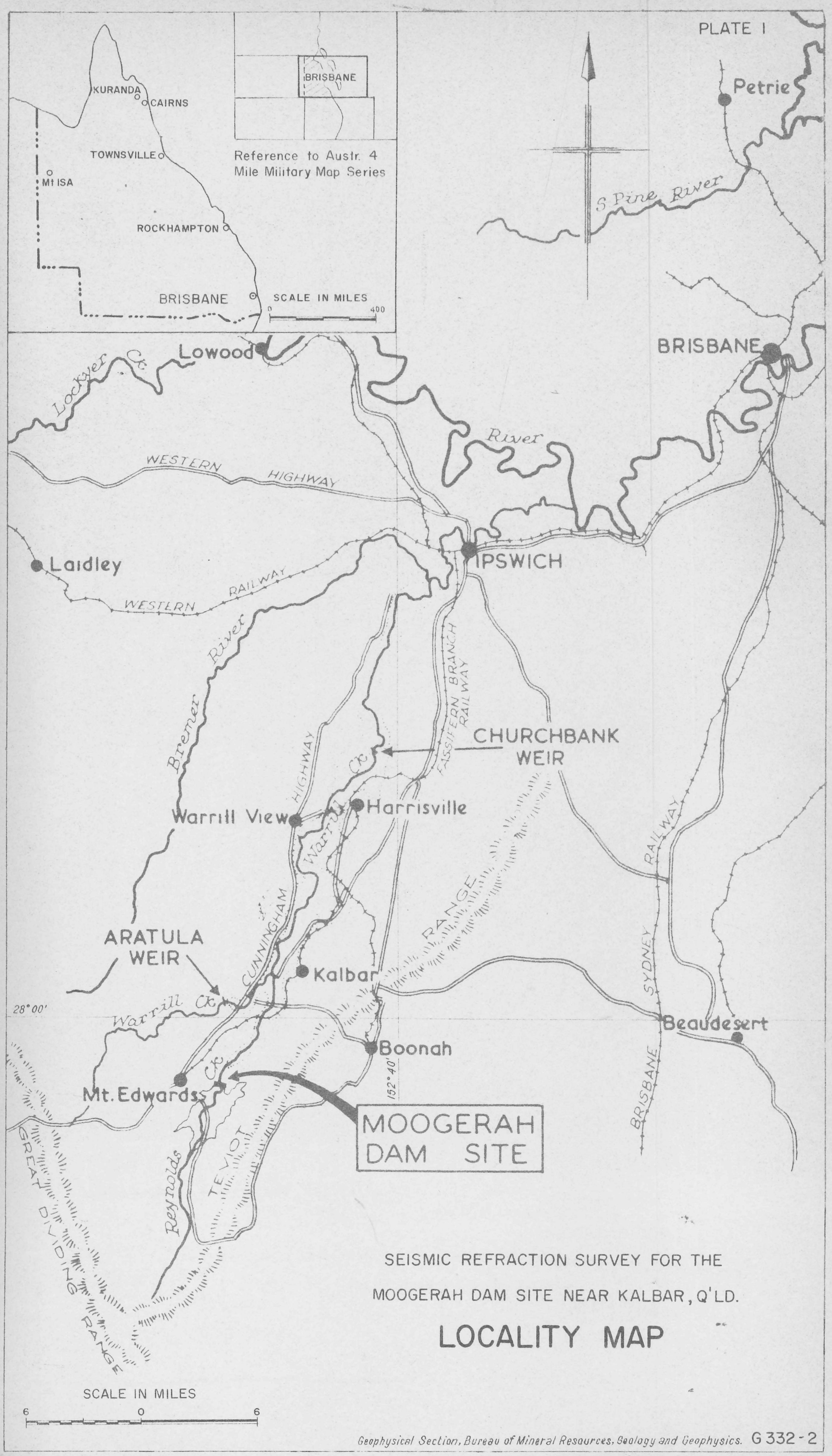
LEET, L.D., 1950 - EARTH WAVES. Harvard University Press, Cambridge, Mass.

POLAK, E.J.
HAWKINS, L.V., 1956 - Seismic Refraction Survey of the Dawson River Damsites, Queensland, B.M.R. Records 1956 No.108.

TUCKER, R.M., Undated - Geological Report on Site of Moogerah Dam, (Unpublished).



SEISMIC REFRACTION SURVEY FOR THE MOOGERAH DAM SITE NEAR KALBAR, Q'LD.

LOCALITY MAP

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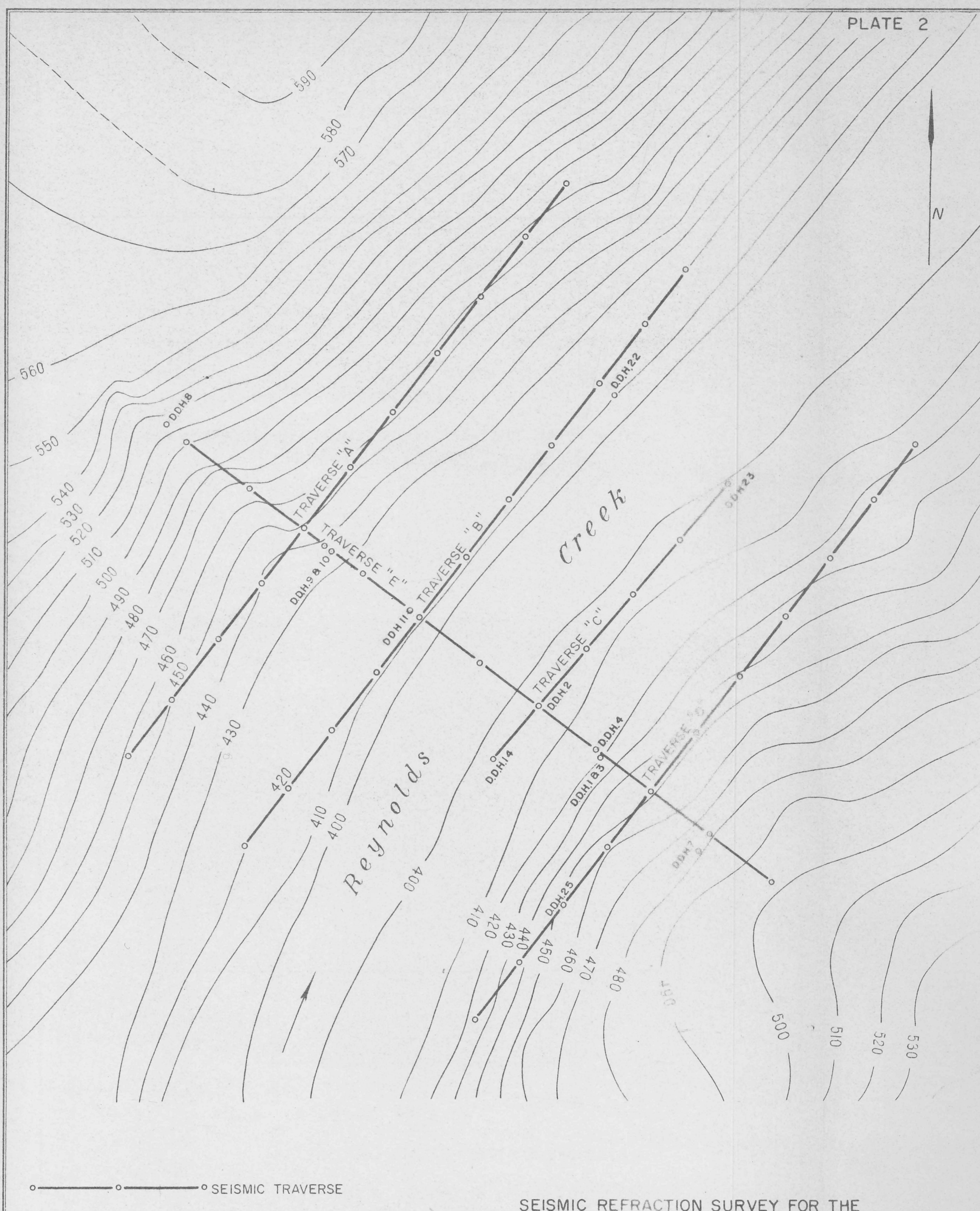
To accompany Records 1959, N° 62

PLATE 2



WARRIL VALLEY Datum (For State Datum Add 7·40 Ft.)

SEISMIC REFRACTION SURVEY FOR THE MOOGERAH DAM SITE, NEAR KALBAR, Q'LD.

TOPOGRAPHY AND SEISMIC TRAVERSES

BASED ON THE I & W.S.C. PLAN Nº 15939

Geophysical Section, Bureau of Mineral Resoures, Geology and Geophysics. G332-3

To accompany Records 1959, Nº 62

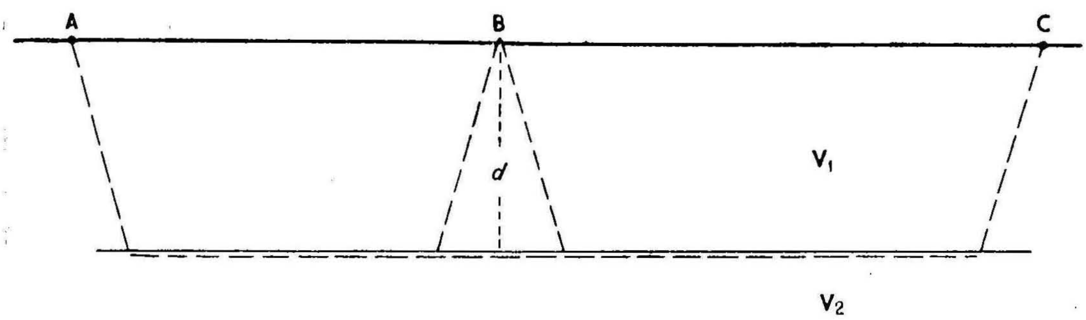


FIG. I. METHOD OF DIFFERENCES.

CROSS-SECTION SHOWING SEISMIC WAVE PATHS.

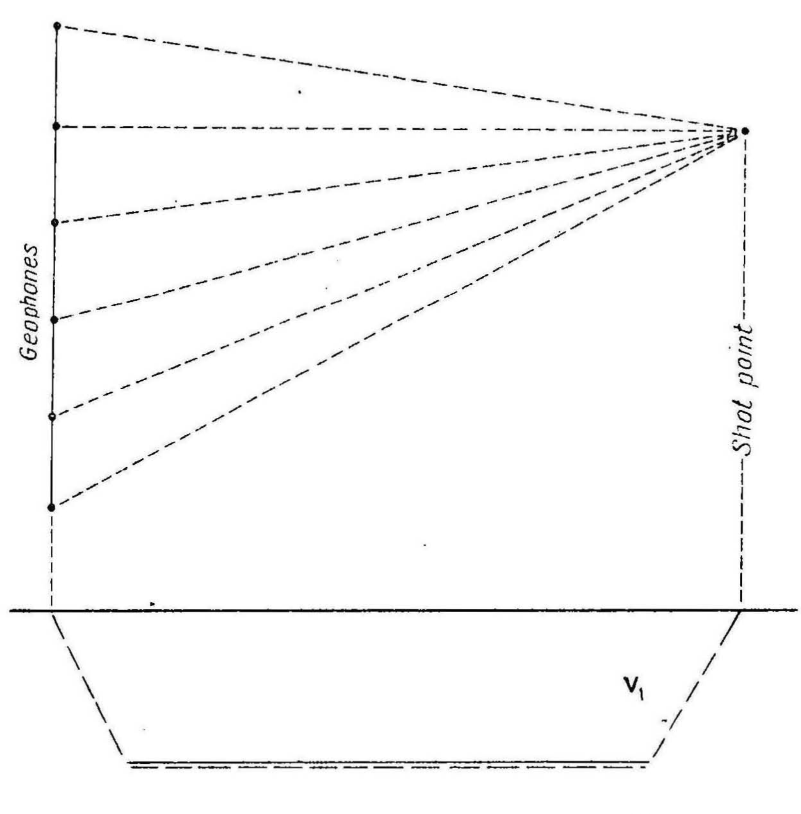


FIG. 2. BROADSIDE SPREADS

PLAN AND CROSS-SECTION SHOWING

SEISMIC WAVE PATHS.

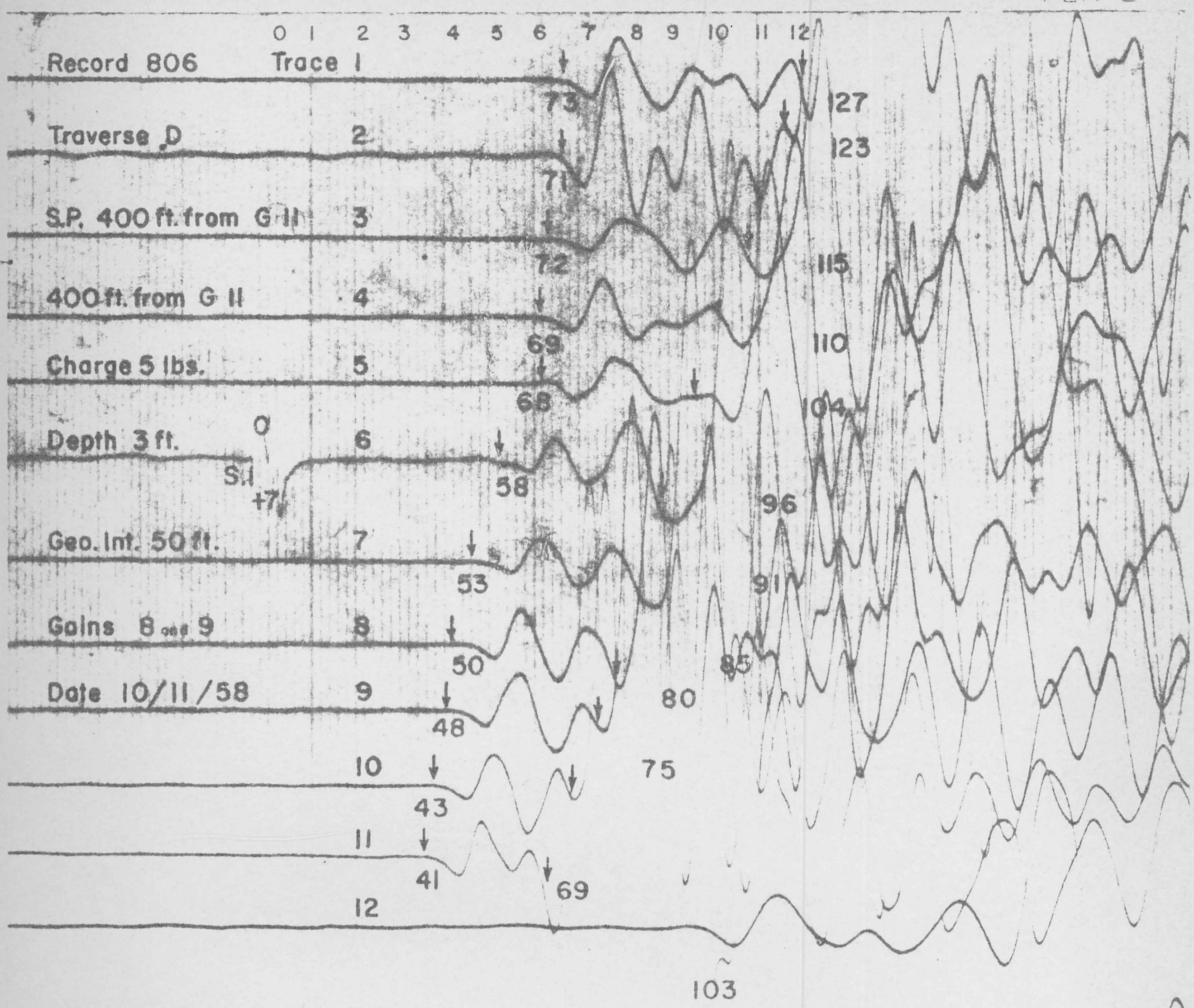

0 1 2 3 4 5 6 7 8 9 10 11 12
Record 806 Trace 1
Traverse D 2
S.P. 400 ft. from G 11 3
400 ft. from G 11 4
Charge 5 lbs. 5
Depth 3 ft. 6
Geo. Int. 50 ft. 7
Gains 8 and 9 8
Date 10/11/58 9
10
11
12
S.I
+7
73 71 72 69 68 58 53 50 48 43 41 69
127 123 115 110 104 96 91 85 80 75 103

FIG. 3

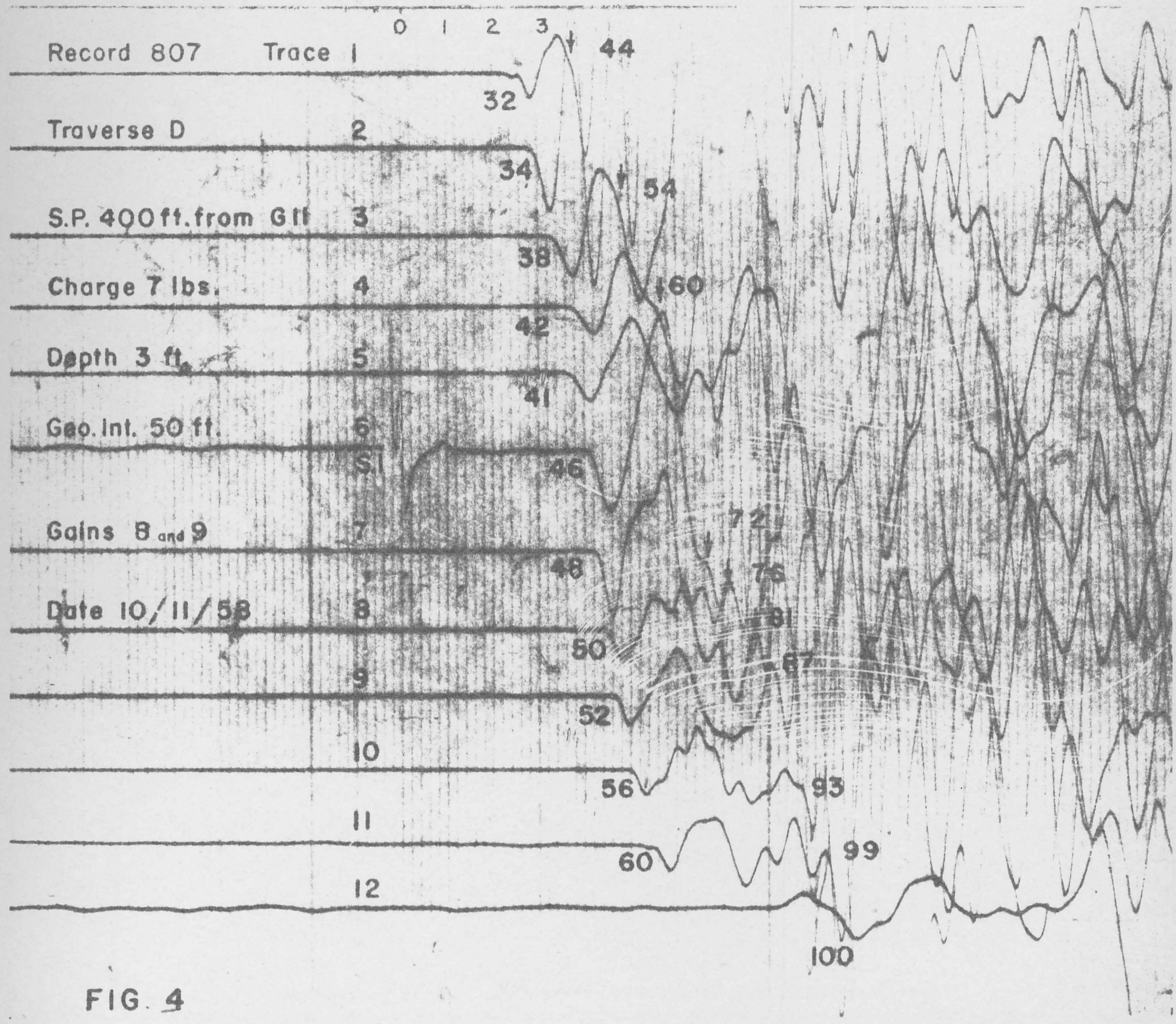

0 1 2 3
Record 807 Trace 1
Traverse D 2
S.P. 400 ft. from G 11 3
Charge 7 lbs. 4
Depth 3 ft. 5
Geo. Int. 50 ft. 6
Gains 8 and 9 7
Date 10/11/58 8
9
10
11
12
S.I
32 34 38 42 41 46 48 50 52 56 60 100
44 54 60 72 76 81 87 93 99

FIG. 4

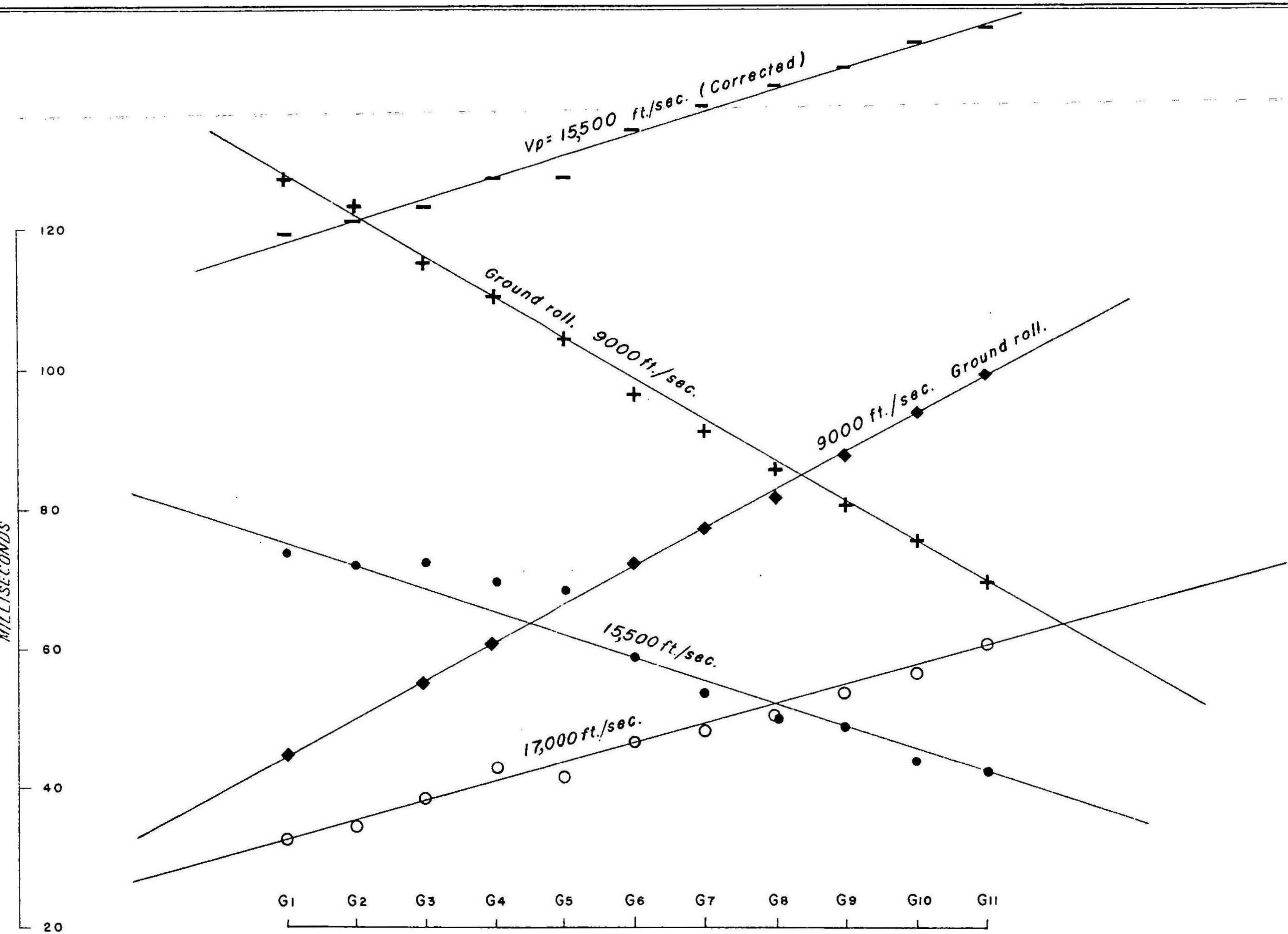


PLATE 5

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To accompany Records 1959, Nº 62

G 332-7

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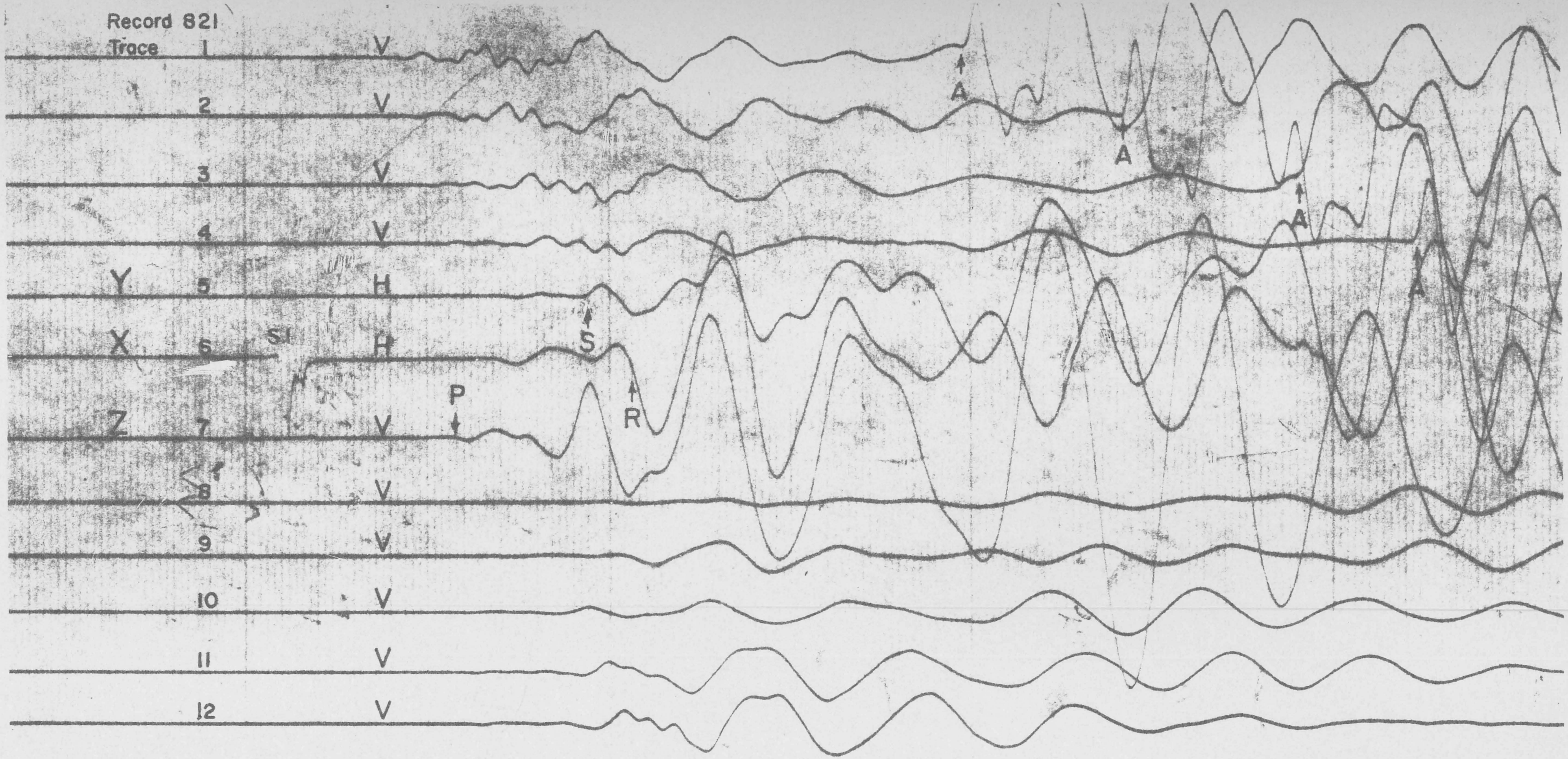
To accompany Records 1959, No 62
G 332-8

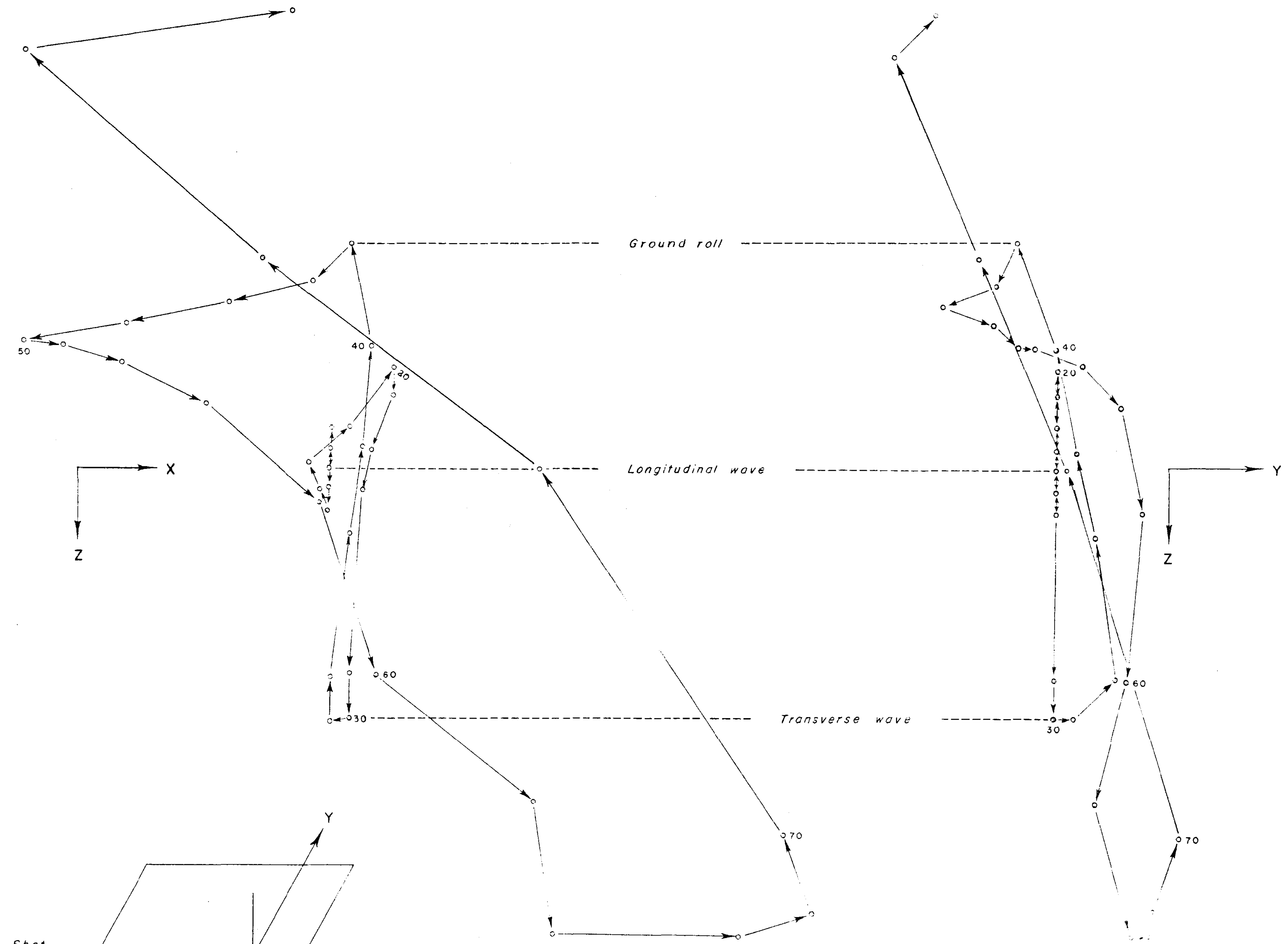
PLATE 6

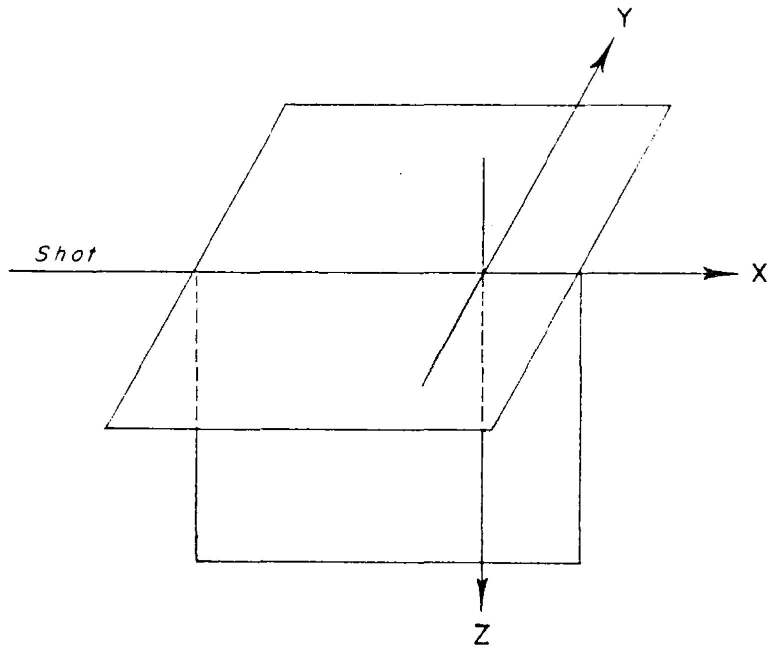


P—Longitudinal wave
S—Transverse wave
R—Ground roll
A—Air wave
S.I—Shot instant

SAMPLE RECORD
HORIZONTAL GEOPHONES ON TRACES 5 AND 6

PLATE 7





ORIENTATION DIAGRAM

o——→o INTERVAL BETWEEN POINTS 2 MILLISECONDS.

70 o TIME IN MILLISECONDS FROM THE ARRIVAL OF LONGITUDINAL WAVE.

APPROXIMATE SCALE OF VECTORS 1" = 0·002 INCHES OF ACTUAL GROUND DISPLACEMENT.

ACTUAL GROUND DISPLACEMENT

PLOTTED FROM PLATE 6.

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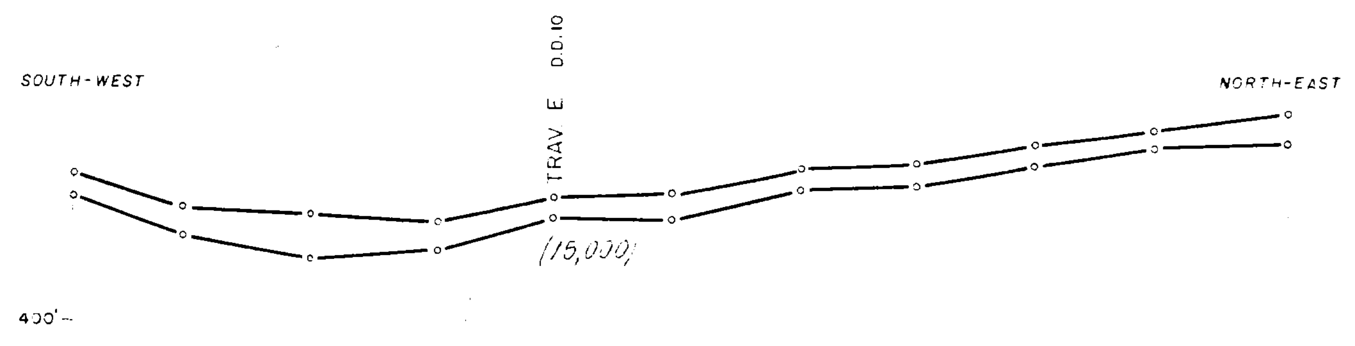
G 332-9

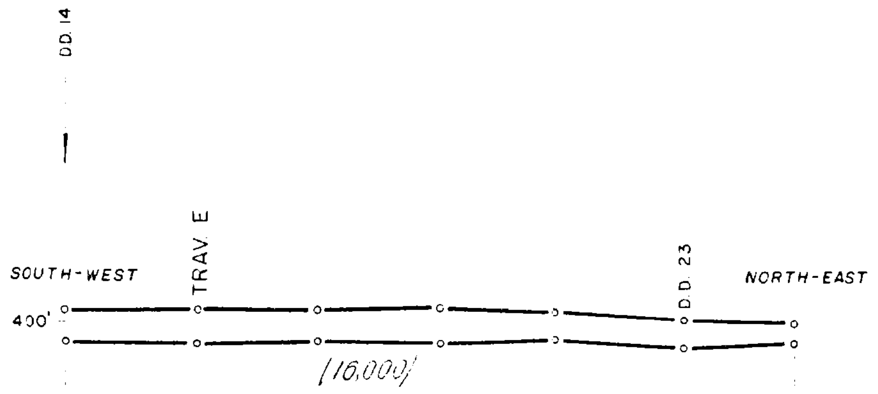
To accompany Records 1959, No 62

TRAVERSE "A"



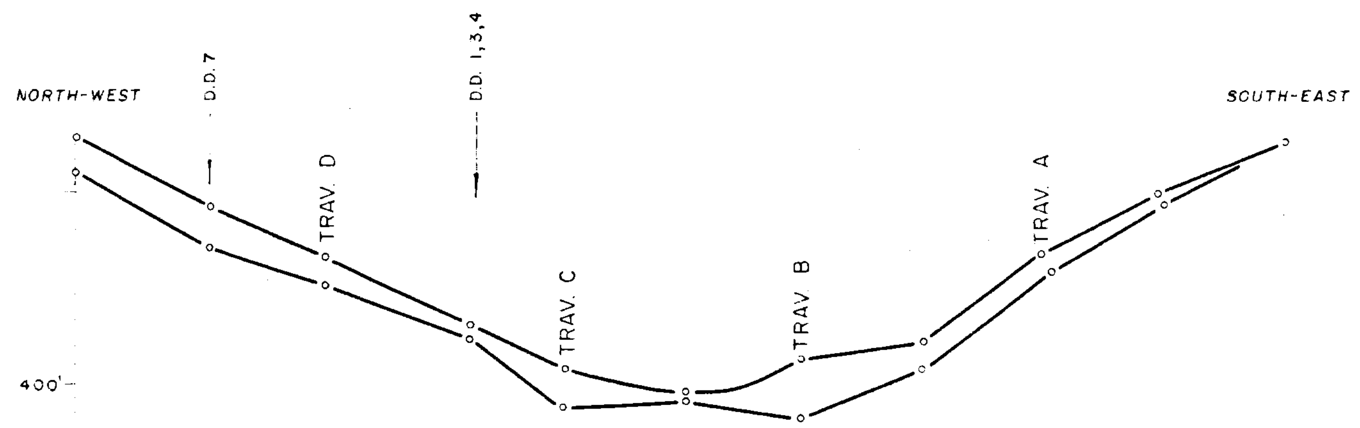
STATION N°	1	2	3	4	5	6	7	8	9	10	11
ELEVATION	460	454	448	442	451	454	463	468	471	478	486
THICKNESS	8	3	14	11	10	9	9	7	8	10	10

TRAVERSE "C"



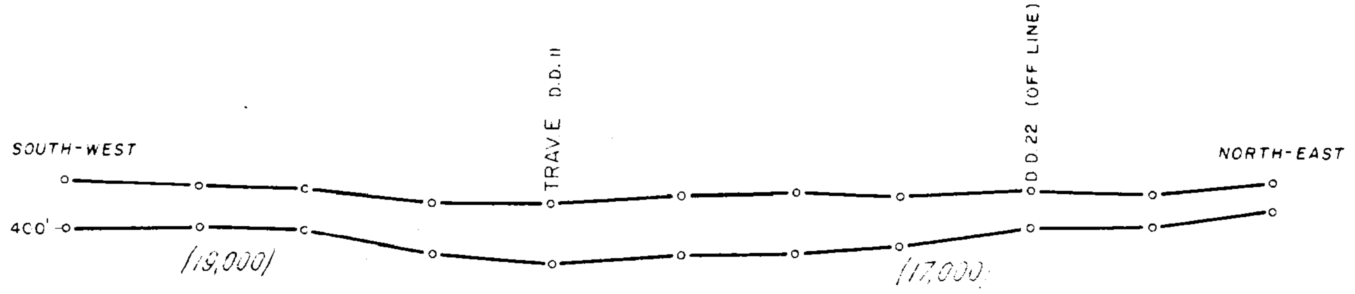
STATION N°	1	2	3	4	5	6	7
ELEVATION	404	405	405	406	405	400	398
THICKNESS	12	14	12	13	13	14	8

TRAVERSE "E"



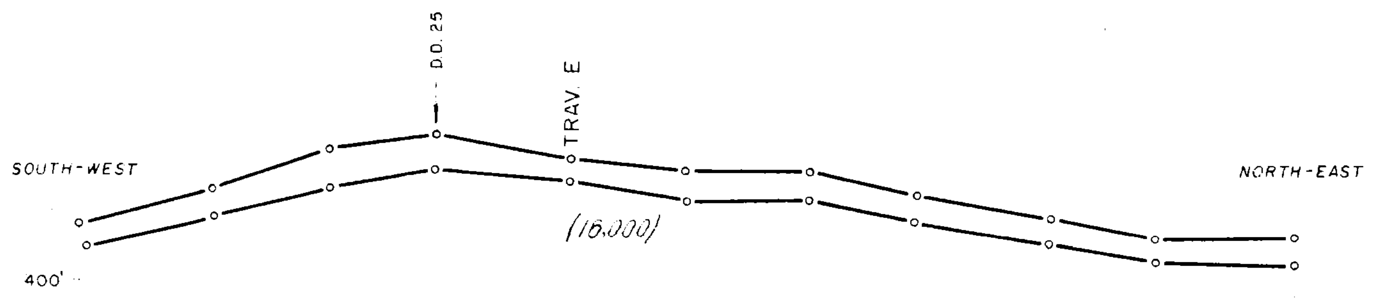
STATION N°	1	2	3	4	5	6	7	8	9	10	11
ELEVATION	502	468	448	424	405	396	410	416	451	476	497
THICKNESS	12	14	8	3	14		25	11	10	5	1

TRAVERSE "B"



STATION N°	1	2	3	4	5	6	7	8	9	10	11
ELEVATION	420	418	415	410	410	412	412	414	416	416	419
THICKNESS	18	17	18	21	25	23	21	[illegible]	17	17	14

TRAVERSE "D"

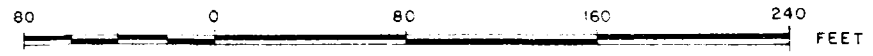


STATION N°	1	2	3	4	5	6	7	8	9	10	11
ELEVATION	422	437	452	458	448	446	443	434	426	421	416
THICKNESS	10	11	13	15	8	13	10	10	10	10	10

SEISMIC REFRACTION SURVEY FOR THE
MOOGERAH DAM SITE NEAR KALBAR, Q'LD.

SECTIONS ON SEISMIC TRAVERSES

HORIZONTAL AND VERTICAL SCALES



(16,000) SEISMIC VELOCITY IN FT./SEC.

ELEVATION - WARRIL VALLEY Datum (For STATE Datum add 7.40 Ft.)

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To accompany Records 1959, No 63

PLATE 9

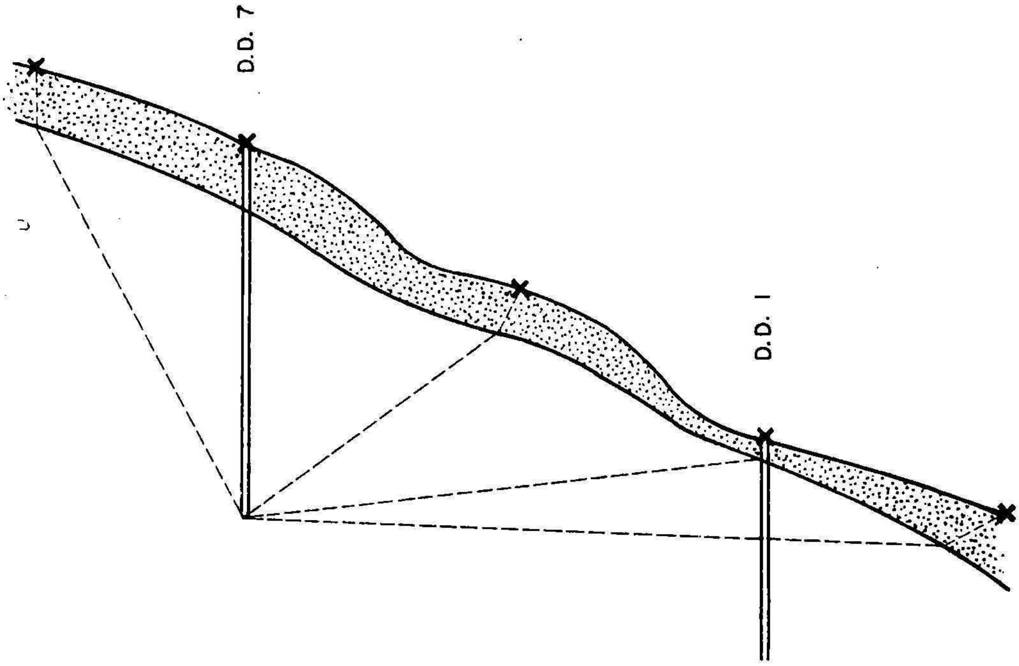

FIG. 1. SHOT IN D.D.7 TO CALCULATE SEISMIC ANISOTROPY.

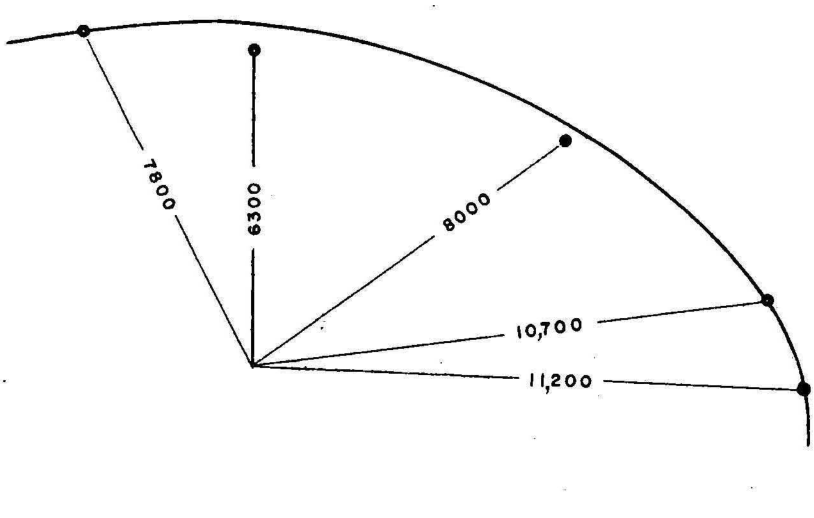

FIG. 2. SHOWING SEISMIC ANISOTROPY ALONG SECTION D.D.7 / D.D.1 (See figure 7)