COMMONWEALTH OF AUSTRALIA

DEPARTMENT OF NATIONAL DEVELOPMENT

BUREAU OF MINERAL RESOURCES,
GEOLOGY AND GEOPHYSICS

RECORDS 1956, No. 82

GEOPHYSICAL SURVEY OF THE

DERWENT DIVERSION TUNNEL, WAYATINAH "A" POWER DEVELOPMENT SCHEME,

TASMANIA

by

W. A. WIEBENGA, D. F. DYSON & L. V. HAWKINS

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ABSTRACT

Results are given of a geophysical survey made by the Bureau of Mineral Resources along the line of the proposed Derwent Diversion Tunnel, which will join the Derwent River and the Wayatinah "A" Tunnel, Tasmania. Part of the tunnel line crosses a basalt-filled valley in dolerite, and a seismic refraction survey was made along this part to find the deepest part of the basalt-filled valley and to determine the depths to the unweathered dolerite.

Three different profiles have been computed using two standard techniques and one new technique. The figures in the results can be considered to be in error to the extent of 25 per cent, due to lack of control data. Depth estimates are considered to be a maximum.

Drilling sites are recommended to check the deepest part of the filled-in valley, and a more accurate revision of the geophysical results will be possible when the drill holes are completed.

A resistivity survey was also made over the greater part of the tunnel line, and shear or fault zones are indicated.

1. INTRODUCTION

The Wayatinah "A" Power Development Scheme is one of the Tasmanian Hydro Electric Commission's projects and consists of the Nive River dam, the Wayatinah "A" power station and penstock lines and the Wayatinah "A" tunnel. Geophysical surveys carried out in connection with these projects are described by Wiebenga, Dyson and Hawkins (1956a and 1956b), Wiebenga, Dyson and O'Connor (1956) and Wiebenga and Hawkins (1956). In addition, the Commission is considering the construction of the "Derwent diversion tunnel" between the Derwent River and the Wayatinah "A" tunnel, meeting the latter at a point about midway between the dam site and the penstocks site (Plate 1). The Derwent diversion tunnel, if constructed, will be used to:-

(a) Boost the quantity of water available to the Wayatinah "A" power station with seasonal water from the Derwent catchment area.

(b) Make available for use in the Wayatinah "A" power station, water diverted from the Tarraleah power station during any periods of shut-down of this station.

At the surface above the proposed tunnel line the rocks are dolerite and basalt, the basalt filling a valley structure in the dolerite. This report describes a seismic refraction survey over the basalt, and a resistivity survey over the greater part of the tunnel line.

The purpose of the geophysical investigation was to determine:-

(a) The location of the deepest part of the basalt-filled valley.

(b) The depth to unweathered dolerite under the basalt, thereby enabling an estimate to be made of the length of tunnel to be driven in the basalt, and in the weathered dolerite between the unweathered dolerite and the basalt.

(c) The positions of any shear or fault zones.

The geophysical party consisted of D.F. Dyson, party leader, L.V. Hawkins, geophysicist, and five field assistants supplied by the Commission.

The work was done during November, 1954.

2. GEOLOGY

The proposed tunnel is to be driven through a hill between the valleys of the Nive and Derwent rivers.

The rock types present are:-

(a) Dolerite

The dolerite is a medium-grained to coarse-grained crystalline rock, dark grey when unweathered and dark green when weathered, due to chloritisation.

(b) Basalt

Along the traverse the basalt occurs approximately between stations 1028 and 1121. It is present as extensive flows filling an old valley eroded in the dolerite roughly parallel to those of the Derwent and Nive rivers. The basalt, which is easily distinguished from the dolerite, is a fine-grained crystalline rock, light grey when weathered and in many places vesicular.

(c) Weathered dolerite between unweathered dolerite and basalt.

Weathered dolerite between the unweathered dolerite and the basalt marks the old land surface of the valley. Available drilling information in the area indicates that the zone of weathered dolerite ranges considerably in thickness, but does not usually exceed 50 feet.

3. METHODS

A. SEISMIC REFRACTION

The application of the seismic method to the mapping of the unweathered dolerite underlying the basalt-filled valley is subject to the following difficulties:-

(a) Loss of transmitted energy due to layering within the basalt.

(b) The large horizontal displacement between the secondary source point on the refractor and the geophone registering the disturbance. This is due to:-

  (i) The relatively low velocity contrast between basalt and dolerite, which gives a large angle of critical incidence.

  (ii) The fairly large thickness of basalt.

  (iii) The steep slopes of the sides of the old valley.

(c) The deepest part of the valley structure is the old river channel, and due to the steepness of its banks, refractions from the floor of the old river channel are not recorded.

Because of the above difficulties none of the computation techniques used in the seismic refraction method is wholly satisfactory. Solutions have therefore been plotted for two standard methods and one new method. These are:-

  (a) The method of differences (Edge and Laby, 1931,339).

  (b) The method of step-out times (Barthelmes, 1946)

  (c) The method of "displacements", which was developed and its application to filled valley structures tested.

These methods are discussed in the Appendix.

Two shot points, at stations 1030.5 and 1120 were sited in shallow drill holes near the outer edges of the basalt-filled valley (Plate 1). These shot points were used throughout and the geophone spread was moved to give a continuous profile. A reciprocal geophone was placed on the shot point not in use, and the shot point and geophone were interchanged for each spread.

The siting of shot points in drill holes in the basalt near the basalt/dolerite contact facilitated the use of the dolerite as the refractor and increased the amount of energy transmitted.

To compute weathering corrections, shot points were also sited at distances of 40 feet and 200 feet from either end of each spread to determine the velocity in the weathered basalt and the depth and the velocity of the unweathered basalt. The geophone interval was 40 feet.

The equipment used was the "Century" 12-channel portable refraction seismograph, model 506.

B. SEISMIC REFLECTION

An experimental shallow reflection technique was tested, using the standard Century refraction seismograph and air and ground shooting. Reflections were obtained despite difficulties involved in using refraction equipment, but the quality of the results was not as good as those obtained in the refraction survey, and they are not included in this report.

C. RESISTIVITY

A resistivity survey was made over most of the route of the tunnel line to locate any shear zones which may be present.

Continuous resistivity profiles were obtained using the Wenner configuration with constant electrode spacings of 80 feet and 160 feet. Readings were taken at 40 feet and 80 feet intervals respectively.

For a description of the application of the resistivity method in tunnel line investigation, see Quilty (1953).

The effective current penetration increases with the electrode spacing. Different electrode spacings are used to extend the range of effective current penetration. In the presence of a dipping shear or fault zone, the effect of increasing the electrode spacing is to move the observed resistivity minimum in the direction of dip.

4. INTERPRETATION OF RESULTS

A. SEISMIC REFRACTION

Computed depth profiles of the dolerite refractor, using the three methods of computation described above, are shown on Plate 2, Figure 1. The differences between these interpretations give an indication of the error to be expected in estimating the depth to fresh dolerite.

The weathered dolerite between the dolerite and basalt is included in the thickness of basalt.

No energy from the dolerite refractor was recorded between stations 1065 and 1070, and no direct information on the depth to dolerite between these two stations is possible.

The results indicate that the deepest part of the old valley is between stations 1067 and 1072.

The method of step-out times gives only an indication of the shape of the profile and does not give absolute depth determinations. The absolute depth of this profile on Plate 2 is tied to absolute depths obtained from the method of differences.

The accuracy of the absolute depth determinations by the method of differences and by the method of displacements depends on timing errors which cannot be reduced, and on the assumed velocity distribution in the basalt.

The horizontal velocity in the basalt immediately below the weathered surface layer is derived from time-distance curves, and ranges from 9,000 to 12,000 feet/sec., but layering within the basalt and the varying thickness of the zone of weathered dolerite of lower velocity make the vertical velocity above the dolerite doubtful.

The accuracy of the adopted vertical velocity distribution would be greatly improved if suitable drill holes were available for velocity logs and absolute depth determinations.

The seismic depth determinations can be considered to be in error to the extent of about 25 per cent, and the estimates indicate maximum depths.

At the surface, a broad shear zone is indicated between stations 1057 and 1071 by deeper weathering, a lower velocity in the basalt, and a resistivity minimum. The shape of the old valley, as indicated on Plate 2, indicates that this shear continues through the dolerite between stations 1067 and 1077, and coincides with a fault suggested by the trend of the old valley and striking approximately 40° west of north.

It is probable that movement along the pre-basalt fault has continued after the extrusion of the basalt and that the fault has a dip of about 55° to the north-east.

B. RESISTIVITY

The resistivity profiles and shear zones indicated at the surface are shown on Plate 3.

Shear zones indicated between stations 1058 and 1069, 1167 and 1172, and 1256 and 1260 appear to dip to the east or north-east.

Other shear zones are indicated between stations 1116 and 1128, 1151 and 1152, 1178 and 1193, 1210 and 1214, 1217 and 1221, 1231 and 1236, 1243 and 1244, 1249 and 1252, and 1266 and 1274, and possible shear zones between stations 1205 and 1208, and 1030 and 1036. The resistivity minimum between stations 1030 and 1036 is near the basalt/dolerite contact and may be due to deeper weathering along the contact.

The shear zone between stations 1116 and 1128 coincides approximately with a zone of low seismic velocity between the shot point at station 1113 and station 1120. This shear zone also appears to be indicated by the pre-basalt topography as shown by geological evidence. The direction of strike is approximately 10° west of north.

5. CONCLUSIONS AND RECOMMENDATIONS

The deepest part of the basalt-filled valley is between stations 1067 and 1072 and coincides with a shear zone.

The geophysical investigations indicate that:-

(i) the basalt may extend to tunnel level, and

(ii) difficult tunnelling conditions may be expected between stations 1067 and 1072 because of the probable presence of the basalt, the weathered dolerite below the basalt, and a shear zone at tunnel level. These factors seem likely to produce poor tunnelling rock together with probable flooding of the tunnel.

(iii) Several shear or fault zones occur (Plate 3) in the dolerite outside the basalt area.

It is suggested that the geophysical results be checked by drilling at stations 1069, 1065 and 1076.

6. ACKNOWLEDGMENTS

It is desired to acknowledge the ready co-operation of the personnel of the Resident Engineer's office at Wayatinah, and the Investigations Branch of the Commission at Hobart.

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APPENDIX

DISCUSSION ON SEISMIC REFRACTION METHODS

Errors common to all seismic methods are:-

(1) Timing errors, including instrumental and weathering errors,

(2) Errors in the assumed velocity distribution.

These are introduced in the depth computation of -

$z = vt$,

where z - is the depth, v the vertical velocity and t the "time-depth".

These errors may be reduced if drill holes are available for vertical velocity measurements and depth control points.

In all refraction methods using first breaks only, two possible sources of error are:-

(1) Sharp depressions in the refractor result in the failure to record from the deepest part of the depression. This causes the deepest part of the refractor to be plotted shallow. Figure 1 shows the travel paths (of first arrivals) in a sharp depression.

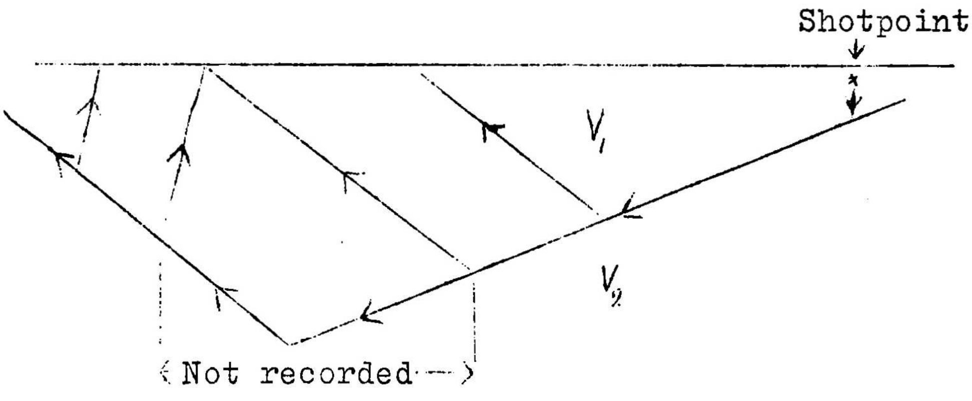


FIGURE 1.

(2) Structural highs in the refractor cause a "spreading of the high" in the plotted profile. Figure 2 shows the travel paths from a structural high.

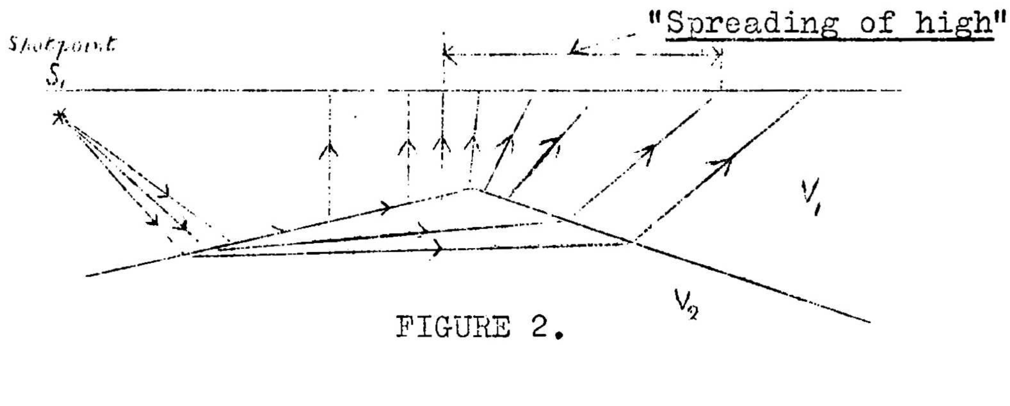


FIGURE 2.

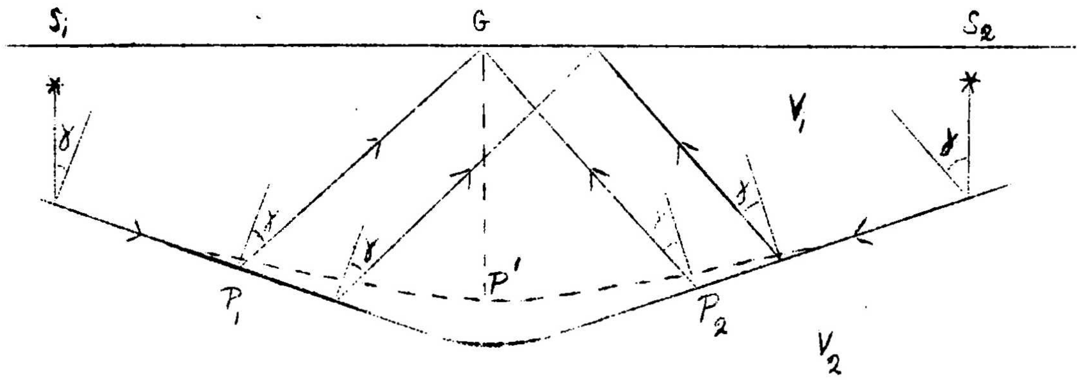


FIGURE 3.

In Figure 3, a geophone at G records energy from the points P_1 and P_2 which act as secondary source points for the shots at S_1 and S_2 respectively.

The computed depth below G is determined largely by the depth of the points P_1 and P_2, and is consequently plotted too shallow (P'). Similarly, a sharp structural high of the refractor will be plotted too deep. This causes an averaging effect in the computed profile of the refractor.

If the failure to record from the deepest part of the refractor in a sharp assymetrical depression is not taken into account, the depression will be misplaced in the computed profile towards the less inclined flank.

In the method of "Step-out Times" (Barthelmes, 1946), the amount of dip of the refractor from geophone to geophone is computed,thus giving the shape of the refractor but not the depth.

Depth control points from drilling or other methods are necessary.

Weathering and elevation corrections are applied to the recorded travel times and the difference in travel times between adjacent geophones (δt_c) is determined.

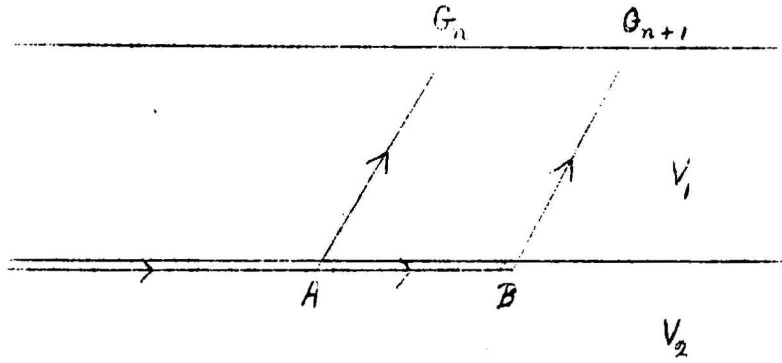


FIGURE 4.

If the refractor is horizontal the difference in travel time between G_n and G_{n+1} is equal to the travel time in the refractor between A and B (Figure 4).

$$\delta t_c = \frac{A\ B}{V_2} = t_{AB}$$

However, if the refractor is not horizontal $\delta t_c \neq t_{AB}$, the difference δt_i is related to the dip, and

$$\delta t_i = \delta t_c - t_{AB}$$

The δt_i curves of shots from opposite sides are matched by calculating the displacements between a secondary source point on the refractor and the geophone registering the disturbances from the opposite shots. To calculate this displacement it is necessary to know the depth, dip and angle of critical incidence of the refractor. Usually the refractor is assumed horizontal, but this introduces errors in the interpretation of valley structures. In this report, the approximate dip and depth of the profile were computed by the method of differences.

The matched δt_i curves are plotted together and the mean δt_i values are used to calculate the difference in depth between adjacent geophones (δz) by the equation:

$$\delta z = \delta t_i\, V_1 / \cos \gamma ,$$

where V_1 is the velocity of the material above the refractor, and γ is the angle of critical incidence.

The solution is a mathematical approximation, but often yields satisfactory results.

The method of displacements was developed and its application tested. A shot point was sited near each edge of the valley structure and the geophone spread was moved to give a continuous profile. A reciprocal geophone was placed on the shot point not in use and then shot-point and geophone were interchanged for each spread.

The method of differences was used to approximate the refractor profile, and the displacement between the secondary source point on the refractor and the recording geophone from each shot was determined graphically.

In Figure 5, ABC is the refractor profile computed from the method of differences, S_1 and S_2 are shot points and P is the common secondary source point for the recording geophones G_1 (from shot-point S_1) and G_2 (from shot-point S_2). G_1 and G_2 are obtained graphically by constructing the travel paths PG_1 and PG_2, knowing the angle of critical incidence (γ) and the dip of the refractor (α).

The horizontal displacement $G_1\ G_2$ may be checked by comparing any common specific character present in the time distance curves of shots from opposite sides.

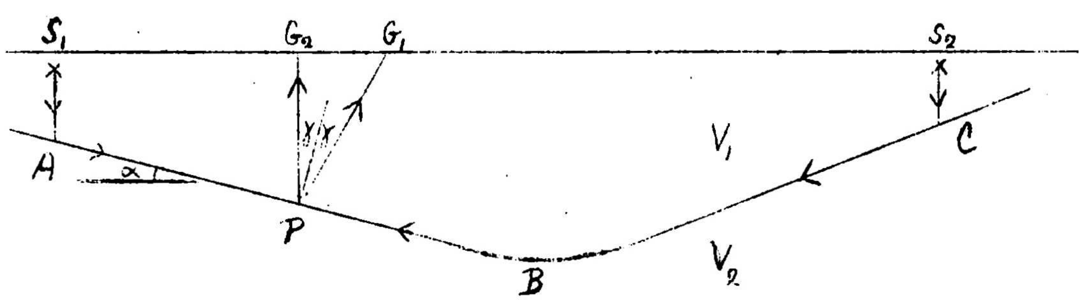


FIGURE 5.

The new position of P is plotted as the intersection of the normal to the plane of the refractor at P and the circumference of an ellipse with G_1 and G_2 as foci and the sum of the radii equal to $(T_1 + T_2 - T_3) V_1$,

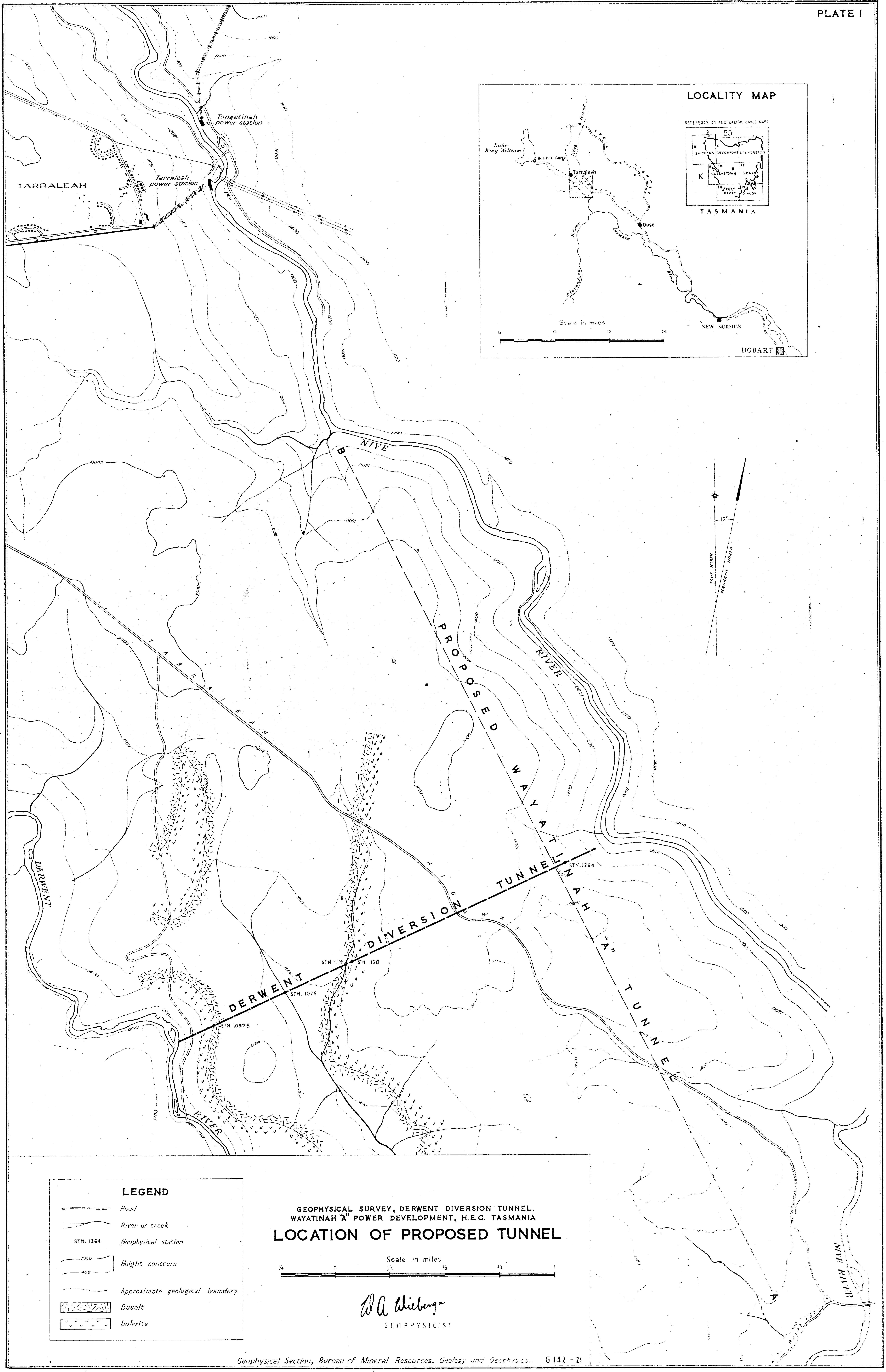
where T_1 is the travel time from S_1 to G_1
T_2 " " " " " S_2 to G_2
T_3 " " " " " S_1 to S_2 or S_2 to S_1,

and V_1 is the velocity of the material above the refractor.

The successive approximation to the refractor profile is repeated until a reasonably clear re-plot is obtained.

As it is not practical to consider the detailed variations of dip of an irregular refractor in determining the horizontal displacement, the general dip of the refractor near P is used.

PLATE I



GEOPHYSICAL SURVEY, DERWENT DIVERSION TUNNEL.
WAYATINAH "A" POWER DEVELOPMENT, H.E.C. TASMANIA

LOCATION OF PROPOSED TUNNEL

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FIGURE. 1
SEISMIC REFRACTION PROFILES
BASALT-FILLED VALLEY

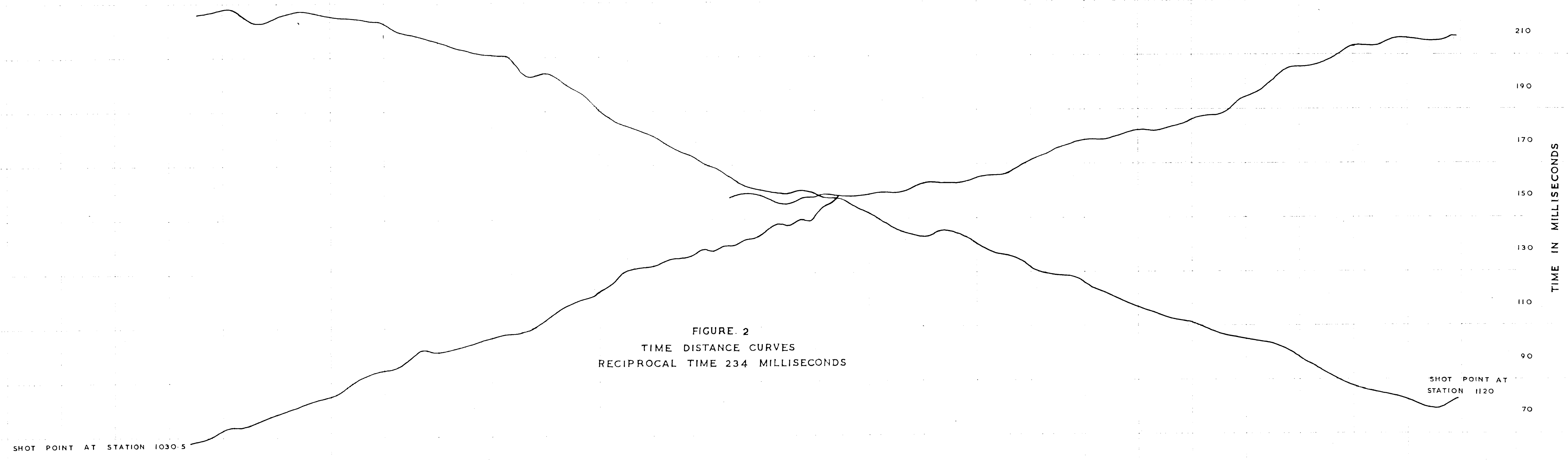

FIGURE. 2
TIME DISTANCE CURVES
RECIPROCAL TIME 234 MILLISECONDS

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GEOPHYSICIST

PLATE 3

LEGEND

——	RESISTIVITY PROFILE 80 FT. SPACING
– – –	" " 160 FT. "
▬	SHEAR ZONE INDICATED AT SURFACE
▬→	SHEAR ZONE WITH POSSIBLE N.E. DIP
1061	STATION NUMBER
—·—	BASALT IN SECTION (INFERRED FROM SEISMIC RESULTS)

HORIZONTAL SCALE IN FEET

100 50 0 100 200 300

VERTICAL SCALES AS SHOWN

W. A. Wiebenga GEOPHYSICIST

GEOPHYSICAL SURVEY
DERWENT DIVERSION TUNNEL
WAYATINAH 'A' POWER DEVELOPMENT SCHEME, TASMANIA

RESISTIVITY SURVEY

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